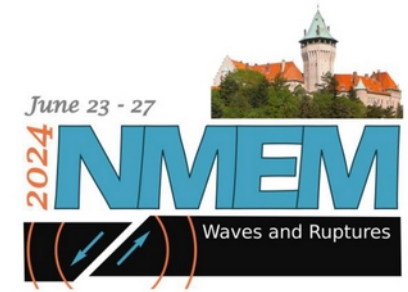# Triggering of very shallow earthquakes by surface mass removal processes - case study of the 2019 Mw4.9 Le Teil, France earthquake
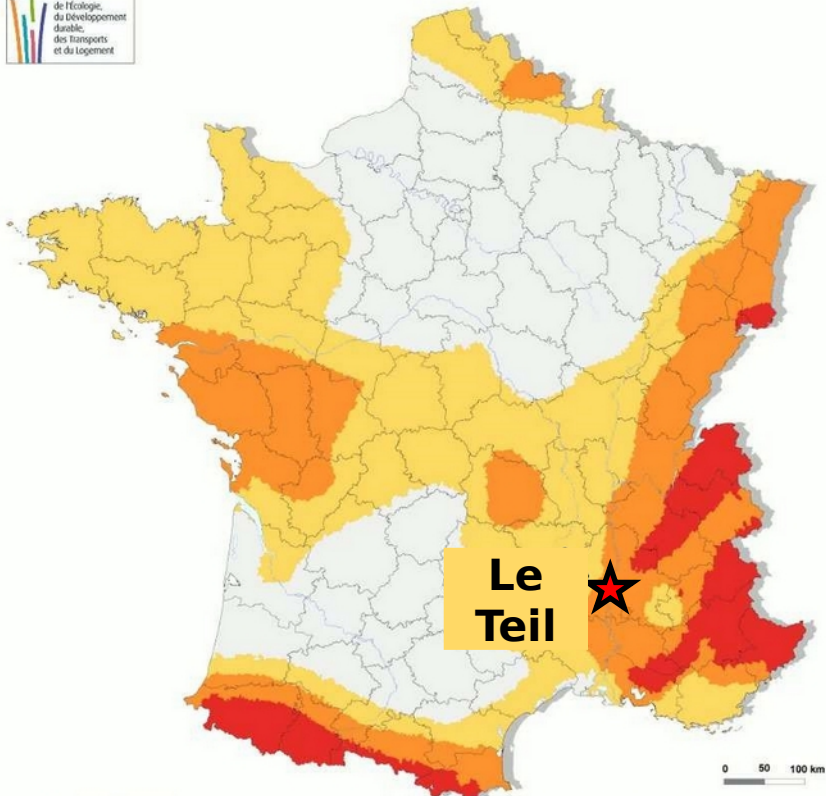
Eyüp Sopacı, Jean-Paul Ampuero, François X. Passelègue

The 2019 M5 Le Teil earthquake
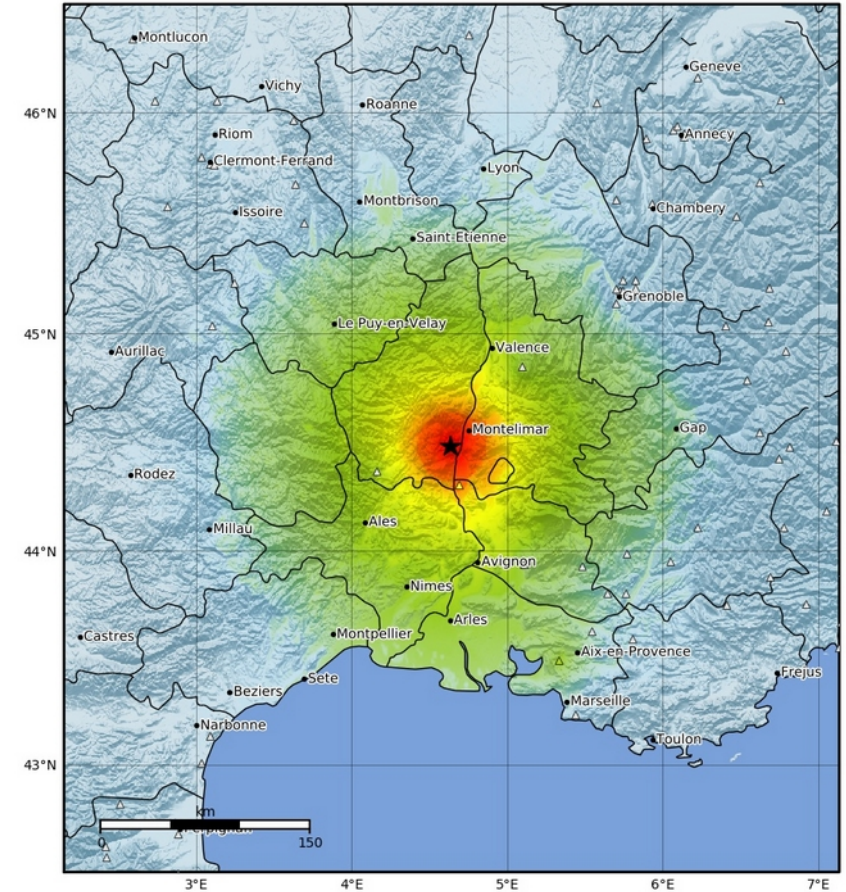
Seismic zones in France

Le Teil ★

Zones de sismicité

☐	1 (très faible)
☐	2 (faible)
☐	3 (modérée)
☐	4 (moyenne)
☐	5 (forte)

Extreme acceleration (>1 g) near fault, local damage
2 nuclear plants nearby (~20 km)

Macroseismic Intensity Map
OCA ShakeMap: oca2019wcnn/44.49/4.63
Nov 11, 2019 10:52:46 UTC M5.1 N44.49 E4.63 Depth: 10.0km
ID:oca2019wcnn

| SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
PGA(%g)	<0.02	0.07	0.28	1.14	4.71	8.6	15.7	28.7	>52.4
PGV(cm/s)	<0.01	0.03	0.13	0.54	2.33	5.52	13.1	31	>73.3
INTENSITY	I	II	III	IV	V	VI	VII	VIII	IX+

Scale EMS 98, based on Caprio et al. (2015)   Version 1: Processed 2019-11-13T13:13:54Z
△ Seismic Instrument   ○ Macroseismic Observation   ★ Epicenter

The November 11 2019 M5 earthquake in Le Teil, France

A surprisingly shallow event

Slip model inferred from InSAR (Grandin, Jolivet and Cavalié)
Surface rupture of La Rouvière fault
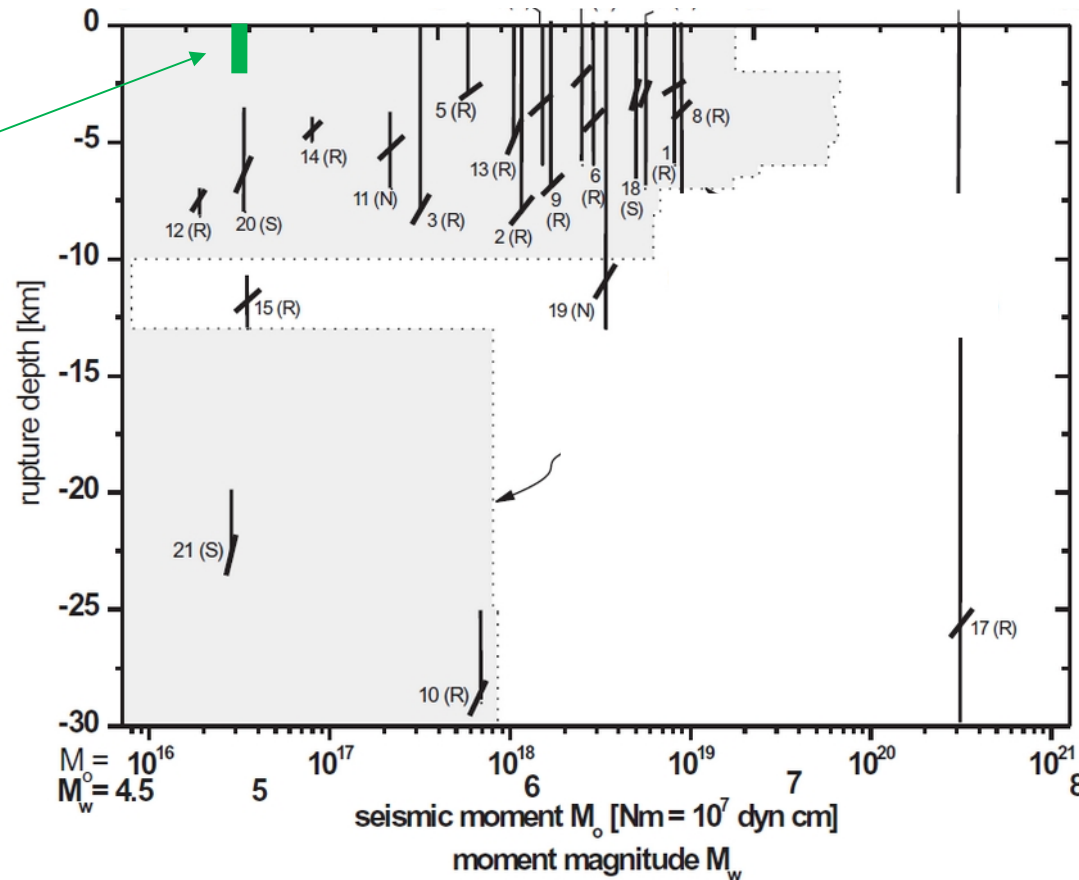
Slip confined at shallow depth <2 km
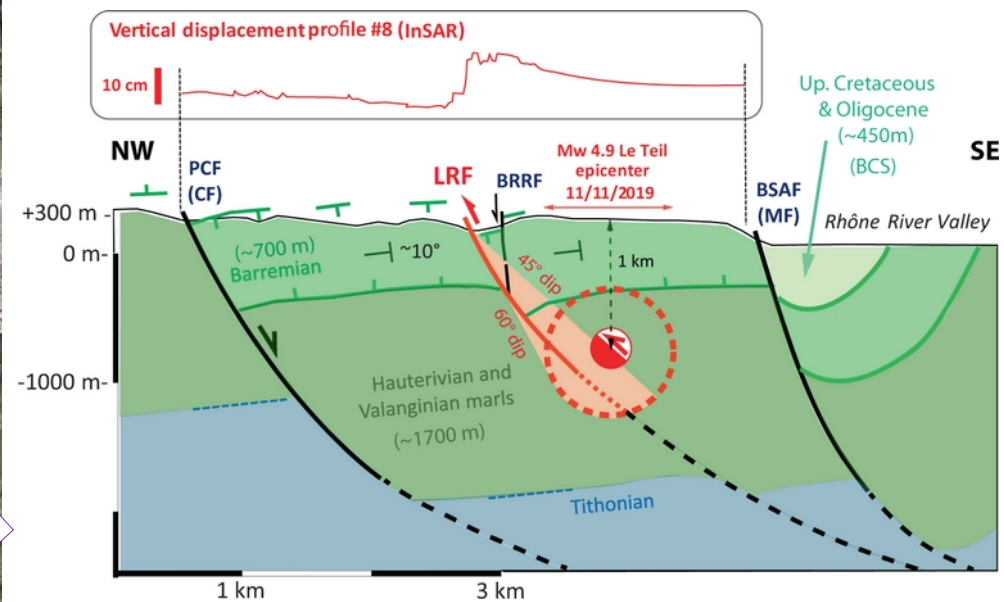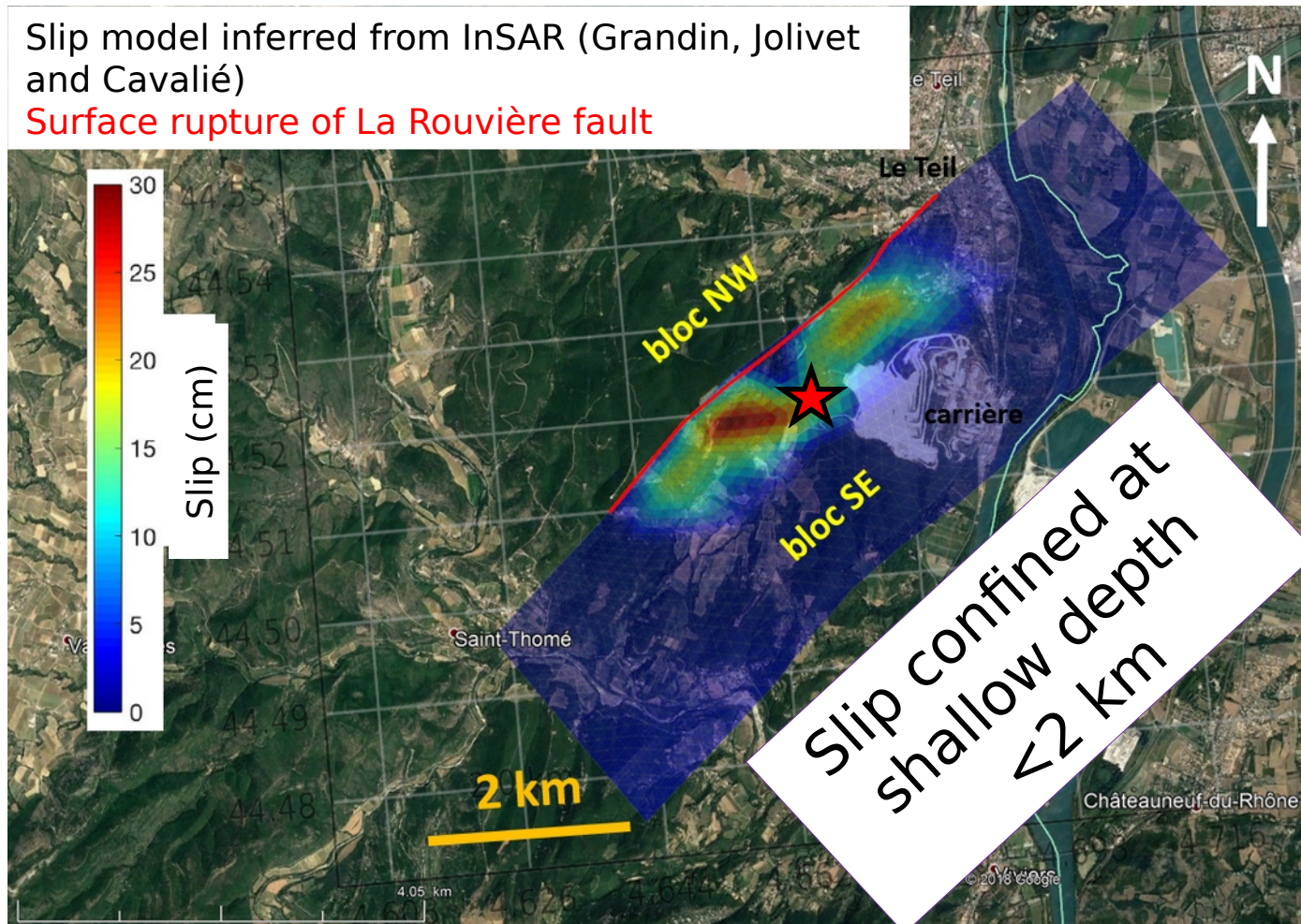
Ritz et al. (2020)

The November 11 2019 M5 earthquake in Le Teil, France

A surprisingly shallow event

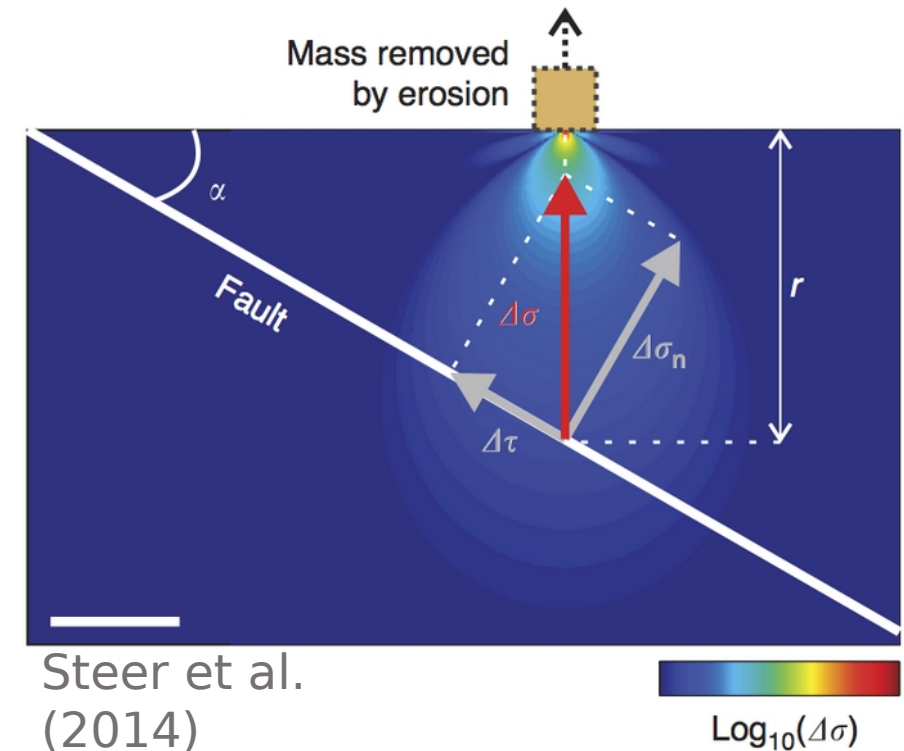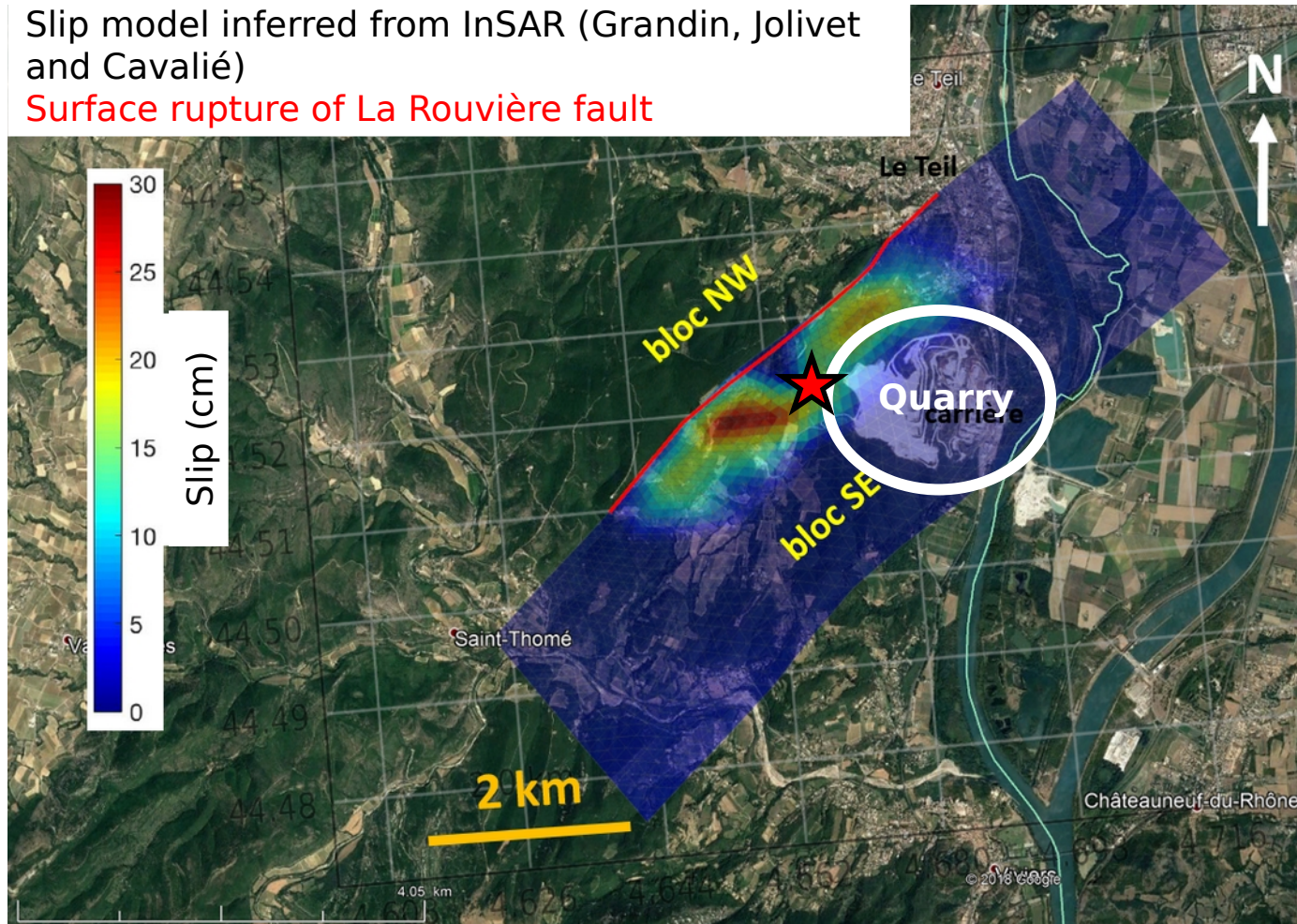Rupture depth of earthquakes
in stable continental regions

Klose and Sieber (2007)

The November 11 2019 M5 earthquake in Le Teil, France

A triggered event?

Slip model inferred from InSAR (Grandin, Jolivet and Cavalié)
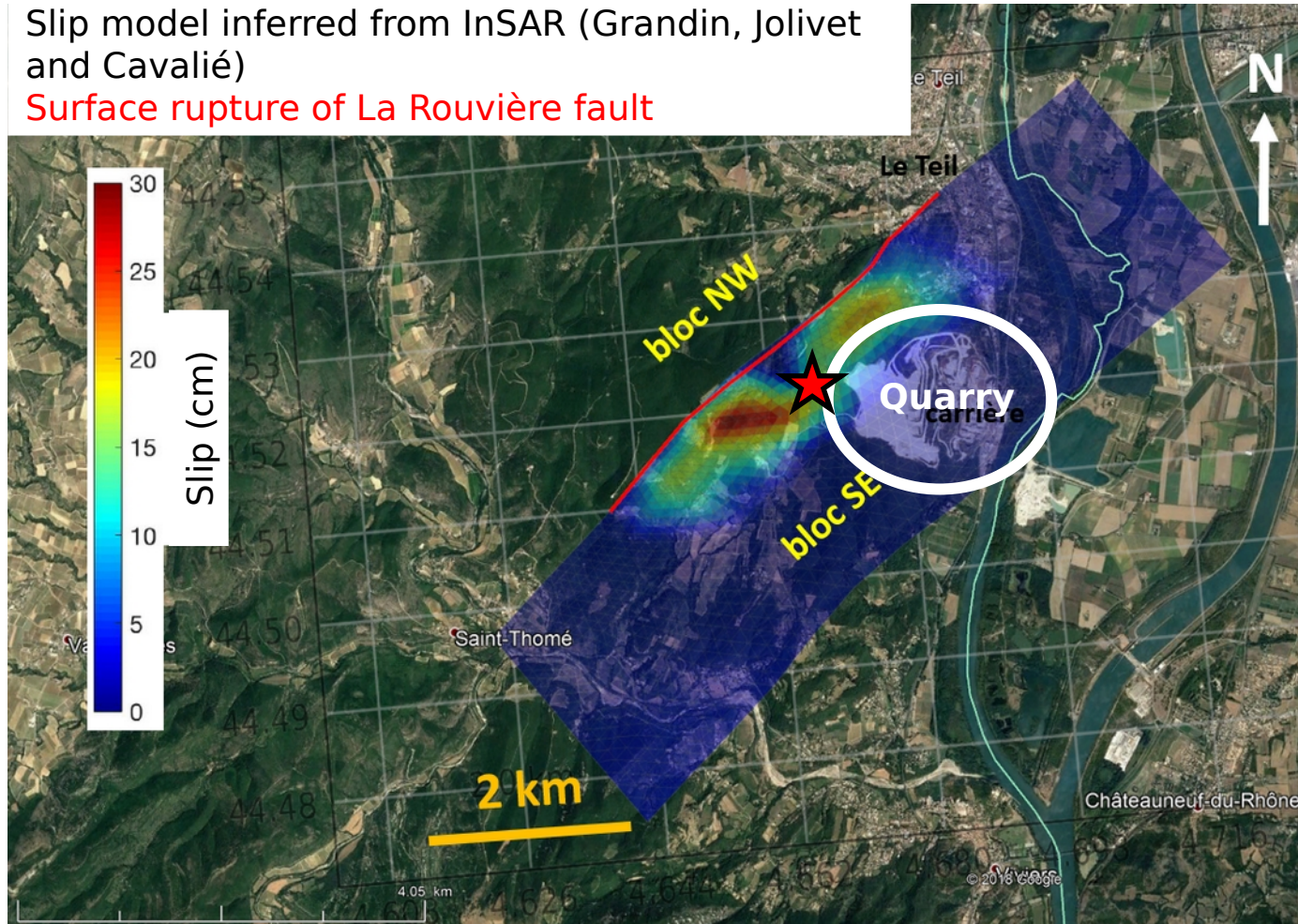Surface rupture of La Rouvière fault

Steer et al. (2014)

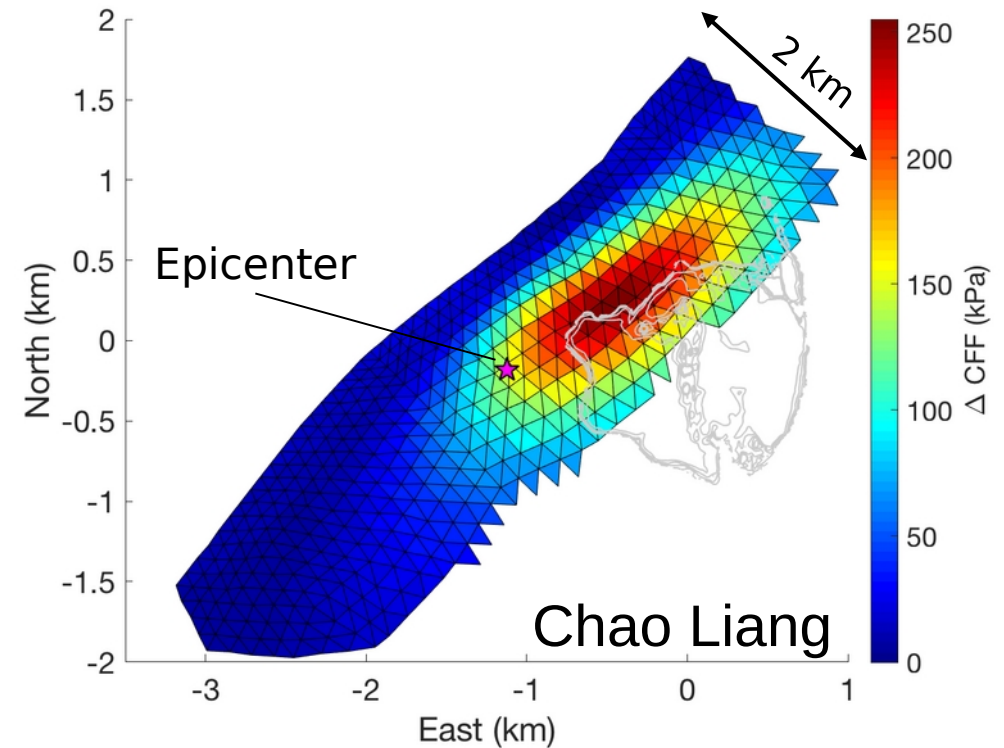# The November 11 2019 M5 earthquake in Le Teil, France

A triggered event?

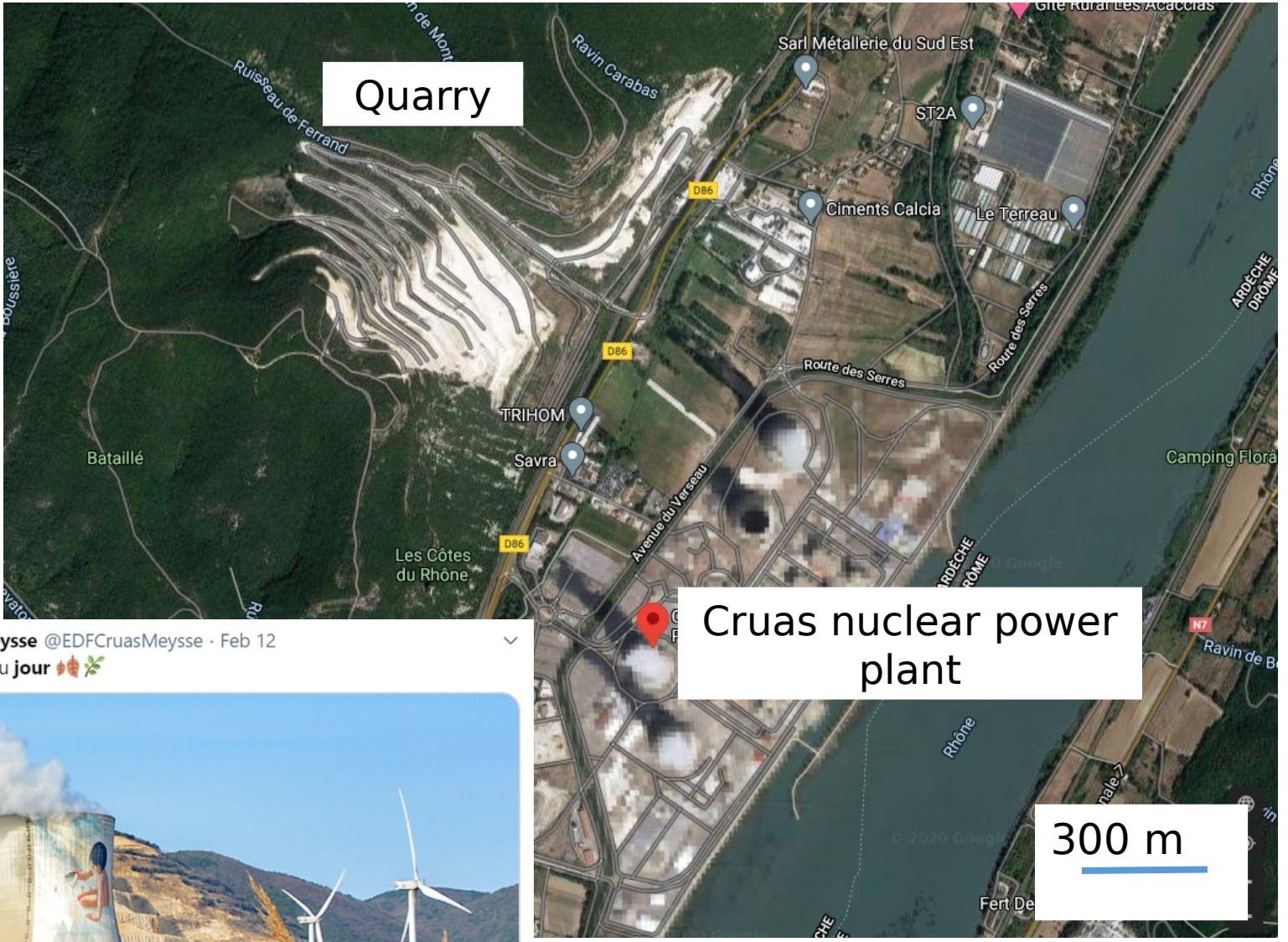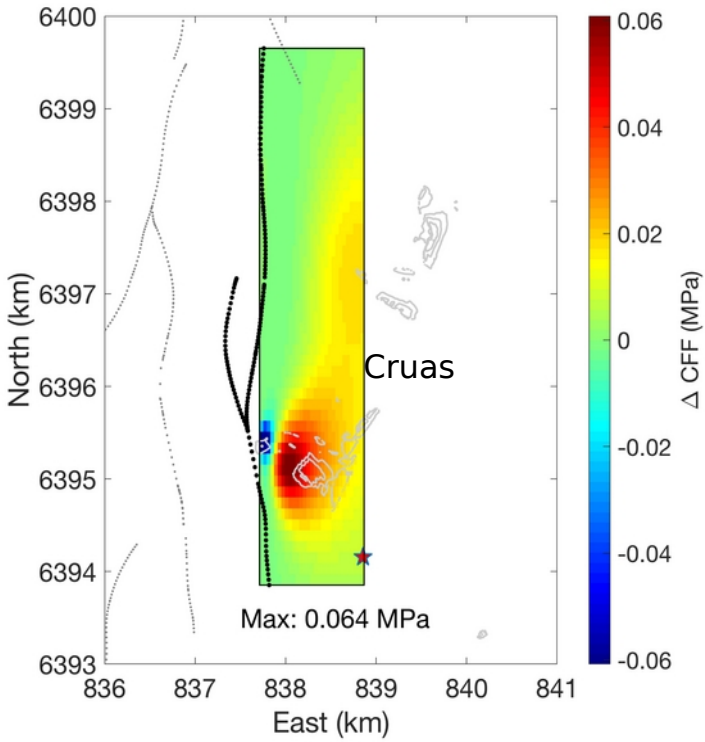Slip model inferred from InSAR (Grandin, Jolivet and Cavalié)
Surface rupture of La Rouvière fault

Coulomb stress induced on the fault by the quarry

Quarries close to nuclear power plants in the south of France

Quarry

Cruas nuclear power plant

Cruas

Max: 0.064 MPa

Coulomb stress induced by quarry on the nearest fault

EDF Cruas-Meysse @EDFCruasMeysse · Feb 12
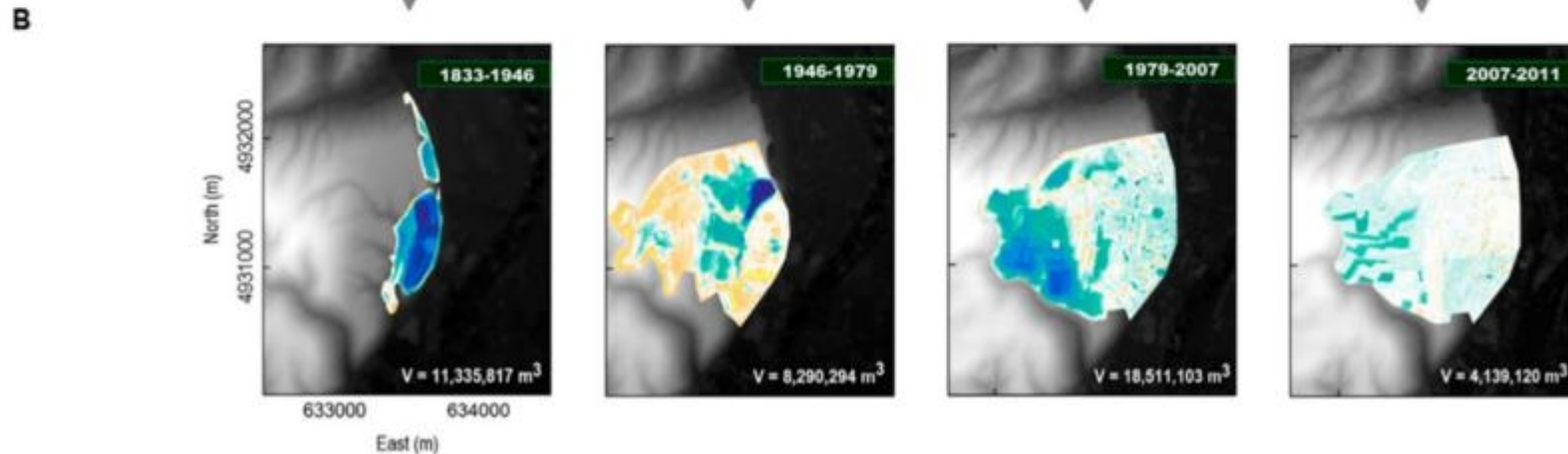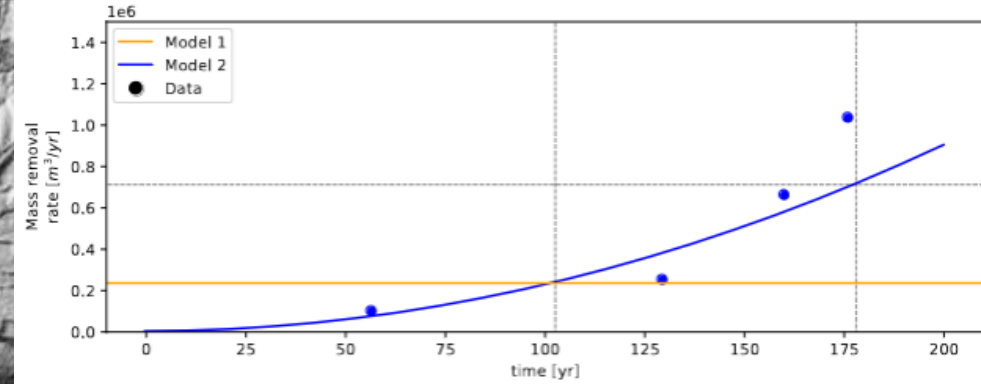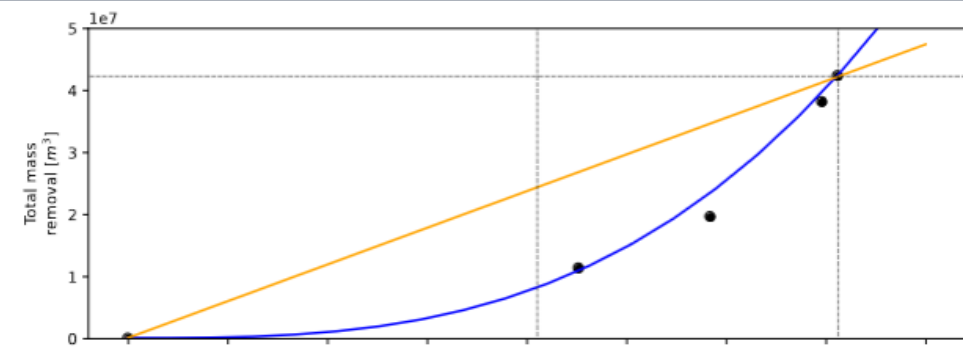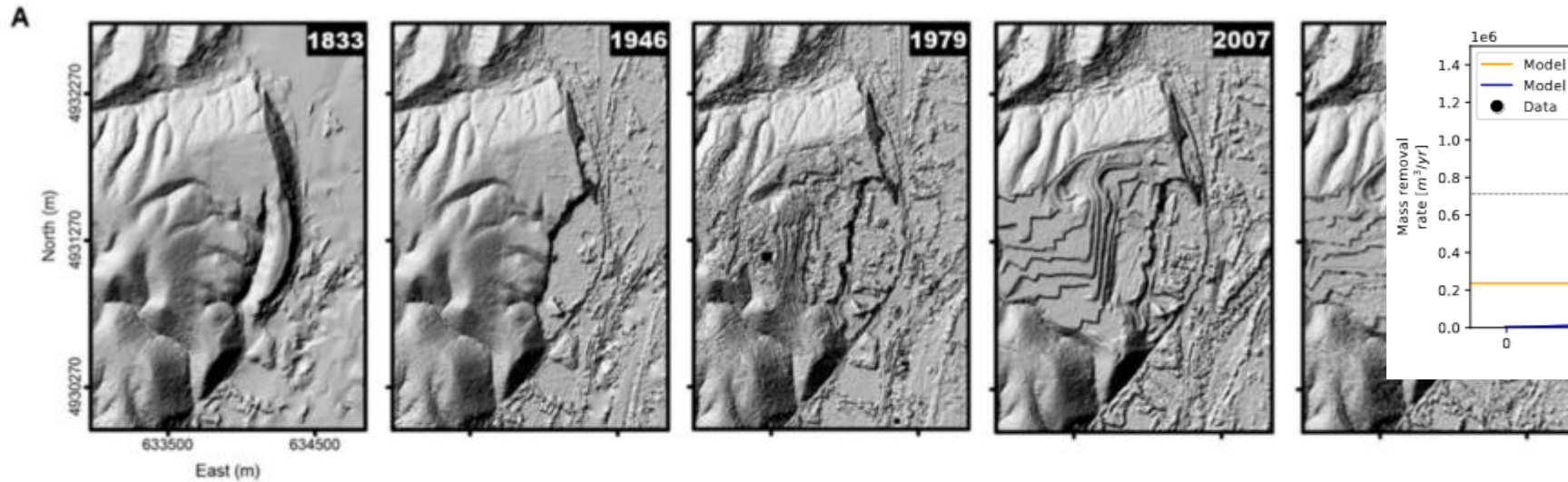🍂🌱 Photo du jour 🍂🌱

300 m

Hypothesis:
Quarry triggered shallow velocity-strengthening, without breaking deeper velocity-weakening
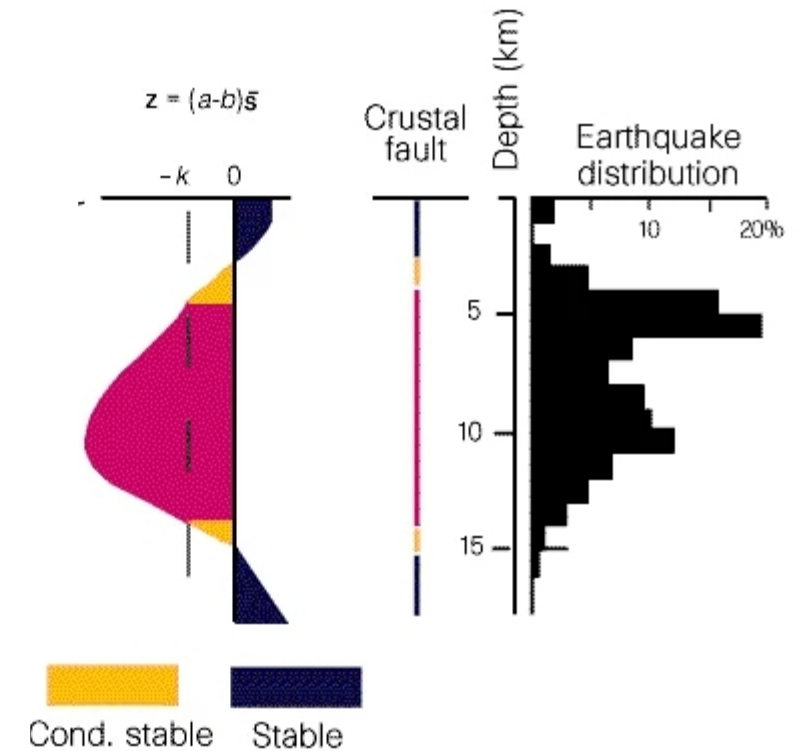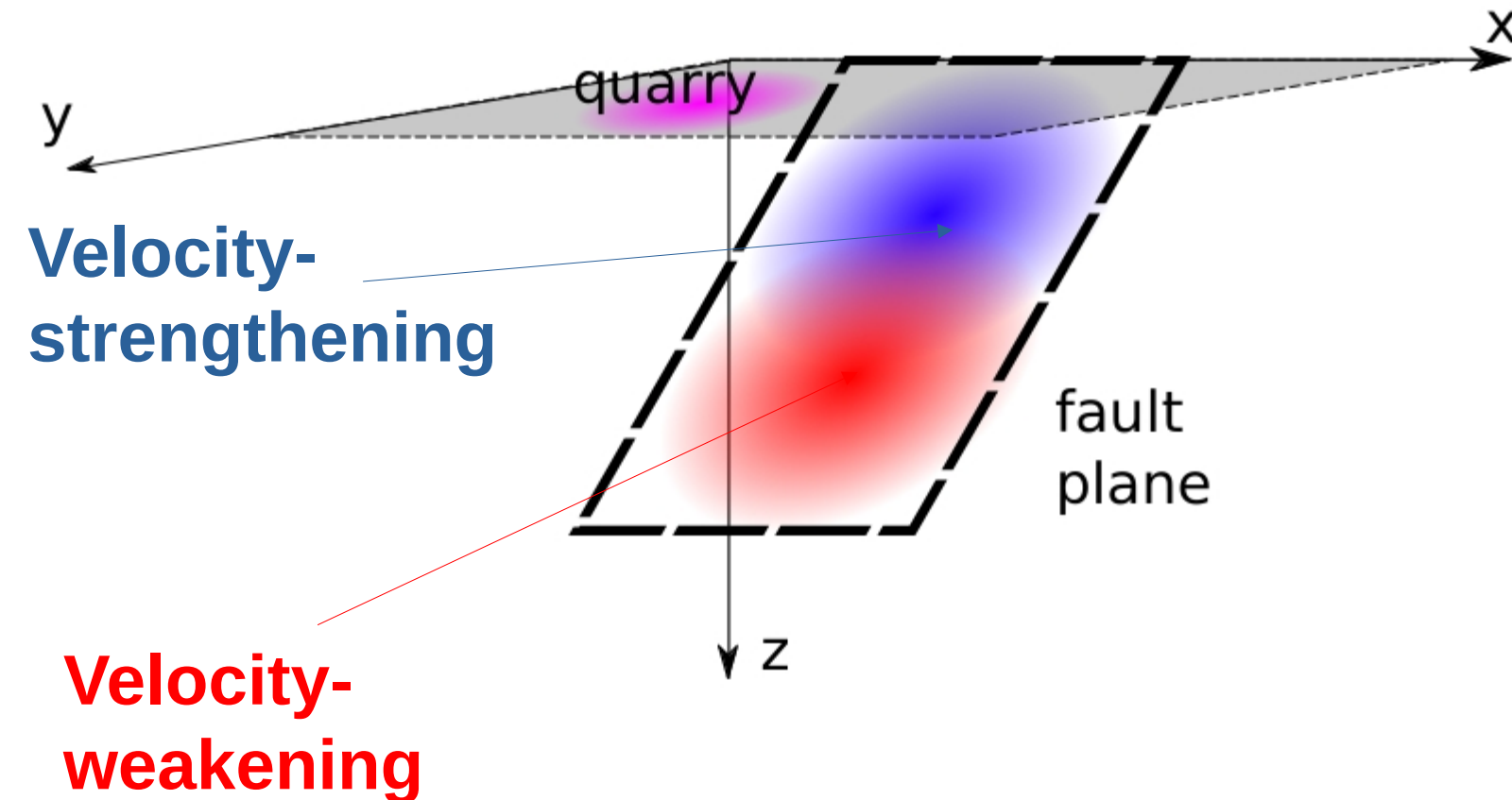
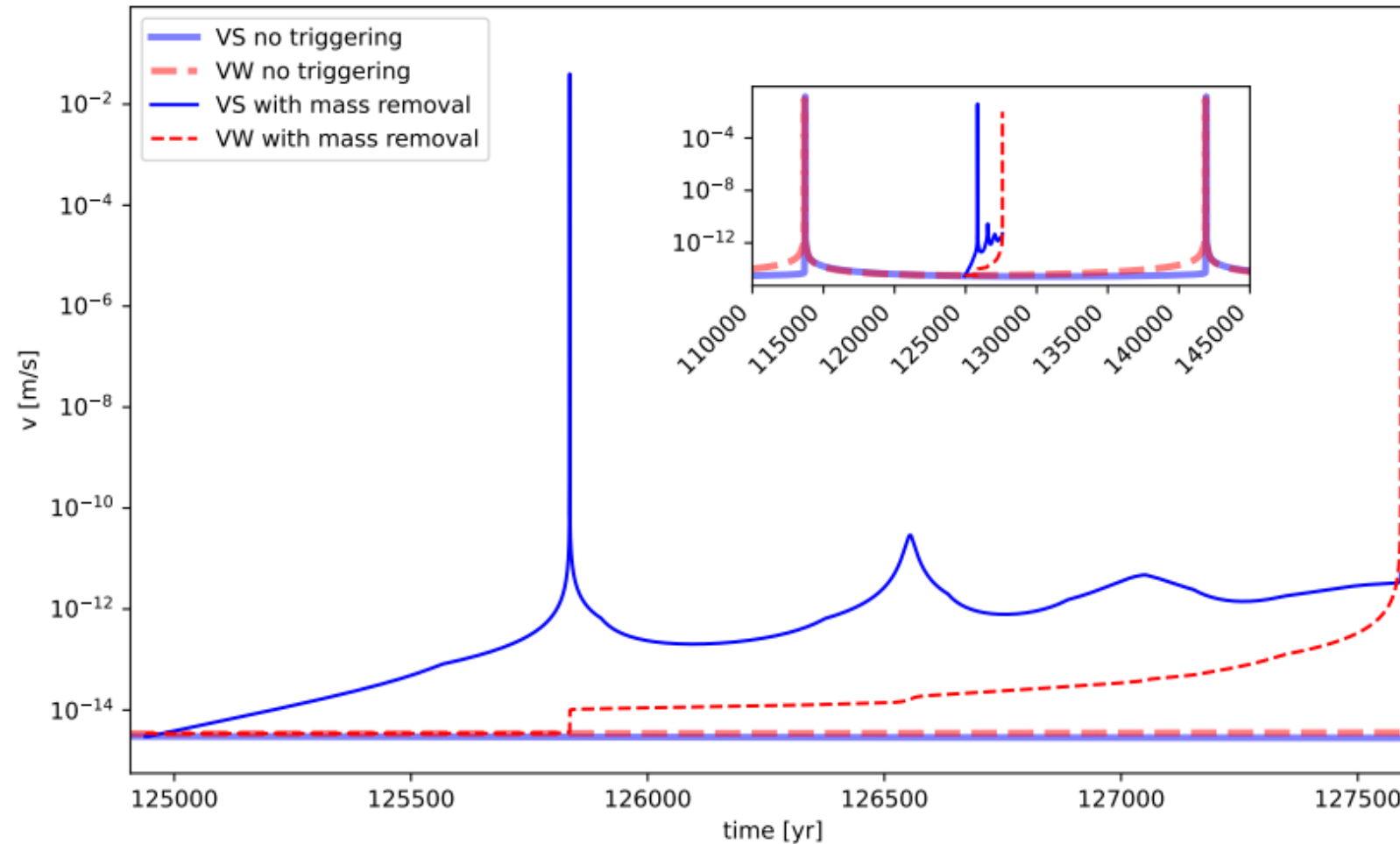Scholz, C. Earthquakes and friction laws. Nature 391, 37–42 (1998).
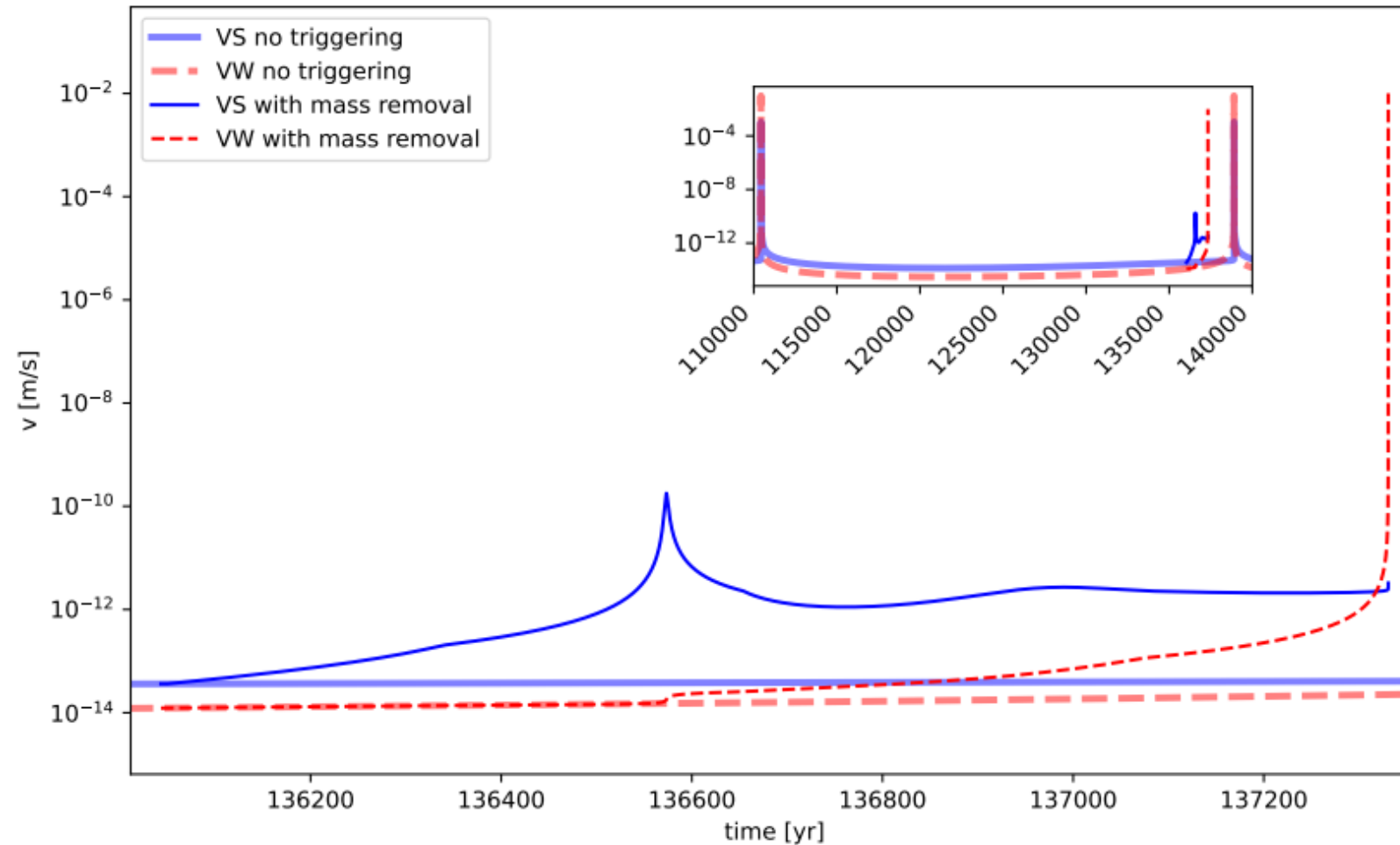
Mass Removal History from aerial imageries
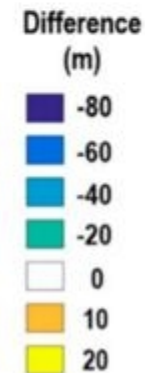
de Novellis + (2020)

Quarry can trigger velocity-strengthening fault without breaking the deeper part!

Depending on the onset time of quarrying and frictional parameters, sometimes can not!

Pinning effect of the deeper VW part and the resistance of the VS patch

$$B \approx \frac{20\,\bar{\sigma}\left(a_{vs}-b\right)D_{vs}}{\beta\,\Delta\tau_{vw}\,D_{vw}}$$
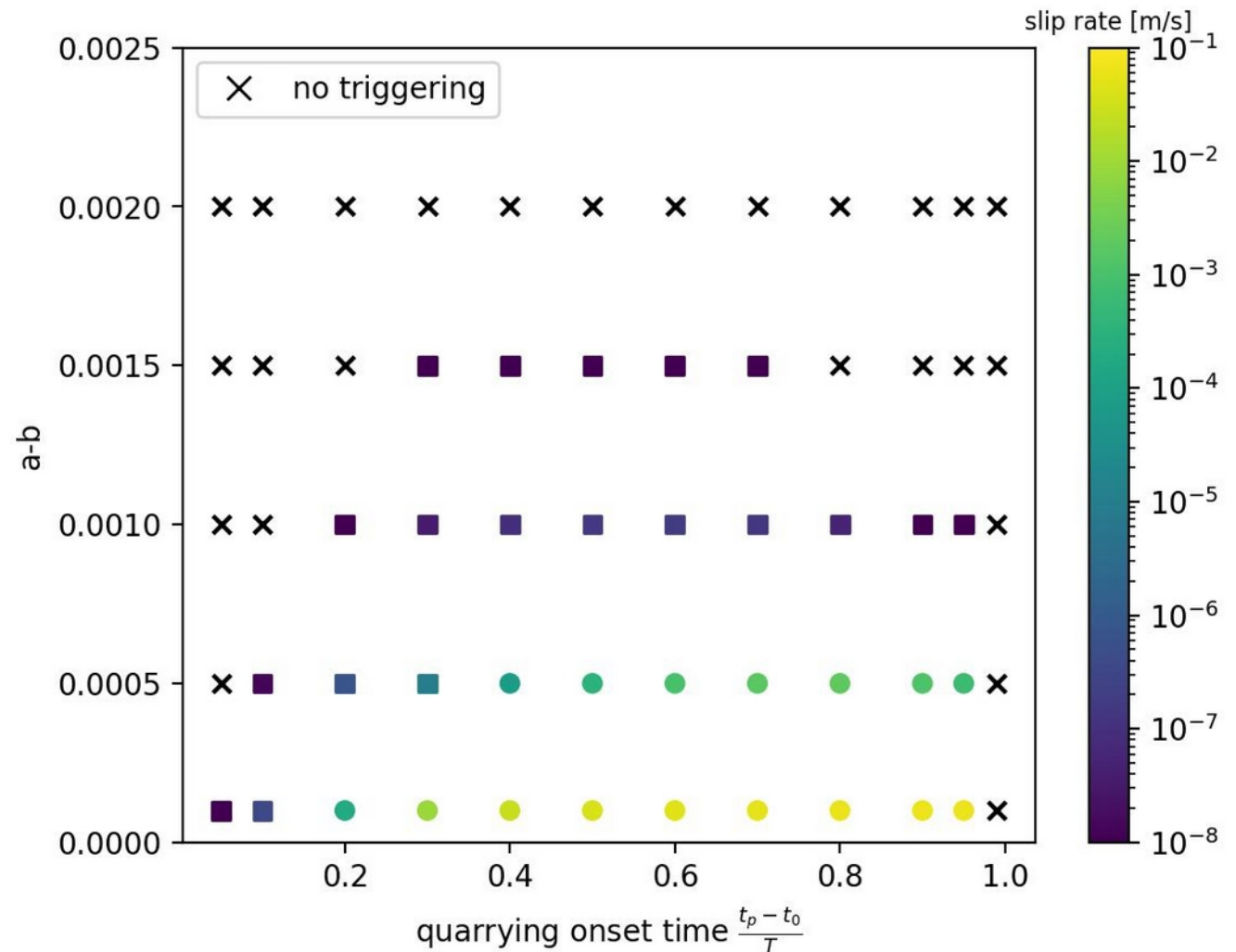
Kaneko, Avouac and Lapusta, (2010)

Larger than nucleation length
Dvs≈Dvw≈8*Lb

Below steady state.
Ω=θV/dc << 1
Li,Niemeijer, & van Dinther,(2023)
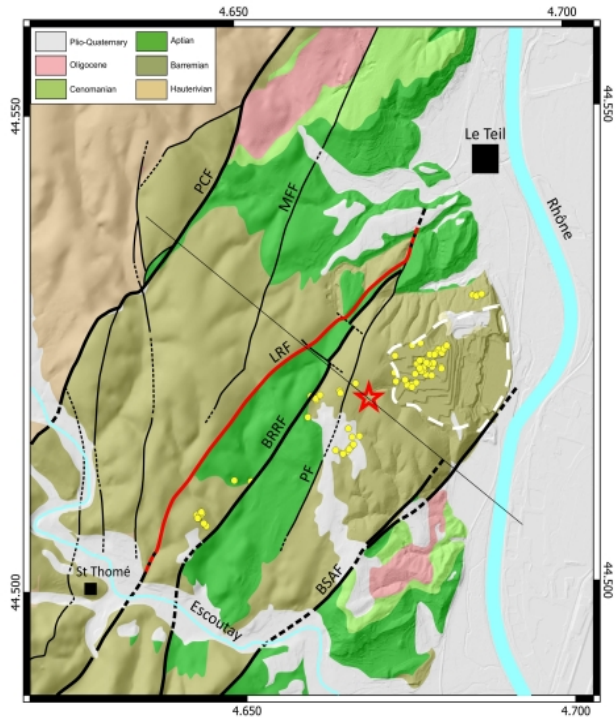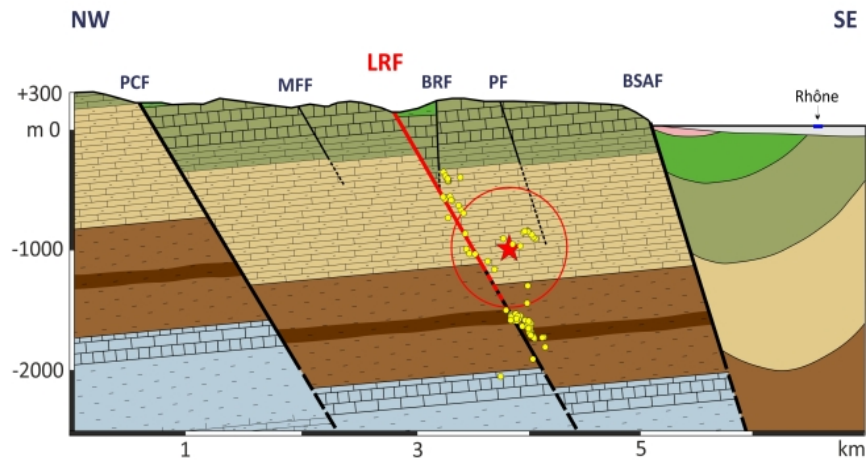
Outcropping surface rock samples

(a)

(b)

Lithologie : carte / terrain / forages

calcaire massif barrémien (~500 m) — n4c5a

calcaire marneux barrémien (~250 m) — n4a

marno-calcaire hauterivien (~900 m) — n3c
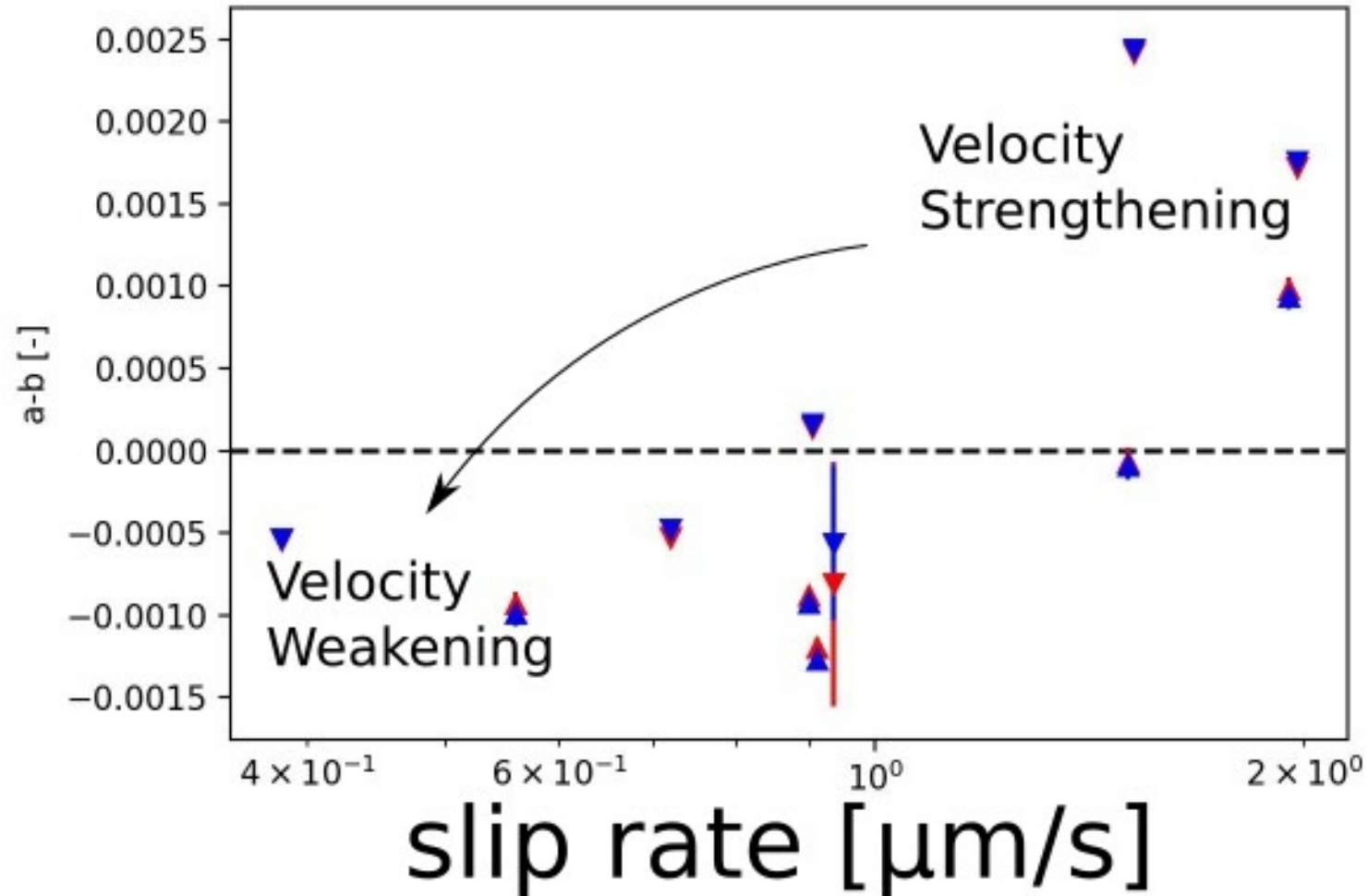
marne valanginien (> 900 m) — n2c
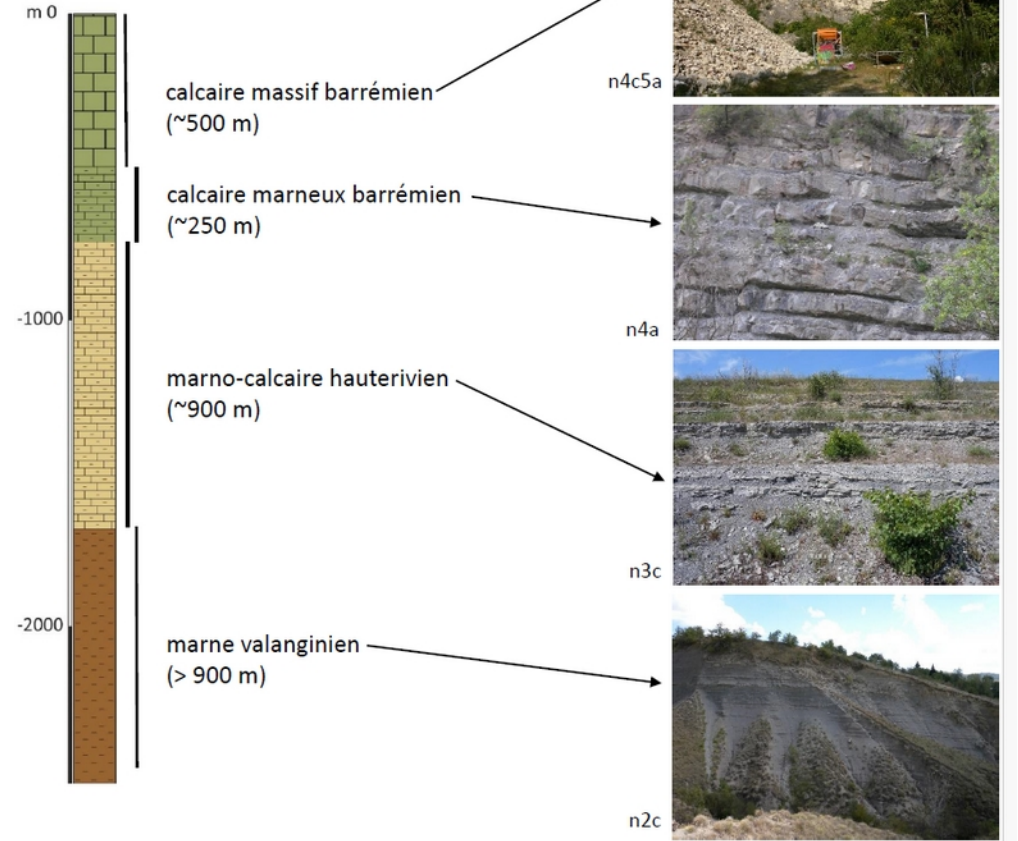
Godano, Larroque et al (in progress)

- **Laboratory Tests**

  François Passelègue's triaxial apparatus

- Velocity step test using Marls and Limestones
- https://github.com/rmskarbek/RSFit3000.git

Laboratory Tests
Velocity step tests on Limestone <50µm, 20MPa

Laboratory Tests
Velocity step tests on Marls
<50μm, 20MPa
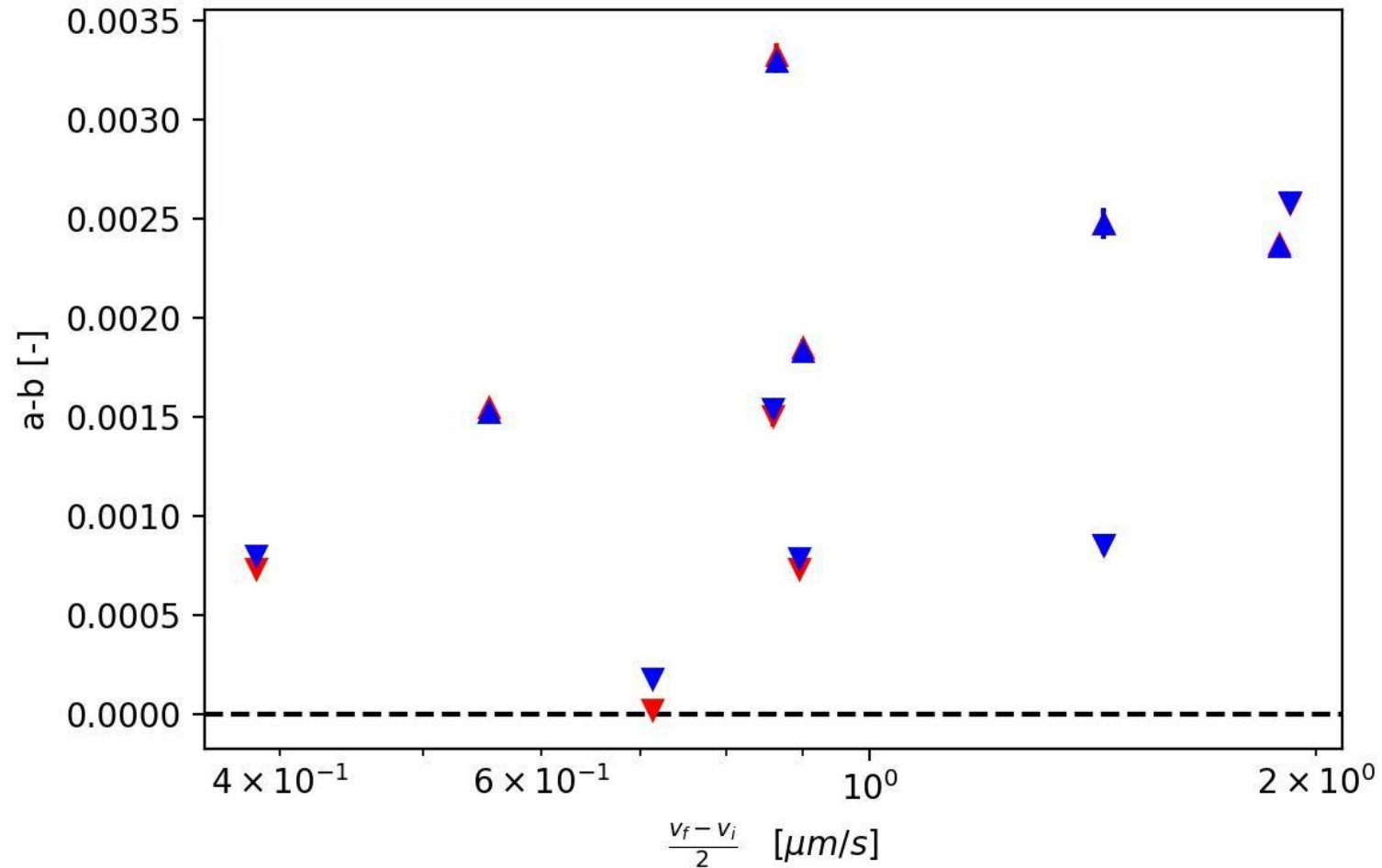
Conclusion and future works

- Stress perturbation due to mass removal can trigger shallow VS faults.

- The frictional properties of the fault play a crucial role.

- Can a similar shallow earthquake occur near Cruas?

- An opportunity drill at hypocentral depth and analyze the frictional behavior.

- EPOS-NL HPT Lab project for more mechanical tests.

Thank you for listening

I am happy to answer your questions