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The Mw4.9 Le Teil surface rupturing earthquake in southern France: New insight on seismic hazard assessment in stable continental regions

J-F Ritz [1], S. Baize [2], M. Ferry [1], C. Larroque [3], L. Audin [4], E. Mathot [5], B. Delouis [3]

1: Géosciences Montpellier, Univ. Montpellier, CNRS, Montpellier

2: IRSN, Institute of Radiological protection and Nuclear Safety, Fontenay-aux-roses

3 : Géoazur, Univ. Côte d'Azur, CNRS, Observatoire de la Côte d'Azur, IRD, Valbonne

4 : ISTerre, Univ. de Grenoble Alpes, CNRS, IRD, Grenoble, France

5: Terradue Srl, Rome

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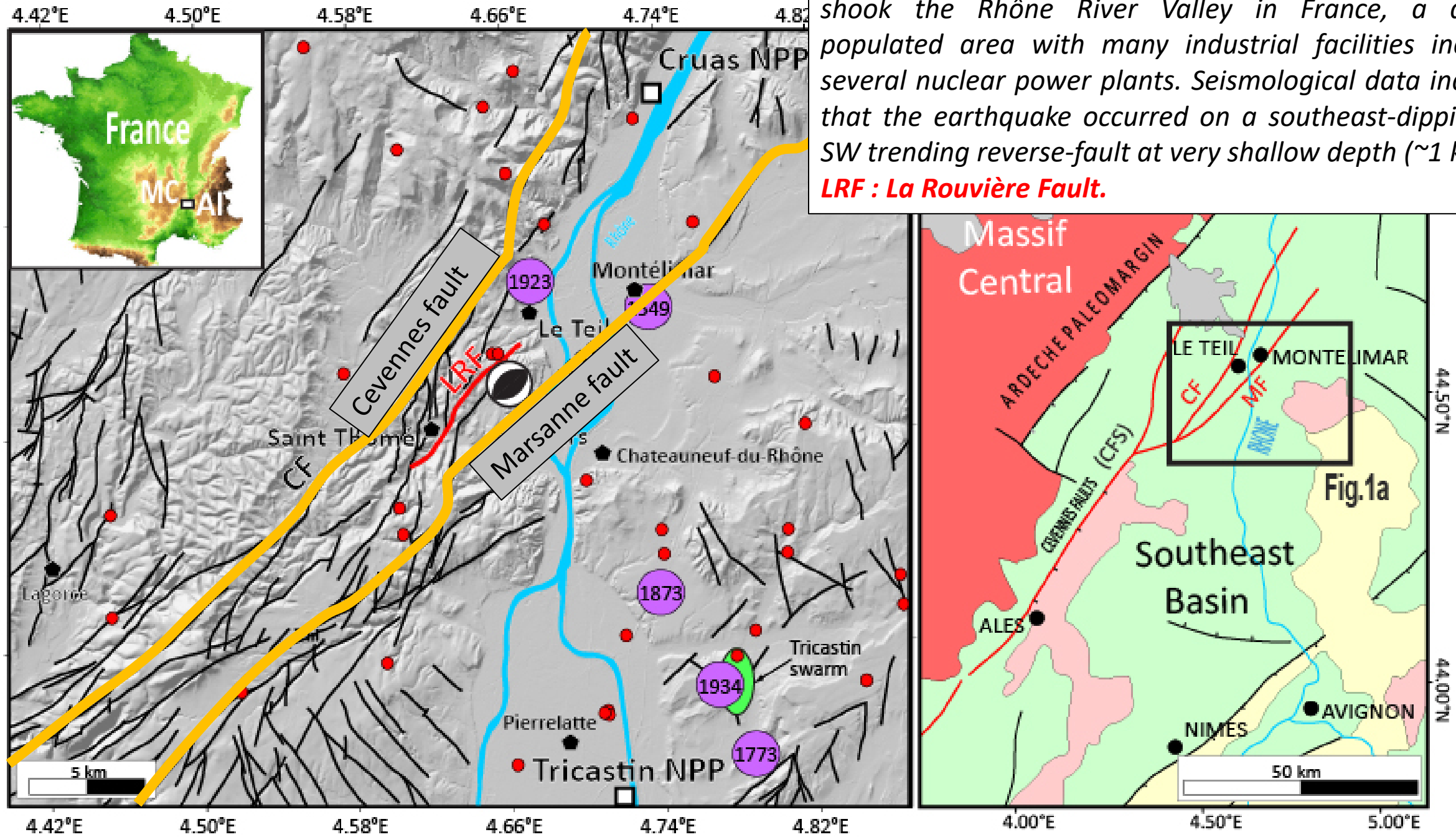
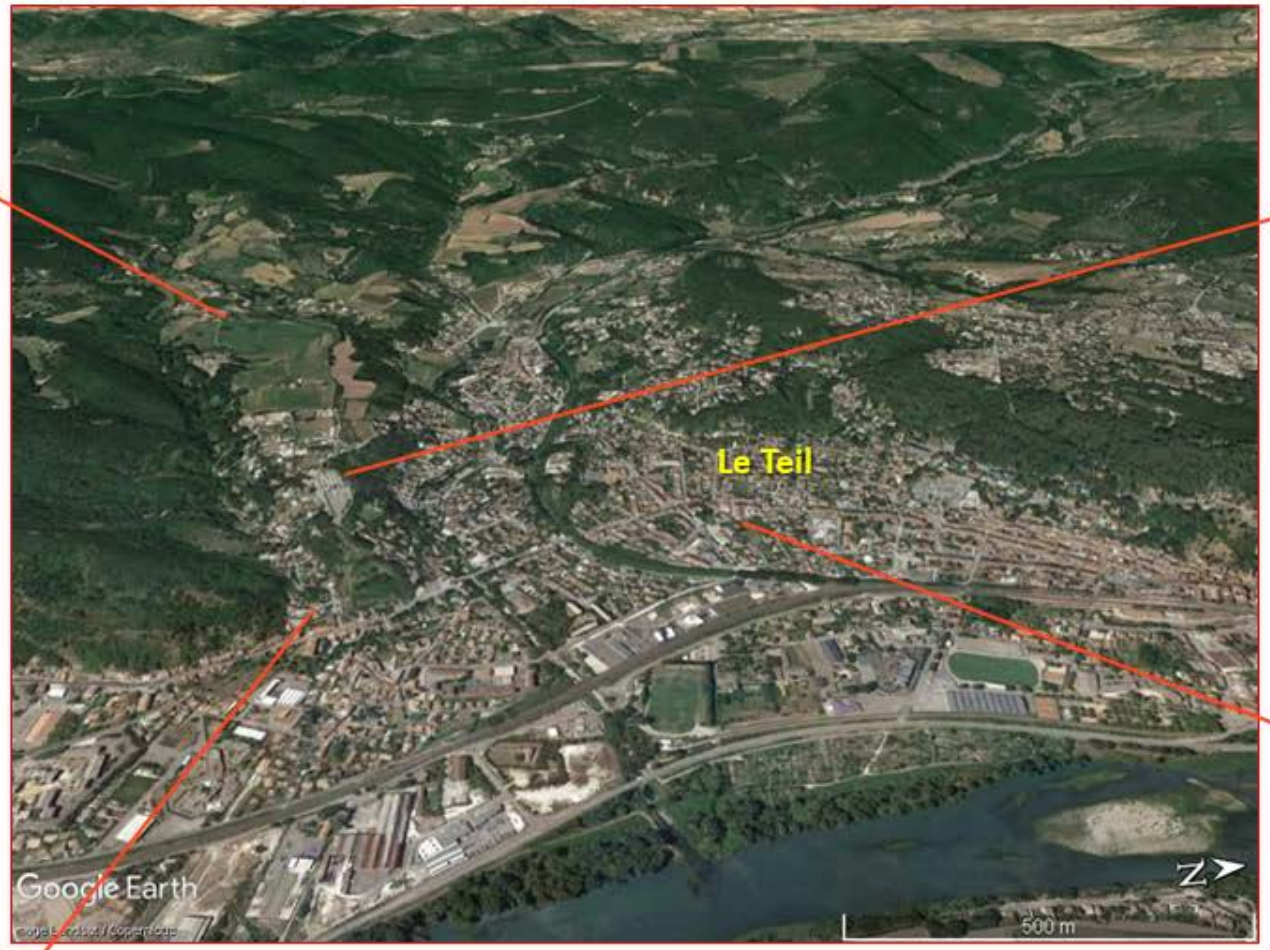
On November 11th 2019, the Mw4.9 Le Teil earthquake shook the Rhône River Valley in France, a densely populated area with many industrial facilities including several nuclear power plants. Seismological data indicated that the earthquake occurred on a southeast-dipping NE-SW trending reverse-fault at very shallow depth (~1 km).

LRF : La Rouvière Fault.

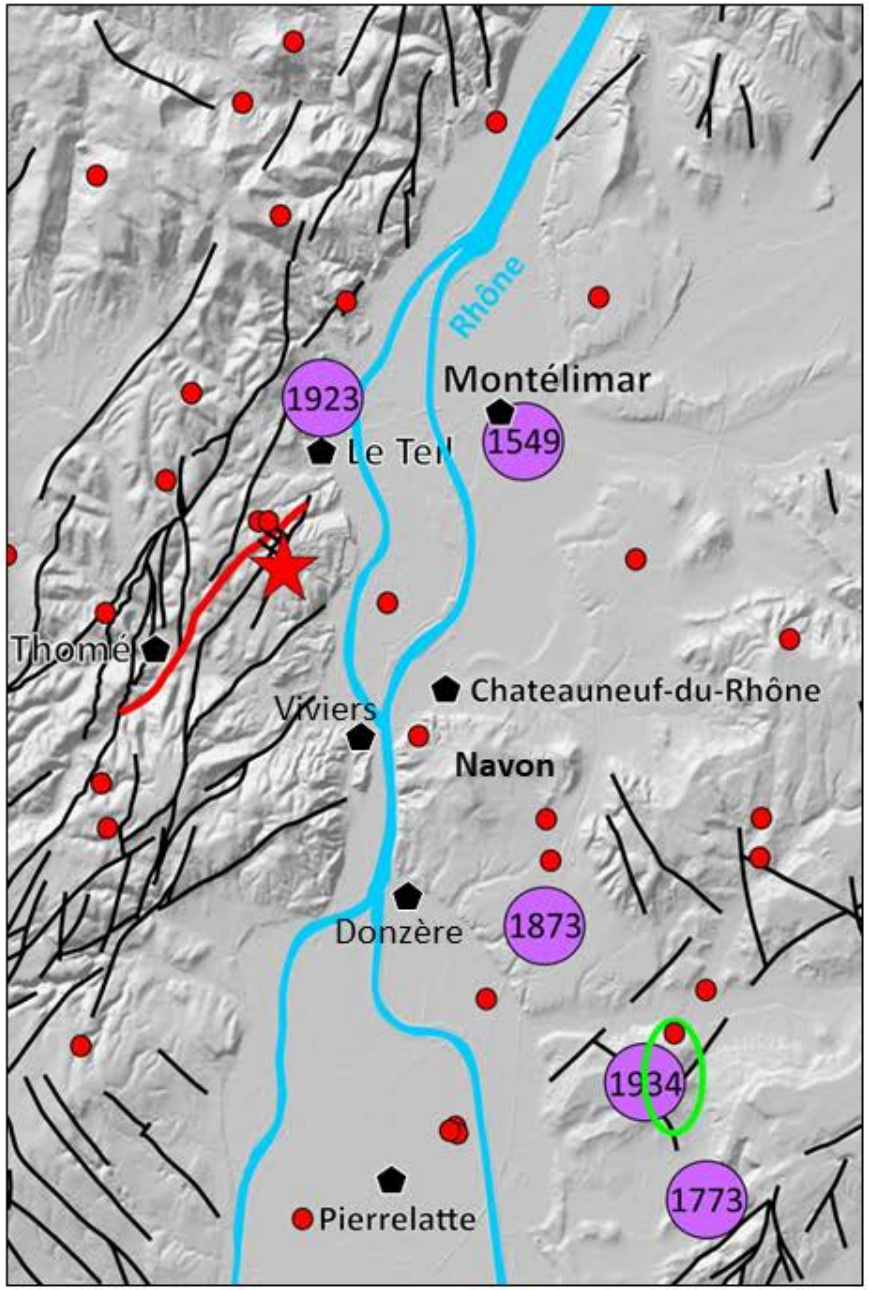


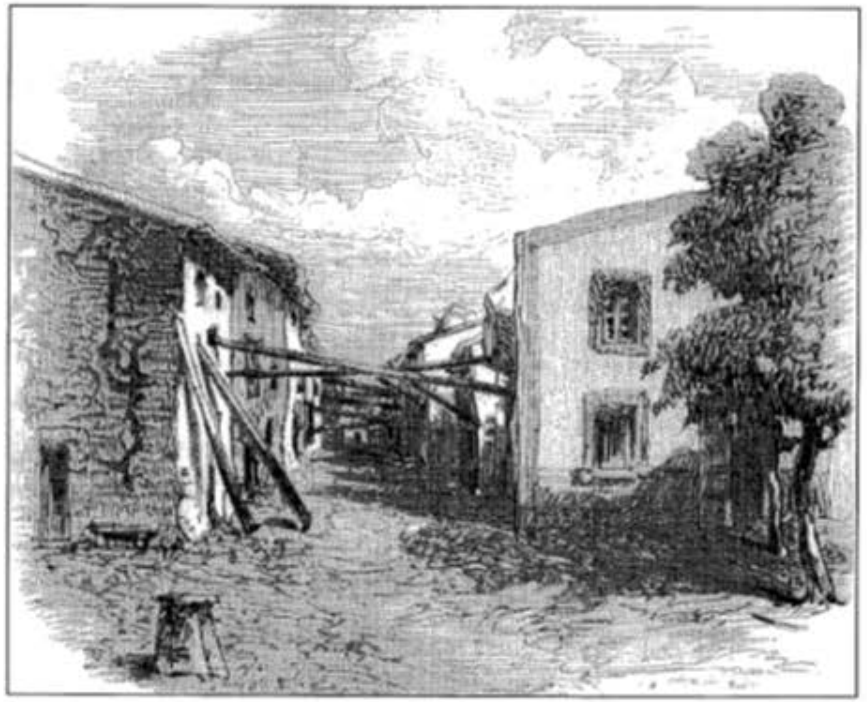
Severe damages in the epicentral area



- Old houses seriously damaged or collapsed
- Many cracks in load-bearing walls
- Collapsed ceilings
- Costs > 50 millions €

The region had already felt some earthquakes in the historical period:





8 August 1873
(estimated magnitude Mw 4.1)

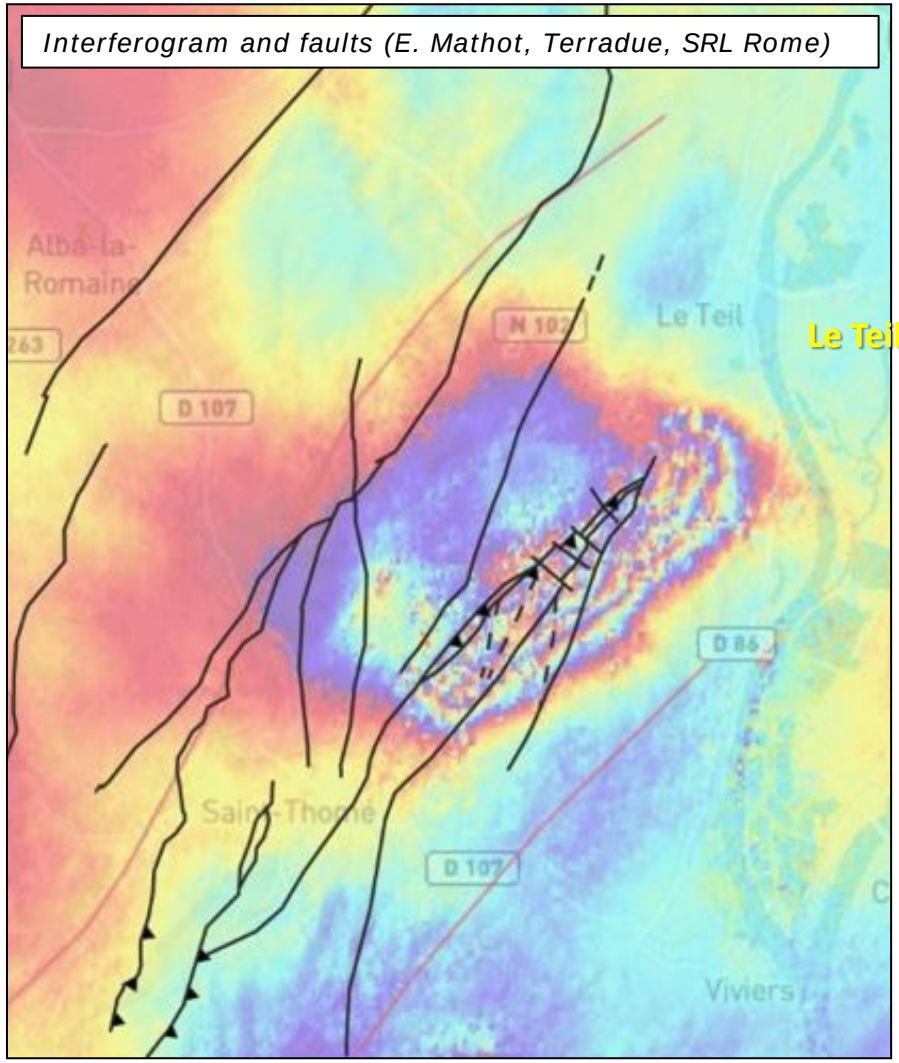
Chateauneuf
Donzère
Viviers

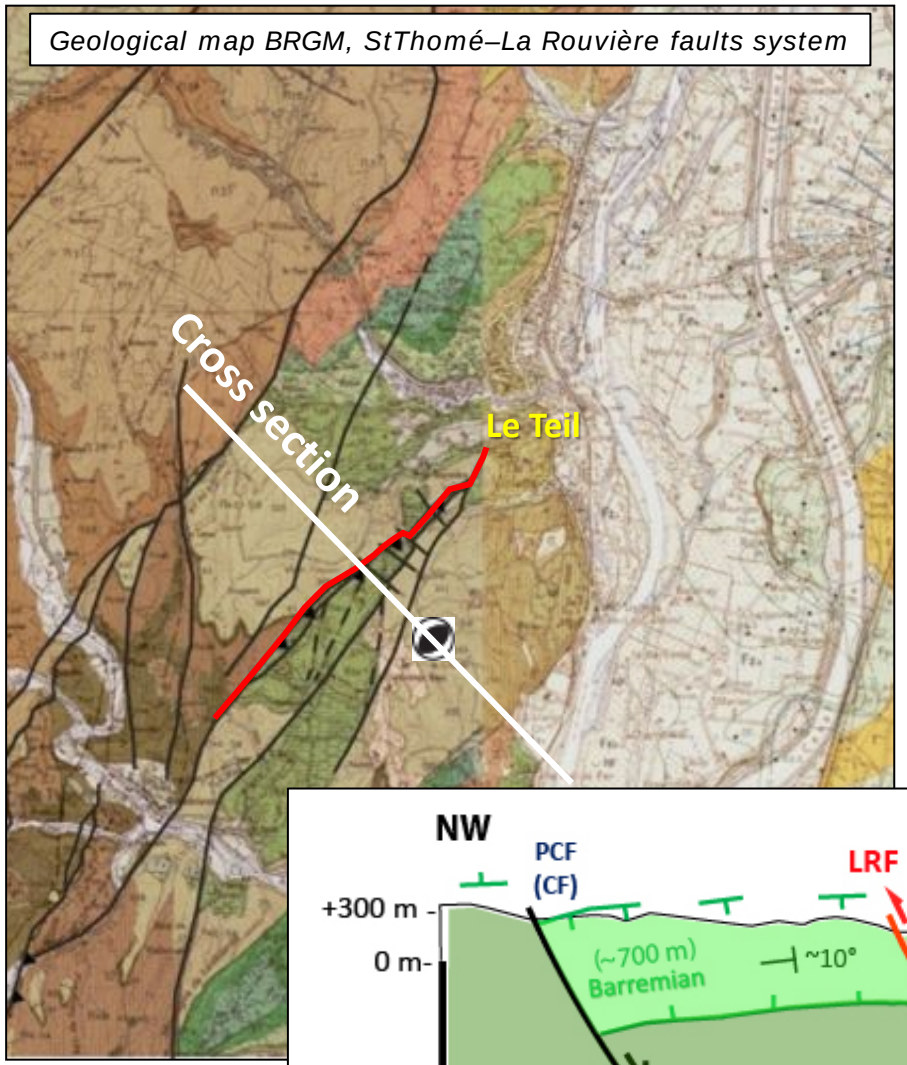
La montagne de Navon, entre Châteauneuf et Donzère, se serait fendue lors des secousses du 8 août 1873. Signalons aussi que l'eau des puits et des sources fut troublée par les vibrations du sol.

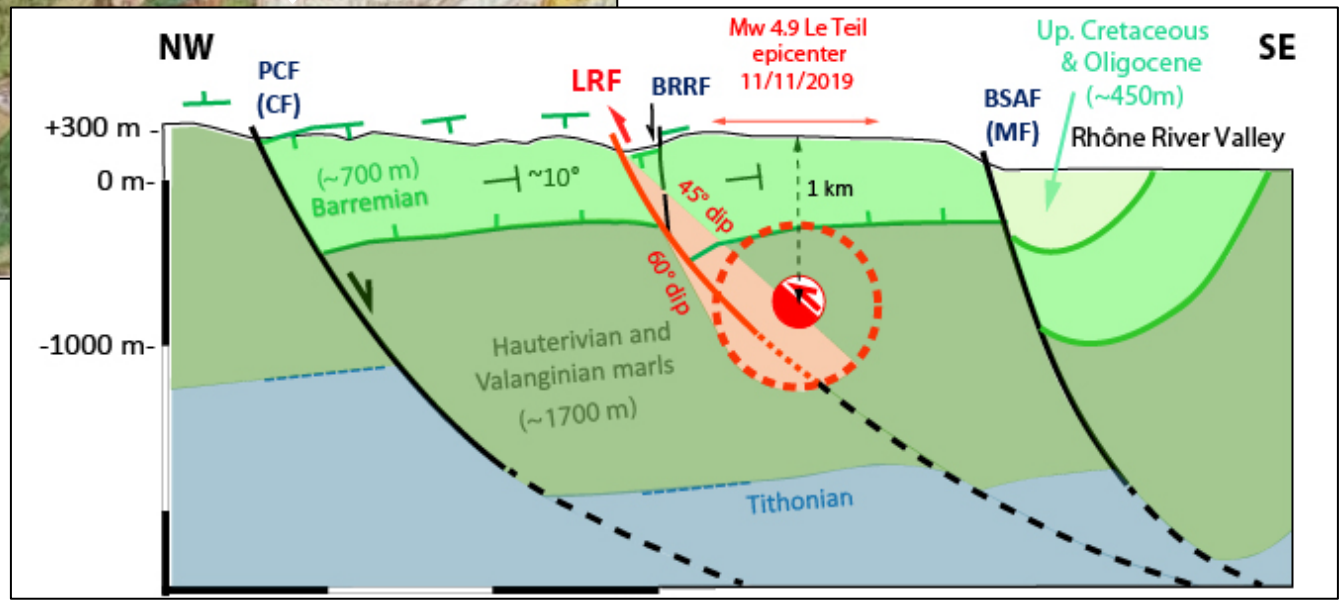
Ratz, 1998

"The Navon mountain between Chateauneuf and Donzère would have split during the tremors of August 8, 1973".

Beams supporting house walls badly damaged at Chateauneuf-sur-Rhône







InSAR observations indicated uplift of the SE hanging wall up to 15 cm along a NE-SW trending ~5 km-long discontinuitY matching with **La Rouvière Fault.**

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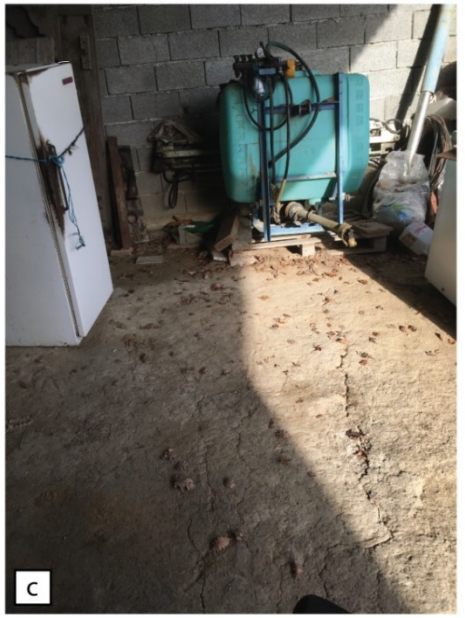
We performed field investigations to search for surface rupture within 48 h after the earthquake. InSAR results were crucial for surface rupture investigations as has already been demonstrated in similar studies. Given the density of vegetation that covers a large part of the area, we focused on roads and paths crossing the InSAR discontinuity.

The documented surface ruptures correspond to open fissures with a NE-SW orientation . In a few cases (4), we observed compressional features such as small folds or reverse faults with the southeastern block thrusting over the northwestern one. In total, we observed evidence of surface rupture at 17 separate locations distributed over 4.5 km along the InSAR discontinuity.



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Fissures_(collapse_talus)
2_Fissures_Goudron_~N160
Indice_7_(Fissure_compressive_N060_Mr Quartier)
Indice 3 (Fissure_18m_N015-050_MrSylvain)
Fissure (petite_~N100_//_talus?) ?
Fissure_Talus_~2m_N045_(collapse ?)
Fissure_Goudron_N090
Indice 6_(Fissure_~10m_N045_//chemin_et //_talus ?)
Indice 2 4(Fissures_N080/090, 1 N045)_piste_extrados_possible)
Indice_8_Fissure_30m_N045_Hangar_Ronjon_(HL)
Indice 4 (Fissure_10m_N045_Champ_Ronjon)
Fissure _~50 m_N090_champ_Lavande_(HJ)
Indce_5_(petit_scarp_chemin)
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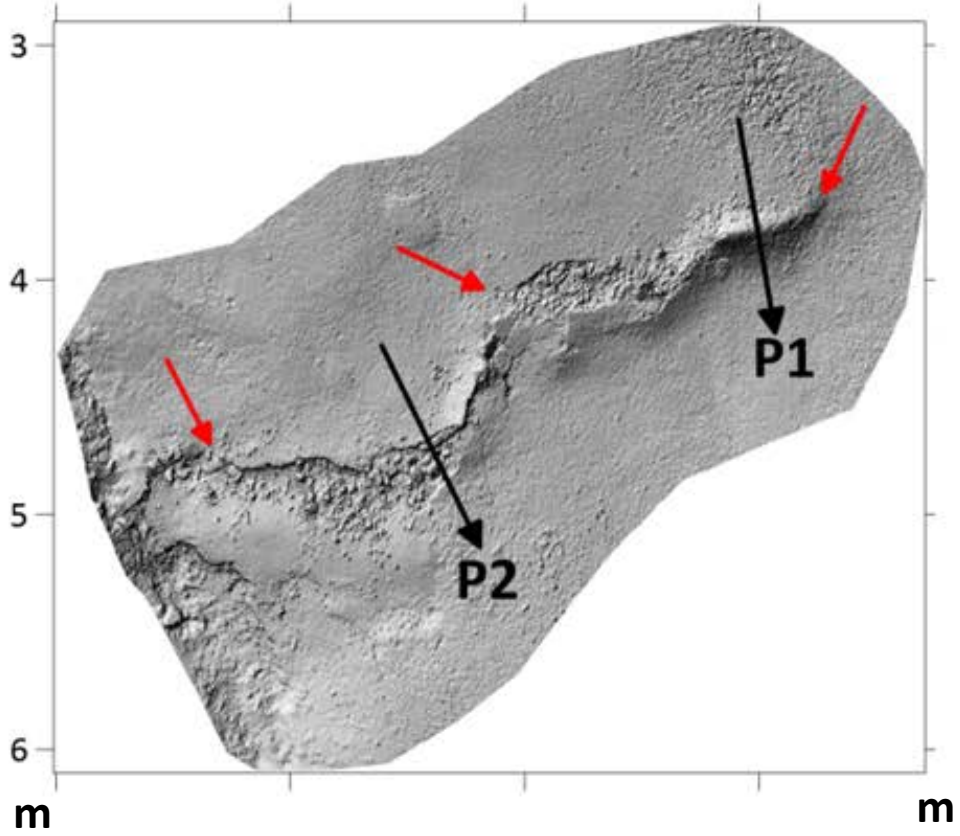
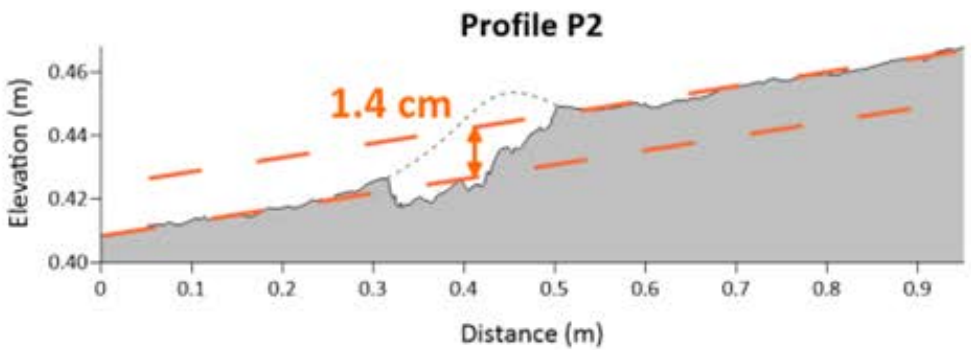
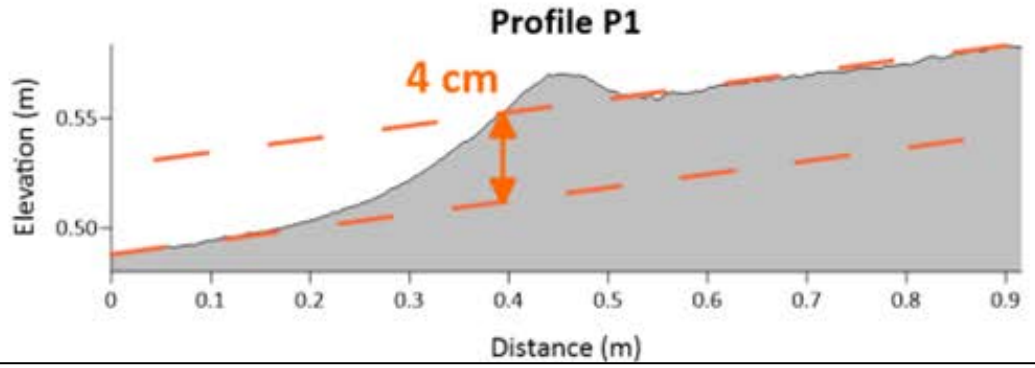
17 evidences of surface ruptures distributed over a length of 4.5 km along the InSAR discontinuities
altitude







In order to accurately quantify the deformation of the ground surface, we surveyed the best locations with a terrestrial laser scanner (Faro), which allowed estimating a vertical uplift of the SE compartment comprised between 2.7 and 13 cm

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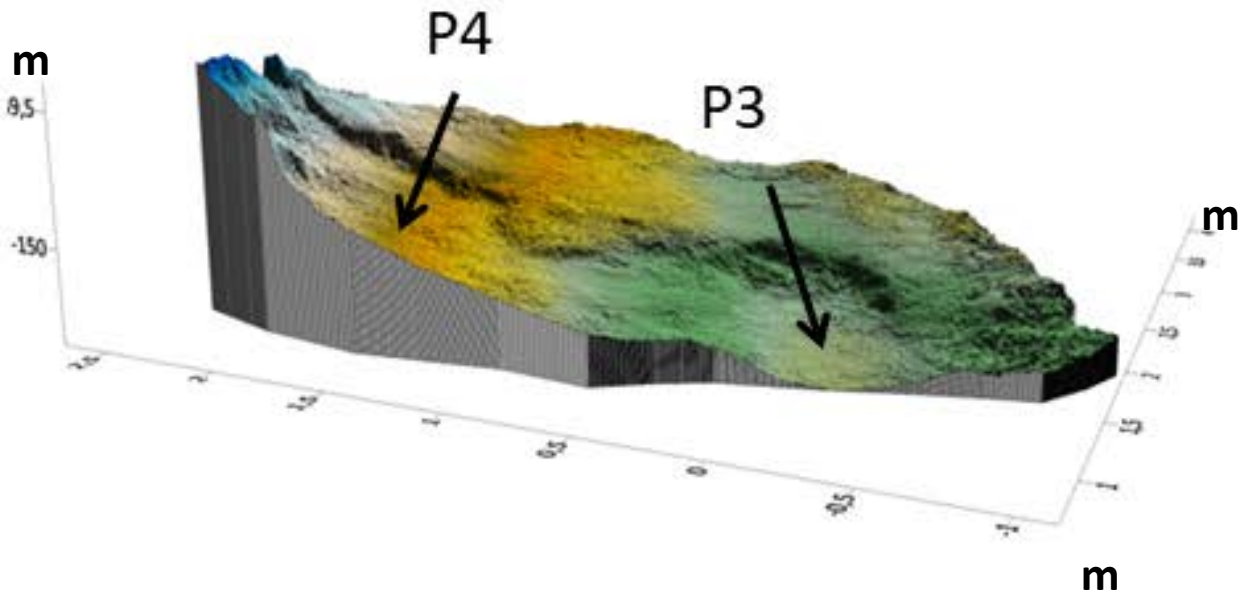

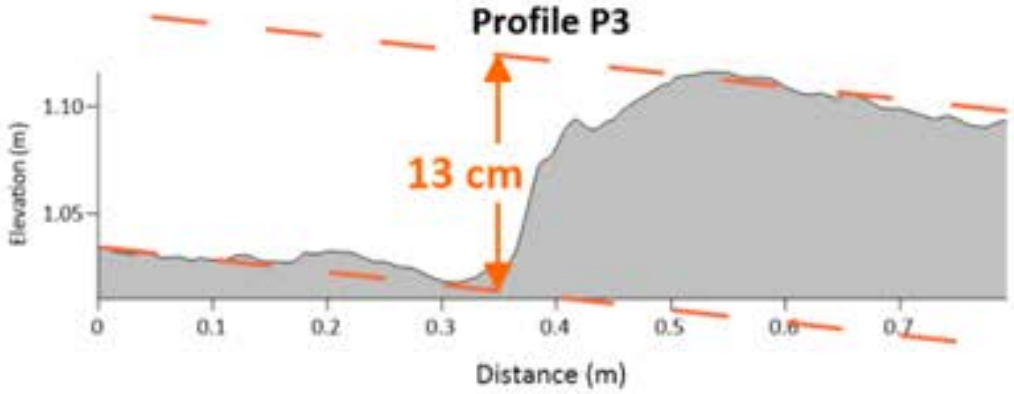

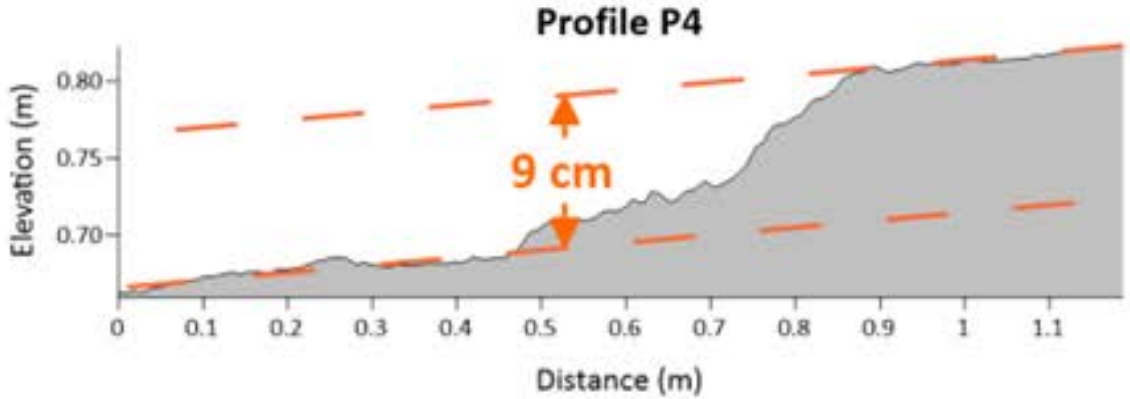

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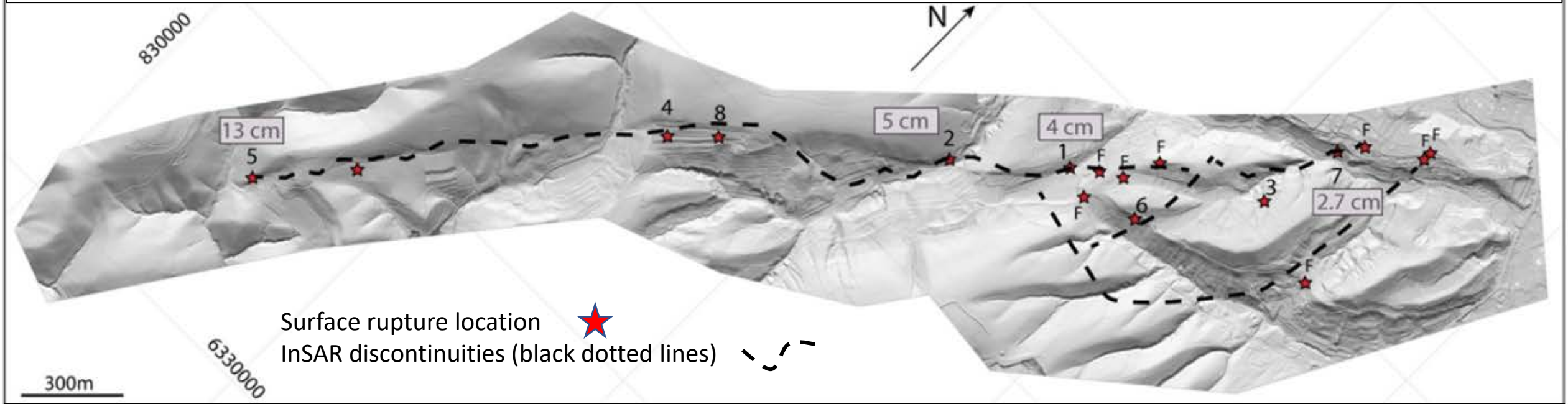
10 over the 17 evidences of surface ruptures – among which the four main evidences 1, 2, 5 and 7 - are located upon the inherited Oligocene normal LRF, which defines a clear and continuous topographic scarp on a 25-cm-resolution shaded relief topographic map (DEM obtained from a post-earthquake airborne LIDAR survey, 500m-high, UTM grid).



We estimated the **equivalent Mw** using measured rupture parameters and the equation **Mw = 2/3log Mo – 6.1** (with Mo = μ.L.W.D) (Kanamori, 1977; Hanks & Kanamori, 1979), expressed in SI units

- **L = 4600** (length determined visually from the interferogram) to **5200** m (detectable length from InSAR profiling),
- **W = 1400** to **2800 m** (considering a focal depth of 1 ± 0.5 km, a fault dip of 45°, and assuming that the rupture extended over 500 m in depth from the hypocenter).
- **D = 0.12 m** (mean vertical displacement) **to 0.14 m** (accounting for a 45° rupture dip),
- **$\mu = 2.10^{10}$** to **$2.5.10^{10}$ N/m2**, accounting for the shallowness of the rupture and determined from density and shear wave velocities in the considered stratigraphic layers (Cornou, personnal communication),

Mw 4.7 - 5.0 (consistent with Mw estimated from the seismological data.

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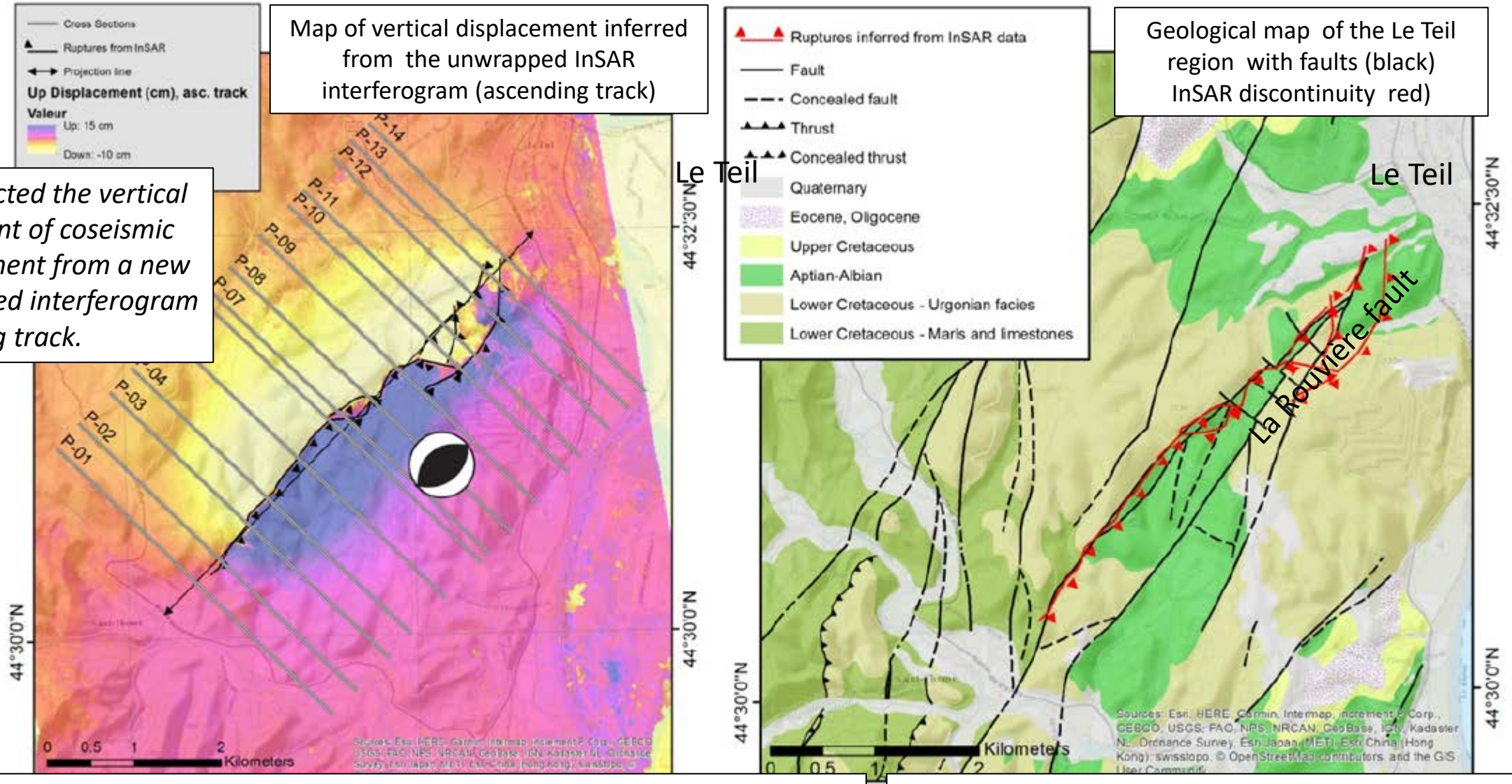
Map of vertical displacement inferred from the unwrapped InSAR interferogram (ascending track)

Geological map of the Le Teil region with faults (black) InSAR discontinuity red)

We extracted the vertical component of coseismic displacement from a new unwrapped interferogram ascending track.



This allowed us identifying the largest displacement gradient lines, which we interpreted as likely surface breaks. Those gradient lines cross a hilly landscape of Cretaceous terrains dipping gently northwestwards with an elevation that decreases eastward from 350 m to 50 m in the Rhône valley, and are almost entirely located along the inherited LRF between contrasting lithologies.

We then extracted elevation changes along 14 profiles cross-cutting perpendicularly a projection line following the NE-SW general trend of the gradient lines. Those profiles allowed estimation of the total deformation produced by the earthquake at the surface.

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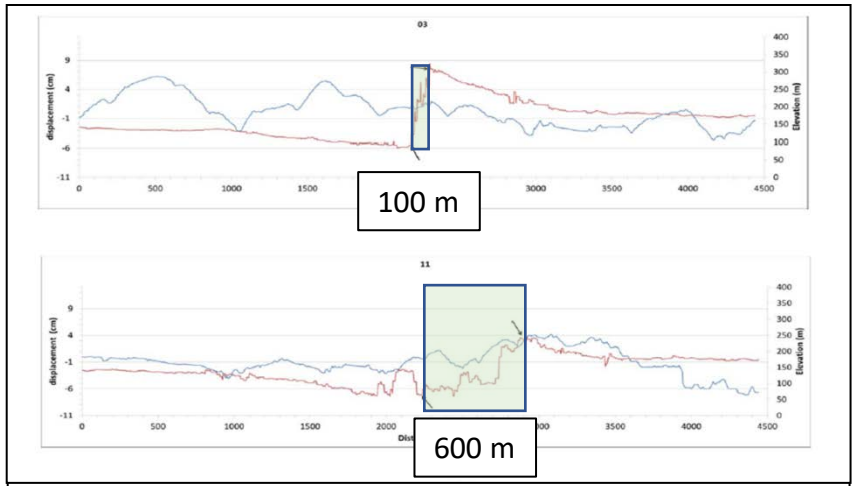
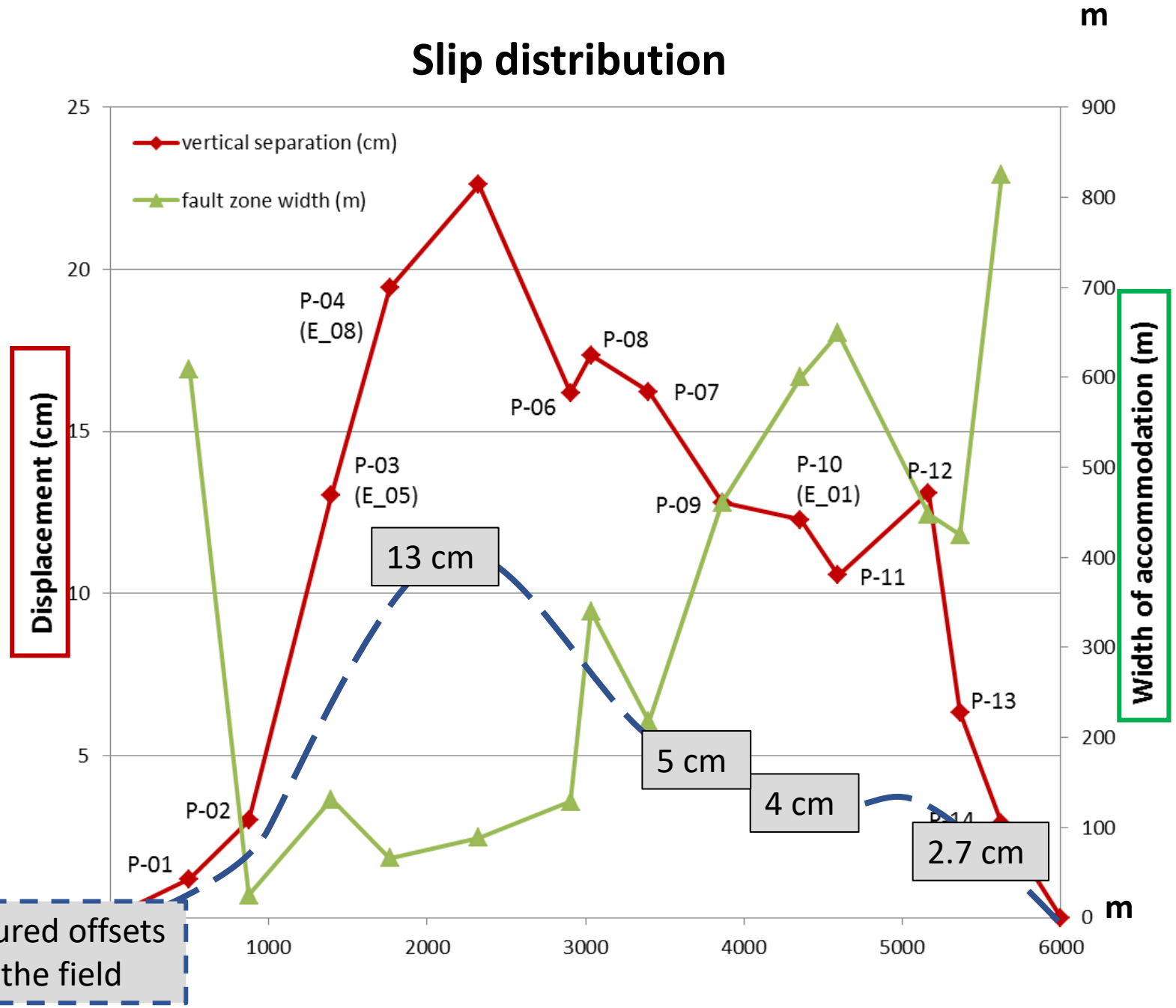


The 14 profiles allowed estimation of the total deformation produced by the earthquake at the surface. We reconstructed the distribution of the vertical component of coseismic slip along the rupture that we compared to the width of the deformation zone. We observed that the deformation is larger and more localized in the southern part of the rupture, with a maximum vertical fault displacement of 23 cm.

> 50% of the deformation is distributed off-fault in a 100-600 m wide zone.

Slip distribution



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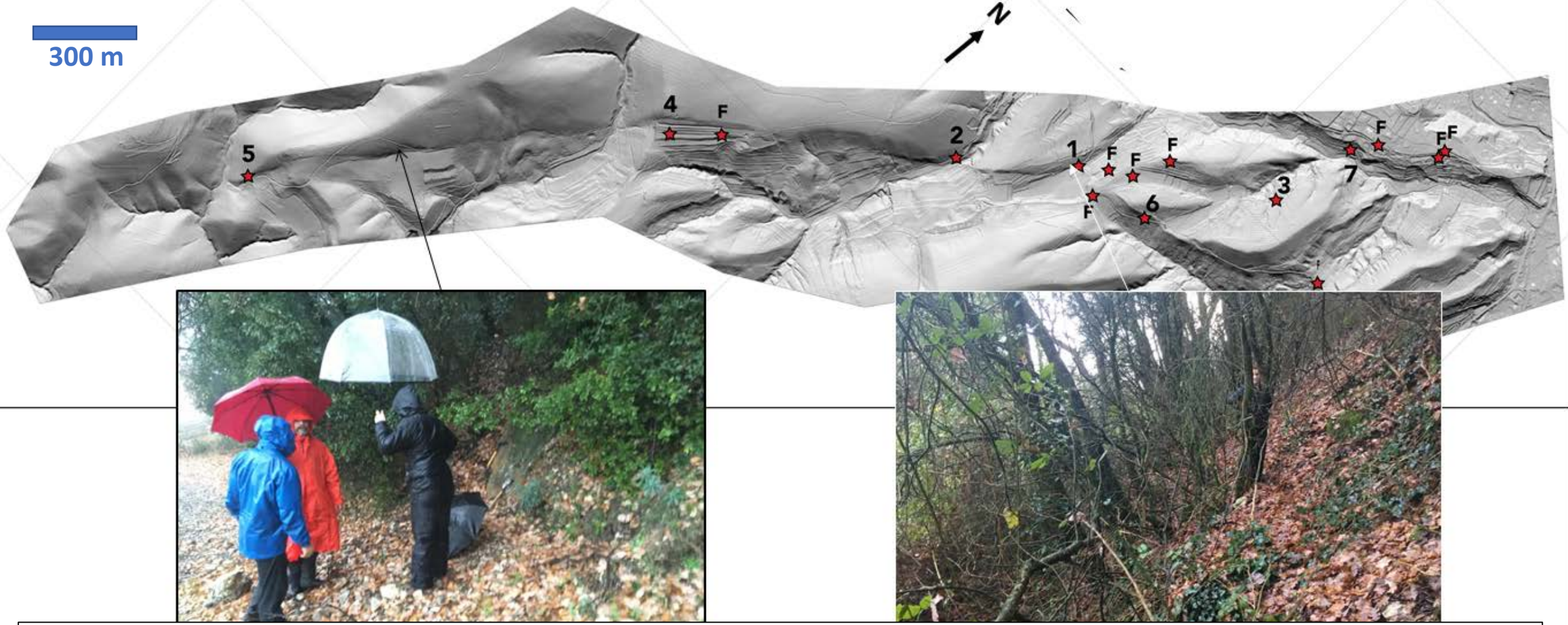
No observation (*a priori*) of multiple (cumulative) deformations associated with the inversion of the Oligocene normal fault



In the field, along the Oligocene normal fault scarp, we observed in few places, normal fault planes in competent lower Cretaceous (Barremian) carbonates exhumed by agricultural land use and/or differential erosion where carbonates are juxtaposed to marl-rich units. These fault planes strike mainly N30-40°E and dip between 45 and 60°E, with steep slickensides indicating in a few places an unambiguous normal cumulative movement with a slight left-lateral component.

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New questions arise / seismic hazard

- 1 / Did the la Rouvière fault moved in the past, or is it the first time that it has been reactivated since the Oligocene?

- 2 / Could the other faults in this section of the Cévenol network behave in the same way, with “one-off” rupture in time, or is there a main fault in the network which accomodates the essential of the deformation?

- 3 / Could the whole Cevenol network behave the same way over its entire length? Or did the local tectonic framework (contact zone between the reliefs of the Massif Central and the SE Basin) play a role in the reactivation mechanism of this part of the network?

- 4 / If one-off ruptures are prevalent within the fault system or throughout the region, should we consider all inherited faults as potential sources of earthquake in future models of seismic hazard?

In conclusion, the 11 november 2019 Mw4.9 Le Teil earthquake is an unprecedented earthquake in France and intraplate Europe for which seismological, geodetical and surface rupture data could be gathered with modern techniques. For those reasons, the Le Teil earthquake represents a turning point in the way of considering seismicity and the risk of surface rupturing events in France or similar stable continental regions where tectonic inheritance is strong and strain rates very low.

Thank you for your interest !

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