The 2019 Le Teil surface-rupturing earthquake along the La Rouvière Fault within the Cévennes fault system (France): What does paleoseismology reveal?

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Abstract. The 2019-11-1, Mw4.9 Le Teil earthquake occurred within the NE termination of the Cévennes faults system (CFS) in southern France, along the La Rouvière fault (LRF), an Oligocene normal fault which was not known to be potentially active. This shallow moderate magnitude reverse-faulting event produced a 5 km-long surface rupture and strong ground shaking. No evidence of previous quaternary activity was observed in the morphology, raising the question whether the fault had been reactivated for the first time since the Oligocene or had broken the surface in the past without being detected in the morphology. To address this issue, we carried out paleoseismological investigations to analyze and characterize evidences of paleo-ruptures in Quaternary deposits. We discovered that at least one event prior 2019, occurred between 13.5 and 3.3 ka within the central part of the fault segment that broke in 2019, and that a possible earlier surface-rupturing event occurred within the northern part of this segment during the 16th century. Further investigations coupling sub-surface geophysical investigations and trenching are now carried out within the southern and northern segments of the LRF as well as along the other fault segments of the CFS.

1 Introduction and Tectonic Setting

The Mw 4.9 Le Teil earthquake occurred in southern France, in the Rhône river valley near Montélimar, on November 11, 2019 (Fig. 1A). It corresponds to a historically

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unprecedented event in several ways. For the first time, a surface rupture associated with an earthquake was observed and comprehensively measured on live in France [1, 2]. It was also the first time that an earthquake was clearly associated with the reactivation and the inversion of an ancient fault – i.e La Rouvière Fault - inherited from the Oligocene extensional period [1]. The La Rouvière Fault belongs to the Cevennes Faults system (CFS) a major crustal structure, inherited from a rich polyphased tectonic history that began during the Variscan orogeny. This NE-SW trending, 120 km-long fault system is located at the boundary between the Massif Central crystalline basement and the sedimentary basin of southeastern France. Several authors stated that this fault system could have been active, either normal [3] or transcurrent [4] during recent times, based on geomorphological analyses. However, definitive evidence of past surface-rupturing events was missing, leading to intense debate [4, 5, 6, and 7]. As for the LRF strictly speaking, no evidence allowing assessing its potential activity have never been reported in the literature, so that this fault segment is not reported in the IRSN fault data base [8].

The rupture, with a focal depth estimated at 1.5 ± 0.5 km [1, 9] generated strong ground motion in the epicentral zone, with maximum vertical and horizontal accelerations exceeding the gravity acceleration near the fault [10]. The heaviest damage was observed in the villages of Le Teil and Viviers, with EMS98 macroseismic intensities of VII, or even locally VIII [11], a level of damage never reached in metropolitan France since the earthquake of Arette in 1967.

This significant earthquake raises important questions in terms of seismic hazard: Had the Rouvière fault already broken in the past? Could other faults of the NE termination of the Cévennes faults system, also produce this type of event? To answer these questions, a collaborative research program (FREMTEIL 2021-2023*) involving several academic laboratories as well as several institutes has been launched, with the support of the CNRS-INSU and the numerous institutional collaborators. In this paper, we present some of our paleoseismological investigations, which allow us to show that the Rouvière fault had already ruptured in the past.

(*) Acronym for "Faults, Ruptures and Strong Movements: What consequences for the seismic hazard in the TEIL region"

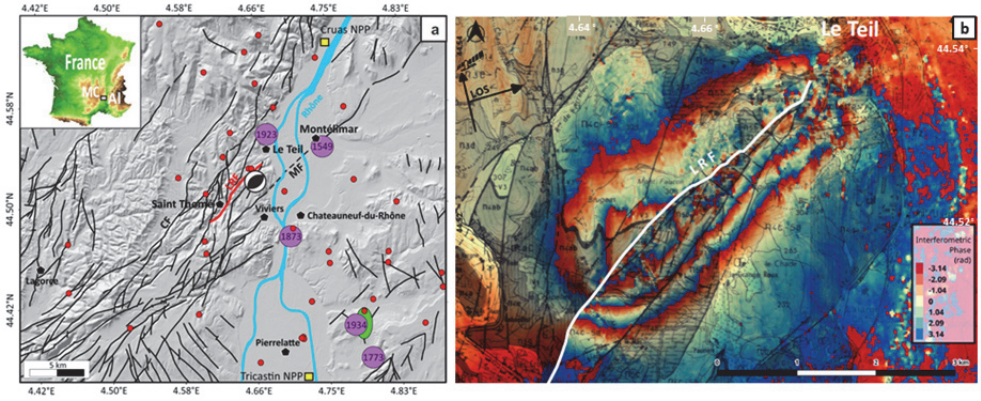

Fig. 1 (a) [after 1]: Seismotectonic map of the Rhône River Valley where the November 11th, 2019 Mw4.9 Le Teil earthquake occurred. The black and white sphere indicates the reverse faulting focal mechanism; red and purple circles are instrumental and historical seismicity, respectively; the green ellipse corresponds to the Tricastin swarm; black lines are faults from the Aubenas geological map [12] with the La Rouvière Fault (LRF) in red; CF: Cévennes Fault, MF: Marsanne Fault; the shaded DTM is from BD ALTI 25 m (IGN); MC and Al in the inset are Massif Central and Alps,

respectively. (b) [after 1]: First interferogram (wrapped phase) obtained using Sentinel-1 synthetic-aperture radar data.

2 Paleoseismological investigations along the La Rouvière Fault

We carried out paleoseismic investigations along the La Rouvière Fault to analyse and characterize evidences of paleo-ruptures in Quaternary deposits. Thirteen trenches spread over five sites were dug along the section that broke the ground surface in 2019 (Fig. 2). Several trenches within 3 sites (LR4, LR1 and LR6) yielded favourable Quaternary deposits (slope colluvium and eolian deposits) lying against the ancient LRF normal fault mirror carved in the Barremian limestones to document past-coseismic deformations.

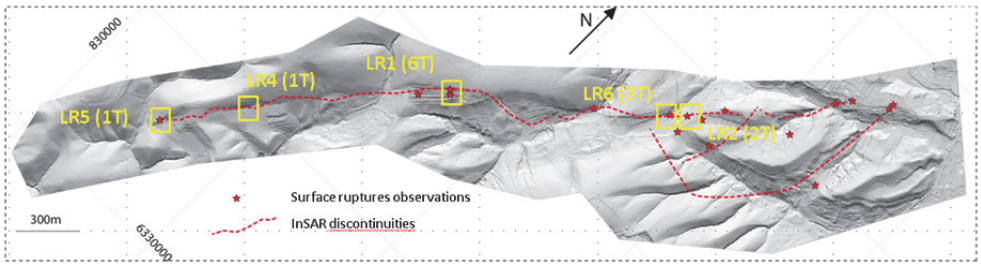

Fig. 2 [after 13]: Location of the 5 sites (number of trenches per site in parenthesis) where 13 trenches were dug across the La Rouvière Fault and/or the traces of 2019 earthquake surface rupture. The 25-cm-resolution shaded relief topographic map with the surface ruptures observations (red stars) are from [1].

The AMS radiocarbon and OSL dates (from “bulks” collected into colluvium clayey-silty matrices) within 3 trenches located in the central and southern parts of the LRF (LR6-TB, LR6-TD, LR4-TA) suggest that at least one event prior 2019, occurred after ~13 ka [13]. In the trench LR1-TB, where we obtained the more age constraints, the age of this previous event is bracketed between 13.5 and 3.3 ka (Fig.3 left) [14].

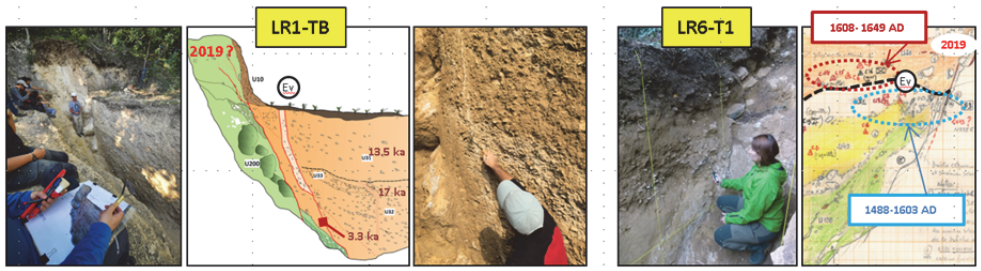

Fig. 3 [after 13 and 14]: Summary of the age constraints obtained within trenches LR1-TB (left) and LR6-T1 (right) dug across the central segment of the La Rouvière Fault that broke on 11-11-2019 during the Le Teil surface rupturing earthquake.

Within the northern part of the 2019 rupture, the radiocarbon dates of charcoals collected within trench LR6-T1 dug in younger deposits suggest that a younger event occurred between the end of the 15th century and the beginning of the 17th century with kinematic characteristics similar to the 2019 event (sense of movement, amount of displacement (Fig.3 right)

3 Conclusions and perspectives

Our study demonstrates that the LRF have had previous surface rupturing earthquakes prior to the 2019 event, without any clear consistent morphological imprint. We thus infer that in plate interiors such as metropolitan France, active faults capable of producing such earthquakes are not necessarily detectable in the morphology. Concerning the La Rouvière Fault example, this can be explained by the small amount of displacement and a long return period (consistent with the 0.5–1.0 x 10^{-9} yrs^{-1} low strain rate measured by GPS in the region [15]), easily balanced or even exceeded by erosion processes.

To go further in the characterization of potential active faulting along the other faults segments of the Cévennes fault system, we are now performing detailed geophysical surveys at the intersection areas between the different faults and the Quaternary markers. Figure 4 shows an example of such an approach within the Marsanne fault, which bounds the northeastern termination of the Cévennes fault system along its southeastern border (see "MF" in Fig.1B).

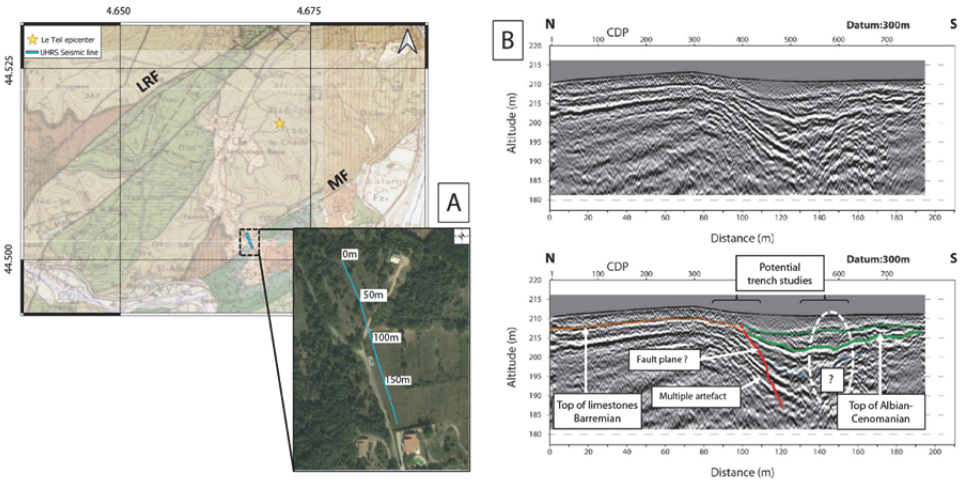

Fig. 4 [after 16]**:** (A) Location of UHRS profile across the Marsanne fault (MF) LRF= La Rouvière Fault. (B) Seismic line (lower section = potential interpretation).

The UHRS (Ultra High Resolution Seismic) survey [see for instance 17] was performed at a site where the Marsanne fault is mapped below Plio-Quaternary deposits (Fig. 4A). It shows an interruption of the horizontal continuity of some reflectors that are interpreted as the occurrence of the fault bellow the young deposits (Fig.4B). This result enables us to precisely locate the trench that we will open soon to analyze the Quaternary activity of the Marsanne fault.

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