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To cite this version:

Nicolas Cathelin, Stephane Baize, Jean-François Ritz, Pierre-Henri Blard. Using Cosmogenic 3 He Dating of Fluvial Terraces for Estimating the Present Uplift of the Massif Central within the Northeastern Termination of the Cévennes Fault System. 5èmes Rencontres Scientifiques et Techniques Résif, Nov 2021, Obernai (67210), France. hal-03442508

HAL Id: hal-03442508

https://hal.science/hal-03442508v1

Submitted on 23 Nov 2021

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Using Cosmogenic ^{3}He Dating of Fluvial Terraces for Estimating the Present Uplift of the Massif Central within the Northeastern Termination of the Cévennes Fault System

N. Cathelin[1,2], S. Baize[2], J.F. Ritz[1], P.H. Blard[3]

[1] Géosciences Montpellier, Univ. Montpellier, CNRS, Univ. Antilles, Montpellier, France. [2] IRSN, Institute of Radiological Protection and Nuclear Safety, Fontenay-aux-roses, France. [3] CRPG, CNRS, Université de Lorraine, 54500 Vandœuvre-lès-Nancy FRANCE

1 Aim and Context

The **Mw 4.9 Le Teil earthquake** (November 2019), produced a 5km long surface rupture with displacements comprised between 5 and 22cm (LR, fig.1). The earthquake reactivated an ancient Oligocene normal fault belonging to the NE-SW trending Cévennes fault system (CFS)[a]. The **LR Fault was not considered as potentially active** neither from the the point of view of instrumental seismicity nor form the point of view of quaternary geomorphology. Only two faults of the CFS were previously mapped as potentially active (Cévennes and Marsanne faults) in the BDFA database[b]. This intra-plate event has highlighted the possibility in metropolitan France, that **faults not mapped as active faults so far, could be reactivated and produce surface rupture**. Paleoseismological investigations carried out after the event suggest that the LR Fault had already produced at least one surface-rupturing event during past 17ka[c]. The present work was performed in the line of those new results.

The aim of this study is to analyze the general deformation across the NE termination of the CFS using uplifted fluvial markers along the Escoutay valley, which watershed crosses perpendicularly the CFS (fig.1). Using ^{3}He cosmogenic and ESR dating methods, we determine incision rates at different localities to analyze the uplift rate within this part of the Massif Central and its possible variations across the CFS.

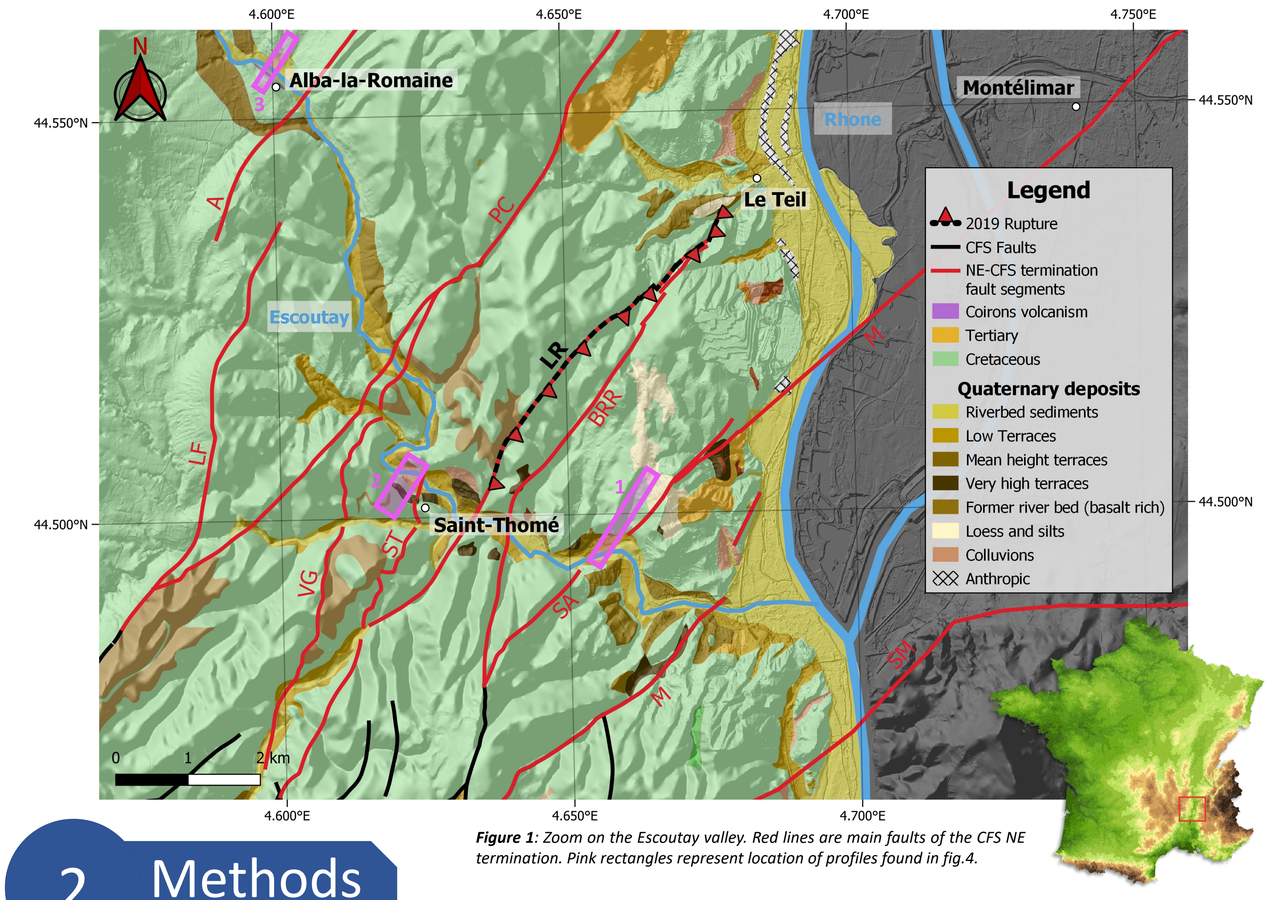

Figure 1: Zoom on the Escoutay valley. Red lines are main faults of the CFS NE termination. Pink rectangles represent location of profiles found in fig.4.

2 Methods

We used a 5m resolution DEM as well as the available 1m resolution Lidar data within the Rhone river banks for a GIS analysis, which included watershed modelling (knickpoints, drainage...), correlation of geological and structural maps, slope measurement to identify potential terraces. Terraces were dated using cosmogenic ^{3}He in basaltic pebbles (fig.2A). ^{3}He concentrations were measured on thinly crushed, sieved and chemically purified olivines and pyroxenes (fig.2B,C) using a mass spectrometer. The measured concentrations are proportional to the exposure time of the pebbles and a local production rate is estimated at 120at.g^{-1}yr^{-1}. The surface ages were corrected from ^{3}He inheritance by subtracting the mean ^{3}He age determined in the riverbed pebbles. Two important corrections still need to be applied to ^{3}He measures: magmatic and nucleogenic.

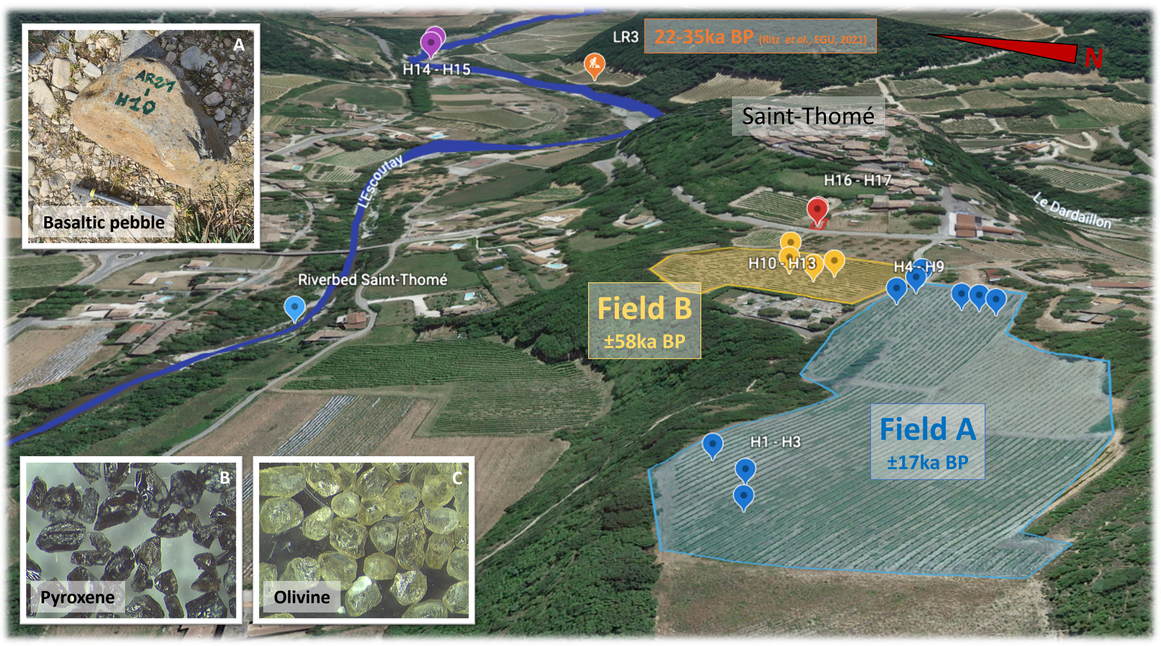

Figure 2: Aerial view of the sampled Saint-Thomé terrace. Because of a slight slope difference, we separated it into field A (blue) and field B (yellow). The red samples were collected on a recently uncovered road, hence we expected concentrations to be lower. Downhill, we see the Escoutay river, the LR3 surface and the sampling spot of the riverbed (H14 and H15).

3 Results

Obtained concentrations, ages and respective incision rates are shown in Table 1 and Figure 3. The riverbed measured inheritance (H14a) of 25±2ka allowed determining the following depositional ages for the Saint-Thomé alluvial terrace: the three samples from the upper field A (H1, H5 and H16) show similar ages around 17ka. H10 on the other hand, H10 from the lower field B, displays a much higher age of 58ka. Although ages from H1, H5 and H16 seem consistent with each other, we kept the H10 result of 58ka, given that a previous alluvial surface (LR3), lower in altitude than the Saint-Thomé surface was precisely dated with several radiocarbon samples at 22-35ka[c].

Sampling and Study Locations

Quartzitic Pebbles	Escoutay Riverbed	LR3 Alluvial Surface	Saint-Thomé	Alba-la-Romaine
Surface under an aeolian sandy cover 3 samples currently dated by ESR	Mean inheritance time associated to transport 7 basaltic pebbles 1 thin sand sample	Previously dated with radiocarbon alluvial surface 10m above the Escoutay riverbed. **22-35ka** (Ritz et al. EGU)	Abandoned alluvial terrace we separated into **two fields**: **Upper A** : 11 samples **Lower B** : 4 samples	Abandoned alluvial terrace 20m above the Escoutay riverbed where we collected and amalgam of **33 samples**.

SE → NW

Location	Elevation over riverbed (m)	Sample(s)	Mean Concentration (at.g^{-1})	Mean exposure Age (ka)	Mean corrected age (ka)	Incision rate (mm.yr^{-1})
Saint-Thomé terrace: field A	48	H1 and H5	5,72×10^6	**42±3**	~~**17±3**~~	~~**1.14±0.1**~~
Saint-Thomé terrace: field B	42	H10	1,12×10^7	**83±4**	**58±4**	**0.51±0.03**
Saint-Thomé Mr. Roux path	43	H16	5,53×10^6	**41±3**	~~**16±3**~~	~~**1.79±0.15**~~
Escoutay Riverbed	-10	H14a	3.31×10^6	**25±2**	-	-

Table 1: Summary of obtained concentrations, ages and incision rates. Uncertainties are instrumental uncertainties from the mass spectrometer.

Those young ages (17ka and 16ka) could be explained by the fact that the uphill part of the terrace (field A) was more exposed to erosional and/or burial processes. Hence, it could have been buried stopping ^{3}He production and only recently unraveled by anthropic action (or the opposite). Note that these results are still surrounded by high uncertainties as we have not performed all corrections on ^{3}He measurements.

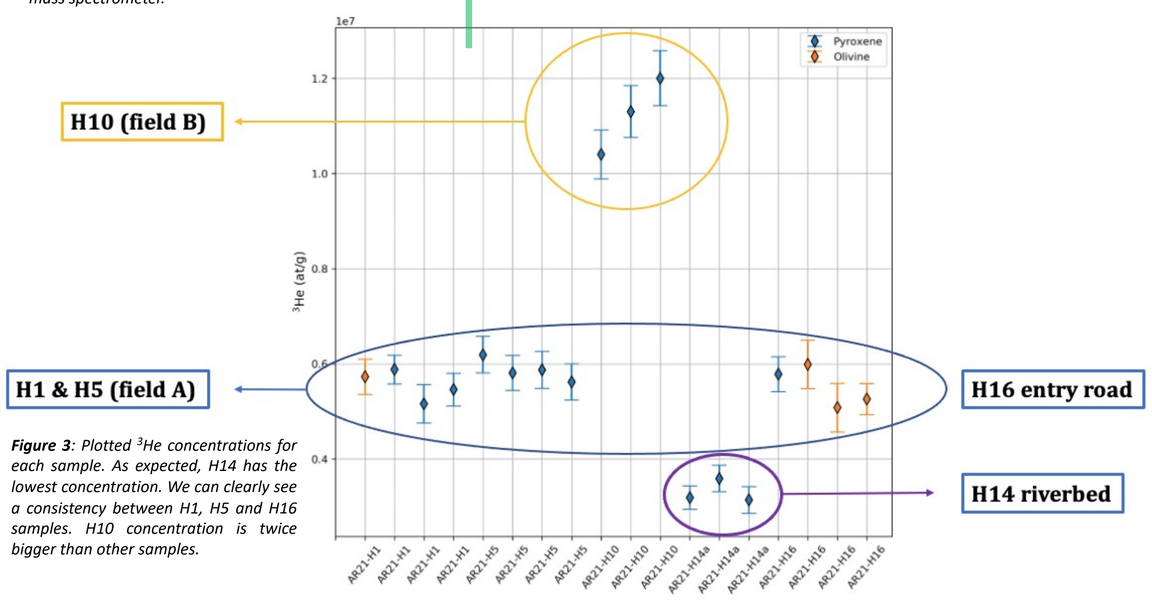

Figure 3: Plotted ^{3}He concentrations for each sample. As expected, H14 has the lowest concentration. We can clearly see a consistency between H1, H5 and H16 samples. H10 concentration is twice bigger than other samples.

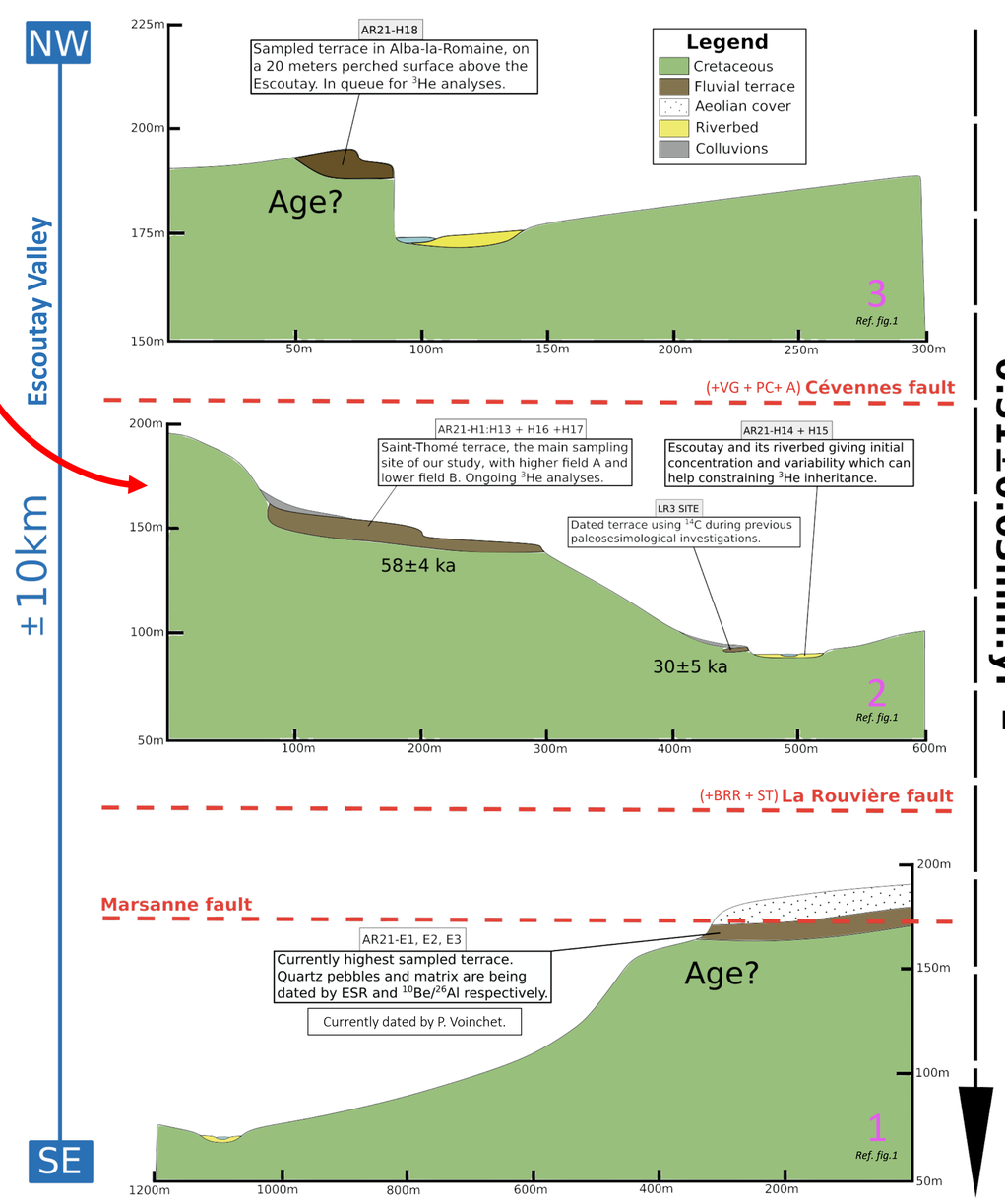

Figure 4: Summary profiles of sampled and studied locations as well as main faults (red dashed lines). Profile locations are represented in fig.1 by pink rectangles.

4 Discussions and Conclusions

We date the Saint-Thomé abandoned fluvial terrace at 58 ± 4ka which allows estimating an uplift rate of 0.51 ± 0.03mm.y^{-1} in the central part of the CFS within its NE termination since the Upper Pleistocene. This uplift rate is consistent with the previous studies (0.5mm.yr^{-1} [d] and 0.6mm.yr^{-1} [e]) in southwestern CFS and with the LR3 alluvial surface. Compared to studies on a million-year scale (0.083mm.yr^{-1} [f] and 0.04mm.yr^{-1} [g]) our results suggest an acceleration of Massif Central uplift rate within its SE border, at least during Upper Pleistocene.

In progress ^{3}He and ESR analyses beyond the NW and SE CFS limits should show whether there is a differential uplift as it seems to be the case within the southwestern CFS[h]. This rises the following question: **is the present higher uplift rate due to short term climatic variations or is it representative of a change in geodynamical processes?** Further investigations in paleoseismology should bring new insights to this question (e.g., ongoing C.Thomasset and N.Cathelin PhD theses in collaboration with GM- EDF-IRSN-INSU).

References: [a] Ritz *et al.*, 2020; [b] Jomard *et al.*, 2017; [c] Ritz *et al.*, *EGU 2021*; [d] Malcles *et al.*, 2021; [e] Ramel *et al.*, 2021; [f] Malcles *et al.*, 2019; [g] Séranne *et al.*, 2001; [h] Malcles *et al.*, PhD 2021.