Thermochronology and REE analyses as new tools to track thermal anomaly and fluid flow along a crustal scale fault (Têt fault, French Pyrenees)

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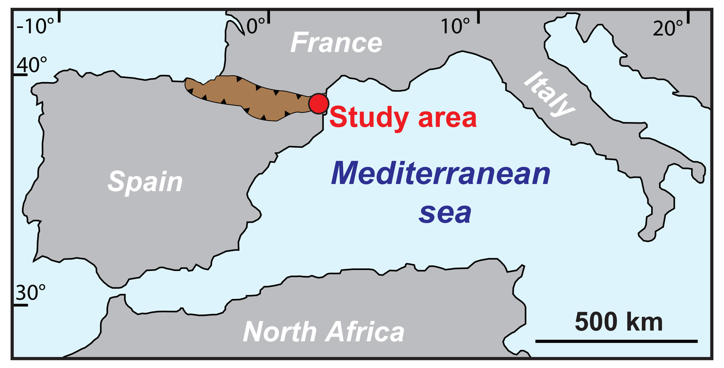
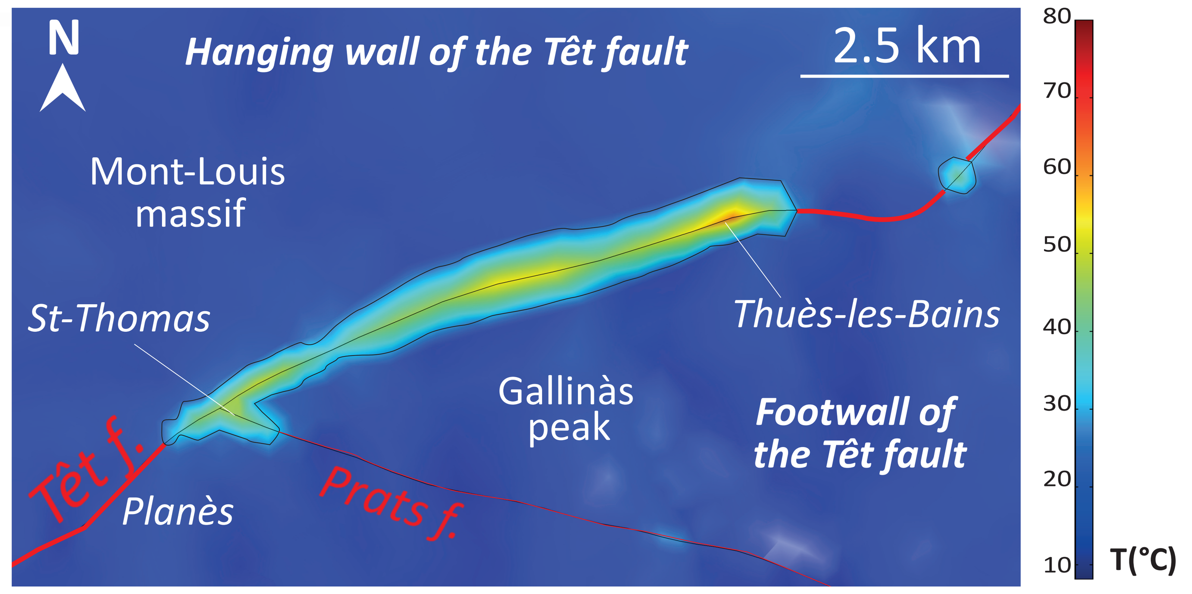
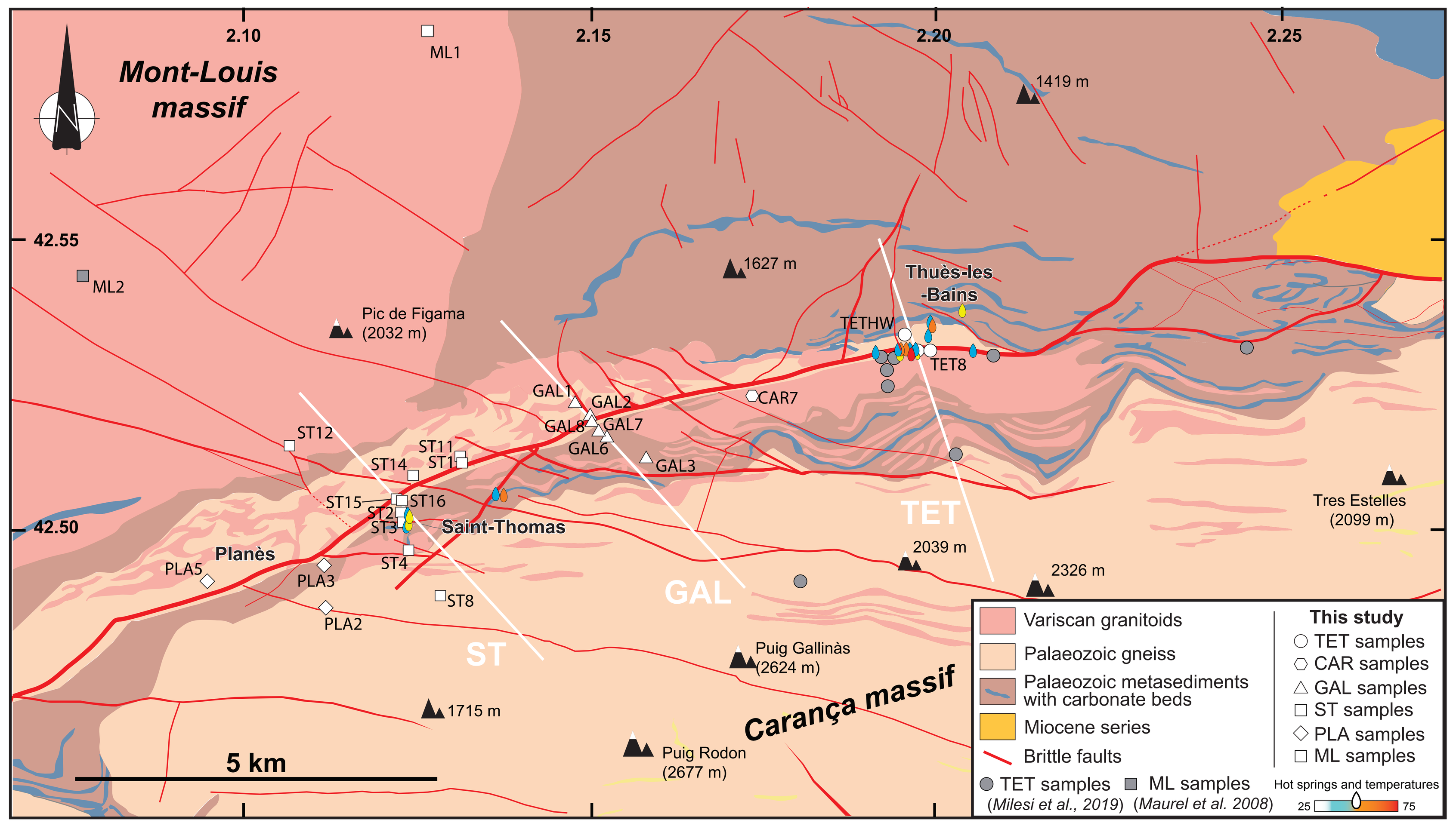


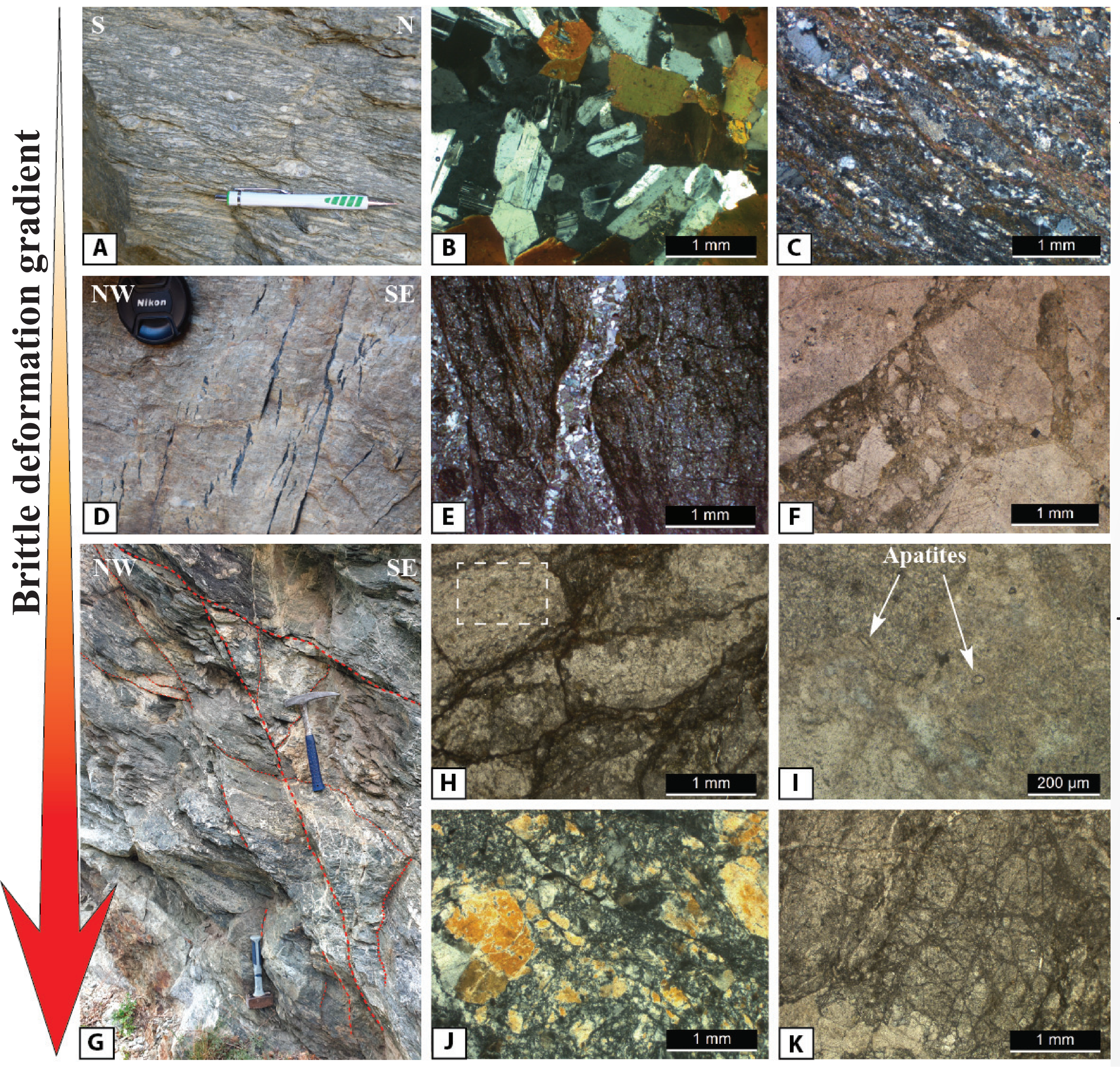
The Têt fault is a crustal scale major fault in the eastern Pyrenees that displays about 30 hot springs along its surface trace with temperatures between 29°C and 73°C. The regional process of fluid circulation at depth has previously been highlighted by thermal numerical modelling supported by hydrochemical analyses and tectonic study (*Taillefer et al., 2017*). Numerical modelling suggests the presence of a strong subsurface anomaly of temperature along-fault (locally > 90°C/km), governed by topography-driven meteoric fluid upflow through the fault damage zone (*Taillefer et al., 2018*). On the basis of this modelling, we focused our (U-Th)/He thermochronological study of apatite on 30 samples collected close and between two hot spring clusters in both the hanging wall and the footwall of the Têt fault, along the most important modelled thermal anomaly (Figure on the right). More than 100 apatites were dated in combination with 63 REE analyses to constrain the intensity and geometry of the geothermal anomally along the Têt fault. Sampling was realised along three main sections perpendicular to the fault and involved mainly gneiss lithologies inside and outside the fault damage zone DZ.



Geological setting and new field data

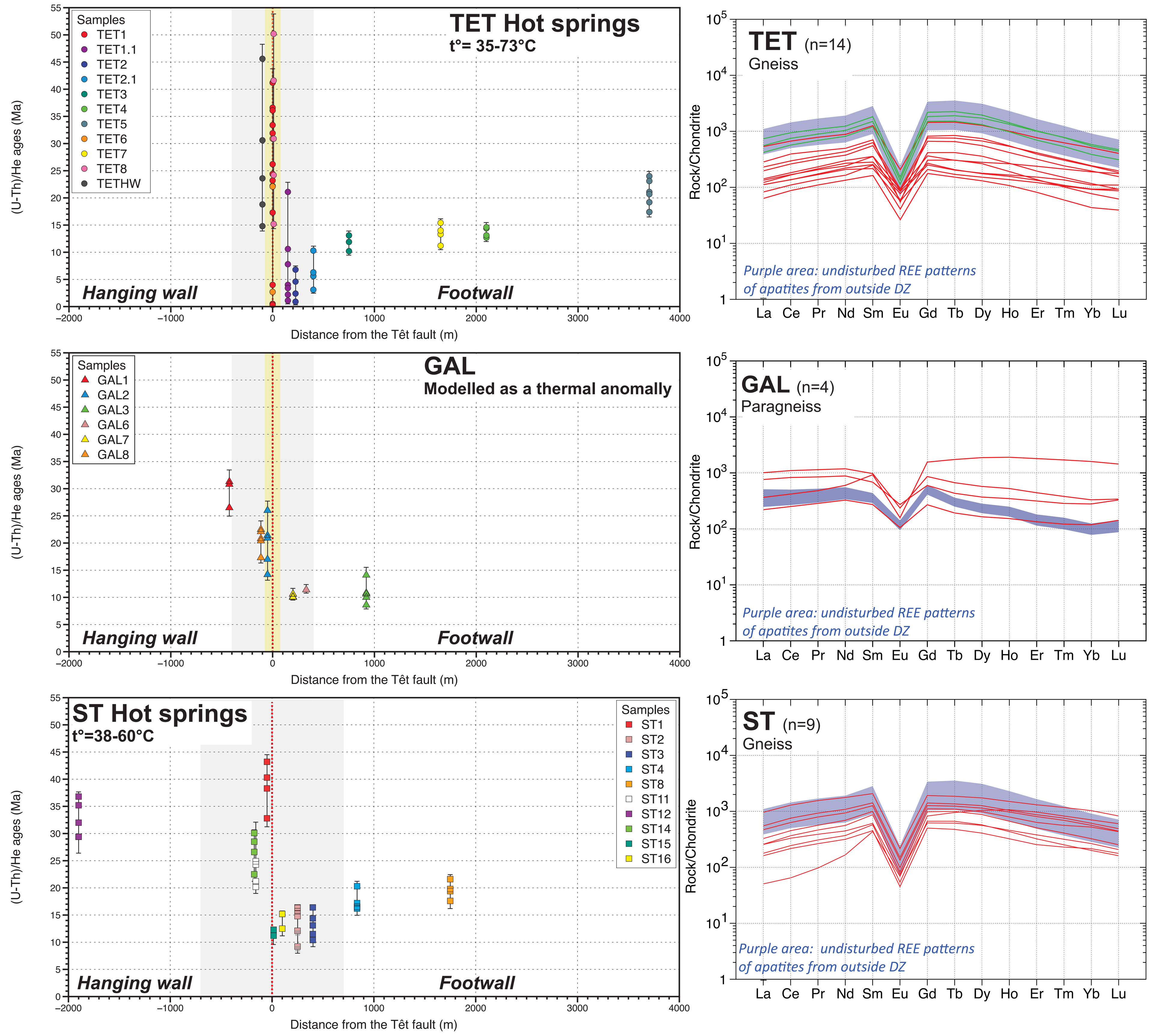


▲ *Structural map modified from Taillefer et al. (2017) showing three sampling transects highlighted in this poster TET, GAL and ST. In grey, samples from previous studies (Maurel et al., 2008; Milesi et al., 2019); in white, new samples of this study (Milesi et al., 2020 submitted).*



◀ ***Samples outside the Damage Zone (DZ):***
A) Typical augen gneiss; B) Undeformed Mont-Louis granite C) Variscan mylonite.
Samples from the outer DZ:
D, E) Silica-filled fractures close to CAR7 sample; F) Fracture filled with a micro-breccia near ST hot spring cluster.
Samples from the inner DZ:
G) High fracturation in the footwall near the Têt fault on ST profile; H) Heterogeneously fracturated and altered gneiss showing lenses less affected by hydrothermal alteration; I) Close view on apatite within a gneiss lens (enlarge-ment of H); J, K) Cataclasite and protocataclasite next to the Têt fault.

(U-Th)/He ages on apatite and REE analyses



▲ *On the letft, AHe ages as a function of distance from the Têt fault. The grey area correponds to the total Têt fault Damage Zone (DZ). The inner DZ (in yellow) has been only delineated for the TET and GAL profiles according to Milesi et al. (2019). Note the double width of the DZ on ST profile consistent with a larger fault network in this area (Mayolle et al., 2019). On the right, chondrite normalised REE patterns (Sun and Mc Donough, 1969) of dated apatite grains within the footwall. The purple areas cover the REE patterns of apatites taken outside the DZ. For TET profile only, samples from the inner DZ (green) and outer DZ (red) are distinguished*

In the hanging wall (HW) AHe ages are between 43 and 18 Ma with more dispersionand ageing close to the fault. In the footwall (FW), very young AHe ages (< 5Ma) and wide age dispersion are recorded in the DZ of the TET profile. The larger age spread is observed close to the fault (inner DZ) in agreement with the HW data. Similar age dispersion but less younging are recorded by apatites within the DZ of ST profile. By contrast AHe ages of DZ samples on GAL profile (free of hydrothermal activity) are concordant at 10.3 ± 0.2 Ma.Compared to the undisturbed REE patterns of apatites from the outside DZ samples (purple area), rejuvenated apatite grains from the TET profile DZ have mainly homogeneously depleted REE patterns that are interpreted to result from hydrothermal circulation (Harlov et al., 2005). REE patterns from ST profile show a similar but less intense depletion of both LREE and HREE compared to the TET profile.
REE patterns of GAL samples are characteristic of medium grade metapelitic rocks (Henrichs et al., 2018) with a lower Eu anomaly compared to the previous augen gneiss. No REE depletion was observed within the DZ in agreement with the lack of evidence of hydrothermal activity and good reproducibility of AHe ages.

Discussion and perspectives

This study shows that AHe thermochronology combined with REE analysis is an efficient tool to track recent geothermal activity along a dormant fault. Along the Têt fault, we identified two main, spatially very restricted (1 or 2 km square), hydrothermal clusters into the DZ (TET and ST) of the Têt fault footwall where apatites exhibit variable rejuve--nation and age scattering depending on the hot spring temperature but also on other parameters such as topography, permeability of the host rocks and fault zone, fracture mineralization or tectonic background around the fault. As fluid flow through fractured rocks is a highly heterogeneous process, even at the thin section-scale, variable 4He loss by fluid advection can account for AHe age dispersion. Helium trapping can be also a source of apatite ageing in the very fault contact. In between these two hot spring clusters,the AHe and REE data suggest that no significant hydrothermal circulation took place within the DZ in the last 10 Ma, in contrast to what the numerical models show. Therefore, the combination of AHe dating and REE analyses can constrain the geometry and intensity of a geothermal anomaly along a fault . As an exploration tool, the use of (U-Th)/He thermochronology appears very complementary to other tools as, for example, hydrothermal fluid chemical analyses, fluid circulation numerical simulations or electrical methods. Moreover, it is a cost-effective tool as it allows constraining such models without the need for drilling.

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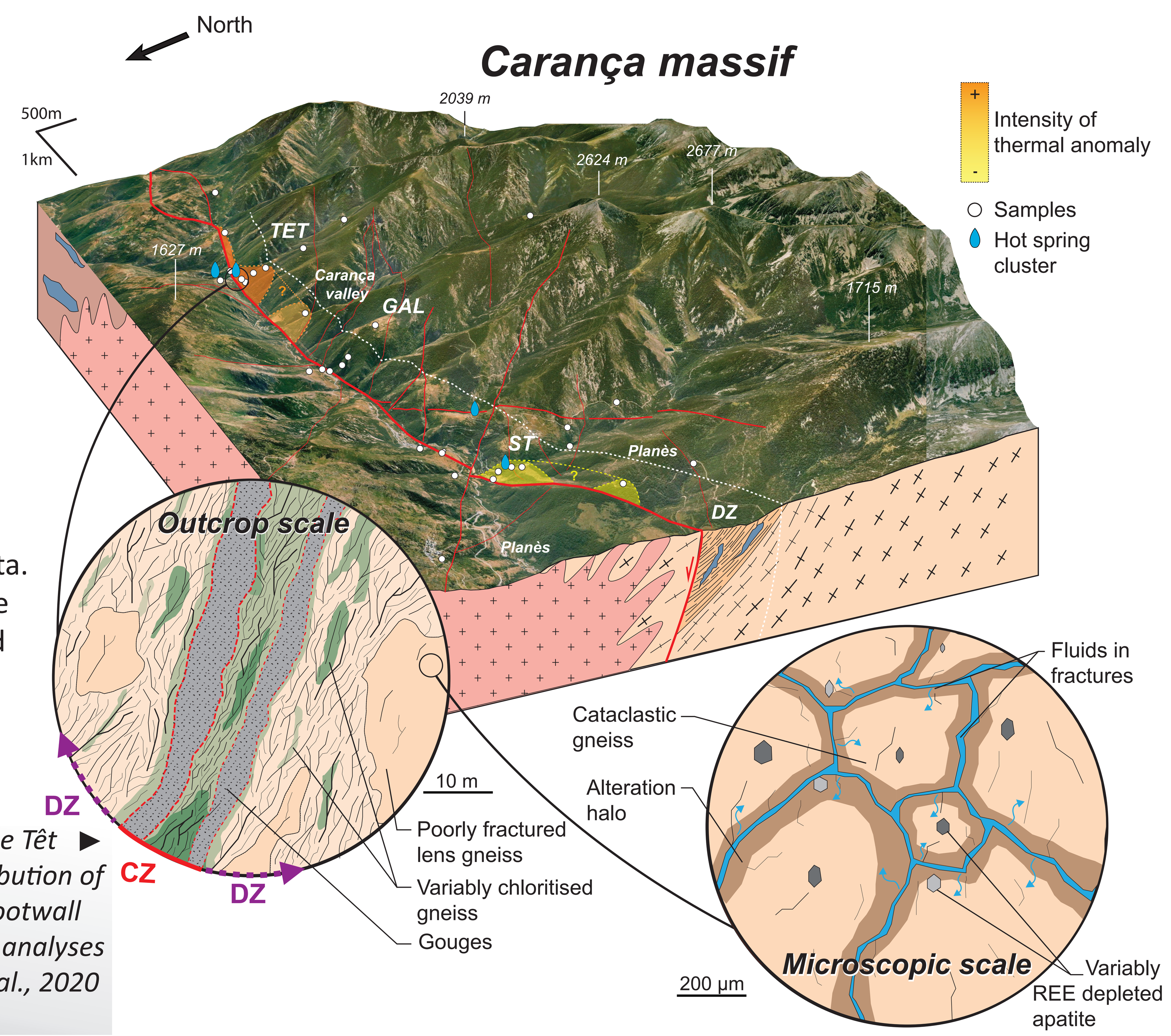

3D synthetic block diagram of the Têt valley showing the surface distribution of thermal anomalies in the fault footwall revealed by AHe dating and REE analyses (additional data are in Milesi et al., 2020 submitted) ▶

References / Acknowledgments
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