Review of

Tracking geothermal anomalies along a crustal fault using (U-Th)/He apatite thermochronology and REE analyses, the example of the Têt fault (Pyrenees, France)

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reviewed by Meinert Rahn

The submitted manuscript and supplementary material presents 99 new (U-Th)/He single grain ages and 63 REE spectra on apatites from the geothermal fields along the Têt fault in the Pyrenees. The study is closely linked to the recently published study Milesi et al. 2019, which already presented a restricted data set from the TET profile, a study that here is extended by new samples and samples along more profiles (STA, GAL, PAL) and a small number of more isolated samples. Samples were taken from the hanging wall and footwall of the fault at variable distance, divided into samples inside a deformation zone (DZ) around the fault and outside of it.
The study concludes that He ages and REE contents can be distinctly influenced by hydrothermal activity, mainly dependent on rock permeability, fault activity and thermal evolution. Apatite ages closest to the fault show a large age scatter and strong depletion of REE contents if compared to samples far away from the fault, which show the original REE patterns and the regional cooling history (as a result of exhumation and differential uplift along the fault).
Ages and REE support the conclusions and I see no substantial or harsh mismatches, even though the reader is left behind by some question marks concerning the ideas of the authors of the processes taking place. Since I have not major drawbacks; I propose that the paper needs minor revision of the text.

Points that the authors should have a closer look to are the following:

1. Normal o rhorizontal distance to the fault plane: The authors should clarify in their paper, whether the cited distances are horizontal distances or distances normal to the fault plane.
2. When the authors refer to Flowers et al. or Gautheron et al. diffusion models, then they should carefully choose their wording. The diffusion models are ok, but it is the fact that the AHe ages scatter too much to be modelled by a common thermal history.
3. The model the authors present for the fault plane suggests that the plane seems to have clearly restrict geothermal activity to the footwall. However, there are faults that crosscut the Têt fault into the hanging wall, and AHe ages next to the fault show considerable age scatter. So, the influence reaches beyond the fault plane. Note, that the rocks are by far not impermeable, in particular if they have undergone tectonic shearing.
4. The reference to Henrichs et al. (2018) to explain a common apatite REE pattern is problematic to me. First, you do not give any information about the degree of metamorphism, second, the paragneisses should contain apatites of different origin and different REE patterns in the beginning. Does the Henrichs et al. study refer to new-grown apatites or detrital apatites? Quoting this study should be checked again. In general, we do not need to know the original REE pattern, we simply need to have differences, but of course, in a paragneiss, there might not be a unique reference REE pattern.
5. The authors do calculate mean ages for some samples, for others they do not (Tables 1 and 2). They should clearly state on the basis of what they decide that a sample has internally consistent ages, but another one shows age scattering. Methodically, this is not clear yet, but would be very important to clarify the next steps. In addition, this may lead to the possibility to independently talk about the thermal history of the footwall on one side and the hanging wall on the other. The authors point to this in their abstract (lines 24/25), but the paper does not discuss the individual thermal histories. Perhaps, it would be wise to do this first.

6. If there is one chapter that I would recommend strong rewriting for, it is the Conclusions chapter, which at the moment caused the highest density of question marks to me.
7. I highly recommend to the authors to not speculate about the processes that have taken place and led to AHe age rejuvenation or increase or REE depletion. There is little evidence presented that would be able to narrow down potential processes that took place. Such work could be done on the same samples, but not based on the her presented evidence.

In my detailed comments below, I have noted the locations of a considerable number of minor issues that definitely need clarification, more than a simple rewording, but clarification with respect to the issue that are listed above. The entire paper, including the figures, tables and references, need some fine-tuning to make the study internally sound. In some cases, this means to delete some side tracks, which deviate more than they provide answers, but in some other cases, we need a more pronounced argumentation to better emphasize the point that should be made.

Detailed comments:

Line 12	"around" instead of "nearby"
Line 12	Since you are mentioning the two hot spring clusters for the first time; I would suggest to shift the bracket from line 17 right after "clusters"
Line 12	"in-between"
Lines 12/13	delete "in an attempt"
Line 16	to be concordant with line 12: "nearby the two hot spring clusters"
Line 17	"resettings" instead of "resetting", we do not know whether the reset occurred at the same time.
Line 18	"around the Thuès-les-Bains …"
Lines 20 and 22	You mention phases of exhumation for footwall and hanging wall. If I compare the numbers (30-24 Ma, footwall, versus 35-30 Ma, hanging wall), the logic consequence would be that the fault has changed from a thrust fault to a normal fault with time. It also means that the background cooling signal at the fault should be different on both sides of the fault. This point is not taken up in your discussion.
Line 21	"little evidence" instead of "few evidences", and then "has" instead of "have"
Line 23	I think you mean "extent" rather than "distribution"
Line 24	You claim that the data from this study provide "new constraints on the tectonic uplift of the footwall and hanging wall massifs". I do not see such a discussion and corresponding conclusions in the paper. I also refer to the fact that these issues have already been addressed in the Terra Nova paper. Here you should restrict yourself to what is new in THIS paper.
Line 27	"Global" instead of "World"
Line 31	Start sentence with "Heat production…"
Line 31	Suggestion: add "e.g." after "provided"
Line 33	Add comma after "Anatolia"
Line 33	I assume that the here quoted temperature is a "downhole temperature", if so, add "downhole"
Line 41	"along" instead of "around"
Line 42	Suggestion: "host rocks and the geometry of the fault zone"
Line 43	"mineralization" or "mineralisation" (see line 46)?
Line 45	Suggestion: "In places where no heat flow data are available…"
Line 45	Bracket: "(no boreholes)"
Line 46	"tuff" instead of "tuffa"
Line 46	The "however" at the end of the line could be deleted. It is not really a counterargument…
Line48	Start sentence with "The past decades revealed …"

Lines 51-53	Suggestion: “In this study, we propose an extended analysis of the (U-Th)/He system in apatite (AHe), sensitive in a temperature range between ….”
Line 53	Can you check the quoted temperature range? You quote two references, but these references quote no range from 30 to 90°C. other people quote a smaller range of 80 to 40°C.
Lines53/54	Suggestion: “in association with Rare Earth element (REE) analysis on dated apatites”
Line 54	The term “hidden thermal system” is used frequently, but is not self-explaining, as you obviously refer to a geothermal system in the subsurface. This should be explained, as this is important to understand your reasoning in the Discussion chapter (see e.g. lines 469 or 492).
Line 55	Suggestion: “In a previous study (Milesi et al., 2019), we showed that …” (see also comment to line 56.
Line 56	“AHe age scattering”
Line 56	Suggestion: Use “illustrate” or “prove” instead of “evidence”
Line 56	“In this previous study” (see comment to line 55)
Line 57	“The present study …”
Line 58	“to test these tools”, as you refer to AHe dating and REE analysis
Line 63	It is not clear what you mean by “main part”. Does this mean “central part”, “inner part”.
Line 63	“of the Pyrenees”
Line 66	“were (re-)activated”
Line 67	delete bracket after “Later,”
Line 68	“led to the formation”
Line 68	“such as the Cerdagne …”
Line 71	Figure 1: In figure B, the white abbreviations “C. b” and “R.b” should be changed to “CB” and “RB” as mentioned in the figure caption. Figure C: I note that four samples from Maurel et al. (2008) in the Mont Louis granite (and one in the Conflent basin) are shown as black squares instead of grey squares (see legend). The rectangle shown with dashed white line is probably the area shown in figure 5A. If yes, refer to it rather than “Our study”. Legend: “Glacial” instead of “Glaciary”, add “basins” after “Cerdagne”.
Line 72	Suggestion: “the outline of the Pyrenees are shown …”
Lines 75/76	Suggestion: “C) Local map with locations of previously published AHe samples”
Line 76	“represented by drops”
Line 77	Suggestion: The Têt fault (eastern Pyrenees) is 100 km long and runs across …”. I did not understand the necessity of the word “accident”…
Line 77	“Palaeozoic” instead of “Palaezoic”
Line 77	The here mentioned “Axial Zone” has not been introduced. Important?
Lines 80/81	Suggestion: “provide important age constraints to the regional thermal history…”
Line 81	“of the eastern Pyrenees”
Line 83	Here, for the first time, the term “hanging wall” is mentioned in the text after the abstract, but the reader has no idea from your introduction, which side is the hanging wall, as you have not described the geometry of the fault in 3D. Thrust fault, normal fault, nothing was said about this.
Line 85	You may delete the word “increasing”, as you talk about a spectrum.
Line 86	“Pyrenean” instead of “pyrenean”
Lines 86/87	“This is consistent with fission track and zircon (U-Th)/He ages …”
Line 89	Figure 2: Strictly speaking, the modelling window stops at 40 or 30°C as the (U-Th)/He method is no longer sensitive to temperature changes below 40 or 30°C (dependent on what reference you are choosing, see comment to line 53)
Line 90	Suggestion: “of the Carança and Canigou massifs (Fig. 1C) in the …”
Line 99	Not clear what you mean by “with a differential estimated at …”. Do you refer to a “difference in total exhumation”? Please, clarify!

Line 100	The statement “was mainly exhumed, and rapidly cooled,” is surprising. What we measure with thermochronology is “cooling”. And this cooling can be interpreted in terms of exhumation. Here, it sounds as if it would be the other way around (which could be the case if exhumation is modelled and the corresponding cooling due to erosion estimated by the model). I would suggest to refer to the original citations in the quoted papers.
Line 100	“in relation with the Têt fault”
Line 102	It is not clear what you mean by “from a large consensus”. It sounds as if the community has debated on this, which would mean that papers could be cited.
Line 102	“but the last period”
Line 105/106	The statement “It must be stressed that some authors consider that any vertical displacement occurred …. First of all, you only quote one source for this (Petit and Mouthereau, 2012), which looks strange if you state “some authors”. Then “any vertical displacement occurred” is not clear. Suggestion: “Petit and Mouthereau (2012) suggest that vertical displacement occurred during …”
Line 110	Suggestion: “on the basis of multi-disciplinary (Gunnell et al., 2009) and thermochronological studies (Fitzgerald et al. 1999).”
Line 111	Suggestion: “Today, the Têt fault shows no evidence of …”
Line 113	“suggests incision rates in the range of 1 to 25 m/m.y. …”
Line 116	“surrounded” instead of “characterized”?
Line 121	You should explain what you mean by “a multi-core pattern”. Is this the same as “a hot spring cluster”?
Line 125	The term “half-thickness” is not clear. Do you mean the distance from fault to outer rim of the DZ? It would be important to know, whether you refer to a horizontal distance of to normal distance to the fault. Depending on the geometry of the fault plane and the local topography, this might cause significant differences between horizontal and normal distance to the fault.
Line 130	The term “fault rocks” comes unexpectedly. So far, we were talking about a fault and surrounding rocks. Please, explain or rephrase.
Line 141	Suggestion: “may be related to the occurrence of impermeable metasediments in the hanging wall at the surface”
Line 143	The here cited “Prats fault near St-Thomas” is not shown in figures 1 and 3. So, how important is it? Note also that you commonly use a hyphen between “St” and “Thomas”.
Line 144	Do you mean “can also increase permeability and localise channelized fluid upflow” Or: “can also increase permeability and localized upflow of channelized fluid”?
Line 144	Figure 3: “Têt Fault” or “Têt fault” (see e.g. “Py fault” in this figure and writing in figure 1)? Should you use same colours as in figure 1? What is the meaning of the green zone in the hanging wall? What is the meaning of “CMNC”?
Line 147	Suggestion: “Figure 4 shows the numerical modelling results of …”
Line 148	“, which takes…”
Line 148	“discontinuities, but does not …”
Line 153	“Gallinàs peak” is shown in figure 4, but also in figure 5 as “Puig Gallinàs” with a noted elevation of 2624 m…
Line 154	“At this locality” instead of “In the latter location”
Line 155	The statement here seems to be in contradiction to what is said in line 149. Please, clarify.
Line 157	Suggestion: “suggesting that this area is a recharge zone”. It does not make sense to state that you “suggest” that something is “interpreted”…
Line 159	Figure 4: The colours in the scale to the right end with dark blue, but the figure also shows patches where the dark blue changes to white. What do the white patches mean? In addition, the figure shows areas surrounded by a thin black line and it is not clear how you defined the black line. What does the black line separate?

Line 159 Figure caption: I do not understand the numbers at the ned of the line. I assume that these numbers should be "7.1^{-15} m^2 and 5.1^{-15} m^{2}". Note that I only refer to one digit after the comma, or is the second relevant? Presumably not as the range given her is much larger…

Line 161 "Thuès-les-Bains" instead of "Thuès"

Line 162 Suggestion: "with respect to sample position."

Line 168 Suggestion: "The here presented thermochronological study extends the study area along the footwall Têt fault to the west, up to the potential Planès recharge zone."

Line 170 "in a way different from numerical modelling."

Line 170 "We also incorporated samples from the hanging wall for comparison."

Line 174 "Palaeozoic"

Line 175 "providing" instead of "representing"

Line 178 Suggestion: "the Carança valley (CAR), at the foot of Gallinàs peak (GAL profile) and further west in the…"

Line 179 "which is a topographic high"

Line 182 "we selected the freshest rocks". Is this a good strategy to find the most altered apatites, the strongest impact of geothermal activity, the strongest geochemical changes? I could understand that you would state that you had to obtain samples that you could carry along and that you could make thin sections from.

Line 185 "Thuès-les-Bains"

Line 191 "crossing the St-Thomas hot spring cluster"

Lines 191/192 "The hot springs at St-Thomas …"

Line 192 Reference to figure 4?

Lines 193/194 Suggestion: "The dimension of the DZ in St-Thomas with a width of 700 m is larger than in …of this fault network."

Line 195 The here quoted samples and their elevation are samples from the footwall.

Line 197 "around the St-Thomas hot springs"

Line 197 "at 250 and 400 m distance"

Line 200 "distance" of 835 and 1750 m normal to the Têt fault." See also comment to line 125. Clarify what distance you mean exactly.

Lines 201/202 "are collected at 5, 160, 175, and 1900 m normal distance from the Têt fault, respectively, and…". See also previous comment.

Line 203 delete "also"

Line 206 Figure 5: The weak point of this figure is that it does not fit to figure 15 with respect to the fault lines. One example: In figure 5, a prominent fault line passes just south of Puig Gallinàs, while in figure 4, the peak is shown N of the Prats fault, and in figure 15, it seems that the fault passes north of the peak. It is also interesting to note that some NW-SE Palaeozoic faults are offset along the Têt fault dextrally (e.g. near CAR7), but some go across it (e.g. next to St-Thomas). Knowing that the fault has been active in the Cenozoic, a fault passing through would mean that there was no lateral offset during this faulting. Furthermore, profile (3) should have two faults at its SE end, but figure B does not show these faults.

Line 206 Figure caption: "showing four sampling profiles" (as in figure B, they are called "profiles". Suggestion: "Grey colours show samples from previous…"

Line 211 The title should be "Areas with no hot springs: …" The same would apply to the titles of chapters 4.1.2 (line 315) and 5.1.2 (line 439).

Line 212 Suggestion: "The GAL profile has been placed across the thermal anomaly…"

Lines 212/213 In my print, the reference "Taillefer et al., 2018" has a blue font. Why?

Line 213 Start sentence with "The samples GAL3, …"

Line 215 delete "sample" after "GAL3"

Line 216 "the same lithology as GAL3"

Line 218 "from the Tête fault, respectively (Fig. 5)." I would avoid to use the term "core", as you have not defined such a "core". Or do you mean the DZ instead?

Line 219	“from the inner DZ”
Lines 221/222	Suggestion: “near the valley bottom at Carança” (if there is a place with this name).
Line 224	The term “retrogression” is commonly used in terms of marine retrogression. I think what you mean is “alteration” (or retrograde metamorphic overprint?).
Line 225	Suggestion: “fractures at the outcrop scale”
Line 226	Suggestion: “In the PLA profile, two dated samples are located …”. Since you refer to an elevation of 1500 m, there are only two samples
Line 228	“fractured with local presence of …”
Line 228	The reference to figure 5 is probably wrong. How can we see iron oxides in figure 5?
Line 233	Figure caption: I am missing a general intro such as “Outcrop and microscopic images of crystalline rocks near Têt fault, eastern Pyrenees”.
Line 234	In figure D, I see mainly dark fillings (chlorite?) for the fractures. Do you mean “silicate fillings or do you refer to quartz?
Line 235	Figure E: Again use “quartz” instead of silica”, as the optical properties clearly indicate the presence of quartz. According to text, this should be sample CAR7, if yes, add this information to all figure parts.
Line 237	“fractured” instead of “fracturated”
Lines 238/239	“(enlargement of dashed rectangle in figure H)”
Line 243	Suggestion: “mineral concentrates were gained by…”
Line 243	“with no evidence”
Line 244	“for apatite grain photos”
Line 245	Start sentence with “Each single grain was packed in …”
Line 247	“achieved by” instead of “with”
Line 253	add comma after “procedure”
Line 255	“were analysed in-between four …”
Line 263	Does “mn” means “minute”? If so, better use “min”
Lines 268/269	Here, the abbreviations LREE and HREE are introduced. You should then use them systematically (see further comments below).
Lines 271/272	I am not sure whether this sentence should be included. If yes, start with “Caused by technical problems, some apatites have not…”
Line 274	“whether” instead of “if”
Line 276	Do you mean “modelled” instead of “modelised”?
Lines 280-288	In this paragraph I am missing a description of the AHe ages…
Line 281	“is observed” instead of “can be evidenced”
Lines 282/283	“a marked EU anomaly (Fig. 8)
Lines283/284	Suggestion: “… 1999). For fine-grained gneiss samples of the GAL profile, this anomaly is less pronounced.”
Line 284	“apatites of GAL3 have…”
Line 284	“consistently” instead of “consistent”
Line 285	“and flatter REE patterns”
Line 286	Suggestion: “are attributed to co-genetic growth of epidote, …”
Line 287	“in the GAL samples” rather than “in our samples”, this would be more specific.
Line 288	The term “at different scales” is difficult to understand. What scales are you referring to?
Line 289	Figure 7: In profile GAL, there seems to be a difference with the distances from the Têt fault for the samples of the hanging wall with respect to figure 5. The labels and numbers along the axes and the font in the legends are on the edge of readability. One may simplify by labelling the axis only once on the left side and bottom of the figure.
Line 290	Figure caption: I think, what you define here for the grey area is the outer damage zone (as the inner is yellow). I would start the sentence with “An inner DZ (yellow)…”
Line 291	“for the TET and GAL profiles”

Line 291	The reference to Milesi et al. (2019) is only half way correct. As written, the reader has to believe that Milesi et al. (2019) also contains samples from the GAL profile, which is not true.
Line 293	“analysed” instead of “dated”
Line 295	“and are younger”
Lines 296/297	Suggestion: “… (Milesi et al., 2019). Age dispersion is evident for this sample.”
Line 297	“of the now analysed grains”
Line 299	Suggestion: “age dispersion from … to …”
Line 304	Suggestion: “grains in each sample (ST15 and ST16, Table 1).”
Line 304	Start next sentence with “The gneiss samples …”
Line 306	add comma after “respectively”
Line 306	delete “comprised”
Line 307	Here, the reference should also be table “1” instead of “2”.
Lines 307/308	The statement “that could be indicative of the occurrence of optically undetected tiny Th-rich inclusions within these apatites” is weakly supported. It is a possible explanation, but you refer to this sample as being a paragneiss, and in paragneisses, the apatites could be of very heterogeneous origin. Thus, the explanation you give could be true for any of the paragneiss samples in your data set. In addition, the initial REE patterns of these apatites could be very different.
Line 310	The statement “A mean age of … is retained for sample ST2.” Is unusual. The statement is only given for this sample, while for no other sample. Delete sentence?
Line 315	Title should be “Areas with no hot springs: GAL and PLA profiles, Car valley” (see also comment to line 211).
Lines 316/317	Suggestion: “… are fine gneisses from outside the outer Têt fault DZ and show both limited AHe age dispersion with … and …, respectively.”
Line 317	The “However” is not needed, there is no contrast to be mentioned.
Line 320	“HREE” instead of “heavy REE”
Lines 321/322	I have serious doubts about the statement “geochemical and paragenetic conditions of growth during medium grade metamorphism of pelitic rocks”. I have checked the study of Henrichs et al. (2018), and my impression is that they talk about new-grown apatites rather detrital ones. At least they refer to the fact that they see a change in REE mobility starting with the uppermost greenschist facies. We do not know, however, what the metamorphic grade of the here sampled gneisses is. Thus, I have two critical questions that should be answered in the paper, if you want to refer to Henrichs et al. study: First, what is the metamorphic overprint your gneisses (in particular the paragneisses) have undergone during Pyrenean metamorphism? Second, do we talk about detrital or new-grown apatites (and what does the Henrichs et al. study talk about)?
Line 323	I would start the paragraph with “Sample CAR7 from the …”, because all CAR samples come from the Carança valley, so this information is redundant.
Line 327	“observed for apatites”
Line 329	“Further” instead of “Farther”
Line 334	No comments to Figure 8 and its caption
Line 336	Table 1: The caption (or “Note” line below the table should explain the meaning of “Ft”. I do not understand, why for some samples, you report mean ages, while for others, no mean age is given. What is the argument behind the selection? The Ft value for TET8-5 is given with three digits, while all other Ft values only with two digits. The Th/U value for TET1-12 is given as “<0.1” (see also “<0.1” for the age “Error”. According to the data for U and Th, the value should be 0.02, if one uses one more digit, similar to ST4-1, where you report a “Th/U” value of “0.0”, and the ratio derived from the data would be 0.02 as well, if expressed with two digits after the comma. Since the number of digits is dependent on the data for U and Th, the number of digits may vary, and I would make a difference.

Line 342	“Apatites from the hanging wall”
Line 343	The statement suggests that you believe that your samples are “S-type granites”. Can you clarify this?
Line 344	The subchapter number should be 4.2.1, and I would recommend to adapt the title to line 292.
Line 345	“In the TET profile, …”
Line 349	I would recommend to quote the age (14.8 ± 0.7 Ma).
Line 351	“In the ST profile, …”
Line 355	“mainly by lithology”
Line 358-361	I would argue that this paragraph is at the wrong place. Sample ML1 is closest to the GAL profile (Fig. 5).
Lines 360/361	Suggestion: from the same sample, and a mean AHe age from granite ST12 …”
Line 362	The subchapter number should be 4.2.2, and I would recommend to adapt the title to line 315.
Line 367	For completion, I would add a sentence such as “No REE patterns have been determined for these samples.” (in reference to lines 271/272, I guess)
Line 368	Suggestion: “A single gneiss sample (PLA5) from ..:”
Line 370	Suggestion: “exhibits a REE pattern with constant LREE values (Fig. 8)
Line 370	The statement “due to the presence of Th-rich inclusions” cannot be valid, as grain PLA5-4 has a very low Th value of 3.6 ppm. See also comment to lines 307/308).
Line 371	The bracket could be reduced to “(Table 2)”, as the grain number is already mentioned two lines above.
Line 371	Suggestion: “Consequently, this apatite grain was discarded from further discussion.”
Line 372	No comment to figure 9 and its caption.
Line 375	Table 2: Here again, you should clarify the argument on which you report mean ages for some samples and not for others. And you should explain the abbreviation “Ft” somewhere (either caption of “Note” line at the bottom).
Line 378	Suggestion: “…DZ, we combined these data with those from samples outside the …”
Line 379	“as a reference”
Line 379	It is not clear, what you mean by “accurate ages”. “Accurate” with respect to what?
Line 379	“low” instead of “weak”
Line 380	“variation” instead of “variations”
Line 381	“S-type granite”, no empty space after “S”
Line 382	Again, the reference to Henrichs et al. (2018) seems to be weak. Is their statement that all apatites in paragneisses show the same REE patterns? At least, they note that a homogenization does depend on the metamorphic grade. And if the input of REE along with detrital apatite varies strongly at the beginning, the REE patterns must look differently, even if the apatites homogenize their REE in medium- to high-grade paragneisses. Furthermore, the amount of new epidote, which depends on the amount of Ca available in the paragneisses will also influence the redistribution of REE. Thus, my recommendation would be: Please, read the Henrichs et al. study carefully, and then decide, whether it is worthwhile citing it.
Line 382	“We then define …”
Line 383	“for all other profiles”
Line 387	Figure 10: Several of the ellipses in these plots are so tiny that one cannot see the colour inside. Thus, I suggest to the authors to make the triangles bigger, they may even overlap, as the ST profile data are concentrated in the centre.
Line 388	“… profile samples.”
Lines 392/393	Suggestion: “…, we identify three fields that overlap partially:”
Line 396	“above 20 Ma, which are interpreted as …”
Line 400	Suggestion: “observed, more pronounced along …”
Line 401	“similarly” instead of “similar”

Lines 401-403 The statement “depleted REE patterns compared to apatites sampled outside the DZ” is not clear. Do you suggest that the apatites outside the DZ have undergone REE depletion? Aren’t the apatites outside the DZ the reference material for the apatites within the DZ? The confusion for me gets worse, when you talk about “global depletion” in line 402. What do you mean by “global”? If all REE patterns are depleted, what reference do we have? I assume that there is a misunderstanding caused by the current text, which should be fixed by some re-writing.

Line 403 Suggestion: “Note, however, that along the ST profile, …”

Line 404 “consistent” instead of “consistently”

Line 405 “do not exhibit REE depletion”

Line 406 Suggestion: “Due to the small numbers of analyses, the result is not interpreted any further.” Is this what you mean?

Lines 407/408 This is the first time that you refer to Flowers et al. (2009) and Gautheron et al. (2009) and state that the intra-and inter-sample age dispersion cannot be simulated. Here, the statement is correct, as you leave the door open, that a simulation would work, if the single apatite grains would be modelled individually. There are, however, places in the text (see e.g. lines 503/504), where the wording has to be changed. Nevertheless, for this passage, I would recommend to change to “cannot be simulated by a common thermal history using existing diffusion models for apatite”

Lines 408/409 Suggestion: “In particular, the young AHe ages do not fit to the regional …” It is not the fact that there are young ages, but the spread in ages that does not allow a common thermal history to be modelled.

Lines 409-411 Suggestion: “In accordance with the results for samples in the outer DZ of the TET profile, they raise questions concerning the origin of the AHe age scattering near the hydrothermal circulation zones (Milesi et al., 2019).”

Line 411 “were subject to”

Line 412 Suggestion: “enhances ^{4}He diffusion and apatite rejuvenation rather than U-Th incorporation, …”

Lines 411/412 The statement “Which is inconsistent with the observed REE depletion” cannot be assessed, as there are some intermediate steps missing in our argumentation. The claim is; I guess, that REE depletion would run parallel to U and Th depletion. Is this true? And what is the argument for it? I do not doubt the argument, but is has to be stated.

Line 415 “reaction zone” instead of “reacted zone”?

Line 416 “have been carried away”?

Line 416 “lattice of reacting apatite”

Line 418 “to be lost from the host apatite”

Line 418 The statement “mainly by advection during hydrothermal alteration processes” Is not sufficiently precise. Within the apatite, the process is diffusion, outside of the apatite, it is advection.

Line 420 According to the reference list, it should be “Andrews and Lee, 1979”

Line 420 Start sentence with “Variable REE loss”

Line 422 “at thin-section scale”

Line 423 After “fluid interaction” you could add a reference to figure 6H.

Lines 423/424 Start sentence with “The chemistry and temperature of the fluid flow may change with time”, then add a comma after bracket, and continue with “…, however, it is ..”

Line 425 “prominent” instead of “important”

Lines 425/426 “hot springs than near St-Thomas (…)”

Line 426 “pronounced” rather than “important”

Line 427 “larger” instead of “greater”

Line 429 “We cannot exclude an impact”

Line 430 “at the St-Thomas areas”

Line 430 Suggestion: “which may be responsible for an increase of rock permeability”

Line 431	“heat dispersion into”
Line 432	observed within the”
Line 432	Suggestion: “This is independently supported by the …”
Line 433/434	One may add references to figure 4 after “Têt fault” in line 433 and to figure 5 after “Têt fault” in line 434.
Line 434	“that are all located adjacent to”
Line 435	Figure 11: In the caption you refer to “blue” and “purple field”s. In my print-out, the “blue” and “purple” seem to be of the same colour. What about having the diagrams on the right with the same x-axis scale?
Line 435	Figure caption: “for the TET and ST profiles”
Line 436	“For the TET profile, “
Line 438	The “consistent” again raises the question of the reference. “consistent” to or with what? How about using “elevated” instead?
Line 438	“contents” instead of “patterns”
Line 438	“The depleting of REE is …”
Line 439	Better use title “Area with no hot springs: …” (see also comment to lines 315 and 362)
Line 440	Suggestion: “Slightly rejuvenated and scattered AHe ages and depleted REE patterns are also obtained for…”
Line 441	“hot spring clusters: Carança valley (CAR) and Planès profiles (PLA, Figs. 12 and 13A)
Line 443	Again, some of the ellipses are very small, so that the colour inside is hard to see, one may shift the triangles so that they overlap with each other.
Line 444	“GAL profile samples”
Lines 447/448	Here, the wording has to be adapted to be more precise. It is not the fault of the diffusion models that you cannot simulate a common thermal history. For wording, see comment to lines 4087/408. The diffusion models work ok, if applied to one single grain, but they cannot come up with a common thermal history.
Line 449	“and young ones peculiarly”: Here, again, it is not the young ages that cause the problem, but the spread of ages. The young grains have a correct thermal history and the old ones as well, but it is not the history of a closed system, but of in-growth or loss of He.
Line 451	“no longer active”
Line 452	“circulation” instead of “circulations”
Line 456	Do you mean “the end of surface hydrothermal activity”?
Lines 456/457	Suggestion: “… recent, while a hidden geothermal system could still exist nowadays in the subsurface.
Lines 458-461	Figure 13 and caption: Several details seem to be at odds with this figure: First, the start of the caption is equal to figure 11, but these are NOT the samples from “within the DZ” as stated in Line 459. Second, in lines 460/461, you state that the purple filed and triangles correspond to samples outside the DZ. Why is there no purple field for the GAL profile, three triangles for this diagram, but no triangles for the Car and PLA plot? Third, you mention in line 462 that there is an associated younging of AHe ages, but this is only visible for the CAR samples, not for the PLA and not for the GAL either. This caption has to be revised completely, I propose.
Line 466	“do not fit to the regional ..:”
Line 466	“depicted in Figure 2.”
Line 467	The statement “which is also inconsistent with the numerical thermal modelling” is problematic. The modelling in figure 4 shows the situation as of today, but the AHe and REE data integrate over the entire geothermal activity period. The hydrothermal activity might have stopped at 13 Ma.
Line 468	I am not sure, what you mean by “very circumscribed”, do you mean “more local” or “more regional”?
Line 469	“St-Thomas”

Line 470	“might then represent potential …”
Line 472	“we note” instead of “we can note”
Line 473	reference to figure 13 or 13A?
Lines 474/475	I would delete the first part of the sentence “This does not support … since 10 Ma”, and connect the rest to the sentence before: “… within the DZ in the last 10 Ma, in contrast to what …”
Line 477	“circulation” instead of “circulations”
Line 477	“Moreover, thermal modelling …”
Line 479	“suggests rapid cooling”
Line 483	“supports” instead of “reinforces”
Line 485	“using” instead of “made with” and then “and” instead of “using”
Line 487	“suggests an” instead of “corresponds to an” as these represent no unique solutions.
Line 489	“even at thin-section scale”
Line 490	You are mentioning “He loss”, but could it also be gain to explain the unusually old single grains next to the fault?
Line 490	I think what you mean is not “actual” but “present-day hot springs”
Line 492	Start sentence with “The combination of ..:”
Line 493	“extensions”
Lines 494/495	Suggestion: “This result questions a straight-forward interpretation of AHe ages, if potential …”
Line 496	Figure 15: Should the scale of intensity (top right) not be called “intensity of present-day thermal anomaly”? For the “outcrop scale”: “Poorly fractured gneiss lenses”
Line 497	Figure caption: Start text with “Synthetic 3D block of …”
Line 497	Suggestion: “of the present-day thermal anomalies”
Line 499	“samples” instead of “sample” (as there are ML1 and ST12)
Line 499	add reference to Table 2 after “AHe ages”?
Line 501	“S-typ granites” instead of “granitic lithology”?
Line 502	“similar to” instead of “as in”
Line 502	“closest to” instead of “nearest”
Line 503	Suggestion: “The AHe age scatter (Fig. 7, Table 2) cannot …” I am sure it should be figure 7 instead of figure 3…
Lines 503/504	Here again, the wording has to be adapted to the comments to line 407/408.
Line 505	“Apatite REE contents appear less …”
Lines 506/507	I do not understand the statement on the Canaveilles hot spring cluster in the hanging wall. The hydrothermal anomaly on the other side of the fault is much closer. You draw a picture of a completely impermeable fault plane, which for several clusters and profiles is shown to not be true. I would rather go for a picture, in which the fault plane is permeable, in particular along existing fractures systems that cross the Têt fault. By such a picture, it is very easy to also explain the Canaveilles hot spring cluster, which is located very close to a prominent fault linked to the Têt fault (Fig. 5). Of course, these neighbouring faults may have undergone some reactivation and local increase of permeability, even if surrounded by less permeable metasediments. Such lenses of metasediments (Fig. 5) may even help to channel and concentrate fluid flow.
Line 507	“just NE of …”
Line 509	“those close to the Têt fault”
Line 511	Here again, I would suggest a rewording to better clarify what you mean by “can be properly modelled with He diffusion models in apatite”. It is not the models that are wrong, but it is the fact that even within one sample fluid circulation may have led to very different thermal histories.
Line 512	“outside the DZ”
Line 513	“shows rapid cooling”
Line 514	According to figure 16, it should be “range of 150 to 50°C” (perhaps even 40°C).

Line 514	“slows” instead of “low”
Line 514	“Low” instead of “slow”, as this time, you refer to “rates”.
Line 514	Suggestion: “may account for” instead of “can account for”
Line 516	“The PLA5 sample” or “Sample PLA5”
Line 517	Suggestion: “lower than the geothermal system along the Têt fault footwall …”
Lines 518/519	The last sentence suggests that everything can be explained by regional slow cooling. Does thie mean that geothermal activity is no explanation for the scattering? Why not? See, e.g., hot springs in Canaveilles on the other side of the fault.
Line 522	Suggestion: “corresponds to a perfect match.”
Line 523	delete “mainly”
Line 525	“even though” instead of “despite”
Line 525	I think the statement that the small numbers do not allow “a straightforward interpretation” is not the issue. The small number allows many interpretations to be supported by the data. The low number of data is not sensitive enough to discredit many of them. So, my suggestion would be “does not allow a clear” or “unique interpretation”.
Line 525	“questions” instead of “question”
Line 527	Do you mean “all samples outside the DZ”. If not, I do not understand the statement…
Line 527	“thermal history together with rocks ..:”
Line 528	“perturbation, in accordance with …”
Line 529	“that hydrothermal circulation is mainly restricted”
Lines 529/530	I would disagree with this statement. First, several profiles show the influence of the geothermal activity on AHe ages also in the hanging wall. Furthermore, the Canaveilles hot spring cluster clearly indicates that there are hot springs on the other side. Even if you suggest a completely impermeable fault plane, AHe ages might be influenced by re-activation of fluids on the other side of the fault by the increase in temperature in the rocks of the footwall.
Line 531	“influenced” rather than “impacted”
Line 532	Start sentence with “We also highlight …”, “in addition” and “also” are redundant.
Line 532	“interaction” instead of “interactions”
Line 533	The here quoted temperature values of “<130°C” has not been quoted in the paper. It is important? If yes, you have to explain, where this temperature has been derived from.
Line 533	“considered a closed system”
Line 534	“released into” instead of “dissolved”. The transport within the fluid is not the critical process.
Lines 534-536	I would not make these statements here. First, you have not discussed the processes that caused He gain and loss and REE loss in this paper. The conclusions should not come up with new (not discussed) issues. Second, I would suggest that the processes could be addressed in a next paper, if you have evidence or modelling results to distinguish between potential processes. But in this paper, the focus clearly is on the hydrothermal activity and how to detect it; there is little evidence that was presented about the processes, certainly nothing about ”nano-channels within the crystal lattice”. So, consequently take these statements out.
Line 536	“As fluid flow through …”
Line 536	“even at thin-section scale”
Line 537	“Again, the “^{4}He loss by fluid advection” is not the limiting process, but diffusion is much more crucial as Flowers et al. or Gautheron et al. have shown.
Line 537	The “global positive correlation” does not exist. It exists for some of the data sets (profiles), but by far not all of them.
Lines 538/539	Suggestion: Start sentence with “The same process may also account for …”
Line 539	“in other cases”

Line 539	“fluid circulation” instead of “fluid circulations”
Line 539	“may occur” instead of “took place”, I would suggest to make this more general, not only relevant for the past.
Line 540	“questions” instead of “question”
Line 540	Suggestion: “AHe ages in cases, for which potential hydrothermal …”
Line 541	Do you mean “active” instead of “obvious”?
Line 542	“palaeo-geothermal” instead of “paleo- geothermal”
Line 543	Suggestion: “As an exploratory tool, (U-Th)/He thermochronology may be applied complementary to …”
Line 544	“geoelectrical” instead of “electrical”
Line 545	It is not clear, what “models” you are referring to.
Line 549	“by Doriane”
Line 550	“during field work.”
Line 552	Suggestion: Data supporting the findings of this study are available in the Supplementary section. Additional details may be obtained upon request …”
Line 556	“models on”
Line 557	“co-wrote”
Line 558	“participated in”
References:	I was unable to locate the reference Sutherland et al. (2012) in the text. Missing in the list is the reference Farley et al. (1996), found in line 254. The reference Shipton & Cowie is at the wrong place. I found strange spellings, spaces or upper case words in lines 677, 683, 703, 742, and 771/772 that should be corrected.

Meinert Rahn, May 17, 2020.