

Constraining metamorphic dome exhumation and fault activity through hydrothermal monazite-(Ce)

Christian A. Bergemann, Edwin Gnoss, Alfons Berger, Emilie Janots, Martin J. Whitehouse

by Meinert Rahn

The study of Bergemann and co-workers presents 480 single spot ages and 33 weighted mean ages from 19 locations and their cleft monazites within the northern Lepontine Dome (and adjacent to it). These ages are used to decipher the exhumation and tectonic history of the Lepontine dome, as the ages are compared with other geochronological data supposed to represent the Neogene cooling history.

To me, there is no doubt that the provided data are interesting for publication in *Solid Earth*. However, for the moment the manuscript and submitted material has for the moment several critical shortcomings that I would recommend to fix prior to becoming acceptable, as I consider them critical, if the paper wants to have the impact the presented topic deserves and the general title promises. My major concerns are the following:

1. The title of the manuscript suggests that the monazite data provide new constraints on the tectonic and exhumation history of the Lepontine dome, while the discussion of the data mostly refer your data to already existing constraints of the dome exhumation and Tectonics. As such the focus of the paper is more on methodical aspects of monazite dating (e.g. monazite formation temperatures, relationship to other dating techniques and their closure temperatures).
2. There is throughout the paper a mess with the figure numbers. My assumption is that the authors may have changed these numbers shortly before submission of the manuscript. I invite the authors to check carefully all figure numbers when revising their submitted material. I also note that at several occasions the authors refer to figure 1 in the appendix, which I was unable to locate.
3. For the moment, the chapter "Results" is ultra-short and lacks important information. In your discussion chapter, you tend to describe your results at several places, which should be done in the "Results" chapter. The "Results" chapter should also be used to clarify, what data you will discuss in the "Discussion" chapter and which data will not further be discussed.
4. My major concern is that the authors are rather vague with their methodical descriptions. Some of these details should be part of the "Introduction" chapter, of a new methodical chapter or part of the "Results" chapter. Let me summarize this in five points that I would expect the authors to provide more information about:
 - a. The authors talk about the "monazite stability field" (e.g. p. 13, line 3; p. 15, line 6; p. 17, line 20), however, they never discuss, what they mean with "stability field". Note that the authors on p. 12, line 5, talk about "disequilibrium", without clarifying what kind of "disequilibrium" they refer to. I would assume that this is not a "thermodynamic stability", but they rather consider a kind of temperature window, in which the cleft monazites were formed. If correct, it might more correctly speak about the "monazite formation temperature window". This aspect is important, because in the "Discussion" chapter you compare the formation of monazite with the closure temperatures of low-temperature thermochronology methods (which seems to suggest some kind of closure-T for cleft monazites).
 - b. The authors present BSE images for each on the investigated monazite crystals (their figures 3 and 4). However, it remains unclear what the visible colour changes mean within each individual crystals (no chemical data are given except for a few selected elements in the supplementary data file) and how the authors have chosen their analytical spots on these crystals. The only information is that the authors state that they have placed the SIMS spots were placed "according to compositional domains" (p. 3, line 29). Accordingly, we would expect that spots of same colour rings in figures 3 and 4 would always represent areas of same gray colour in the BSE image. This clearly is not the case for e.g. in the DURO1 crystal the yellow spots seem to only roughly follow a lighter lamella, but overlap with darker areas around, in the DUTH2 crystal the orange spots lie within a lighter rim, but spread into the darker centre next

to it. The authors have to state clearly their criteria in how to assure that spots are not mixtures between to different generations of monazite formation.

- c. The authors state that they have avoided measurements next to cracks and holes (p. 15, line 30). This statement is in contradiction to e.g. the red spots in BETT11, the blue spots in VANI6, the red spots in VANI5 etc. I assume that the criteria is more likely defined by the analysis itself showing a deficit in elements rather than the geometric vicinity. The authors have to clarify this issue.
- d. The authors have to clarify on the basis of which criteria they have chosen the weighted mean ages out of the spot analyses. In Figure 5a (VANI6), it seems obvious that the orange group weighted mean age is formed out of all orange spots. Age-wise, however, these spots seem to overlap with the gray spots. So, how have the authors separated between orange and gray? In figure 5b (BETT11), the four red spots show age overlap, but they are not combined to one weighted mean age. Why not? In figure 5c (DURO1), the four blue spots form a weighted mean age, but the gray spot next to it (same age) is not part of it. Why not? I could continue the same way for most of the diagrams in the figures 5 to 7. I am sure that there are good reasons for the authors' choice of the weighted mean ages, but for the moment, this choice cannot at all be assessed by the reader and looks very arbitrary, not scientifically founded. The authors have to explain to the readership their selection criteria, and for such purpose, it may be needed to better illustrate the different compositional variations among the individual monazite analyses.
- e. According to figure 1, there are three age groups (with some samples showing more than one). In figures 5 to 7, however, the authors have several samples with more than two weighted mean ages, in figure 8, the three age groups are no longer visible, and in your discussion chapter, you discuss a much finer distinction among the age groups (see also figure 9). We would recommend to the authors to clarify this issue of age groups in an early stage (e.g. in the results chapter and then stick to it throughout the entire discussion chapter. For the moment, the reader gets lost due to the many age groups and the inconsistency between the figures.
- f. Figure 8 shows the ages again, but in probability density plots. Up to here (in particular in the figures 2 to 7, the reader has gained the impression that single spot data are clustered to weighted mean ages. Here, however, the authors seem to have split the ages again in single spot ages to form new curves and density plots. The same is true in the "Discussion" chapter on pages 15 and 17: Sometimes, the authors refer to single spot ages and sometimes they refer to weighted mean ages. I do not understand why the authors refer to weighted mean ages at all, if they afterwards selectively use the information that fits best their arguments. The authors have to clarify their strategy in interpreting their results. They have to clarify the meaning of their "weighted mean ages" in that sense. They also have to explain how uncertainties were calculated for the different types of ages.
- g. Figure 8 shows a kind of clustering of the single spot ages. In this plot the authors also show previous literature data (in gray), but these are not included in their clustering pattern (we do not know, whether this is the case for the curves in the inset below). In Figure 9, however, their interpretation includes all the literature data (e.g. for the Gotthard nappe and the Aar Massif). This is inconsistent. Either you use all data or you do not. The authors have to lay out their strategy on what data are to be interpreted and then stick to it.
- h. Figure 2 shows nicely how the authors divide their samples into regional groups. However, in the "Discussion" chapter, their division seem to not make sense in many respects as they tend to again subdivide their division. I make two examples: (1) On p. 15, line 19, the authors refer to "the entire (north)eastern region that seem to act differently than the rest of the region. This "sub-region" is not well defined. (2) Figure 2 places sample DUTH6 to the edge of the "Center" region, but in figure 9, this sample rather behaves like the samples in region "West", so why DUTH6 is part of the "Center" area?
- i. In chapter 5.3, the authors compare their data with data from other thermochronometers. However, this comparison is incomplete in that sense that sometimes ages are quoted, sometimes not, sometimes the authors only refer to the interpretation of the previous workers without referring to the geochronological evidence. This should be done in a more careful, systematic and transparent way. I recommend e.g. that they authors clearly state what time and methodical information they use for their discussion (e.g. they refer to K/Ar ages, ZFT and ZHe ages, but they do not use AFT or AHe ages.
- j. The "Discussion" chapter starts with an interesting subchapter on hydrothermal monazite crystallisation. This is exactly the information needed to understand

methodically the authors' strategies. However, as far as I understand, this chapter is not a "result" but a initially chosen "strategy" on how the monazite ages are to be interpreted (it looks therefore misplaced in the "Discussion" chapter). The authors should somewhere clarify their strategy of the understanding on how monazite is formed.

5. From the title of the paper, the reader expects some new information about exhumation and tectonics within the Lepontine Dome. However, in such respect, the "Discussion" chapter has been disappointing for me. The authors support existing cooling/exhumation paths and tectonic events, but they have no courage to suggest any new "events". I agree that the paper title could be understood as "Confirming metamorphic dome exhumation", and I also agree that the problem with monazite dating is the fact that the ages cannot be related to a temperature value (closure temperature) in contrast to other methods. Nevertheless, I also see potential about the information of the monazite ages that the authors seems to keep untouched. What e.g. is the function of the Rhone-Rhine line (e.g. in figure 9e, f)? Where do the new results show an extension of previous time windows or a focussing on smaller windows for existing phases of tectonic activity? In the end, the "Discussion" chapter does not seem to provide any new information.

Looking through these comments (and the detailed comments below) I would recommend to the authors to thoroughly revise their manuscript (major revisions). For me, there is no doubt that this study would be an excellent contribution to Solid Earth. However, for the moment, publication of the extensive data set would fail to gain credibility among the readers, because so many methodical details are only vaguely described and therefore lack credibility.

Detailed comments:

The following comments are sorted according to page numbers and text lines (in the pdf provided). They were continuously gathered while reading. Many of them have later been clustered to major comments (see above). With respect to grammar or English style corrections, this reviewer confesses to not be a native English speaking person; accordingly, suggestions concerning grammar and phrasing are to be seen as suggestions. I also highlight, if a comment is thought to be a suggestion (for e.g. clarifying a statement or shortening the text).

Page 1

- | | |
|--------|---|
| Title | The authors always refer to "monazite-(Ce)". This is ok as the IMA points out that monazites could be dominated by different REE in their formula. However, the authors never confirm that Ce is the dominating RE element in the formula of their 19 samples. The paper has no compositional data except for those in the supplementary data set. I assume that much of the division of the analysis spots (figures 3 and 4) is due to compositional arguments. However, the reader has no chance to assess this division. The reader has not even a chance to find out, whether the "monazite-(Ce)" in the title is correct or not. |
| Title | Looking back to the "Discussion" chapter, this reviewer has rather the impression as if the authors do not "constrain" but only confirm previous information on the exhumation and tectonic history of the Lepontine Dome. I suggest to thoroughly revise the manuscript and then decide on whether to change the title of the paper. The same might apply for the "Abstract". |
| Title | The term "hydrothermal monazite-(Ce)" is varied in the manuscript. Sometimes, the authors refer to "clefth monazite-(Ce)", sometimes to "hydrothermal clefth monazite-(Ce)", and the reader gets puzzled about the different expressions. It would help to clearly state somewhere in the manuscript that these monazites all come from clefts. I am not so happy about the term hydrothermal as it suggests that these monazites have formed in a flush of "hot" fluid, the temperature of which might not have been in equilibrium with the surrounding rock. If so, any later comparison with closure temperatures of thermochronologic systems may not be useful, as the temperature of the monazite formation may have been completely different from the temperature controlling closure of other geochronologic methods. |
| Line 2 | The authors refer to the "Central Alpine Lepontine metamorphic dome", which is a rather unusual term. First, figures 1, 2 and 9 show that the study area does not cover the south of the dome (along the Insubric Line), but its entire E-W extension (so, "Central" may not be needed). Second, the Lepontine Dome is an Alpine structure, so, I would suggest that there is no need to use the term "Alpine" here. |

Line 4	Suggestion: delete "The" at beginning of sentence
Line 5	There seem to be a double space between "between and "19"
Line 6	The authors use the abbreviation "Ma" (= mega annum) for both, specific moments in time and timer periods. Please check the instructions for authors that suggest to use "Ma" for time spots", however, "Myr" for time periods. I fully support such instruction. Accordingly, the authors should write here "lifetime of 2 to 7.5 Myr"
Line 6	Suggestion to put "combined with age distribution" into brackets.
Line 9	Suggestion: "In the east and south of the northern Lepontine dome"
Line 9	Suggestion: delete "the" before "units"
Line 9	Suggestion: add ", respectively," after "Ma"
Line 10	Suggestion: "at 15-10 Ma. Cleft monazites..."
Lines 10/11	There seem to be a mismatch with the statement "youngest" in line 10 and "A last phase" in line 11. "Youngest" means "last phase", thus these phase should be the same... Furthermore, I would suggest using the term "age signal" instead of "phase" as the latter already suggests that this has been a distinct tectonic or thermal "event".
Line 11	Suggestion: "along the Simplon Fault". One further note: If you quote names of domes and faults, make sure that they are constantly with upper case or lower case. So, either Lepontine Dome or Lepontine dome, Simplon Fault or Simplon fault.
Lines 11/12	Add hyphen: "strike-slip"
Line 12	Suggestion: "faults along the Rhine and Rhine-Rhone faults"
Line 13	Do you mean "stability" or "formation"?
Line 13	"directly" instead of "direct"
Line 15	"experience" instead of "experienced"
Line 16	Suggestion: Start line with "For the Lepontine Dome, this evolution is an interplay ..."
Line 16	Suggestion: "motion along" instead of "activity of"
Line 16	Suggestion: "define" instead of "dominate"
Line 17	Suggestion: "the western edge of the dome" instead of "the western parts of the area". Note that throughout the text, you frequently use "in this area", but you are not very specific, what area exactly you are referring to. I would expect to get some references here.
Line 17	The statement "Although much of the (thermo)chronological history of the area is well known" is rather cryptic. Does this refer to the fact that there are a lot of data concerning the post-peak metamorphic history? Or does this mean that the tectonic history is known in detail? Since you do not provide any references and the statement is rather broad, the reader cannot assess the meaning of this statement.
Line 18/19	Interestingly, here you refer to AFT and AHe ages, while in the Discussion chapter, you do not refer to any of the existing studies including such data and you do nowhere cite any of them. This is ok with me (as e.g. AFT and AHe ages may already be influenced by topographic evolution. Nevertheless, there is a mismatch between this statement and the discussion of your data afterwards. Finally one suggestion for a rewording: "existing cooling ages of the Rb-Sr, fission track (FT) and (U-Th)/He systems".
Line 20	Suggestion: "(e.g. Parrish, 1990). It is highly resistant..."
Line 21	"by diffusion" instead of "through diffusion"
Line 22	not clear, what "geologically reactive" means

Page 2

- Line 1 "by" instead of "through".
- Line 1 What do you mean by "mediation"?
- Line 3 Suggestion: "occasionally contain monazite-(Ce). They represent voids..."
- Line 7 Suggestion: "were" instead of "could be"
- Line 11 Suggestion: "...tectonic activity. Accordingly, fissures and clefts are ..."
- Line 13 "interacted" instead of "interacts"
- Line 13 Suggestion: Start new sentence with "Dissolution and precipitation..."
- Line 14 Suggestion: "led to" instead of "causing"
- Line 18 Suggestion: "by using secondary ion mass spectrometry (SIMS)"
- Line 19 At the end of this introduction, I miss a paragraph that presents the aims of this study. I addition, I miss an introduction to the methodology of monazite dating, not the technical issues, but the prerequisites that define the strategy of the study.
- Line 22 Add "European" to "Alps"
- Line 23 This bracket lists examples of metamorphic domes, but their allocation is once to a country ("Austria") and once to the part of an orogeny ("western Alps"). I would suggest referring either to Switzerland/Austria or to eastern and western Alps.
- Line 25 The references listed here have a strange ordering, either alphabetic or with decreasing age. Please check the author's instructions.
- Line 26 The statement that the Western and Central Alps had a "complex tectonic and metamorphic history" is not very convincing. "Complex" with respect to what? Orogens tend to be complex anyway (fortunately, this keeps us going to find out more details of this history!), but the statement is too vague, too general. You may start the chapter with such a statement. Furthermore, I refer to the detail that Schmid et al. (2004) did not use the term "Central Alps", but divided the Alps into western and eastern Alps.
- Line 31 You may put "in excess of 650°C in some regions" into brackets.

Page 3

- Line 1 not clear, what you mean by "staggered exhumation", I am doing research in the field of exhumation for 20 years, but have never heard of this expression.
- Line 1 I would recommend to add references to this statement
- Line 4 Suggestion: "later in time at 18-15 Ma"
- Line 5 I would recommend to use the term "normal faulting, rather than "detachment", as the term "detachment" has no direction.
- Line 9 Here, the term "Simplon Fault zone" is used, but in line 11 "Simplon shear zone". If these terms describe different zones, then the authors should explain the difference.
- Line 10 "Alpine" instead of "alpine"
- Line 14 From figures 1 and 2 it is evident that the study area is the northern Lepontine dome. Nevertheless, the exhumation of the Lepontine Dome cannot be described without the Insubric Line. (15 km of differential vertical exhumation!). The authors should consider including the Insubric Line in their "Geological setting".

- Line 15 "area" instead of "Area"
- Line 16 Suggestion: "The study area comprises the northern half of the Lepontine ..."
- Line 17 "Forcola Fault"
- Line 17 The "Val d'Ossola" is not visible in any of the figures.
- Line 18 Suggestion: "Aar massif to the north (see Fig. 1 for the tectonic position of the samples)..."
- Line 19 Should not Janots et al. 2009 be added to this list, as it also contains monazite ages?
- Line 20 The statement that the four groups correlate "to tectonic subdivisions" cannot fully be assessed by the reader: First, there is no tectonic subdivision between central and western part (the Ticino and Toce domes are separated by what tectonic feature?). Second, In figures 1, 2 and 9, the Forcola Fault ends south of the study area, and if the authors refer to the extension of the Forcola Fault to the north, the sample VALS would be located in the central part. How about separating along the western rim of the Adula nappe?
- Line 22 "bound" instead of "bounded", as it is related to "to bind"
- Lines 23-25 I would shift the last sentence to the beginning of the next chapter.
- Line 28 Note that there are different spellings of "backscatter". In figures 3 and 4, you write "back-scatter".
- Line 28 Suggestion: "Backscatter electron (BSE) images were used to define spots suitable for analytical investigations." It is, however, unclear to me, how you defined the different groups (of different colours) and how you have chosen the analytical spots. This needs more information.
- Line 29 The statement "according to compositional domains" cannot be understood without further information: How do you define a compositional domain? What compositional data were available? I refer to the fact that a change in RE element (but otherwise constant composition of the monazite) may not really show a difference in colour in the BSE image... It would be helpful to know what analytical data were available, and which of these data were used to "define the compositional domains".
- Line 30 Suggestion: "As far as possible, spot measurements next to cracks or holes were avoided".
- Line 30 Looking at e.g. figures 5a, 5j, or 5l, this statement cannot be understood. In the corresponding crystals, there are measurement spots directly next to cracks...
- Line 31 Suggestion: "in such areas"

Page 4

- Figure 1 This figure is not yet finished. First and foremost, there are no coordinates, there is no scale and there is no north direction. I would recommend to enlarge the map on top (a), and enlarge the labels (b) to (e). The legend contains the abbreviation "mzt" that is not explained in the caption. According to the thick black line in map (a), the profile (c) should end at the border to the Aar Massif, but in (c), it extends into it. Profile (d) has gray units that do not show up in the map (a). Each of the profiles has its own scale, thus, scales should be added to figure parts (b) to (e). Faults are not labelled.

One methodical problem is that the authors in this figure's legend refer to three age groups, but in the discussion chapter (and in figure 9), there are more age groups. This is inconsistent. Do you need to mark the different groups in this figure already?

- Figure caption Line 1: switch the two references, as they are not in correct order, line 4: There is no Wiederkehr et al. 2008 reference in your reference list. Do you mean the 2009 reference? Line 4: Why does the caption uses a different text for profile (e)?

Page 5

Table 1 In this table, all samples are given names with upper case spelling. However, in figures 1 to 7, the authors sometimes use lower case or upper case. In addition, sometimes, there is a gap between name and number, sometimes not. I recommend adapting the names throughout the paper and figures and tables, and I would use a space between name and number, as several names end with "I", which then might be interpreted as a "1".

For some of the samples, you note coordinates with "~". What is the difference? If the location of the sample is not sure; I would rather recommend to reduce the digits after the comma of the angle minutes (e.g. sample SALZ2) rather than adding a "~".

Page 6

Figure 2 The frame in the inset does not fit to the area of the large map. Similar to figure 1, coordinates and north direction are missing, the abbreviation "mzt" should be explained, The label of the "Centovalli Fault" is partly covered with blue colour.

Line 4 Suggestion: *by" instead of "with

Line 7 delete "presented"

Line 8 Suggestion: "reported" instead of "given"

Lines 10/11 Suggestion: "... pending). Table 2 provides an overview and Figures 3 and 4 show measurement positions and the division of the analysis spots into different age groups, represented by different colours.

Lines 11/12 The statement "As there are difficulties with the U-Pb system for hydrothermal monazite-(Ce)" is very cryptic. What difficulties do you mean? And how have the authors dealt with these difficulties?

Line 13 "see discussion in chapter 5.2".

Line 13 I note that the "Results" chapter only contains these four lines. I strongly recommend describing the results. What should the reader see? The next pages are figures 3 to 7 and table 2, and if the reader goes through these many data, there is no guarantee that the reader will come to the same conclusions as the authors about what is important and what is not. As noted in the general comments above, I have rather collected doubts about the usefulness of the chosen strategy of the authors and the credibility in their chosen analytical spots, derived weighted mean ages etc. I would argue that a careful description of the results would help much not losing the reader half way. You should add a description on how the spots have been selected, grouped in the diagrams of figures 5 to 7, how the weighted mean ages were afterwards grouped. It may help starting with figure 8 instead that shows an overview of all ages.

Page 7

Figure 3 Many of the colours of the spots are hard to be distinguished (e.g. figure e). All sample names should be similar to tables 1 or 2. For several sub-figures, the numbers are too small to read (perhaps enlarge figure to full page). You should clarify that this BSE images show all spots made for this study.

Figure caption "Back-scatter" or "Backscatter"? (see comment to page 3, line 28). You have to add the information that the grains shown are from the south and west areas only, e.g. "Backscatter electron images of all studied cleft monazite-(Ce) grains from the South and West areas." Line 1: "content" instead of "contents", "Coloured ovals" instead of "Spots". Line 2: "different colours indicate different chemical ...". Lines 2/3: "indicates those data, for which a weighted mean $^{208}\text{Pb}/^{232}\text{Th}$ age could be calculated.

Page 8

Figure 4 For this figure, see comments to figure 3 and figure 3 caption. Again, it should be clarified in the caption that these samples are from the Center and East areas.

Page 9

Table 2 The caption of this table does not fit. The information given here should be placed elsewhere. Most of the numbers in the "Figure" column are wrong. Obviously, the authors have changed the figure numbers in a late step and not adapted text and tables. The last column to the right lists the range of single grain ages. I do not understand why there are empty lines in this column as the range can also be given to those age groups that are combined to a weighted mean age. For sample "GRAESER1", the number of points for the older weighted mean age should be 6 instead of 5 (see figure 3e), and the second weighted mean age is missing in figure 5e. I would recommend to draw lines between the four different areas (South, West, Center, East).

Page 10-12

Figures 5-7 Looking at these diagrams, I have many questions about how you define a weighted mean age. In some cases, all spots of the same colour form such a weighted mean age (e.g. 5a, 5b, 5g). More frequently, the weighted mean ages are calculated for a selection of ages of the same colour only (see e.g. 5b, 5e). In some cases, it is obvious that only one colour bar is far off (e.g. in 5e, red), but in other cases (e.g. 5b, red), I do not know, why one age has not been included, even though the vertical bars overlap. Finally, there are examples, where age bars overlap, but were not used to calculate a weighted mean age (e.g. in 5e, young yellow ages, in figure 7s, gray bars in the figure centre). The authors have to explain their selection procedure in detail, otherwise there is no credibility to their ages at all.

In figure 6p, one vertical bar has a lighter blue colour; why?, In figure 7s to the left, there is a short bar without colour.

Page 12

Line 2 To me the content of chapter 5.1 is misplaced. The reasoning given here is not the result of the study, but a strategy that the authors have chosen beforehand, as far as I understand. If there are observations, features, analyses that support your reasoning, then they should be presented as results and used to interpret your ages properly. For the moment, the content of this chapter should be transferred elsewhere, e.g. in a new chapter on methodology.

If you argue that "later reactions may be aided by secondary porosity and fracturing induced by the previous dissolution-reprecipitation/recrystallization events", then show evidence for it. Show what you mean, add another figure like figs 3 or 4 to show corresponding features. For the moment, the entire chapter 5.1 is a black box to the reader, as the authors do not present any evidence for dissolution, reprecipitation, recrystallization. The authors should better define, what they mean with these processes and present examples for it.

Line 5 Suggestion: "later reactions may occur"

Line 5 The term "disequilibrium" is hard to understand. "Disequilibrium" with respect to what?

Line 5 Suggestion: "The may be caused by a tectonic event for a ..."

Line 10 Suggestion: "phase may precipitate"

Line 12	Suggestion: "fluid remains connected to a ..."
Line 12	Suggestion: Start sentence with "A dissolution ..." as this process has not been defined.
Page 13	
Line 2	There is no 2018 reference for Grand'Homme et al. in the reference list. Do you mean the 2016 reference?
Line 8	The statement "placed ... according to growth domains" cannot be assessed by the reader. The authors should show their arguments, e.g. with one example. How do you define a growth domain? How do you define what is old, what is younger? Do ages from different growth domains fit to the measured ages (same age order)? Have you tested the order?
Line 9	The statement "on the basis of chemical composition" cannot be assessed by the reader. What chemical information did the authors gather and what chemical arguments did they use? This information is of major importance if forthcoming studies should apply the same methodology.
Line 11	The reference to "Fig. 7" should probably be "Fig. 5-7".
Lines 11/12	The statement "It appears that dissolution-precipitation may largely preserve the chemical composition of an affected crystal part" cannot be assessed by the reader. Is this an assumption? If not, what is the evidence you found? What are the conclusions drawn from it?
Line 12	"areas of" instead of "areas with"
Line 13	Not clear, what you mean by "this" ("Despite this,...")
Lines 13/14	The statement "only in a few, clear cases" cannot be assessed by the reader. Which cases? And what means "clear"?
Line 14	Suggestion: "age calculation, to avoid ..."
Line 15	Suggestion: "single" instead of "distinct"
Line 18	Suggestion: "New growth on an existing crystal results in sharp chemical (or colour) boundaries between growth zones." Note however, that this is only the case, if the growth zones differ in composition. Thus, it is an argument, but it does not need to be...
Lines 18/19	I wonder whether this discussion on the dissolution-reprecipitation should be shifted to the chapter 5.1, where these issues are raised already.
Lines 20/21	Suggestion: Start sentence with "Accordingly, events of monazite growth may not..."
Line 21	Suggestion: "if looking at the weighted mean ages only."
Line 21	Suggestion: "To avoid age mixture"
Line 22	What is the reason for a 0.5 Ma time interval? And use 0.5 "Myr" (instead of "Ma"),
Line 22	Does the content in the bracket mean: "see at figure 1 and the appendix"? Or is there a figure in the appendix (which I have no access to)?
Lines 22/23	Suggestion: "In a subsequent step..."
Line 23	What do you mean by "plateau"? Could the "plateau be simply made of several distinct intervals that a time step of 0.5 myr is not sufficient to resolve individual age peaks? Is there geological evidence that would support a plateau due to continuous monazite formation? Can we see this in the BSE images (e.g. continuous colour gradients)?
Line 24	The authors should clarify, whether their interpretation is based on their ages only, on their ages and the already published ages together, or on the weighted mean ages only.

From here on, there is mix between all types, which does not enhance the credibility of your interpretation.

Lines 24/25 The statement “to visualize distinct events or phases of tectonic activity (Fig. 8) is difficult to understand. First, the visualization is dependent on your chosen time interval (see comment above). Second, you have to clarify for figure 8, what you do with the gray ages (literature data): Are they included or not? If not, why not? Third, you have to specify the different colours used in figure 8, there are colours of different intensity (in the West area three shades, but no explanation).

Line 25 Suggestion: “are possible to be obtained for each grain”

Line 2

Line 29 “listed” instead of “given”

Line 30 Suggestion: Start sentence with “An alternative reason ...”

Line 30 I suggest that the authors speak of a “plateau” if they claim a “spread out age pattern”. The nomenclature should be clarified.

Lines 30/31 Suggestion: “tectonic activity by multiple small...”

Line 31 “In such a case ...”

Line 31 Do you really mean “reprecipitate” or only “precipitate”?

Line 32 Suggestion: “This may lead to ...”

Line 32 Can you specify more precisely, what you mean by “unclear crystal zonations”?

Page 14

Figure 8 In this figure, there are black and gray data. It is obvious that the gray data were not used for the colour coding of the denser and less dense age areas. The authors should clarify on what data set they base their interpretation. Does the inset (with the curves) show the ages of this study only or all data? The authors talk about the “complete data set”. What is the complete data set?

What are we expected to see? What is the meaning of the different colour shades (only the West area has three different shades (why?). How were they defined (what are the boundaries between the shades)?

Figure caption Line 4: Suggestion: “frequency” instead of “number”. The inset shows a probability density plot, not a histogram.

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Line 2 Suggestion: „tend to show sharper zonation“

Line 6 The “monazite stability field” has not been defined. If the authors talk about a “field”, there should be at least two parameters that define the stability “field”. But I assume that they rather mean a temperature range in which monazite in clefts are formed. It has nothing to do with the thermodynamic stability of monazite.

Line 7 “2.5 to 7 Myr”

Line 7 The bracket should refer to Figs. 5-7 and table 2.

Line 9 In the bracket I would more specifically refer to Fig. 9a and b.

Line 10	If the authors start here to separate another area (the “northeastern” area), the reader wonders why they do not specify such area in figure 2...
Line 13	For the sake of completeness: Tony Hurford (in Hunziker et al. 1992) has produced a zircon FT age for the Splügenpass, not far from your sample locality, which is 20. 3 Ma, There are also AFT ages for this locality in Hunziker et al. (1992, 15.3 Ma) and Rahn (2005, 16.9 Ma).
Line 13	Start new paragraph after “Rubatto et al. 2009).” Start new paragraph with “At the same time...”
Line 12-18	In this discussion you sometimes refer to geochronological data, sometimes to references that quote time intervals for a specific “event”. I would argue that such time intervals are also based on geochronologic data. Thus, the authors may as well quote those data or at least refer to the dating method used. The presentation so far is rather inconsistent.
Line 14	The sentence starts with “At that time...” (or my suggested change) but then a time interval of 19-18 Ma is quoted. Is this the same time interval? Is this the relict of a former statement?
Line 15	It is not clear, what the authors mean by “After this”. What does “this” refer to?
Line 15	Suggestion: “Afterward, temperature decrease due to exhumation, ...”
Line 16	The “Valsertal” is not visible in any of the figures. Thus, a reader not familiar with Swiss geography is lost. My suggestion: “started ar 16 Ma near sample VALS (Figs. 2, 7t) ...”
Line 18	Suggestion: “biotite recrystallization ages (Wiederkehr et al., 2009).”
Lines 19/20	Suggestion: “after which the record ends around sample VALS where cooling below...” By the way, I refer to the apatite FT age by Rahn (2005), which for this locality is 8.6 Ma.
Lines 20/21	Suggestion: “The sample VALS age range of 16-12 Ma...”
Line 21	I do not understand the “perfectly”, in particular if the time interval in line 22 is only “ca.”.
Line 23	“within the dome”
Line 25	“Fig. 6m” instead of “Fig. 4m”
Line 27	The statement “as fault gouge ages seem to typically coincide with the end of monazite-(Ce) growth” is rather strange. This should be carefully illustrated. If you have a fault gouge, you are in a process of brittle deformation. But to form cleft monazites you have to be in a brittle deformation state anyway. Is this an important statement? If yes, the authors have to show more evidence for it or more specifically refer to a study that has shown such a coincidence. Here I do not know where “below” is.
Line 29	Start paragraph with “ ⁴⁰ Ar/ ³⁹ Ar cleft muscovite ages...”
Line 30	Stop sentence after “crystallization” and restart with “Further west...”
Line 31	reduce to “(2017, 2019), however, ZFT ages predate ...”
Line 33	The statement “suggests slow cooling rates” cannot be assessed by the reader. What is the arguments for slow cooling?
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Figure 9	I like this figure very much. To me, it is the heart of this study. Note that similar to figure 2 (same inset), the frame in the inset does not fit to the chosen map outline. Line 2 of caption: “quoted” instead of “given”. Line 2: Since the study area mostly extends in a E-W direction, the term “outer region” is difficult to understand. Metamorphically, the inner region would be in the South towards the Insubric Line, not towards the Simplon Line.

- Line 1 Suggestion: „continued deformation and monazite formation“. Is this what you mean?
- Line 1 The statement “as the systems closed” is not clear to me. What “systems” are you talking about?
- Line 2 The term “the lower end of the closure temperature window” is wrong. The closure temperature sensu Dodson (1973) is the moment when a geochronologic system closes, and for one cooling history, there is only one closure temperature, not a closure temperature window. You may argue that the closure temperature of a geochronologic system may vary depending on the cooling rate (see e.g. Bernet 2009 for the ZFT system), but then you are talking about different cooling histories. Do not mix the term closure temperature with the terms partial retention (He methods) or partial annealing zone (FT methods).
- Line 4 double space before “17”
- Line 4 Suggestion for bracket: “(VANI 6, Fig. 5a)”
- Line 5 The authors make a jump in their discussion from S of the RSF to N of the RSF, which is hard to understand and follow.
- Line 9 “Fig. 9c, d”
- Lines 14/15 I do not understand this statement. Next to the RSF, there are weighted mean ages as low as 7.2 Ma (sample VANI 5).
- Line 15 Suggestion: “Correspondingly, the 12-10 Ma phase also marks...”
- Line 16 The first bracket should be “(Figs. 5c, d and 6j)”, the second “(Fig. 6k)”.
- Line 17 Suggestion: along the eastern side of the RSF tend to predate, but still are in agreement with...”
- Line 18 Suggestion: “In the vicinity of sample VANI 6 south of the RSF (Figs, 2, 5a), ZFT ages show a scatter ...”
- Line 20 The statement “leave the hydrothermal stability field ...” should be avoided. Fact is that you have no younger monazite. This should not be mixed up with monazite no longer being stable.
- Line 20/21 Here you should refer to “Fig. 9e and f”
- Line 21 Suggestion to start a new paragraph before “The number”
- Line 21 The “clear age patterns within the crystals” remain completely cryptic to me (see comments further above). I do not know, how the authors have sorted out what is a cluster to be combined to a weighted mean age. They have to provide this information in the “Results” chapter to gain credibility for their study.
- Line 21 Rather than “staggered”, I recommend using the word “stacked” or “clustered”.
- Lines 24/25 The content in the bracket should be “(Figs 5b, d and 6j-l)”
- Lines 27/28 I do not know why the authors here refer to results from the Mont Blanc Massif. The only reason might be that they want to point out that there is a tectonic link by the Rhone Line, which starts in their study area and reached west to the Mont Blanc Massif. If yes, they should make this link. Otherwise, I would suggest deleting the entire sentence. Alternative suggestion: “Overall, the 10-7 Ma time interval ...along the extended RSF system, as far as to the Mont Blanc Massif (...”
- Line 29 Suggestion to add “Fig. 6l” to the bracket.
- Line 31 Add reference after “occurred”

- Line 32 The ages are “6.4-5-4 Ma”.
- Line 32 The reference to a “muscovite age” is cryptic. What muscovite has been dated? From the host rock or from clefs or fault gouges?
- Line 33 The statement “of the area” is cryptic as well. What area?
- Line 34 The statement in this line (“similar...”) is not clear. What does this statement tell us? I do not understand your reasoning. Note, this is your last sentence of the discussion. Do not stop with a loose end...

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- Lines 2/3 Is this first sentence a conclusion out of this study? My suggestions would be to start with: “Hydrothermal cleft monazite-(Ce) provides an important record...” You should not use the word “fissure” here, after having used the word “cleft” only so far... I would have preferred “fissure”.
- Lines 3/4 Suggestion: “provides a important record of shifting tectonic activity associated with the regional exhumation history.” Delete “within the monazite stability field” as this is a term that has not been defined.
- Lines 5/6 The statement “that age clusters within individual crystals from a simple exhuming area have a less clear age distribution than samples from fault zone areas” is not clear to me. First of all, you state that the Lepontine Dome has a “complex metamorphic and tectonic history” (see above), thus you should not refer to “a simple exhuming area”. Second, this statement, if quoted in the “Conclusions” chapter, should have been prepared in the “Discussion” chapter, but I cannot see such a discussion.
- Line 6 Here, the authors talk about “fast exhuming area”. What is considered to be “fast”? The authors did not distinguish between slow and fast exhumation before. Why do they do this in the “Conclusions” chapter?
- Line 6 Do you really mean “recrystallization”? I realize that the authors have not explained where the monazites are crystallized and where they underwent recrystallization. Therefore, the statement remains cryptic to me. The authors should carefully define the different processes and explain, what pattern they generate and what this means for the age interpretation.
- Line 7 If you state “in these areas”, the reader does not know where. Try to be more specific.
- Line 7-9 These statements have not been discussed in the previous chapter.
- Line 10 This is the only place where the authors use the term “²³²Th-²⁰⁸Pb monazite-(Ce)”, Why only here?
- Line 10 double space before “19”
- Line 11 The temperature range given here is not a result of this study. If yes, this should be presented with more clarity in your “Discussion” chapter.
- Line 12 double space before “19”
- Line 12 The bracket content should be “(Fig. 9)”
- Line 13 Suggestion: “Within the Lepontine Dome...”
- Line 14 Here you refer to the “eastern Gotthard nappe”, but on p. 15, line 17, you refer to the “southern edge” of it...
- Line 14 What do you consider to be “slow exhumation” (see also comment further above concerning “fast exhumation”)?
- Line 15 The sentence here seems to be incomplete, something does not fit, at least I do not understand.

Line 19 "Swiss National Science Foundation"

Line 21 Suggestion: "in providing monazite-(Ce) material for this study."

References There are several references listed that are not in the text: Frisch 1979, Frisch et al. 2000, Glotzbach et al. 2010, Keller et al. 2006, Kralik et al. 1992, Putnis 2002, Schmid et al. 1996.

References There are some type errors, e.g. at Keller et al. 2005 and 2006, check spaces between first names, e.g. with Steiger and Jäger 1977 (What is "S.o."?), with Townsend et al. 2000 (is the name "DAndrea" correct?).

Meinert Rahn, March 10, 2019