

## Response to Dr. Bernard Hallet (Reviewer #2) to manuscript TC-2020-82

*Italic:* Referee comments

**Bold:** Authors comments

Referee:

*This is a fine paper, clearly presented and well illustrated, but only with skeletal captions that do not do justice to the figures...*

Authors:

**Incorporating also all the following comments, the figure captions have now been updated.**

Referee:

*One important improvement would be to add credibility to the ages reported by providing more explicit details about the impact on the calculated age of the initial content of Thorium 230 in the precipitate. One effective way of doing this is in table form much as that shown below from Fitzpatrick, J. J., Muhs, D. R., & Jull, A. J. T. (1990). (Saline minerals in the Lewis Cliff ice tongue, Buckley Island quadrangle, Antarctica. Contributions to Antarctic Research I, 50, 57-69). In particular, for 230/232 values of 4, for example, the age could be as much as 40% younger than the age calculated that does not assume there is any 230 initially. Also, the text should reflect as accurately as possible the corresponding large uncertainties.*

Authors:

**We added extra data to the text, stating that we assumed an initial 230Th/232Th ratio of  $0.825 \pm 50\%$  (the bulk-Earth value, which is the most commonly used for initial/detrital 230Th corrections). In addition, the reader is referred to the Supplementary table showing the detailed data and including the detailed analysis procedures, which are furthermore referenced. For example, the 230Th/238U and 234U/238U activity ratios of the samples were calculated using the decay constants given in (Cheng et al., 2000). The non-radiogenic 230Th was corrected using an assumed bulk-Earth atomic 230Th/232Th ratio of  $4.4 \pm 2.2 \times 10^{-6}$ . U-Th ages were calculated using the Isoplot/Ex 3.75 Program (Ludwig, 2012).**

Referee:

*The authors may also wish to consider leveraging the limelight of Ötzi, the Iceage Man, and its climate implications, as referenced by Solomina et al (2015) in their supplementary material.*

Authors:

**A helpful suggestion, which we included now in the text with appropriate referencing.**

Referee:

29. ...significant volume fraction of what?

Authors:

**It is a significant ice volume fraction. We corrected this in the text.**

Referee:

*41. Also reported from the southern tip of S. America (Tierra del Fuego, Personal communication, Rabassa), New Guinea (Peterson and Moresby, 1979), and from sites where they formed under LGM ice.*

Authors:

**We added New Guinea to the text, but, for now, left S. America out as it can only be cited as ‘personal communication’. Nevertheless, we consider the reviewer’s suggestion of S. America as very important, because it is assumed that the lack of available ‘published material’ is a likely cause that subglacial carbonates in S. America are ‘missing’.**

Referee:

*56-57. The units, kg/m<sup>2</sup>/yr, seem unusual. Why not report ice thinning rate in m/yr, or the rate of increase of exposed bedrock, m<sup>2</sup>/yr? This rate must be averaged over a certain area, but what is it? This reference, Gabrovec et al., 2014, does not help; it is incomplete and insufficient.*

Authors:

**We changed the units and used and cited the newly published data about the Triglav Glacier retreat (...around 0.6 m/yr (1952-2016) (Triglav-Čekada and Zorn, 2020)).**

Referee:

*Fig. 1 caption should be more informative, explaining to unfamiliar readers*

- *what is what (bedrock vs. precipitate)?*
- *the orientation of surface imaged relative to horizontal and to the former sliding direction*
- *the morphology of the precipitates*

Authors:

**We updated the figure caption.**

Referee:

*Fig. 2. What are is the pink areas? Replace these terms in legend; in English they are incorrect or awkward.*

***From:***

***Relief types***

*Erosional topography*

*Depositional topography*

*Periglacial topography*

***Relief Shapes***

*Main ridge*

***To:***

### ***Terrain types***

*Erosional surfaces*

*Depositional surfaces*

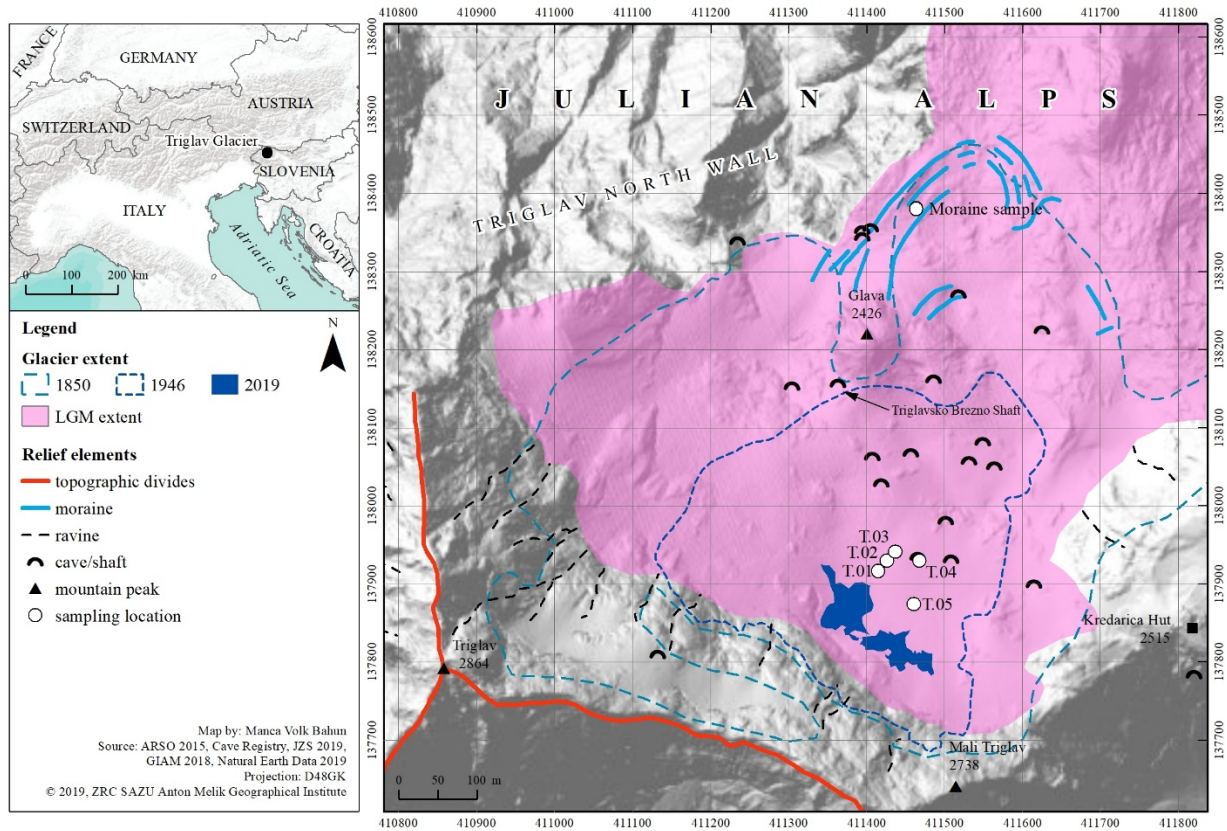
*Periglacial terrain*

### ***Relief Elements***

*Topographic divides*

Authors:

The terms have been corrected accordingly – note that the whole Figure 2 has been extensively edited, and eventually joined with the Figure S2, which makes the message of the figure itself more condensed and clearer. We omitted the topography types as their boundaries cannot be strictly defined (in places they are coinciding), and rather made the glacier extents throughout the history clearer.



Referee:

60. Replace “...the recently exposed subglacial carbonate deposits due to glacier retreat.” by “...the subglacial carbonate deposits recently exposed by glacier retreat.”

Authors:

**Corrected.**

Referee:

78. (...targeting carbonate) cement ought to be replaced by the more appropriate word, precipitate

Authors:

**Corrected.**

Referee:

103. Replace “They are fluted and furrowed crust-like deposits characterized by brownish, greyish or yellowish colour.” by “The fluted and furrowed crust-like deposits are brownish, greyish or yellowish in colour.”

Authors:

**Corrected.**

Referee:

115-6. “Depending on the angle of the lee side of bedrock protuberances, columnar calcite crystals grow either perpendicularly to the host rock (Fig. 5a) or with a lower angle, generally oriented downslope...” Replace “angle” by “inclination” or “slope”. It would be good to explain how the crystal orientation varies with bedrock surface inclination less ambiguously. For example, do vertical crystals grow perpendicular to the rock when bedrock surface is near vertical or near horizontal? Is there a relation between the crystal orientation and the former glacier sliding direction?

Authors:

**To avoid ambiguity, we have changed the cited sentence to the following “Calcite crystals grow perpendicularly to the substrate on the steeper, nearly vertical areas of the bedrock (Fig. 4a) while in the less steep, nearly horizontal areas, crystals grow inclined, oriented downslope, presumably in the sliding direction of the forming glacier (Supp. Fig. S6).”**

Referee:

124. Replace is by are.

Authors:

**Corrected.**

Referee:

127. For the isotopic ratios, the ranges should be included in the text, as well as averages. The reader should not have to look up the supplement for this basic information.

Authors:

**Corrected.**

Referee:

*129-134. Briefly explain what ages you expected. Weere the “two U-Th ages of stratigraphically younger cement” obtained from the same sample? If any of the thin sections are from this sample, you should mention it in the text, and help understand the stratigraphic setting of these younger deposits. Why would the former glacier be thick, and what do you mean by thick?*

Authors:

**The expected ages were of Little Ice Age, as it was assumed that glacier was completely melted during the Holocene Climactic Optimum – we added this in the text. We also referred readers to Figure 3 for more details where sample were obtained from (drilling locations), which also explains ‘stratigraphically younger/older’ situations. In the main text, we changed “of stratigraphically younger cement of the thickest ...” to “corresponding to samples drilled in more surficial calcite layers of the thickest”. By ‘thick -glacier-’ we mean ‘of sufficient thickness to cause regelation’, which is now clarified in the text.**

Referee:

*147. I'd replace low supersaturated solutions by slightly supersaturated solutions*

Authors:

**Corrected.**

Referee:

*148-9. Replace “high Mg/Ca ratio in the water partially could be the trigger for the precipitation of aragonite” by “high Mg/Ca ratios in the water partially be responsible for the precipitation of aragonite”.*

Authors:

**Here we have rewritten the sentence to make it clearer. The new sentence is: “In some freshwater systems like spring deposits (Jones, 2017), and specially in speleothems, Mg/Ca ratios seem to be the main factor controlling aragonite vs calcite precipitation (Frisia et al. 2002; Wassenburg et al. 2012; Rossi and Lozano, 2016)”.**

Referee:

*150-1. Recast sentence to avoid circular logic.*

Authors:

**Corrected.**

Referee:

152. I suggest replacing “pose a challenge to determine” by “raise the difficult question of”

Authors:

**Corrected.**

Referee:

159-160. What is it about the moment that matters in the following “... factors such as the percentage of initial aragonite and the moment of the aragonite to calcite transformation...the possible additional redistribution of Th .... or the degree of opening of the system”? How about this rewording: “... factors such as the initial relative amount of aragonite and the timing of its transformation to calcite ...the possible additional redistribution of Th .... and the extent of chemical exchange with widespread subglacial meltwater”?

Authors:

**Corrected.**

Referee:

162-4. Suggested edit from:

“Based on the U concentration in samples within this study (in ppm; Supp. Table S2), it is notable that the youngest sample (2ka; T.03\_b1) has 1.77 ppm of U concentration, whilst two of the old samples (LGM and YD; T.01\_a1 and T.03\_a1) have around 0.41 and 0.46 ppm of U concentration, respectively”

To

“It is notable that the U concentration (in ppm; Supp. Table S2) in the youngest sample (2ka; T.03\_b1) within this study is 1.77 ppm, whereas it is around 0.41 and 0.46 ppm in two of the old samples, T.01\_a1 and T.03\_a1, respectively LGM and YD.”

Authors:

**Corrected.**

Referee:

165. Replace contrary by to the contrary

Authors:

**Corrected.**

Referee:

166 & 168. Replace In case of the first possibility...by Assuming the first possibility...The same goes for line 168.

Authors:

**Corrected.**

Referee:

Figure 4:

An informative caption is needed for this important figure. The labels are ambiguous. I assume, but am uncertain, that upper and lower “sides” refers to the surface (facing open air before being collected) and underside of the carbonate samples. In any case, how is depth measured? Is it relative to the surface or to the underside? For T.03, does the “lower side” include limestone bedrock as well as subglacial precipitate? It would be helpful for the reader to indicate clearly in words or graphics how the ages vary with stratigraphy. Perhaps, this could be done easily by providing the ages that correspond to the depths written on figure. Is this the only sample for which several dates have been obtained?

Authors:

**Upper and lower sides refer to the surface (facing open air before being collected) and underside of the carbonate samples, respectively (the most appropriate side was chosen for drilling and consequently for visual presentation within this figure). The depths were measured relative to the starting drilling point of each sample as they are shown in this figure (lower side perspective for sample T.03 and upper side perspective for all the other samples); only the T.03 sample had precipitates thick enough that allowed to obtain several dates in three different depths. We also made the figure clearer in terms of differentiating what is subglacial carbonate and what is limestone bedrock.**

Referee:

*192.  $\delta^{18}O$  differences of a few per mill in the carbonate precipitate can also arise due to variations in subglacial hydrology shifting from closed to open geochemical systems (see Hanshaw & Hallet)*

Authors:

**Corrected.**

Referee:

*197. Replace “lighter in deuterium compared to the Triglav...” by “lighter in deuterium than those from Triglav...”*

Authors:

**Corrected/**

Referee:

*199. The last clause (constraining the implications that the Triglav Glacier was constant during the Holocene.) does not follow logically from the preceding text. Clarify or delete it.*

Authors:

**Corrected.**

Referee:

*203. I am unsure of your intent with the leading sentence of this section. If it is consistent with the heading, I would suggest this revision: The LGM and YD ages are the first physical evidence that Triglav Glacier persisted through the Holocene to the present day (Solomina et al., 2015). If your intent is different, describe it clearly.*

Authors:

**We made the leading sentence of this section clearer.**

Referee:

*210. I suggest replacing “not being documented in the literature” by “not having been reported in the literature”*

Authors:

**Corrected.**

Referee:

*214. This paragraph ought to be updated in view of more recent work reporting even slower denudation (e.g. Steinemann et al., 2020), but still supports the contention that the 5mm crust would have weathered off during the HCO if exposed to the elements.*

Authors:

**The recent work of Steinemann et al. (2020) has been incorporated into the text.**

Referee:

*221. Delete the last 3 words because once exposed the subglacial carbonate deposits they cannot be glacially abraded. Moreover, I would not expect them to be abraded even under the glacier because they form in lee positions where I would expect abrasion to vanish as abrading rock fragments diverge from the bed at sites of subglacial precipitation due to regelation ice growth.*

Authors:

**Corrected.**

Referee:

*228. Delete “assessment of”*



Authors:

**Corrected.**

Referee:

240. Replace “quick rate of 21st” by “rapid 21<sup>st</sup>”

Authors:

**Corrected.**

Referee:

243. Replace “show a lower sensitivity to climate fluctuations” by “are less sensitive to climate fluctuations”

Authors:

**Corrected.**

Referee:

245. This remark about bright limestone substrate reminds me of the photographs, which begs the question: what is responsible for the color difference (greys vs. beige & brown on the more recently exposed bedrock surfaces)?

Authors:

**To our knowledge, this has not been studied on that particular location. In general terms, the discolouration of the limestone is usually due to microbial (and lichen) activity (e.g. Dias et al., 2018). The more recently exposed bedrock surfaces have, assumingly, been affected less (for the shorter time) by microbials than the long-exposed bedrock in further surroundings. We inserted this remark in the Figure 1 caption.**

Referee:

250. What do you mean here? The preliminary data shows a high possibility that subglacial carbonate deposits may endue unprecedented retreat... Might you mean the following? The preliminary data suggest that subglacial carbonate deposits can archive valuable datable records of glacial retreat, including hints that the current and ongoing retreat is unprecedented.

Authors:

**Yes. We paraphrased the sentence to make the statement clearer.**

Referee:

255. Replace observe by determine.

Authors:

**We replaced ‘observe’ by ‘detect’.**

Referee:

*260. Replace considerably fast by relatively high. This section should also leverage, and be updated by, recent work (Steinemann et al., 2020).*

Authors:

**Corrected. We also referred the reader to the Section discussion limestone denudation and glacial erosion on limestone substrate, which includes recent work by Steinemann et al., 2020.**

Referee:

*264-5. Replace “particulates on the present remnants of ice (and possible ice cores, if a glacier has not disappeared completely)” by “material on the small remaining ice masses and, if possible, ice cores)*

Authors:

**Corrected.**

Referee:

*274. The conclusion would be stronger and clearer without the first sentence. I would replace it as follows: Subglacial carbonate deposits recently exposed by the retreating Triglav Glacier contain the first direct evidence of the existence and extent of Triglav Glacier since the Last Glacial Maximum and Younger Dryas. The deleted sentences should be incorporated in the previous section and clearly explained: “U-Th ages of subglacial carbonate with the combination of aragonite and calcite are regarded as maximum ages as aragonite-to-calcite transformation, evident in fabrics, might have occurred in calcite crystals that could have been falsely considered as primary.*

Authors:

**We re-arranged the conclusion, especially the first sentence. The previous message of the sentence is a part of Section 4.**

Referee:

***Missing refs***

*Hanshaw, B. B. and B. Hallet. 1978. Oxygen isotope composition of subglacially precipitated calcite: possible paleoclimatic implications. Science, 200,1267-1270.*

*Peterson, J. A., and Moresby J.F. 1979 Subglacial travertine and associated deposits in the Carstensz area, Irian Jaya, Republic of InCorrectedsia. Zeitschrift fur Gletscherkunde und Glazialgeologie. 15(1), 23-29*

*Steinemann, O., Ivy-Ochs, S., Grazioli, S., Luetscher, M., Fischer, U. H., Vockenhuber, C., & Synal, H. A. 2020. Quantifying glacial erosion on a limestone bed and the relevance for landscape development in the Alps. Earth Surface Processes and Landforms, 45(6), 1401-1417.*

Authors:

**All these references are now included and cited in appropriate places within the text.**

Referee:

*Figure S2:*

*The caption states “The recently exposed surface with shafts and subglacial carbonate deposits” but does not address the distinct colors, ranging from greys to rusty brown. Do the color boundaries correspond to, or parallel outlines of glacial extent in Figure S4? The figure should also show where the subglacial deposits or shafts are. In fact, what do you mean by shafts?*

Authors:

**Figure S2 has been deleted as very similar photograph with more detail is shown in Figure 1. Colour boundaries generally correspond to the glacial extent in the 19<sup>th</sup> century, but note that deposition of graviclastic material (which is of brighter colour as well) took place in some areas, which correspond to the glacial extent coincidentally. However, in general it matches to the oldest extent documented, and we included the observation to the caption.**

**By shafts we mean vertical caves, which we added now in the text where the word ‘shaft’ first appear.**

Referee:

*Figure S8: XRD graphs. A short caption is needed to explain what these samples are, how they differ from one another, and which are bedrock (if any).*

Authors:

**We have improved the caption: “XRD diagrams of all the studied samples (for precise location, see Figure 3 in the main manuscript). Samples TRG-01 C and TRG-03 D correspond to the bed rock. Green lines mark the reflections corresponding to calcite and red lines, those corresponding to aragonite.”.**

Referee:

*Comments and questions in italics. Figure S9: a) Short columnar calcite crystals alternating with brown micritic bands constitute the first phase of calcite precipitation on the bedrock. Plane polarised light (PPL); b) columnar calcite crystals predominantly oriented towards the right (downslope) .[what is the orientation of the thin section relative to the former sliding direction? Same question for Fig S10]. The growth of the crystal on the center crosscut the direction of growth of previous crystals.[what is the center crosscut?] Crossed polarised light (XPL)*

Authors:

**The figure captions have been modified according to the suggestions. The sentence referring to how some crystals crosscut the previous has been deleted and we have added information on the orientation of thin sections. “Thin sections orientation is parallel to the former glacier sliding direction.”.**

Referee:

*Figure S11- caption needs a brief explanation of what the figure shows. What are the various curves?*

Authors:

**Figure S11 represented a location photo and a graph of  $^{14}\text{C}$  results of dated moraine organic matter by Karsten Grunewald and his team in the laboratory in Erlangen. We initially included it in the paper as these results have not been published elsewhere. However, since the focus on the paper is on U-Th dates of subglacial carbonates and discussion about their preservation, and since discussion of dating techniques of moraines are not included, we feel that this figure rather confuses readers. We deleted this figure now.**