

Geochronology Discuss., author comment AC1
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Reply on RC1

Brent M. Goehring et al.

Author comment on "Reconciling the apparent absence of a Last Glacial Maximum alpine glacial advance, Yukon Territory, Canada, through cosmogenic beryllium-10 and carbon-14 measurements" by Brent M. Goehring et al., Geochronology Discuss.,
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We thank Dr. Lamp for the constructive comments. They will no doubt improve the manuscript overall. Below, we have replied inline to review comments (general and line by line). Where comments are minor in nature (e.g., typos, etc.) we will make all suggested changes. Comments on figures are greatly appreciated, and we appreciate encouragement to include at least one table, as we will do in the final revised manuscript.

General Comments:

A table with (at least) the sample names, exposure ages, and $^{14}\text{C}/\text{Be}$ ratios should be included in the main text instead of the supplement. It would be helpful to see this information in a table near Figure 4, which would be easier to read and refer to than going through the text for individual exposure ages.

This is a good idea. We will add a summary table of sample names, inner or outer moraines, ages, and isotope ratios.

Can you comment on the likely source of the moraine boulders? If known, does this affect the applicability of your nuclide inheritance models?

Beyond a statement of up-valley we have no other constraints on the origin of the boulders sampled in this work. We are not sure that speculation would benefit or hinder the present manuscript.

Expand on the evidence supporting the division of moraines into two groups (inner vs outer). How do you know one or some of the moraines don't represent a different third advance?

This is a very valid a request, and we will expand on the logic behind our classification.

In order for readers to recreate the analyses, a table of the CRONUS-A data used to calibrate the ^{14}C production rate is required (can go in the supplement).

All the CRONUS-A data are compiled in Goehring et al. (2019) as referenced. We argue that compiling again in the supplement is redundant when a reference to the full dataset is provided.

Near the end of the methods section where you describe how cosmogenic exposure ages were calculated, add that the ages are based on 0-erosion. How appropriate of an assumption is 0-erosion for these samples?

This is a very fair request and we will add such a statement. While certainly erosion is playing a part, the effect on ^{14}C results will be negligible given production-decay systematics and the likely rate of boulder surface erosion operating. Effects on ^{10}Be will be more pronounced, but not affect the overall conclusions of the manuscript. Thus we decline to explore or report further effects of erosion on resulting surface exposure ages, particularly because the argument of Holocene exposure means the boulder erosion rates would have operated on most of the samples for a very short amount of time, thereby not affecting the apparent exposure age significantly.

In the conclusion, local cold-based glaciation is mentioned; can you introduce that information into the text earlier on and expand on how that may or may not affect your measured exposure ages?

Yes, we can incorporate this more into the introduction so that it is set up better. The other reviewer made a similar request.

Figures

Figure 1: Add approx. dates for the 3 shaded glacial limits in the figure (either on the figure or in the caption). Add labels on the figure for some of the surrounding features/locations mentioned in section 1.2.1. Add north arrow + scale bar. In the caption: add a mention of the red box, e.g., "...delineating the Grey Hunter Massif (red box) as shown in Figure 2...". "Massif" is capitalized in the figure caption but is lower case throughout the text.

We appreciate the thorough comments on Figure 1, and along with the other reviewer will have a better figure as a result.

Figure 2: Indicate which moraines equate to which site numbers used in Figure 4 and throughout the rest of the text. Indicate which samples were analyzed for both nuclides. Needs north arrow. "Massif" capitalized again.

Thank you for the suggestion; we will incorporate all of them.

Figure 3: Add the names of the two samples in the images

We will add sample names as requested.

Figure 4: Again, add the site numbers used in this plot to Figure 2. Add the number of samples in each site group ($n=X$), perhaps above each box and whisker plot. In the caption, describe the components of the box and whisker plots (e.g., what do the triangles represent? What are those non-bolded thin vertical lines visible in some plots?, etc.)

Site numbers are represented by the bottom axis, but we can relabel to make clearer. We can certainly add the number of samples. We will add more details in the caption as requested.

Figure 5: Specify what the error bars represent in figure caption.

Error bars represent one-sigma uncertainties, but we will certainly add a statement to the caption.

Figure 6: Specify what the error ellipses represent in the figure caption. For the 3 inner moraine samples to be affected by ^{10}Be inheritance, as mentioned in the caption, the amount of inheritance would have to be minor for them to still overlap the simple exposure region, correct?

Error ellipses represent one-sigma uncertainties as well. We will add this to the caption. Yes, it is correct that the level of inheritance would need to be minor, as they would shift up and to the left if there was no ^{10}Be inheritance.

Figure 7: Caption: Change "older moraine" to "outer moraine". What elevation did you assume for the headwall-derived saturated rock for scenario 2? See comment below for lines 216-217.

Thank you for correcting that. We will make sure all model assumptions are clearly stated in the main text.

Figure 8: Caption: add "(35 ka)" after "...minimum age of the outer moraines" in line 266. For clarity, in the next sentence ("Orange shading represents the range of exhumation-exposure duration pairs compatible with saturated ^{14}C concentration"), specify that the range of compatible exhumation-exposure duration pairs are those that sum to ≥ 35 ka.

Thank you, we will add the anecdote of 35 ka and that the age/exhumation duration pair sums to 35 kyr.

Line by line comments: We appreciate the detailed comments by Dr. Lamp. Where comments are small corrections or suggestions, we have made them as proposed. For more detailed comments, we reply in line below.

14: Remove "potential" (since you use potentially later in the statement)

15: Change "provide" to "provides"

71: Add "likely around" or "approximately" in front of -10.8C since it's an estimate 81: "dividing" instead of "breaking"?

107: If applicable: after mentioning the calibration data set add "...(sourced from <http://calibration.ice-d.org/>, accessed XX-XX-XXXX)"

Here, this is not applicable as calibration.ice-d.org does not yet contain ^{14}C data. Instead, we refer readers to the ^{14}C data in Goehring et al. (2019). For ^{10}Be , we use the dataset detailed in Borchers et al. (2016), which is not compiled as a single dataset in ice-d.org.

115: LIA has not been defined yet; change to "Little Ice Age (LIA)"

159: You write: "Samples from the inner moraine set are consistent with continuous exposure and steady state erosion or fall below the continuous exposure curve because of ^{10}Be inheritance." The way this is written makes it sound like at least 1 sample falls below the curve. However, error ellipses for all 3 samples fall within the continuous exposure region (and in the figure 6 caption it says "...the three inner moraines samples are consistent with continuous exposure"). Perhaps change to "...consistent with continuous exposure and steady state erosion with the possibility of minor amounts of ^{10}Be inheritance."

We appreciate the suggested wording and will revise as such.

184-186: "...; however, because of the wide range in apparent ^{10}Be exposure age for a

given moraine rather than consistently too young, we discount boulder surface erosion as the cause for too young exposure ages and do not discuss further." The first half of this sentence reads as if you already concluded that the 10Be ages are not too young, while the second half reads as if you have already concluded that the 10Be exposure ages are too young. Replace with something along the lines of "...; however, due to the wide range in apparent 10Be exposure age for a given lithologically-homogenous moraine and no evidence for systematic underestimation of exposure ages, we discount rock surface erosion as a significant post-depositional process affecting apparent exposure ages."

We appreciate the suggested wording and will incorporate as such.

188: "...10Be exposure age distributions are predominantly old-biased..." based on what? The 14C data? Specify.

This statement is based on the distribution as observed in the box-whisker plot. Given enough samples measured (not the case in our data), a PDF would show a right skew to the data, indicative of inheritance.

194: After "...within a single valley." specify the site with where the morphostratigraphic requirement isn't met. E.g., "...within a single valley (e.g., site X)."

216-217: The text says: "The second scenario envisions delivery of a pre-exposed paraglacial boulder to a supraglacial setting prior to burial and englacial transport to a moraine" whereas in the caption for Figure 7 it says the boulder is just transported supraglacially. Which is correct?

Both are correct, except that the caption neglects to mention the paraglacial exposure period. We will adjust the caption as such.

231-232: Add text in italics for clarity: "...deposition, and, due to the short half-life of 14C, only the youngest moraines (<10 ka) would have any memory of pre-exposure."

Done.

233: Insert the "plausible age ranges" in parentheses for the inner and outer moraines.

We can certainly add those ages.

262-263: "For a given depositional age (exhumation duration plus exposure duration), the deeper the exhumation depth, the faster the exhumation rate, and thus the less time spent at low production rates; the concentration is then more dependent on the duration of surface exposure." I would rephrase this; even though the total time spent in the subsurface is less for the deeper samples, the deep samples spend some amount of time at lower production rates than shallower samples. Something along the lines of "For a given depositional age (exhumation duration plus surface exposure duration) the deeper the exhumation depth, the lower the effective or average nuclide production rate during exhumation largely due to the exponential decrease in spallation with depth. Therefore, for deeper samples a longer exposure duration is required at the surface (where consequence exhumation rates are faster.)"

We appreciate the suggestion and will rephrase accordingly.

273: Specify in parentheses the name of the "one sample" being referred to.

Done.

280: Is the 32 +/- 8.2 ka value based on the “grand group median” referenced earlier in the paper? State as such. In section 5.1, this value is quoted as 31.3 +/- 8 ka. Check and keep them consistent.

The value is indeed based on the grand group median and apologize for the rounding error. We will correct.

280: Move “regardless of the depth of sample exhumation” to between “western-Cordillera sense” and “and is 32 +/- ka.” Otherwise it reads as if the date of moraine deposition is 32 ka regardless of the whether or not samples were exhumed.

Good catch, thank you.

281: Define the age range of the McConnell glaciation and add a reference.

We will add these ranges to the introductory and background material to avoid repetitive references.

282: Is 11.2 +/- 0.1 ka the group median again? Similarly to line 280, this value is written as 11.4 +/- 0.1 ka earlier in the text.

We will correct this error.

290-291: Add a reference for the statement: “In contrast, the northern margin of the CIS appears to have classical LGM maxima ages...”

References will be added.

294: Should “precipitation” be “moisture” instead?

Either word should work, but we will change to moisture.

298: Is a “the” missing in front of “Yukon”?

Yes, word added.

318: Move “not only” to be between “are” and “informative”

Done.

322: Change “positive mass balance” to “glacier expansion”

Agree in the context of the sentence, glacier expansion is a better phrase.

322-323: Expand on the statement: “The cold-dry climate likely operating at Grey Hunter also means that glaciers were cold-based and resulted in the complicated exposure age distribution observed...” Specify in what way cold-based glaciation at the site would have led to the exposure age observations. Also discuss this earlier in the text when first interpreting the data.

We will expand this idea earlier in the manuscript to allow for a return to this topic towards the end.