

Geochronology Discuss., referee comment RC1  
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## Comment on gchron-2021-43

Jennifer Lamp (Referee)

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Referee 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.*, <https://doi.org/10.5194/gchron-2021-43-RC1>, 2022

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Goehring et al. present *in situ*  $^{14}\text{C}$  and  $^{10}\text{Be}$  data from two groupings of alpine moraines located in the Grey Hunter massif in the Yukon territory. They use the resulting apparent exposure ages coupled with models of potential nuclide inheritance and sample exhumation to conclude that the outer set of moraines likely pre-dates the Last Glacial Maximum (LGM) ( $\sim 35$  ka) with evidence of sample exhumation after deposition, while the inner set of moraines likely post-dates the LGM ( $\sim 11$  ka). They attribute the absence of LGM moraines to a local reduction in precipitation due to atmospheric circulation changes induced by the LGM expansion of the Laurentide ice sheet (LIS) and Cordilleran ice sheet (CIS).

The paper is well-written, and provides a good example of (1) the advantages of measuring multiple cosmogenic nuclides on moraine samples, and (2) how one should investigate the effect of post-depositional surface processes on apparent cosmogenic surface exposure durations. They present a strong case for their conclusions, and I support acceptance of the manuscript with minor revisions. Most of my comments are in regards to providing further explanations for statements made in the manuscript, and improving the clarity of figures and text.

### General Comments:

- A table with (at least) the sample names, exposure ages, and  $^{14}\text{C}/^{10}\text{Be}$  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.

- Can you comment on the likely source of the moraine boulders? If known, does this affect the applicability of your nuclide inheritance models?
- 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?
- In order for readers to recreate the analyses, a table of the CRONUS-A data used to calibrate the  $^{14}\text{C}$  production rate is required (can go in the supplement).
- 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?
- 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?

## 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.

**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.

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

**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.)

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

**Figure 6:** Specify what the error ellipses represent in the figure caption. For the 3 inner moraine samples to be affected by  $^{10}\text{Be}$  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?

**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.

**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  $^{14}\text{C}$  concentration"), specify that the range of compatible exhumation-exposure duration pairs are those that sum to  $\geq 35$  ka.

#### **Line by line comments:**

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

15: Change "provide" to "provides"

65: "overtopped it" sounds a bit awkward. Maybe just "over"?

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)"

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  $^{10}\text{Be}$  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  $^{10}\text{Be}$  inheritance."

184-186: "...; however, because of the wide range in apparent  $^{10}\text{Be}$  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  $^{10}\text{Be}$  ages *are not* too young, while the second half reads as if you have already concluded that the  $^{10}\text{Be}$  exposure ages *are* too young. Replace with something along the lines of "...; however, due to the wide range in apparent  $^{10}\text{Be}$  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."

188: "... $^{10}\text{Be}$  exposure age distributions are predominantly old-biased..." based on what? The  $^{14}\text{C}$  data? Specify.

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?

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

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

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 production rates are highest) to accumulate the measured amount of  $^{14}\text{C}$ , and as a consequence exhumation rates are faster."

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

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.

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.

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

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.

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

294: Should "precipitation" be "moisture" instead?

298: Is a "the" missing in front of "Yukon"?

318: Move "not only" to be between "are" and "informative"

322: Change "positive mass balance" to "glacier expansion"

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.