

Geochronology Discuss., referee comment RC2  
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## **Comment on gchron-2021-43**

Joseph Tulenko (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-RC2>, 2022

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Goehring et al. present a new dataset of in-situ  $^{10}\text{Be}$  and  $^{14}\text{C}$  measurements on boulders embedded in several moraines deposited in the Grey Hunter massif, which lies just beyond the limit of the last glacial maximum extent of the Cordilleran Ice Sheet in the Yukon Territory of Canada. The goal of the paper is to constrain the timing of moraine deposition for two moraine groups, one relatively older ('outer moraines') and the other younger ('inner moraines'), deposited in multiple valleys that have been correlated across the massif based on preliminary ELA reconstructions. Since relatively smaller bodies of ice (ie alpine glaciers) are generally more sensitive to changes in climate compared to large ice sheets, the chronology may shed light on climatic forcings that drove glacier change in the region. However, the authors note challenges associated with moraine dating and find a scattering in  $^{10}\text{Be}$  ages that were likely impacted by both inheritance and post-depositional processes, namely boulder exhumation. The authors attempt to address these issues by measuring  $^{14}\text{C}$  in a select number of samples already measured for  $^{10}\text{Be}$  to 1) determine that some boulders from the outer moraines have a complex exposure-burial history and were therefore likely exhumed and exposed long after deposition, 2) estimate the amount of moraine degradation to account for apparent  $^{10}\text{Be}$  ages and  $^{14}\text{C}$  ages on exhumed boulders embedded in the outer moraines and 3) generate plausible scenarios of the timing of inner moraine deposition using apparent  $^{14}\text{C}$  exposure ages that the authors demonstrate were likely unaffected by inheritance. The authors conclude that the older set of moraines ('outer moraines') were deposited some time prior to the Last Glacial Maximum and that the younger set of moraines ('inner moraines') were deposited after the end of the Younger Dryas cold period, and that any advance during the last glacial maximum was overridden by the late glacial advance. They argue that large North American ice sheets may have influenced climate during the LGM to prevent a significant LGM advance in the Grey Hunter massif.

The paper presents a novel approach to determine the likelihood and magnitude of boulder exhumation, which is common in high northern latitude settings where moraines are often ice-cored and can degrade substantially. The paper also uses the new  $^{10}\text{Be}$  and  $^{14}\text{C}$  exposure ages to present evidence that may suggest a limited LGM advance in the Grey Hunter massif, although I feel that this idea and others can be expanded on a bit. My comments are focused mainly on strengthening the background and local glacial history section of the paper, providing some clarity in data/figure presentation, and exploring/testing other potential scenarios in the discussion beyond their preferred interpretation. I support acceptance of the manuscript with revisions.

General comments:

- Readers would likely benefit from a deeper background/literature review/problem set up from the authors.
  
- The authors use local nomenclature for ice advances (ie McConnel, Reid and pre-Reid) but there isn't information about what previous literature suggest the ages (relative or absolute) for those advances are. I suggest they define each local glacial advance that they reference and review relevant literature about the age of each advance.
  
- It is not clear without looking through the figures what previous studies would suggest for the relative ages of the inner and outer moraines. Based on figure 1 it looks like the outer moraines were originally mapped as McConnell? Is that correct? I suggest making that clearer in the text and in Figure 2.

- the authors mention that  $^{10}\text{Be}$  ages from other studies dating CIS deposits in the region are ambiguous but do not actually make any comparisons between results from this previous work and their new dataset. For example, how do the  $^{10}\text{Be}$  ages on the inner moraines compare to  $^{10}\text{Be}$  ages from previous work on CIS deposits? Are they comparable or not? I suggest discussing explicit ages from previous studies in the background or discussion section (or both).
  
- in the discussion, the authors mention studies from coastal AK and BC that show LGM advances, but do not say what ages those studies report for the LGM. I suggest the authors present that information in either the discussion or background section (or both) for comparison with their results.
  
- The audience would benefit from a little more clarity in the way they present their data through their figures and tables (see below comments on specific figures).
  
- I believe the discussion could be more complete by exploring other possible scenarios beyond their preferred interpretation.
  
- what is the likelihood that the inner moraines were deposited near the end of the classically defined LGM? There appears to be some scatter in the  $^{10}\text{Be}$  ages, but enough clustering to suggest some moraines may have been deposited at the end of the LGM between 17 – 19 ka.

- to this end, how representative are the  $^{14}\text{C}$  ages for all the inner moraines if they only come from one moraine?
  
- alternatively, if the inner moraines were all deposited sometime during the late glacial, what is the likelihood that the outer moraine was formed some time prior to the LGM and then re-occupied during the LGM? Is there any evidence from the new  $^{10}\text{Be}$  and  $^{14}\text{C}$  measurements to support or refute this hypothesis? For example, ages from moraine 1 show relatively low scatter and are within the timing of the LGM, is it possible that boulder ages from that moraine are representative of an LGM re-occupation?

If the authors believe either of these scenarios are unlikely, I would like to see them at least mentioned/addressed.

Figure comments:

Figure 1: Could the authors include a terrain/hillshade/DEM base map below the ice limits in this figure? Can the authors also include the mapped ice limits in the inset?

Figure 2: It would appear based on figure 1 that the outer moraines are originally mapped as McConnel, is that correct? Could the authors overlay the ice limits from figure 1 onto this figure to make that less ambiguous?

- Is it also possible to somehow include  $^{10}\text{Be}$  and  $^{14}\text{C}$  ages onto map along with sample names so all the data is visible in one place? I recognize that might make the figure a bit busy, but if possible, could the authors do this?

Figure 3: In the text (beginning line 114), the authors first discuss inner moraines then outer moraines, and show Figure 3 in that order as well, but then outer moraine ages are presented first (line 130) followed by inner moraine ages (148). Could the authors fix this for general consistency?

- related to figure 3. I was once asked by a co-author on this manuscript to share photos of all sampled boulders at least in a supplementary file, and I thought that was quite beneficial. If it is possible for the authors to do the same, I would recommend it.

Figure 4: while I appreciate the box and whisker plot for each set of moraines to demonstrate the relatively high degree of scatter in some of the outer moraines, I feel this plot (or perhaps a second plot) would benefit from somehow displaying each individual age. Or perhaps, if considering all ages from inner moraines as one dataset and all ages from outer moraines as one dataset as the authors do, some histograms for inner and outer moraine ages may be appropriate. Could the authors find some way to show each individual age in a plot in the main text?

- Also, I am unsure what each triangle for the moraine ages is supposed to represent. Please provide more detail in the figure description or on the plot.

Figure 8 and/or Line 272-274: it may not be necessary, but I would be interested to know total exhumation based on  $^{14}\text{C}$  and  $^{10}\text{Be}$  measurements if the (re-occupied) moraine were to be LGM in age (for example the mean age from moraine 1). Could the authors either do this and report values in the main text, or add an additional/supplementary figure?

Line by line comments:

Line 59: Fix this. Should that header be 2.1.1? If there aren't any other subsections here (although I think there could be), perhaps consider removing the subsubheader and place everything in just one subsection.

Line 75: Should this be section 3? If yes, then also fix the other subsections.

Line 107: can the authors justify the use of the default production rate from Borchers et al. (2016)? Do the authors argue that it is more representative of this site than other production rates (e.g. the Arctic Production rate from Young et al., 2013)?

Line 130: could the authors either report all individual ages here in the text or represent them in a table somewhere in the main text?

Line 147: same comment as in line 130.

Line 169: I might argue good coherence of  $^{10}\text{Be}$  ages in moraines 1 and 2, and moraines 4, 6, and 7 have at least two ages each that are somewhat coherent. I have certainly seen a lot worse in other places in Beringia. Can the authors do a little more justification here of not considering several  $^{10}\text{Be}$  ages?

Line 274: See also comment on Figure 8. Is there any precedent for exhumation of ~4-5 meters since ~35 ka? If there is some literature on the topic, please cite.

Line 280: can the authors justify the reason for averaging  $^{10}\text{Be}$  ages from the outer moraines? How likely is it that all outer moraines correspond to the same climatic event?

Line 281: is there a typo here? Their preferred interpretation is that the older moraines are not McConnell in age, correct?

Line 290: could the authors include citations here, and perhaps explicitly report and discuss the evidence for classical LGM maxima ages along the CIS margin?

Line 295: citations here are generally based on model results. If there is other terrestrial evidence the authors might lean on to suggest relatively dry conditions in the region during the LGM, please report.

Line 300: authors should report when the literature suggests the CIS-LIS saddle collapse occurred. How well do 14C ages from the inner moraine line up with the collapse? I feel the authors should spend a little more time discussing this idea.