

Clim. Past Discuss., author comment AC2
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Reply on RC2

Tamara Pico et al.

Author comment on "Was there a glacial outburst flood in the Torngat Mountains during Marine Isotope Stage 3?" by Tamara Pico et al., Clim. Past Discuss.,
<https://doi.org/10.5194/cp-2021-132-AC2>, 2022

Reviewer 2

Pico et al's manuscript provides evidence of an outburst flood from Glacial Lake Koroc in the Torngat Mountain of northern Quebec and Labrador, Canada. Using two ^{10}Be cosmogenic exposure ages they suggest this outburst occurred during MIS 3 and the flood volume could have contributed to surface ocean freshening and measurable meltwater signal in $\delta^{18}\text{O}$ records. The manuscript is, for the most part, clearly written, and is well supported by figures. However, I have a number of concerns that need to be addressed before this manuscript is ready for publication.

We thank the reviewer for this positive appraisal of our manuscript. We have addressed the concerns of Reviewer 2 below.

1). The authors constrain the age of Glacial Lake Koroc using two ^{10}Be cosmogenic exposure ages. My main concern is the small sample size and the possibility of inheritance in these samples. The presence of a cold-based ice sheet covering the study area is highlighted in the text (lines 293-296). It, therefore, seems equally plausible that the high elevation shorelines dated in this study could be one of the earliest stages of a post-LGM lake in the region and samples simply appear older due to inherited ^{10}Be concentrations. The authors explore the possibility of erosion and burial of the sample site but no mention of inheritance in the samples is made.

We agree that the possibility of inheritance is an important question to address in our manuscript for the reader. We will add the following text to the methods section of the manuscript:

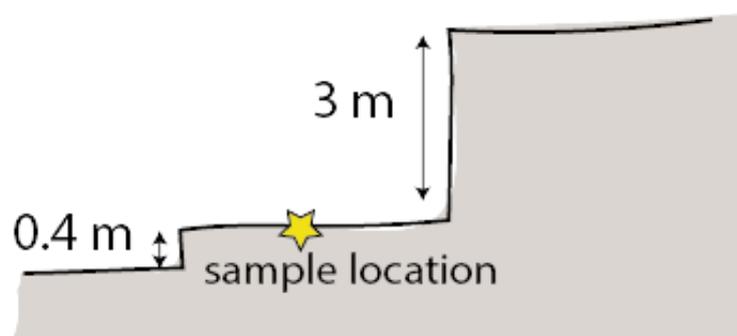
The lowest elevation wave-cut bench was sampled to avoid possible inheritance of cosmogenic nuclides. We believe that substantial inheritance is unlikely because the sampled wave-cut bench is 3 meters below the highest observed platform elevation (Figure 4C). Because there is a relationship between cosmogenic nuclide concentration and depth, we can calculate the expected inheritance at 3 meters depth.

We use the following equation,

where N is cosmogenic nuclide concentration, x is depth below the surface, ρ is rock density, and λ is attenuation length. We assume density is 2.9 g/cm^3 and attenuation length is 165 cm.

If we consider the maximum inheritance expected at the surface in the Torngat Mountains region to be 5.7×10^6 atoms/g quartz (340 ky equivalent) (Staiger et al., 2005), the maximum concentration at 3 m depth below surface elevation should be near 2.8×10^4 atoms/g quartz (4.5 ky exposure). If we do not use the maximum concentration found but use a more realistic value found for similar altitudes 1×10^6 atoms/g (0.9 ky exposure), the possible inheritance is within our external age uncertainty of 3 ky.

We have added an additional figure to show the sampled location on the wave-cut platforms and benches, which will now be included in Figure 4.



2). More detail is needed regarding the geomorphic/sedimentological evidence for pre-LGM Glacial Lake Koroc. No details regarding the mechanism of failure and evidence for a spillway that drained the lake are discussed, despite 'outburst flood' being in the title. During LGM ice recession, multiple glacial lakes occupied the Torngat Mountains. Could this not have been the case for pre-LGM and if so, what is the likelihood that this lake didn't drain into another lower elevation lake nearby? Is it likely that the whole lake drained during the outburst event? Without the elevation of the spillway, this cannot be assessed.

We agree with the Reviewer that more detail is needed regarding the geomorphic sedimentological evidence for pre-LGM Glacial Lake Koroc. However, our study relies on legacy data from a 2003 field expedition, and we do not have data from additional shoreline sites. Attaining such information will be the focus of future field studies.

We agree that this point should be clarified in the text. We have added the following text:

There is no evidence that the lakes drained to lower elevation regions, as no lower elevation shorelines were identified. However partial or complete draining of the lake to lower elevation locations is possible. Future work focused on obtaining sediment cores in the valley could allow us to learn whether multiple lake levels occurred.

In response to this comment, and similar comments by reviewer 1, we have changed the wording in the title to "glacial lake" instead of "outburst flood" to be more cautious in our interpretation of evidence.

3). The main conclusion drawn in this study is the contribution an outburst flood from this

lake could have had to surface ocean freshening and possible implications this may have had for Heinrich events.

'A freshwater volume of $1.14 \times 10^{12} \text{ m}^3$, associated with the glacial lake outburst described in this

study could contribute to the large $\delta^{18}\text{O}$ recorded for MIS 3 Heinrich events (minimum volume

required = 1.4×10^{13} - $2.3 \times 10^{14} \text{ m}^3$; Hemming, 2004).'

The minimum volume stated is from Hemming, 2004 is 'a value assuming a volume the area of the Heinrich layers, and the thickness of the mixed layer is mixed one time with enough ice and water to make the $\delta^{18}\text{O}$ excursion'. However, my understanding of the paper is that 0.6 -1.9 Sv of water over 1 yr to 500 yrs is needed to explain the observed $\delta^{18}\text{O}$ excursion. The estimate presented in this manuscript is 0.004×10^6 over 3 days. This seems to be significantly less water than is needed to contribute to the $\delta^{18}\text{O}$ excursion observed during a ~500 yrs of a typical Heinrich Event.

In response to these comments, we will edit the text to include the following explanation: "Pre-LGM Glacial Lake Koroc represents one freshwater source, which, in addition to other freshwater sources from other glacial lakes that may have coexisted in the region, could constitute a substantial freshwater input to the ocean."

Line edits:

Line 24: Provide a value for the magnitude of freshwater flux in the abstract. Consider also *adding the lake name to the abstract*

According to this suggestion and that of reviewer 1, we have edited the abstract to include the name "pre-LGM glacial lake Koroc". We will also add the estimate of freshwater flux to the abstract.

Line 27: Present freshwater flood volume in km^3 rather than m^3

Done!

Line 123: Delete space

Done!

Figure 3: Please add the drainage route to panel B. It would also be useful to add the location of mapped shorelines to this figure

Thank you for this suggestion. We have added the potential drainage route to this figure. We also note that the mapped shoreline site is shown by the white circle in Figure 3.

Line 206: Evidence for outlet needs to be clearly stated

To clarify evidence for the glacial lake inlet we will add the following text:

Evidence for outburst flooding is based on the rounded, imbricated cobbles in inlet channels. We found these deposits in multiple inlet channels leading to the sample site, which we interpreted as a lake shoreline. We hypothesize that the lake level may have

fallen rapidly because there is no evidence for bands of lake shorelines at progressively lower elevations. Nevertheless, future work is required to verify such evidence for glacial outburst flooding.

Line 232/233: More information is needed regarding the duration of ice cover during the LGM. The uncertainty surrounding the 20 kyr ice cover is very briefly mentioned and needs to be more clearly stated

The issue of ice cover duration is addressed on lines 281 to 284:

Although the duration of ice cover at this site is unknown, there is evidence for ice cover at the LGM (Staiger et al., 2005), and this region likely deglaciated between 11 and 8 ka (Dalton et al., 2020). The age correction for ice burial depends on the timing of glaciation, which occurred after the existence of pre-LGM glacial lake Koroc. For example, if ice advanced over our site at 30 ka and the entire area was glaciated until 10 ka, then there would have been 20 ky of ice cover, which would shift the age to 56 ka. We therefore consider 36 ± 3 ka to represent a minimum age, and 56 ± 3 ka a likely age for the identified pre-LGM glacial lake Koroc.

We have added the following sentence to include a recent publication reviewing possible ice margin configurations during MIS 3:

"Although poorly constrained, Dalton et al., 2022 suggest the Laurentide Ice Sheet margin may have been to the east of Ungava Bay in the Torngat Mountains during MIS 3 (Dalton et al., 2022)."

- *S. Dalton, C. R. Stokes, C. L. Batchelor, Evolution of the Laurentide and Innuitian ice sheets prior to the Last Glacial Maximum (115 ka to 25 ka). Earth-Science Rev. **224**, 103875 (2022).*

To flag the question of ice cover duration in the methods section, we will add the following text:

"Uncertainty on ice cover duration will impact sample age constraints (see Discussion)"

Line 232: Add space 'concentration(Gosse and Phillips, 2001)'

Done!

Line 235: Add space 'calculation(Jones et al., 2019)'

Done!

Line 230: Add a brief statement to highlight that this is a minimum age

We have incorporated this suggestion now by adding the following text to line 230: "and thus represent a minimum age".

Line 234: You describe the impact of GIA on your ages however no age GIA correct age is available to the reader. Consider adding these ages to the text and Table S2.

In the text we have explained that we do not account for GIA in the age correction since it is smaller than the uncertainty (line 235).

Line 206: 'The shoreline is an erosional feature, and there is a small inlet channel at this elevation with rounded imbricated cobbles, suggestive of outburst flooding.' Imbricated

sediment can be produced by outburst events. However, is these are within a small inlet channel how do they suggest outburst flooding?

The reviewer is correct that the rounded, imbricated cobbles are not necessarily indicative of outburst flooding. We found these deposits in multiple inlet channels leading to the sample site and at other parts of the discontinuous eroded notch, which we interpreted in the field as a lake shoreline. We hypothesize that the lake level fell quite rapidly because we don't see bands of lake shorelines at progressively lower elevations. Indeed, it is somewhat hard to imagine a lake margin at 890 m elevation dammed from the ocean by ice ending in any way other than a geologically near-instantaneous event. It is possible that these were simply not preserved. However, in the field, we believed that we saw spillway features similar in morphology to those at lower elevations in the region (those at lower elevation date to the ~8-9 ka) lake draining events that have been documented by (Dube-Loubert et al., 2018).

We hope that this report inspires further investigation of the features in this important field area. Unfortunately, we ran out of time for further investigations in 2003 and don't want the fact that these features exist and have curious ages to be lost to the glacial geologic history. This discussion paper serves the purpose of making these features known so that the community can investigate in the future.

Line 263: Should glacial not be capitalized in 'Pre-LGM glacial Lake Koroc'?

We will now capitalize this term throughout the manuscript.

Supplementary Material Line 18: Table S2 seems to be identical to the table above

The top table in Table S2 is repeated from Table S1c to include this information alongside the location information.