Climate of the Past Discussions

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Reply on CC2

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-AC4, 2022

Community Comment # 2

The manuscript of Pico et al. presents evidence for a glacial lake that developed before the LGM in the Koroc River valley and adjoining basins, to the west of the Torngat Mountains (NE Quebec-Labrador). It is then hypothesized that the drainage of this lake into the Labrador Sea may have contributed to climate perturbations (Heinrich events) during Marine Isotope Stage 3 – an interval of the last glacial cycle for which the authors claim to be characterized by a significantly reduced ice cover in the region formerly covered by the Laurentide ice sheet (LIS).

As glacial geologists working since several years on the deglaciation of the greater Ungava Bay region, we were extremely enthusiastic about this new piece of information. Indeed, the Labrador-Ungava region is a key area for the study of the evolution of the LIS during the last glacial cycle. Previous work in this region has showed the occurrence of several ice-dammed lakes that developed during the last deglaciation and their location near a critical sector of the North Atlantic makes freshwater forcings from this region highly relevant to paleoclimate studies. It is also a remote area difficult to access and as such, many aspects of its geological record remain to be studied.

The conclusions drawn in this study are mainly based on the assumption that a glacial lake existed and that it drained during MIS 3. The geological evidence presented in support to this MIS 3 ice-dammed lake and flood are:

1) a wave-cut bench (c.f., shoreline) at an elevation of 890 m used to reconstruct a high-elevation ice-dammed lake in the Koroc River valley;

2) an inlet channel filled with cobbles recording the abrupt drainage of the lake;

3) two cosmogenic ages from bedrock surfaces exposed by lakeshore erosion indicating an age of ~36 ka (MIS 3).

It appears that these landforms and 10Be ages come from a single site (as suggested by the geographic coordinates in the Table). Also, no geological evidence is presented for the damming mechanism of the lake, which is based on the presumed occurrence of the LIS margin in the lower reach of the Koroc River and valley glaciers in its upper reach.

Careful examination of the manuscript and data therein, and consideration of available geological maps (see below), leads us to conclude that, at this stage, the geomorphological evidence and geochronological data reported are unfortunately too fragmentary to support the existence of this glacial lake and outburst flood during MIS 3. More importantly, we believe that the interpretation of the geomorphological features reported may be incorrect, while the proposed ice margin configuration for the LIS and valley glaciers appears inconsistent with the reduced ice cover scenario presented for MIS 3 in the study.

We further expand these points in the paragraphs below, in addition to comment on geochronological approach used.

We thank the comment's authors for their constructive feedback on our manuscript.

Geomorphological evidence for a pre-LGM glacial Lake Koroc and outburst flood

The evidence supporting the existence of this glacial lake is essentially enclosed in the two photographs presented in Figure 4. In Fig. 4A, it is not clear to what geomorphological feature(s) the authors refer to when "interpolating" a former lake level running up high across the valley. Despite the low resolution of the photo, an apparent trim line can be seen and from this distance, it seems to separate permafrost terrains (frost-shattered bedrock and felsenmeer) present on the high mountain top from the lower freshly glacially-eroded valley walls. In the foreground of this photo, it is also difficult to identify the geomorphological feature supposed to represent a former shoreline, but the action of freeze-thaw processes on the bedrock and deposits is clearly present with slopes partly covered by solifluction lobes dissected by meltwater channels.

There are solifluction lobes in this region, however these tend to be present in the valleys where there is abundant unconsolidated material. These are not present in the forefront of the photo of the wave-cut shoreline. The noted shoreline is not in line with any fracture plane, and because it is eroded into bedrock it cannot be a solifluction or gelifluction lobe. For other glacial erosion processes we would not expect to see such a planar surface. Therefore, we interpret this geomorphic feature as a shoreline platform.

The photo in 4B is supposed to show a wave-cut bench and bedrock surfaces exposed by lakeshore erosion. However, the entire feature lacks the continuity that would normally characterize a shoreline. Based on this photo, this setting could be interpreted as a frost-shattered erosional bedrock surface (felsenmeer), while the presence of the smoother rock surfaces on the gently sloping terrain may reflect erosion (block removal) by meltwater. Erosion of Archean gneissic rocks by lakeshore wave-action would require a lot of time, which is generally not the case with the short-lived ice-dammed lakes of Ungava-Labrador.

Although the bedrock in our study region is gneiss, it is highly fractured rock. Frost action and ice wedging acts on preexisting pervasive fractures, resulting in a more easily weathered rock. Studies based on glaciated gneiss terrains suggest that such fractured rock results in plucking-dominated erosion, which is likely for our study area (Krabbendam & Bradwell, 2014)

- *Krabbendam, T. Bradwell, Quaternary evolution of glaciated gneiss terrains : pre-glacial weathering vs . glacial erosion. Quat. Sci. Rev.* ***95****, 20–42 (2014).*

Given the importance of this glacial lake in the study, and considering the associated implications for paleogeographic reconstructions, the manuscript should better document the characteristics of the shorelines reported. An unanswered question concerns the number of sites with shorelines that have been documented? The manuscript reports currently one, although it is mentioned that "this glacial lake was identified based on geomorphological mapping of shorelines, spillways, and drainage channels" (Lines199-200). Indeed, these features form key indicators for identifying a glacial lake and the results from this mapping should be clearly presented to constrain the areal extent of the lake and build a proper case for its existence. A glacial lake of this importance should have left several geomorphological evidence of its presence in the study area, even in the context of preservation by a non-erosive cold-based ice.

Future fieldwork should be aimed at assessing the areal extent of this lake. We agree that there are likely other localities where this glacial lake shoreline can be documented, and such investigation will be the subject of future inquiry.

Similarly, the claim of the "first direct evidence on land for an MIS 3 jokulhaup" (Lines 363 and 407) can be questioned. This outburst flood was identified on the basis of "a small inlet channel at this elevation with rounded, imbricated cobbles" (c.f. Fig. 4). Again, the geological support for this outburst flood should be better documented and the feature reported here should be better detailed, especially regarding its spatial relationship with respect to the lake configuration (location in the study area?).

In response to this comment, and similar comments by reviewers, we will edit the text to emphasize evidence for a glacial lake shoreline, rather than an outburst flood.

As mentioned in the manuscript, the drainage of glacial lakes through outburst floods occurred during the last deglaciation in the Ungava-Labrador region. The nearby Lake Naskaupi indeed drained through outburst flooding events that left behind a wealth of large-scale geomorphological deposits and landforms, such as km-size ripples and other features like multi-tens of meters thick alluvial bars (Dubé-Loubert and Roy, 2017; Dubé-Loubert et al., 2018). Even if we assume that part of these features was eroded by the ice advance of the last glaciation (MIS 2), evidence for the outburst drainage of a lake the size of the hypothetical pre-LGM Lake Koroc should still be present in the geomorphological and sedimentary records of this region.

Future work could focus on assessing the nature of pre-LGM glacial lakes and potential outburst floods in this region. For example, sediment cores sampling the Koroc valley may provide clues for the history of past lake levels.

In response to this comment and that of Reviewer 1, 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.

We note that insights on whether a pre-LGM glacial lake existed in the Koroc River valley may gained in part from two detailed Quaternary geology maps produced by the Geological Survey of Canada that cover the whole Koroc River drainage basin (Paradis and Parent, 2002a, 2002b). These maps do show evidence for glacial lake(s) at lower elevations in the Koroc River valley, but these glacial lake deposits and landforms (deltas and shorelines) are part of a morpho-sedimentary assemblage typical of the early Holocene deglaciation. Small and scarce occurrences of glacial lake deposits are found in places at higher elevations, but they likely relate to ephemeral lakes that were dammed by small retreating glacier tongues during the last deglaciation, as indicated by belts of minor moraine crests in these minor valleys. The maps also show that the high-elevation terrains of the study area consist essentially of bedrock exposures that are commonly blanketed and flanked by block fields (felsenmeer) produced by frost action, with abundant solifluction lobes – a setting reminiscent of the features presented in the photos of Figure 4. Given the ease of access to these maps (references below), this critical information should have been taken into consideration when attempting to reconstruct such a lake.

We are aware of these geologic maps, and these maps were available for earlier studies in this region conducted by one of the coauthors. For these higher elevation regions, where the study site is located, these geologic maps are largely based on analyzing airphotos. The features are hard to see in airphotos. Ground truthing through field mapping could help to better document these features in published geologic maps.

Configuration of the ice masses damming the lake

Accepting the premise that a pre-LGM glacial lake occupied the Koroc River valley also raises other important questions regarding the configuration and origin of the ice masses that dammed the lake at that time. Given the lack of geological data constraining ice-margin positions during MIS 3 in Labrador-Ungava, the authors use a series of assumptions about the ice dam locations.

Some of these are coherent with paleogeographic reconstructions of the last deglaciation, when the lower reach of the rivers flowing into southeastern Ungava Bay was dammed by the margin of the retreating Labrador Ice Dome – a damming mechanism that resulted in the accumulation of large amount of meltwater in river valleys such as the Koroc River. Although this scenario is consistent with the last deglaciation, it nonetheless involves a substantial ice mass located in north-central Quebec in order to have an ice margin extending down into the Ungava Bay lowlands. This ice margin would also have to be very thick and voluminous to hold the large meltwater body (high hydrostatic pressure) associated with a pre-LGM Lake Koroc with a surface-elevation at ~900 m. These considerations appear counterintuitive in the context of a drastically reduced ice cover for MIS 3 that is presented in the manuscript.

Damming a high-elevation glacial lake (~900 m) in this region also requires the presence of ice masses in the upper reaches of the Koroc River drainage watershed, without which, the lake would drain via different low-elevation outlets. To circumvent this problem, it is stipulated that several valley glaciers occupied low-lying topographic depressions to prevent excess meltwater to flow eastward across the continental divide separating the Ungava Bay and Labrador Sea watersheds. Unfortunately, no geological evidence is presented to support the existence of these valley glaciers. The manuscript refers to the work of Ives to support the existence of these valley glaciers in the Torngats, although it does not relate to old valley glaciations. Accordingly, the manuscript should build a better case for this aspect of the reconstruction.

Again, drawing comparisons based on the geological maps reported above, the deglacial (Holocene) geomorphology of the numerous secondary valleys of this region shows a record of small-scale moraines and ice-contact deposits that tend to suggest that these valley glaciers were perhaps not large enough to hold such a large lake. For these valley glaciers to be efficient for the damming of the pre-LGM Lake Koroc would imply larger valley glaciers and ice caps, which in turn calls for a large amount of ice above the Torngats at that time – a scenario inconsistent with the hypothesis of a significantly reduced ice cover presented for this time interval.

We agree with the comment authors that MIS 3 ice margin locations in this region are poorly constrained. It is plausible that evidence from pre-LGM glacial lakes in this region could appear quite differently in the geological record compared with deglacial lake records. Unlike pre-LGM features, deglacial geomorphic features are more likely to be preserved as they would not have been eroded by advancing and retreating ice cover.

While we do not report evidence for ice margin locations damming pre-LGM Glacial Lake Koroc, future fieldwork could be tasked with mapping out the extent of pre-LGM glacial lake shorelines in this region, which would help bound the ice-dammed locations of this lake.

Since we are unable to make a stronger case for the existence of valley glaciations (or other ice margin locations) barring additional field data collection, we make assumptions for the locations of ice-dammed glacial lake boundaries.

In response to these comments, and those by Reviewer 1, we performed additional calculations that vary ice margin location to explore the uncertainty on estimated lake volume, and we will add the following text:

The total lake volume depends strongly on the assumed ice margin positions that bound the glacial lake. Given the uncertainty on the ice-dammed locations of this lake, we explored three possible scenarios varying the assumed southern position of the ice margin that bound pre-LGM Glacial Lake Koroc. For the intermediate scenario, the southern ice margin boundary is at 58 N, resulting in an estimated lake volume of 1.14×10^{12} m^3. For the smaller lake scenario, we shift the assumed ice margin boundary northward from 58 N to 58.25 N (~28 km), which reduces the estimated lake volume from 1.14×10^{12} m^3 to 7.62×10^{11} m^3 (reduced by ~30%). For the larger lake scenario, shifting the assumed ice margin boundary southward from 58 N to 57.75 N increases the estimated lake volume 1.14×10^{12} m^3 to 1.44×10^{12} m^3 (increased by ~25%).

Geochronological constraints

An important limitation regarding the conclusions reached by the study relates to the fact the MIS 3 age assigned to the old glacial Lake Koroc is based on only two cosmogenic ages. This represents an extremely low number of geochronological constraints considering the method employed here and given the complexity and variety of terrains present in formerly glaciated environments.

For instance, several studies have documented complex arrangements of subglacial thermal conditions in the Labrador-Ungava region, which show evidence that high-elevation regions were likely characterized by at least a partial cold-based ice cover (Marquette et al., 2004; Staiger et al., 2005; Rice et al., JQS 2019; Dubé-Loubert et al., Geomorph. 2021). Although this provides a setting for a non-erosive ice cover and thus the preservation of old geomorphological features, it does warrant caution in the interpretation of cosmogenic ages, which may be affected by inheritance signal from previous exposures and result with age overestimates.

However, the manuscript presents a different interpretation for the two pre-deglaciation 10Be ages obtained. The favored age of ~56 ± 3 ka derives from a correction applied to the two samples to take into account a period of burial by ice; a plausible choice of calculation and consistent with the hypothesis presented in the study. Still, considering the inheritance problem inherent to high elevation terrains of this region, it would have been essential to carry out paired isotope (Al/Be) measurements to characterize the history of ice cover of this site – an approach that would greatly facilitate the interpretation of the results. In addition, as for the geomorphological evidence for the lake, it would have been important to present 10Be ages from more than one site in order to support the deductions made on the basis of the two geochronological constraints.

We are in full agreement with the authors of this comment that an accurate age for this glacial lake shoreline feature will require future analysis that incorporates paired cosmogenic isotope systems to derive a burial history for this site.

Summary

We believe the manuscript presents an interesting hypothesis regarding the possibility of a pre-LGM glacial lake to the east of the Torngat Mountains and the potential contribution of its drainage to the forcing mechanisms responsible for the climate variability (Heinrich events) of MIS 3. Unfortunately, the geomorphological evidence and geochronological data supporting the existence of a glacial Lake Koroc during MIS 3 are too fragmentary and unconvincing at the moment, while the proposed configuration of the damming LIS margins and valley glaciers appears inconsistent with the scenario of significantly reduced ice cover presented. As stated at numerous places in the manuscript, we concur with the authors that further fieldwork is required to convincingly show that old (relict) geomorphological features are present on high-elevation terrains of Labrador-Ungava. At this point we would simply urge caution in using such a small amount of geological evidence to claim the existence of a glacial lake and outburst flood, especially when using the reconstruction to constrain the ice margin of the Laurentide ice sheet during MIS 3 in one of its core sectors.

We thank the authors of this comment for their positive remarks and constructive comments. 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 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.