TYPE General Commentary
PUBLISHED 01 June 2023
DOI 10.3389/feart.2023.1186972

Check for updates

OPEN ACCESS

EDITED BY
Xingqi Liu,
Capital Normal University, China

REVIEWED BY
Steven L. Forman,
Baylor University, United States

*CORRESPONDENCE
Riko Noormets,
Riko.Noormets@unis.no

RECEIVED 15 March 2023
ACCEPTED 22 May 2023
PUBLISHED 01 June 2023

CITATION
Noormets R and Kirchner N (2023), Commentary: Glacial history and depositional environments in little Storfjorden and Hambergbukta of Arctic Svalbard since the younger dryas. *Front. Earth Sci.* 11:1186972. doi: 10.3389/feart.2023.1186972

Commentary: Glacial history and depositional environments in little Storfjorden and Hambergbukta of Arctic Svalbard since the younger dryas

Riko Noormets[1]* and Nina Kirchner[2]

[1]Department of Arctic Geology, University Centre in Svalbard, Longyearbyen, Norway, [2]Department of Physical Geography and Bolin Centre for Climate Research, Stockholm University, Stockholm, Sweden

KEYWORDS

Svalbard, Hambergbukta, deglaciation, Holocene, terminal moraine, glacier surge, multibeam bathymetry, shallow seismic stratigraphy

A Commentary on
Glacial history and depositional environments in little Storfjorden and Hambergbukta of Arctic Svalbard since the younger dryas

by Joe YJ, Jang K, Forwick M, Laberg JS, Kong GS, Kang M-H, Yoon S-H and Nam S-I (2022). Front. Earth Sci. 10:1017594. doi: 10.3389/feart.2022.1017594

Introduction

In their paper "Glacial history and depositional environments in the Little Storfjorden and Hambergbukta of Arctic Svalbard since the younger dryas", Joe et al. (2022) suggest that the Terminal Moraine Complex (TMC) at the mouth of the Hambergbukta was formed during the Little Ice Age (LIA). This conclusion is based on analysis of a sediment core from the Little Storfjorden approximately 4 km east of the crest of the TMC and a few multibeam bathymetric and subbottom acoustic profiles in the central part of the TMC. We agree with Joe et al. (2022) that the age range of the TMC formation is poorly constrained. This comment highlights prominent features of the TMC which, in our opinion, are incongruous with formation during LIA advances. The analysis of these features by Joe et al. (2022) has resulted in an incomplete assessment of the morphology and structure, and consequently the formation of the part or the whole of the TMC during the LIA.

Discussion

Important features in this context are the debris flows on the distal flank of the TMC. The sedimentary architecture of the distal flank of the TMC and the total number of debris flows stacked there is unknown because of the limited coverage and insufficient penetration depth of the subbottom acoustic data. However, at least three sets of partially overlapping and cross-cutting debris flow lobes suggest that the Hambergbreen glacier has reached the TMC

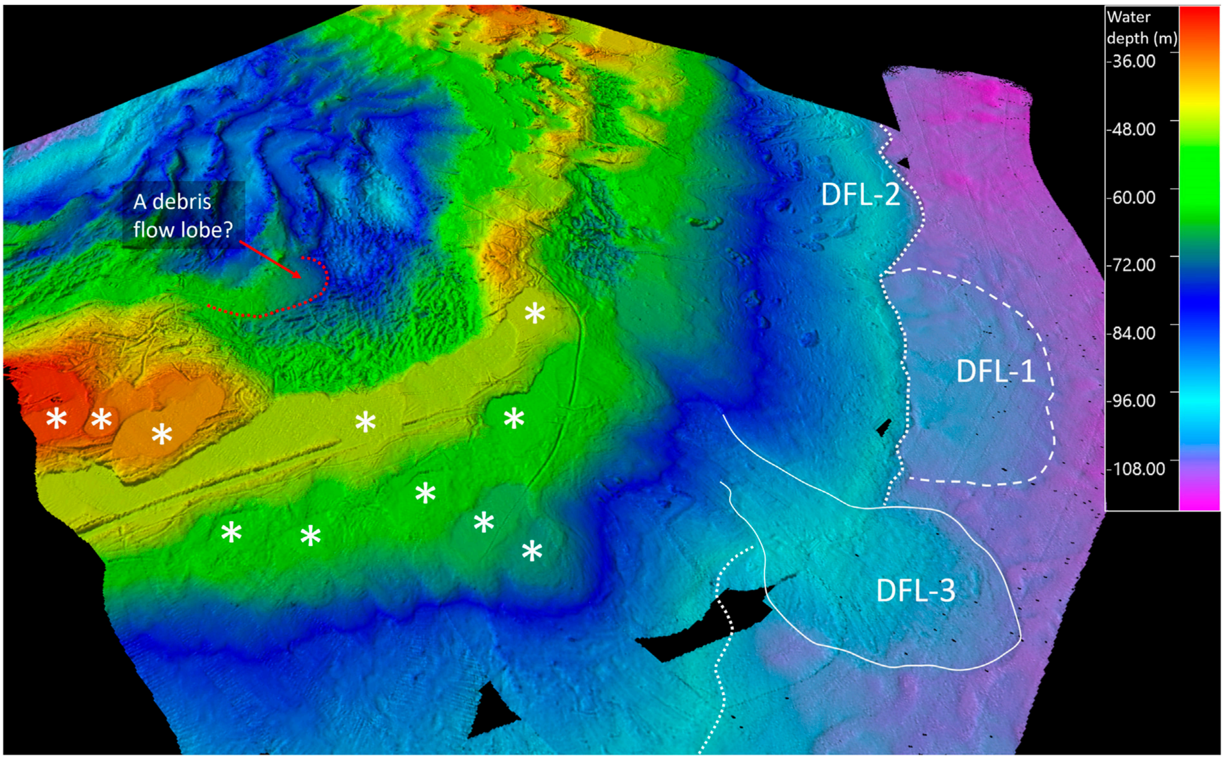

FIGURE 1
Oblique view of the Hambergbukta Terminal Moraine Complex (TMC) from southeast based on data in Noormets et al. (2016; Noormets et al. (2021). Possible debris flow lobe on the distal flank of the LIA end moraine is marked with red dotted line. Asterisks (*) mark the flattened crest areas and terraces at multiple depth levels on the distal flank of the TMC. DFL-1, DFL-2 and DFL-3 mark the different generations of debris flow lobes (from oldest to youngest) displaying their overlapping and cross-cutting relationship.

several times since the initial formation (Figure 1). Based on acoustic data from one debris flow lobe and associated sediment core analyses, Joe et al. (2022) suggest that the formation of the entire TMC took place during a LIA advance of the Hambergbreen glacier. A LIA advance alone, however, does not explain the complex architecture of the multiple large debris flow lobes, let alone the formation of the entire TMC.

Furthermore, based on subbottom acoustic profile linking the core 905 to one of the debris flow lobes, Joe et al. (2022) suggest that the Facies F-4C is superimposed by the debris flow lobe Facies F-1B (Figure 4 in Joe et al., 2022). However, this subbottom acoustic profile shows change from undisturbed, basin in-fill type of layering at the core site in the Little Storfjorden to clearly disturbed sediments near the TMC. These sediments possibly reflect debris flow and iceberg scour processes, as evidenced by iceberg ploughmarks highlighted by Joe et al. (2022). The criteria for tracking seismic reflectors through the disturbed sediments of the TMC remains unjustified, nor is this correlation permissive, with likely palimpsesting arrangement of stacked deposits, from multiple glacier advances and retreats.

We also indicate the insufficient vertical resolution of the subbottom acoustic data that do not permit reliably linking the key lithological units to seismic facies. For example, the lithological unit corresponding to Facies F-4C at the top of the core 905 is a 12 cm thick layer of glaciomarine deposits with suggested age of ca. 0.4 ka (Figure 7 in Joe et al., 2022). Due to the vertical resolution limitations of the subbottom acoustic data, the authors acknowledge that "*The strong surficial reflector of F-4C presumably includes the Facies 4 and uppermost parts of Facies 3, which might have been deposited since approximately 1 ka*". This age uncertainty is inconsistent with the conclusion by Joe et al. (2022) regarding the LIA formation of the TMC and the debris flow lobe. Moreover, considering that the suggested ages in the upper half of the core are interpolated ages based on single radiocarbon date of ca. 0.6 ka from a shell fragment at 19–20 cm core depth, the age of the seismic reflector marking the base of the debris lobe has large uncertainty. This implies that the debris flow lobe could be considerably older than approximately 1 ka, pre-LIA in age, counter to Joe et al. (2022). It is also noteworthy that an increasing number of such terminal moraines in Svalbard, generally assumed to be from LIA (cf. Lefauconnier and Hagen, 1991), have been shown to be significantly older than LIA by later studies (Kempf et al., 2013; Farnsworth et al., 2018; Flink et al., 2018; Flink and Noormets, 2018; Dowdeswell et al., 2020 and references therein). However, local reshaping of these moraines by later glacier advances, including during LIA, cannot be excluded.

Another feature, which is incongruent with the LIA formation of the TMC and the debris flow lobes on its distal flank, is the prominent flattened crest areas and multiple terraces (Figure 1). These features can also be seen in Joe et al. (2022) in their Figures 3–5 and in the first panel of table 2. Previous analysis suggests that these features were eroded by large tabular icebergs with plane bases originating outside of Hambergbukta because there are no similar features in the fjord or proximal flank of the TMC (Noormets et al., 2016). It is noteworthy that Hambergbukta TMC is the only one among several tens of similar terminal moraines identified offshore of Svalbard (cf. Ottesen et al., 2017; Dowdeswell et al., 2020) that exhibits clear flattened crests and terraces, hence implying a nearby source of large tabular icebergs with minimum drafts of 70 m. This keel depth, required to rework the TMC, is far too deep for a nearby LIA source considering that the glacio-isostatic rebound has been marginal since the LIA and only approximately 2 m during the last c. 2,700 years in southern Spitsbergen (Ziaja and Salvigsen, 1995). The limiting shallow depth of the inner Storfjorden and of the submarine Mid-ridge between the Storfjorden and Little Storfjorden (Nielsen and Rasmussen, 2018; Svalbard Navigational Charts, 2020) would have prevented the icebergs with keel depths greater than approximately 50–60 m reaching the Hambergbukta TMC during the LIA. Thus, there was no obvious source for tabular icebergs with keel depth reaching approximately 70 m to explain the formation of terraces at Hambergbukta TMC during and post LIA. However, considering the northwards increasing gradient of glacio-isostatic response of the Storfjorden area (Salvigsen and Mangerud, 1991; Bondevik et al., 1995; Forman et al., 2004 and references therein), the glaciers would have been able to produce icebergs with required keel depth to rework the TMC earlier in the Holocene. Also, the large Storfjorden ice stream (or potentially ice shelf) during the deglaciation (cf. Nielsen and Rasmussen, 2018) within a short distance from the Hambergbukta TMC could well have produced such icebergs suggesting considerably earlier time than the LIA for formation of the TMC.

Joe et al. (2022) also state that the lack of debris flow lobes on the distal flank of the LIA end moraines suggested by Noormets et al. (2021) indicates their non-terminal morainal structure. This assertion does not acknowledge that surge end moraines have been documented without associated debris flow lobes (cf. Flink et al., 2015). Moreover, a closer inspection of bathymetric data indicates presence of a sediment lobe emanating from southern part of a clear moraine form and may be a debris flow lobe associated with the formation of the surge end moraine (Figure 1).

The increased content of IRD in the top 10–12 cm of the sediment core in the Little Storfjorden may reflect the increased glacier (surge) activity in Hambergbukta and in the other fjords in the area as Joe et al. (2022) suggest. Numerous studies have also linked IRD content variations in fjord sediments to ice sheet dynamics, glacier activity, ocean circulation as well as sea ice and iceberg processes (cf. Szczucinski et al., 2009; Fransner et el., 2017; Allaart et al., 2020; Rasmussen and Thomsen, 2021). However, Joe et al. (2022) conclusion that the increase in IRD is evidence for the broader formation of the TMC during LIA, has according to our knowledge not been supported by studies across Svalbard.

In summary, considering the oversight of the complex structure of the multiple debris flow lobes and flattened crest and terraces of the TMC, the insufficient resolution for seismic stratigraphic correlations within debris flow deposits, particularly with subsequent disturbance with iceberg scouring, and the uncertainties arising from the age interpolation of the top part of the sediment core, the conclusions about the processes and age of the TMC formation are premature. The complexity of the Hambergbukta TMC suggests that it was probably formed and modified during multiple glacier advances and retreats post the Younger Dryas chronozone similarly to many other terminal moraines in Svalbard (cf. Kempf et al., 2013; Farnsworth et al., 2018; Flink et al., 2018; Flink and Noormets, 2018; Dowdeswell et al., 2020 and references therein). The number and timing of advances of Hambergbreen (and other glaciers in Svalbard) since the deglaciation after the LGM requires detailed morphological and sedimentological studies of the terminal moraine complexes, and better age control of individual features within them.

Author contributions

RN and NK have contributed equally to the analysis and writing of this commentary. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Allaart, L., Müller, J., Schomacker, A., Rydningen, T. A., Håkansson, L., Kjellman, S. E., et al. (2020). Late Quaternary glacier and sea-ice history of northern Wijdefjorden, Svalbard. *Boreas* 49, 417–437. doi:10.1111/bor.12435

Bondevik, S., Mangerud, J., Ronnert, L., and Salvigsen, O. (1995). Postglacial sea-Level history of edgeøya and barentsøya, eastern svalbard. *Polar Res.* 14, 153–180. doi:10.3402/polar.v14i2.6661

Dowdeswell, J. A., Ottesen, D., and Bellec, V. K. (2020). The changing extent of marine-terminating glaciers and ice caps in northeastern Svalbard since the 'Little Ice Age' from marine-geophysical records. *Holocene* 30, 389–401. doi:10.1177/0959683619887429

Farnsworth, W. R., Ingolfsson, O., Retelle, M., Allaart, L., Håkansson, L. M., and Schomacker, A. (2018). Svalbard glaciers re-advanced during the Pleistocene-Holocene transition. *Boreas* 47, 1022–1032. doi:10.1111/bor.12326

Flink, A. E., Hill, P., Noormets, R., and Kirchner, N. (2018). Holocene glacial evolution of Mohnbukta in eastern Spitsbergen. *Boreas* 47, 390–409. doi:10.1111/bor.12277

Flink, A. E., Noormets, R., Kirchner, N., Benn, D. I., Luckman, A., and Lovell, H. (2015). The evolution of a submarine landform record following recent and multiple surges of Tunabreen glacier, Svalbard. *Quat. Sci. Rev.* 108, 37–50. doi:10.1016/j.quascirev.2014.11.006

Flink, A. E., and Noormets, R. (2018). Submarine glacial landforms and sedimentary environments in Vaigattbogen, northeastern Spitsbergen. *Mar. Geol.* 402, 244–263. doi:10.1016/j.margeo.2017.07.019

Forman, S. L., Lubinski, D. J., Ingolfsson, O., Zeeberg, J. J., Snyder, J. A., Siegert, M. J., et al. (2004). A review of postglacial emergence on svalbard, franz josef land and novaya zemlya, northern eurasia. *Quat. Sci. Rev.* 23, 1391–1434. doi:10.1016/j.quascirev.2003.12.007

Fransner, O., Noormets, R., Flink, A. E., Hogan, K. A., O'Regan, M., and Jakobsson, M. (2017). Glacial landforms and their implications for glacier dynamics in Rijpfjorden and Duvefjorden, northern Nordaustlandet, Svalbard. *J. Quat. Sci.* 32, 437–455. doi:10.1002/jqs.2938

Joe, Y. J., Jang, K., Forwick, M., Laberg, J. S., Kong, G. S., Kang, M-H., et al. (2022). Glacial history and depositional environments in little Storfjorden and Hambergbukta of Arctic Svalbard since the younger dryas. *Front. Earth Sci.* 10, 1017594. doi:10.3389/feart.2022.1017594

Kempf, P., Forwick, M., Laberg, J. S., and Vorren, T. O. (2013). Late Weichselian and Holocene sedimentary palaeoenvironment and glacial activity in the high-arctic van Keulenfjorden, Spitsbergen. *Spitsb. Holocene* 23, 1607–1618. doi:10.1177/0959683613499055

Lefauconnier, B., and Hagen, J. O. (1991). Surging and calving glaciers in eastern Svalbard. *Nor. Polarinst.* 116, 1–130.

Nielsen, T., and Rasmussen, T. L. (2018). Reconstruction of ice sheet retreat after the Last Glacial maximum in Storfjorden, southern Svalbard. *Mar. Geol.* 402, 228–243. doi:10.1016/j.margeo.2017.12.003

Noormets, R., Flink, A. E., and Kirchner, N. (2021). Glacial dynamics and deglaciation history of Hambergbukta reconstructed from submarine landforms and sediment cores, SE Spitsbergen, Svalbard. *Boreas* 50, 29–50. doi:10.1111/bor.12488

Noormets, R., Kirchner, N., Flink, A. E., and Dowdeswell, J. A. D. (2016). "Possible iceberg-produced submarine terraces in Hambergbukta, Spitsbergen," in *Atlas of submarine glacial landforms: Modern, quaternary and ancient* Editor J. A. Dowdeswell, M. Canals, M. Jakobsson, B. J. Todd, E. K. Dowdeswell, and K. A. Hogan (London: Geological Society), 101–102. Memoirs 46.

Ottesen, D., Dowdeswell, J. A., Bellec, V. K., and Bjarnadottir, L. R. (2017). The geomorphic imprint of glacier surges into open-marine waters: Examples from eastern Svalbard. *Mar. Geol.* 392, 1–29. doi:10.1016/j.margeo.2017.08.007

Rasmussen, T. L., and Thomsen, E. (2021). Climate and ocean forcing of ice-sheet dynamics along the Svalbard-Barents Sea ice sheet during the deglaciation ~20,000–10,000 years BP. *Quat. Sci. Adv.* 3, 100019. doi:10.1016/j.qsa.2020.100019

Salvigsen, O., and Mangerud, J. (1991). Holocene shoreline displacement at agardhbukta, eastern spitsbergen, svalbard. *Polar Res.* 9, 1–7. doi:10.1111/j.1751-8369.1991.tb00398.x

Svalbard Navigational Charts (2020). *Navigation Charts: Svalbard series, main sheets 528, 532 and 533*. Norwegian Mapping Authority.

Szczucinski, W., Zajaczkowski, M., and Scholten, J. (2009). Sediment accumulation rates in subpolar fjords – impact of post-Little Ice Age glaciers retreat, Billefjorden, Svalbard. *Coast. Shelf Sci.* 85, 345–356. doi:10.1016/j.ecss.2009.08.021

Ziaja, W., and Salvigsen, O. (1995). Holocene shoreline displacement in southernmost Spitsbergen. *Polar Res.* 14 (3), 339–340. doi:10.1111/j.1751-8369.1995.tb00721.x