

We thank reviewer 2 for their comments on our paper. Their suggestions are very fair and have helped to improve the paper. In particular, reviewer 2 had two major comments, in response to which we have made significant changes. This includes, (i) expanding on the original pioneering work on esker beads by De Geer and removing reference to our study being the most robust demonstration of these beads as annual features; and (ii) modifying our explanation for the close relationship between eskers and De Geer moraine to remove reference to the terrestrial study by Price (1970) and instead focusing on the potential for winter re-advance of the ice margin or that ice-marginal advance/retreat is out-of-phase with the start/end of the melt season. We have also responded to the more specific comments by the reviewer.

Our responses can be found below. Reviewer comments are in black and our replies in [blue](#).

On behalf of all co-authors,

Kind Regards,

Stephen Livingstone

### Reviewer 2

The paper by Livingstone et al. titled “A quasi-annual record of time-transgressive esker formation: implications for ice sheet reconstruction and subglacial hydrology” is presented in high quality concerning both the text and figures. The study uses new methods (ArcticDEM) to map and analyse a large number of esker segments over a wide area in central Nunavut, Canada, to discuss esker formation and the implications for reconstructing subglacial drainage. The paper is within the scope of, and well suited for, *The Cryosphere*. The authors present interesting new results on the morphometric properties of the eskers and their relationship with de Geer moraines. These finds have the potential to have important implications and significance for reconstructions of subglacial drainage and sediment transfer of ice sheets.

[Thank you for these kind comments!](#)

However, I do have some major concerns, both concerning the originality and the quality, of the interpretations of, and suggested models of formation for, esker beads and de Geer moraines which I would like to see addressed before I can recommend this manuscript for publication. My concerns and comments are specified below.

Originality of the proposed model of esker formation: One of the main finds put forward in this manuscript is the identification of annual esker “beads”. The authors do mention that esker beads being annual has been proposed in earlier studies but argue that their data “provides a more robust demonstration” (p. 15, line 304), a statement I strongly disagree with. The annual nature of such eskers beads were exemplified over 100 years ago based on many years extensive mapping and detailed sedimentological and stratigraphic work in Sweden, where such “beads” were correlated to annual (“de Geer”) moraines and even individual glacial varves (see: de Geer 1897; 1905; 1910; 1940). The early works are published in Swedish (de Geer 1897; 1905) and German (de Geer 1910), but nonetheless they are well cited and by no means “hidden” in the literature. There are also a more recent English translation of de Geer (1910) by Dullo & Hay (2002), and the works by de Geer is also summarized in English in de Geer (1940), which is actually cited in this manuscript. As a matter of fact in Sweden, and also in some Canadian work (e.g. Allard, 1974), this type of eskers (with annual “beads”) are referred to as De Geer type - eskers. The results presented

in this manuscript are still new, interesting and important data from a remote and not so well studied area, but it is not more robustly or convincingly demonstrated in this manuscript that these beads are annual when compared to previous studies. If you disagree, please provide an explanation of why your data provides a more robust demonstration. I recommend adding some of the key references relating to the early pioneering works on beaded esker formation, i.e. de Geer (1897; 1910), and include a discussion how these relate to your findings. We should not let the hard and impressive work of our old heroes to fall into oblivion and take credit for “reinventing the wheel”!

This is a very helpful comment and we agree with the reviewer that we overstretched the originality of our work. In particular, signposting us to the English translation of De Geer (1910) was particularly helpful – we have not come across this before. To rectify this, as proposed by the reviewer, we have removed the statement “provides a more robust demonstration”, included some of the key pioneering references of De Geer (see reply to specific comments below) and also expanded a few of the paragraphs. This includes, adding a description of how De Geer correlated esker beads to De Geer moraine and the varve record in Sweden (final paragraph of section on: ‘A model for quasi-annual deposition of esker beads in an ice-marginal marine setting’), a sentence on the implications for esker ridge formation, which De Geer actually described in his 1940 paper (in section on: ‘Implications for understanding subglacial drainage’) and a note in the final bullet point of the conclusion making reference to how our work agrees with his pioneering work.

Esker bead- and De Geer moraine formation model:  
In this manuscript, the annual nature of the esker beads are based on their relation to, assumed, annually formed de Geer moraines (similar to de Geer, 1910). De Geer moraines are assumed to be annually formed following the original hypothesis of them being formed during winter advances/standstill of the ice margin during overall retreat (de Geer, 1889), so far, so good. However, in this manuscript the authors then argue that, based on the relation between esker beads and moraines, the moraines are formed during summer melt seasons by deformation and squeezing of saturated till to the ice margin and refer to the process described by Price (1970). Price (1970) is, however, a study of a terrestrial ice margin on Iceland, so say that this process did produce the moraines, why do we not see De geer moraines above the marine limit (line 170)? and how can one still explain that they still are formed annually? How can you explain the gap between the moraines? What is there that speaks against the moraines simply being formed during winter advances that reaches the esker bead from the previous year, by the same process you describe on line 226-228? Or, that esker beads start to form prior to the onset of summer retreat from the moraines? Ice marginal advance/retreat is not necessarily in phase with the start/end of melt season as observed at present day ice margins (e.g. Schild & Hamilton 2013).

On reflection, we agree that a summer formation for the De Geer moraine is not the simplest explanation, particularly in light of reading Schild & Hamilton (2013), and the observation that De Geer moraine are not always associated with esker beads. We have therefore simplified the key paragraph, by removing the reference to Price (1970) and summer De Geer moraine formation, and concentrating on the options proposed by the reviewer. We have added the following section in place of the previous text: “This can be explained by the ice-margin re-advancing to the previous year’s esker bead, and/or deposition of the esker bead prior to the onset or after summer retreat from the moraine. The latter suggestion is consistent with observations at present day ice margins, which indicate that ice-marginal advance (retreat) is out-of-phase with the start (end) of the melt season (e.g. Schild & Hamilton, 2003).”

Further comments (line number, followed by comment):

18, give calibrated ages and be consistent with the use of either “yr” or “a” (kyr/ka), here you use “yr” but further down in the manuscript you suddenly use “ka” change throughout the manuscript.

We have decided to stick to kyr and yr, and have corrected throughout the manuscript.

19, choose either kyr or ka

Done

22, choose kyr or ka

Done

41, here I miss a reference to the pioneering work by de Geer (1897). De Geer (1910) and/or de Geer (1940) would also suffice.

We have added in De Geer (1897, 1910, 1940).

85 (Figure 1), use either ka or kyr in the figure.

Done. We have used kyr to be consistent with the rest of the document.

139, how do you distinguish “till blankets”? From ArcticDEM or aerials? Geological maps? please specify.

We agree this is obtuse and have added a line in the methods where we state where these data are from, how they were derived and defined the key units referred to in this manuscript.

Figures 3-4, Beautiful figures!

Thanks.

184-185, as also mentioned above on line 41, here I miss a reference to the work by Geer concerning “hypothesis 1”.

We have added a couple of the key De Geer references here – De Geer (1897, 1910).

Figure 5, See my comments on the proposed model for esker bead and de Geer moraine formation above.

We have removed reference to the variable pressure axis in light of the simplifications we have made to our proposed model and also modified the caption to make clear when the beads and De Geer moraine likely formed in relation to each other.

228-229, This view of these smaller interannual moraines proposed by Möller (1962) is not a generally accepted view. Please rephrase this sentence with e.g.: “proposed” or “suggested by Möller (1962).

We have rephrased this sentence along the lines proposed by the reviewer: “Möller (1962) suggest that...”

251-264, See my comments on the proposed model for esker bead and de Geer moraine formation above.

See reply to major comment above, we have adapted our model to keep the simplest idea that esker beads are formed in summer and De Geer moraine in winter.

273-275, This sentence reads like you are the first to come to this conclusion, please add a reference to e.g. de Geer (either 1910 or 1940), who suggested and showed that this was the case.

We agree and have added a reference to De Geer (1910).

277 & 281, use either “yr” or “a”

See above, we have decided to use kyr and yr throughout the manuscript and we have checked for consistency.

304, see my comments above concerning if your results are more robust.

We have deleted “...but we suggest our data provides a more robust demonstration” and also added in the 1897 and 1910 De Geer references.

309-310, use either “yr” or “a”

Done

329, “Identification” is a strong word. You have not proven that the beads are annual, you can however suggest that they are based on the assumption that the de Geer moraines are annual. Please rephrase.

We agree and have rephrased to “Our suggestion that beaded eskers are an...”

368 & 370, use either “yr” or “a”

Done

Figure 9, Please add north arrow to the maps.

Done.

409-412, See my comments on the proposed model for esker bead and de Geer moraine formation above.

We have removed the idea that the De Geer moraine formed in summer and replaced this sentence with: “The co-alignment between De Geer moraines and esker beads suggests that the ice-margin re-advanced to the previous years’ esker bead, and/or the esker bead was formed prior to the onset or after summer retreat from the moraine.”

420, To say that the beads “records a high-resolution (annual) record” is too strong. You infer them to be annual but have yet to prove that they are. Please rephrase.

Have rephrased to “We propose that the downstream spacing of esker beads records a high-resolution (quasi-annual) record...”

422-423, use either “yr” or “a”

Done

433, again, how do you know the thickness (and presence) of a till blanket?

See comment above, we have added in details of these data we used and how it was derived in the methods.