Kirkham et al. (2019) Past water flow beneath Pine Island and Thwaites glaciers, West Antarctica. The Cryosphere Discussions

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General Comments

This paper presents new mapping of over 1000 subglacial channels and basins exposed by the retreat of Pine Island and Thwaites glaciers since the LGM. The distribution and morphology of these channels are analyses and compared with the Labyrinth channels. To assess the volumes and routing of subglacial water beneath the Pine Island and Thwaites system, hydrological modelling of LGM conditions is utilised. The methods appear to be generally robust and appropriate and the results are detailed and address the important challenge of identifying how large (kms scale) bedrock cut channels/tunnel valleys form. Using these data, the authors favour an origin by episodic high magnitude discharges from subglacial lakes. The paper is well written and the figures generally clear and informative. I certainly favour publication of this paper. However, I do have a number of points that should be considered, in particular the four below under general comments.

1. Relationship between channel metrics and modelled discharges. Although the morphometric analysis presented in Figure 4 is really informative, it would have been nice to also see the spatial variation in channel size analysed and presented. Given the authors have already calculated variations in the potential mean discharges and flow discharges for four potential subglacial lakes on the palaeo-ice stream bed using hydrological modelling, it would be relatively straightforward to also compare how the local morphologies of the channels in these different regions relate to these findings. If the channels were cut by cascading lake drainages, you might expect a scale association between flood discharges (from your model) and the size/morphology of your mapped channels. Put simple, are the larger channels associated with regions associated with the largest discharges? As well as looking at your particular areas, you could compare the average size of channels in the many tributaries, to the channels in the main channel, where they converge. If an association can be shown, it would be really strong evidence that your interpretation is correct, and I recommend you carry out this additional analysis.

2. Exploration of less catastrophic drainages – In lines 486-510 you argue against multiple small subglacial lake drainage events. Given your recharge times are on the order of years to decades, there is the potential for high frequency (1000s of events), small-medium magnitude subglacial lake drainage events over multiple glacial cycles. The authors seem to discard this possibility too easily, especially given some recent work by Beaud et al. (2018) who suggest that bedrock channels on the scale of tunnel valleys can be excavated over several thousand years from seasonal meltwater discharge. Could relatively small yearly to decadal drainage of subglacial lakes produce a similar distribution of channels over a glacial cycle or two, especially given the large catchment area and significant volume of water modelled to be contained in lakes upstream of the channels?

- *Beaud, F., Venditti, J.G., Flowers, G.E. and Koppes, M., 2018. Excavation of subglacial bedrock channels by seasonal meltwater flow. Earth Surface Processes and Landforms, 43(9), pp.1960-1972.*

3. Channel cross-section - Looking at the picture of the Labyrinth channels in Fig. 3B, I am surprised that they do not come out as more U-shaped. It would be nice to see a few different examples of 'typical' cross-profiles for the two regions so the reader can relate the b-index numbers to a

tangible cross-profile. I also wonder what b-index values a trapezoid channel would produce? In general, I have typically linked mega-flood events (in subaerial settings at least) to more canyon-like channel forms (e.g. Channelised Scablands – Bretz references in paper; mega-flood channels in the English Channel – e.g. Gupta et al. 2007). The tendency towards V-shaped forms in both settings should be discussed in relation to the above literature given your interpretation.

- *Gupta, S., Collier, J.S., Palmer-Felgate, A. and Potter, G., 2007. Catastrophic flooding origin of shelf valley systems in the English Channel. Nature, 448(7151), p.342.*

4. Bedrock Geology – This might not be possible, but do you have any clue about the geology of the bed that could be used to help frame your discussion – e.g. is the bedrock hard or soft?

Specific Comments

L49: Also see Siegfried, M.R., Fricker, H.A., Carter, S.P. and Tulaczyk, S., 2016. Episodic ice velocity fluctuations triggered by a subglacial flood in West Antarctica. Geophysical Research Letters, 43(6), pp.2640-2648.

L74: It is odd to reference Denton and Sugden and Evatt here given you are referring to Glacial Lake Missoula. Also, although I think it is fine to reference this flood as an example of the scale of mega-floods, that this flood was proglacial not subglacial does not make the comparison entirely fair. Do we expect pressured subglacial floods to behave in the same manner as proglacial outbursts? This difference should be made clearer.

L83: I agree here that it is inconsistent with a single/ few drainage events. But if given enough time could these not eventually produce significant channels?

L135: In the example in Figure 2a the channel illustrated is a composite feature (and also shown in Figure 6e). How would this effect the b-index? I think some discussion of this would be appropriate in the methods; it would also be useful to describe how common this configuration is in the results.

L253: Refer to Figure 4.

L255: The 19 flat-bottomed depressions are not mapped in Figure 3.

L257: The channels also appear to run through the basins.

L265: Need to refer to Figure 4.

L274-277: I like this, but am then surprised that this difference is not apparent in the form ratio (depth: width). Is there an explanation for this?

L345-346: Or could it be a composite meltwater signature formed over a long time. You seem to pre-empt your discussion here, and I suggest initially presenting every possible scenario.

L366-369: An alternative explanation for the Figure 6e cross-profile is it is a U-shaped channel cut by ice that has then had meltwater erosion at the base cutting the two smaller v-shaped channels. Can this scenario be ruled out?

L377: I don't follow the logic of this sentence with respect to the last – if there is enough water and a crack to initiate hydrofracture water will get to the bed.

L415: "with observed discharges of..."

L428: I would not include the Bretz references here as you are referring to subglacial channel formation. I also suggest you remove the British-Irish Ice Sheet references as there is a scale difference. Some of the classic literature on bedrock cut tunnel valleys could also be referred to here (e.g. Boyd et al., 1988; Mullins and Hinchey, 1989; Kor et al., 1991; Brennand and Shaw).

- *Brennand, T.A. and Shaw, J., 1994. Tunnel channels and associated landforms, south-central Ontario: their implications for ice-sheet hydrology. Canadian Journal of Earth Sciences, 31(3), pp.505-522.*

- *Kor, P.S.G., Shaw, J. and Sharpe, D.R., 1991. Erosion of bedrock by subglacial meltwater, Georgian Bay, Ontario: a regional view. Canadian Journal of Earth Sciences, 28(4), pp.623-642.*

- *Mullins, H.T. and Hinchey, E.J., 1989. Erosion and infill of New York Finger Lakes: Implications for Laurentide ice sheet deglaciation. Geology, 17(7), pp.622-625.*

L437: Can you quantify the erosion rate?

L464: Could also cite: *Livingstone, S.J., Chu, W., Ely, J.C. and Kingslake, J., 2017. Paleofluvial and subglacial channel networks beneath Humboldt Glacier, Greenland. Geology, 45(6), pp.551-554.*

L466: See also the above reference and *Cooper, M.A., Michaelides, K., Siegert, M.J. and Bamber, J.L., 2016. Paleofluvial landscape inheritance for Jakobshavn Isbræ catchment, Greenland. Geophysical Research Letters, 43(12), pp.6350-6357.*

L469: See the Livingstone et al. (2017) reference for an example of subglacial channels beneath the Greenland Ice Sheet. I also wonder whether this result is a function of the different setting of Greenland – for instance, infilling of valleys/fjords with sediments, potentially burying valleys; and less (and less detailed) sea-floor mapping.

L486-503: How do you reconcile this paragraph with that on lines 512-523, where you cite multiple papers presenting palaeo-evidence for active subglacial lakes and drainages across bedrock?

L522: "drained" might be a better word than "utilised" here.

Figures

Figure 3 – You also state that you identify 19 former lake basins. It would be useful to include these here if mapped? Or are these based on the modelling results?

Figure 4 – It is not clear what the dotted lines and the arrows in the V/U shaped plots refer too.

Figure 5 – Plot (d) rather reproduces Figure 3a. Could you have included the basins in Fig. 3 and rather overlay the modelled basins and channels here so the reader can directly compare how they match up. For (b) and (c) I would find it helpful if the current grounding line was included to help give some context to the reader.