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13 March 2024

Re: Review of Doctoral thesis by Benjamin James Stoker

To whom it may concern,

I offer my report on Benjamin Stoker's thesis entitled: *'The dynamics of the north-western Laurentide Ice Sheet margin'*, submitted for PhD in the Physical Geography and Geoecology programme at the Faculty of Science, Charles University, Prague.

Thank you for the invitation to review this thesis. It contains a strong body of novel research, written and presented to an excellent standard. I find the thesis to be of high quality, with four published papers: three fully through peer-review, and one currently undergoing peer-review and online discussion. All papers are published in respected, international journals relevant to the fields of geomorphology and glaciology, and work well together to meet the clear aims set out in the PhD. The quality of scientific investigation is excellent and it is my impression the candidate meets the requirements for a PhD.

Scientific value

Reconstructing the nature and timing of former ice sheets provides crucial insights into how they respond to various forcing factors over a range of timescales. Recent Intergovernmental Panel on Climate Change (IPCC) reports highlight the particular importance of ice sheet reconstructions in understanding how current ice sheets will respond to future warming. Of particular note are remaining uncertainties surrounding contemporary ice sheet feedbacks that could produce high-end future sea-level rise. Hence, detailed ice sheet reconstructions during periods of deglaciation provide vital analogues for future change.

Ben's thesis focuses on a poorly-understood sector of the former Laurentide Ice Sheet that once covered much of North America, of strategic importance as an ice outlet from the saddle that formed between the neighbouring Laurentide and Cordilleran Ice Sheets. Modelled 'saddle-collapse' during deglaciation—a potentially important but poorly-understood ice sheet instability—can be reconstructed from improved glaciological reconstruction in this region. Ben has addressed this gap in knowledge with two particularly important new contributions: a refined chronology of ice sheet sector retreat, and an improved reconstruction of ice-flow during marginal retreat. Both offer significant advances in understanding the response of this sector of the Laurentide Ice Sheet to ice-saddle collapse and climate change.

The majority of the thesis comprises four papers, each providing a novel contribution. The first two papers summarise the mapping of large quantities of glacial geomorphology over the Mackenzie Mountains region and northwest sector of the Laurentide Ice Sheet. The third and fourth papers are very strong analysis and discussion papers that use the new geomorphological mapping alongside further geochronological analysis, ice-sheet modelling, and ice-flow reconstruction to yield valuable new insights into the timing and nature of

deglaciation. These are major contributions that fill important gaps in our understanding of ice sheet variability and speak to wider issues of past and present glacial and climatic change. The first two papers report large quantities of new, high-quality geomorphological data, without further analysis and discussion—a requirement of the particular journal within which they are published. I find the second two papers make up for this with a wealth of discussion and new ideas that have the capacity to become important reference points in the scientific literature.

The published works are all group-efforts that bring together expertise from well beyond the PhD supervisory team, including ten authors for each of the two main discussion papers. This is common in the discipline and contributions are clearly explained at the start of the thesis. The volume of data presented and range of methods used requires large teams. The thesis highlights Ben's ability to lead different teams to maximise each paper's outputs and impact. He has drawn together a range of individuals to develop new approaches and present valuable ways of conducting research, such as co-mapping of glacial geomorphology and combining empirical data with advanced model simulations. That Ben is first author on three of the four papers, including the two large discussion papers, is testament to his leadership and ownership of these sizeable projects and the thesis as a whole.

In Papers I and II, Ben demonstrates excellent skills in data collection and presentation. It is very good to see explanations of uncertainties from the start, and an acknowledgement of the potential and limitations behind this sort of work: an important level of pragmatism that helps to clearly explain the parameters of the investigation. These are important scientific skills that help ensure conclusions stand up to scrutiny and are reproducible. I see these papers as strong examples of how to conduct this sort of data collection, and Paper II as a particularly fine example of co-production and cross-checking during geomorphological research.

Paper III presents new geochronological data to constrain a glacial reconstruction over the Mackenzie Valley. It is excellent to see careful, considered approaches to interpreting these chronological data and accompanying ice sheet modelling outputs in terms of uncertainties and factors that may affect calculated ages. I can see this paper being used as a key example of ice sheet response to saddle collapse and integrated into important empirical databases of ice sheet-wide response to climate change.

Paper IV presents an interpretation and discussion of glacial geomorphology for the whole northwestern sector of the former ice sheet, with detailed discussion of the implications for changing glaciation style during retreat. This is a sizeable contribution and I see particular value in its ideas around potential climatic and non-climatic controls on fast-flowing ice stream dynamics through time.

Quality of writing and presentation

The thesis is written and presented to a very high standard. Figures are consistently excellent and the text is clear, detailed and thorough in its examination of the large amount of data presented. The separate overview chapter offers an interesting discussion of key themes and contributions. The discussion of uncertainties, limitations and future work is particularly strong. However, I do feel that a common theme in the overview chapter and papers is a focus only on the implications locally and regionally in relation to the Laurentide Ice Sheet, with opportunities missed to explain more clearly the implications for ice sheets more generally. The thesis offers valuable new insights into the broader nature of ice-saddle collapse and the behaviour of ice streams, but these are framed only in terms of the Laurentide Ice Sheet and not for glaciology more generally.

Key points for discussion in the PhD defence

1. I welcome Ben's thoughts on the contribution of his work to our wider understanding of ice sheet change, past and future, and beyond the Laurentide Ice Sheet.

2. Data in Paper I is relatively underutilised in Paper III (compared to Papers II and IV). I would like to hear how mapping of the Mackenzie Valley in Paper I might inform a local reconstruction, combined with the chronology from Paper III. E.g. meltwater channels cross-cutting moraines imply preservation of mountain glacier geomorphology beneath an advancing ice sheet. Does this say something important about the erosional, thermal or hydrological regime of this readvancing ice?

Additional minor points for brief (1–2 line) clarification during defence or after
Here, I indicate with **(D)** where I would particularly welcome at least a brief response from Ben during his PhD defence. Other points may be answered later or if there is time during defence.

Paper I

- **(D)** You assign meltwater channels to categories based on particular origins (Laurentide, Cordilleran, montane and unknown). How was this determined, and does assigning an origin present potential issues to subsequent reconstructions?
- **(D)** There were many fewer landform types mapped here than in Paper II. Does this say something about the different nature of glaciation in the Mackenzie Mountains, or is it the result of a different methodological approach?
- Spillways are mentioned, and the location of glacial lakes discussed throughout the thesis, but no shorelines are mapped in this paper (they were for Paper II). What is the reason for this? Are lake shorelines not preserved in this study area?

Paper III

- **(D)** Dipsticks are a valuable means of reconstructing the rate of ice thinning, but can thinning be differentiated from lateral retreat of the ice margins, particularly if samples at different elevations are spread over a wide area?
- Adjusting exposure ages for Glacial-Isostatic Adjustment (GIA) is an excellent exercise in constraining uncertainties. Should GIA models be primarily based on empirical data and, if so, is calibrating exposure ages using GIA models a potential circular issue?
- Some of the exposure dating samples were taken in areas of high relief. Is it surprising that all shielding factors were '1' in such mountainous terrain?
- **(D)** The Bayesian approach to chronological modelling is a fascinating one that might help constrain errors and reduce uncertainty, but it presents a number of questions:
    - Bayesian analysis suggests Katherine Creek deglaciated at ~15.8 ka but the three exposure ages are all older. Given this is the oldest site in the dataset, what constrains the upper age limit in order to produce a younger deglacial age from older samples? (i.e. what determines the boundary start?)
    - The Katherine and Norman Ranges overlap within errors and are at similar altitudes. The Bayesian approach dictates the latter was exposed before the former, and constrains deglaciation accordingly. Is it possible sites could have been exposed synchronously with implications for the Bayesian order?
    - External errors used in the modelling (Supplementary Table S3 and S4) appear to be lower than those presented in Table 1 (e.g. Katherine Creek errors are reported in Table 1 as 1.4 ka and in Table S3 as 1.0 ka). What is the rationale here, and would using the larger errors change the modelling outcomes?

Paper IV

- **(D)** Why do you think event flow-sets might be so uncommon?
- Looking at Figure 9, could you clarify ice flow directions?
    - Fig. 9C: The red flow-sets flow west, described as 'westerly'; the dark blue Flow-set 26 appears to be flowing south, described as 'northerly'. Does 'northerly' here mean flowing north, or flowing south?
    - Fig. 9B: 'Ice flow reversal' is mentioned several times. Is this actually a reversal, or a change in direction? It looks to be the latter.
- Section 6.4.1 discusses controls on the reduction in ice stream activity:
    - Line 908 mentions the significance of ice stream changes occurring prior to the Younger Dryas. Given terrestrial temperatures are relatively poorly constrained in North America during this time period, how confident are you in assigning a non-climatic control on the reduction in ice stream activity?
    - **(D)** Could you briefly clarify why you deem ice drawdown as the primary control on the reduction in ice streaming, rather than changing basal conditions (e.g. transition to a harder bed)? Line 960 notes that it is challenging to determine the relative influence of these factors (also including climate-driven ice retreat), so how confident are you in this conclusion?

Concluding remarks

I wish to congratulate Ben on presenting an excellent thesis and a range of new contributions to the scientific literature. It has been a pleasure to read his thesis and examine its content. My conclusion is that he has clearly demonstrated an ability to conduct original, important research in Physical Geography, and I therefore recommend the submitted thesis as worthy of the qualification of PhD.

Yours sincerely,

Dr Christopher Darvill

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