



January 27th, 2015

RE: Response to the M. Bentley referee interactive comments

In response to the referee's comment, we provide a point-by-point response, summarizing how we have addressed the concerns. We wish to thank M. Bentley for his insightful and constructive review we certainly could not have asked for a better informed reviewer. We hope that our replies are considered satisfactory.

Yours sincerely,

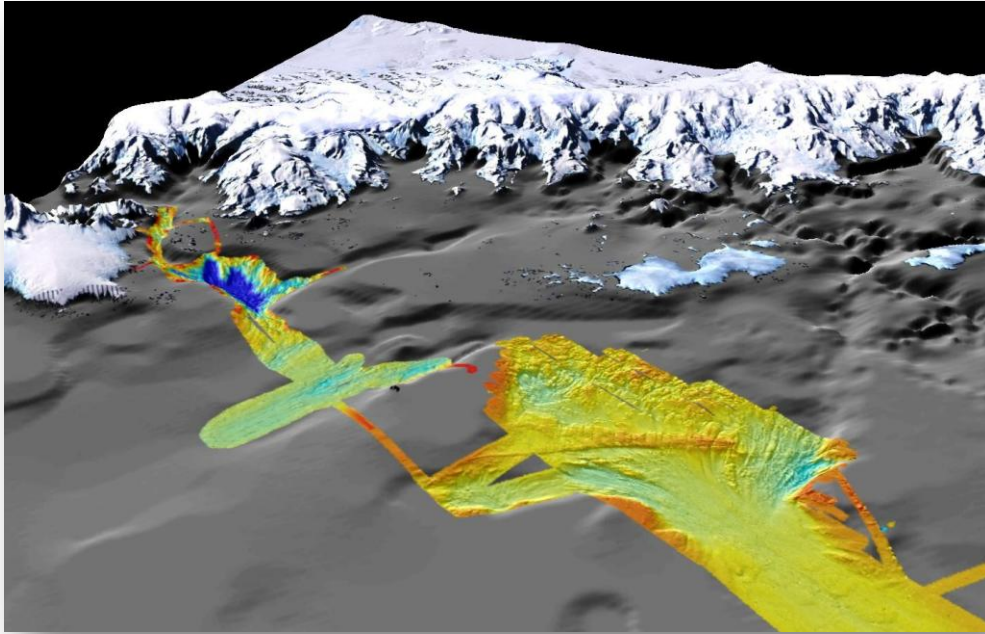
Caroline Lavoie and Eugene Domack on behalf of the contributing authors

Reviewer's comments:

Domes

The reasoning behind and evidence for the inter-stream areas being domes is not well presented. This is a critical part of the paper but it is split into several parts of the paper (e.g. 5333, line 19-20; but also a whole section (Sec 4.3) much later on 5337; and seems to be a mix of results and assumptions). We are reworking this part of the next to present better the reasoning behind the domes. Although the key elements of the logical argument may all be there and the interpretation of former ice domes in these areas may be one reasonable explanation for some of the observations the inference needs to be explained more clearly, and other explanations discussed (e.g. explain why there was not sheet flow between the streams). For example on 5337 – line 13 it says they (ice domes) ‘must’ have been centred without fully explaining why. Why were these areas not composed of other thicker (higher) parts of slow-moving ice without them being domes ?

First of all there is good, but admittedly limited, evidence for separate centers of ice accumulation on the outer shelf banks. The swath data from the perimeter of the Biscoe Trough for instance is illustrated below. Here one can clearly see flow emanating from the bank and joining off-shelf flow from a coastal fed ice stream. This flow pattern could only be explained by an elevated center of accumulation located out on the outer shelf, at the same time as the paleo ice streams were flowing toward the shelf break. The dome model is the most reasonable explanation for this. Admittedly the other domes we propose do not have nearly the same set of data by which to examine flow patterns, we use this Hugo Dome example as analogy to the others.



Why do they have to be domes instead of sloping slowly moving ice? It is possible that at their maximum, they were ridges of slow moving ice, but if

a. their existence is due to a difference in basal drag, then they would still have been elevated above the surrounding ice streams because in order to overcome their high basal drag, they need to be thicker and higher surface slopes. If there were no domes, then the surface slope and thickness would be limited by the max at the spine of the peninsula to the minimum at the ice edge - domes allow locally higher thickness and surface slopes.

b. their existence is due to a local high (shoal) in the bed topography, then they would flow more slowly due to thinner ice, this naturally would lead to a local thickening, and diversion of the ice into the surrounding streams.

So, in the end yes, a small change in the basal drag or a small change in the bed topography would not create a dome, it would create slightly differing ice speeds and maybe a subtle long sloping ice ridge, but the strong difference in geological evidence for ice flow between the streaming areas and the non streaming areas suggests to us that the difference in velocity between the two was too great to only be a subtle shift in the basal drag or topography.

It is notable that there are not major domes in other reconstructions, whether they are field-based (Davies et al 2012; O’Cofaigh et al, 2014) or models (Golledge, 2014, Antarctic Science – I accept that this is a new paper but the resultant ice sheet is similar to other models) so it is particularly important to explain why this reconstruction does now include domes.

There aren't domes in other reconstructions - we think the other papers don't have domes because they were not working with the full detailed data set we have in this paper. Although we do not wish to be overly critical of the reconstructions of Davies and O’Cofaigh we should point out that these schemes utilize only one flow arrow to illustrate the drainage direction of only a single or even only a partial trough and/or paleo ice stream. As such there is no accounting for the divergence around the banks, contribution of flow along the ice stream path or the degree of flow convergence captured by the single large troughs. It is an evolving picture and simply reflects a difference in detail. I should say also that I



was involved in the earlier drafts of the O’Cofiaigh effort and was surprised to see the change in flow arrow direction in the Larsen B system that was apparent from the penultimate version(s) to the one that was finally published in 2014.

We are not sure that Golledge actually examined any detailed multibeam images from the areas he reconstructed his ice mass across. If he had, he would or should have included some time variant model in his reconstruction. It’s almost as if he assumed an “East Antarctic Profile” from the spine of the Peninsula out across the shelf to both sides. But if you look closely at the flow lines of Golledge 2014, we can observe some ridges that almost look like domes where a small variation in basal conditions or more detailed topography would turn his ridges into actual domes. Our reconstruction is based heavily on the data and assumptions going into them, providing strong evidence of inter-stream areas being domes (We are reworking this part of the next to present better the reasoning behind the domes).

5338 – 10: Alexander Island is not an ice rise or ice dome in the same way as the domes grounded on continental shelf you are discussing.

This comment is totally correct, the Alexander Island (AI) system was a clear center of accumulation separate from the AP because of its relief and elevation, just as the case with the South Shetland Islands. We discuss it as we do the South Shetland Islands more to keep the accounting on track. What we are defining out on the shelf are indeed different kinds of dome systems. We see no conflict or contradiction in including the AI system.

Place names

There are several place names that are not on maps, or incorrect orientations given (some examples: Dyer plateau (5332, 11): I think this is mostly S of your study area so not sure why its mentioned Correct. Our mistake;; Hugo Island Trough (5332, 20) Added; Biscoe Trough (5333-5) Added; Graham Land coast (5332, 24 and 26) is a huge area stretching several degrees of latitude so usage here seems inconsistent with mention of individual bays) We constrained the area and deleted the individual bays... the text has been modified: '... from the Graham Land Coast between 65°S and 66°S and ice which..'; 5330 – 1: I think this is SE not SSW. See comments below (Tables and Figures Section).

Age of features

It would be helpful to see a discussion of the potential for, or real, over-print of the LGM flow features by younger (deglacial) flow patterns. How do you know the patterns are all GM relicts ? You are right when pointed out the importance to assume that the flow lines are LGM or younger. We added text to be more specific 'While it is possible that the preserved flow line features we examine are representative of the “death mask” state of the APIS (i.e., Wellner et al., 2006) rather than the mature LGM stage of the system, we suggest that this in general is not the case. We base our assertion upon specific observations and assumptions that include:

- only slight modification of flow trajectory as preserved along recessional grounding zones (i.e. Evans et al., 2005; Fig. 7, pg. 752), and such flow relationships are easily resolved;
- clear association of converging flow paths from areas that would have provided divergent flow during stages of retreat (i.e. as from shelf domes, see below);
- a general shelf slope that does not, except very locally, provide significant reversal in relief to have influenced evolving flow paths as ice would have thinned (drawn-down) and receded toward the coast.

Major reorganizations of flow during an ice mass recession are well documented from the southern margins of the Laurentide Ice Sheet and elsewhere. But these nearly-90 degree re-orientations are when a large ice mass is thinning across major mountains and valleys, such as the SE margin of the



Laurentide across the Adirondack Mtns. and Mohawk Valley. The general relief of the continental shelf does not provide the same character of topography that would have allowed such major flow reorientations. This is because the major source of ice was the AP whose elevation and proximity did not provide a low profile ice sheet derived from distant sources and subject to changes in emergent relief (as was the case for the large ice sheets of the past). We do recognize that some flow lines may be altered slightly and we have pointed out in the literature where this might be the case. We also recognize that overprinting can take place, but we see no major evidence for this in our data. Rather it seems the “death mask” of the system was pretty much representative of the mature or vital extent and character of the APIS. We feel that this has to be the working hypothesis until good 3-D seismic is available over vast areas—something which might be a long way off in the future.

Links to regional geology

There is a discussion of geological control for one of the ice streams discussed but less so for the whole study area. It would be interesting to discuss what controls the gross location of the major ice streams – are they along major geological faults or across geological boundaries ?

This is an excellent point and reminded the authors about some possible feedback in the system related to deep basins, streaming flow, and bed deformation across thick mud deposits. This is now added to the text and we are thankful for this constructive comment.

Technical corrections

5324 – 18-25 – this is a result of this work rather than background (unless it can be independently referenced) It's a result.

24 – believed by whom ?

In general it is quite apparent that the AP would have this aspect, given the breadth of the shelf on both sides and the narrow modern center of accumulation. All the other embayments are fed by large ice sheets today. General knowledge does not need citation.

5325 – 1 – but AP ice sheet glacier change is at least partly driven by oceanographic change. Probably. Rebesco et al. (2014) demonstrated that the surface processes drove the ablation of Larsen-B make it most closely tied to surface driven ablation and accumulation changes than driven by oceanographic change such as in WAIS; 8 – ‘enhance our knowledge’ – I believe this paper does more than that and this phrasing sounds rather ‘incremental’ We agree. The text has been modified.

16 – We highlight the geomorphic features: : .. The text has been modified.

16-20 – split sentence into two The text has been modified.

24 - ..acquired from several regions including those recently: : . The text has been modified.

5326- 18 – NGDC – in full The text has been modified.

21 – flow line reconstructions The text has been modified.

22 – interval and that The text has been modified.

5327- 25 – what values of A were used We used values of A based on the table presented in Cuffey and Paterson (Physics of Glacier, 2010) that is based on a summary of the existing research. The specific values we used were Warm ice: $6.8e-15 \text{ s}^{-1} \text{ kPa}^{-3}$ and Cold Ice $4.9e-16 \text{ s}^{-1} \text{ kPa}^{-3}$. The text has been modified.



5328 – 3 – *min and max what (b-dot ?)* Min and Max bdot for each dome are shown as the end points of the major axes of the red ellipses in Fig. 8. The text has been modified to avoid confusion. In 5328-3 "We based the minimum and maximum dome volumes (table 2) on a low-end and high-end approximation of the accumulation rates,"

6 – *accumulation rate* The text has been modified.

7 – *resulting in* The text has been modified.

11 – *IBCSO – in full* The text has been modified.

20 – *what is 'it' ? Slope ?* Yes "it" refers to the "surface slope" The text has been modified.

22 – *would lead to a slightly* The text has been modified.

5329 – 18 – *Hektoria – ambiguous which way it goes on basis of Fig 2* From the shelf bathymetry (showing a connection between Hektoria and Cold Seep basins) probably S-SE.

20 – *from the southern edge of SCAR Inlet* The text has been modified.

25 – *Our flowline bedform* The text has been modified.

26 – *in the southern part of the Larsen-B embayment* The text has been modified.

5330 – 2 – *they're in a similar orientation but not parallel* The text has been modified.

11 – *evidence of what ?* The evidence is for the establishment of two major outlets:.....

5331 – 2 – *may have been developed* The text has been modified.

9 – *un-named channel is called Active Sound – see <http://apc.antarctica.ac.uk/>* Thanks, the text has been modified.

21 – *Fig 6 implies this is ice shelf but text suggests grounded ice* The Figure has been modified to avoid confusion.

22 – *should be Fig 6* The text has been modified.

23 – *what fans ?* We mean trough-mouth fans (grounding zone fans) (defined by Simms et al. 2011). The text has been modified.... surface of the grounding zone fans (i.e. mouths of both Maxwell and Admiralty fjords)....

24 – *How is a trough named after a snowfield?* The text has been modified.

5332 – 7 – *use NNW to be consistent* The text has been modified.

14 – *odd phrasing – 'are added'* The text has been modified.

20 – *there are more than three – do you mean it has 3 tributaries?* No. it is one of the three major tributary systems

25 – *NE not NW* The text has been modified.

26 – *Along the Graham Land Coast* The text has been modified.

5333-1 – *directed flow to* The text has been modified.

4 – *around the N end of Anvers* The text has been modified.

8 – *SW and NE direction – where ?* In the main branch of the Biscoe Trough. The text has been modified.

13 – *ice divide between what and what ?* a distinct flow divide between the Biscoe Trough and Palmer Deep and Hugo Island Trough systems, and south along the trend defined by Hugo Island. The text has been modified.

5334 – 18 – *followed what ?* We deleted those 2 words that were part of an older sentence.

5335 – 2 – *these topographic highs could have divided the glacial flow* The text has been modified.



16 – *The two mechanisms could have* The text has been modified.

19 – *has been observed* The text has been modified.

24 – *I think the topo obstacle might be an island/nunatak rather than ice ?* The topo obstacle in Knight (1994) paper is about ice overtopping the obstacle, not a nunatak. The author is discussing what is happening at the bottom of the Greenland Ice Sheet.

5336 – *reword this section. Need to explain the reasoning by which you define ice divides. We define ice divides based on: : :: : :x and y* We agree, we reworded the first sentences of this section.

5339 – 1-20 – *this looks like methods* We agree, part of this section has been moved to the methodology.

5340 – 17 – *Need to clarify here that the ice volume that matters in this context is that above buoyancy so actually thin ice couldn't harbour very much, whether there was large areal extent or not.* The text has been modified

26 – *different number to table* The text has been modified

5342 – 15-18 – *cite Livingstone et al 2012 (Earth Sci. Rev.) here as this paper considers many of these factors and how they differentially affect individual ice streams.* Cited. The text has been modified

20 – *be more specific about what purpose GIA modelling might serve* Ok

Title – would be helpful to insert 'LGM' or 'at LGM' in title to make study focus clearer The title has been modified..... to include not only the paleo-ice flow directions and also LGM. "Configuration of the Northern Antarctic Peninsula Ice Sheet at LGM based upon a new synthesis of seabed imagery"

Grammar – *The paper needs a close read – there are many instances of plurals/singular not matching and tense changes repeatedly including within sentences (e.g. 5329, 13-15). I have included examples for the first few pages but have not corrected after 5330.* The reviewed version of the paper will be closely read for the Grammar.

Tables and Figures

Table 3: Not clear how 'systems' are defined – do they include the central parts of the AP (and therefore is underlying topography subtracted ?) They do not include the central parts of the AP, only the path along the continental shelf. Text has been modified to avoid confusion.

Fig 1 – see comments on place names. We reviewed the text carefully to add the place names missing (Biscoe Trough, Trinity Peninsula, Maxwell and Admiralty fjords, Lafond, Laclavere and Mott Snowfield troughs, Hugo Island Trough) and put the labelling larger not only in Fig. 1, but also Figs. 2, 6 and 7.

Fig 3- 25m here, 30m in text: It's correct. The images in Fig 3. were plotted in a resolution of 25 m x 25 m and the maps (Figs. 1 and 2) at 30 m x 30 m. To avoid confusion we have included the following text in the Sect. 2.1 The data set was gridded at a cell size of 30 m x 30 m and analyzed with illumination at variable azimuths. The seabed morphology close-up were gridded at a cell size of 25 m x 25 m.



Fig 4- SSW direction doesn't make sense based on these images and orientation arrows. This is a typo in the text corrected to ESE. Also, not sure if the bedrock flutes might in fact be meltwater features These are not meltwater features, they are bedrock whalbacks or linear bedrock ridges.

Fig 7 – images and their annotation are far too small to be readable. We agree and put the labelling and the map larger.

Fig 8 - : : domes with ice temperature averaging: : : The text has been modified