

The Cryosphere Discuss., author comment AC2
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Reply on RC2

Astrid Oetting et al.

Author comment on "Geomorphology and shallow sub-sea-floor structures underneath the Ekström Ice Shelf, Antarctica" by Astrid Oetting et al., The Cryosphere Discuss.,
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Abstract:

—MSGL end 11 km from shelf break indicating LGM position. That is minimum position but not necessarily max. Make this clear.

Sentence will be changed to: "Our surveys show that Mega-Scale Glacial Lineations cover most of the mouth of this trough, terminating 11 km away from the continental shelf break, indicating the most recent minimal extent of grounded ice in this region." Sentence in line 359 will be changed as well.

--What does beneath ~30 km of ice shelf mean? Is this the outer portion? Just make explicit.

This refers to the area below the ice shelf, from the ice shelf front/edge to ~30 km inland. The sentence will be changed to: "Beneath the front ~30 km of the ice shelf measured from the ice shelf edge towards inland direction, the sea floor is characterised by an acoustically transparent sedimentary unit,..."

--Till isn't usually 45 m thick. Is this really a single unit or multiple tills? If it is really 45 m, is that unique? Seems like a lot. (See below.)

It seems to be one unit in the seismic data. However, the resolution is not high enough to identify individual layers.

--Why does lack of over-printing indicate rapid retreat? It could be slow retreat. It simply indicates gradual, continuous retreat, with a lack of pauses along way. It doesn't have to be rapid.

Based on investigations by Shipp et al. (1999), Dowdeswell et al. (2004), Mosola & Anderson (2006) Cofaigh et al. (2008), good preserved MSGs (e.g. at Marguerite Trough) and the absence of grounding-zone features a result of rapid ice sheet retreat. Citation will be added to line 364.

Shipp, S., Anderson, J., & Domack, E. (1999). Late Pleistocene–Holocene retreat of the West Antarctic Ice-Sheet system in the Ross Sea: part 1—geophysical results. *Geological Society of America Bulletin*, 111(10), 1486–1516.

Dowdeswell, J. A., Ó Cofaigh, C., and Pudsey, C. J.: Thickness and extent of the subglacial till layer beneath an Antarctic paleo-ice stream, *Geology*, 32, 13–16, <https://doi.org/10.1130/G19864.1>, 2004.

Mosola, A. B., & Anderson, J. B. (2006). Expansion and rapid retreat of the West Antarctic Ice Sheet in eastern Ross Sea: possible consequence of over-extended ice streams?. *Quaternary Science Reviews*, 25(17–18), 2177–2196.

Cofaigh, C. Ó., & Stokes, C. R. (2008). Reconstructing ice sheet dynamics from subglacial sediments and landforms: introduction and overview. *Earth Surface Processes and Landforms: The Journal of the British Geomorphological Research Group*, 33(4), 495-502.

Line 23-24: The sentence "Recent studies have shown that ice shelves in this region are underlain by deep glacial troughs (Nøst, 2004; Eisermann et al., 2020; Smith et al., 2020), indicating ice advanced towards outer continental shelf areas in the past." doesn't make sense. If the ice shelf has a trough under it, all it means is that grounded ice advanced as far as the modern-day ice shelf edge in the past. If showing that ice advanced towards the outer continental shelf in the past, need to say that the trough in fact extends that far, beyond the edge of the ice shelf.

The MSGs prove, that grounded ice occurred maximal 11 km from the current calving front as well as 11 km from the continental shelf. The overdeepened trough beneath Ekström is assumed to be a result of former ice stream erosion (e.g. Smith et al. 2020). Therefore, the grounded ice extended shortly before the bathymetric sill (see line 214). Floating ice, however, has probably reached across the continental shelf (Grobe and Mackensen, 1992, Smith et al. 2020).

Sentence will be changed to: "Recent studies have shown that ice shelves in this region are underlain by deep glacial troughs (Nøst, 2004; Eisermann et al., 2020; Smith et al., 2020), indicating that grounded ice advanced to the continental shelf in the past."

Line 34 (and related to the above): how narrow is the continental shelf? "Narrow" doesn't tell much.

The continental shelf is located 25 km from the current ice shelf front. As e.g. in Nøst, 2004, who as well describes the area at in the eastern Weddell Sea as narrow, we think an exact number does not really help to understand the geological setting. If interested, it can be measured in Fig. 1 and 7.

Nøst, O. A.: Measurements of ice thickness and seabed topography under the Fimbul Ice Shelf, Dronning Maud Land, Antarctica, *Journal of Geophysical Research: Oceans*, 109, <https://doi.org/https://doi.org/10.1029/2004JC002277>, 2004.

Line 48: "front" of the ice shelf is not especially clear. State seaward or from edge.

Sentence will be changed to: "Our study area covers the continental shelf and the sea floor under the first 50 km (measured from the calving front) of the EIS cavity (Fig. 1)."

Line 52: Not clear exactly what is being measured, from where to where. Annotate the figure and show these measurements so that it is explicit.

This makes the figure look rather chaotic than helpful. Therefore, we consider the description "...most landward location of the current grounding line (8°6'W at the southernmost point) to the continental shelf. The distance to the grounding line is measured along the trough axis." to be sufficiently clear.

Lines 57-58: Did the Grobe and Mackensen paper really claim that the ice extended beyond the continental shelf break? That would be quite extraordinary. I thought they looked at slope records and IRD, but not evidence of actual ice extending that far.

In the Grobe and Mackensen paper on page 373 'Glacial Maxima' as well as in Fig. 12 they state that grounded ice extended across the continental shelf break of East Antarctica. However, the sediment cores taken in the EIS region were too short to grab any datable material from the LGM.

Lines 60-70: In addition to the model estimates of LGM timing here, are there any estimates from dated cores?

The only chronological constraint is mentioned in Grobe and Mackensen, 1992, who set the age of their cores to the Holocene. Further dated sediment cores have, to my knowledge, not yet been published.

->4.1.2 and Figure 3: Certainly sounds like MSGs that are being described. However, there is nothing convincing in the figure. Zoom in, show more, consider color, mark with arrows, etc. As it is, the figure is not convincing.

An overview of the found MSGs are marked in blue in Fig. 3a. A zoomed-in section of the multibeam echosounder is displayed in Fig. 3c, and an example for the MSGs in the echogram is shown in Fig. 3e. Since 3c and e show exclusively the MSGs additional arrows were omitted.

->For comparison of how these sizes compare to other MSGs, consider: Wellner, J. S., Heroy, D. C., & Anderson, J. B. (2006). The death mask of the Antarctic ice sheet: comparison of glacial geomorphic features across the continental shelf. *Geomorphology*, 75(1-2), 157-171. Or: Newton, M., Evans, D. J., Roberts, D. H., & Stokes, C. R. (2018). Bedrock megagrooves in glaciated terrain: A review. *Earth-Science Reviews*, 185, 57-79.

There are many MSGs described in the literature, which allow a comparison with the found MSGs at EIS. However, since our landforms can be identified unambiguously as MSGs and are of typical dimensions, we do not aim to list detailed values for MSGs of other study areas.

->For comparison of till and drape thicknesses, consider: Shipp, S., Anderson, J., & Domack, E. (1999). Late Pleistocene–Holocene retreat of the West Antarctic Ice-Sheet system in the Ross Sea: part 1—geophysical results. *Geological Society of America Bulletin*, 111(10), 1486-1516.

Sentences will be change to: "For example, studies on the Marguerite Trough show sediment thicknesses reaching 15 m (Ó Cofaigh et al., 2002) and 20 m (Dowdeswell et al., 2004), both similar to the minimal thicknesses seen in our study. In the Ross Sea, Shipp et al. (1999) describe a 2 m – 9 m thick transparent drape-unit and Karl et al. (1987) interpreted an up to 40 m thick overlying layer to be basal till.

Karl, H. A., E. Reimnitz, and B. D. Edwards. "Extent and nature of Ross Sea unconformity in the western Ross Sea, Antarctica." (1987).

->4.1.3: Many small moraines were noted in Antarctica much before the references cited.

Yes, a variety of different kinds of moraines are described in the literature. Here, publications were selected, due to the use of similar marine geophysical methods and study areas, in order to allow a more direct comparison with our identified landforms.

->For comparison of small-scale retreat features like moraines, consider: Shipp, S. S., Wellner, J. S., & Anderson, J. B. (2002). Retreat signature of a polar ice stream: subglacial geomorphic features and sediments from the Ross Sea, Antarctica. *Geological Society, London, Special Publications*, 203(1), 277-304.

Many different moraine types are discussed in Shipp et al. (2002). However, there is no unambiguous indication of retreat moraines in their zone 3 and 4. They identified retreat moraines in their Zone 5, but their dimensions are not given, which does not allow a sufficient comparison with our landforms.

Lines 201-202: Calling on a core that is not included in the data of the paper, nor apparently published elsewhere, is not a fair line of evidence.

We refer to the sediment core PS1385 (Figure 1 and Table 1), published in Grobe, H. and Mackensen, A.: Late Quaternary climatic cycles as recorded in sediments from the Antarctic continental margin, in: *Antarctic Research Series*, vol. 56, pp. 349–376, <https://doi.org/10.1029/AR056p0349>, 1992. They limit the age of the sediment core to

the Holocene. The location of the core, where many iceberg plow marks are evident in the multibeam data, suggests that there is no longer undisturbed sediment deposition.

Lines 203-205: If evidence from slope cores indicates that ice reached shelf edge, but your MSGL data stops 11 km in and therefore you suggested ice maybe didn't reach the edge, how do those agree? Or, conflict?

The MSGL are replaced by the iceberg ploughmarks at about ~10 km from the current ice shelf edge. The iceberg ploughmarks were formed after the ice shelf retreated. They have overprinted the seafloor and destroyed potential MSGLS that no conclusions can be made about whether the MSGLS (and thus grounded ice) were present further toward the continental shelf.

Lines 236-240: It's a big stretch to say that your measurements of 45 m of till are "similar" in thickness to other places where it has been 15 m or 20m. That is more than 2x thicker, at least. Seems like a big difference! How does such a thickness of till work with the mode of formation of MSGLS? (See for example: Clark, C. D., Tulaczyk, S. M., Stokes, C. R., & Canals, M. (2003). A groove-ploughing theory for the production of megascale glacial lineations, and implications for ice-stream mechanics. *Journal of Glaciology*, 49(165), 240-256.) And, what does the statement about removal of loose sediments from under the ice by water have to do with the general idea of these being MSGLS?

Sentences will be changed to: "...show sediment thicknesses reaching 15 m (Ó Cofaigh et al., 2002) and 20 m (Dowdeswell et al., 2004), both similar to the minimal thicknesses seen in our study. In the Ross Sea, Shipp et al. (1999) describe a 2 m – 9 m thick transparent drape-unit and Karl et al. (1987) interpreted an up to 40 m thick overlying layer to be basal till."

Karl, H. A., E. Reimnitz, and B. D. Edwards. "Extent and nature of Ross Sea unconformity in the western Ross Sea, Antarctica." (1987).

MSGLS usually form under grounded ice in subglacial till. About the till thickness, on which the MSGLS are formed in the tough centre, we do not make any statement, since the marine geophysical data do not provide the needed in-depth data. In areas where the subglacial till deposits (with up to 45 m thickness) were detected with reflection seismics, MSGLS could not be resolved with our data.

The removal of loose sediments by water flow beneath the ice shelf does not question that these are MSGLS, but it might explain why rarely drape can be found on top of them.

FIGURES

Figure 1: Labels not clear in part a when text over ice boundaries. Define ice edge line in legend; differentiate grounding line from floating margin. Consider making this a three part figure as part a is currently not quite covering a large enough area to show people unfamiliar with Antarctica where the location is, but nor is zoomed in enough to show the region. Make an a and a b that are less/more zoomed in.

Labels and ice edge will be added. The white infill represents grounded ice, which will be clarified. A three-part figure will be made.

Figure 2: Very helpful schematic. Consider making more of the ice shelf under sea level and less of it above sea level. Also, consider moving the label of Ekstrom Ice Shelf out to the left a little, so that it is clearly on the ice shelf.

Figure will be changed, so that more of the ice shelf is below sea level and the label will be moved to the left.

Figure 7: Make it bigger! So much in there and way too hard to see!

Figure will be changed to full page width.

