Cartelle et al., Sedimentary architecture and landforms of the Late Saalian (MIS 6) ice sheet margin, offshore the Netherlands

General comments

The paper is well written and presents timely, interesting and new insights into the lateral extent and ice marginal dynamics of the MIS 6 palaeo-ice sheet in the southern North Sea using both geophysical and sedimentological data. The paper is thorough in its assessments of available sedimentary and geotechnical data from engineering boreholes and shallow, high resolution 2D seismic and I would recommend it for publication with some relatively minor revisions listed below.

Framing of the research question or gap in knowledge that this paper will address has to be tightened in the Introduction section. At the moment when reading through the intro it sounds like the paper will tackle MIS6 ice sheet forcing mechanisms, ice sheet dynamics, spatial and temporal advance and retreat of the ice sheet and palaeo-sea-level. Of course it is fine to mention wider implications of the research but actually this paper focuses on the southerly extent of the ice sheet and ice marginal dynamics within one marine sector of the MIS6 ice sheet. This is by no means a weakness of the paper, as is eloquently described in the final section of the paper (5.4), focusing in on specific ice sheet sectors where detailed, high resolution data is available can lead to i) far greater certainty in ice sheet extent, ii) revision of previous reconstructions based on older low res data sets, iii) better interpretation/reinterpretation of ice marginal dynamics and iv) highlight the complexity of near-surface geology in the North Sea. I would try and frame the intro more towards these very important focused questions which are dealt with throughout the rest of the paper rather than far more general possible ice sheet dynamics/sea level implications.

Specific comments

L59: Avoid using the term “late Quaternary” throughout the manuscript. Use either Late Pleistocene or Late Pleistocene and Holocene since these are officially recognised epochs and subepochs.

L61: What time period is covered by the “late Saalian”? State this at first use. In addition state what time period or age ranges are covered by “pre-late-Saalian” and “post-Saalian”.

L64-65: This relates to the comment above. Firstly how does this study investigate ice sheet morphology? This study is focused on the margin of one sector of the very large MIS6 ice sheet so I don’t think you can make this claim. What do you mean by the “style” of an ice sheet as oppose to the “dynamics” of an ice sheet? I think this sentence needs a slight refocus. I don’t think this paper gives so much information of broad scale advance and retreat of the ice sheet since the dataset used is from a very localised ice marginal area. Again, I don’t necessarily think this is a weakness, looking at modern polar ice sheets, it is the highly complex 3-5 km marginal zone of these ice sheets that models struggle with and that are so crucial to understand ice sheet dynamics. However, I think large scale MIS6 ice sheet dynamics are beyond the remit of this paper. Thus, I would focus on the fact that you have a very detailed dataset from the ice sheet margin to allow corresponding detailed interpretation of ice margin dynamics which in turn is useful to e.g. palaeo-ice sheet modellers etc.

L93: by “glaciotectonic deformations” do you mean glaciotectonic structures?

L215: I think it is significant that mapped tunnel valleys are V-shaped, in the North Sea they can be both V- and U-shaped relating to various hydrological and/or geological factors, there are several papers on tunnel valley morphology from the North Sea (e.g. Kristensen et al. 2007; Lohrberg et al. 2020) so possibly one additional sentence could be added regarding the significance of the V-shape?

L217: why would tunnel valleys “typically form during phases of ice advance”? Surely there would be larger volumes of meltwater during deglaciation?

L218-219: What kind of “glaciotectonic deformation”? Is this a thrusted sequence? If so considering the gridded seismic data it should be possible to provide some structural measurements or the orientation of the thrusts to provide useful information on ice flow direction as has been done in the paper that is referenced by Phillips et al.

L220: Maybe worth quickly mentioning something about the peat layers from the borehole log in Fig 4 found in U1.

L260: Something that needs to be clearly explained here and throughout the manuscript is the orientation of the thrusts within the glaciotectonic ridge and the relation of these thrusts to the orientation of the ridge. From Figure 5 it seems that the thrusts within the ridge suggest ice flow from the NE while the orientation of the ridge suggests ice flow from the N.

L283: I think you have an interesting result here: a transparent or semi-transparent acoustic facies (sf1) that corresponds to a laminated and interbedded sedimentary facies. Similar transparent or sometimes termed “chaotic” acoustic facies are commonly found in the North Sea (and many other formally glaciated continental margins) and often they are simply linked to “till” or diamictons. This result highlights how important it is to be able to ground truth seismic interpretations. This very point, that transparent or chaotic acoustic facies cannot be assumed to represent till was made in a paper by Stewart and Stoker (1990, *Problems Associated with Seismic Facies Analysis of Diamicton-Dominated, Shelf Glacigenic Sequences*) where they demonstrated that several stratified glaciomarine sequences can give a similar transparent/chaotic acoustic response. Here it seems you have evidence of this and even more diverse sets of laminated/interbedded sediments that can appear acoustically transparent. It may be worth an extra sentence highlighting this here or in the interpretation.

L301: what is “slightly erosive”?

L356: Here it is stated that chronostratigraphic connection was made between the study site and onshore chronological frameworks but earlier in the manuscript it is stated that “The low resolution sub-sampling for palynological assessment in the RVO-commissioned surveys prevented a detailed correlation with established chrono-biostratigraphic frameworks.” This seems somewhat contradictory.

L340-349: I wonder if there is any explanation for the lack of till in U1? Obviously S1 is a product of glacial erosion but it is interesting that only a thin till layer is present in borehole HKN10. Was this the case for other boreholes in HKN? Acoustic facies sf4 corresponds to till but that seems to be laterally discontinuous? Another point, sf4 appears to be relatively uniform in thickness at least from the seismic profiles? All of this would have interesting wider implications for subglacial processes/ice flow (i.e. the “bed mosaic” model of ice flow and depth of deformation).

L448: ridge morphology suggests ice flow from N, and thrusts from the NE, see comment above.

L478-479: but detailed structural analysis of the thrust blocks within the ice push ridge may indicate variation in flow direction?

L507-512 and figure caption 9: There seems to be quite a bit of speculation here regarding ice sheet margin stagnation. Just because there is evidence of dead ice does not necessarily mean stagnation of the ice sheet margin. Surely a rapidly retreating ice margin could also leave behind areas of dead ice. Secondly, while the NCIS switched on and off numerous times during multiple ice advances throughout the Mid and Late Pleistocene, it is not known when streaming switched on or off during individual ice advances and what influence the NCIS had on other parts of the ice sheet in terms of ice dynamics. The referenced Sejrup et al. (2003) paper relates to specific dynamics of the NCIS. For interpretations of ice margin retreat style in this SW sector of the ice sheet, either better geomorphological data or chronological data is needed.

L527: Section 5.4 is strong, I think the questions relating to these finding should be more clearly integrated with the aims in the Introduction (see general comments above).

L563: again I assume "ice margin stagnation" is linked to dead ice but could surely equally relate to rapid retreat?

L567-568: why would "flat subglacial topography" equate to stagnation of an ice sheet margin? There are numerous examples of rapid ice retreat across "flat" continental shelf areas. Several areas of the North Sea, Irish Sea, Norwegian Sea, Barents Sea etc. were deglaciated relatively rapidly after the LGM with a highly dynamic ice margin over the continental shelf. In fact I am not aware of any direct geological or chronological evidence that suggests ice margin stagnation during retreat along the NW European continental shelf other than to stabilise long enough to form grounding zone wedges or ice marginal moraines.

Comments relating to Figures

Fig 1. The key/legend should have a space between "Hijma et al. (2012)" and "Batchelor …" The colour schemes in several of the figures don't seem to correspond very well. In fig 1 till is outlined in green, in fig 2 till is a stippled yellow/brown and diamicton interpreted as till in the core log HKN10 is dark grey. Why not stick to dark grey for diamicton/till deposits for all figures.

Fig. 3 Again, ice-pushed ridges appear purple in my version whereas the same feature in other figures is pink.

Fig 4. Both clay and U3 appear to be the same green colour, they should be different colours.

Fig 5. Is there any diamicton in core log HKN56? If not it should be removed from the key. In the figure caption should it read "In seismic section C-C', the side of the ridge…."?

Fig 6. Again, diamicton appears to be obsolete in the key so remove.

Fig 8A. Again, colours are slightly confusing, the same glaciotectonic ridge is light grey in Fig 5 but here it is dark grey. Choose one and be consistent. Also, since you provide a colour key for all other units also include a legend for U1, even if it just says multiple sedimentary facies (I realise it is more challenging to group these sediments).

Fig 8B and 9B. At first glance the reader may wonder where the ice-push ridges across HKZ shown in Fig 1 are. Obviously you have reinterpreted these features as glaciofluvial so I think you should include

them here in Fig 8B and 9B in a different colour and label them as such to highlight that this too is a key finding of your study, i.e. reinterpretation of legacy data.

Technical corrections

L59: Delete space after “investigations”.

L89: remove space after “Offshore”.

L122: “and” should be “at”? and “conducted” should be “drilled”.

L371: replace “or” with “of”.

L475: should be “..observed to the northeast..”

L556: remove “is”