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Interactive comment on "Subglacial sediment transport upstream of a basal channel in the ice shelf of Support Force Glacier (West Antarctica), identified by reflection seismics" *by* Coen Hofstede et al.

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This is a well reported high-resolution seismic reflection survey targeting the form and physical properties of an ice shelf channel and the sub-seafloor sediments beneath it at Support Force Glacier (SFG), East Antarctica. The seismic analysis is supported by some airborne ice-penetrating radar data. The methods are sound and detailed, the description and presentation of the data is reasonably good, and the science is high-quality and of potential interest to the readership of TC. The data are hard won field geophysical data from a remote part of the Filchner Ice Shelf, Antarctica and

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certainly deserve to be published in some form. I do, however, have some serious concerns about the way the data are 'pitched' and argued in the current version of the manuscript. Specifically, I am very unconvinced by the association between the ice shelf channel, the "subglacial landform", and the sub-seafloor sedimentary structures, and the argument for sediment transport subsequently developed.

General comments 1. The manuscript does not engage at all with glacial-geological literature relevant to glaciomarine processes and sediment deposition in a grounding zone and ice shelf environments. Such process literature is key to understanding the sedimentary structures imaged in the seismic data. Without reference to such literature you cannot make the link between the present-day ice shelf channel and the sediments beneath the sea floor. Though there are clearly more modern literature available, a good place to start would be David Drewry's textbook on Glacial Geological Processes (1986). What are the processes that the seismic observations of the cavity and the subsea sediments give insight into? What might be the glaciological processes that determine sedimentation in ice shelf cavities and at grounding lines?

2. I am not, at present, convinced that the observations of the stratified sediment beneath the ice shelf channel have any bearing on the ice shelf channel and modern-day "sediment transport" itself. The manuscript makes no convincing case that the sediments were deposited by present-day processes. These sediments could be much older than the ice shelf channel and may have absolutely no relationship with modern-day processes at the grounding line or beneath the ice shelf. The authors need to either (1) provide a much stronger justification for the direct link between the sediment and the modern-day glaciology (e.g. by using the literature on glaciomarine sedimentary processes I refer to above and/or better describing and presenting the data they report). It is not enough to simply say on page 21 that "we conclude the landform is hosting the transport of sediments that are deposited in the ocean cavity close to the GL" – what is the evidence?; or (2) reframe the paper so that it is a detailed characterisation of the form and physical properties of (a) the ice shelf channel; (b) the sub-shelf bathymetry;

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and (c) the sub-bottom sediments of SFG, but doesn't link them directly. For what it is worth I think a manuscript describing '2' would be useful and worthwhile. We know so little about Support Force Glacier at present.

3. The assertion in the abstract and section 4.5 that the "landform is hosting the transport of sediments that are deposited in the ocean cavity close to the GL" (page 21) is very poorly supported by any evidence apart from the spatial coincidence between the landform (described in other parts of the manuscript, e.g. section 4.3, as a "subglacial drainage feature") and the ice shelf channel. What is the process that is being inferred here? In the conclusions it is suggested that the sediment transport is by subglacial meltwater, but that is not developed from a detailed, carefully constructed and coherent argument in the manuscript.

Please don't get me wrong, I think the manuscript is full of great data and interesting observations, but at present it seems to lack a clear focus, and many of the assertations are not fully thought through or developed from a process-oriented perspective. It's all very well to justify the landform identified in the ice-penetrating radar as being comprised of sediment from the seismic reflection coefficient analysis (though it is clear that the seismic data are not perfectly acquired to do this), but the manuscript makes some very large leaps from 'this is a subglacial sedimentary landform (with possibly a bedrock core)' to the stratified sediment offshore is the direct result of focused melting from the ice shelf channel. What is the process by which this happens? It needs to be justified.

An idealised conceptual model of the ice shelf cavity/grounding line/ice shelf channel processes and environments might be useful. See examples in Le Brocq 2013; Drews et al. 2017; and Jeofry et al. 2018 (Suppl Info). A conceptual model like these would really help pull together how the SFG system works and make the manuscript far more accessible to prospective readers. I suspect that developing one might also help the authors think through the processes and allow them to piece together a much more coherent argument and explanation for their observations.

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Please note that there are a few typos and minor grammatical errors throughout the manuscript that will need correcting before publication. I have highlighted some below, but I have not been comprehensive in this.

Specific comments

Page 1

Title: Support Force Glacier is East Antarctica, not West.

Title: Where is the evidence for “sediment transport” in the paper?

Addresses: ‘Natural Environment Research Council’ (i.e. not National Environmental).

Abstract (L1): “surface channels” not “flow stripes”. Flow stripes are something different, and are not associated with basal ice shelf channels.

L5: “beneath” rather than “on”?

L6: “part” of what?

L8: “initiates” rather than “forms”?

L10: What is the justification for the 200 m thick sequence of sediments being “grounding line deposits” – what is the evidence and argument for this? At present the manuscript doesn’t provide this.

L10: “the landform hosts the subglacial transport of sediments” – why not just “the landform is composed of sediments”. That seems to be as far as you can take the interpretation of the seismic data as far as I can make out from the manuscript. There is no evidence for subglacial transport of sediments from the data presented.

L15: “shear margins” are introduced here, but figures 1a&1b suggest that the subglacial hydrological pathway does not correspond to the shear margin.

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L4: surface expressions of basal ice shelf channels are not the same as flow stripes, and sometimes they 'jump' across flow stripes. They are surface features associated with linear depressions in the ice shelf surface.

L25-27: some misrepresentation of Jeofry et al. 2018 here – the hard rock landforms at Foundation Ice Stream (FIS) actually determine subglacial hydrological pathways & it is the basal water that forms the ice shelf channels, not the bedrock bumps per se. The marine landforms presented in Jeofry et al. 2018 did not "confirm" anything. That particular figure was simply included to demonstrate how common such hard bed landforms were offshore and presenting them as a plausible analogues for the ridges beneath the FIS grounded ice.

L29: I do not understand "become spots at the ice shelf base when adjusting the hydrostatic equilibrium"

L32-33: I do not think that this manuscript provides information on the "type of material and structure of the bed upstream of a basal channel". Yes the apparently offline seismic reflection in figures 2&8 is analysed to suggest that it is composed of unconsolidated sediments, but it certainly doesn't reveal the structure of the subglacial bed.

Page 3

L4: it is interesting to note that the modelled subglacial outflow in figure 1b does not map exactly against the ice shelf channel (i.e. they are offset by $\sim$5 km despite a new high-resolution bed topography of the SFG trunk).

L8: "into the precise"

L9: "typically penetrate"? There are some examples.

L11: I do not understand "..or does the substrate also consist of sediments in which case we can expect recent sedimentation on the seabed?" – even if the bed is hard bedrock you can still have sedimentation on the seabed by (a) subglacial erosion of bedrock; and (b) transport of sediment from upper parts of a glaciers catchment un-

derlain by sediment.

L16: “supported” rather than “backed up”?

L17: “continue” rather than “proceed”

L18: “active/current” subglacial drainage?

L23-24: Support Force actually lies between Academy Glacier and Recovery Glacier. It may also be worth making clear that “northwest” is “grid northwest”.

L24: “constrained” rather than “tugged in”?

L30: reference Bedmachine as well/instead of Bedmap2?

L33: I would not describe the survey as a “grid”. Refer to figure 1 at the end of line 33.

Page 4

L2: “Ice surface velocities”?

L11: I do not believe that the DLR acronym has been defined earlier in the manuscript.

L14: Jeofry et al. ESSD, 2018 might be a better reference than Rippin et al.? see https://essd.copernicus.org/articles/10/711/2018/

L14: think you mean 312.5 Hz here? See section 2 of https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2018GL077504

L16: “laser surface terrain”?

L27: Paden et al. reference is 2010 in reference list? Please also be specific about which years of OIB data were used (e.g. up to Dec 2018 Antarctic surveys)?

L30: how extensive was the model domain for the hydrological routing presented in 1b? Was it just the domain shown in 1b, or was it more extensive (e.g. entire SFG catchment)?

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Page 5

Figure 1: Please annotate start and end of seismic lines in figure 1 and corresponding seismic profile figure.

L1: as stated previously, the modelled subglacial meltwater outflux location does not correspond that well with the surface channel, despite the new high resolution ice thickness/bed data.

Page 6

Table 1: Why is it important to have the column “position from GL”? From which part of the profile is this measured? Suggest deleting it.

Pages 7-9

Given the expertise of reviewer 1 I have not assessed the description of the seismic methods in detail.

Page 10

L16: After “ice shelf thickness.” it might be a good idea to refer to figure 1 to provide an example of the artefacts.

L18: “structure of the seafloor” or “morphology of the seafloor”?

L20: Figure 2 should be split into 2a and 2b, rather than TOP and BOTTOM. Therefore, sentence should begin “Figure 2a shows. . ..”

L20 (and throughout manuscript): Delete references to along-profile and across-profile, just label the profiles I-V (e.g. “profile I” rather than “along-profile I”).

L21: Start “Figure 2b. . .”

L24 (and throughout manuscript): “reflectivity zones” rather than “intervals”. These zone should also be clearly marked on figure 2.

L28: call figure 1 after “interferometry”

L30: “uncoupled” – uncoupled from what? Do you mean “floating”?

Page 11

Figure 2: label ‘a’ and ‘b’. Need to annotate the start and end of the seismic line (see comments on figure 1). Note that where “bed” is annotated in 2a it is not actually the ‘bed’. It is the subsea sediments. What is the weak reflection between ∼SP46 and ∼SP160 (between the labels “ICE” and “BED”)? Please define the different reflectivity zones in figure 2 (see comments above). Provide zoomed-in views of all the detailed features described in section 3.2.

L1: “. . ..elongated feature above the flat bed. . ..”?

L3-4: I suggest that this reflection not be described as a “subglacial drainage feature” at this point in the manuscript. Later in the paper, the reflection is interpreted as a “landform” anyway, so it is very confusing. Simply describe it a reflection at this stage, and then only once section 4.3. has been worked through should it be described as a “landform”. It would be useful to have the zoom in of the reflection in figure 2 rather than figure 8.

L6 (and throughout manuscript): “anticlines” – this is a specific geological term not normally used in the description of morphology. I recommend “concave cavity” instead.

L8: “ocean cavity thickens” (rather than deepens)?

L10: what is the observation that constrains the sediment thickness to 200 m? I don’t see a clear sediment-bedrock reflection at 200 m in Figure 2, so do the authors instead mean “of at least 200 m”?

L10 (and throughout manuscript): what is meant by “transparent”? How can a material be transparent yet stratified and disturbed? Page 12

L15: Call figure 1 after “at the same distance”?

L20: call figure 3 after “have been marked”?

L21: After “the seabed” add “so is not presented here”?

L22: “sequence of stratified sediment” rather than “stratification sequence”? If the authors are trying to avoid interpretation here, then it shouldn’t even be “stratification sequence”, it should be a geophysical description like “a series of horizontal reflections”.

L23: “of stratification below the basal channel” rather than “.. of a stratification sequence in the basal channel”. The seabed and sub-bottom sediments are not in the basal channel.

L24: call figure 3a at end of sentence.

L31: “terraced” not “terrace-shaped”

L32 (and throughout manuscript): instead of “as indicated in Figure 4” just have “(Figure 4)”. There are a lot of wasted words throughout the manuscript when figures are being called. Authors should make their statement/describe the data etc. and then simply cite the relevant figure at the end of the sentence. See Box 1 of https://aslopubs.onlinelibrary.wiley.com/doi/full/10.1002/lol2.10165 for a better explanation of what I mean. There is also no need to repeat figure caption information in the text (e.g. page 12, line 26 opening line of section 3.4).

Page 13

Figure 3: what are the reflections above the seabed? It is not clear in the figure what all the complex reflections are. More annotation is required.

Figure 3: Again, authors should not refer to sub ice shelf sediments as “bed”. Bed should only be used when referring to grounded ice.

L3-7: This paragraph should refer to figure 4.

L6-7: I do not think that I understand the sentence “The across-profiles. . .. . ..across-profile III”. I have a suspicion, however, that this sentence might actually be quite key to the authors’ suggestion that there is a relationship between the ice shelf channels and the sediment beneath it. If I understand it correctly, here they are suggesting that there is a thicker stratified sequence in the parts of the sub-sea sediments directly beneath the ice shelf channel. Is that correct? At the very least, the authors need to annotate the thicker sequence below the ice shelf channels to assist the reader understand exactly what is being described here.

Page 14

Figure 4: This figure appears to be critical to the argument that the sediments beneath the ice shelf channel were deposited by the ice shelf channel (i.e. there is a spatial coincidence between the channel and a thick sequence of sediments subsea). What is the thickness of the sediment package beneath the ice shelf channel in figure 4a (note that figure subplots need to be labelled throughout the manuscript)? Is it, as implied by the y-axis, 400 m? If so, that is a phenomenal amount of sediment to be deposited 40 km from the grounding line solely from melting beneath an ice shelf channel. The authors should calculate the sedimentation rate for this package of sediment. Is it possible for their sedimentation rate to be valid (e.g. assuming a certain proportion of sediment in the ice, and known melt rates for ice shelf channels as calculated from ApRES). Figure 4 needs to be better described in the text and the key features (e.g. sediment packages) need to be better annotated. I assume that the ages of transit time from grounding line are based on current ice velocity (i.e. figure 1a)?

Page 15

Figure 5: why not just make this a 3D figure and show all 4 profiles (figure 2b of https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2010GL042884 is an example of what I mean)?

L5-12: There is lots of text in this paragraph that is direct repetition of the figure caption

of figure 6.

L5: “We selected ten across ice radar profiles. . .”?

L6: what is the evidence for the subglacial landform “shaping the channel upstream of the GL”? How does it do this, and what is the process?

L11-12: This sentence needs some expansion to make 100% clear the spatial coincidence between the landform and the ice shelf channel. Reference to figure 1 would help too. I don’t understand the phrase “. . .after which the landform become indistinguishable from the bed”? Surely if it is a basal landform it is the bed? It would also be useful to get a better idea and description of the wider bed topography around the landform (e.g. entire bed of SFG) to understand the context. Figure 1b is of little use in this regard – its colour scheme is very uninformative.

Line 15: again, lots of text that should be in the figure caption, or already is.

Page 16

Figure 6: Indicate very clearly which radargrams are over grounded ice and which ones are over floating ice.

Figure 6: are the authors absolutely sure that radar profile 5 is fully grounded all the time? Could there be tidally-induced grounding line migration?

Page 17

Section 4.1: It is a little difficult to link section 4.1 with figure 1, as the text in section 4.1 refers constantly to shot points, but these are not apparent on figure 1.

Line 14: “topographically constrained flow”?

Page 18

Figure 7: it took me quite a while to figure out exactly what this figure was. I suggest that it simplified by removing the bed profile picks. The key point of this figure is to con-

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ceptualise the idea of the offline reflection. Is the red semi-circle a “possible drainage feature” or it is a “landform”?

Section 4.3: I recommend not describing the feature being evaluated as either a “subglacial drainage feature” or a “landform” until the authors actually determine which of the two hypotheses are their preferred one. Whilst the unusual (offline?) reflection they describe is referred to throughout as a “subglacial drainage feature” the author then state on page 19 lines 16-17 that they “prefer interpretation 1” which is that the reflection is from the landform. This is a bit of a mess, and suggests that the authors have changed their preference during the writing of the manuscript but not updated all parts of the manuscript. A “landform” is not a “subglacial drainage feature”.

Section 4.3: change heading to “Does the seismic data record a subglacial drainage feature or a subglacial landform?” or something along those lines. Section 4.3 evaluates these two hypotheses on the basis of the seismic data and geophysical theory. The section heading should reflect that in some way.

Line 13: provide some additional detail about what is meant by a “separate drainage feature on a hard bed” – In essence this is a Röthlisberger (R-) channel incised into the overlying ice and should be described as such here.

Page 19

L17-20: This is an important admission here, and one that is entirely inconsistent with the title of the manuscript “Subglacial sediment transport upstream of a basal channel. . ...”. So far, the data don’t even unequivocally demonstrate the presence of subglacial sediments.

Page 20

L14: “floating ice” rather than “uncoupled ice”?

L16 (and throughout manuscript): what do the authors mean by “disturbed”? This needs defined and highlighted/annotated in a figure. Do the authors mean “deformed”

sediments or stratigraphy?

L17-19: apart from the reflection coefficient values and the “disturbed and stratified” stratigraphy, what other lines of evidence for these materials being grounding line deposits do the authors have? This is where reference to glacial geological literature is essential.

L31: “. . .are positioned on the western side of SFG near its shear margin.”?

L32: I disagree that you can track the landform at least 7.7 km. It is not apparent in profile 3 (Figure 6), so it can therefore be tracked for a maximum of 5.2 km (i.e. up to profile 4).

L33: “some degree of consolidation” – so is it unconsolidated sediments, or not?

Page 21

L1-23: I am totally unconvinced at present by the argument the authors make linking the sub cavity sediment stratigraphy with the ice shelf channels. I see no evidence at all that (a) sediment is being discharged at the grounding line from a subglacial hydrological channel; or (b) that sediment is being deposited directly from basal melt within the ice shelf channel. There seems to be a huge leap of faith being made in this part of the discussion, particularly in L4-5 i.e. “Taking the evidence together we conclude the landform is hosting the transport of sediments that are deposited in the ocean cavity close to the GL” – I see absolutely no evidence presented in this manuscript supporting the transport of sediments. If the authors wish to pursue this angle in a revised manuscript then they will also need to explain the transport mechanism. Is it subglacial deformation advecting sediment to the grounding line? Is it sediment transport by subglacial meltwater? Or, is it englacial sediment transport and then melt out?

L12-14: Here, the authors state “What we do see is more stratification in all across-profiles below the sub-shelf channel than outside of it and that this stratification extends to the eastern side of across-profile III.” If this is the case then this is potentially

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important, but at present (except perhaps a hint on page 13) this observation is not effectively presented in the current version of the manuscript. This needs strengthened considerably if the authors are to underpin their argument robustly. I remain unconvinced though that their survey layout is extensive enough to permit this statement. I would also like to see an assessment of the implications of thinner ice (and therefore < englacial signal attenuation) over the ice shelf channels – could this lead to higher amplitudes reflections from subsea interfaces beneath the channels compared to the sediments beneath the thicker ice beyond the channels? I also think that the authors need to carefully consider the entire sediment package (i.e. the stratigraphic relationships between the sediment beneath the ice shelf channels and those beyond the channels).

L29: My understanding of reflection coefficient analysis is that it characterises the physical properties of the upper few metres below the interface. As such it is a stretch to state "the eastern side of the landform consists of sediments. . .". Perhaps make this statement more specific (e.g. "Reflection coefficient analysis indicates that the upper few metres of the landform is unconsolidated sediment. . .")?

L31: OK, so here, finally in the conclusions section, the authors are specific about the actual process they believe is at play, i.e. "The landform hosts a channelized subglacial drainage which transports sediment downstream". I therefore ask the following questions (1) what is the evidence for subglacial drainage? (2) how does a landform "host" channelized subglacial drainage? (3) where is the evidence for sediment transport?

L32: How do the authors know that the 200 m thick sediment package has any association with the current processes at the grounding line? These sediments could be ancient and have nothing to do with modern-day grounding line processes. The spatial relationship could merely be coincidence.

Page 22

L18: Since reviewer 1 has sung the praises of Bradley Morrell, I will sing the praises of

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Dave Routledge - A brilliant field guide - he's also great!

Final comment: I appreciate that the majority of comments above will be viewed by the authors as perhaps overly negative. However, I do want to emphasise to the authors that I have provided the comments above because I feel that the acquired data are excellent and potentially very important. I would certainly like to see these data and results being published in some way, but I do believe that a stronger more carefully thought-through and coherent argument needs to be developed to place the assertations and findings put forward on a more secure foundation. I do hope that the comments provided above will assist the authors to achieve this.

Dr Neil Ross Newcastle University 3rd July 2020

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