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Interactive comment on "Deciphering the evolution of the Bleis Marscha rock glacier (Val d'Err, eastern Switzerland) with cosmogenic nuclide exposure dating, aerial image correlation, and finite-element modelling" *by* Dominik Amschwand et al.

Leif Anderson (Referee)

leif@gfz-potsdam.de

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Review of "Deciphering the evolution of the Bleis Marscha rock glacier (Val d'Err, eastern Switzerland) with cosmogenic nuclide exposure dating, aerial image correlation, and finite-element modelling" by Amschwand et al..

By Leif Anderson

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Discussion paper

The manuscript considers both the modern and past states of Bleis Marscha rock glacier in Switzerland. The authors use field observations, surface velocity estimates, finite-element modeling, and surface exposure ages to explore the evolution of the rock glacier. Ultimately the authors use their datasets to interpret the Holocene history of the rock glacier as related to climate and erosion rate from the headwall.

General Comments

This is truly an exceptional amount of work and it is really an ambitious project and manuscript! The authors should be proud of this achievement. I am especially impressed with the bringing together of the methods of a glaciologist/physicist with the methods of a geomorphologist/paleoclimatologist. The comments below are mostly related to the presentation of the work, with some suggestions which could improve the analysis.

It would be great if the surface velocity estimates, the field observations, and the model could be better used to justify the interpretation of the surface exposure ages. Right now the manuscript seems to touch on these different features and then transition into the Holocene history of the Bleis Marscha rock glacier without too clear of a connection between the modern and paleo perspectives. It would better honor all the work in the manuscript if logic behind the assumptions being made was laid out in connection to the modern analysis of the rock glacier. This is no easy task, but I think one that will really highlight the broad scope of methods brought to bear in this body of work.

I think that the uncertainty in the surface velocity estimates could re-done using off-rock glacier velocities adjacent to the rock glacier itself. Right now I suspect that the surface velocity error is too small. Comments below explain this more fully.

The modeling analyses could be improved with some sensitivity tests exploring assumed parameters and the ice-rock ratio but I am not sure they are necessary. Really a more clear statement of which parameters are assumed and how those parameters where chosen is enough.

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I suggest that the authors go through the full manuscript with a discerning eye for which observations and analyses are really needed to support the main take homes from the manuscript. There are various classifications provided of the rock glacier surface Units and surface zones on the glacier that do not coincide. These multiple classifications are difficult to keep straight so some simplification would be helpful for the reader. As can be seen in the detailed comments below I suggest in some cases for material to be moved into a supplemental section and for some figures to be simplified. Perhaps figures 4 and 7 could be combined into a 3 panel figure? The text should be simplified to improve the reader's experience and their ability to access the science. Terminology needs to be used consistently throughout the manuscript especially regarding section titles from the methods, to the results and discussion.

Overall this manuscript will be great contribution to the field, but it needs a clean up in terms of presentation, readability, and connection between the diverse datasets produced.

Line-by-line comments

Line 11. "2003/2011" is unclear to me. Perhaps note that repeated surface velocities measurements were made.

line 12. I am not sure what "orthophoto orientation correlation" means here.

Line 19. Consider rewording as I am not completely sure what is meant. "Nuclide loss from boulder erosion, affecting the nuclide inventory of boulders independently"

line 31. change 'is' to 'are'

line 32. revise this sentence

line 33. remove 'resources'

line 35-50. You might emphasize the considerable differences in the timescale between these two concepts.

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Line 55. I am not aware of ‘dynamic inactivation’ is there a citation for this term? It confuses me a bit because I tend to think of ‘dynamics’ as the flow of the rock glacier body and not a processes related to changing headwall erosion rate to the rock glacier.

Line 63. It is not clear what ‘interactions with glaciers’ refers to.

Line 65-66. Consider revising to make the meaning more clear. Could new methods / approaches help resolve this issue though?

Line 73. Why this rock glacier? A sentence about why you chose this rock glacier would resolve this.

Line 78. instead of ‘present’ maybe use ‘modern’

Line 106-7. The materials and methods section would benefit from a bit more generalized and expanded text here more broadly introducing the methods. A road map into the diverse methods applied in this study would help. This is easily fixed!

Line 109. Perhaps a bit more detail about the mapping performed? What sort of mapping did you conduct? For what purpose what the mapping conducted?

Line 115. It would be nice to have a map of the rock glacier with the locations of CRN sampled boulders referenced in this section if not before this section.

Line 116. Expand or combine this paragraph as it is only one sentence. This sentence itself can be simplified as well.

Line 146-147. How were these erosion rate values chosen? How much does these assumed erosion rates effect your exposure ages and your conclusions? Perhaps a few extra sentences would help here as well as some citations to support the assumption.

Line 150 . It might be easier for the reader if the heading here is ‘surface velocity’ or ‘surface creep rate estimates.’

Line 152. reword ‘The used’

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Line 163-165. “We estimate the uncertainty by correlating a reference area in the valley floor considered as stable.”

I suspect that this will under estimate the error on the rock glacier because the area. Is there reason to expect that the off-rock glacier areas in figure 7a are moving at 10 cm/a? It seems to me that a more robust estimate of the error of the surface velocities would come from the large off-rock glacier areas in figure 7a that show velocities up to 20 cm/a. This is also consistent with the lack of correlation between slope and velocity on the rock glacier in figure 7b.

Line 166-177. These paragraphs are interesting and well written but I am not sure why they are being included. How does calculation of strain rates relate to the larger framework of the manuscript? Maybe a few sentences of introduction to the section at line 151 could provide a road map for the calculations made related to the surface velocity/creep estimates.

183-4. Is this the only process by which rock glaciers move? How about translation along shear zones/ sliding? Does it make sense to state that you assume that movement of this rock glacier occurs by internal deformation?

202-204. It seems you should state clearly that you assume that this 3 layer structure applies to Bleis Marscha rock glacier.

209-10. If you give a few general observations here the reader does not need to search for the justification in the later section.

211-12. “a 3 m thick basal low-viscosity shear zone (constant).” Does this not also contribute to the movement of the rock glacier? How is the viscosity in the low-viscosity shear zone constrained? If this low viscosity portion of the rock glacier is included here then it seems it should be discussed above where you mention processes leading to rock glacier movement.

Furthermore it seems that the actual values of effective viscosity produced by the

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model are highly dependent on the assumed relationship between the viscosity and the viscosity in the shear layer at the base of the rock glacier. How important is the assumption that the shear layer contains a viscosity 10% of the rest of the rock-ice mixture? I don't think this has a large bearing on the main results of the manuscript though.

215. What is the Salteras terrace? Is it composed of river gravel or bedrock or till?

219-225. Is there a local justification for the 60% ice by volume? If not this should be stated as an assumption. Or further down a sensitivity test should be shown to highlight how much your results depend on this assumption.

Section 4.1 It would help the reader if the approach to mapping was outlined in the methods section. Right now there is scant mention of mapping methods, despite a rather large results section dedicated to it.

While there are valuable observations from the field here. I find that the section contains a lot of details that I am not sure how they connect to the rest of the exciting work presented in this manuscript. Perhaps it could be simplified and only the most necessary observations included. Other additional observations could be moved to the supplemental materials.

246. It would help the reader if you simplified the section title here.

250. Maybe describe what the estimate of volume was based on (i.e. what was the assumed mean thickness)?

Also I am not sure 'Internal' is needed here.

258. I am not sure what 'well-localized' means.

261-2. I am not sure I totally follow the reasoning here. It would help to spell it out more clearly.

266-69. If the ice patch was not flowing then it is not clear why geomorphological

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evidence in the landscape would be expected.

293. Is there data to support this observation?

298-9. It is not immediately clear why this is calculated or how it ties into the rest of the manuscript.

351-2. Here I think you need to describe what those processes are. Boulder rolling seems like an important potential process on rock glaciers. You might see Crump et al., 2017 as well.

380. Simplifying the section heading will benefit the readability

386. What is the significant level based on? It seems that much of the off-rock glacier area in Fig. 7 is moving up to 10-15 cm/a. This makes me think that the error associated with the surface velocities should be higher.

390-412. It is hard for me to keep track of the different lobes as well as the newly presented creep rates here. Perhaps this section can be synthesized a bit more.

Section 4.4 This section could be simplified and maybe extra text moved into the supplemental section.

503-5. How can you be sure that these jumps aren't just associated with the steepening slopes at these lobe boundaries?

547-549. This suggests to me that these velocities are not the result of active flow but rather the motion of boulders due to surface processes, shadows, and spurious correlation. As suggested above I think the error uncertainties for the velocity estimates should be redone.

558. maybe 'preserves' instead of 'memorizes'

Line 560. "The exposure ages are rather inactivity or stabilisation ages than travel time estimates, as previously reported (Moran et al., 2016; Steinemann et al., 2020)." I don't

understand what is meant here.

560-63. I do not understand how the travel time is within the uncertainty of the exposure age on the lower part of the rock glacier. Maybe the travel time constitutes half of the exposure age for Err12 and 13, but certainty not the other samples.

564-70. This paragraph is hard for me to follow.

566-68. I do not understand how travel time can be neglected in this case. Perhaps the logic can be laid out more here.

599-602. I suggest that you state that these are 'back-of-th-envelope' estimates as a lot of assumptions go into them.

Conclusions : It would be good to see a bit more incorporation of the results from the velocities and model with the paleoclimate story.

Table 1. How sensitive are these results to the assumed surface erosion rate of the rock samples?

Tables 2 and 3. Perhaps move this table to the supplemental as the sample is assumed to be an outlier.

Figure 1. Very nice map and inset of Switzerland.

Figure 2. Panel (b) the '5 m' and '2 m' labels are for the boulder mantle and basal shear layer but that is not clear in the figure. The 0.1 x viscosity in the basal shear layer should be discussed in the methods portion of the manuscript and described as an assumed value.

Caption: what is the Salteras terrace? Maybe reference it as the lower geomorphological surface?

Figure 4. Making the fill less transparent for the CDN ages would improve legibility, as well as making the boxes around the CRN ages tighter. What does 'active high-

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elevation lobes' refer to? I do not see any active lobate features

Figure 5. I find the caption difficult to follow. There is a not of information here, which is great, but I am not sure how it ties into the broader manuscript. Perhaps it could be moved into a supplemental section because it adds good background info.

Figure 6. This figure is a good synthesis of the different datasets produced. But I think the legibility of the figure can be substantially improved. Maybe the vertical dashed lines do not need to extend across the full height of the figure. It might instead work well to move this figure to the supplemental and then just include the exposure ages and the surface profile as a figure in the main text? It seems like the local topography and thrust activity are secondary controls that complicate the figure.

From the caption:

'This suggests that pre-travel nuclide concentrations are negligible.'

maybe add 'typically' in front of 'negligible.'

"Active thrusts coincide with sharp velocity gradients (cf. Fig. 7); this differential movement results in overriding lobes."

To me the assertion that the front of lobes can be positively linked to active thrusts is an interpretation here and throughout the manuscript.

Figure 7. Panel (a) The blue dots are not explained in the caption. The pink is hard to see. It seems that much of the off rock glacier area also produces significant velocities. Is this real motion?

Panel (b) the principle strain rates are very hard to read. Consider reducing the number of plotted strain rates (same for Panel b arrows) or creating a raster of dominant compression versus extension areas of the rock glacier.

Figure 8. The colors between the panels should match otherwise it is very hard to read. It seems that velocities.

Panel (a) based on the histogram up to 20 cm/a

Below 20 cm/a there does not seem to be a positive correlation between velocity and surface slope. Based on the velocities from off the rock glacier of up to 15 cm/a does this not indicated that the below $\sim$ 20 cm/a the velocities could be noise?

Either use only ‘surface velocity’ or only ‘surface creep rate’ throughout the manuscript.

Figure 9. Lots of great information here but I would suggest just including the lower panel.

Figure 12. I would suggest that this figure be moved into a supplemental section.

Crump, Sarah E., et al. "Interpreting exposure ages from iceâĂŘcored moraines: a Neoglacial case study on Baffin Island, Arctic Canada." Journal of Quaternary Science 32.8 (2017): 1049-1062.

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