Reviewer 3 comments: and authors' reply

Reviewer:

"-should we talk about stadials here?

... stadials, two occuring during Marine Isotope Stage 8 (MIS 8) at 284 +- ka and 257 +- 7 ka and one during MIS 6 at 147 +- 4 ka"

Author's reply:

The term glaciation was here replaced by stadial: in this sentence: "*We find the outermost margins of the study site depict at least three distinct pre-Last Glacial Cycle stadials occurring around 290-270 ka, 270-245 ka, and 130-150 ka*", and the next sentence also. However, acronyms should be avoided in abstracts so Marine Isotope Stage should remain as such here.

Reviewer:

"Maybe the deposits have not been found yet. The lack of evidence cannot be the base for argumentation."

Author's reply:

We add the term "may" in the sentence : "This may illustrate former longitudinal and latitudinal asynchronies in Patagonian Ice Sheet mass balance during these Marine Isotope Stages". Moreover: this sentence is located in the abstract, where there is little space for argumentation. Further argumentation and detail about this statement are found in the discussion section of the manuscript.

Reviewer:

"This is too far fetched as you simply do not have the data set in hand to make these kind of inferences."

Author's reply:

We beg to differ with this comment: The sentence "*Our findings thus enable to explore the potential roles of seasonality and seasonal duration in driving southern mid-latitude ice-sheet mass balance and facilitate novel glacio-geomorphological interpretations for the study region*" makes it quite clear that we are not making any direct inferences, but instead we are "exploring" different hypotheses, described as such. This is a key difference as we make it clear that we are using conditional and conservative language to propose that our results might support a certain set of hypotheses: whithout going further. These hypothese may well be further tested and proven wrong, which would make science progress.

Reviewer:

“Figure 1: the star refers to what.”

Authors’ reply:

This was modified during the first round of reviews: to precise the publications that these ages refer to.

Reviewer:

“Figure 1: maybe state again what RC and RH stand for”

Authors’ reply:

The changes were made accordingly.

Reviewer:

“You should give more info about the localisation of these boulders. What is a moraine complex? Several morainique ridges? Are the six boulders on the same ridge? This is an important detail given the scatter in your exposure age results. “

Author’s reply:

We describe the morphology of these moraine complexes in further detail in the result section 4.1: as such detail do not belong to the methods and are a finding as such.

“*In the RC valley, the three most distal preserved moraine complexes (RC 0-II) are morphologically distinct from the younger LGM moraines (RC III-VII). They display greater relief (70-90 m) than the RC III – VII moraines (10-40 m; Leger et al., 2021a), are more subdued, and have broader-crested ridges. Along our sampling transect, the three moraine complexes are 14 km (RC 0), 12 km (RC I) and 5 km (RC II) more distal than the outermost-dated LGM moraine (RC III). The sampled RC II moraine is a ~1 km-wide multi-ridge complex presenting a flat-topped, subdued crest surface elevated up to 45 m above its ice-distal outwash plain. Ice-distal slope gradient is variable but does not exceed 5°, a relatively low grade compared to the slopes of the younger, better preserved LGM moraines which feature slope gradients of 9-19° (Leger et al., 2021a). The RC I moraine complex features slope gradients (>5°) and surface geomorphologies for individual moraine ridges comparable to the RC II moraine belt, but is much wider in places (up to 4.6 km) and exhibits a greater concentration of distinct hummocky ridges and moraines. The subdued moraine geomorphologies characteristic of the RC 0-II margins are suggestive of progressive lateral slope downwasting and moraine surface erosion of fine material post-deposition (Clapperton, 1993; Glasser and Jansson, 2008; Hein et al., 2017). Geomorphological observations thus suggest the RC II and older moraine complexes were deposited significantly prior to the local LGM.”*

However we also added this information to the sentence in the methods commented by the reviewer:

", six moraine boulders located along a single broad ridge of the RC II moraine complex"

Reviewer:

"Why not sample cobbles on the moraine if the boulders are subject to higher erosion than cobbles?"

Authors' reply:

The boulders are indeed subject to more erosion than the cobbles: but more importantly: at our study site: it is the moraine themselves that are subject to much more erosion through time than the proglacial outwash surfaces, due to their higher topographies being more prone to lateral diffusion and wind/rain erosion. Thus any samples (boulders or cobbles) found on the surface of the moraine will be more subject to exhumation caused by moraine surface erosion, causing younger ages, than if found on the surface of outwash plains. This was shown by Hein et al. (2017): see figure 8: who also sampled cobbles on the moraine surfaces, boulders on the moraine surfaces, and cobbles on the outwash surfaces. Indeed this technique was tested and explored before our study, in Patagonia.

Furthermore: we remind the reader of these findings in our introduction: "*While moraine boulders are well-suited to dating glacier advances of the LGC, Hein et al. (2009) revealed that targeting outwash terraces in eastern Patagonia can be more appropriate for dating pre-LGC glacial margins, because their low-gradient surfaces are less prone to degradation via gravity-driven diffusion when compared to steep-sided and unconsolidated moraines*"

We thus believe that this point is already covered in the paper.

Reviewer:

why not use STD11?

Author's reply:

NIST_27900 standardisation is the one recommended by the SUERC lab scientists and the large majority of our samples were treated there. Moreover, the *STD11* standardization isn't available as an input in the CRONUS online calculator version 3, which is widely used by the international TCN dating community. Moreover, it is equivalent to STD-11 within rounding error.

Reviewer:

"what is the diference between the two production rates?"

Author's reply:

This question cannot actually be fully addressed in this situation: because we here use a time-dependent scaling scheme: the LSDn scaling scheme (Lifton et al., 2014): which causes the production rate to changes through time when calculating the ages.

To provide further details: we however added this sentence to the methods section: "*This local production rate yields a current sea-level high-latitude production rate of 3.96 ± 0.24 10Be atoms g-1 yr-1 using Lm scaling, versus 4.09 ± 0.19 10Be atoms g-1 yr-1 for the global mean of Borchers et al. (2016).*"

Reviewer:

"since you report the differences in exposure ages when using other scaling schemes you should consider simplifying your table 2 and not report the results using St and Lm scaling schemes."

Authors' reply:

We beg to differ as we think the transparency of the results in table 2 enable the reader to properly assess the impact of using different scaling schemes on our ages, and is important to display.

Reviewer:

"post-depositional"

Authors' reply:

Change made accordingly.

Reviewer:

"Are you sure about this value? This seems to be a mistake or it was a particularly bad blank?"

Authors' reply:

We double-checked and we are sure about this value.

Reviewer:

Typos in table 1 footnotes

Athors' reply:

Changes were made accordingly.

Reviewer:

"this is a very widely distributed population and statistically you should first justify that the population is normally distributed before calculating a straight mean"

Authors' reply:

We agree with this comment and also point out that we don't use the arithmetic mean in our discussion for this landform. This was initially included for consistency but we removed this sentence from the paragraph according to the reviewer's comment.

Reviewer:

"what is the range of ratios for which you can consider that the exposure ages are continuous? Maybe add a sentence and few references about the ongoing debate on this subject."

Author's reply:

In order to provide more information on this, we added this sentence to the paragraph:

"*From the ^{26}Al measured in two samples (RC20-13 and RC20-15) from this population, the resulting $^{26}Al/^{10}Be$ concentration ratios are 6.4 ± 0.3 and 6.0 ± 0.6, respectively. These ratios are consistent with the canonical $^{26}Al/^{10}Be$ surface spallation production ratio of ~6.75, the value currently used in the CRONUS Earth online calculator (Balco et al., 2008), and are here interpreted as indicating a single, continuous exposure history (within uncertainty) post erosion (Granger and Muzikar, 2001; Balco and Rovey, 2008; supplementary materials figure 1).*"

Note that we also changes the term : "are consistent with" for "are here interpreted as indicating": thus using a more conservative language.

Reviewer:

"You need to provide stronger arguments to justifiy chosing the oldest three ages of the population. At this point the sentences have the sweet taste of cherry picking.

You could have easily made the choice of the youngest ages : 108, 80 and 108 ka to calculate your mean."

Author's reply:

We do not solely analyse these ages statistically: but we importantly take into account the geology, the geomorphology and the paleoclimate history when making out age interpretation.

-the geomorphological and stratigraphical relationship between the RC II moraine and RC II outwash surface is quite straightforward and we can be confident that these landforms were

formed by the same glacier expansion event : see figure 1. Thus comparing the RC II cobble and moraine ages is a strong argument for considering the three young RC II boulder ages as outliers. This is included in the same paragraph and is our main reason for this interpretation of the young boulders as outliers.

Moreover, we expect young RC II moraine boulders to be outliers due to the high potential for boulder exhumation related to the highly eroded nature of these old moraine complexes.

Sentences pointing to these interpretations are located directly after the reviewer's comment:

"*We consider 10Be inheritance an unlikely source of exposure-age scatter compared to the high potential for boulder exhumation causing young outliers. Moreover, the RC II outwash and RC II moraine belt are geomorphologically likely to represent the same glacier expansion event.*"

Moreover, we consider it unlikely that such extensive glaciation occurred during the MIS 5 interglacial: which displayed significantly warmer conditions in Antarctica for instance.

Furthermore: and this likely is the most important point we make in this reply: because of the scatter in the moraine boulder ages: our final interpretation for the timing of the RC II advance is based mainly on the outwash cobble ages, and not the moraine boulder ages, because they show much less scatter. This is further covered in the discussion. The key result from this experiment was indeed to show that moraine boulder ages cannot fully be trusted here and this is what we conclude with this paper. In other words, the removal of these three young ages does not yield any influence on our final interpretation of the timing of the RC II glaciation.

In line with this reply: we added the information about the warmer MIS 5 interglacial to the related paragraph: "*These three younger boulder ages, which furthermore would indicate a glaciation occuring during the warmer MIS 5 interglacial, a less probable alternative, were thus rejected as stratigraphical and statistical outliers (Table 2).*"

Reviewer:

"can you clarify the meaning?"

Authors' reply:

We added the information "*Such ratios are interpreted as indicating a continuous exposure post erosion of the sampled boulders*"

Also: see previous reply to previous comment about the 26Al/10Be concentration ratios.

Reviewer:

Table 2 footnotes:

Typos were corrected accordingly

“You should report the year of sampling but you should remove the "BP" explanation as it is the only place in the manuscript that you use this format”

Authors’ reply:

Change was made accordingly

Reviewer:

“is it the one updated with the ICE-D dataset? If so, you should add the info here.”

Authors ‘reply:

We added this information.

Reviewer:

“in the table you refer the "internal" and "internal + PR%"

you should report consistently the uncertainties and use one format or another (text, figures, tables).”

Authors ‘reply:

We replaced “internal” for analytical in the table and table footnotes

Reviewer:

“in addition to the analytical ones.”

Authors ‘reply:

Change made accordingly.

Reviewer:

“is this info really necessary?

In addition, this type of mean can only be calculated for populations that have been demonstrated to be normally distributed. This can be done using a Shapiro-Wilk test for example.

But again is the info adding something to the already busy summary?”

Authors ‘reply:

We removed that information accordingly

Reviewer:

“you need to refer the reader to the section where you argue for this interpretation.”

Authors’ reply:

We added the information: “see justification in section 4.3” to this sentence of the footnotes.

Reviewer:

Figure 4

“If you set you mind on the oldest age being the most representative age of the landforms you dated, I think this figure is not necessary.

It adds way too much information about all possible alternative ages. What is a peak age? What is the significance of a peak age in a multimodal distribution?

Given the scatter in your age populations, the weighted-mean age is not relevant.

I think you should keep the info to one you are using in the discussion, while discussing briefly other methods to calculate a mean age (if relevant).”

Authors’ reply:

We removed the detail concerning the wtd mean and the peak age, as suggested here by this comment.

However we beg to differ with the statement that this figure is not necessary. This figure was quite well received by the two other reviewers and it brings visual information about the spread vs clustering of exposure ages and puts them on a visual time scale: which is not always easy to fully comprehend simply when reading numbers and uncertainties frem a table. Moreover, this figure was further improved after comments from reviewer 1, and it makes a clear point when comparing cobble and moraine ages from the RC II margin.

Reviewer:

“You should use the external error in your discussion because you compare your ages to other chronologies (MIS,...) that have been dated by other means than cosmonuclides.”

Author’s reply:

We agree with the reviewer and changes in relation to this comment were made to the discussion and the conclusion in reply to reviewer 1’s comment on the same point. We ended up using more conservative age brackets (which include external uncertainties) rather than just the analytical and external uncertainties associated with the ages.

Reviewer:

“ Please provide examples of erosion processes that could produce such desintegration.

Is it a difference in the lithology that could be the cause?"

Author's reply:

This sentence was added to provide further interpretation as suggested: "*The coarser grained and flat nature of this rock surface may have caused it to be more subject to frost wedging than rounded moraine boulders*"

Reviewer:

"Could it be exposed in the mountain cliff?"

Author's reply:

It is indeed possible that source rocks transported are exposed to atmosphere in the mountain cliff prior: but because rocks were transported over more than 80 km by the outlet glacier: we consider it highly unlikely that supraglacial debris would have remained unbroken on the glacier surface. Over such distance, we expect the majority of rocks to be brought to the subglacial environment where they would have been grinded down: thus causing the rounded, polished and lineated nature of these boulders.

Reviewer:

"But you previously suggested that such ratio is a sign for continuous exposure."

Author's reply: We struggle to understand this comment: as it refers to this sentence: "*The 26Al/10Be concentration ratio from this sample (6.3 ± 0.3) does not suggest a prolonged period of boulder burial*"

If taking into account the uncertainties in these concentrations: the terms "continuous exposure" and "not a prolonged period of boulder burial" are similar and mean the same, the later being slightly more accurate scientifically.

Reviewer:

"This is quite a stretch to incorporate all chosen ages from different geomorphological feature in one bag on the sole basis that they are "similar"."

Author's reply:

These 12 ages aren't just selected here because they are "similar": but because they come from two landforms that were interpreted as stratigraphically related to the same glacial event: 6 ages from the RC II moraine, and 6 ages from the RCII outwash surface located directly outboard of this moraine. The geomorphological and stratigraphical relationship between these two well-recognised features is quite straightforward (fig. 1) and we are quite confident in this interpretation: which is the consequence of numerous field investigations and careful mapping. We think that this point is made clear in the paper.

Reviewer:

“I think I asked this before: why not sample cobbles on the moraine?

Plus, your moraine boulders did not seem to be particularly eroded.”

Author’s reply:

See previous answer to the same comment.

Reviewer:

Is this document or is it speculative?

Author’s reply:

This is documented. See Hein et al. (2009, 2017) : here referenced in this sentence, and see our Figure 8 where we show their results.

Reviewer:

“Please explain what is mean the first time you use it.”

Author’s reply

Change made accordingly

Reviewer:

“There are few exposure ages from MIS6 and MIS4 reported for the EIS in Tylmann et al., 2019 (QSR, Poland), Rinterknecht et al., 2018 (QSR, Russia), Rinterknecht et al., 2014 (QG, Germny), Rinterknecht et al., 2012 (QSR, Germany).”

Author’s reply :

Unless we are mistaking, we checked and no MIS6 or older ages could be found reported in the Tylmann *et al*. (2019) QSR paper, nor in the Rinterknecht *et al*., 2018 (QSR, Russia) paper, nor in the Rinterknecht et al., 2014 (QG, Germny) paper.

We however found two ages that belong to the MIS 6 or older in the Rinterknecht et al., (2012) paper, and thus added this citation to this paragraph.

Reviewer:

“you must include all uncertainties.”

Author’s reply:

Agree, we added the external uncertainties for the individual cobble ages to the diagram as red horizontal bars.

Reviewer:

“what does it include?”

Author’s reply: indeed including the sign (1σ) here was a mistake as it makes little sense for a kernel density plot. We removed that sign from the sentence.