Reviewer 1

Jongejans et al. present a study that uses bulk and organic geochemical measurements to investigate the organic matter stored in the ~55 m headwall of the Batagay slump. This is quite intriguing as this slump is a unique insight into a long history of permafrost accumulation (and degradation) that may be useful for both understanding the evolution of permafrost landscapes as well as predicting future impacts of carbon stored in permafrost sediments as the environment is transformed by anthropogenic climate change. Overall, I find their manuscript to be well-written and quite detailed, but not overly long. I deeply appreciate the technical detail presented in the biomarker work (Table 2 is a delight) that is sometimes overlooked or omitted by organic geochemists.

Thank you for your constructive feedback to our manuscript. We responded to all comments below. Note: the line numbers refer to the preprint version

I have relatively few questions and comments as this paper seems to fit nicely into the recent series of papers involving the ongoing investigation of the Batagay slump. Here are a few worth considering:

- The authors note that the interglacial units appear to have “decreased OM quality” whereas the glacial periods have “variable but overall higher OM quality”. This makes sense when thinking about relative temperature and rates of cycling and, perhaps, the different residence time of OM within the active layer where OM degradation occurs. However, the OM stock sizes between the interglacial and glacial periods must be quite different. Therefore, we might consider the differing consequences of releasing a relatively small amount of “fresh” glacial-era OM compared to relatively large amounts of “degraded” interglacial-era OM. Additionally, regardless of the characteristics of sediment-bound particulate OM, the Woody Layer contains, of course, wood and other plant detritus that will be readily remineralized upon thaw.

We agree that the stock information is a logical and needed next step to continue OM research at the Batagay site. As in this study we focussed on the biomarker approach, testing its applicability to very old permafrost, but we did not yet assess and quantify horizon-specific OM volumes yet. A remote-sensing and UAV-based study is in progress and might provide basic morphological information to allow for OM release estimates from individual stratigraphic (glacial/interglacial) horizons. Furthermore, the interglacial deposits are characterised by a small thickness and consist partly of eroded/reworked material, while the glacial deposits are in situ accumulations and account for more than 80 % of the headwall’s vertical extent.

- Related to the above, I think a worthwhile and interesting calculation would be to estimate (even roughly) the relative sizes of C stocks within each of the types of units. If we could estimate the average C stock (i.e., organic C density per unit area) of these units, could we then also estimate (again, roughly) the amount of C mobilized by the Batagay slump since its formation?

The volume of sediments, C and nutrients mobilised in the Batagay thaw slump is enormous and unique. The quantification of these volumes is important, but, as mentioned above, a separate detailed study is in progress that considers the complex 3D stratigraphy of the Batagay permafrost deposits. With the present study, we aimed to quantify the biogeochemical carbon characteristics, but do not estimate stocks or fluxes as relevant additional data still need to be obtained and analysed. Adding a OM volume assessment taking into account stratigraphy to this biomarker-focused study would substantially inflate the paper size due to the need to explain several additional methods and distract from the core message on OM quality in our view.

- Combined with stock estimates, the authors could incorporate some of the biomarker-based degradation insights to categorize the pools of carbon mobilized as either "pre-processed" or "fresh" to perhaps get some insight into if we expect the mobilized material to be quickly remineralized or simply redeposited downstream. Combining this with knowledge of other thaw slumps could be useful for developing some insights into the consequences of this type of extreme thaw into local (nutrient loading), regional (source of deltaic organic matter), and even global (atmospheric) carbon cycles.

Unfortunately, as we did not perform incubations in the present study, we have no information on the freshness or the "pre-processing" of the OM. Furthermore, as we did not calculate stock estimates as mentioned above, we feel unable to implement this undoubtedly valuable recommendation at this point, but leave it to upcoming research.

- This may be more appropriate for a different article (perhaps one with a stronger focus on cryostratigraphy and geomorphology), but, is the size/scale of Batagay a unique feature? Retrogressive thaw slumps are well-studied and widely documented, but the scale of Batagay is quite impressive. While we can expect that as we warm the Arctic, we will have more thaw-related features, will we expect more Batagay-scale slumps? And, do we think there is anything unique in terms of biogeochemical cycling and/or consequences for local/downstream ecosystems of a single Batagay-scale slump versus multiple, smaller slumps whose total volume of mobilized permafrost might be similar to Batagay?

Rapid permafrost thaw is indeed assumed to accelerate and thus to create more megaslumps in some ice-rich permafrost regions in near future. Multiple studies point at an accelerating rapid degradation of ice-rich permafrost landscapes by thaw slumping, including regions with buried glacial ice but also syngenetic Yedoma ice wedges (Lantz et al., 2008; Lacelle et al., 2010; Kokelj et al., 2017; Lewkowicz and Way, 2019; Runge et al., 2022). In their study of thaw slumps in northwestern Canada, Lacelle et al. (2015) found 189 active slumps of which 10 exceeded 20 ha. Kokelj et al. (2015) referred to slumps as mega slumps when they reached 5-40 ha. Also, recent remote sensing work on thaw slumps (e.g., Kokelj et al., 2015; Runge et al., 2022) suggested that mega slumps (up to 52 ha or larger) are rather rare so far. Therefore, at this

point the Batagay thaw slump is very unique in its size and the largest as far as we know. There might be similarly large or larger slumps that are not researched yet. As the initial disturbance and the onset of the Batagay megaslump are believed to be anthropogenic, it represents however an outstanding example of rapid permafrost thaw that is promoted, but was not originally caused by arctic warming. It would require permafrost modelling for rather detailed local to regional conditions to determine whether large thaw slumps are more likely to form in the future. Here, we hesitate to upscale insights from the Batagay megaslump as its setting and dynamics seem rather unique. Regarding the location of the slump, previous studies reported that thaw slumps inland become more and more important in northwestern Canada in comparison to coastal thaw slumps (Riedlinger and Berkes, 2001; Lewkowicz and Way, 2019).
We added the following sentences in the last chapter of the discussion: "Multiple studies pointed to accelerating rapid degradation of ice-rich permafrost landscapes by thaw slumping, including regions with buried glacial ice but also regions with large syngenetic Yedoma ice wedges (Lantz et al., 2008; Lacelle et al., 2010; Kokelj et al., 2017; Lewkowicz and Way, 2019; Runge et al., 2022). In their study of thaw slumps in northwestern Canada, Lacelle et al. (2015) found 189 active slumps of which 10 exceeded 20 ha. However, recent remote sensing work on thaw slumps (e.g., Kokelj et al., 2015; Runge et al., 2022) suggested that mega slumps (up to 52 ha or larger) are rather rare so far. Therefore, at this point the Batagay thaw slump is very unique in its size and the largest feature as far as we know. As the initial disturbance of the Batagay megaslump is possibly anthropogenic, it represents an outstanding example of rapid permafrost thaw that is promoted, but was not originally caused by arctic warming." (L357)

- The authors note that an unconformity exists between the Lower Sand Unit and the Woody Layer and that the Woody Layer occupies erosional gullies that formed during the last interglacial. While I realize precise dating of accumulation rates is difficult, I would be curious to see an estimate of the amount of carbon mobilized from the Lower Sand Unit due to the warming-induced erosional processes during the last interglacial.

This is a very interesting suggestion and we appreciate this thought. Given the very nature of an unconformity that an entire sediment package is missing due to erosion, the data for such an assessment unfortunately is missing. We actually have no information on how much sediment was removed during past permafrost thaw events. Therefore, we do not see any potential to quantify this with our data from the present study. Given the large age uncertainties of the dating methods applicable to such ancient deposits, i.e. the Lower Sand Unit: >123,200 yr (OSL); 142,800 ± 25,300 yr (OSL) and 210,000 ± 23,000 yr (IRSL; see Murton et al. 2022, https://doi.org/10.1017/qua.2021.27), there is no sensible approach to calculate accumulation rates from the remaining Lower Sand unit, and to capture its material loss by thaw during the Last Interglacial. This may change once there are new and consistent dating results available. Luminescence dating is currently in progress but results will not be available until the end of this year.