

Interactive comment on “Organic matter quality of deep permafrost carbon – a study from Arctic Siberia” by J. Strauss et al.

J. Strauss et al.

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Received and published: 13 February 2015

Comments by O.S. Pokrovsky (Referee)

Referee: *This work presents the results of comprehensive, state-of-the-art research on organic matter chemical composition in two contrasting but dominant sites of permafrost development in eastern Siberia: thermokarst and yedoma. The topic is of high interest and will certainly be useful for a large community of permafrost scientists.*

Response: Thank you for this evaluation and the helpful comments!

Referee: *Few technical comments should be addressed to make the text clearer. The last sentence of the Abstract is somewhat contradictory to the statement of 10 lines above that OM vulnerability and quality are independent on their age. If so, why*

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recent input should yield a better quality of OM?

Response: Thank you for this suggestion, we deleted part "independent from radio-carbon age".

Referee: *p.15948: The notations 83 +61/ -57 and similar are unclear.*

Response: Changed to \pm including 1 mean uncertainty estimation.

Referee: *Section 2.3.2, L25. The C/N ratio interpretation implies a similar source signal. How efficient is such an approach for paleo-reconstruction if the sources of OM (say, terrestrial versus aquatic or different plant species) changed over past periods?*

Response: Of course, a change of OM sources would have an influence on the C/N values. Thus, our generalization is not suitable for a detailed paleo-reconstruction. But based on our multi-proxy study including e.g. ACL, a dramatic change is unlikely. To avoid any misunderstandings we deleted the sentence "This assumption implies a similar source signal".

Referee: *Section 2.3.6, Acetate: Justify the choice of 1 mg/L as threshold value. This is especially important given that the median value of the Yedomia sample falls exactly on this threshold.*

Response: This threshold value was defined basing on our measurement experience. Since acetate data can be extremely variable between different habitats, we decided to remove this threshold from the manuscript and use acetate concentrations as a parameter to assess the quality of the organic matter in the different deposits with respect to future microbial degradation. We changed the respective sentence in section 2.3.6. ("We use the acetate pore water concentrations in the different deposits as a parameter to assess the quality of the organic matter and to compare the potential of the different deposits for future microbial degradation.")

Referee: *p.15963, L 9: It is hard to accept "quite stable" the value "between 0.1 and 4.9" this is a factor of 50 variation*

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Response: Thank you for this suggestion. We changed the sentence to "the hop-17(21)-ene concentration at Buo-05 varies between"

Referee: *There is a lack of clear quality difference between yedoma and thermokarst in the Abstract. The higher the acetate, the better the quality of OM. Mean 6.7 mg/L (Yedoma) and 23.5 mg/L (thermokarst) are distinctly different. The difference between median values is also perfectly visible. Some inconsistency is seen here. Note that the medians and means C/N also indicate at a lower degradation state better organic matter quality in thermokarst deposits (p. 15966, L19).*

Response: Thank you for this comment. In the manuscript, we changed the imprecise use of the words 'significant' and 'clear'. To evaluate a quality difference, we now introduced statistical significance testing (section 2.4.1) using the Mann-Whitney-Wilcoxon test (because of the non-normal distributed parameters in our database) for comparing the two groups, Yedoma and thermokarst and the Kruskal-Wallis rank sum test for comparing all 5 profiles.

Referee: *p. 15966, L8-10: The authors state that thermokarst basins can act as a local sink for the carbon released from thawing permafrost.*

Response: This is not a statement by us, but one of the cited reference (van Huissteden and Dolman, 2012, doi:10.1016/j.cosust.2012.09.008). Moreover, we cited another reference of this statement below: "Walter Anthony *et al.* (2014) found a net accumulation in thermokarst basins since the last deglaciation"

Referee: *This is highly questionable statement given strong aerobic heterotrophic respiration of thermokarst lakes (Shirokova *et al.*, 2013 Biogeochemistry). Methane production here is only a fraction of total CO₂ evasion to the atmosphere from the sediments (frozen peat), mediated by the thermokarst waters.*

Response: We agree with the reviewer, therefore we already included the following sentence to the manuscript: "Nevertheless, at the same time thermokarst lakes

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also promote intense organic matter degradation including methane production in the anaerobic environments of organic-rich lake sediments and unfrozen deposits (Walter *et al.*, 2007b)". We added Shirokova *et al.* 2013 as a citation to this statement.

Referee: *p. 15967, L15-17: This is contradictory to L20-24 of the Abstract and allows one to think that "blind" PCA analysis is misleading.*

Response: We do not see any contradiction to L20-24 of the abstract ("Supported by principal component analyses, the sediment parameters and quality proxies of Yedoma and thermokarst deposits could not be clearly separated from each other. This lack of clear quality differences revealed that the organic matter vulnerability is heterogeneous, independent from radiocarbon age and depends on different decomposition trajectories and the previous decomposition and preservation history") and p. 15967, L15-17 ("Therefore, the $\delta^{13}\text{C}$ would indicate somewhat lower organic matter degradation for the thermokarst samples, implying a better quality than that found in Yedoma samples."). We visualized in Figure 7 and the PCA that no unambiguous separation is possible.

Referee: *Instead, one by one parameter analysis is capable to assess the true difference between two types of deposits.*

Response: Thank you for this comment. We clarified this fact in the manuscript, as there are differences between the two types of deposits, but these differences are not leading in the same direction.

To clarify the presence of significant differences, we added statistical significance testing (section 2.4.1) to evaluate a quality difference. Thus, we the Mann-Whitney-Wilcoxon test for comparing the two groups Yedoma and thermokarst (because non-normal distributed parameters) and the Kruskal-Wallis rank sum test for comparing all 5 profiles.

Referee: *p.15968, L 23-25: The reader is left with a conclusion that the differences are not significant, yet the thermokarst organic matter is of better quality.*

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Response: We changed this paragraph to: "Summing up Fig. 7, thermokarst organic matter is partly less degraded compared to the organic matter sequestered in Yedoma deposits (see table S1, significance for C/N, $\delta^{13}\text{C}$, and the HPFA index). The CPI points in the other direction (Fig. 7 and table S1). For hop-17(21)-ene, we do not see significant differences. Nevertheless, the interquartile ranges show an overlap for most proxies".

Moreover, we introduces following paragraph: "We interpret this as following: Compared to unaltered Yedoma deposits, degradation during thermokarst processes, but also heightened amounts of OC input during climatically more favorable Holocene times, are balancing each other concerning the organic matter quality for future degradation. Nevertheless, as there is more carbon stored in the thermokarst basins (Strauss *et al.* 2013), thermokarst deposits imply a higher intrinsic potential to contribute greenhouse gases in a warmer future. This is supported by the acetate data indicating a higher mean content for the thermokarst deposits. Acetate is an excellent substrate for microbial turnover e.g. acetoclastic methanogenesis (Kotsyurbenko *et al.*, 2004)."

Referee: *It makes sense to compare the measured parameters of two sites with those of other permafrost deposits in Siberia or Northern America to illustrate how variable the organic matter quality of the permafrost regions. The reader may be puzzled: what if all permafrost carbon fall in the range of parameters reported in this study*

Response: This study is designed as a detailed case study of the permafrost carbon quality basing on our state-of-the-art biomarker approach. Further works on samples from other Siberian and Alaskan areas are planned, but no more data is available so far.

Referee: *p.15970, L 8: Why the units are mg/L? per L of interstitial solution? May be the units are mg/cm³ or mg/g soil?*

Response: We separated the pore water from the sediment by centrifugation. The

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pore water was measured with an ion chromatograph and the data are provided in mg acetate per Liter pore water.

Referee: *p.15971, L 7-12: Organo-mineral bonds as protecting mechanism of organic matter. It makes sense here to distinguish suspended ($> 0.45 \mu\text{m}$), dissolved ($<0.45 \mu\text{m}$), colloidal ($0.45 \mu\text{m} - 1 \text{KDa}$) and "truly dissolved" or low molecular weight ($<1 \text{kDa}$) OM. See for instance size fractionation scheme in thermokarst lake waters (Pokrovsky *et al.*, 2011, *Biogeosciences*). Large-size, organo-mineral colloids may be poorly bioavailable, yet being dissolved in the water column.*

Response: Thank you for this suggestion. Of course, a more detailed separation would be useful. To be as precise as possible, we changed the sentences to "When it becomes available and is exported as dissolved OC to e.g. river systems, Vonk *et al.* (2013) and Mann *et al.* (2014) found that dissolved OC ($<0.45 \mu\text{m}$) in ancient Yedoma is exceptionally biolabile. But if it is not dissolved, the suspended ($>0.45 \mu\text{m}$) eroded ancient organic matter could be protected from extensive degradation by organo-mineral bonds, which stabilize the organic matter (Höfle *et al.*, 2013) and, in an aquatic environment, promote rapid settling because they weigh down the organic matter (Vonk *et al.*, 2010)." As we are citing other studies, a further separation in colloidal ($0.45 \mu\text{m} - 1 \text{KDa}$) and "truly dissolved" or low molecular weight ($<1 \text{kDa}$) OM is not possible.

Referee: *p. 15971, L 17-19: Thermokarst processes are not so local. A million of km² of non-Yedoma region in western Siberia is subjected to thermokarst lake formation.*

Response: Yes, we agree with the reviewer that thermokarst is not a local phenomenon. The statement on p. 15971, L 17-19 was included to highlight that the processes happen on the local scale, but if summed up they are "widespread on the regional scale". Thus we clarified the sentence. "Thermokarst processes, despite being local in nature, are widespread on the regional scale (Grosse *et al.*, 2011a) and may constitute the crucial process making the deep OC studied here microbiologically

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available."

Referee: *I also noted some references without capitals in geographical names; please correct*

Response: Changed accordingly.

Referee: *Figure 3 and Figure 4 are totally unreadable in pdf format. Separate each of them in several sub-figures, otherwise the main results of this work will be lost.*

Response: Thank you for this suggestion; we changed figures 3 and 4 to improve their readability. The diagrams for radiocarbon age, grain size, Oleanen ratio and acetate are now included in the supplement (Fig. S5 and S6).

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