Permafrost carbon in thermokarst deposits

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We suggest that the disagreement about "peat carbon" is a semantic issue, that our estimate of total yedoma region carbon is nearly identical to that of Hugelius et al. (2014) when taberites are accounted for, and that the more important scientific issue is the size and nature of climatologically-sensitive carbon stocks.

Walter Anthony et al. (2014) followed internationally accepted terminology in geological sciences (Andreev et al. 2009, Lozhkin et al., 2004; Kanevskiy et al., 2014), including predecessor research on thermokarst-lake deposits (Hopkins and Kidd, 1988; Murton, 1996; Murton 2001) and the standard glossary definition for peat in permafrost research, "A deposit consisting of decayed or partially decayed humified plant remains" (Van Everdingen, 1988), all of which suggest that thermokarst-lake deposits are peat-rich. As Hugelius et al. (Biogeosciences Discuss.) note, this definition differs from the soil science definition of peat, namely "40 cm surface thickness, autogenic organic material", and we regret any confusion that may have arisen. Our field data agree with the independent data summarized by Hugelius et al. (Biogeosciences Discuss.) in that only 16% of the 49 thermokarst features we studied adhere to the soil science definition of peat. Most thermokarst organic carbon was found either in thick, subsurface lake-sediment deposits with a high mineral fraction and characterized by autogenic or detrital peaty layers (mm-scale to >1-m thickness, Figure 1) or in benthic peat (82 ± 3% organic matter, n = 34) and buried peat facies (50 ± 4% organic matter, n = 67) that extended >6m below the ground surface. This lacustrine organic carbon, frozen in permafrost today since the lakes have drained, is consistent with the geological definition of peat but not the soil science definition of peat.

We agree that more dialog across disciplines regarding terminology will be fruitful in continuing investigations of permafrost dynamics. We feel, however, that the more important issue is the size and nature of climatologically-sensitive carbon stocks. Walter Anthony et al. (2014) estimated that the 159 Pg C being discussed here is strictly the Holocene-aged component of the soil/sediment profiles in the yedoma region, and showed that additional Pleistocene carbon is also mixed with the Holocene carbon throughout the profiles. [See suggested corrections to Figure 2]. The soil carbon stock values Hugelius et al. (Biogeosci. Discuss.) report from previous literature are total organic carbon, a combination of Holocene-aged and Pleistocene-aged carbon in the yedoma region. While this 159 Pg C represents a newly-recognized pool of Holocene-aged yedoma-region thermokarst carbon, Walter Anthony et al. (2014) reported a yedoma-region pool of Pleistocene-aged carbon that was smaller than previous estimates (Zimov et al. 2006; Tarnocai et al. 2009; Hugelius et al. 2013a,b). By accounting for both Pleistocene and Holocene carbon in the yedoma region profiles, Walter Anthony et al. (2014) showed that the total carbon pool size of the yedoma region (456 ± 45 Pg C) is not different from previous estimates (450 Pg C by Zimov et al. 2006; Tarnocai et al. 2009; Hugelius et al. 2013a,b). It is also not different from the mean-based estimate by Strauss et al. (2013; 462 Pg C) or Hugelius et al. (2014) when the Pleistocene C of taberites (in situ thawed and refrozen yedoma) beneath alases are considered (Walter Anthony et al. 2014, Suppl. Sec. 3.5 and Figure 2 below).

We suggested that the 159 Pg Holocene carbon in thermokarst deposits of the yedoma region (i.e. *peat*, by geologic definitions) increases the previous estimate of northern circumpolar permafrost-zone *peat* carbon (277 Pg; Tarnocai et al. 2009) by >50% because the 277 Pg peat C were primarily mapped outside of the yedoma region, avoiding spatial overlap. While this comparison is perfectly valid for a sedimentary geologist who recognizes both surface and deeper organic-rich deposits as peat, we acknowledge that the comparison is problematic for soil scientists who define permafrost region peat as >30cm thick Histels at the ground surface. The majority of the 159 Pg Holocene carbon we describe in alases should not be added to the pan-arctic frozen peatland (Histel) carbon pool because its origins are different. This 159 Pg Holocene carbon does not increase yedoma region or pan-arctic permafrost soil carbon pool sizes; it just reveals that a large fraction of the yedoma region carbon is actually of Holocene age (not Pleistocene aged) and occurs in deep horizons.

Walter Anthony et al. (2014) never claimed that yedoma-region thermokarst features should be classified as frozen peatlands. On the contrary, we showed that they differ from northern peatlands in the following ways: the positive radiative forcing due to yedoma-region thermokarst-lake formation was much higher than that of circumpolar peatlands in the early Holocene despite a relatively smaller area of the thermokarst lakes (Walter Anthony et al. 2014, main text p. 453); the present-day negative radiative forcing of peatlands is larger than that of thermokarst features (Frolking and Roulet 2007; Walter Anthony et al. 2014, Fig. 3); and long-term C accumulation rates in yedoma-region thermokarst lakes were on average 2.5 times higher than those of northern peatlands (Walter Anthony et al. 2014, Fig 4). Therefore, we suggest that thermokarst lakes and basins are an important and unique geomorphological feature that should be distinguished from and compared to northern peatlands, another climatologically important carbon pool in the North.

Finally, we emphasize that quantifying the relative proportions of Holocene-aged *versus* Pleistocene-aged carbon sequestered in thermokarst deposits in the yedoma region is important, as it improves understanding of glacial versus interglacial carbon source and sink fluxes and associated impacts on climate. Separating the Holocene *versus* Pleistocene sediment carbon components allowed us to determine that on long timescales, Holocene-aged thermokarst lakes acted as an atmospheric carbon sink instead of a source. In permafrost regions, distinguishing carbon age is also critical for predicting the fate of permafrost carbon in a changing climate.

Figure 1. Photographs of peat-rich alas sediments studied by Walter Anthony et al. 2014. Lacustrine peat, consisting of benthic peat (82 ± 3% organic matter, n = 34) and buried peat facies (50 ± 4% organic matter, n = 67), often extend >6m below the ground surface.

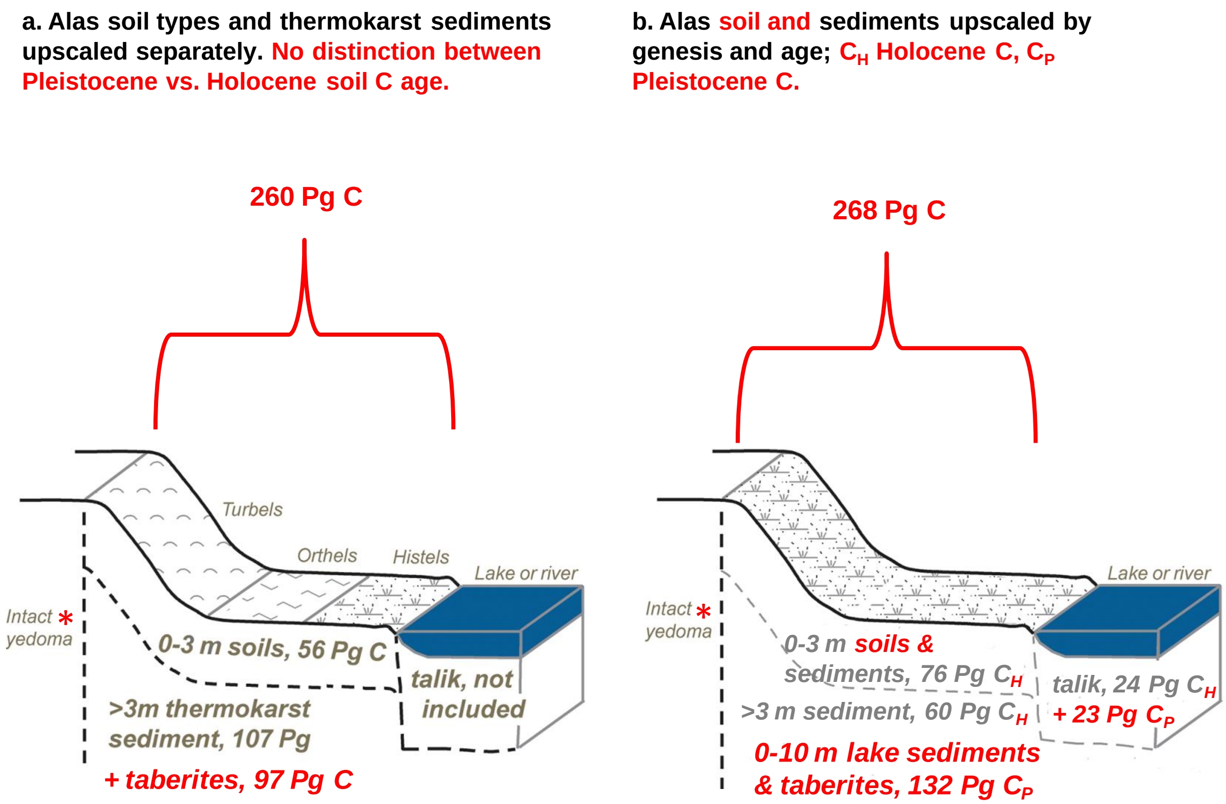

Figure 2. Modified from Hugelius et al. (Biogeosciences Discuss. Fig. 2):"Conceptual diagram illustrating how organic soil/sediment C in Yedoma region alases is described and estimated by (a) Hugelius et al. (2014) and (b) by Walter Anthony et al. (2014)."
Our suggested corrections to the figure are shown in red font. It is interesting to note that the total values for alas carbon pool size are similar in *a* and *b* despite being based on independent soil carbon data sets. Walter Anthony et al. (2014) never suggested that the 159 Pg Holocene C described for yedoma region alases should be added to existing estimate of regional carbon stocks. In fact, we showed clearly that our new work did not change previous estimates of the total regional carbon pool size estimate; rather, it shed light on the ages of the carbon subpools therein. The novelty of Walter Anthony et al. (2014) was distinguishing Holocene vs. Pleistocene carbon age and its implication for greenhouse gas fluxes during the past 10,000 years.

***The estimates of Walter Anthony et al. (2014) for the intact yedoma C pool (129 Pg, based on arithmetic means because data were normally distributed) is also similar to the mean-based estimate for the intact yedoma C pool (112 Pg) by Strauss et al. 2013. However, data of Strauss et al. (2013) were not normally distributed, and therefore a median-based upscaling approach was used (50 Pg C).**

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