Distribution of mineral constituents in Yedoma permafrost: implications for Yedoma formation

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Abstract

Ice-rich permafrost deposits such as Yedoma are highly sensitive to thaw and given that they contain up to one third of the organic carbon content of the Northern circumpolar permafrost region, their degradation is considered to be a potential climate tipping point on Earth. Accurately predicting the impact of climate warming on the fate of organic carbon in Yedoma requires better constraints on the mineral element reserve in these deposits. This study provides evidence for the homogeneity of chemical composition and mineralogy of Yedoma deposits with depth. This suggests that upon deep thaw through thermokarst or thermo-erosion a high reserve in mineral nutrients is likely to be exposed also from deeper deposits.

Keywords: mineral constituents; Yedoma; thawing permafrost; Alaska; Siberia

Introduction

With thermokarst processes, Yedoma degradation not only exposes organic carbon but also mineral constituents. The exposure of a previously frozen reservoir of mineral nutrients may boost biological activity (Jansson & Tas, 2014), thereby modifying the balance between carbon input and output from these permafrost deposits. To predict more accurately the fate of organic carbon from Yedoma upon thawing, it is required to assess local variability of their mineral reserve and better understand the controlling factors on this local variability, i.e., the conditions of Yedoma formation. More specifically at the site scale, it is important to know how homogeneous the mineral reserve locked into Yedoma throughout its depositional history may be and thus how deep thaw may expose varying ranges of mineral constituents. Is the source of mineral grains in a deposit homogeneous over time? Is it a local source? This study provides preliminary data from the two major Yedoma domains in Alaska and Siberia, to contribute to answer these questions.

Study sites

Archived samples previously collected to study organic carbon stocks in Yedoma were gathered to characterize their mineral constituents. This includes samples from natural outcrops at the Colville River in North Alaska (Grosse, unpublished data), at the Itkillik River in North Alaska (Strauss *et al.*, 2012), at Buor-Khaya Peninsula in Northeast Siberia (Schirrmeister *et al.*, 2017), and from cores along a toposequence at Sobo Sise Island in the Lena Delta in Northeast Siberia (Fuchs *et al.*, 2017). A total of 117 samples were analysed in this study. The sites cover deposits from the Late Pleistocene until the early Holocene (55 000 - 8000 yr BP).

Results and discussion

Chemical composition of Yedoma

Based on the Total Reserve in Bases (TRB = total content [Ca + Mg + K + Na] measured by ICP-AES after alkaline fusion), the chemical composition of the deposits can be compared between sites. The TRB values are generally higher in Yedoma deposits from Alaska than in those from Siberia. More specifically, in Alaska, the TRB values are lower in Colville (299 to 441 $cmol_c.kg^{-1}$) than in Itkillik (460 to 579 $cmol_c.kg^{-1}$), and are dominated by Ca at ~66 % then by Mg at ~22 %. In Siberia, the two sites are characterized by TRB values in the same range (between 168 and 313 $cmol_c.kg^{-1}$), and are dominated by Na at ~32 % and Mg at ~29 %. These observations support that the chemical composition of Yedoma deposits is a local signal corresponding to the local environment of the site during deposition. The dominance of Na contribution in deposits from Siberia suggests that the sediment sources may include a marine contribution or a Na-rich mineral phase, by contrast with Yedoma from Alaska.

The evolution of the TRB with depth in the deposits corresponds to an evolution over time of deposition, knowing that the sites cover deposits from 55 000 - 8000 yr BP. The results indicate a higher variability of the TRB with depth in Yedoma from Alaska, than in those from Siberia. This could possibly be attributed to temporary changes in sediment sources during deposition in Alaska, or alternatively to post-depositional processes such as pedogenetic processes.

Implications of mineralogy for Yedoma formation

The mineralogical analyses indicate the presence of chlorite, mica, kaolinite, quartz, plagioclase in all Yedoma deposits studied, as illustrated for a Siberian site (Fig.1). Carbonates (calcite and dolomite) are detected only in deposits from Alaska, but not in those from Siberia. Together with the dominance of Ca (~66 %) in the TRB from Alaska, this observation suggests a strong contribution from carbonate sources to Yedoma deposits in Alaska, but not in Siberia.

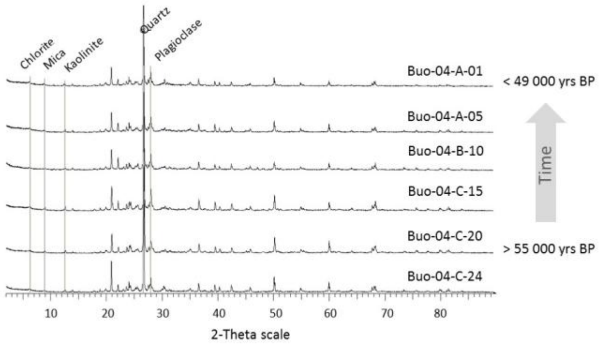

Figure 1. Mineralogy of a Yedoma deposit in Siberia, the profile Buo-04 in the site of Buor Khaya previously described and dated (Strauss *et al.* 2015).

In each deposit studied, the mineralogy is similar with depth, and hence over time (Fig.1). This observation supports the hypothesis that local sources of fine-grained material dominate contributions to the deposition. Sedimentological studies have highlighted different sediment facies types corresponding to contribution from both Aeolian and alluvial processes to Yedoma deposits (Strauss *et al.*, 2017). The homogeneous chemical composition and mineralogy observed in each site over time converge to support that the sources of fine-grained material for Aeolian and alluvial deposits are similar and are largely reflecting the local source materials and environmental conditions during Yedoma accumulation.

Conclusion

The data, at the site scale, support the homogeneity of the chemical composition and the mineralogy of Yedoma deposits with depth. This is an important parameter to take into account in the context of permafrost degradation. Given the high sensitivity of Yedoma deposits to thawing, thermokarst processes rapidly expose deep material to biogeochemical processes. This study supports that a high reserve in mineral nutrients, similar to that found at the surface, is present in deeper deposits and thus similar biogeochemical responses compared to near surface deposits maybe expected upon thawing.

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