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The permafrost mineral reserve: identify potential mineral nutrient hotspots upon thawing

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Abstract

The thawing of permafrost exposes organic matter to decomposition but also mineral constituents to water. To evaluate the potential to create mineral nutrients hotspots upon thawing, an inventory of the mineral element content and its local variability in permafrost terrain is needed. Based on measurements from major Arctic regions (Alaska, Greenland, Svalbard and Siberia), it is suggested that the mineral reserve in permafrost is firstly controlled by the local lithology. More specifically, the data highlight the potential for mineral nutrient hotspots to be generated upon thawing in soils derived from deltaic deposits, but not in thermokarst deposits. Finally, we suggest that portable X-ray fluorescence (pXRF) may present a quick and low-cost alternative to total digestion and ICP-AES measurements to build a mineral element inventory in permafrost terrain at a large spatial scale.

Keywords: mineral constituents; thawing permafrost; Yedoma; Northern Circumpolar region; pXRF

Introduction

Accurately predicting the impact of climate warming on the fate of organic carbon in thawing permafrost requires quantifying the mineral element reserve in the permafrost. In contrast to organic carbon, mineral constituents from the permafrost have received little attention. These minerals are exposed to a wide range of chemical, biological and physical weathering reactions in response to permafrost thaw, both with deepening of the active layer and with thermokarst processes exposing deeper permafrost to the surface. Unlocking a frozen reservoir of mineral nutrients may boost primary productivity and plant growth, thereby modifying the balance between carbon input and output in the thawing permafrost. A mineral element inventory in permafrost terrain, which accounts for local variability, is needed to better constrain the impact for the carbon balance at larger spatial scale. With this study we provide data from major Arctic regions to initiate the build up of this inventory and investigate its local variability. Moreover, we evaluate the potential of a fast and cost-effective method like portable X-ray fluorescence to improve the resolution and spatial diversity of the mineral element inventory in the permafrost in the future.

Study sites

In order to generate a first inventory of the northern permafrost region mineral reserve, a total of 230 available samples were selected from the circum Arctic permafrost region including near-surface and deep permafrost. With this set of samples including both active layer and permafrost samples we were able to cover a wide range of parent materials. Our dataset includes near-surface permafrost soil samples from Greenland (Zackenberg), Siberia (Cherskiy, Shalaurovo), Svalbard (Adventalen), and deep Yedoma permafrost samples from Alaska (Colville, Itkillik), and from Siberia (Kytalyk, Buor-Khaya, Sobo Sise) (Fig.1).

Results and discussion

The total mineral reserve of the permafrost

The Total Reserve in Bases (TRB = total content [Ca + Mg + K + Na] measured by ICP-AES after alkaline fusion) measured in permafrost from five different regions (Alaska, Svalbard, Greenland, East Siberia, Central Siberia) and combined with available data from the literature ranges between 50 and 580 $cmol_c.kg^{-1}$. The lowest TRB values are found in Alaska (NCSS database; USDA, 1994) and is attributed to peat soils with limited content in mineral constituents. The highest TRB values are found in the Yedoma deposit from Itkillik, Alaska. We attribute this high values to the presence of carbonates (Mauclet *et al.*, this conference). High TRB values are also found in Central Siberia and in Greenland. We link this to the presence of basalt as a parent material (Bagard *et al.*, 2013; Hirst *et al.*, this conference). The low TRB values in Svalbard likely reflect the composition of the mixed sedimentary rocks of this site. Interestingly, all TRB values in permafrost from East Siberia fall in the same range, including near-surface permafrost (Cherskiy, Shalaurovo) and deep Yedoma permafrost (Buor-Khaya, Sobo Sise, Kytalyk).

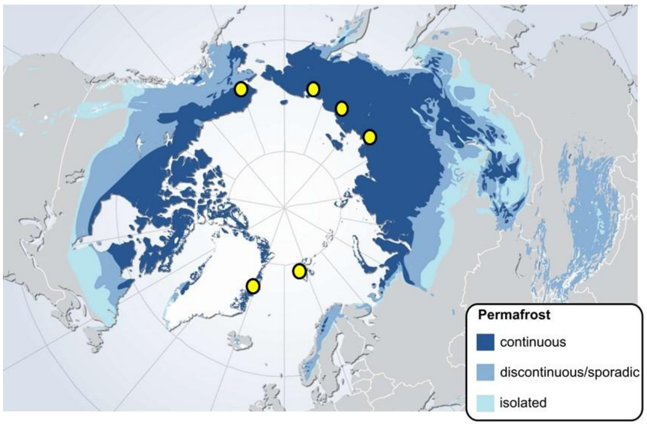

Figure 1. Location of the studied sites in the circum Arctic permafrost region (map from Brown *et al.*, 2001).

Following Hirst *et al.* (this conference), there is an increase in TRB values in permafrost relative to active layer in sites derived from deltaic deposits, but no increase in sites with boulder fields or ridge crest (Greenland, Siberia). Data from Kytalyk (Siberia) suggest that sites that experienced thermokarst in the geologic past (i.e., a drained thermokarst lake basin) show no increase in TRB in the permafrost relative to the active layer. Our hypothesis is that mineral elements have been leached from the deposit during the thermokarst stage before it became permafrost again after lake drainage.

Mineral element inventory in permafrost: testing pXRF

Alternative methods to ICP-AES to measure element content, faster, low-cost and non-destructive, such as the portable X-ray fluorescence (pXRF) are now used in the lab or in the field, including in permafrost regions (e.g., Weindorf *et al.*, 2014). For elements such as Ca, Fe, Sr, Ti, Zr, there is a strong linear relationship between the values obtained by ICP-AES and those obtained by pXRF ($R^2 > 0.85$). For other elements such as Si, Al, K, the linear relationship is lower ($0.4 < R^2 < 0.6$). For an element such as Mg, pXRF values are generally close to the quantification limits ($R^2 < 0.15$). Our observations support that the pXRF method provides an efficient way to build an inventory of the mineral elemental content of in permafrost terrain for important macronutrients such as Ca or micronutrients such as Fe.

Conclusion

This first inventory of the total mineral reserve in the northern permafrost region highlights that the potential for mineral nutrient hotspots upon thawing (i.e., higher mineral reserve in the permafrost relative to the active layer) depends on the types of deposits. In a next step we plan to test this hypothesis at a larger scale. As a hands-on recommendation, we suggest with this study that pXRF devices may represent a good alternative to the classical methods for a quick and low-cost mineral element content measurement in permafrost soils, and thereby to better understand the variability of the mineral reserve in permafrost at a larger scale.

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