年輪を用いてカナダ永久凍土の炭素蓄積プロセスを復元する

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Reconstructing carbon accumulation processes in Canadian permafrost soil using tree ring records

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Introduction and objectives: Why are the large amounts of organic matter stored in permafrost soils? In Northwest Territories of Canada, black spruce forest exhibits the largest soil organic C (SOC) stocks among permafrost ecosystems. Organic matter decomposition can generally be limited by cold climate, water flooding, and input of recalcitrant litters. In addition to these processes, black spruce forests can develop mounds and troughs called hummocky soil structure. This process is hypothesized to play roles in enhancing SOC storage, however, hummock formation and SOC accumulation in permafrost soils are still unclear. Development of hummock soil structure could induce tree tilting, as black spruce trees typically grow on the shoulder of hummock soil. Tree rings of reaction woods could record tree tilting and soil hummock dynamics (Fig. 1). Using tree ring analyses and litter decomposition experiments, we attempted to reconstruct hummocky soil dynamics and their impacts on SOC storage over 200 years.

Materials and methods: Soil C stocks, micro-relief, and organic/mineral soil thickness were measured in black spruce forest on fluvial sediments in Northwest Territories, Canada. To analyze the relative importance of soil condition and substrate quality on organic matter decomposition, the following environmental parameters were also measured: soil temperature and moisture, aeration index [Eh, reducible iron (Fe) oxides] of soils, and the decomposition rates of litters (lichen, moss, and root litters) and cellulose filter paper buried in the soils. To reconstruct the history of soil hummock formation, tree ring widths were measured year by year. The magnitude of tree tilting was calculated by the maximum tree ring width dividing by the minimum tree ring width.

Results and Discussion: Tree ring analyses suggested that hummocky soils were formed through freeze-thaw cycles over 200 years. The magnitude of tilting increased with air temperature, which suggested that permafrost thawing in warm summer and re-freezing induced development of hummocky soil structure. This provides diverse habitats, dry mounds for lichen and wet troughs for moss. Mass losses of lichen and moss litters were <20% after 2-year field incubation. The development of hummocky soil micro-topography resulted in accumulation of sparingly-decomposable lichen in mounds and accumulation of moss in troughs. The thick layers of lichen and moss litters appeared to limit deep melting of permafrost soil during summer. Soil water dynamics indicated that seasonal flooding events were observed following spring snowmelt and permafrost melting in summer. The redox cycles of iron were recorded as accumulation of oxalate-extractable Fe oxides. Cold climate and poor drainage, which are imposed by hummock soil structure, contribute to the largest C stocks in black spruce forests.

Conclusion: Tree ring analyses suggested that the hummocky soil structure could be formed by freeze-thaw cycles, especially thawing events of warmer summer over ca. 200 years. Development of hummocky soil structure accumulates lichen and moss litters. Cold climate under thick organic layer and poor drainage on permafrost table can enhance SOC storage.

Figure 1. Tree ring of black spruce