

Preliminary results of the micro-topographical change and its effects on the active layer in boreal forest near Yakutsk, Eastern Siberia

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1. INTRODUCTION

Microtopographic processes can be a key factor for controlling carbon budgets in boreal forest. In areas dominated by permafrost, cryoturbation (mixing of soils from various horizons by freeze-thaw action) removes the surface organic matter down into the subsurface frozen horizon, resulting in a considerable amount of carbon stored in the active layer and in the upper permafrost (Hobbie et al., 2000). It can change the calculation result of total amount of soil organic carbon (SOC) in the boreal forest. Michaelson et al. (1996) measured carbon stocks in tundra soils in Arctic Alaska, concluding that the total amount of carbon can be doubled if estimation is based on both permafrost and active layer, than the estimation based on the surficial layer only. Thus, it is fundamental to estimate how the cryoturbation contributes to the terrestrial carbon budget in the boreal ecosystem. In this study, microtopography and related cryoturbation structures are described. The goal of this study is to assess the formation mechanism of cryoturbation structures and related microtopography on the ground floor of Larch forest.

2. CRYOTURBATION AND MICRO-TOPOGRAPHY

The term “cryoturbation” has two meanings: One is the soil movements due to frost action, and the other is the irregular structures formed in soils by deep frost penetration and frost action processes (French, 1996, p141). In this study, “cryoturbation structures” and “cryoturbation processes” are used respectively, to avoid any misunderstanding. Frost action processes include several kind of soil movement such as frost heave, gelifluction, frost creep, and cryostatic pressures occurred within the wet unfrozen pocket sandwiched by the upper and lower frozen layers. All these movements are related with the formation of periglacial landforms (e.g. solifluction lobe or patterned ground). A well known process in permafrost environment is the formation of earth hummocks (e.g. Mackay, 1980). Earth hummock is one of the non-sorted patterned ground (Washburn, 1956), and is distributed widely among the continuous permafrost and seasonal frost areas of the world (See review in Grab, 2005).

3. METHODS

The study site is located in Neleger (62°18'N, 129°30'E), 30km from Yakutsk city in the Republic of Sakha, Russia. Annual mean air temperature (MAAT) is approximately -10°C. It is on the river terrace of the Lena river, where Larch forest and numerous alas (depression by

thermokarst) are the predominant landscapes. A plot was established in the mature Larch forest (*Larix Cajanderi*). Two methods were used in this study. One is micro-scale topography measurements by digital photogrammetry, and the second method is hand descriptions on the pit-wall opened in the active layer. Field survey was conducted on 6–10 September, 2005.

Photogrammetry is a fundamental method used for geomorphological mapping. In recent years, advances in image processing techniques allow the use of digital images taken with consumer-grade digital cameras for DTM (Digital Terrain Model) generation. This technique has been used successfully in micro-topographical measurements in the resolution of less than 1 mm (e.g. Rieke-Zapp and Nearing, 2005).

A couple of measurements were carried out to compare the microtopographies on organic soil (humus) and mineral soil surfaces in a 4m² quadrat. Four wood angles were anchored on every corner of the quadrat as the reference points of the measurements. Before the first measurement, all ground cover vegetation (mainly *Vaccinium vitis-idaea*) was cleared by pruning shears, to measure the true topography on the organic soil (humus). After the first measurement, the organic soil layer was removed by hand, and second photo-data were obtained. A 3D modeling software KURAVES-K (Kurashiki Boseki Co., Ltd., Japan) was used to create DTMs. Finally, DEMs (Digital Mesh Map) were generated by GIS software ArcView.

The 4m² quadrat was dug to the frozen depth. Frozen table appeared in the depth of -80cm when the pit was opened (8 Sep., 2005). The soil layer structures in two sidewalls (north side and east side) were carefully described in reference to the 10cm grid of leveling strings. Special care was paid to the Colors of mineral soil layer, because darkness of soil reflects the content of organic carbons.

4. RESULTS

4.1 Microtopography of the mounds

The microtopography of the organic soil and mineral soil surface of the 4 m² quadrat is shown in Fig. 1. Although the organic surface seems nearly flat, the contour line and micro-scale DEM indicate the presence of gentle ridges and troughs on the organic surface. The relative height between ridges and troughs are approximately 4-6 cm. The positions of two main troughs on the organic surface (indicated by dashed line A and B in fig. 1a) agree with the coordinates of the main troughs on the mineral soil surface (Fig. 1b).

The troughs on the mineral soil surface defined the distribution of small mounds (Fig. 1b). Mean diameter of the mounds and interval are approximately 30-50cm, and relative height is 10-20cm. As discussed later, these mounds can be classified as earth hummocks. Dead old root and tube-like funnel were found in the main trough “A” on the mineral soil surface (Fig. 2), indicating that there were root expansion through the troughs in the past. The dead root was rather wet, indicating the moist condition within the trough. On the other hand, currently living lateral roots are expanded on the summit area of the mounds. Kajimoto et al. (2002) reports the lateral roots of *Larix Gmelinii* in central Siberia tend to climbed up to the top of earth hummocks, because its dry and warm conditions are much favorable for root expansion than the surrounding troughs. The living lateral roots expansion on the quadrat follows this pattern.

4.2 Cryoturbation structure

Mixed soil layer (cryoturbation structure) appeared both in the north and east walls in the quadrat pit (Fig. 3). The soil texture was divided into five categories based on degree of decomposition and soil color. A 10cm layer of decomposed organic materials (humus) covered

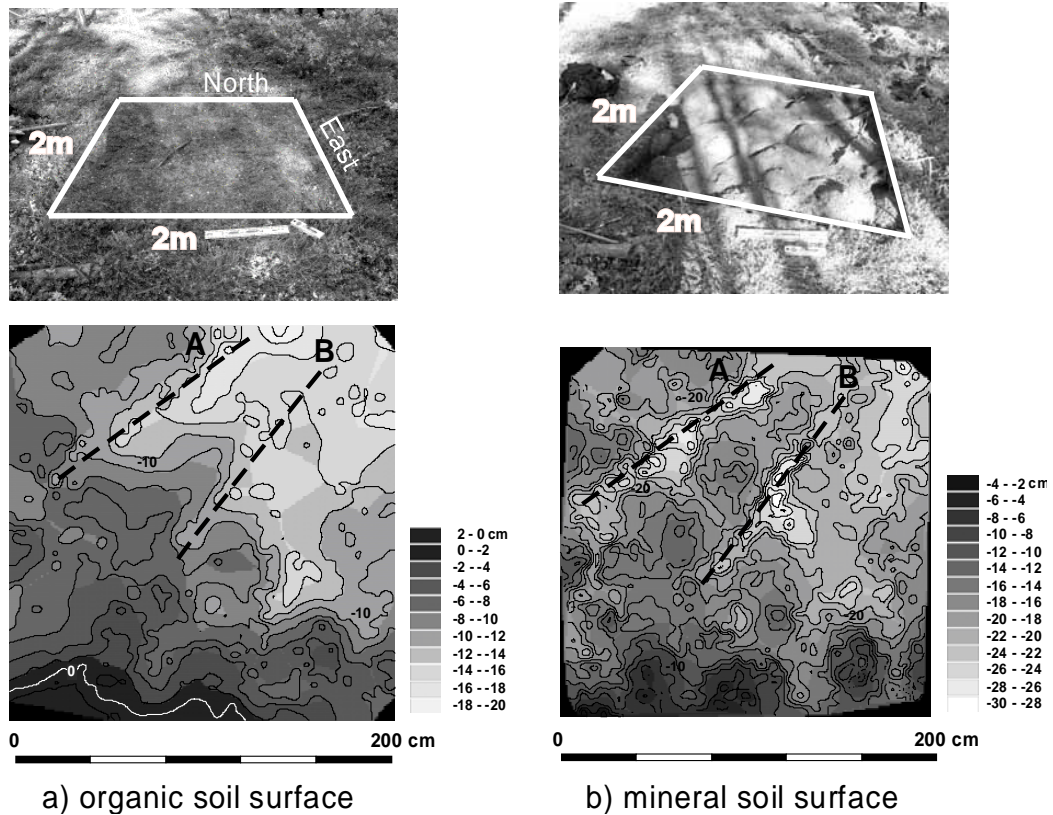


Fig. 1. Contour and DEM (Digital Elevation Map) of organic soil and mineral soil surfaces. Contour interval is 2cm, and mesh size of DEM is 1cm. Lines A, and B indicate the lineaments that organic and mineral soil surface have in common.

the mineral soil surface. The mineral soil layer, which extended down to the frozen table, is characterized by silty soil texture with no boulders. Color pattern of the mineral soil layer is chaotic, due to soil mixing by cryoturbation processes.

Upper and lower boundaries of the mixed layer have a wave-like form (dashed line in Fig. 3). The upper boundary corresponds to the sequence of ridges and troughs on the mineral soil surface (Fig. 1). The concave, bowl-shaped depressions in the lower boundary are located under the convex mounds on the mineral soil surface. The wave length of the lower boundary is approximately 1m.

Black mineral soils are deposited in the troughs (white triangle in Fig. 3a and b), and they had an extension down to the large pools of the black mineral soil. On the north section, organic-affected black mineral soil is deposited within the trough (No.1 in Fig. 3a) and a fragment of black soil (No. 2) reached down the large mass of black soil below the mounds (No. 3). Similarly, a pillar of mineral soil darkened with organic matter (No. 4) extended from the surficial depression toward the subsurface. These structures indicate that the surficial mineral soil darkened with organic matter submerged into the active layer, and these were finally stored in the pools of black mineral soil within the active layer. Same structures are also found in the east section (No. 5, 6, 7, 8 in Fig. 3b).

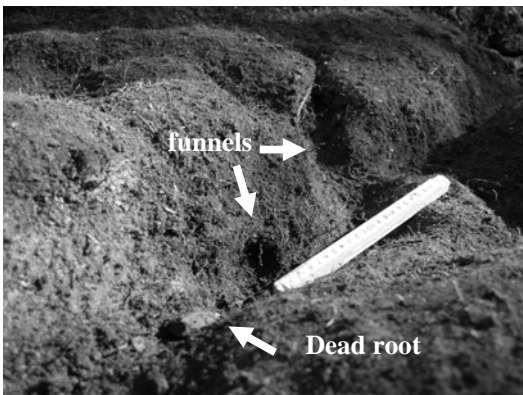


Fig. 2. Photograph showing the dead root and funnels in the main trough A on the mineral soil surface.

Up-casting tongues of black mineral soil could be seen ascending from the pools of black mineral soil (white arrows in fig. 3a, b). These tongues apparently indicate the upward injections from the black soil pools. The injection seems to occur not beneath the troughs but rather below the mounds.

Some remarkable textures were also found in the two pit sections. First, there were dropping forms of organic-affected mineral soil through the lower boundary of the cryoturbated layer (e.g. No. 5 in Fig. 3a). Second, fine roots were abundant among the pit sections even in the deeper part. Number of fine roots was counted in 10cm grids on the east section, highlighting the high density of fine root ($14\text{--}15/100\text{cm}^2$) between -60 and -70cm .

5. DISCUSSION

5.1 Possible formation mechanism of cryoturbation and frost mounds

Cryoturbation structures that appeared in the pit sections strongly indicate upward and downward movements of soil within the active layer. The soil movements can be explained by the circulation model, which has been proposed for earth hummock growth by Mackay (1980).

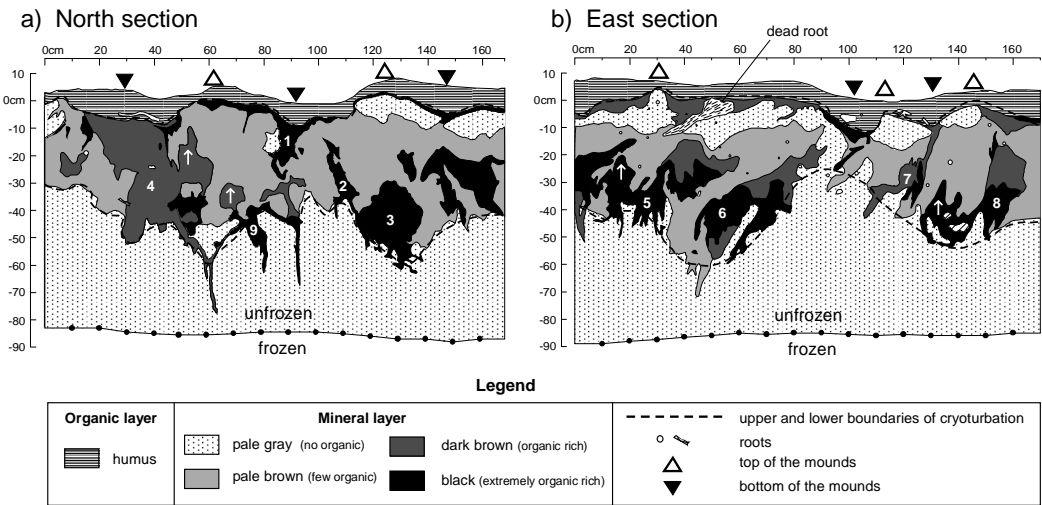


Fig. 3. Section sketches of a) North section and b) East section on the pit wall. Black triangle indicates the ridges of the mineral earth hummocks. Depth of frozen ground on 9 Sep. (North section) and 10 Sep. (East section) are shown by the dot line.

Based on this model, it is possible to demonstrate that the cell-like soil circulation occurs due to the upward and downward movement of melting soil with gravity (Fig.4; Mackay, 1980). Unfrozen pore-water in the frozen active layer migrates upwards to the top of the active layer when the active layer is frozen. It forms ice lenses, resulting in upward and outward frost heave (Fig. 4 left). Meanwhile, ice lenses developed at the base of the active layer produce frost heave that is upward and radially inward (Fig. 4 left). In the spring and summer, melting of frozen soil initiates downward and radially outward subsidence due to gravity. With the bowl-shaped frozen table, downward movement results in subsequent upward migration of the bottom soil (Fig. 4 right). Given the opposite curvatures at the top and bottom of the active layer, a cellular circulation occurs (Fig. 4 center; Mackay, 1980).

The opposite waves of the upper and lower boundaries of the mixed layer that appeared both in north and east sections (Fig. 3), strongly indicate that cell-like soil circulation occurred in the active layer with subsequent growth of earth hummocks. In terms of such cryoturbation structures, the small mounds on the mineral soil surface can be categorized as the earth hummocks. Bowl-shaped lower boundary was probably associated with the frost table when soil circulation occurred.

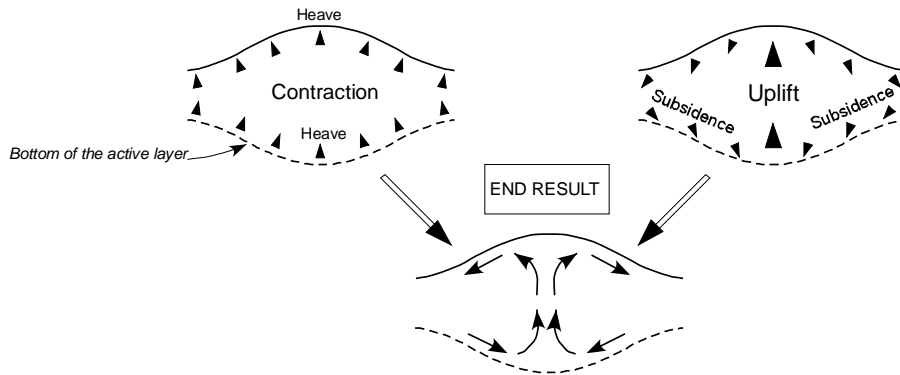


Fig. 4. The cellular circulation model proposed by Mackay (1980).

5.2 Morphological characteristics of the small mounds

The circulation theory by Mackay (1980) leads to a hypothesis that a bowl-shaped depression is inevitably paired with single mound. However, the interval of mounds of 30-50cm (Fig. 1) apparently disagreed with the wave length of 1m on the lower boundaries (Fig. 3a, b). This contradiction may be caused by the lateral root expansion of Larch trees. Troughs and their sidewalls on the mineral soil surface have an apparent straight shape (Fig. 1), indicating that there are some mechanisms to force the inter-hummock troughs being straight. The dead root and funnels in the main trough (Fig. 2) suggests that the lateral root had expanded into the troughs in the past.

Kajimoto et al. (2002) reports that the lateral root of *Larix Gmelinii* in central Siberia tend to extend into warmer soils on the hummocks than the colder and wetter inter-hummock troughs. They proposed four stages of the reconstruction processes of Larch trees: 1) After fire disturbance, vertical tap root expand into the deepened active layer. 2) The vertical tap root aborted because of the recovery of ground floor vegetation and thinning of the active layer. 3) Lateral roots expand horizontally into warmer soils on the earth hummocks. 4) Asymmetric root network is constructed in mature stage (Kajimoto et al., 2002).

There may be one more stage between 1) and 2). The lateral roots expanded into the inter-mound troughs, and some of the roots submerged into the mounds. Thereafter, subsequent death of lateral roots occurred due to active layer thinning. If this stage existed, the segmentation and elongation of the mounds, as the funnels and straight troughs indicate, can be explained. Probably, the current microtopography of the small mounds and troughs is a result of interaction between the development of root network and cryoturbation processes.

6. CONCLUSIONS

Small mounds and cryoturbation structures in the Larch forest are demonstrated by the digital photogrammetry and pit survey. Findings and speculations are summarized below.

- 1) Large amount of organic-affected black soils is subsided and stored within the active layer.
- 2) Formation processes of cryoturbation structure and small mounds can be explained by the cellular circulation theory by Mackay (1980).
- 3) Small mounds may be a result of interaction between the development of root network and the cryoturbation processes.

Many questions arise in this study. Is cryoturbation active or not? When cryoturbation started? Is fire disturbance related with cryoturbation activities? Detail quantitative description and sampling are needed.

Acknowledgements. I thank Prof. Hatano and Prof. Fukuda (Hokkaido Univ.), for their kind assistance to the research project and useful comments. I also thank Dr. Fedorov and members of the Permafrost Institute, Russian academy of Science, Yakutsk for their kind assistance, discussion, and field support. I thank Dr. Iwahana and Dr. Shiota in Hokkaido Univ., for their help in the field and meaningful discussion. I thank to Dr. Lopez in Hokkaido Univ., for useful comments and improvement of the manuscript. This study is supported by JSPS Core to Core Program.

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