Soil Physical Properties of Active Layer in Alas, Eastern Siberia

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ABSTRACT

- Soil physical properties of active layer are important to understand the hydrological processes in permafrost regions. We have measured the soil physical properties in six soil profiles of active layer on a 500 m-line in Ulakhan Sykkhan alas during the summer of 2000. The soil physical properties, such as temperature, bulk density, hardness, water content, electrical conductivity of soil pore water, hydraulic conductivity and ignition loss, had unique aspects for each pit and depth on the 500 m-line. Two facts are important to understand the thaw mechanism of frozen soil in alas; saline soil layer exists in about 40 cm depth and vertical macropores are built by insect in the area where frozen soil thaws fast.

Introduction

- The active layer, i.e., the annually freezing and thawing soil in permafrost areas, is of hydrological importance and a good sensor for global warming. From the observation in East Siberian tundra, we found that the active layer thickness varied spatially mainly due to vegetation cover (1999). However, since the active layer in the tundra was under water in summer, it was difficult to observed the soil profiles. To understand the relation between active layer thickness and soil properties we observed the soil profiles in an alas, which was a grass field in East Siberian tiga, instead of tundra.

Field site

- Field observation was carried out during the summer of 2000, July 13 to 22, in Ulakhan Sykkhan alas (62° 09'05" N, 130° 31'25" E) within the framework of a GAME project. We made five pits on a 500 m-line in the alas with 100 m interval and a pit in forest near the alas (Fig. 1). No.1 is located in forest, No.2 , No.5 and No.7 are in center, south and north edges of alas, respectively. In this paper, we describe mainly the soil properties of No.2, and No.5 and No.7. (See the report of Mizoguchi et. al (2000) for all sites)

Methods

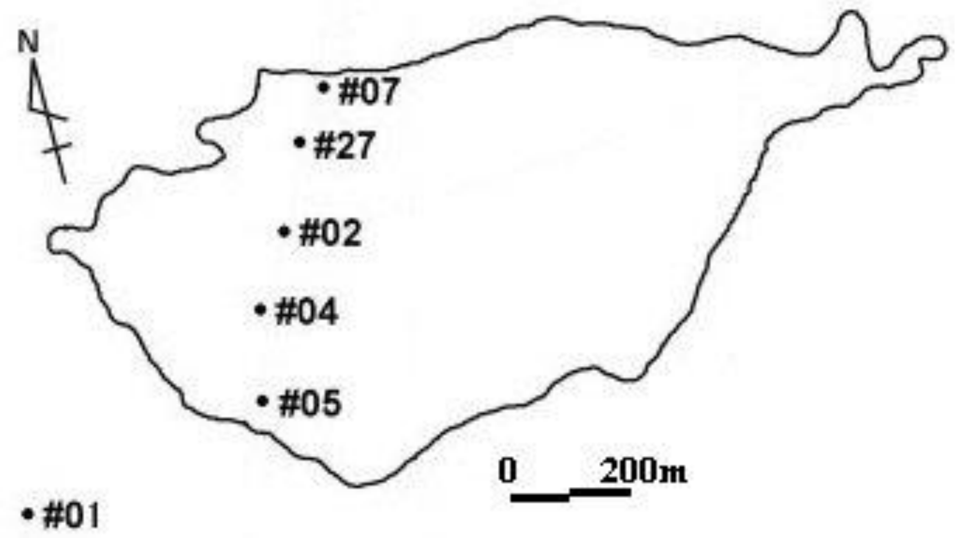
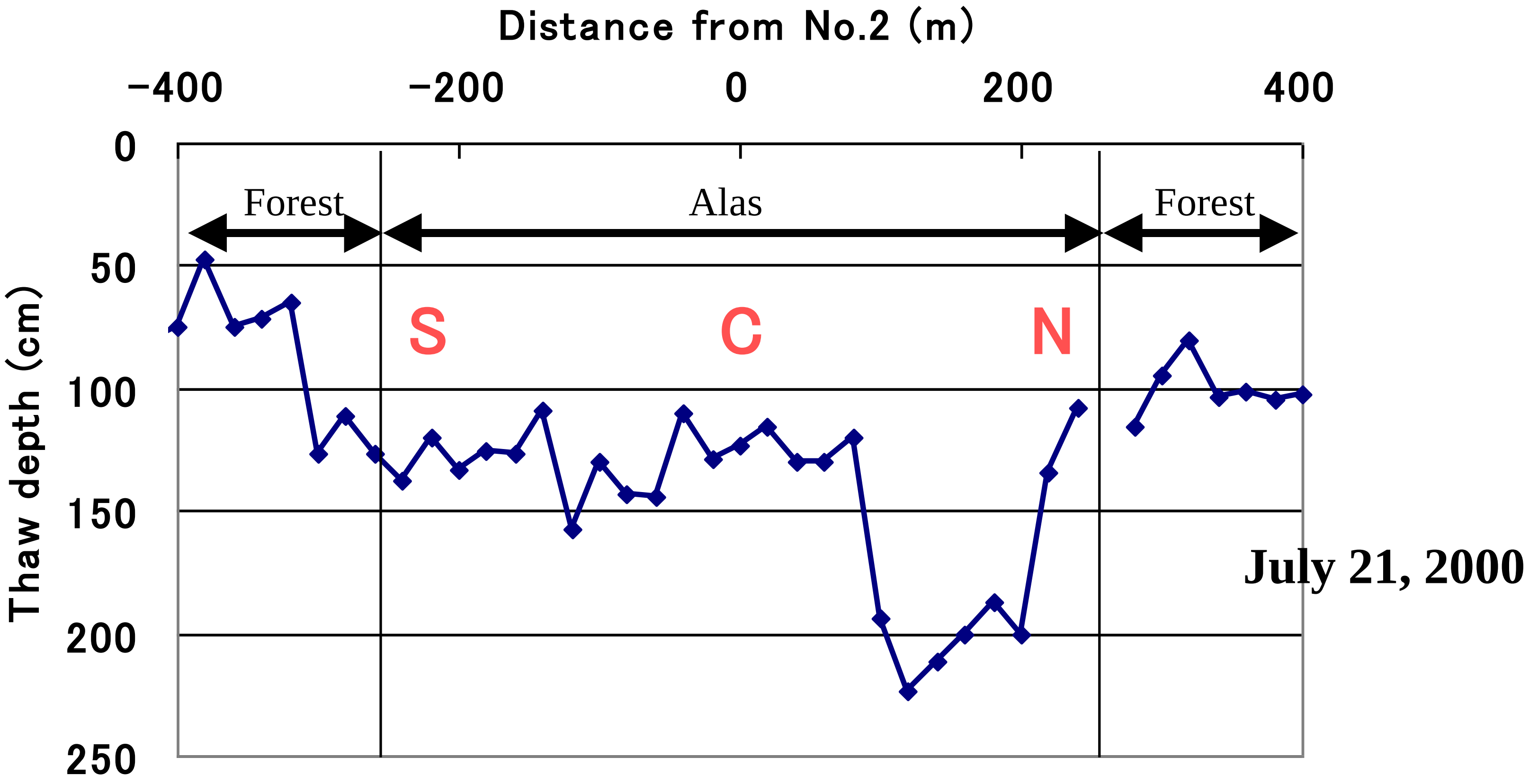


Fig. 1 Location of observation pit in alas

- Immediately after made a soil profile until the permafrost table, we measured in-situ soil properties: soil temperature of the profile by a thermometer, volumetric water content by a TDR (Hydrosense, Campbell Scientific Australia Ltd., Australia), electrical conductivity of soil pore water by a sensor (Sigma probe, Delta-T Ltd., UK), and hardness by a cone penetrometer (Yamanaka, Daiki, Japan) in each 5 cm interval. Then we collected three 100 cm^3 samples in 5 cm interval depth at each pit and measured bulk density, water content, organic matter content and hydraulic conductivity for the samples imported in Japan.

Fig. 2 Thaw depth distribution along a south to north line



- Figure 2 shows thaw depth distribution along a south to north line on July 21, 2000. The X-axis denotes the distance from No.2. Alas is located between -300 m and 270 m while forest is in the area < -300 m and > 270 m. The thaw depth was larger in alas than forest. In alas, it was larger in northern than southern area. Note that the thaw depth were over 200 cm in the northern area between 100 m and 200 m. The thaw depth difference in the direction may be dependent on sunshine, vegetation and soil physical properties.

- Photo 1 shows pictures obtained in six soil profiles at each pit. Soil profiles had unique aspects for each pit and depth. Horizontal layers were observed in the soil profiles of No.1, No.5 and No.4, but mixed layers were found in the profiles of No.2 and No.7. These observations indicate that soil profiles are different at each pit apart from only 100 m and that all soils in alas are not always susceptible to cryoturbation.

Fig.3 Soil temperature profiles

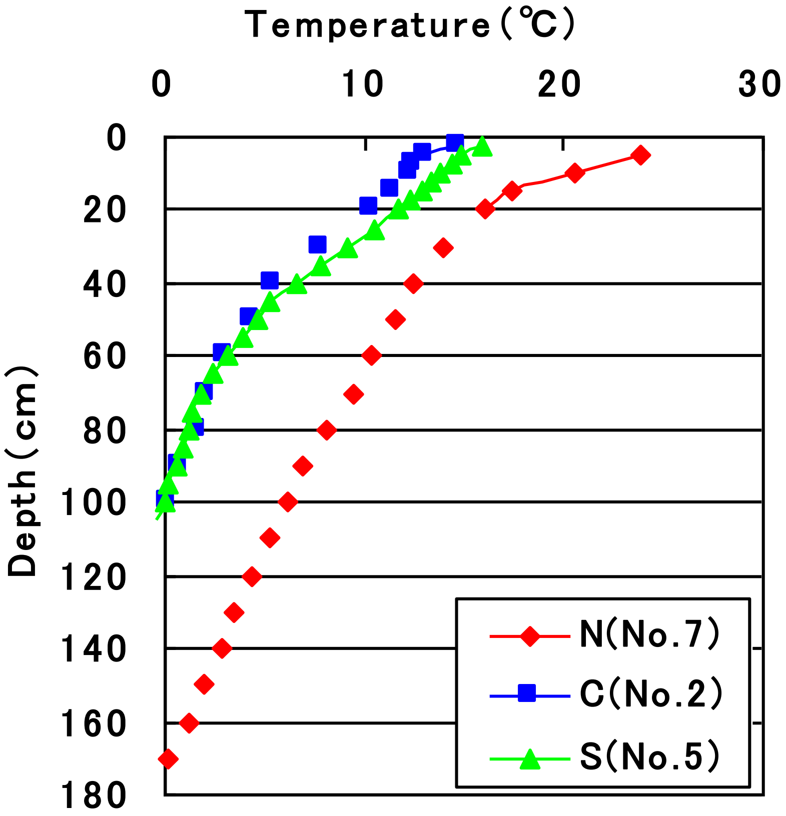
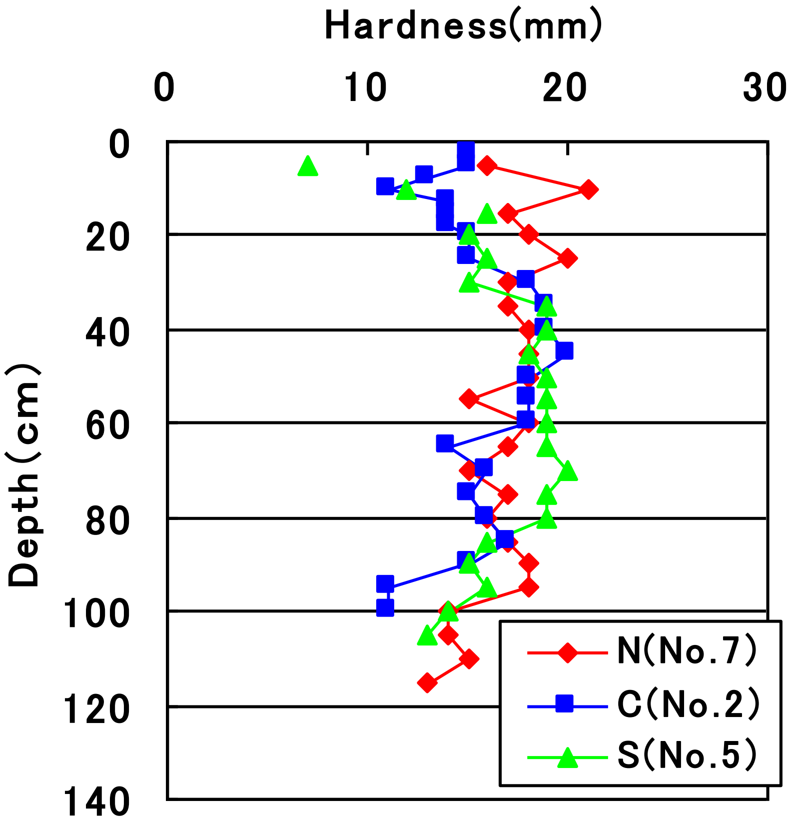


Fig.4 Soil hardness



- Figure 3 shows the temperature profiles at each pit.Although the temperature might increase slightly due to thermal conductance from the surface of the profile during digging a pit, the temperature decreased gradually from the ground surface to the permafrost table; especially the temperature decreased linearly under about 40 cm depth and reached to 0 degree at the permafrost table. This indicates that the variation of air temperature, thermal wave, penetrates until at most 40 cm and that the steady-state heat flow occurs in the soil under 40 cm. In addition, this figure shows that the active layer thickness, the maximum of thaw depth, is different at the pits, which is correspondent to the Fig. 2. This suggests that the thawing process of frozen soil depends on the soil thermal properties.

- Figure 4 shows the soil hardness measured by inserting a cone penetrometer horizontally from the surface of the soil profile. The hardness was small in the topsoil except No.7. This is attributed to the characteristics of the topsoil such as bulk density, water content and organic matter content. Indeed, Tanaka et. al (2001) showed the spatial distribution of organic matter content and bulk density along the same line in the alas.

Fig.5 Volumetric water content by TDR

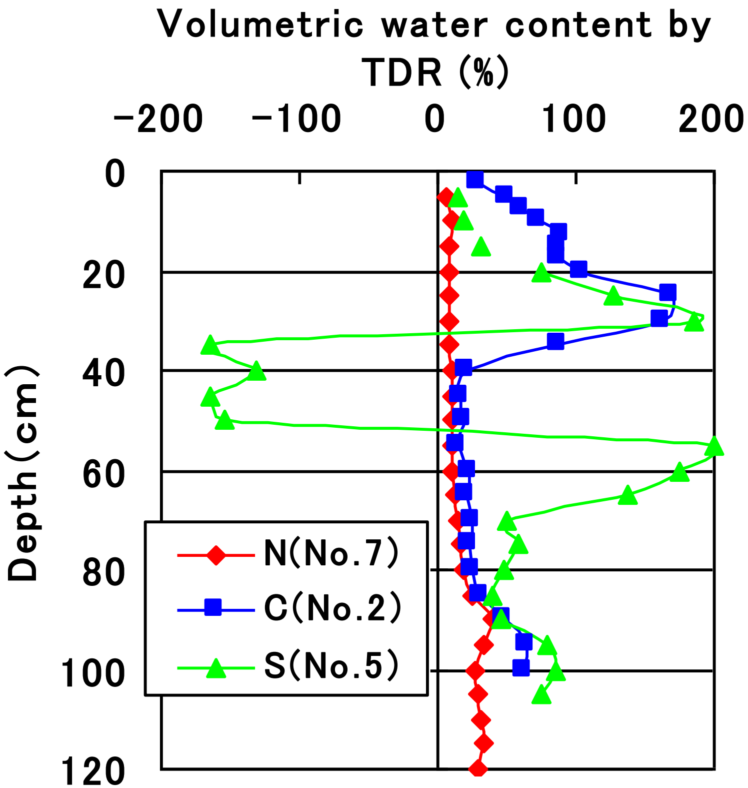
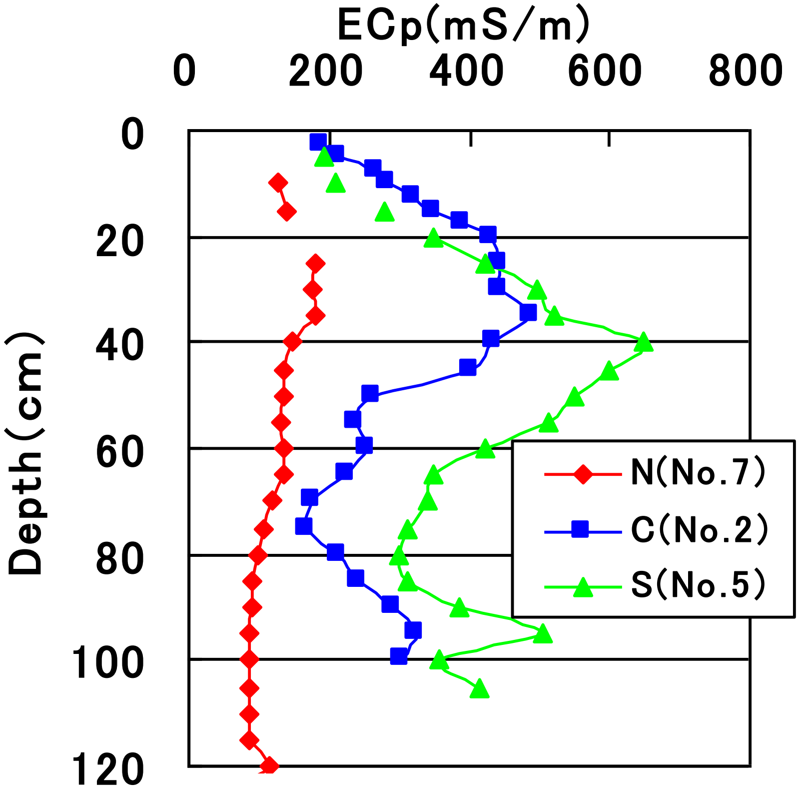


Fig.6 Electrical conductivity of soil water, ECp



- Figure 5 shows the volumetric water content in-situ measured by a TDR (Hydrosense). Although the value of volumetric water content must be 0-100 % theoretically, the values over 100 % or under 0 % were recorded in the soil layer of 40-60 cm depth at the pits of No.5 and No.2. On the other hand, the values within 0-50 % were obtained at the pits of No.1 and No.7. Generally TDR method is known to be not valid for saline soil. Indeed, as shown in Fig. 6 electrical conductivity of soil pore water was high in the soil layer with extraordinary volumetric water content. Therefore the values measured by this TDR sensor are unreliable for the real volumetric water content but are quite important to indicate the fact that the extraordinary soil layer exists in about 40 cm depth in the alas.

- Figure 6 shows electrical conductivity of soil pore water (ECp) measured by Sigma probe (Delta-T Ltd., UK) which was newly developed recently (Hilhorst, 2000). According to the manual, the probe can measure ECp for the soil with the volumetric water content over 10%. Therefore some data are deficient in the topsoil of which water content was low. Nevertheless data shows that ECp is much higher in the layers near 40 cm depth at the pits of No.5 and No.2 than in the pit of No.7. The high electrical conductivity is due to soluble salts in the soil pore water although we do not know the origin of the salts. Nonetheless the fact that there is the saline soil layer is important information to characterize alas soil.

Fig.7 Soil bulk density

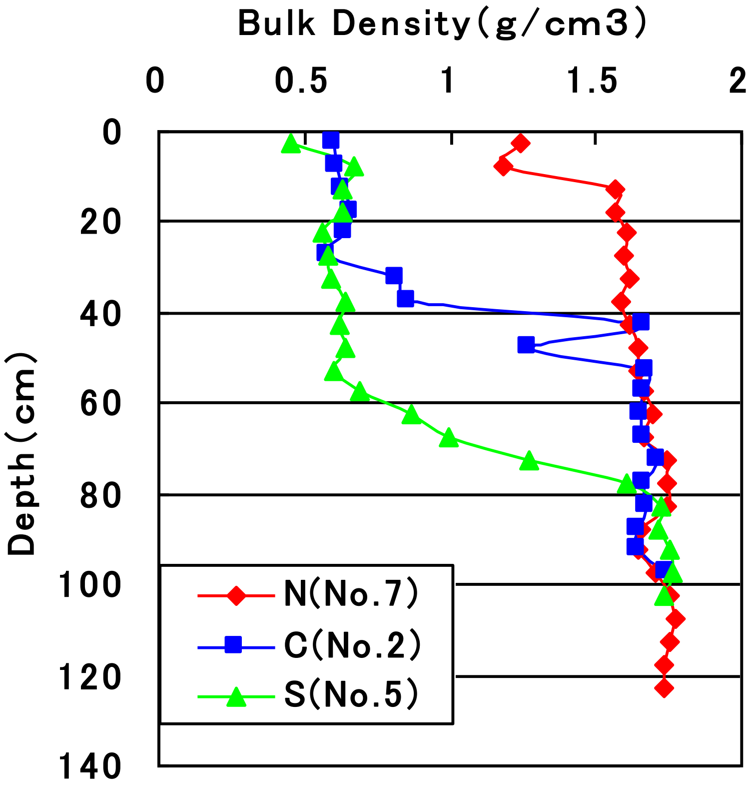
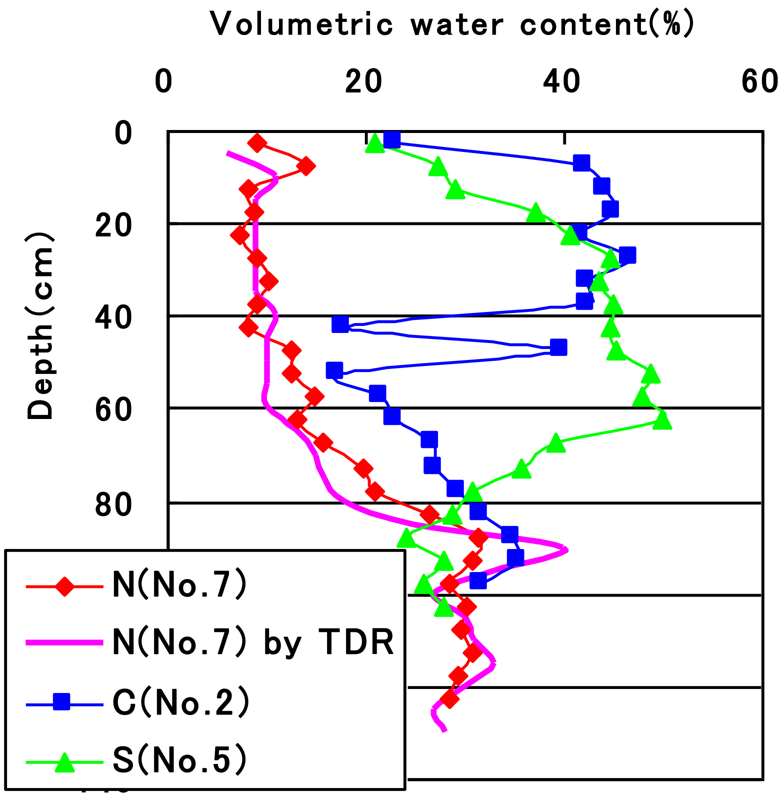


Fig.8 Volumetric water content by oven-dry



- Figure 7 shows soil bulk density measured for the imported samples. The bulk densities of the topsoil of 0-40 cm depth at the pits of No.5 and No.2 are 0.5-0.6 g/cm3 while those of the subsoil are about 1.5 g/cm3. On the other hand, only a thin topsoil of about 10 cm has low bulk density and the subsoil has high bulk density at the pit of No.7. The low bulk density of topsoil may be related to the organic matter content; the bulk density of topsoil is low because the soil contains much organic matter while the bulk density of subsoil is high because the soil is sandy and contains less organic matter.
- Volumetric water content measured with the oven-dry method is more reliable than the water content measured by TDR. Figure 8 shows volumetric water content measured with the oven-dry method for the samples at each pit. A solid line is the volumetric water content measured by TDR at the pit of No.7. The water content of topsoil is relatively high at the pit of No.2 while low at No.7. At the pit of No.5, the water content is high in the layer of 20-60 cm depth where the electrical conductivity of soil pore water is high and TDR method cannot be used.
- Since the values by TDR and oven-dry method for No.7 are in agreement, we can judge that TDR method was applicable to the soil at No.7. Therefore the extraordinary values by TDR for No.2 and No.5 in Fig. 5 are attributed to the high salt content (> 300 mS/m).

Fig.9 Organic matter content

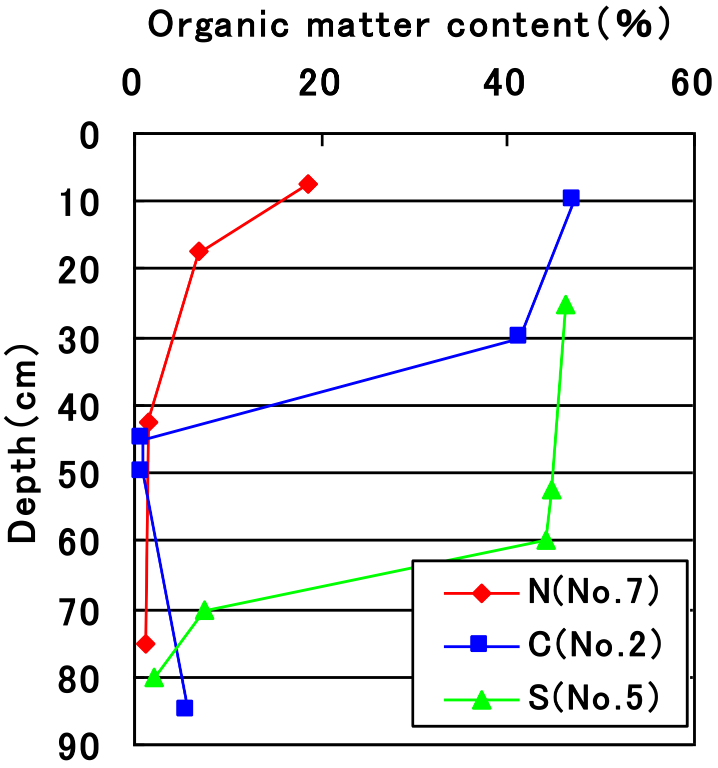
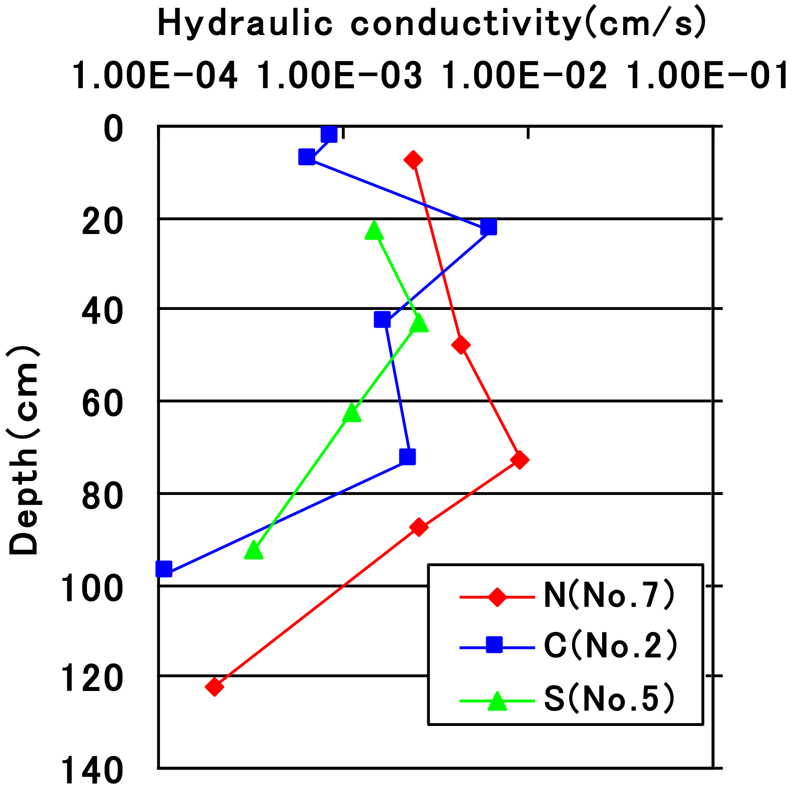
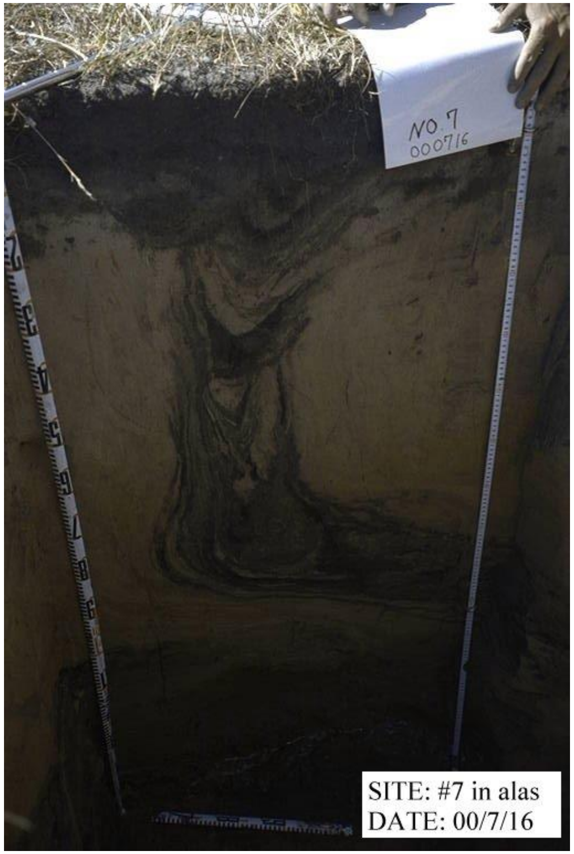


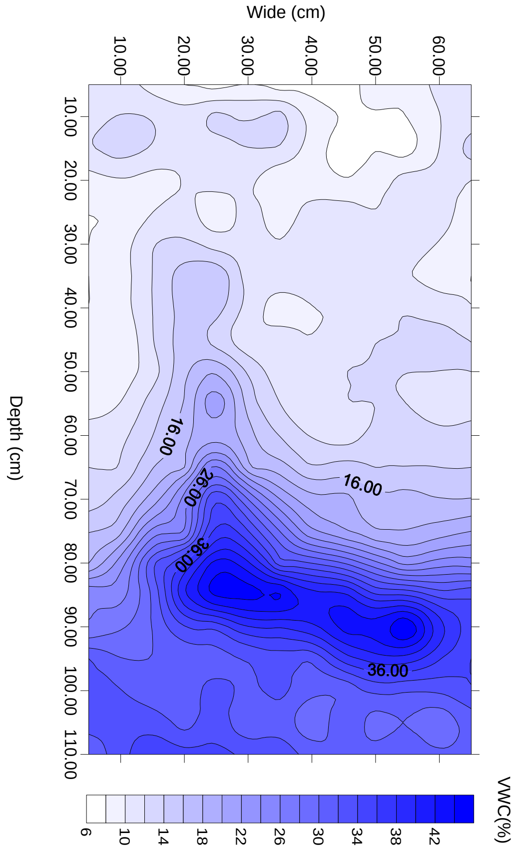
Fig.10 Hydraulic conductivity (HC)

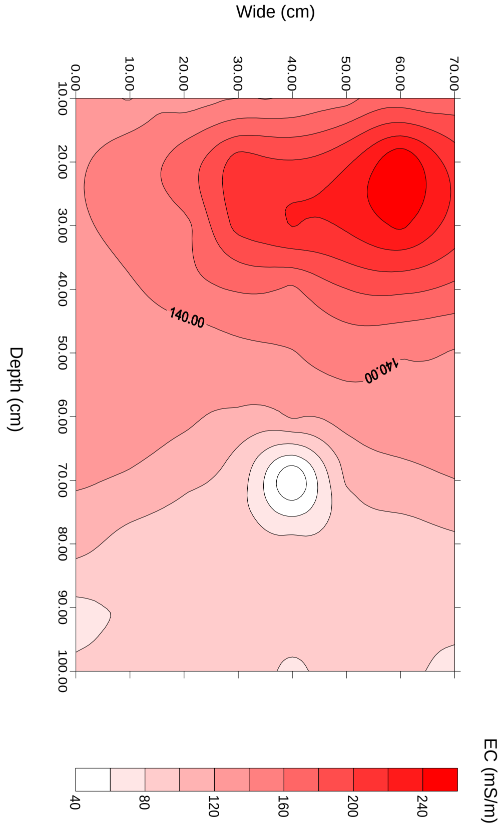


- Figure 9 shows ignition loss for the typical soil at each pit. The ignition loss is normally used as an index of soil organic matter content. Organic matter content of the topsoil was lower in forest than alas. In alas, it was higher at the pits of No.5, No.2 than No.7. This result indicates that degradation of organic matter is slower at No.5 and No.2 than No.7. In other word, the degradation of organic matter is so fast at No.7 that soil may become sandy and increase hydraulic conductivity, then accelerate thaw of frozen soil.
- Figure 10 shows hydraulic conductivity (HC) measured with a falling-head permeameter method for the typical soil at each pit. The HC is high in the upper layer and low in the lower layer. This result indicates that water moves easier in the upper layer than lower layer. That is the reason why the "streamline" patterns were formed naturally in the profile of the pit of No.7 as shown in Photo1.

Fig.11 Contour maps of volumetric water content and ECp







- Figure 11 shows contour maps of volumetric water content and ECp measured at the grids with 5 cm interval on the surface of the profile at the pit of No.7. Volumetric water content was high in the "stream line" soil. This result means that water containing organic matter would infiltrate through macropore such as ice wedge and change the stream direction because the hydraulic conductivity is much lower in the bottom than the upper layer of No.7.

Mocropore

- Photo 1 (right) shows a macropore by insect, ant or tiger beetle, pictured in the deepest area of thaw depth after pouring white paint. The macropore was 5 mm in diameter and over 50 cm in length, and developed vertically from the ground surface. There were a lot of macropores at the density of 30 holes/m^2 in the area. Judging from the fact that macropres as shown in photo 1 were found in the soil heaped up when we made the pit, the macropres should be built by insects who crawled out of lower soil layer for only a few days. If the macropres are held under snow in winter, snow-melt water will flow and transport heat through the macropores into the lower frozen soil in spring, then frozen soil will thaw faster than the other area without macropore.
- The spatial distribution of thaw depth in alas will be made by several factors such as sunshine, vegetation and soil physical properties. Our finding of a insect macropore suggests that bypass flow of snow-melt water though macropores is one of important factors to explain the thaw mechanism of frozen soil in alas. In any case, it is interesting that thaw rate of frozen soil in large alas can be controlled by small insects living there.

Conclusion

- We measured the soil physical properties in six soil profiles of active layer on a 500 m-line in Ulakhan Sykkhan alas during the summer of 2000. The soil physical properties had unique aspects for each pit and depth along the line of only 500 m distance. Especially, two facts are important to understand soil in alas; saline soil layer exists in about 40 cm depth and vertical macropores are built by insect in the area where frozen soil thaws fast. The soil physical properties, including macropore, are important to understand the thaw mechanism of frozen soil in alas.

References

- Hilhorst, M.A., 2000: A pore water conductivity sensor, Soil Sci.Soc.AM.J, 64, 1922-1925
- M. Mizoguchi, K. Watanabe, K. Fukumura and H. Kiyosawa, 1999: Spatial distribution of active layer on a hillslope in Siberian tundra, Proceedings of 3rd International Science Conference on the Global Energy and Water Cycle, 302-303
- M. Mizoguchi, N. Kondo, H. Tanaka, H. Kiyosawa, 2001: Soil Physical Properties in Soil Profiles of Active Layer in Alas, Eastern Siberia, Activity Report of GAME-Siberia 2000, GAME Publication No. 22, 111-122
- H. Tanaka, M. Mizoguchi, N. Kondo, H. Kiyosawa, R.V. Desyatkin, Y. Ishi and H. Yabuki, 2001: Spatial distribution of Topsoil Characteristics and Active Layer in Alas, Eastern Siberia, Activity Report of GAME-Siberia 2000, GAME Publication No. 22, 123-126