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Soil Characteristics of Forest Ecosystems in Circumpolar Region (Extended Abstract)

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1. Introduction

Zonal distribution of vegetation and soil along the climate gradient is widely accepted knowledge of ecology in northern hemisphere (Archbold 1995, Aber and Melillo 2001). Podzolic soils and organic soils developed under cold climate with evergreen coniferous forest is typical biome in circumpolar region (Larsen 1980, Jarvis *et al*., 2001). However, FAO world soil map showed a different pattern of soil distribution in northeastern Eurasian continent (FAO 1978, 1993). The zonal distribution is interrupted at the eastward of the Yenisei River, where continuous permafrost is prevailing at relatively lower latitude, about 60 degree N (Brown *et al*., 1997). Moreover, larch, deciduous conifer dominates in the vast area of northeastern Eurasia where continuous permafrost exists. Evergreen taiga limit and southern boundary of continuous permafrost distribution broadly coincide in North America and Scandinavia. Tundra biome occurs on continuous permafrost there. On the contrary, deciduous forests exist on the continuous permafrost in northeastern Eurasia. Podzolic and organic soils are not typical there, according to researches in eastern and central Siberia (Matsuura *et al*., 1994, Matsuura and Abaimov 1999).

Although field data of typical or representative sites in particular northern biomes should be collected to build up models for the prediction of ecosystem behavior, basic understanding and knowledge of "typical sites" is critical for further research. In other words, is it possible to deal with the circumpolar region as a uniform biome with similar structure and function in plan-soil systems? Is the accepted knowledge of typical sites in textbook of ecology really applicable to whole circumpolar region? Forest and forest tundra biomes in central and eastern Siberia showed quite different characteristics in several aspects (Kajimoto *et al*., 1999, Osawa *et al*., 2000), compared to other northern evergreen coniferous biomes. A revised understanding of circumpolar region presented in this paper, based on the field research of soil characteristics in both northeastern Eurasia and North America, will provide useful concept for comparative study on circumpolar region.

2. Soil survey sites and Datasets

Soil survey sites of northeastern Eurasia were located on ranging from 62° to 72°N latitude, from 125° to 160°E longitude in eastern Siberia, and ranging from 64° to 68°N, from 96° to 100°E in central Siberia. I surveyed twenty-four profiles in eastern Siberia, and eleven in central Siberia.

Soil surveys in North America were conducted in Interior Alaska and Northwest Territories Canada. Nine profiles were located on Caribou Poker Creek Research Watershed, northwest of Fairbnaks (65°N-145°W), and two in black spruce forests near Delta Junction (64°N-146°W). Eleven soil profiles were surveyed in Wood Buffalo National Park, NWT, Canada (59°N-61°N and 112°W-115°W). Site condition and brief description for each area is as follows.

2.1. Sites in eastern Siberia

Among 24 profiles, 12 were forest and grassland soils in Yakutian Basin, and the rest of 12 were forest tundra soils in lower Lena River, Kolyma lowland, and upper Indigirka River. Forest soils were surveyed under larch (*Larix cajanderi*), birch (*Betula platyphylla*), and pine (*Pinus sylvestris*). Grassland soils were developed on the thermokarst landscape, which is specific to ice-rich permafrost region. Soils of forest tundra were developed on the flat river terrace (Kolyma lowland), cryoplanation terrace (lower Lena), and on a slope of mountain forest tundra (upper Indigirka). Soils, except for upper Indigirka, were derived from old fluvial deposit material, with very low rock fragment content.

2.2. Sites in central Siberia

Ten profiles were located on the gently sloping landscape covered with *Larix gmelinii* around Tura, where the Nizhnyaya Tunguska River, one of big tributary of Yenisei, merges another tributary from northern Putorano Mountains. One profile was located on the southern part of Putorano Mountains, where forest tundra with lichen ground disappears on the slope of table-shaped plateau mountain landscape. Tura is located on the western boundary of continuous permafrost distribution (Brown *et al.*, 1997), and most area of Putorano Mountains was glaciated or periglacial condition in Pleistocene (Velichiko *et al.*, 1984). Most of the soils examined in central Siberia were derived from weathered basalt rock fragment and less contribution of fluvial deposit.

2.3. Sites in Interior Alaska

Caribou Poker Creek Research Watershed (CPCRW) is one of long-term ecological research sites, in which mosaic pattern with spruce, birch, and aspen stands were developed along moisture gradient and forest fire history. Five black spruce stands and four birch/black spruce mixed stands were surveyed. Rock fragment of weathered schist was common in subsoil among CPCRW profiles. Two black spruce forest soils in Delta-Junction were derived form fluvial deposit with round-shaped stones and boulders in subsoil.

2.4. Sites in Northwest Territories, Canada

Soils in Wood Buffalo National Park were derived from glacio- and/or lacustrine-deposit. Soils contained fine sand texture with boulders or platy stones that indicated glaciation process. Most part of examined area in Wood Buffalo National Park, NWT, was covered with sand dune belt, partly due to aeolian processes (French 1996). Five soil profiles were in pure jack pine (*Pinus banksiana*) stands, three in aspen stands, and three in pine/aspen mixed stands.

2.5. Methods and Datasets

Soil profiles were examined to the permafrost table or until bedrock. Soil organic carbon (SOC) storage in all soil profiles was estimated within 1-meter depth, excluding surface organic material. If permafrost table exists within 1-meter depth, organic carbon content in permafrost layer is assumed to be the same in lowest subsoil sample. Soil organic carbon and total nitrogen were analyzed by dry combustion method, using NC-analyzer (SUMIGRAPH-NC 800). Soil C/N ratios were calculated for whole 1-meter depth in all profiles. I used Mann-Whitney's U-test in comparison for C/N ratio and for SOC storage regime.

3. SOC and C/N ratio regimes in both northeastern Eurasia and North America

3.1. Soils in eastern and central Siberia

The SOC storage in both eastern and central Siberia varied site to site (Fig. 1). Large SOC storage occurred on waterlogged soils in Kolyma lowland, mountain forest tundra in upper Indigirka, and thermokarst grassland in Yakutian Basin. Soils of thermokarst grassland in Yakutian Basin showed strong alkaline pH above 8 in subsoil, with distinct carbonate-C accumulation. The average soil C/N ratios and ± 1 SD for eastern and central Siberia were 14.2 ± 5.8 and 19.8 ± 2.6, respectively, which was statistically significant ($p = 0.0021$). According to previous reviews (Anderson 1992, Post *et al.*, 1982, 1985), the average value of SOC storage in taiga biome is between 15 and 20 kg cm^{-3}, with C/N ratio above 20 in wet cool life zone. Though SOC storage regime in permafrost region of Siberia has large variation, the average SOC is higher (average = 22.6 kg cm^{-3}, $n = 35$).

Another interesting is that C/N ratios are statistically significant between soils in eastern and central Siberia, as I mentioned above. Climate in those two regions are almost the same type of severe continental condition, with hot summer/cold winter and low precipitation. Annual difference in the warmest and the coldest monthly temperature in Tura, central Siberia, and in Yakutsk, eastern Siberia are 52.9, and 62.4, respectively, from which calculated indices of continentality are 79 in Tura, and 97 in Yakutsk (Thukanen 1984). Glacial history and ice sheet distribution in Pleistocene were also similar in eastern and central Siberia (Velichiko *et al.*, 1984). Thus, the main factor that

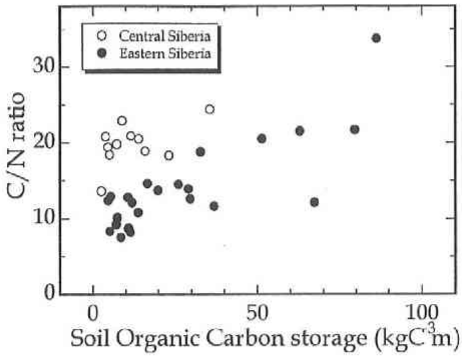

Fig. 1. SOC storage-C/N ratio diagram for soils in eastern and central Siberia.

affected soil characteristics is nature and origin of parent material. Soils derived from weathered rock fragments (weathered bedrock origin) showed high C/N ratios, on the other hand, soils derived from fluvial/lacustrine deposit of fine texture showed relatively lower C/N rations than reviewed by Post *et al.*, (1985). Typical thick fluvial deposit (Edoma) developed during Pleistocene and Holocene occurred at Kolyma lowland and Yakutian Basin. Such comparison between "bedrock-origin versus deposit-origin" may be useful for classification and evaluation of ecosystem structure.

3.2. *Soils in Interior Alaska and Northwest Territories, Canada*

Soils in Interior Alaska and Northwest Territories, Canada, showed lower regime of SOC storage than that of Siberia (Fig. 2). Spruce and birch/spruce mixed forest soils in Alaska had more SOC storage than pine soils in NWT. The lowest SOC storage occurred in a jack pine forest developed on sandy soil derived from glacio-fluvial deposit (0.59 kg cm^{-3}). The average and 1 SD of SOC in these two regions is 4.25 ± 1.85 kg cm^{-3}, less than one-fifth of average SOC in Siberian soils. More SOC storage with lower C/N ratio occurred in aspen forest soils developed on fine texture glacio-fluvial deposit.

Soil C/N ratios varied site to site, however, soils of Interior Alaska showed higher average C/N ratio than those of NWT soils (18.3 ± 4.2 in Alaska and 13.3 ± 2.4 in NWT, with $p = 0.0164$ by Mann-Whitney's U-test). These C/N ratios in higher and lower regimes between different soil parent materials indicate the applicability of "bedrock origin vs. deposit origin" ecosystem comparison under the same climate condition.

3.3. *SOC regime between northeast Eurasia and North America*

Figure 2 shows two different SOC regimes between North America and northeastern Eurasia. The SOC storage in northeastern Eurasia is significantly higher than in North America (Mann-Whitney's U-test, $p = 0.0000$, $n = 57$). Though the SOC storage values varied much site to site in northeastern Eurasia, SOC regime is larger at one order of magnitude than those of North America. The index of continentality in Fairbanks is 57, which is rather milder than eastern and central Siberia (Thukanen 1984). Therefore,

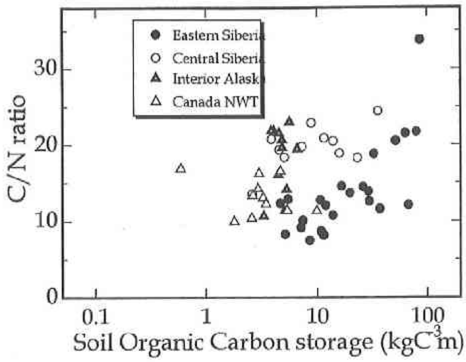

Fig. 2. SOC storage-C/N ratio diagram for soils in circumpolar forest ecosystems. Note that the X-axis is log scale.

SOC storage may be larger in North America than in northeastern Eurasia, because the milder climate condition slightly enhances productivity and litter decomposition rate in ecosystems. But the fact is that more SOC accumulated under severe continental climate condition where larch forest dominates on continuous permafrost.

Several factors that govern soil-forming process are critical even in northern biomes, where soil development occur slowly. The most critical factor that determined SOC storage regime of both regions is whether there had been glaciated or not in Pleistocene and Holocene. This geological history and ice sheet distribution is also important factor, which affected the permafrost distribution at present. Soil development on glaciated regions started from relatively young parent material; on the other hand, parent material in non-glaciated regions was rather old fluvio-lacustrine deposit that might contain secondary sediment of humus material. Thus, different SOC regimes in northeastern Eurasia and North America occur in the circumpolar region. The concept of "glaciated versus non-glaciated" is also useful for comparative study in circumpolar region.

4. Conclusions

Two conceptual framework in comparative study on circumpolar region were presented; the first is "bedrock origin versus deposit origin", and the second "glaciated versus non-glaciated" comparison. These concepts explain the different SOC storage regime and difference in C/N ratio observed in circumpolar region.

Permafrost distribution and its type (including SOC storage) is also critical factor that determines ecosystem structure and function. Better understanding of these northern biomes may lead to precise model construction and validation.

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