Fate of dissolved organic matter (DOM) in forest tundra soil systems with differing permafrost regime

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1. INTRODUCTION

Despite of a small fraction of organic matter in soils, dissolved organic matter (DOM) strongly concern with carbon and nitrogen dynamics in various ecosystems (Kalbitz et al., 2000). Biodegradation of DOM, which is probably most active in surface organic horizons, is a process to release gaseous carbon from soils to atmosphere by preferential metabolisation of carbohydrates leaving recalcitrant constituents mainly composed of lignin-derived phenols (Kalbitz et al., 2003). Sorption of DOM onto soil minerals is one of the most important geochemical processes for preservation of carbon and nitrogen included in lignin-derived and microbial synthesized acidic compounds in soils (Kaiser and Zech, 2000, Guggenberger and Kaiser, 2003). After passing through soil systems, DOM might be discharged into aquifers as allochthonous DOM in natural water systems, stream, river, ocean, and so on (Lobbes et al., 2000, Amon and Benner, 2003). These geochemical processes change not only concentrations but also compositions of DOM. The properties of DOM in aquifers are likely the consequences from these geochemical processes of DOM through soil systems.

In northern hemisphere, permafrost regime affecting temperature and moisture in soils is probably a significant control for the fate of DOM during its geochemical processes in the soil systems. The permafrost table rises from south to north changing its type from sporadic, discontinuous to continuous permafrost. This permafrost distribution results in decreasing soil temperature and stronger hydromorphy towards north. Soil moisture and temperature affects net primary production as well as accumulation and/or decomposition of litter (Wang et al., 2003, Bond-Lamberty et al., 2004). Despite of low net primary production, strong hydromorphy and low temperature at the north constraints biological activity, resulting in accumulation of organic matter at the surface accompanied by relatively high rate of dissolved organic carbon (DOC) production (Judd and Kling, 2002). Concurrently, hydromorphy also affect the formation of pedogenic oxides, which are the strong adsorbents for DOM in mineral soils (Kaiser et al., 1996, Kahle et al., 2004). Reductmorphic condition may precede dissolution of iron oxides followed by further formation of low crystalline oxides (Wada et al., 1975, Maie et al., 1998, Alekseev et al., 2003), while attenuate crystallization of the pedogenic oxides. Therefore, weathered horizons showing yellow-reddish matrix color become less pronounced from south to north in central Siberia (Guggenberger et al., 2001).

Since sorption of DOM onto soil minerals is the more rapid abiotic reaction than biodegradation in soil systems (Qualls and Haines, 1992, Kalbitz et al., 2003), deeper active layer can probably allow substantial removal of DOM from seepage water during its vertical transportation through the soil. The sorbed DOM onto pedogenic oxides by a strong chemical bond, ligand exchange (Kaiser et al., 1996, Shen 1999) could be stored in soil for a long-term period, changing into in-situ humic substances. Properties of humus in permafrost affected soils were likely originated from surface organic horizons (Dai et al., 2001). This suggests that the sorbed DOM might probably contribute to soil humus, which allows permafrost-affected soils

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to be a large global carbon sink. Therefore, the permafrost regime is a strong control for sequestration of soil organic matter as well as for microbial food web in aquatic environment.

The Yenisei is the longest river with the second largest basin area in Siberia and has the largest discharge of all rivers in the arctic region. On its way to the Arctic Ocean, the Yenisei runs through every type of permafrost, which is sporadic, discontinuous and continuous permafrost from south to north (Kotlyakov and Khromova, 2002) giving excellent conditions to study the effects of changes in the permafrost regime on DOM dynamics. The first objective of the present study is to test the sorption of DOM originating from organic horizons to the underlying mineral horizons of soil profiles having different active layer thickness. Here the difference in DOM properties depending on active layer thickness was also addressed. Concurrently, properties of humic substances in mineral soils were used to interpret contribution of sorbed DOM to the recalcitrant organic matter in soils. The second objective is to confirm the effect of DOM sorption of mineral soils on discharged DOM. The tributaries sampled as discharged DOM from soil systems along the Yenisei from south to north were analyzed to relate contents and properties of DOM with latitude and to estimate the potential impact of DOM in the aquatic environment by its biodegradation.

2. OUTLINE OF THE STUDY SITE

The area is characterized by a transition of the eastern Siberian permafrost which is in equilibrium with the present climatic conditions and the partly relictic western Siberian Permafrost (Astakhov and Isajeva, 1985). According to Jershov et al. (1988) the permafrost

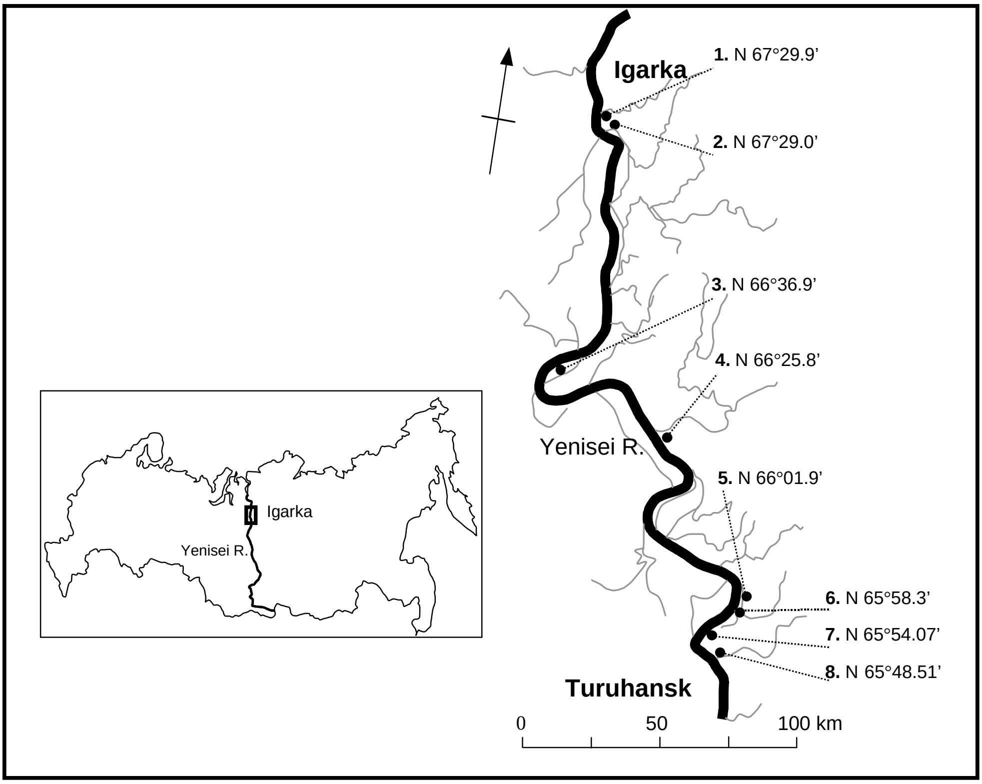

Fig. 1. Location of the study site on east bank of the Yenisei river.

temperatures are within the range of –0.1 to –2.5°C, with higher temperatures usually measured in the south (Baranovskij and Kasanskij, 1998, personal communication). These comparably high permafrost temperatures indicate a high susceptibility of the permafrost to climate change.

Parent materials in the study area are Quaternary sediments, primarily derived from the Zyryansk stage (122–59 kyrs BP) and the Karginskaya interstage (59–24 kyrs BP) of the last glaciation (Sachs, 1948). The tributaries all drained small catchments (<2 km^2 in size) of the Karginskaya terrace that is of glaciofluvial to glaciolimnic genesis (Fig. 1). The Karginskaya terrace follows the Yenisei river from Turuhansk to the mouth of the river and is composed of a homogeneous coarse silty to fine sandy substrate. The catchments were covered with *Larix sibirica*, *Picea obovata*, and *Pinus sibirica* stands, becoming less dense to the north. Towards north, mosses become more abundant. Mean annual temperature varies between –7.4°C (Igarka) and –6.8 ^{o}C (Turuhansk). Total precipitation is around 500 mm with about 50% of it during the growing season (Lieth et al., 1999).

Development of soils in the study area strongly depends on the permafrost regime. All soils showed thick mor-type forest floors. In the southern part, Guggenberger et al. (2001) found distinct weathering and enrichment of secondary Fe oxides in Bw horizons. To the north, the weathered horizons become less pronounced. Concurrently, there is a transition from only weak stagnic properties in the deep active layer of the southern soils to strong gleyic properties in the shallow active layer of the northern pedons. From south to north, Inceptisols and Gelisols appeared depending on the active layer thickness. On a catchment, similar soil transition was observed depending on the active layer thickness affected by the topography.

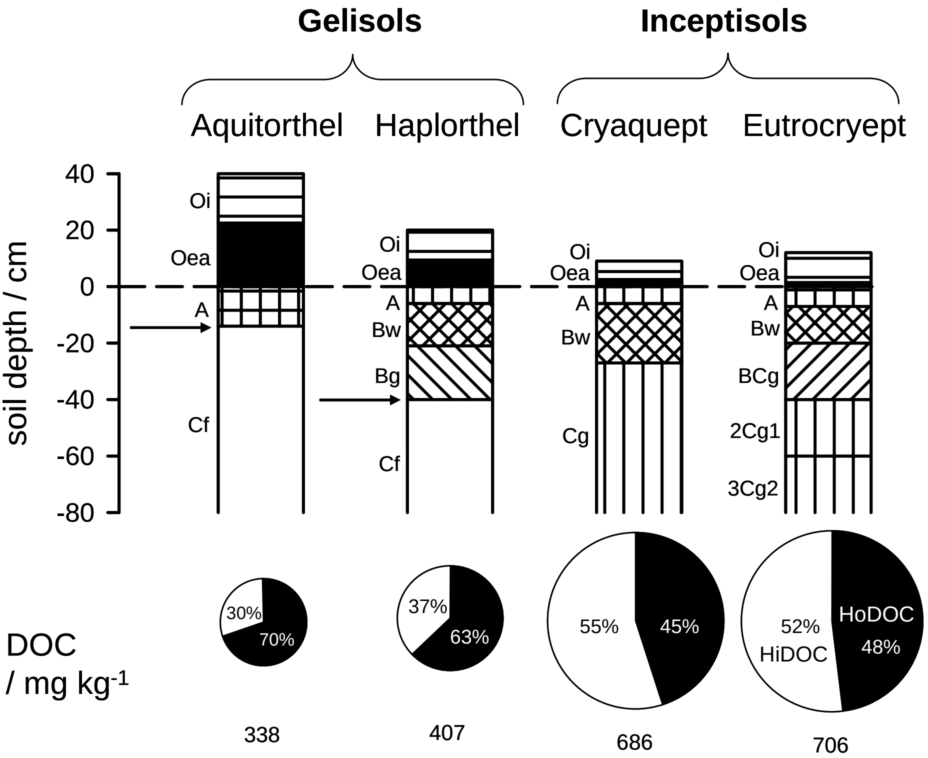

Fig. 2. Soil profiles and concentrations and distribution among fractions of DOC extracted from O horizons at soil profiles. Arrows indicate permafrost tables in Gelisols.

3. SORPTION OF DOM ONTO MINERAL SOILS

To test the sorptive control of permafrost-affected soils in Siberia on DOM dynamics in the soil systems, four soils representative for tundra ecosystems were selected at Igarka site taking account of active layer thickness (Fig. 2).

Permafrost tables were not observed at two Inceptisols but active layer thickness of two Gelisols were 14 and 40 cm. After taking soils from pits followed by air-dried and homogenized by sieving <2mm, soil samples were used for the sorption experiment. General soil properties were summarized in Table 1. DOM samples from each organic horizon, Oea, were prepared according to Kaiser et al., (1996) just before the sorption experiment. The DOM solutions were used as stocks for preparation of the working solutions.

Table 1. Descriptions and chemical properties of soils

Soil	Horizons	Depth (cm)	pH ($CaCl_2$)	C	N	C/N	Fe_{dc}[†]	Fe_{ox}[‡]	Al_{ox}	SSA[¶] (m^2 g^{-1})
				(g kg^{-1})				(g kg^{-1})		
Aquiorthel	A	14	5.9	62.3	3.4	18.3	10.0	6.5	2.2	5.2
Haplorthel	A	6	4.5	43.3	2.8	15.6	14.0	8.1	2.9	13.2
	Bw	15	6.2	12.8	1.0	12.6	14.0	6.8	1.7	28.5
	Bg	19	6.9	10.3	0.9	11.4	15.3	7.5	1.5	30.3
Cryaquept	A	6	3.9	52.0	2.4	21.6	12.2	5.1	2.9	9.0
	Bw	21	5.0	8.2	0.7	12.4	11.1	2.2	1.1	19.3
	Cg	53+	7.0	3.6	0.4	8.0	10.7	4.2	2.1	28.6
Eutrocryept	A	7	4.5	21.0	0.9	22.2	12.6	5.0	3.1	15.2
	Bw	13	4.7	13.1	0.7	19.0	11.3	5.1	3.1	21.6
	BCg	20	6.2	4.5	0.5	9.7	10.3	2.4	1.3	27.4
	2Cg1	20	7.3	5.1	0.5	10.5	9.6	2.9	1.3	20.6
	3Cg2	65	7.3	2.0	0.2	9.9	8.0	2.3	1.1	10.9

[†] dc means ditionite citrate extractable irons. [‡] ox means oxalate (pH 3.0) extractable iron and aluminum. [¶] SSA is specific surface area determined by adsorption and subsequent desorption of N_2

Sorption of the DOM on the mineral soil samples of the respective profile was tested by batch sorption experiments (Kaiser et al., 1996). Carbon concentrations in solutions before and after the sorption experiment were determined. The distribution of DOC between the hydrophilic and hydrophobic fraction after the sorption was estimated by XAD-8 column chromatography (Aiken and Leenheer, 1993). Previous research suggests that the hydrophobic fraction is composed of colored, aromatic compounds whereas the hydrophilic fraction comprises primarily polysaccharide-type biomolecules and their monomers (Aiken and Leenheer, 1993). The results of the sorption experiments were analyzed using the initial mass approach (Nodvin et al., 1986).

The relationships between the added and the sorbed amounts of DOC were linear for all soil samples (Fig. 3). From the first regression analysis of the relationship, the slope, *m*, indicates the affinity of DOM to minerals and the intercept, *b*, is relating to DOC from indigenous soil organic carbon. The values of the partition coefficient *m* indicate a stronger sorption of DOC, especially of HoDOC, to all horizons of Gelisols and A horizon of Cryaquept than to almost all the horizons of Inceptisols (Table 2).

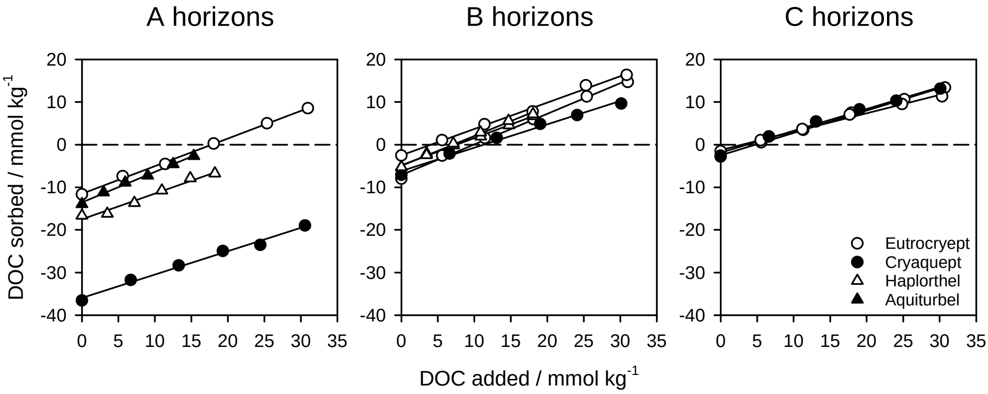

Fig. 3. Initial mass relationships for the sorption of bulk DOC to the mineral horizons of an Aquiorthel, a Haplorthel, a Cryaquept, and an Eutrocryept.

Table 2. Parameters of the initial mass isotherms of the sorption of bulk, hydrophilic and hydrophobic DOC to mineral soil horizons.

Horizons	Bulk DOC			Hydrophilic DOC			Hydrophobic DOC		
	m	*b*	r^2	*m*	*b*	r^2	*m*	*b*	r^2
Aquiorthel									
A	0.72	13.56	0.995	0.45	6.78	0.867	0.83	6.78	0.973
Haplorthel									
A	0.60	17.50	0.976	0.18	11.00	0.393	0.86	6.43	0.989
Bw	0.64	4.82	0.995	0.52	2.59	0.970	0.71	2.23	0.994
Bg	0.70	4.93	0.996	0.64	2.95	0.985	0.73	1.98	0.998
Cryaquept									
A	0.55	35.98	0.976	0.35	28.00	0.829	0.80	7.97	0.976
Bw	0.55	6.18	0.988	0.53	3.36	0.963	0.57	2.82	0.997
Cg	0.51	1.87	0.992	0.52	0.90	0.988	0.51	0.97	0.992
Eutrocryept									
A	0.65	11.50	0.998	0.65	7.13	0.998	0.65	4.38	0.993
Bw	0.72	7.14	0.996	0.70	3.62	0.996	0.74	3.52	0.996
BCg	0.62	2.50	0.995	0.62	1.02	0.996	0.62	1.48	0.983
2Cg1	0.53	2.49	0.997	0.60	1.29	0.997	0.45	1.20	0.992
3Cg2	0.43	1.25	0.993	0.53	0.56	0.995	0.33	0.69	0.983

The sorption of HoDOC seems to be controlled by the contents of iron oxides present in the soils (Fig. 4). Partial correlations with organic carbon as a controlling factor show that the partition coefficient m for HoDOC relates closely to extractable iron ($r = 0.81$, $P < 0.01$ for Fe_{dc} and $r = 0.69$, $P < 0.05$ for Fe_{ox}). This indicates that the contents of iron oxides are important controls to the soils' sorption of DOC. This agrees well with previous results for northern hemisphere forest and agricultural soils (Moore et al., 1992, Kaiser et al., 1996, Kahle et al., 2004).

Except A horizon of Cryaquept, the sorption coefficients of A and B horizons in Inceptisols were almost same between HiDOC and HoDOC. Variations in reductive and oxidative conditions might be smaller in Inceptisols due to well drainage in thicker active layers. This condition probably hampers newly dissolving iron from primary substrates, resulting in decrease active sorption sites for HoDOC in Inceptisols. Crystallized iron oxides represented by larger rate of Fe_{dc} to Fe_{ox} in Inceptisols presumably have already been occupied by preloaded DOC. Moreover clay minerals having low zero point of charge can work for HiDOC retention by Van der Waals force and/or hydrophobic interaction in these horizons.

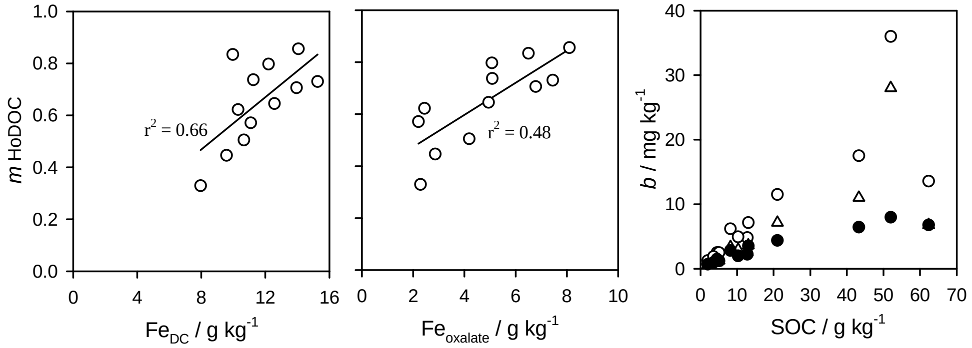

Fig. 4. Relationship between the sorption parameter (m) for hydrophobic DOC and iron extractable with dithionite–citrate (Fe_{dc}) and with acidic oxalate (Fe_{ox}); relationships of sorption parameter (b) for total, hydrophilic and hydrophobic DOC and soil organic carbon (SOC).

The Cg horizons from Inceptisols, showing relatively small partition coefficients m for bulk DOC, preferentially sorbed HiDOC. The competition between the hydrophilic and hydrophobic fraction of DOM for binding sites at the surfaces of oxides should be minimized because of repulsion between negative charges on oxide surfaces and HoDOM at pH>7 (Schlautman and Morgan, 1994). Instead, the hydrophilic fraction, mainly comprising polysaccharides, may be favorably adsorbed due to van der Waals forces (Greenland, 1971, Cheshire, 1977, Sugiyama and Kumagai, 2001). However, due to the weak bonding strength, HiDOC can be easily desorbed from mineral surfaces (Gu et al., 1994, Kaiser and Guggenberger, 2000). Therefore, the thick Cg horizons may not preserve sorbed HiDOC for a long period but just retard its efflux to tributaries when concentrations of HiDOC in the soil solution are large. During periods with small concentrations of DOM in the soil solution, HiDOC retained may gradually leach from the Cg horizons.

The release of indigenous organic carbon as expressed b value of the initial mass isotherm was largest for the A horizons and decreased with depth (Table 2). Partial correlations between contents of organic carbon and b values with the extractable iron (Fe_{dc}) as controlling factor were strong ($r = 0.79$, $P < 0.05$ for bulk DOC, $r = 0.72$, $P < 0.05$ for HiDOC, and $r = 0.98$, $P < 0.001$ for HoDOC). The linear relationship between the b values for bulk DOC and soil organic carbon (Fig. 4) suggests that the proportion of potentially soluble organic carbon was same in all tested soils. It seems that release of indigenous organic carbon depend on the quantity of organic carbon in the soils. That means that besides of the organic horizons the A horizons are also likely sources for the DOC discharged from soils, especially when the DOC concentration in the entraining solution is small. The indigenous organic carbon released from the mineral horizons was predominately in the hydrophilic fraction (Table 2). Displacement by HoDOC from the organic horizon may enhance the release of indigenous HiDOC (McCarthy et al., 1996, Kaiser and Zech, 1997), mainly in the upper parts of the soil profiles where the sorption of HoDOC is favored.

4. PROPETIES OF HUMIC SUBSTANCES

Strong sorption of DOM could influence stored carbon in soils, i.e. humic substances. To recognize the effect of DOM on carbon sequestration, properties of humic substances were investigated. Humic substances were extracted with the alkali solution (0.1M NaOH-0.1M $Na_4P_2O_7$) from the A and Bw horizons. The extract was acidified to $pH<1.5$. The precipitate and supernatant were prepared by modified IHSS method to obtain humic and fulvic acids, respectively (Kawahigashi et al., 1998). The total and inorganic carbon of the extract and fulvic acid fraction was determined using TOC-5000 (Shimadzu, Kyoto, Japan). The organic carbon of each solution was determined by subtraction of inorganic carbon from total carbon. The organic carbons in humic acid fractions were calculated from the differences between those of extracts and fulvic acid fractions. Humus composition was calculated from the proportion of carbon contained in the fulvic and humic acid fractions. The degree of humification was represented by absorbance at 600nm in a unit carbon in the humic acid fraction (Watanabe et al., 2001). ^{1}H NMR spectra of the humic acids and fulvic acids were recorded under the condition according to Kawahigashi et al., 2006. The recorded ^{1}H NMR spectra were divided into five signal regions: aromatic H, 6.0 - 9.0 ppm; carbohydrate H, 3.0 – 4.3 ppm; aliphatic H_α, 1.6 - 3.0 ppm; aliphatic H_β, 0.9 - 1.6 ppm; aliphatic H_γ, 0.6 - 0.9 ppm (Kawahigashi et al., 1996). Signal area for each type of hydrogen was calculated by electronic integration.

The extractable organic carbons were ranged between 43 and 65 % of total soil organic carbon. That seems to be larger in Inceptisols than in Gelisols and then larger in the Bw horizon than in the A horizon in each soil (Fig. 5). The lower extent of biodegradation in soil organic carbons due to stronger reductomorphic conditions in Gelisols might decrease extractability of

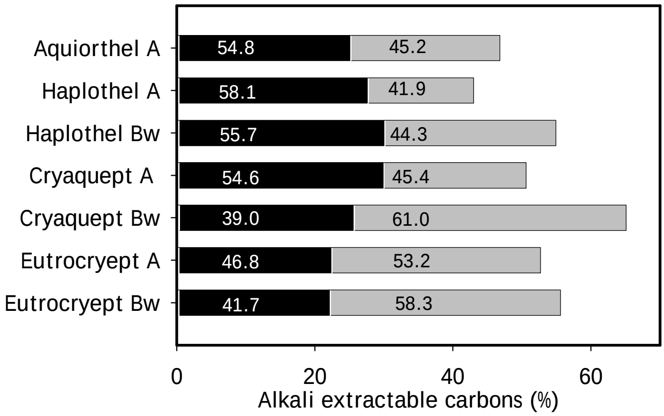

Fig. 5. Alkali extractable carbons in soils. Proportions (%) of humic acid (black bar) and fulvic acid (gray bar) were indicated in bars.

humus in alkali solution. This could be supported by the lower humification index in Gelisols ranged from 11 to 23 than those between 15 and 30 in Inceptisols. The contents of carbons in the fulvic acid fractions occupied from 53 to 61 % of the extractable carbons in Inceptisols, except A horizon of Cryaquept, while 55 to 58% of the extractable carbons were distributed in the humic acid fractions of the other soils (Fig. 5). These soils containing larger share of humic acid carbons were prone to strongly adsorb HoDOC than HiDOC (Table 2). This sorption process in these soils may probably contribute preferable accumulation of the humic acids, which is considered as the most refractory organic substances to microbial attack in soils.

From the ^{1}H NMR spectra (Fig. 6), differences in the property of organic matter probably relating to pedological processes were observed (Fig. 7).

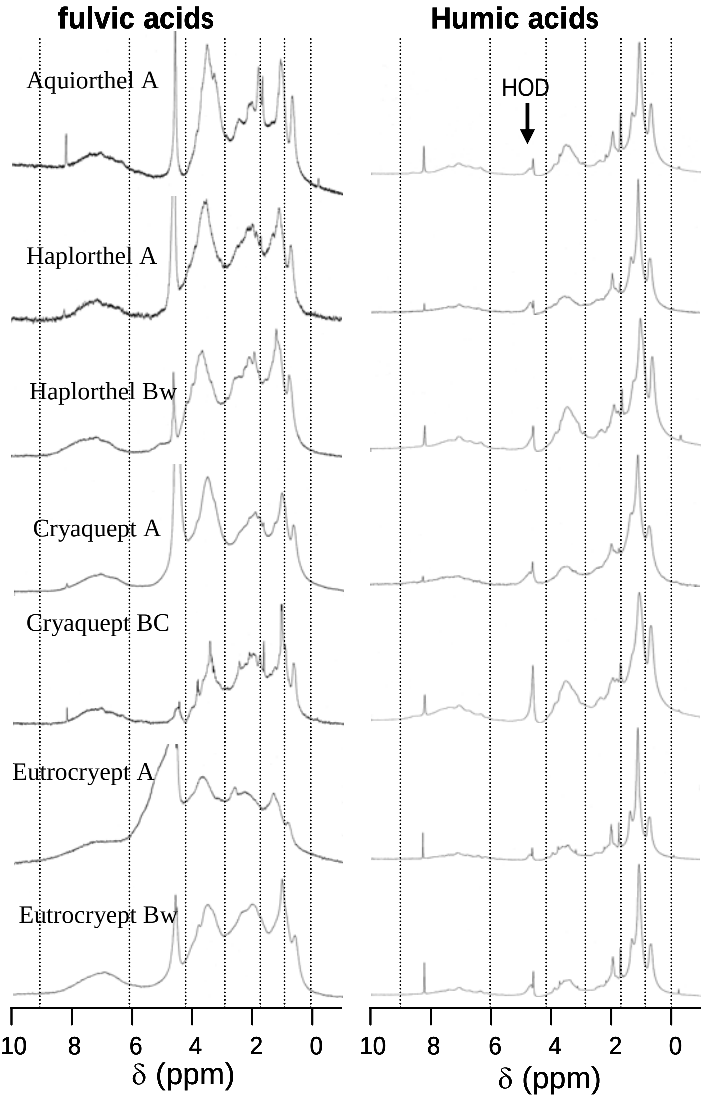

Fig. 6. ^{1}H NMR spectra of humic and fulvic acids obtained from the sample soils.

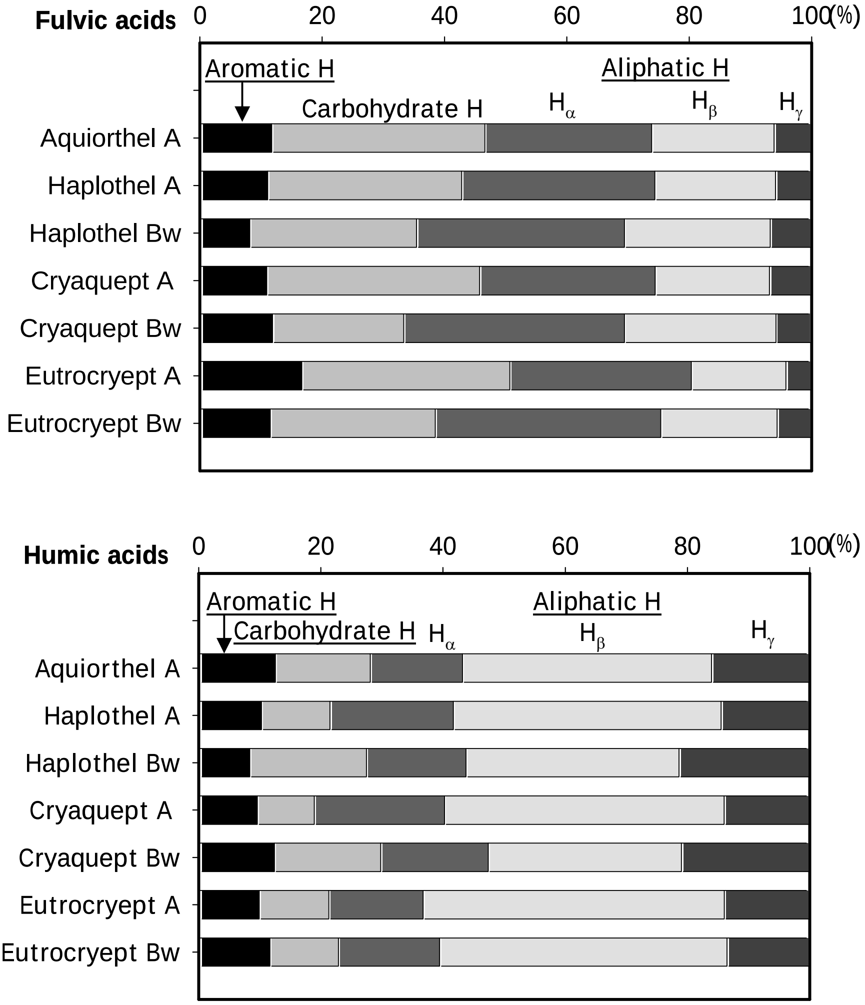

Fig. 7. Proportion of hydrogen types observed from ^{1}H NMR spectra of fulvic and humic acids.

The contribution of aromatic H was remarkably small in both fulvic and humic acids of all soils, indicating that the oxidative degradation and/or the humification of soil organic matter is quite slow due to low soil temperature resulting in the low biodegradation. Carbohydrate H, which is a substantial constituent in the fulvic acid, distributed more in the fulvic acid from the A horizon than that from the B horizon in each soil. In contrast, the humic acid contained less carbohydrate in the A horizon than the Bw horizon. The vertical decline of carbohydrates in the fulvic acids might relate to attenuation of the carbohydrate biodegradation toward the deeper horizons depending on the microbial biomass. Selective sorption of sugars originating from lingo-cellulose onto the Bw horizon, which has strong affinity to pedogenic oxides (Gugegnberger and Zech, 1994, Kaiser et al., 2004), probably contributes to the carbohydrates in the humic acids. The compositions of aliphatic H were completely different between the fulvic acid and the humic acid. The long alkyl chains originating from lipids appear to be substantial constituents in the humic acids. The rate of H_β, which can be assigned to methylene

H, was larger in the A horizons than in the Bw horizons. Concurrently, the humic acids in Inceptisols appear to contain the higher contents of lipids than those in Gelisols. These differences in alkyl chains constructing lipids appear to be relating to the density of vegetation because long alkyl chains probably originated from waxes from higher plants (Tulloch 1976). Due to low solubility in aqueous phase, lipids could be preserved in the humic acids for a long term.

5. DOM IN TRIBUTARIES ALONG THE LATITUDE

To confirm the implication of sorption for DOM discharge, the properties of tributary waters directly flowing in several catchments with differing the permafrost regime were investigated. Water samples were collected from eight small tributaries between Turuhansk and north of Igarka located at 65°49' to 67°30' latitude, along the east shore of Yenisei (Fig. 1). Time of sampling was mid August 2002, when the discharge of Yenisei was similar to the mean annual monthly discharge and well after peak flow during snowmelt (June–July). Surface water samples were collected at the outlet of the small tributaries. Total carbon, dissolved inorganic carbon (DIC) and total nitrogen were determined by high temperature oxidation (High-TOC, Elementar Analysensysteme GmbH, Hanau, Germany). Dissolved organic carbon was calculated by difference between DIC and total carbon. Nitrate and ammonium were determined by ion chromatography (DX-500, Dionex Corp., Sunnyvale, CA) and photometrically (FIA-LAB II, MLE GmbH, Dresden, Germany), respectively. Because of inorganic nitrogen (NO_3^--N plus NH_4^+-N) being below the detection limit (<0.02 mg N l^{-1}) dissolved organic nitrogen (DON) was equal to total nitrogen. The small concentrations of inorganic nitrogen are in agreement with results from other studies (Dittmar and Kattner, 2003).

Concentrations of biochemical molecules (hexoses, pentoses, amino acids, proteins and phenols) analysed by colorimetric method (Kawahigashi et al., 2003) were normalized to the DOC concentrations. The distribution of DOC between the hydrophilic and hydrophobic fraction was estimated by XAD-8 column chromatography (Aiken and Leenheer, 1993).

Biodegradability of DOM was estimated by determination of CO_2 evolution through 97 days liquid incubation experiment (Kalbitz et al., 2003). Biodegradation in this study was quantified as mineralization of organic carbon. (Kalbitz et al., 2003, Marschner and Kalbitz, 2003).

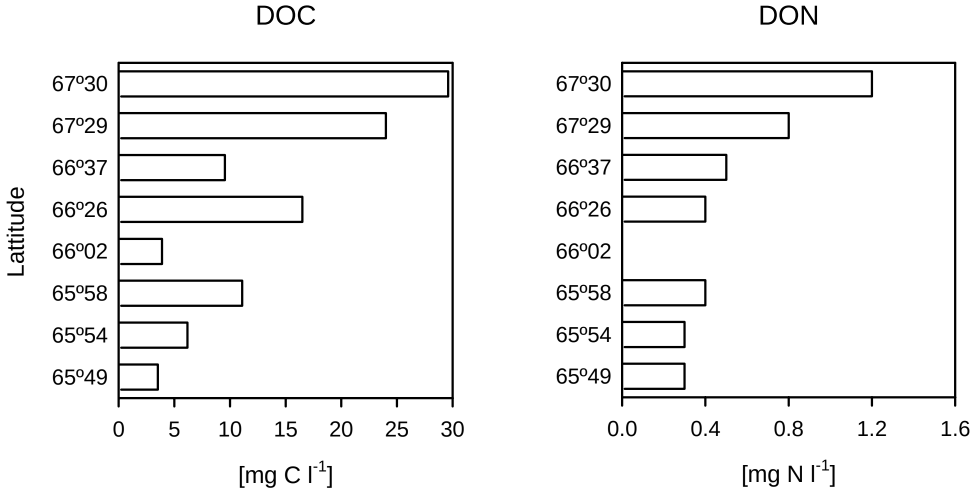

Fig. 8. Concentrations of dissolved organic carbon and nitrogen (DOC and DON).

Dissolved organic carbon and especially DON concentrations increased with increasing latitude (Fig. 8) and were significantly (*P* <0.01) correlated to each other (*r* = 0.92). Export of DOC and DON appear to be controlled by the active layer thickness (MacLean et al., 1999). The contents of oxides and its sorption capacity for DOM under the field condition could be effective for the DOM preservation in mineral horizons (Table 1 and 2). While surface and subsurface horizons in Gelisols have larger contents of iron oxides as well as the high efficiency of sorption DOM, thickness of mineral soil horizons were less than Inceptisols. Weak sorption but frequent contact of mineral surfaces for percolated DOM might decrease initial DOM concentrations in southern soil ecosystems.

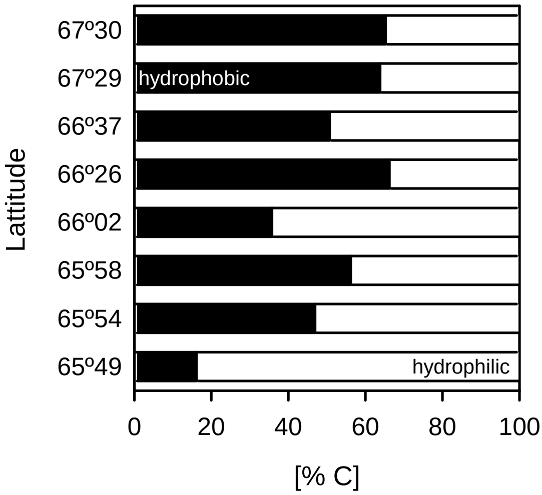

Fig. 9. Proportions of hydrophilic and hydrophobic organic fractions in the sampled stream waters.

The larger removal of HoDOC during percolation through Inceptisol profiles probably increases the rate of HiDOC in the discharged water at southern tributaries (Fig. 9). However mineral soils in Northern Gelisols also prefer to retain HoDOC. Its strong sorption of HoDOC should increase HiDOC in discharged waters. The high rate of HoDOC in northern tributaries should be compensated by additional input of initial DOC, which was occupied by 70% of HoDOC (Fig. 2), by lateral flow on ground surfaces. At the north, strong hydromorphic soils underlain by permafrost can be prone to prevent infiltration of seepage water and probably directly drain as surface running water (Quinton et al., 2000, Carey and Woo, 2001, Carey, 2003).

The yield of DOC being identified decreased from south to north (Fig. 10). While the contribution of sugars to DOC was larger in the southern than in the northern streams, the

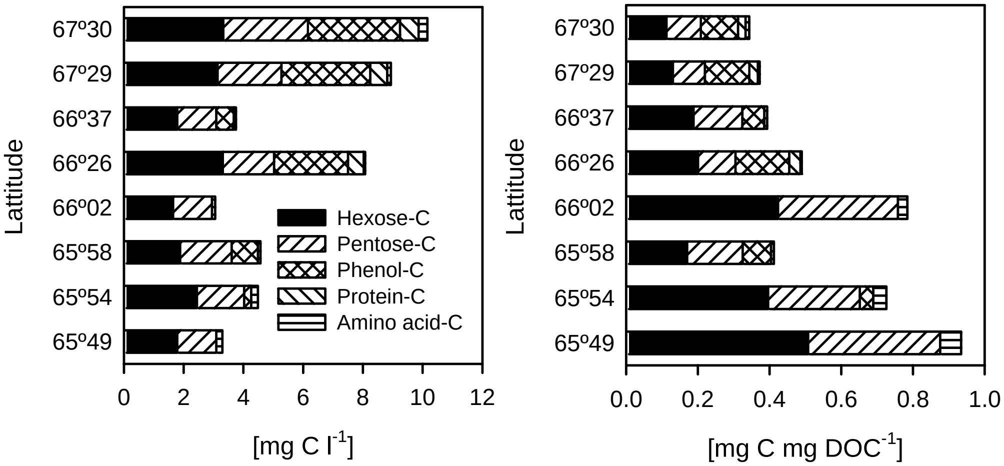

Fig. 10. Concentrations and distributions of organic compounds in the sampled stream waters.

contribution of phenols to DOC tended to increase from south to north. Hydrophilic fractions were rich in hexoses while the hydrophobic fractions were characterized by high contents of pentoses and phenols. Protein occurred only in hydrophobic fractions. The contribution of lignin-derived phenolic acids by direct input of lateral flow on ground surfaces is probably large at the northern tributaries. At the south, the plant derived constituents, such as phenols and pentoses might be preferentially removed by sorption onto minerals. Moreover, hexoses consisting of microbial products seem to be largely incorporate into DOM in the southern tributaries during vertical percolation in soil systems. This indicates that in the north larger proportions of plant-derived compounds, probably lignocelluloses, enter the streams. Vice versa, the proportions of carbon in hexoses increased from north to south, suggesting larger contributions of microbial products (Guggenberger and Zech, 1994).

This composition of DOC seems to relate to mineralization of DOC. After 97 days incubation, 4–28% of the initial DOC was mineralized (Fig. 11). This result appears to fit the carbohydrate contents in DOC (Fig. 11). The proportion of mineralized carbon was significantly ($P<0.05$) larger for southern samples than for northern samples. The large proportions of sugars are likely the reason for the relative high portion of biodegradable carbon found for samples taken from the most southern streams (Volk et al., 1997; Kalbitz et al., 2003).

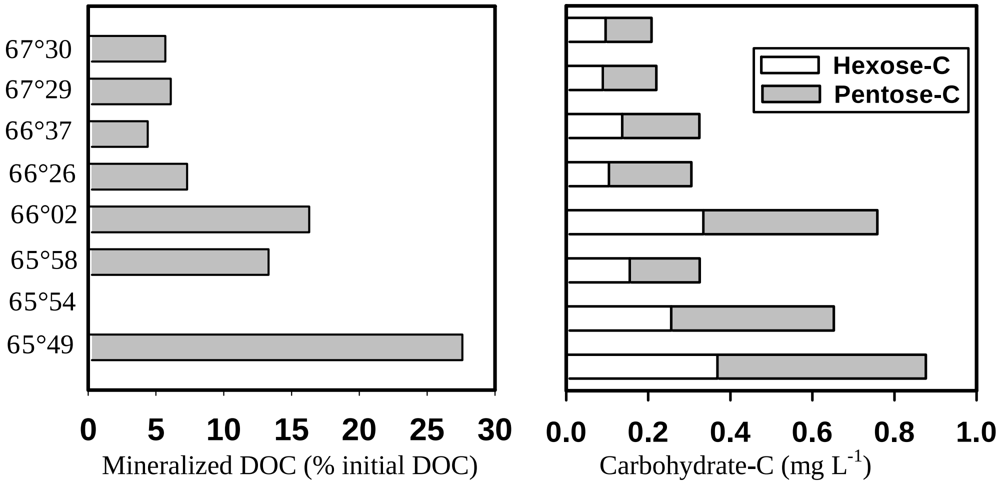

Fig. 11. Proportion of mineralized DOC and carbohydrate-C to initial DOC of tributaries with latitude.

In contrast, larger proportions of lignin-derived phenols in the HoDOC seem to represent the most refractory DOM components (Qualls and Heines, 1992) and thus appear to be preserved from the biodegradation. The refractory and hardly degradable DOM in northern tributaries suggest that the northern basins of high latitude rivers, underlain by continuous permafrost with shallow active layers, are the major source for the large inputs of terrigenous DOM into the Arctic Ocean (Opsahl et al., 1999, Lobbes et al., 2000).

6. FATE OF DOM ALONG PERMAFROST REGIME

In summary, the composition of DOM produced in organic horizons changes during the vertical percolation due to preferential sorption of HoDOC in the A and B horizons and due to concurrent release of indigenous HiDOC, especially in A horizons (Fig. 12). The preferential retention of HiDOC by C horizons, were present, may buffer the release of HiDOC. Nevertheless, in all soils the DOM discharged vertically should be dominated by HiDOC. The proportion of HiDOC therefore seems to be a function of the thickness of organic horizons and the depth of mineral soil horizons, and thus be a direct consequence of the permafrost regime. In northern Siberia, with soils having shallow active layers, lateral flow of DOM from the organic horizons may increase the portion of HoDOC in tributaries as compared with the soil having deep permafrost table where much of the discharge is due to vertical percolation.

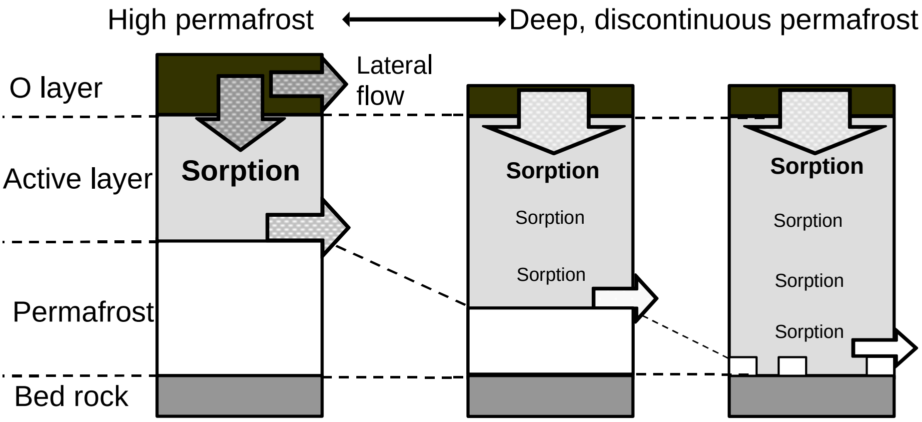

Fig. 12. Illustration of flux of DOM along with decreasing the permafrost table. Sizes and color density of arrows mean concentration of DOC and contribution of hydrophobic DOC in total DOC, respectively.

Thickening the active layer by the permafrost degradation slowly by global warming and rapidly by the forest fire will change soil temperature and moisture. The oxidative condition will promote the degradation of organic horizons and thus will change the produced DOM into the greater share of hydrophilic DOC. Concurrently, well drainage after decreasing the permafrost table might increase removal of HoDOC from percolating water by increasing DOM contact with thicker mineral horizons. Both the decrease in HoDOC in the initial DOM and subsequent HoDOC removal by mineral soils probably induce drastic decrease of HoDOC discharge into the aquifer and may change carbon cycling in the terrestrial ecosystems of Siberia.

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