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Preliminary Measurements on Methane Content in Permafrost, Central Yakutia, and some Experimental Data

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ABSTRACT

The concentration of methane in air bubbles within permafrost was sampled from both alluvial deposits and ice wedges in Eastern Siberia. The values of methane concentration were as high as 6000 ppmv in both frozen soil and ice wedges. The anti-proportional relationship between methane and carbon dioxide concentration values in permafrost was examined. Values of methane concentration in ice wedges are smaller than those in frozen soils. Values of total volumetric air content, water content and density were obtained by on-the-spot investigation. Increases of methane and carbon dioxide concentrations were detected in accordance with increases of water content of frozen soil. Geologically older permafrost contained higher values of methane concentration than younger permafrost. Samples of frozen soils were incubated at temperature −5 °C in order to study possible methane production. A slow production in different soils was observed, although the experiments took a long time before measurable changes of methane content could be found. The rate of methane production decreases in time; therefore, long-term forecasts of methane content in frozen soils are still problematical. Copyright © 2002 John Wiley & Sons, Ltd.

KEY WORDS: frozen soils; permafrost; methane; carbon dioxide; Siberia

INTRODUCTION

Methane (CH_4) is one of the most effective greenhouse gases. It is important to identify sources of methane and to estimate the total flux of methane on a global level. Present northern ecosystems that include the cryolithosphere and its vegetation indicate that they contain about 500 Gt of carbon (Gorham, 1995). The majority of carbon stock is stored in the active layer as dead organic matter and in the uppermost layers of the permafrost. It is considered that the decomposition rate of organic matter in permafrost is very slow, and results in removal of carbon from circulation for thousands of years (Gorham, 1995; Clymo and Hargreaves, 1994; Clymo, 1996). However, studies demonstrate that microbial processes can be active in cold (0–5 °C) and even frozen soils (Mazur, 1966, 1970, 1980; Coxson and Parkinson, 1987; Janssen and Bock, 1994). Also, Gilichinsky (1993) and Gilichinsky and Wagener (1995) report upon the extraction of living microorganisms from permafrost. Therefore, there is some possibility for methane production under cold environments. It has been found that the methane concentration at the beginning of winter in the active layer is less than at the end. For example, methane in the active layer in the winter period is about 100 ml/kg, and is larger by four to nine times than in summer

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(Glotov, 1991). There is a methane flux at negative temperatures of up to 0.05 g/m^2 a day (Ota *et al.*, 2000). Reported methane emissions in tundra are about 80 mg/m^2 a day in summer. However, winter emissions of methane are poorly known. Because permafrost is almost entirely impervious, gases can be trapped in ice and empty pores for a long time. It is suggested that permafrost contains 40 ml/kg CH_4 on average (Pearce, 1989). Methane concentrations in permafrost at the Bovanenkovo gas field are ≈500 ml/kg in gas-saturated layers (probably as a gas hydrate) and ≈5 ml/kg in others (Yakushev and Chuvilin, 2000). Edoma deposits on the Arctic coast of Siberia contain up to about 10,000 ppm (Moriizumi *et al.*, 1995). This is much larger than the present atmospheric concentration (1.8 ppm). Sudden gas blowouts in permafrost have been encountered during well-drilling operations in different regions (e.g. Yakushev and Chuvilin, 2000). The flux intensity of blowouts reaches to several tens of thousands of cubic metres of gas per day. Gas hydrate accumulation at the Mallik L-38 well in the Mackenzie Delta-Beaufort Sea region of Canada has determined a total amount of about 4,284,000,000 m^3 in the 1 km^2 area surrounding the drill site (Collett and Dallimore, 1998). Ginsburg (1993) claims that the Messoyakha Gas Field, Russia, is fed by natural hydrates in permafrost. The origin of other known fields of gas hydrates in permafrost, as at Prudho Bay and elsewhere, is not explained yet.

A number of unsolved questions relate to methane in permafrost, and the measurement of methane concentrations in permafrost is of interest to many.

SUBJECT OF STUDY, LOCATION OF SITES AND METHOD

Air bubbles from frozen soil and ice were sampled in the uppermost 1–5 m of permafrost in Central Yakutia, Russia. The major study site (Neleger 62°18′54″, 129°30′04″) is located on the Tyungylyn Terrace of the Lena River. This is the second terrace and the site is approximately 25 km northwest of the city of Yakutsk. The terrace surface is covered with boreal forest (taiga); the elevation above sea level is about 200 m. Estimated depth of permafrost at the site is about 450 m and the active layer in forested areas is about 1 m thick. Other sites were located on the right bank of the Lena river along the shoreline of Lake Sirdah, and on the left bank of the Aldan River, at the locality called Mammoth Mountain.

Figure 1 Ice wedge exposed along the bank of the Aldan River, Yakutia, Siberia, about 40 m above water level.

At the Neleger site, samples for air bubbles were obtained by shallow borehole drilling, and at the Aldan River and Sirdah Lake sites block samples were cut off directly from exposures by means of a conventional chainsaw (Figure 1). Over-saturated salt water was used for the collection of air bubbles from ice and frozen soil so as to avoid additional air entry to the sample holder, which is placed on the top of a funnel in hot water. Each air sample contains 10 ml in volume. Soil composition, density and water content were also measured as well as the concentration of gases in the air bubbles. Total number of air samples was about 120. Methane and carbon dioxide (CO_2) concentrations were analysed by gas chromatography.

The massive ground ice that is defined as the *Ice Complex* or *Edoma* is distributed widely in the permafrost of Central and Eastern Siberia; it occurs in the major river valleys and was formed in the Late Pleistocene as large syngenetic ice wedges. The average thickness of the Ice Complex is about 40 m. Previous works have shown (Fukuda, 1999a) that the general tendency of methane concentration in the Ice Complex is low, with a concentration of 0.1–1 ppmv in the air bubbles of the middle layer (10–20 m deep) and a higher concentration up to 10,000 ppmv in the upper layer (0–10 m deep). The origin of the methane is assumed to be biogenetic based on the C^{13} stable isotope data (concentration about −60 ‰ on average). The storage of highly concentrated methane is assumed to occur according to the following process: in mid-summer, small water pools between the ramparts that are formed by ice-wedge growth, and peaty sediment tends to decay under anaerobic conditions. In the following autumn, the freezing front penetrates downward into the active layer, while in the lower unfrozen layers methane production is underway. The methane that is produced is then trapped in frozen material at the completion of freezing. In mid-winter, due to shrinkage of the frozen layer under severe cold, cracks tends to occur with opening distances of a few mm. In early summer, as the surface layer gradually thaws, water percolates into the cracks. Penetrated water with highly concentrated methane freezes up instantly. Repeated cycles of cracking and ice infilling may result in the storage of highly concentrated methane in air bubbles in ice-wedge ice. If so, a high concentration of methane in air bubbles may imply high summer temperatures and anaerobic conditions in the active layer. Measurements of oxygen isotope ^{18}O have shown that its concentration decreases from −25 ‰ in the upper layers to −32 ‰ in the lower layers of the Ice Complex (Fukuda, 1999a). As a major part of the water on the ground surface is water from melted snow accumulation, then the ^{18}O values indicate winter temperatures. ^{18}O values from the upper and lower layers suggest that winter temperatures in the upper layer are higher than in the lower layer. A correlation between methane concentration and oxygen isotope fluctuations has been established (Fukuda, 1999b).

RESULTS OF MEASUREMENTS IN CENTRAL SIBERIA

Results of measurements of methane and carbon dioxide concentrations are shown in Figure 2. It is illustrated that highly concentrated methane occurs in permafrost at different depths. When the concentration values of methane and carbon dioxide are compared to each other, the anti-proportional relation is obtained (Figure 3). Ratios of methane and carbon dioxide concentrations are different in frozen soil and ice. The highest values of methane concentration are found in frozen soil. On the other hand, very low values of methane concentrations occur in some parts of frozen soils. Values of methane in the many samples of frozen soils analysed exceed 1000 ppmv. Maximum value is about 6000 ppmv. The obtained values of methane from permafrost at the Neleger forest site are high in general.

Results of measurements of ice wedges at the Neleger, Aldan and Sirdah sites were different

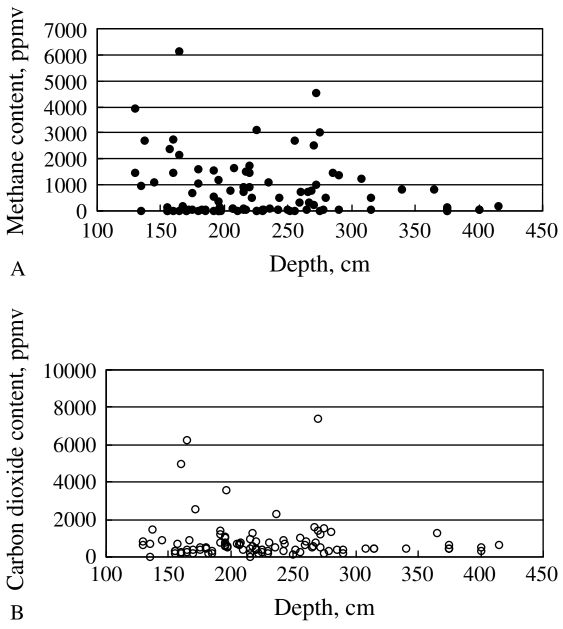

Figure 2 Content of methane (A) and (B) carbon dioxide in frozen soils.

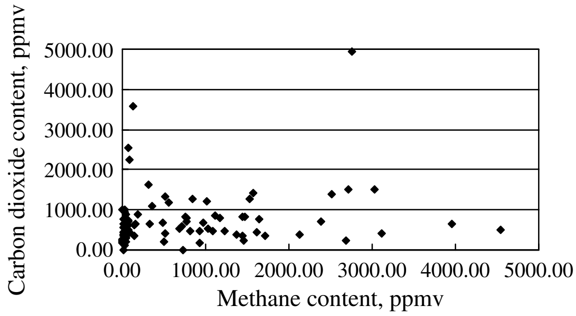

Figure 3 Relationship between methane and carbon dioxide content in permafrost.

(Table 1, Figure 4). Less concentrated values of methane in ice wedges are exhibited than those in frozen soils. In spite of lower methane concentration values, high values of carbon dioxide in the ice wedges are detected. The ice wedges at the Aldan and Sirdah sites contain relatively small amounts of methane. But the average value of methane concentration in ice wedges at Neleger is 1078 ppmv. In the case of carbon dioxide in ice-wedge ice, high values of methane concentration are exhibited at Neleger (Table 1). Major source of carbon dioxide in the active layer is assumed to occur through respiration of roots and the decay of organic deposits

Table 1 Gas content in air of ice wedges of Central Yakutia.

Location	Site	Depth, cm	Methane Content, ppmv	Carbon Dioxide Content, ppmv
Aldan River	A-1	130	18.8	13103.0
	A-2	210	17.3	7785.4
	A-3	290	1.6	11128.7
	A-4	420	78.3	19312.2
	A-6		193.5	11650.1
	A-7		13.5	8615.8
Sirdah Lake	S-1	200	12.6	23211.8
	S-2	700	12.9	0.0
Neleger	Point 1-1	225	3118.1	401.0
		255	2681.4	246.8
		280	520.5	1336.8
		308	1232.6	461.0
	Point 1-2	192	1566.4	1416.4
		215	922.9	184.5
	Point 1-8	165	2134.5	373.3
		180	1608.6	453.3
		195	1172.9	791.3
		205	776.2	705.3
		220	933.7	472.8
		243	491.8	670.7
		266	711.7	595.0
		290	1371.3	394.4
	Point 2-7	182	36.5	197.0
	Point 2-11	175	28.6	397.8
		215	28.6	939.2
	Point 2-17	207	74.0	635.7

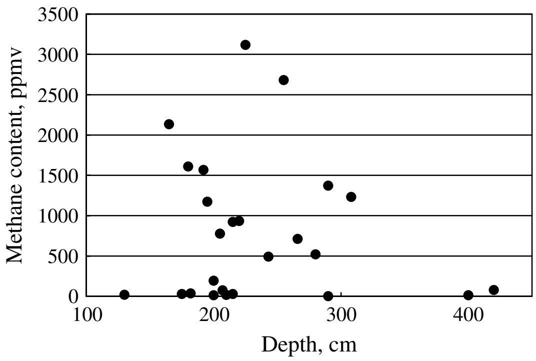

Figure 4 Methane content in air of ice wedges.

by microorganisms. Some portion of carbon dioxide is also a product of oxidation of methane. As Fukuda (1999b) points out, additional sources of carbon dioxide in frozen soil might occur in a palaeo active layer.

Figure 5 (A) Forest (B) slope and (C) alas area of sampling, Neleger site (62°18′54″, 129°30′04″).

METHANE CONTENT, LANDSCAPES AND SOIL PROPERTIES

Two parallel sampling transects (east-west direction) in the permafrost site at Neleger, from forest, slope and alas areas, were made (Figures 5 and 6). The length of each transect was about 180 m. The first transect was located at a higher elevation than the second. The two transects were about 100 m in distance from each other. Soil profile characteristics are shown in Figure 7. Results of measurements of

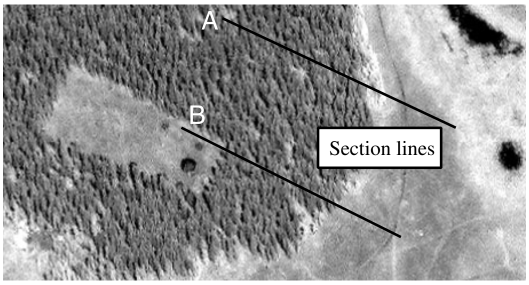

Figure 6 Air photos showing methane content profile section lines at Neleger site.

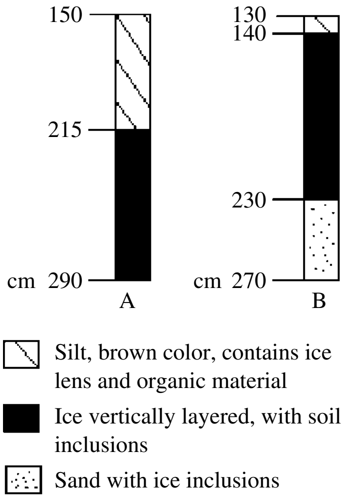

Figure 7 Boreholes (A) and (B) located in the forest along the first section (upper section line in Figure 6).

methane concentration along the transects are shown in Figures 8 and 9.

It appears that the permafrost in the higher elevated parts of the forest are characterized by higher methane contents than the lower-elevated parts. Values of methane concentration in air bubbles of frozen soils in the forest ranged between 1000–6000 ppmv. The topographical change from a higher position in the forest to a lower position may imply that previous surface disturbances due to forest fire cause thawing of near-surface permafrost and for the ground surface to subside. The upper part of frozen soil, therefore, contains previously thawed permafrost and (also refrozen) permafrost. During the process of previous thawing, any stored methane with high concentration values would have been released to the atmosphere. Alas deposits are a transition between these two landscapes: the amount of methane in permafrost

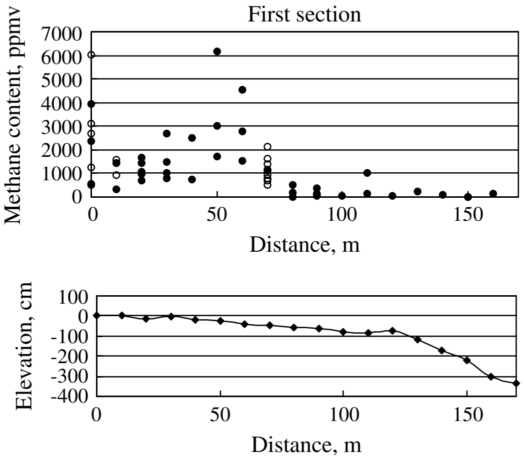

Figure 8 Methane content in the air of frozen soil, first section, Neleger; black circles = frozen soil; white circles = ice wedges.

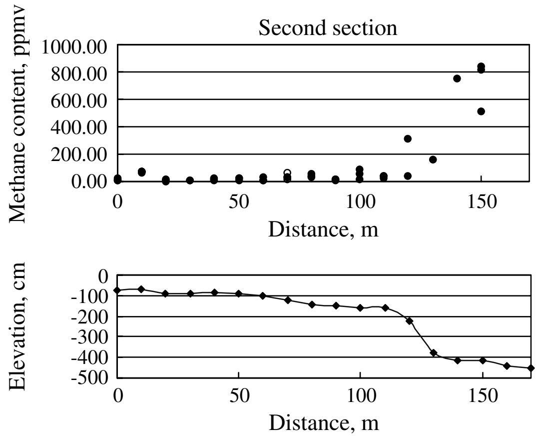

Figure 9 Methane content in the air of frozen soil, second section, Neleger; black circles = frozen soil; white circles = ice wedges.

here is less than in the forest, but more than in the young forest. Carbon dioxide content is also higher in alas areas (Figures 10 and 11).

Volumetric air contents in permafrost are plotted in Figure 12. Some features of layered ice-rich frozen soil are shown in Figure 13. The relationships between water content and the values of both methane and carbon dioxide in permafrost are shown in Figure 14. No obvious tendencies were found between water contents and concentration values of both methane and carbon dioxide. In general, methane content rises with water content increase, if data on ice wedges are plotted (Figure 14), and carbon dioxide contents become lower. Data collected on ion

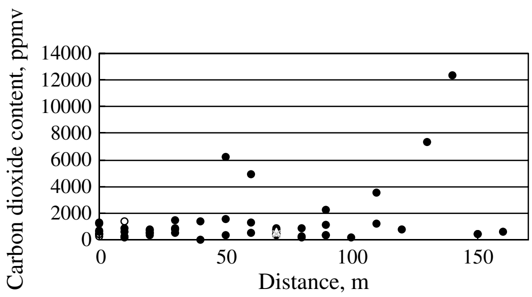

Figure 10 Carbon dioxide content in the air of frozen soil, first section, Neleger; black circles = frozen soil; white circles = ice wedges.

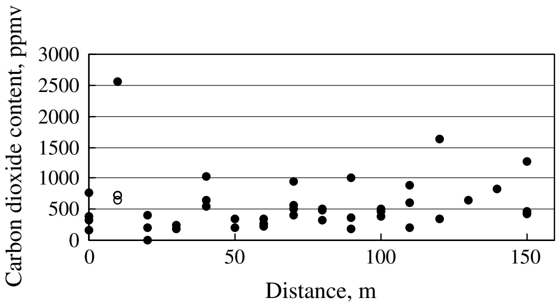

Figure 11 Carbon dioxide content in the air of frozen soil, second section, Neleger; black circles = frozen soil; white circles = ice wedges.

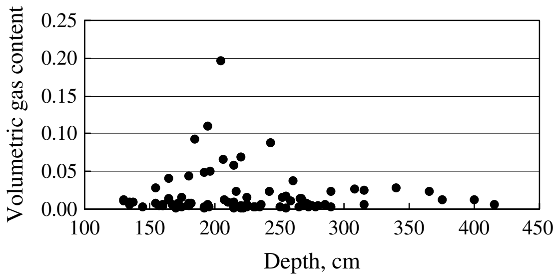

Figure 12 Volumetric gas content in frozen soils.

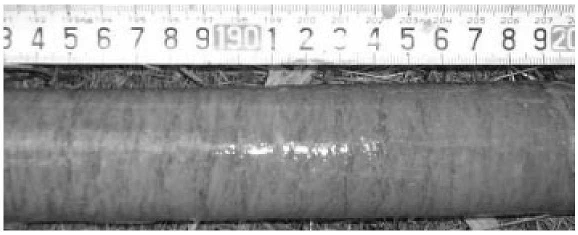

Figure 13 Layered high-ice content cryogenic structure of frozen silt, Neleger site.

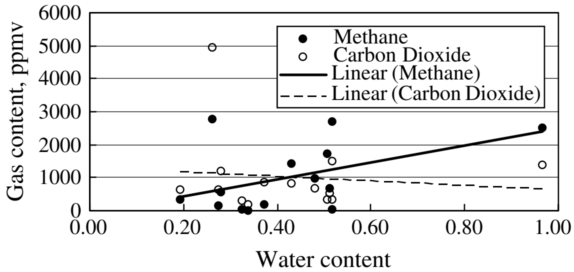

Figure 14 Relationship between water and gas content in permafrost.

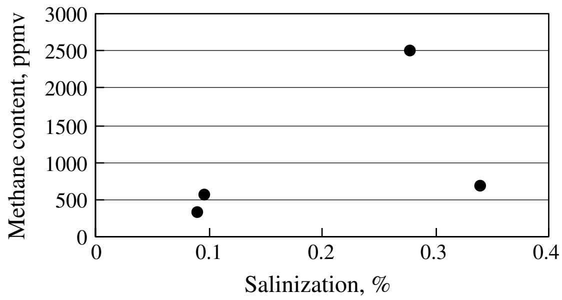

Figure 15 Methane content versus salinization of soil.

(salt) content are limited (Figure 15), but methane content rises as salinization increases. Low methane content and low salinization at the same time could possibly be connected to thawing of permafrost when soil would be 'washed' or illuviated. The relationships between volumetric gas content and values of methane and carbon dioxide are shown in Figure 16.

EXPERIMENTAL STUDY OF METHANE PRODUCTION IN FROZEN SOILS

Samples of frozen soils were incubated at the temperature of −5 °C in order to study possible methane production. Experimental studies were carried out upon a frozen Yakutsk (Russia), Alaska (USA) and Tomakomai (Japan) soil. Two were typical permafrost soils; the Yakutsk soil sample was from the Neleger site at a depth of 50 cm in the active layer. This is mostly a larch forest area of the high Lena River terrace. The sample was a sandy loam and had a natural salinization of about

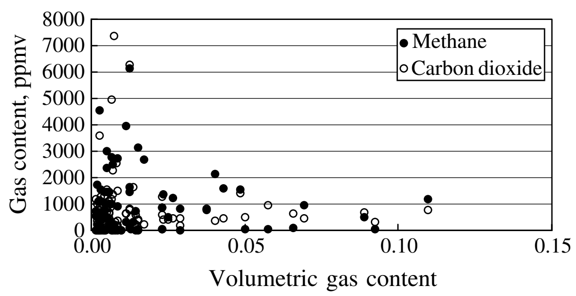

Figure 16 Relationship between volumetric gas content and methane and carbon dioxide content in permafrost.

0.08%. The Alaskan sample was taken from near Fairbanks, Alaska, from an active layer consisting of eluvium deposits. The Tomakomai sample was taken from the experimental forest of Hokkaido University, in a flood-land of a creek. All samples were over saturated by de-ionized water to keep anaerobic conditions of incubation. The weight of each soil sample was about 300 g of wet soil. The soil was put into glass-flasks that were covered by a rubber plug of diameter of about 2 cm. The total number of flasks was ten. The flasks were placed in a refrigerator in a vertical position and frozen at the temperature of −5 °C for three days. The cryogenic texture produced was chaotic ice lensing; the thickness of the lenses was up to 0.5–1.0 mm. After freezing the air in the flasks was exchanged to nitrogen to create anaerobic conditions; however, a certain amount of methane (0.5–1.5 ppmv) was present in the flasks at the beginning (Table 2). Some samples were sterilized at 120 °C for 20 min; air-dried and vacuumed samples were also tested. Then, the flasks were placed in the refrigerator at the temperature of −5 °C for incubation; fluctuations of temperature were in the range of $-5.0\,°C \pm 0.3\,°C$. The measurement of methane content in the air of the flasks was conducted though the rubber plug by a syringe. The amount of each air sample was 10 ml. The samples were incubated for more than six months. One of the flasks was left empty; it was a control sample. The gas chromatograph that was used had an accuracy of the methane content measurements of 0.002 ppmv. Methane can be present in soil not only in the soil water but also adsorbed on the surface of soil particles. The solubility of methane in water is rather low: at 20 °C it is 0.033 (v/v) (Yaws and Yang, 1992). According to Henry's law, the amount of methane in the samples, at the average air content of 2 ppmv in the room during samples preparation, could be about 1.8×10^{-5} ml. In case of release of this amount, the air of flask would contain 0.018 ppm, which is negligible.

The results of our study of methane production are shown in Tables 2 and 3 and Figures 17–19. There was an increase of methane content in the air of the flasks, especially during the first 20–50 days of the experiments.

It was determined that the change of methane content occurred logarithmically (Figures 17–19). In all cases, the methane content was low and did not exceed 2.5–3.0 ppmv; the maximum contents for different soils were close. One of the flasks with the Tomakomai soil was filled with a mixture of nitrogen and carbon dioxide (Table 3); the carbon dioxide content was 20,000 ppmv. The methane content in the air of this sample increased to 5 ppmv. One of the

Table 2 Methane content in the air of flask, ppmv.

Days of experiment	Soil samples (numbered)/Methane content, ppmv		
	Tomakomai—1	Alaska—3	Yakutsk—6
1	1.43	0.91	1.23
2	1.18	1.54	—
23	2.06	1.98	—
70	2.05	2.12	1.98
209	2.08	2.02	2.29*
230	2.01	2.02	—

* 148 days

Table 3 Methane content in the air of flask, ppmv; normal, sterilized and air-dried soil.

Days	Tomakomai soil			Yakutsk soil		
	Normal	Sterilized	With CO_2	Normal	Vacuumed	Air-dried
0	1.09	1.43	1.20	0.85	0.54	1.98
22	1.80	1.47	5.47	2.00	2.00	—
50	1.89	1.36	5.80	2.07	2.16	3.12

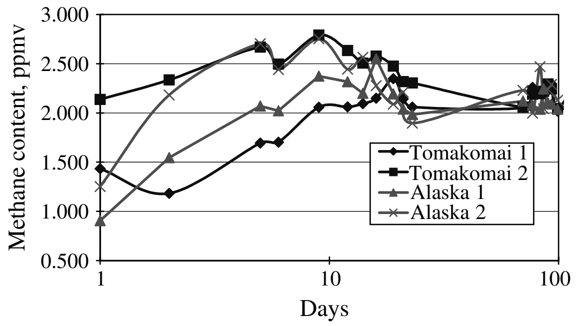

Figure 17 Methane content in the air of flask, ppmv; Tomakomai and Alaska soil, samples are numbered.

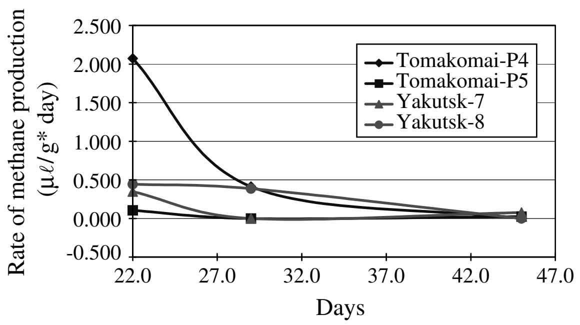

Figure 19 Rates of methane production, microlitre of CH_4 per kilogram of soil per day.

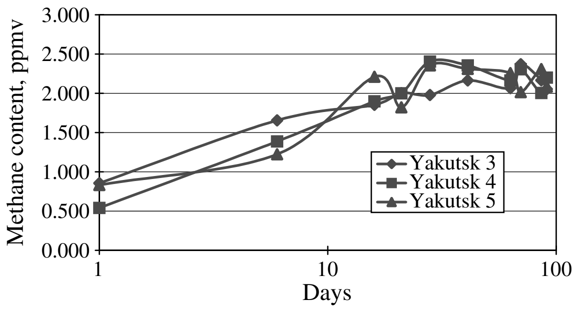

Figure 18 Methane content in the air of flask, ppmv; Yakutsk soil, samples are numbered.

samples (P5) of Tomakomai soil was sterilized; no increase of methane content occurred in this sample. The air-dry sample of Yakutsk soil differed by having a larger amount of methane (Table 3).

The rates of methane production (microlitre of CH_4 per gram of soil per day) were calculated based on the results of these experiments (Figure 19, Table 4). Trend equations of the change of methane content in empty pores of different soils at −5 °C were found. For example, 100 g of frozen Yakutsk soil produced about 0.04 μl of methane a day, or 14.6 μl a year. However, the rates of production decrease in time, and the long-term forecast of methane content in frozen soils is still problematical. The low permeability of ice and soils and insignificant solubility of methane in water (or particularly in unfrozen water films) strongly limits its possible diffusive transport in the frozen soil. The release of methane by diffusion through the icy soil was expected to be extremely small, and the experiments took months before measurable amounts could be found. That was probably the reason for the bigger methane release in the air-dry Yakutsk soil (Table 3). According to the experiments, the increase of methane content in pores of the frozen Yakutsk soil could be estimated as:

$$C = 156.5 * \ln(D) \quad (1)$$

where C = methane content in ppmv; D = number of days.

Table 4 Rates of methane (CH_4) production, microlitre of CH_4 per gram of soil per day.

Sample	CH_4 production(μl/g*day)		
Days of experiment	22	29	45
Tomakomai P4	0.00207	0.00041	0.00000
Tomakomai P5 (sterilized)	0.00010	0.00000	0.00000
Tomakomai P6 (CO_2)	0.01247	0.00670	0.00092
Yakutsk—7	0.00035	—	0.00008
Yakutsk—8	0.00044	0.00039	0.00000
Alaska—3	0.00022	0.00040	0.00057
Alaska—4	0.00019	0.00040	0.00060

As soon as the total volumetric gas content in the permafrost is about 0.01–0.02, the methane content can increase significantly. According to equation (1), for 10,000 years, if the value of empty porosity is 0.02, the methane content in the pore air of Yakutsk soil could increase up to 2000 ppmv. This seems reasonable. However, it is difficult to calculate the amount of produced methane for thousands of years based on a few months experiments because production could be stopped at some given conditions. The temperature is also not stable: it can be argued that methane production is larger at higher temperatures. The type of soil, organic material and water content are also essential for microbial activity.

DISCUSSION

Diffusion of stored methane might take place in two forms. The first is air-bubble diffusion in frozen soil. Along with the temperature gradient, air bubbles tend to diffuse. If similar to air-bubble diffusion in glacier ice, the rate of diffusion in frozen soil might be very small. The second form of diffusion is molecular movement under potential gradient. The possible diffusive flux of methane at the molecular level might be calculated: based on:

$$J_D = -D_S * \left(\frac{dC}{dh}\right) \quad (2)$$

where J_D is diffusive flux; D_S is the methane diffusion coefficient (cm_2/s); and *dC/dh* is the methane concentration gradient termed as osmotic pressure (Eletsky, 1991). The diffusion coefficient value of unsaturated and unfrozen soils is estimated as 10^{-5}–10^{-6} cm^2/s, and that of frozen soil is estimated as 10^{-8}–10^{-9} cm^2/s (Brouchkov, 2000). If one assumes osmotic pressure gradient to be about 10^{-5} cm^2/cm, based on the conversion of volumetric concentration to osmotic potential, then the estimated flux that results is 10^{-7} cm^3/year. This may suggest that methane content in permafrost is stable even in long-term periods. According to ground surface flux measurements of methane by means of the chamber method (Morishita *et al.*, 2001), the forest soil is a sink of methane. Reflecting this tendency, methane concentrations in forest and grassland soils in the active layer are very low (Morishita *et al.*, 2001). However, values in areas of alasses are larger than those in areas of forest. It can be argued that alasses contain a high water table around the central pond and an anaerobic environment prevails that is favourable for methane production.

The possibility of methane production and movement within permafrost remains unclear. One of the authors has made measurements on the Arctic coast of Siberia (Moriizumi *et al.*, 1995). The results of ^{14}C dating indicate that formation of the Edoma deposits was between 40,000–23,000 yBP. Edoma ice air contains 0.21% methane, 1.4% carbon dioxide and 76.69% nitrogen (Oijyagorskii Yar) and 4.57% methane (Big Lhyavosky Island), but the methane is younger (Table 5) than the previous dating of deposits (Moriizumi, *et al.*, 1995). In this case, there is a chance that methane could be produced or transferred after freezing of the deposits. Carbon in massive ground ice in Alaska could also have the same origin (Moorman *et al.*, 1996).

The possibility of methane production at low temperatures is established by our experiments; however, it is generally poorly known. For example, methane concentration in permafrost deposits in the Yamal peninsula, or Edoma deposits on the Arctic coast of Siberia, is high (up to 500 ml/kg). This is much larger than the present atmospheric content. Our study also shows the large amount of methane that is trapped in the permafrost of Central Siberia. However, these facts do not directly suggest the production of methane in permafrost, even when considering the possible production of methane under freezing temperature. Also, our study of the distribution of methane concentration in the frozen soils of different landscapes has shown that the oldest permafrost in the forest is characterized by the higher methane contents (Figure 8). Deposits in the lower-elevated part of the forest contain less methane; probably, this area was burned, because it consists of younger trees and permafrost could have thawed.

The anti-proportional relationship between concentration values of methane and carbon dioxide in permafrost indicates the possible occurrence of methane oxidizing processes. Ice wedges do not contain as much methane as frozen ground because methane could not be produced without organic material in ice and it may only percolate into the ice via an outside source. The increase of methane and

Table 5 Methane (CH_4) content of air bubbles in ice from Edoma.

Sample	CH_4, % in air of Edoma	δC^{13}(‰)	C^{14} dating, years
OG34	0.21	−71.3	3539
LZ-1	4.57	−72.1	4782

carbon dioxide concentration values with water content (Figure 14) may be explained by assuming the transport of gases in water is by percolation of water into permafrost. An adjacent anaerobic environment for methane production is necessary for the supply of water containing methane in highly concentrated air bubbles. In frozen soils, low air contents suggest that previously thawed permafrost has refrozen. In the process of thawing and refreezing, previous air bubbles might be released. In association with this release of air, any trapped methane and carbon dioxide are lost. Based on published data (Cicerone and Oremland, 1988; Wahlen *et al*., l989; Pearce, 1989; IPCC Report, 2001; Fukuda, 1999b) and our research, an estimation of additional emission of methane from permafrost areas shows that a considerable increase of methane emission is possible in case of permafrost thawing to only 0.5 m depth.

Estimates made on the average content of methane in permafrost and the rate of retreat of exposed ice cliffs show that methane release due to erosion processes could also be significant (Fukuda, 1999a).

CONCLUSION

1. Values of methane concentration are high in both frozen soil and ice in Central Yakutia. There is no clear relationship between methane concentration and depth. An anti-proportional relationship between methane and carbon dioxide concentration in permafrost was established for both frozen ground and ice wedges. Highest methane concentration values were found in certain frozen soil samples, but some frozen soils contain very low concentrations of methane. Ice wedges contain less methane than frozen soils and average values of methane concentration are larger than present atmospheric concentrations.
2. In general, methane and carbon dioxide concentrations increase with an increase in water content. According to recent studies of methane flux in the active layer, under anaerobic condition, meltwater traps air with highly concentrated methane in the process of freezing in autumn. Cracking of near-surface permafrost tends to occur in mid-winter and water with trapped air bubbles percolates into cracks afterwards in spring. Repeated cycles of cracking and water filling may cause high accumulations of methane in frozen soils. Permafrost in undisturbed forest is characterized by the existence of maximum methane concentrations. Lower-elevated parts of the forest contain lower concentrations of methane. Along the transects our measurements suggest that the depressed ground surface in forest areas may represent thawing and refreezing of the near-surface permafrost in the past. Established relationships between volumetric air content and values of both methane and carbon dioxide concentration also suggest thawing-freezing history. Methane and carbon dioxide contents rise in general with water content increase. According to recent studies of gas content in the active layer, the freezing of water-saturated soil in alasses or other landscape depressions, and its transfer to a permafrost state, probably causes high methane concentrations in the near-surface permafrost.
3. Experiments show a slow production of methane in different soils at $-5\,^{\circ}C$. The experiments take several months before measurable change of methane content can be found. The change of methane content occurs according to logarithmical law; the rates of methane production decrease in time. Thus, there is the possibility that methane forms at low temperatures. However, any long-term forecast of methane content in frozen soils is still problematical.

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