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Characteristics of methane emission from different vegetations on a wetland

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ABSTRACT

Methane flux was observed on a floating mat of temperate sphagnum bog, Mizorogaike, Japan, during the period April to October in 1993, to investigate the factors controlling CH_4 emission, especially differences in vegetation and variation of water level. Comparing the CH_4 flux among reed dominant site, marsh trefoil (a broad-leaved perennial aquatic herb) dominant site and sphagnum dominant site, the largest CH_4 flux was observed at the marsh trefoil site and the smallest flux was at the sphagnum site, reflecting the difference in decomposability of organic matter. Namely, the decomposition rate of marsh trefoil was high, while that of sphagnum was extremely low. At the marsh trefoil site, lowering of the water table below the surface during summer caused an increase of surface soil temperature due to direct exposure to solar radiation. Consequently, it caused a low Eh and enhanced methane production which was supported by the supply of organic matters with high decomposition rate derived from marsh trefoil. At the reed site, CH_4 flux increased in late summer. Such a delayed CH_4 emission at the reed site was possibly caused by decomposition of roots growing during the summer and delay of soil temperature increase due to the waterlogging. Average CH_4 fluxes for seven months were 450, 290, and 70 $mgC/m^2/day$ for the marsh trefoil, reed and sphagnum sites respectively. The $\delta^{13}C$ of dissolved CH_4, higher than that of bubbles, suggested CH_4 oxidation in the soil water. However, oxidation was not a deterministic process controlling CH_4 flux at the observed temperate wetland where CH_4 production rate was high because of high soil temperature. Sphagnum can only grow in oligotrophic (limited amount of nutrients) water, and its domination suppresses growth of other plants because of low concentration or low availability of nutrients. However, sphagnum can be easily replaced by other wetland plants, if the water in a sphagnum bog becomes rich in nutrients due to water pollution or change in the water circulation in the area. Such a vegetation change from a sphagnum dominant bog to a fen dominated by other wetland plants can accelerate CH_4 emission to the atmosphere.

1. Introduction

Atmospheric methane concentration is one of the important factors controlling the earth's climate (Hansen et al., 1988). About 80% of methane emitted from the surface is estimated to be of "bacterial origin", such as wetlands, rice paddies, enteric fermentation, and termites (Cicerone and Oremland, 1988). It is believed that the variations of methane source strengths with natural origin such as wetlands have caused the correlation between the CH_4 concentration and surface air temperature observed in the Antarctic ice core (Chappellaz et al., 1993). Wetland ecosystems, which are widely distributed in the world, are estimated to account for about 20% of the total CH_4 emission (IPCC, 1994). Furthermore, it is predicted that CH_4 emission from northern wetlands will be enhanced by future global warming

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(Christensen and Cox, 1995), and that the soil moisture regime will affect the CH_4 emission (Roulet et al., 1992).

Methane flux from wetlands has been extensively observed to know the correlation between CH_4 flux and weather elements such as air temperature and precipitation (Dise, 1993; Whalen and Reeburgh, 1992), and also to investigate the factors controlling CH_4 emission (Whalen et al., 1991; Whiting and Chanton 1993; Fechner and Hemond, 1992). There are many possible factors controlling CH_4 emission from wetlands: soil temperature, water level, Eh (reduction-oxidation potential), and productivity. The effect of soil temperature on CH_4 emission is straightforward if the other factors are constant: the higher the soil temperature, the larger the CH_4 emission. In contrast, the effect of water level on the CH_4 flux is variable. Low CH_4 fluxes caused by lowering the water tables were observed due to CH_4 oxidation in an oxidized layer (Sebacher et al., 1986), whereas, there have been observations showing no correlation between the water table and CH_4 flux (Wilson et al., 1989; Yavitt et al., 1990). Differences in CH_4 flux among different types of wetland have also been observed. According to Dise (1993), fen peat emits more CH_4 than bog peat because of the longer wet period in fen peat. Whiting and Chanton (1993) have pointed out a positive relationship between CH_4 flux and net primary production.

CH_4 is produced in a soil with strongly reductive state. A reductive state is formed by inhibition of oxygen intrusion, existence of decomposable organic matters and higher soil temperature, so that the relationship between CH_4 flux and water table is not always clear. From the viewpoint of decomposability of organic matter, different vegetation means a different quality of organic matter which is supplied to the soil.

We observed CH_4 flux from a temperate sphagnum wetland where variation of CH_4 flux depending on variation of vegetation and water level can be investigated, since several different vegetations cover it mosaically.

2. Observations and analyses

2.1. Observation site

Observations were made on a floating mat of sphagnum peat in Mizorogaike pond (Fig. 1) located in Kyoto City (30°04′N, 135°45′E), Japan. The floating mat is about 1.5 m thick and about a 50 cm of water column exists below; this floating mat shows seasonal buoyancy. On the surface of the floating mat, various plants grow in different microtopography: hummocks (micro ridges with a height of about 20 cm) and pools (microtroughs). There are about 130 hummocks with an area of 0.2 to 200 m^2 (Shimizu, 1986). Several trees (pine, juniper, hollies and billberies) grow on a hummock, which is fringed with *Sphagnum palustre* L. The other species of sphagnum, *Sphagnum cuspidatum* Hoffm., makes a small mat with a level similar to the winter water level. Marsh trefoil (*Menyanthes trifoliata* L.), a broad-leaved aquatic herb, dominates in the large area of pools; another dominant vegetation in pools is a species of reed (*Phragmites australis* (Cav) Trin. ex Steud.).

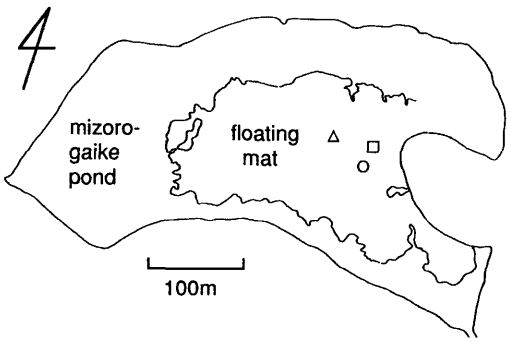

Fig. 1. Observations were made on a floating mat of sphagnum peat in Mizorogaike pond, which is located in Kyoto city, Japan. The floating mat is about 1.5 m thick and about a 50 cm of water column exists below. The three symbols on the floating mat are the observation sites: reed site (circle), marsh trefoil site (triangle) and sphagnum site (square).

Observations were made at the following three sites with typical vegetation and characteristic seasonal cycles of water level on the floating mat (Fig. 2).

(1) Reed site: *P. australis* dominates in the pool with marsh trefoil. Shoots of *P. australis* open twice a year (June and September). The reed site is waterlogged throughout a year, because the roots of reeds reaches to the bottom of the pond and are anchoring the floating mat.
(2) Marsh trefoil site: *Menyanthes trifoliata* L. shoots twice a year in Mizorogaike, the southern limit of distribution. The first one comes

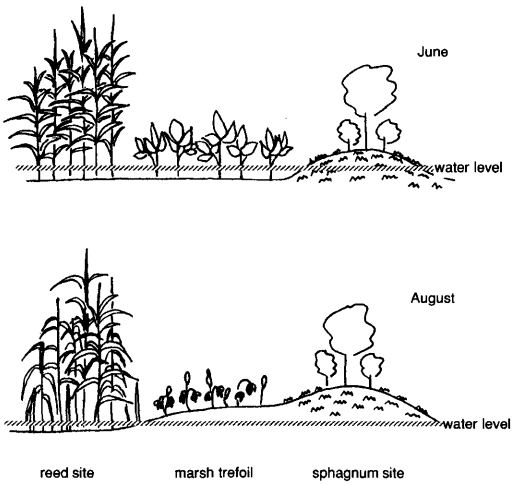

Fig. 2. Schematic figures of typical vegetation at Mizorogaike in June and August. The observations were made at three sites with different vegetation and different variation in water level: At the reed site, water level is above the soil surface throughout the year, whereas, at the marsh trefoil site water level is below the surface during mid-summer. At the sphagnum site, water level is below the surface throughout the year.

out in mid-April and dies in July, and the second one grows during the period of September to October. Marsh trefoil site shows a clear seasonal variation in water level: water table lowers below the surface during summer.

(3) Sphagnum site: *S. palustre* grows on the small hummock and *S. cuspidatum* grows along the perimeter. On the hummock, the water table is below the surface throughout the year.

Observations were made every month during the period April to October, 1993.

2.2. CH_4 flux

Methane flux was measured with chamber method. Several kinds of chambers were used. For the reed site, cylindrical chambers (25 cm in a diameter, 1 m or 1.5 m height) were used. For the other two sites, a chamber (25 cm × 25 cm × 30 cm height) was used with or without a float. Chamber air (10 ml) was sampled with gas tight syringe at times 0, 30 and 60 min. Duplicate chamber fluxes were measured for each site. To avoid the disturbance of the soil, we stayed on a rigid plant shoot or on a small boad put on the soil during sampling. Fluxes were calculated only from the data showing linear increase of concentration with time.

The flux measurement at each site was made at roughly the same time for every observation, around 10–11 a.m. at the reed site, 0–1 p.m. at the marsh trefoil site and 2–3 p.m. at the sphagnum site.

2.3. *Eh and temperature*

The oxidation-reduction potential (ORP) was measured with a portable ORP meter (TOA HM-11P). The ORP probes with platinum and reference (AgCl) electrodes were inserted into the soil to depths of 10 cm and 40 cm, and the Eh value was read out 1.5 to 2 h after the insertion of the probes, at the same time as the CH_4 flux measurement. Eh value (relative to the normal hydrogen reference electrode) was calculated by adding the potential of the reference AgCl electrode (203–214 mV) depending on the soil temperature. Soil temperatures at depths of 10 cm and 40 cm were measured at almost the same time at all three sites (3–4 p.m.) for every observation.

2.4. *Bubbles and dissolved* CH_4

Bubble gas was sampled using an inverted funnel with rubber septum by agitating soil at the surface and a depth of 40 cm for carbon isotope measurement. The volume of bubble gas collected at the surface from the area of the funnel (177 cm^2) was also measured to estimate the accumulated gas volume in the floating mat. It is not easy, however, to extract all of the gas from the peat. Accordingly, the soil was agitated until no more gas came up, and then the collected gas volume was measured. For the analysis of dissolved CH_4, water was sampled with a two-hole syringe at surface and a depth of 40 cm. In the case of water table higher than soil surface, surface water was sampled, while, when the water table was lower than the soil surface, the water at the level of water table was taken as surface water.

2.5. *Analyses*

CH_4 concentrations were analyzed with GC-TCD (gas chromatograph with thermal conductivity detector) (Shimadzu GC-8A) with a

series of columns (Porapack Q 5 m, empty 10 m and Molecular Sieve 5A 2 m) for bubble gas and GC-FID (flame ionization detector) (Shimadzu GC-14A) with a column of Porapack Q (2 m) for chamber air. The concentration of dissolved CH_4 was obtained by the headspace method with GC-FID. Carbon isotopic composition of CH_4 was analyzed with a GC/C/IRMS (Finnigan MAT deltaS/GC) (Sugimoto et al., 1991) or GC/GC/C/IRMS (Sugimoto, 1996). Carbon isotopic composition was expressed by $\delta^{13}C$:

$$\delta^{13}C = \left(\frac{Rsa}{Rst} - 1\right) \times 1000 \quad (‰),$$

where Rsa and Rst are isotope ratios ($^{13}C/^{12}C$) for the sample and standard (PDB).

2.6. *Incubation experiments*

Wet soil at each site was taken at depths of 0 to 10 cm and 30 to 40 cm. The wet soil (about 40 ml) was put into a truncated glass syringe (50 ml in the volume) and capped with a butyl rubber stopper in situ with care to prevent exposure to the air. The syringes were incubated at 30 or 15°C in the dark, and the volume of gas produced was measured.

3. Results of field observations

3.1. CH_4 flux and soil environments

Daily mean air temperature and precipitation observed at Kyoto Weather Observatory (5 km southwest of Mizorogaike) are shown in Fig. 3. The amount of precipitation during the summer (June to August) in 1993 was 1.7 times larger than the average.

Water levels at all three sites showed typical seasonal variations. The reed site was waterlogged during the whole summer, whereas, the water table was below the surface at the marsh trefoil site (Fig. 4). During the period July to September, at the marsh trefoil site, the soil surface was raised by the volume of formed gas and by the buoyancy of the floating mat itself. Although the water table lowered, surface soil was wet all the time.

A large CH_4 flux was observed at the marsh trefoil and reed sites (Fig. 5a). The average CH_4 flux for April to October was 450, 290, 70 $mgC/m^2/day$ at the marsh trefoil, reed and

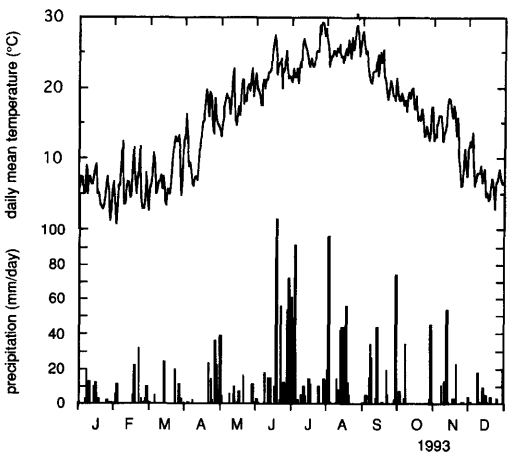

Fig. 3. Daily mean temperature and precipitation observed at Kyoto Weather Observatory (5 km southwest of Mizorogaike). The amount of precipitation during summer (June to August) in 1993 was 1.7 times greater than the average.

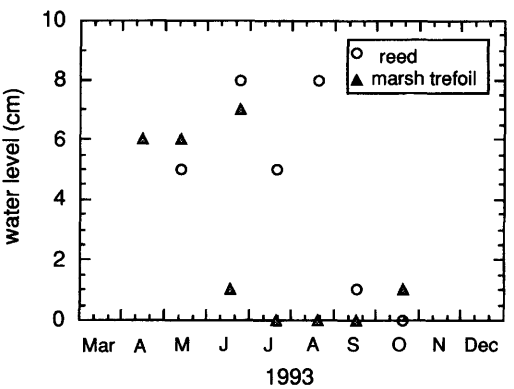

Fig. 4. Water levels (depth of water above soil surface) observed at reed site and marsh trefoil site. Water level at the reed site was above the surface during the whole summer, whereas at the marsh trefoil site, the water table lowered below the surface during the period July to September.

sphagnum sites, respectively. The CH_4 fluxes at the marsh trefoil and reed sites are on the same order as those observed at many temperate rice paddies (IPCC, 1992), and are larger than those observed in northern wetlands (Harriss et al., 1993).

To compare the variation of CH_4 flux seasonally among the three sites, statistical analyses (Welch test, one-way, 5% significance level) were con-

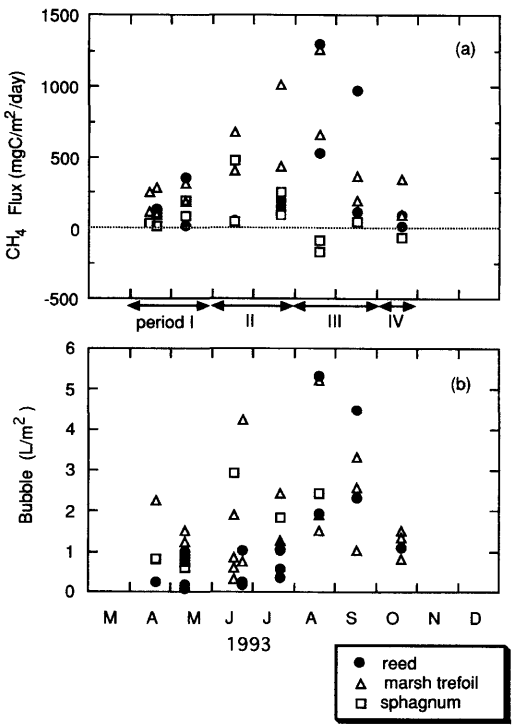

Fig. 5. The CH_4 flux (a) and the volume of bubbles accumulated in the soil (b) observed at the three different vegetation sites.

ducted for the periods I to IV (Fig. 5a and Table 1); spring (period I, April and May), summer (period II, June and July), late summer (period III, August and September) and autumn (period IV, October). For all period, CH_4 flux at marsh trefoil was significantly larger than that of sphagnum. The difference in CH_4 flux between reed and marsh trefoil was significant only for the period II, while, that between reed and sphagnum sites was significant only for the period III.

For the period I (spring), the difference in CH_4 flux between marsh trefoil and reed sites was not significant. In summer (period II), CH_4 flux at marsh trefoil increased, while, that at reed site was the same level as that in spring. The CH_4 flux at marsh trefoil site was large during summer and late summer (periods II and III), although the water table lowered. The reed site showed increase of CH_4 flux in late summer (period III), consequently, the difference in CH_4 flux between marsh trefoil and reed sites was not significant for this period. In October (period IV), CH_4 flux decreased at both of reed and marsh trefoil sites. The variation of CH_4 flux at the reed site corresponded with the volume of bubble gas accumulated in the soil: a large volume of bubble gas was observed at the reed site in late summer (August and September) (Fig. 5b). The observed bubble gas volume at the sphagnum site was not small compared to the other sites, although the CH_4 flux was smaller than those at the others. The range of CH_4 concentration in a bubble was 3.0–68.0%, averages for the reed, marsh trefoil and sphagnum sites being 28.5, 18.8 and 23.9% respectively.

The observed soil temperature variation at the depth of 40 cm was almost the same for all sites, whereas, a 2 to 5°C higher surface soil (10 cm) temperature was observed at the marsh trefoil site where the soil surface was exposed to solar radiation (Fig. 6). The soil temperature variation at the reed site was almost the same as that at the sphagnum site.

The Eh lowered at the reed site and marsh trefoil site during the summer, whereas that at the sphagnum site stayed positive (Fig. 7). It is notable that the Eh at a depth of 10 cm was lower than that at 40 cm, especially at the marsh trefoil site, although the water level lowered below the surface

Table 1. *Observed CH_4 fluxes for periods I (April and May), II (June and July), III (August and September), and IV (October) at each site*

	CH_4 flux ($mgC/m^2/day$)		
Period	reed	marsh trefoil	sphagnum
I	151 ± 73 ($n=4$)	207 ± 37 ($n=6$)	77 ± 27 ($n=6$)
II	111 ± 38 ($n=4$)	632 ± 139 ($n=4$)	217 ± 97 ($n=4$)
III	727 ± 258 ($n=4$)	617 ± 235 ($n=4$)	-71 ± 64 ($n=3$)
IV	53 ± 37 ($n=2$)	215 ± 126 ($n=2$)	-68

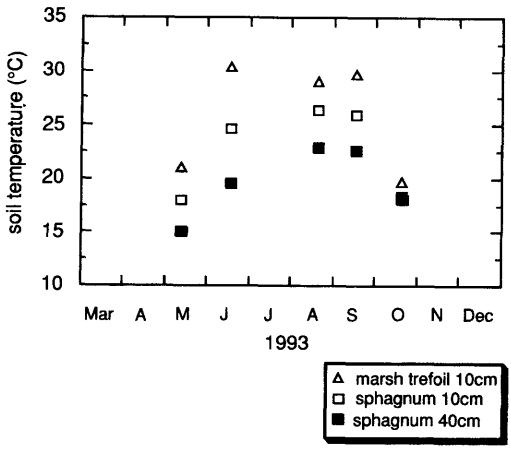

Fig. 6. Soil temperatures at depths of 10 cm and 40 cm. Soil temperature at 40 cm was almost the same for the reed, marsh trefoil and sphagnum sites.

during the summer at the marsh trefoil site. Such a decrease of Eh at the beginning of summer has been widely observed at the marsh trefoil dominant site on the floating mat in Mizorogaike pond (Haraguchi, 1991).

3.2. *Methane $\delta^{13}C$ values*

The $\delta^{13}C$ of bubbles collected at 40 cm (−78.8 to −60.0‰) was lower than that collected at the surface (−65.0 to −52.5‰) at the marsh trefoil site (Fig. 8a). The bubble $\delta^{13}C$ for the other sites showed similar variations: those at 40 cm and 10 cm were −67.8 to −59.4‰ and −64.9 to −52.8‰ at the reed site, and −68.9 to −58.5 and −61.5 to −54.0‰ for the sphagnum site, respectively. The bubble $\delta^{13}C$ at the marsh trefoil site at 10 cm showed no clear seasonal variation, while those at the other sites showed a seasonal variation with high $\delta^{13}C$ during summer at both depths.

The concentration of dissolved CH_4 at the marsh trefoil site at 40 cm depth was higher than that at the surface, and the $\delta^{13}C$ values of dissolved CH_4 were higher than those of bubbles at the marsh trefoil site (Fig. 8b). Especially, in the surface soil water, dissolved CH_4 with high $\delta^{13}C$ up to −35.8‰ was observed. At the other sites, the $\delta^{13}C$ of dissolved CH_4 was higher than that of bubbles, except for that at the reed site at 40 cm, where the $\delta^{13}C$ of dissolved CH_4 was similar to that of the bubbles.

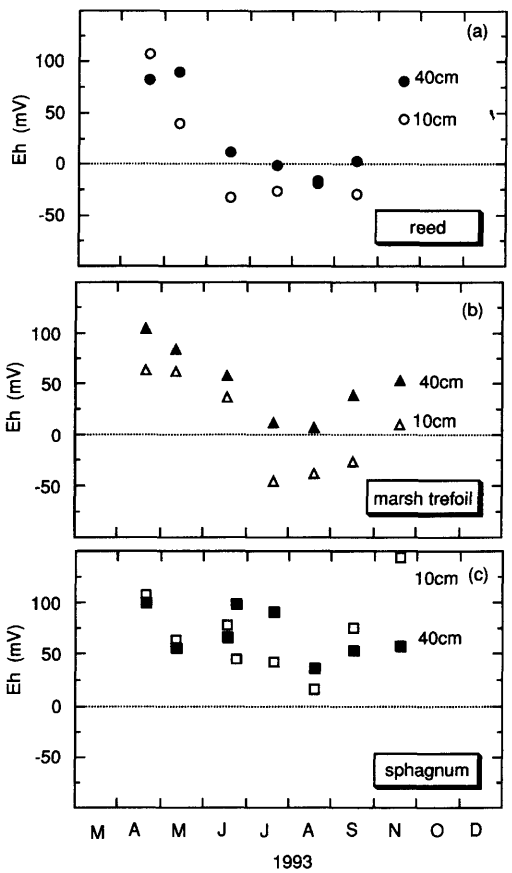

Fig. 7. The Eh values (oxidation-reduction potential) for the depths of 10 cm and 40 cm observed at the reed site (a), marsh trefoil site (b) and sphagnum site (c).

4. Discussion

4.1. *Factors controlling CH_4 flux: water level and production and decomposition rates of organic matter*

Comparing the CH_4 fluxes among the three sites, the marsh trefoil site showed the largest CH_4 flux (Fig. 5a), although the water level of this site lowered below the surface during the summer. The effect of water level at the marsh trefoil site on CH_4 emission has positive feedback. At the marsh trefoil site, the lowering of water level causes increase of soil temperature due to the exposure of soil to solar radiation. Consequently, the Eh decreases as the reducing process is enhanced by the decomposition of fresh organic matter in the

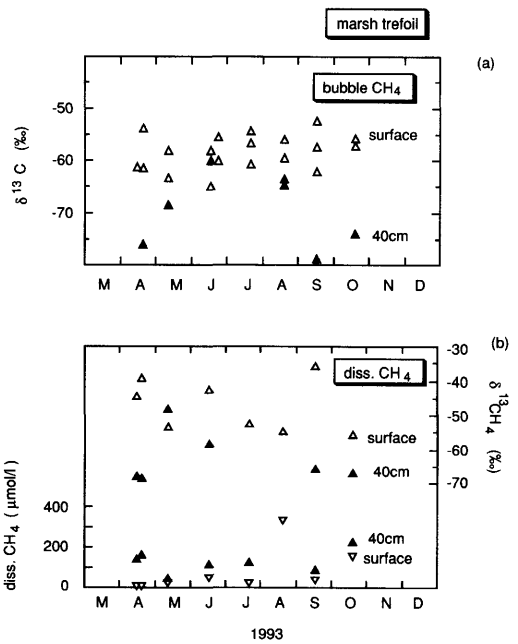

Fig. 8. The $\delta^{13}C$ of bubble methane collected at the surface (open symbols) and at the depth of 40 cm (closed symbols) (a), and the amount of dissolved CH_4 and its $\delta^{13}C$ value in the soil water observed at depths of 10 cm and 40 cm (b) at the marsh trefoil site.

surface soil. Gas produced in the soil produces buoyancy in the floating mat and lift up the soil surface. The rise of the soil surface causes the relative water level to drop again.

The lowering water level at the marsh trefoil site causes, therefore, a reducing environment rather than an oxidative one. On the Amazon flood plain, a decrease of CH_4 flux at the time of increase of water level has been observed at the beginning of the rainy season due to development of an oxidative environment in the soil, because oxygen was introduced into the soil with water (Wassmann et al. 1992). These examples and also the results observed by Wilson et al. (1989) and Yavitt et al. (1990) show that high water level does not always indicate a reductive environment.

Another important factor controlling CH_4 flux is the rate of decomposition of organic matter. Different vegetation means a different quality of organic matter. It has been known that sphagnum tissue decomposes very slowly (reviewed by Van Breemen, 1995) because it consists of sphagnum acid (Karunen and Ekman, 1982; Rudolph and Samland, 1985) and polysaccharides (Clymo, 1963) which are decomposed very slowly. To compare the rate of decomposition among the three vegetations, wet soils collected in situ were incubated at a constant temperature (30 or 15°C) in the dark and the produced gas volume was measured. The rate of decomposition of sphagnum was extremely low compared to the others (Fig. 9), while, that of marsh trefoil was high. This result agrees with the observed difference in the CH_4 flux. The decomposability of marsh trefoil can enhance the decomposition activity of microorganisms in the surface soil, consequently, the development of low Eh and anaerobic gas production in the soil were enhanced when the soil temperature increases.

On the other hand, at the sphagnum site, the low water level is responsible for the high Eh during the whole observation period. However, the Eh at a depth of 10 cm decreased, during the summer (Fig. 7c). Namely, a reducing process due to increase of soil temperature occurs at the sphagnum site too, although the magnitude of the increase of soil temperature is smaller than that at the marsh trefoil site. A strongly reducing environment, however, is not developed at the sphagnum site, and also the gas production rate is low, because of the low rate of decomposition of sphagnum.

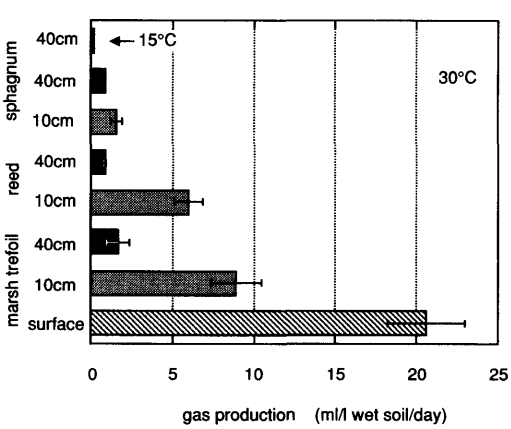

Fig. 9. The amount of gas volume produced in a soil incubation experiment. Soils collected at the surface and at depths of 0–10 cm and 30–40 cm at the reed, marsh trefoil and sphagnum sites were incubated anaerobically at 30 or 15°C. Error bars are standard deviations for duplicate experiments.

The reed site showed smaller CH_4 emission compared to the marsh trefoil site, nevertheless, the Eh at the reed site decreased earlier than that at the marsh trefoil site at the beginning of the summer. It should be noted that the obtained Eh is an average value around the Eh probe. In a culture experiment, CH_4 is produced under the condition of Eh lower than -200 mV (Mah et al., 1977). In soil, such a low Eh is achieved in a micro-site in a particle of soil organic matter where CH_4 is produced. The high water level at the reed site is possibly responsible for the observed low Eh by cutting off air intrusion. The water, however, suppresses the increase of soil temperature, and, consequently, suppresses the development of low Eh and CH_4 production in a micro-site. The slow rate of decomposition of reed compared to that of marsh trefoil also delays CH_4 production and emission.

The rate of production of plants, namely the rate of supply of fresh organic matter to the soil, is also one of the factors controlling CH_4 emission. Generally, the rate of primary production of sphagnum is lower than the other wetland plants, such as reed and sedge (Mitsch and Gosselink, 1993). At our observation site, Mizorogaike located in temperate region, sphagnum growth is more than 10 cm/year. The production of reed, however, is considered to be much more greater than that of sphagnum.

The average CH_4 fluxes during the period of April to October were 450, 290 and 70 $mgC/m^2/day$ for the marsh trefoil, reed and sphagnum sites, respectively. The difference in CH_4 flux among the three sites agrees with the facts observed by several researchers. Dise (1993) observed that a fen dominated by sedge and arrowgrass showed a higher CH_4 flux than a sphagnum bog. In tundra, Whalen and Reeburgh (1992) showed that the CH_4 flux at the sedge dominant site was larger than that at the other sites. Dise (1993) pointed out the importance of the labile carbon from root exudate for higher CH_4 flux in a sedge dominant area. Our result of the incubation experiments indicates that not only the root exudates, but also the quality of the organic matter, namely the decomposability of plants, is responsible for the CH_4 flux.

Especially, the extremely low decomposition rate of sphagnum is important to control CH_4 flux as described later. The correlation between CH_4 emission and net primary production has been pointed out by Whiting and Chanton (1993). Northern sphagnum bogs represent data points for low CH_4 emission and low productivity, and cattail (*Typha*) fens in the temperate region do so for the high CH_4 emission and high productivity. The higher decomposability and higher growth rate of the fen plants might be responsible for the correlation between CH_4 emission and net primary production.

4.2. *Formation pathways and consumption of CH_4*

The observed $\delta^{13}C$ of CH_4 reflects the formation pathways and oxidation process. There are two main pathways for CH_4 formation in a freshwater area: CO_2/H_2 reduction and acetate fermentation. In freshwater environments, the $\delta^{13}C$ of CH_4 from acetate (-43 to -30‰) is higher than that from CO_2/H_2 reduction (< -60‰), and the variation in CO_2 $\delta^{13}C$ can cause the variation in $\delta^{13}C$ of CH_4 (Sugimoto and Wada, 1993). Therefore, the change in formation pathway can cause the change in $\delta^{13}C$ of CH_4. While, the CH_4 oxidation also causes an increase of the CH_4 $\delta^{13}C$, since a light isotope (^{12}C) is preferentially oxidized to CO_2 (Coleman et al., 1981).

In freshwater soil containing fresh organic matters, CH_4 is produced from both acetate and CO_2/H_2; consequently, -50 to -60‰ of bubble CH_4 is generally observed (Whiticar et al., 1986; Burke et al., 1992; Sugimoto and Wada, 1995). Accordingly, we cannot conclude that the increase of bubble CH_4 $\delta^{13}C$ up to -52.5‰ was due to oxidation of CH_4. Besides, the increase of CO_2 $\delta^{13}C$ (up to -5.7‰) was observed. The observed increase of CH_4 $\delta^{13}C$ during the summer in most bubbles is, therefore, possibly caused by the change of formation pathway from CO_2/H_2 to both acetate and CO_2/H_2 and by the increase of $\delta^{13}C$ of CO_2, although the possibility of CH_4 oxidation cannot be rejected as the cause of a part of the observed $\delta^{13}C$ increase. Details of the $\delta^{13}C$ of CH_4 and its formation pathways will be described elsewhere.

The produced CH_4 is, however, possibly oxidized in the water column. The observed $\delta^{13}C$ of dissolved CH_4 at a depth of 40 cm was similar to or lower than that of bubble CH_4, while the $\delta^{13}C$ of dissolved CH_4 in the surface water was remarkably higher (up to -35.8‰) than that observed

in bubbles at the marsh trefoil site (Fig. 8). Such a high $\delta^{13}C$ of dissolved CH_4 was possibly caused by CH_4 oxidation in the surface water. However, the CH_4 oxidation in the soil and water is not a deterministic process controlling the CH_4 emission in a temperate bog such as Mizorogaike where the CH_4 production rate is much higher than that in a cold region.

5. Effect of vegetation change on CH_4 emission

The three different vegetation sites observed on the floating mat in Mizorogaike pond showed characteristic CH_4 fluxes. The largest CH_4 emission was observed at the marsh trefoil site, where fresh organic matters derived from marsh trefoil (a broad-leaved aquatic herb) with high decomposition rate are supplied into the soil, supporting high CH_4 emission. At the marsh trefoil site, the rate of gas production in the soil at 40 cm was also higher than that of the other sites (Fig. 9), because the sphagnum peat was replaced by the roots of marsh trefoil. This means that easily decomposable fresh organic matters from marsh trefoil enhances decomposition of sphagnum peat below the surface. Actually, the floating mat has been thinning at the marsh trefoil site.

Small or negative CH_4 flux was observed at the sphagnum site, which consists of organic matter with extremely slow decomposition rate. Sphagnum grows in a low pH environment and the acids excreted by themselves are also responsible for the low pH environment, which can inhibit bacterial activity causing a low rate of decomposition. The sphagnum plant body also suppress an increase of temperature, acting as an insulator for heat and causing a further delay of decomposition.

The reed site showed a high CH_4 emission rate at the end of summer with a delay, comparable to the marsh trefoil site. The decomposition rate of reeds is lower than that of marsh trefoil, but much higher than that of sphagnum (Fig. 9). Reeds also shoot twice a year, but their first leaves open in June and they grow one or two months after the growth of marsh trefoil. In August, the first shoots die, but the plant above ground stands for a while without being decomposed. The bubble production and CH_4 emission at the end of the summer are possibly caused by the decomposition of roots of reeds growing during the summer. Accordingly, the delay of the growth of reeds, namely the delay of the supply of organic matter to the soil, is responsible for the delay of the CH_4 emission at the reed site. The delay of the increase of soil temperature may also be responsible for the delay of CH_4 emission.

Such vegetations as sphagnum, marsh trefoil (broad-leaved aquatic herb) and reed are typical vegetations observed in temperate and boreal wetlands. However, these three vegetations are discerned from the condition of nutrients in their habitat (Mitsch and Gosselink, 1993). Sphagnum can only grow in a low pH and oligotrophic (limited amount of nutrients) peat land (called a bog) (Koerselman et al., 1990; Van Breemen, 1995). Marsh trefoil can grow in a wide range of nutrient level (Hewett, 1964), and reeds grow in eutrophic water (rich in nutrients; called a fen). In Mizorogaike pond, these vegetations grow on different microrelief (Shimizu, 1986). Sphagnum builds hummocks where nutrient is supplied mainly from precipitation. Meanwhile, in a pool, nutrient is supplied not only from precipitation but also from decomposition of organic matter and water input into the pond from the catchment area. Marsh trefoil and reed cannot invade into the sphagnum dominant site, because of the environment with low concentration or low availability of nutrients established by sphagnum (Malmer et al., 1994). However, in Mizorogaike pond, the reed and marsh trefoil dominant sites are now expanding, because of the retreat of sphagnum caused by input of nutrient rich water unfavorable for sphagnum (Haraguchi and Matsui, 1990). Sphagnum cannot survive in water with pH higher than 6 or in water with high nutrient level, especially if it is rich in phosphoric acid (Fujita and Shibasaka, in preparation). When sphagnum grows healthy, other plants which can shade and kill sphagnum cannot invade into the sphagnum dominant area. But once sphagnum retreates, reeds and marsh trefoil take over the area rapidly, and consequently CH_4 emission is accelerated.

Sedges are another typical plant in wetlands and grow in a wide range of nutrient levels like marsh trefoil, although they are not dominant in Mizorogaike. From the viewpoint of decomposability or CH_4 emission, they are similar to reeds.

In other natural wetlands, sphagnum bogs are formed where the altitude of the surface is high

enough to prevent water input, namely the nutrients are supplied only from precipitation and decomposition there (Van Breemen, 1995). While, reeds, sedges and other herbs grow in a wetland where river water or ground water flows into the area with a supply of nutrients. If polluted water flows into the area, or if river water or ground water enters the area due to a change of water circulation caused by global warming, the vegetation can change from sphagnum to the other plants such as reeds and water plants. Such a vegetation change can accelerate CH_4 emission from the wetlands. Not only the effect of temperature increase but also that of vegetation change on the emission of CH_4 from a wetland should be taken into consideration when the future CH_4 source strengths are estimated.

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