Environ. Sci., Hokkaido University	13 (1)	93～156	June 1990

Environmental-Geomorphological Study on the Holocene Mire Development in the Daisetsuzan Mountains, Central Hokkaido, Northern Japan

Nobuyuki Takahashi

Department of General Education, Hokkaigakuen University,
Sapporo, 062, Japan

Abstract

The Daisetsuzan Mountains has been under a favorable climatic condition for mire development since about 7,500 y.B.P. There is, however, a difference in origin of mires between below and above the timber line. The occurrence of the mires below the timber line was significantly controlled by topographic factors, related to volcanic activities and landslides which caused the destruction of forest vegetation and the formation of depressions. On the other hand, the occurrence of the mires above the timber line, that is in the alpine zone, was controlled by climatic factors, affecting the position of timber line, the structure of alpine vegetation and the distribution of snow patches. The beginning of the mire formation in the Daisetsuzan Mountains dates back to about 7,500 y.B.P. After about 4,000 y.B.P., many mires began to develop in the alpine zone: according to the result of pollen analysis, *Picea* and Cyperaceae increased remarkably, which suggests that the climate became cooler than the previous period and the meadow dominated by Cyperaceae expanded in the alpine zone. Since about 2,000 y.B.P., the cool climatic condition has been kept, and the peat accumulation in the mires has continued. Bank (Kermi) and hollow (Schlenke) complexes and palsas are the most important microtopographies in the mires of the Daisetsuzan Mountains. Bank and hollow complexes are originated from solifluction lobes which were formed before the beginning of peat accumulation. Palsas related to permafrost are located only in the mire on the south of Hiragatake (1,720 m a.s.l.) in the Daisetsuzan Mountains of all the mountains of Japan.

Key Words: the Daisetsuzan Mountains, mire, alpine zone, pollen analysis, bank and hollow complex, palsa.

1. Introduction

1.1 Significance and purpose of the study

The formation of mires is controlled by complex interactions among topography, climate, hydrology and vegetation. Therefore, the deposit of mire, especially peat, plays a very important role in the reconstruction of paleoenvironment around the mire. In mountains where erosional processes are generally dominant, the mire studies are more significant, since the paleoenvironmental records are well preserved in mires than in other locations. Not only the deposit, but also various kinds of microtopography of mires reflect themselves the past and present environments in which mires have developed.

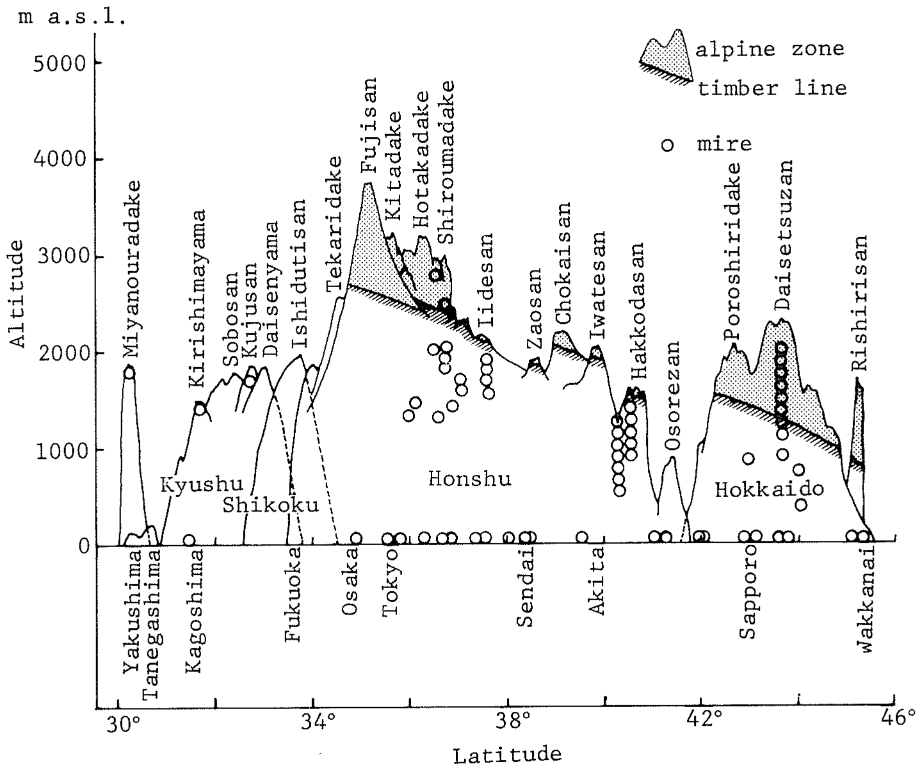

Figure 1 Distribution of present alpine zone (after Kaizuka, 1986) and mires (after Sakaguchi, 1974) in Japan.

According to Sakaguchi (1974), most of mires in Japan are located on the alluvial lowland from north to the central Japan and on young volcanos (Figure 1). Abundant paleoenvironmental and paleogeographical studies have been carried out on the mires on the alluvial lowland, however, mires in mountains have been much less studied. As far as mires on the mountains are concerned, they are distributed from Hokkaido to Yakushima in Kyushu. These mires are the peatlands which were formed during the Holocene. Most of mires in Japanese mountains develop in the subalpine zone and scarcely in the alpine zone (Figure 1). Although the alpine zone stretches widely in the Japanese Alps, central Japan, their topographic condition is not suitable for the mire development. It is only in the Daisetsuzan Mountains where the mires develop widely in the alpine zone in Japan; firstly because the timber line is lower than in the Japanese Alps, and secondary because most of the area above timber line in the Daisetsuzan Mountains consists of flat or gentle slopes. Another factor which characterizes the alpine zone of the Daisetsuzan Mountains is the existence of alpine permafrost, which has been known only in this area (Fukuda and Kinoshita, 1974; Sone and Takahashi, 1986) and on Mount Fuji (Higuchi and Fujii, 1971) in Japan. However, the environmental and geomorphological relation between the alpine permafrost and the mires have never been studied before.

The purpose of this study is, therefore, to give the basic data on the age and the development history of mires in the Daisetsuzan Mountains. For this purpose, the author summarizes first the previous studies on mires in mountains in Japan. In the Second Chapter, the author describes the topographical and geological settings, the climate and the vegetation of the Daisetsuzan Mountains. The relation between the mire distribution and these natural factors will be also discussed. The Third Chapter is devoted to the detailed description of each mire, where the results of the age determination and palynological studies will be given. The Forth Chapter treats with the microtopography of mire in the Daisetsuzan Mountains: especially bank (Kermi) and hollow (Schlenke) complexes. In the Fifth Chapter, the author describes the palsa mire in the Daisetsuzan Mountains which he discovered first in Japan. The Sixth Chapter is the last one in which the author summarizes the whole results of the present study and discusses the paleoenvironmental changes around the mires in the Daisetsuzan Mountains during the Holocene.

1.2 Previous studies on the mires in the mountains of Japan

Paleovegetational, paleoenvironmental or geomorphological studies of mires in mountains are limited. Among them, a series of studies on the Ozegahara mire, the Tohoku district, northern Japan, by Sakaguchi (1954; 1959; 1979), Sakaguchi et al. (1982a; b), Sakaguchi and Sohma (1982) etc. is noticeable. In these studies, they dealt synthetically with the genesis and the development of the Ozegahara mire from geological point of view. Their studies include pollen analysis, sedimentology, and radiocarbon dating of mire deposits which enabled the reconstruction of paleoenvironment and the origin of microtopographies. Recently, Morita (1984a; b; 1985) and Morita and Aizawa (1986) carried out palynological studies on the mires in the subalpine zone of the Hakkodasan and the Hachimantai Mountains and Azumasan in the Tohoku district, where Yamanaka (1977; 1978) did the similar works. Kanauchi (1987) also carried out a palynological study on the Kinu bog in the subalpine zone of the northern Kanto district. These studies made clear the Holocene vegetational history of the northern Kanto and the Tohoku districts:

According to Sakaguchi (1974), the onset of the Holocene peat accumulation of the Ozegahara mire (about 1,400 m a.s.l.), the northern Kanto district, is up to 8,000 y.B.P. On the basis of the result of pollen analysis, Sakaguchi (1976) concluded that the postglacial climate around Ozegahara was dry and warm before 500 B.C., wet and warm between 500 B.C. and 100 A.D., wet and warmer between 100 A.D. and 1,300 A.D. and wet and cooler between 1,300 A.D. and present. In the mire ranging from 1,460 to 1950 m a.s.l. in Azumasan, the southern Tohoku district, the onset of peat accumulation is estimated at 7,500-7,000 y.B.P., and the modern subalpine coniferous forest zone is considered to have replaced a meadow vegetation around 3,000-2,500 y.B.P. (Morita,1984a). In the Kinu bog (1,800-2,040 m a.s.l.) of the northern Kanto district, the peat accumulation started around 6,100 y.B.P. and the montane forest zone before 1,700 y.B.P. was higher than at present (Kanauchi,1987). In the mire located at 1,580 m a.s.l. in the Hachimantai Mountains, the northern Tohoku district, the accumulation started before 4,600 y.B.P. (Morita,1985). The upper limit of beech forest zone on the northeastern slope of Naebayama (1680-1960 m a.s.l.), the northern Kanto district, before 3,000 y.B.P. was at least 350 m higher than that of present time (Kaji, 1982).

According to the palynological study at the mire on the Midagahara plateau (1,000 - 2,000 m a.s.l.) in Mt. Tateyama (Yoshii and Fujii, 1981), central Japan, the climate had already become somewhat milder and more humid before about 9,000 y.B.P. After about 6, 500 y.B.P., it became colder, and around 3,570 y.B.P., it was more humid. The peat bog itself had become drier and smaller in area as a result of the invasion of arboreal plants.

In Yakushima Island, southwestern Japan, Sohma (1984) studied the changes of slope stability around a mire on the basis of stratigraphical analysis and that of variation of inorganic content in peat deposits.

Palynological studies in the mountains of Hokkaido are almost restricted to the Teshio Mountains (Igarashi and Fujiwara, 1984), the Shiretoko Peninsula (Katsui et al., 1985) and Shokanbetsudake (Morita, 1985; Miyagi et al., 1987) other than those in the Daisetsuzan Mountains by the author (Igarashi and Takahashi, 1985; Takahashi and Igarashi, 1986).

At the Pankenai mire (470 m a.s.l.) in the Teshio Mountains (Igarashi and Fujiwara, 1984), northern Hokkaido, peat accumulation started at about 1,500 y.B.P. and since that time the vegetation hardly changed.

In the Shiretoko Peninsula (Katsui et al.,1985), eastern Hokkaido, the peat accumulation on the southeastern slope (420 m a.s.l.) of Onnebetsudake was started by the occurrence of landslide at about 300 y.B.P. The peat accumulation at the swamp (750 m a.s.l.) on the northeast of Lake Rausu started about at 3,000-2,500 y.B.P. Since that time the vegetation had hardly changed except within the landslide depression. The vegetation had been almost stable except some changes in *Abies, Quercus* and wetland or aquatic plants. Sohma (1985) discussed the changes of slope stability of the surroundings of the mire in the Shiretoko Peninsula by the same method as adopted in Yakushima Island. He also referred to the fluctuation of precipitation.

In the Uryunuma mire, mid-western Hokkaido, in addition to the pollen analysis (Morita, 1985), Miyagi et al. (1987) studied the development of the moor in relation to the mass movement on the surrounding slopes. The beginning of peat accumulation was about 10,000 y.B.P. there. Around 7,000 y.B.P. nivation hollows were formed on the surrounding slopes due to a heavy snowfall, and abundant mineral materials were removed to the mire by melting water. After about 3,800 y.B.P., forest vegetation was established around the mire.

Most of the studies on the mires mentioned above mainly aimed to reconstruct paleovegetation or paleoenvironment. However, in the Ozegahara and the Uryunuma mires, the development of mires was discussed also from viewpoints of geomorphology, pedology or sedimentology: Sakaguchi (1980; 1985) and Sakaguchi and Sohma (1982) discussed the genesis of bank (Kermi) and hollow (Schlenke) complex. According to them, this complex in the Ozegahara mire is developed only on the bog surface whose slope is less than 0.03. They also pointed out that the complex characterizes microtopography in the peat bogs in heavy snowfall regions, and the formation of bank and hollow complex was caused by climatic change which started almost simultaneously, after about 3,000 y.B.P. all over the world.

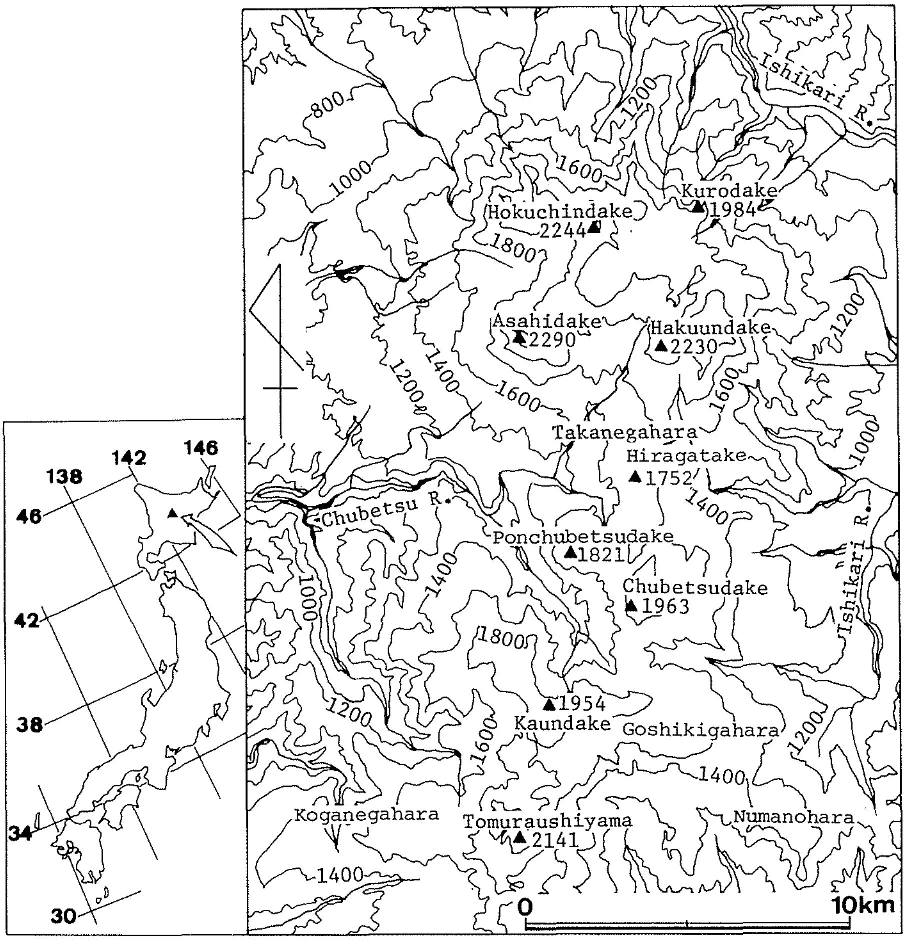

Figure 2 Study area.

2. Regional Settings of Study Area and Distribution and Age of Mires

2.1 Introduction

In this chapter, the author describes first the regional settings of the study area: topography, geology, volcanic ash, climate and vegetation. After briefly describing the general distribution of mires, he discusses the relation between it and the geological and topographical conditions. Furthermore, he shows ^{14}C data in relation to mire development.

The Daisetsuzan Mountains are located in the central Hokkaido, northern Japan. They compose a part of the Daisetsuzan National Park, the largest one in Japan which occupies an area of about 230,000 ha. The study area, which covers the main part of the Daisetsuzan Mountains, stretches about 26 km from north to south and about 20 km from east to west (Figure 2).

2.2 Regional settings of study area

2.2.1 Topography and geology

The Daisetsuzan Mountains are composed of andesitic lava plateau and a number of volcanic cones constructed on the former, of which Asahidake (2,290 m a.s.l.) is the highest summit in Hokkaido. The volcanic landforms of the Daisetsuzan Mountains consist of the following five elements : (1) wide and flat lava plateau ranging from 1,400 to 1,800 m a.s.l., (2) dome-shaped volcanic cones whose summits are around 2,000 m a.s.l., (3) Ohachidaira crater about 2 km in diameter, (4) Asahidake strato-volcano (2,290 m a.s.l.), and (5) large-scale landslides.

The formation history of the Daisetsuzan Mountains is grouped into the following four stages (Konoya et al., 1966; 1968) (Figure 3):

I: stage of the formation of the basement of the Daisetsu volcanic group; Plio-Pleistocene.

II: stage of the formation of the Older Daisetsu Volcano; a detailed age is not known.

III: stage of the formation of the Younger Daisetsu Volcano, including the formation of Ohachidaira; a detailed age is not known.

IV: stage of the formation of the Asahidake Volcano; Holocene.

Major lava plateaus are called Takanegahara, Goshikigahara, Numanohara and Koganegahara. They are located in the central part of the Daisetsuzan Mountains, the southeastern part, the southeastern part and the southwestern part respectively. Major dome-shaped volcanos are Hokuchindake (2,244 m a.s.l.), Kurodake (1,984 m a.s.l.) and Hakuundake (2,230 m a.s.l.) in the northern part and Tomuraushiyama (2,141 m a.s.l.) in the southern part. They are composed of the ejecta of Stages II and III. Ohachidaira in the northern part is the largest crater in the Daisetsuzan Mountains and was formed about 30,000 y.B.P. (Katsui and Ito, 1976). Although there is no standing water at present, the bottom is covered with lake deposits. Asahidake strato-volcano is composed of the ejecta of Stage IV and have gentle slopes on its northwestern to southern mountainside.

A number of landslide areas are distributed around flat surfaces and gentle slopes (Figure 3). For example, on the east of Takanegahara and on the north and the south of Goshikigahara, large-scale landslides of more than 100 ha are distributed and consist of long and steep scarps and landslide blocks and depressions. The ages of ash layers and peats in the landslide depressions indicate that the landslides occurred frequently during the Holocene (Takahashi, 1983).

In the alpine zone various kinds of patterned ground, solifluction lobes, earth hummocks and nivation hollows are formed as a result of periglacial processes.

2.2.2 Volcanic ash layers

Four volcanic ash layers (Figure 4) are found on Takanegahara in the central Daisetsuzan Mountains (Igarashi and Takahashi, 1985). They are called Takanegahara ash layers a, b, c and d (Tk-a, Tk-b, Tk-c and Tk-d) from the upper to the lower. Tk-a, Tk-b and Tk-c cover extensively on the Daisetsuzan Mountains, and Tk-c is sometimes subdivided into two horizons (Tk-c and Tk-c) at one site. Tk-a is correlated to Tarumae-a ash (Ta-a) which was erupted in 1739 (Katsui et al.,1979), while the sources of other ash layers have never been known. Judging from the intercalated humus or peat layers which are less than

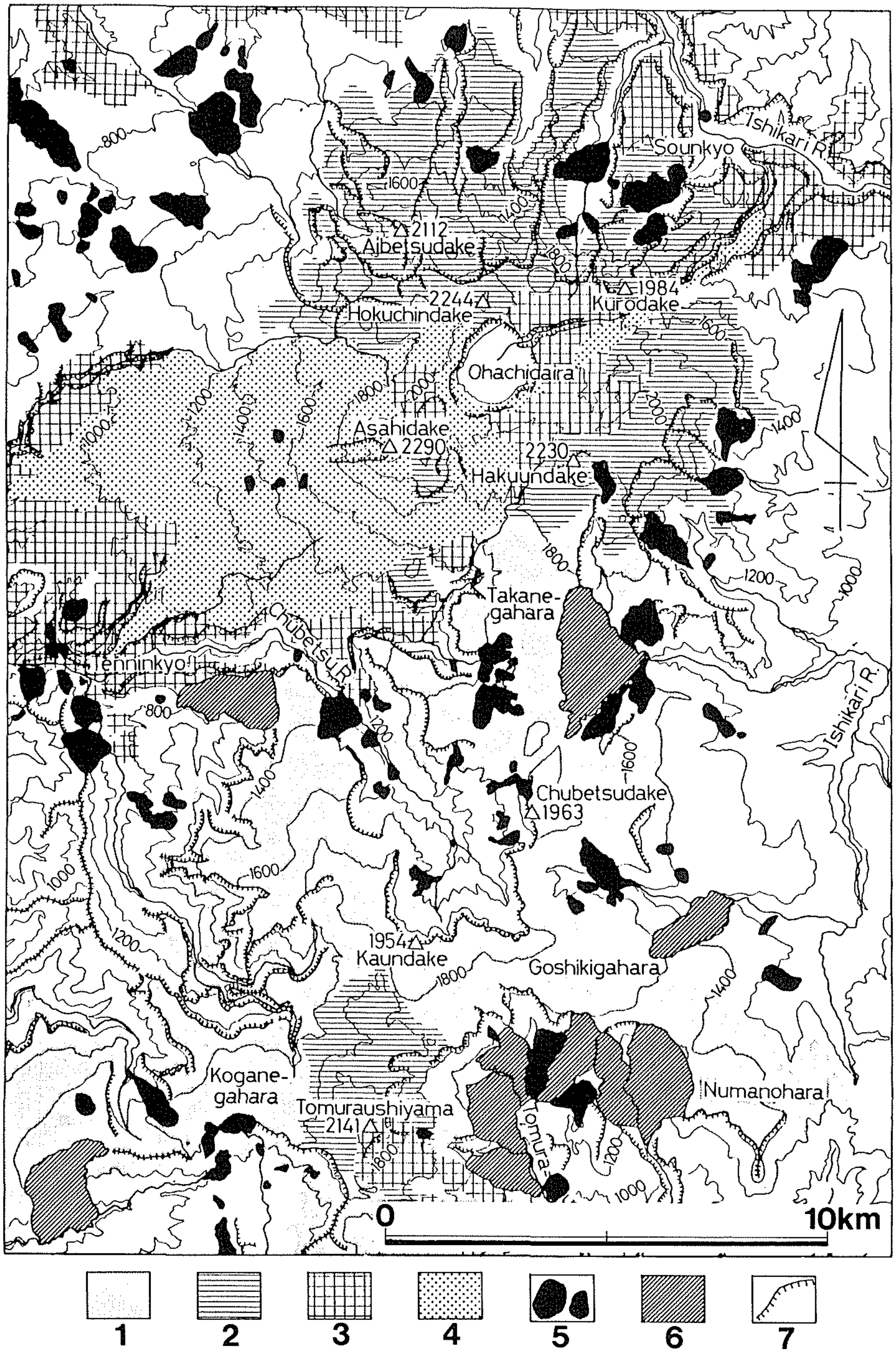

Figure 3 Distribution of ejecta (after Konoya et al., 1966 ; 1968) and landslide areas in the Daisetsuzan Mountains.
1 : ejecta of Stage I, 2 : ejecta of Stage II, 3 : ejecta of Stage III, 4 : ejecta of Stage IV, 5 : landslide area (less than 100 ha), 6 : landslide area (100 ha or more), 7 : erosional scarp.

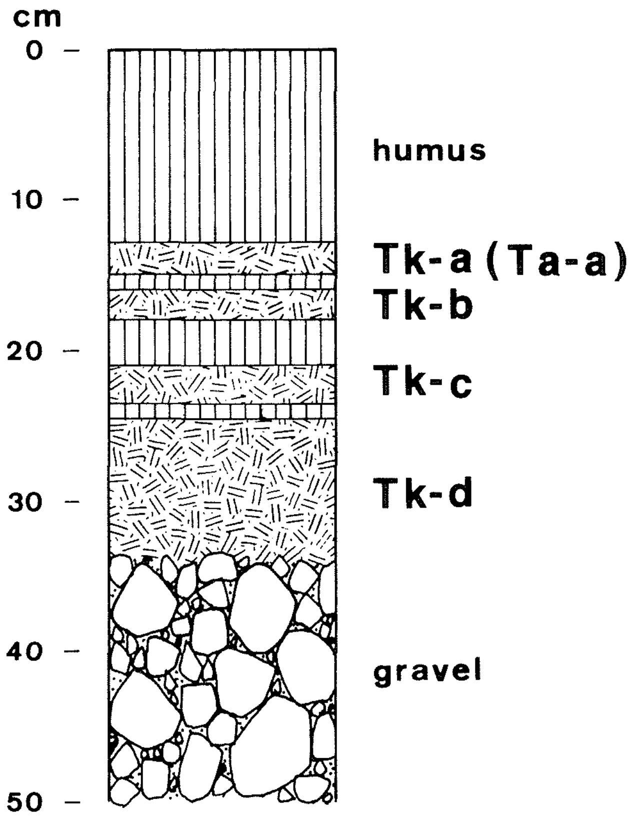

Figure 4 Superficial deposits intercalated with four ash layers (Tk-a, Tk-b, Tk-c and Tk-d) on Takanegahara.

1 cm thick between Tk-a and Tk-b, Tk-b is considered to have been erupted little before 1739.

2.2.3 Climate

As there is no meteorological recordings on the Daisetsuzan Mountains, the author measured a whole year round air temperature at Hakuun hat (ca. 2,000 m a.s.l.) in 1985 (Sone et al., 1987). It was measured by a thermo-junction thermometer, and the data were stored in a battery powered IC (Data logger, C57-0218AS). Table 1 shows the main results: the annual mean temperature, −3.8°C; the mean temperature in the coldest month (January), −21.3°C; the mean temperature in the warmest month (August), 13.9°C; the freezing index, 2,588 degree-days. These values correspond to those of Fairbanks, Alaska, locating in the zone of discontinuous permafrost. In fact, permafrost occurs at an elevation of about 2,000 m in the Daisetsuzan Mountains (Fukuda and Kinoshita, 1974; Koaze et al., 1975; Ono et al., 1982). The author also verified the existence of permafrost at Hokkaidaira, 2,060 m a.s.l. (Sone and Takahashi, 1986). The thickness of permafrost seems to be about 4.2 m, and that of active layer is about 1.2 m (Sone et al., 1988). The author also discovered palsas which are typical features developed in discontinuous permafrost zone.

Table 1 Air temperature at Hakuun hat (2,000 m a.s.l.) in 1985 (after Sone et al., 1987). A : mean monthly temperature (°C), B : number of days with mean daily temperature below 0 °C, C : number of days with mean daily temperature below −10 °C, D : number of days with mean daily temperature below −20 °C, E : freezing index (degree-days), F : number of freeze-thaw days.

	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Auh.	Sep.	Oct.	Nov.	Dec.	Year
A	−21.3	−15.9	−13.2	−3.2	0.6	5.5	11.1	13.9	4.5	−1.9	−9.2	−17.6	−3.8
B	31	28	31	26	16	1	0	0	5	18	27	31	214
C	31	28	24	1	0	0	0	0	0	0	15	30	129
D	21	2	2	0	0	0	0	0	0	0	0	7	32
E	659.4	443.8	410.1	99.2	43.7	0.8	0	0	5.8	101.6	278.4	545.1	2588.1
F	0	0	0	20	15	6	0	0	11	14	5	0	71

Table 2 Precipitation at Asahikawa (1951-80) about 45 km WNW of the study area. A : precipitation (mm), B : total snow depth (cm), C : number of snowfall days.

	Jan.	Feb.	Mar.	Apl.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
A	79.9	64.3	61.6	64.5	73.9	78.1	118.7	168.3	134.2	103.7	115.9	94.7	1157.9
B	143	107	75	18	1	−	−	−	0	4	97	154	598
C	29.0	25.6	23.9	9.4	1.1	−	−	−	−	2.0	16.9	27.5	135.4

The annual mean precipitation measured at a meteorological observatory of Asahikawa, about 45 km WNW of the study area, was 1,158 mm between 1951 and 1980 (Table 2). Most of precipitations between November and March are snow. According to Yamada (1982), the maximum snow depth at Asahidake was 200 cm at the altitude of 1070 m. However, the snow depth became less at lower altitude than this. Above timber line, the maximum snow depth was 120 cm on the windward slope of Asahidake. Westerly prevailing wind in winter brings about a large amount of snowfall on the eastern slope. On the eastern slope of Takanegahara, the maximum snow depth reaches 25-30 m (Wakahama et al., 1968; 1969). A part of snow remains throughout summer and forms perennial snow patches.

Takanegahara plateau, which is located on the main ridge running from north to south, is more frequently covered with clouds or fogs in summer than other places in the Daisetsuzan Mountains. As a result, it receives less insolation than in the other places.

2.2.4 Vegetation

According to Ito and Sato (1981), the natural vegetation of the Daisetsuzan Mountains is divided into alpine, subalpine, montane vegetations and others (Table 3). Alpine vegetation involves seven communities and four community complexes. Subalpine vegetation stretches around and below the timber line, and consists of *Sasa kurilensis* and *Alnus maximowiczii* communities, *Betula ermanii* forest, upper mixed forest and coniferous forest from the higher to the lower. Montane forest occupies comparatively narrow area below 600 - 800 m a.s.l. Pioneer herbaceous communities occupy the western slope of Asahidake, and many high mires are scatter in subalpine and alpine zones.

Table 3 Actual vegetation of the Daisetsuzan Mountains (after Ito and Sato, 1981).

Natural vegetation	Alpine vegetation	1. Alpine snow-hostil scrub (Vaccinio-Pinetum pumilae)
		2. Alpine snow meadows (Alpine tall perennial herbaceous communities)
		3. Alpine snow-bed communities
		4. Alpine wind-blown dwarf scrub (Arcterico-Leuseleurietum procumbentis)
		5. Alpine wind-blown dwarf scrub (Arctous alpinus var. japonicus-Vaccinium uliginosum community)
		6. Alpine wind-blown rocky gravel dwarf scrub·herbaceous community (Salici-Oxytropidetum yesonensis)
		7. Alpine wind-blown rocky gravel herbaceous community (Dicentro-Violetum crassae)
		8. Community complex (4 and 7)
		9. Community complex (3 and 4)
		10. Community complex (1 and 12)
		11. Community complex (1 and 14)
	Subalpine vegetation	12. Sasa kurilensis community
		13. Alnus maximowiczii community
		14. Betula ermaii forest
		15. Upper mixed forest
		16. Picea jezoensis forest
		17. Picea jezoensis·Abies sachalinensis forest
		18. Picea glehnii forest
		19. Picea glehnii·P.jezoensis·Abies sachalinensis forest
Natural vegetation	Montane vegetation	20. Populus maximowiczii·Toisusu urbaniana forest
		21. Lower mixed forests of conifers an broadleaf trees
		22. Montane broadleaved forest
		23. Ulmus davidiana var. japonica·Cercidiphyllum japonicum forest
		24. Salix spp. forest
		25. Quercus mongolica var. grosseserrata forest
		26. Betula spp. forest
		27. Upland meadows
	Others	28. Pioneer herbaceous communities on active volcanos
		29. High moor
Anthropogenic vegetation and others		30. Cutover land
		31. Man-made forests
		32. Abandoned field
		33. Artificial grassland
		34. Urban sites
		35. Open water
		36. Non-vegetation-cover
		37. Perennial snowdrift glacier

According to the air photograph interpretation, the timber line rises to about 1,700 - 1,800 m on the eastern side of the mountains, and goes down to about 1,300 - 1,400 m on the western side (cf. Figure 6). The area above timber line is about 15,860 ha.

2.3 Distribution and age of mires

Figure 5 shows the distribution of mires basically plotted on a map of 1 : 25,000 on the basis of air photograph interpretation and field survey. Figure 6 shows the vertical distribution of mires on the eastern and western slopes of the Daisetsuzan Mountains. Although the distribution of mires ranges from about 1,000 to 2,000 m a.s.l., the mires are concentrated in the following different altitudinal zones: between 1,000 and 1,700 m a.s.l. on the western slope of Asahidake in the northern part; between 1,500 and 1,700 m a.s.l. on the western slope of Takanegahara in the central part; between 1,200 and 1,500 m a.s.l. on the eastern slope in the central part; around 1,400 m a.s.l. on Numanohara; between 1,500 and 1,800 m a.s.l. on Goshikigahara and its surroundings; and between 1,400 and 1,700 m a.s.l. on Koganegahara in the southern part. Mire distribution is strongly biased in the Daisetsuzan Mountains. It is rare in the northeastern part, and it is dense on the western side, while it is restricted on the east of Takanegahara and on and around Goshikigahara and Numanohara on the eastern side.

Figures 5 and 6 also show a relation between the mire distribution and the timber line. Main mires such as on Takanegahara, Goshikigahara, Numanohara and the upper half of Numanotaira on the northwest of Asahidake are located above the timber line. On the other hand, the mires below the timber line are restricted in the western slope of Asahidake and in the large-scale landslide areas such as on the east of Takanegahara, around

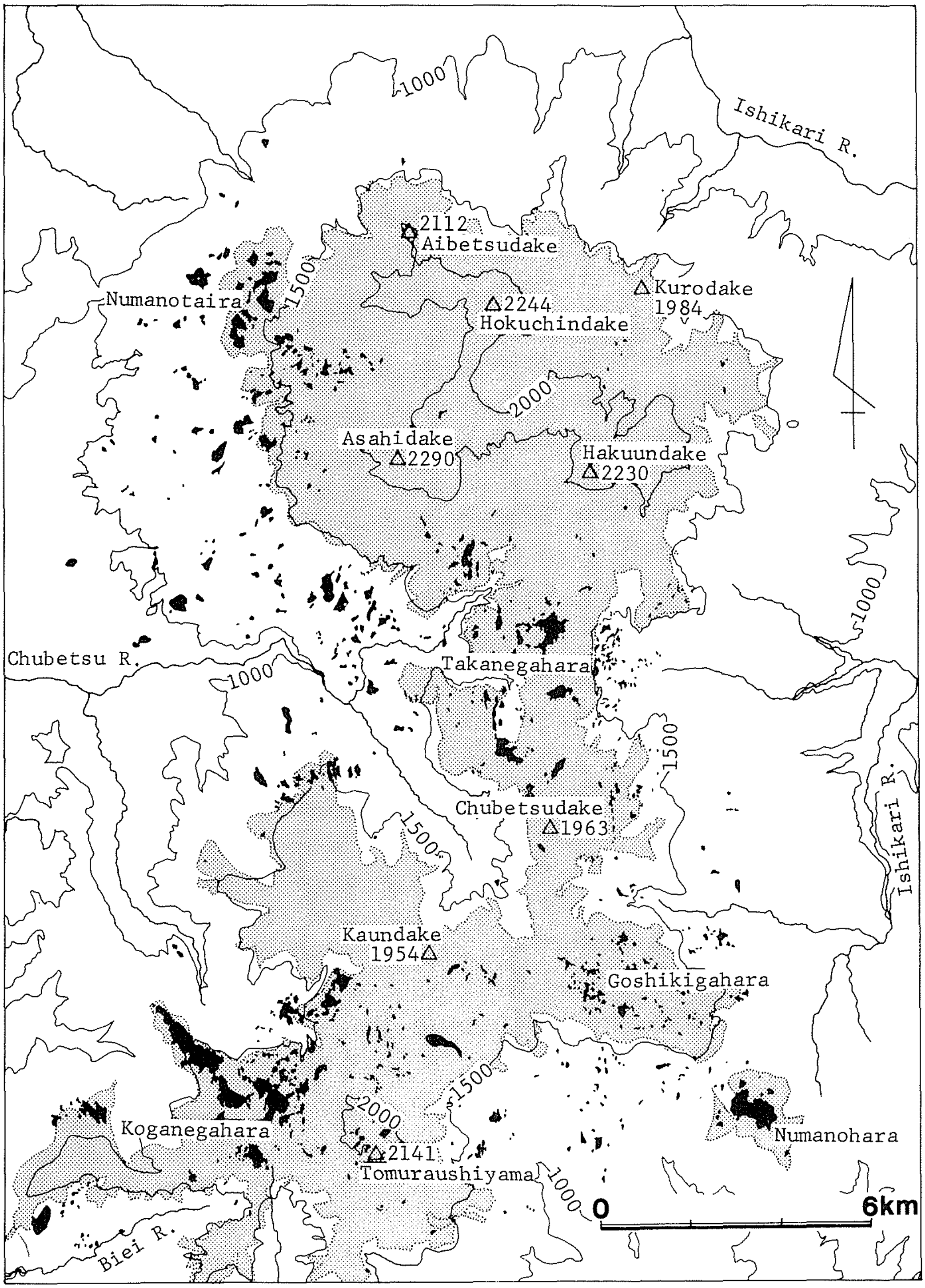

Figure 5 Distribution of mires (black part) in the Daisetsuzan Mountains. Shaded part shows an alpine zone.

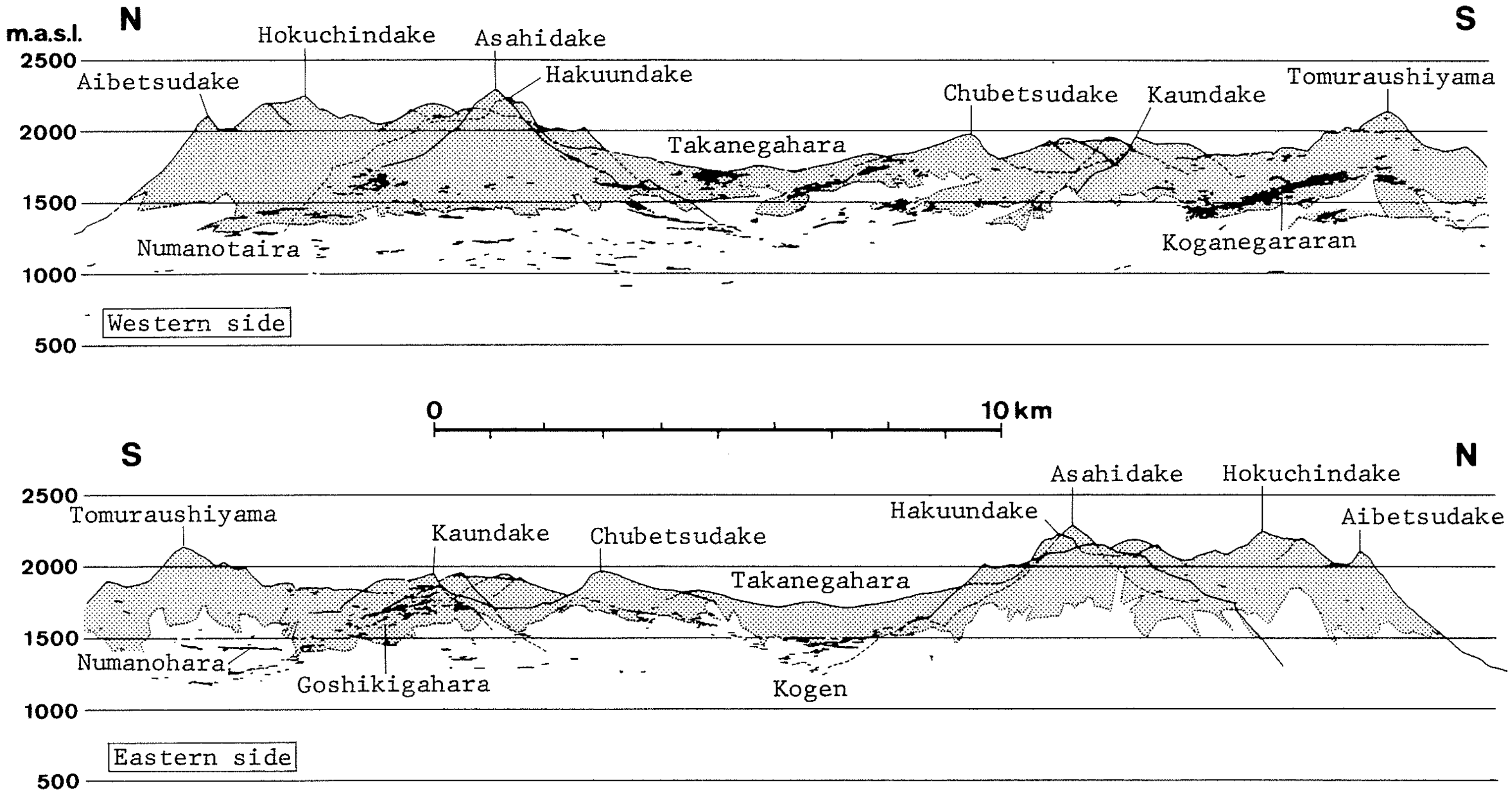

Figure 6 Vertical distribution of mires on the cross section from north to south of the Daisetsuzan Mountains. Hatched part shows an alpine zone.

Goshikigahara and to the southwest of Koganegahara.

Except the landslide areas, there is a good relationship between the distributions of ejecta and mires (Figure 7). Most of mires are located on the ejecta of Stages I and IV. As mentioned before, the ejecta of Stage I form a volcanic plateau whose flat or gentle slopes are favorable for mire development. On the other hand, many depressions and gentle slopes occur on the ejecta, especially on the lava flows, of Stage IV which forms a strato-volcano of Asahidake. These topographic conditions are favorable for a stagnation of water leading to mire development. While, there are hardly mires within the distribution area of the ejecta of Stages II and III except in several craters, because these ejecta form dome-shaped mountains which are poor in favorable topographic conditions mentioned above.

The distribution areas of mires below the timber line have been subjected to remarkable volcanic activities and landslides, which lead to unstabilization of slopes and often form flat or gentle slopes and depressions. As a result, mires are thought to be temporarily formed only in the areas with favorable topographic conditions, such as gentle slopes and depressions, before complete recovery of forest vegetation. This indicates that topography is the most important factor on mire formation below the timber line. The mires in the landslide areas, which are located in the shade of prevailing wind in winter, are preserved by melting water from snow patches on a scarp in addition to rainfall and ground water. The mires on the western slope of Asahidake seem to be mainly preserved by ground water.

The location of mires which are above the timber line is likely to be determined by the local topography and climate.

Flat or gentle slopes widely stretch above the timber line. The slopes have not been subjected to any processes, except solifluction, leading to unstabilization of slopes. Solifluction is thought to have prepared a rather favorable topographic condition for mire development. Therefore, above the timber line, a favorable topographic condition for mire development widely exists. The location of mires is mainly determined by the climatic or hydrological condition. Above the timber line, the main source of water maintaining mires is snow patches and precipitation. Therefore, mires develop around snow patches on the flat or gentle slope which is subjected to much snowfall in winter, represented by Koganegahara and Goshikigahara, and on the pass which is frequently covered with clouds or fogs, such as Takanegahara.

In seven mires, eleven peat samples were obtained for ^{14}C dating. Among them, seven samples were taken from the bottom of peat layers. The results of ^{14}C dating are shown in Table 4. Among the mires, only the Midorinonuma mire is located below the timber line. The ^{14}C data of the bottom of peat layer are grouped into about 7,500, 4,600-3,600 and 1,300 y.B.P. The mean rate of peat accumulation generally ranges from 0.2 to 0.4 mm/y.

According to the ^{14}C data of the bottom of peat layer, in the mire above the timberline, peat accumulation started in the ages of 7,500 and 4,600-3,600 y.B.P. In many mires above the timber line, the thickness of peat layer is about 1 m. Considering the mean rate of peat accumulation shown in Table 4, peat accumulation seems to have started around 5,000-2, 500 y.B.P. in these mires.

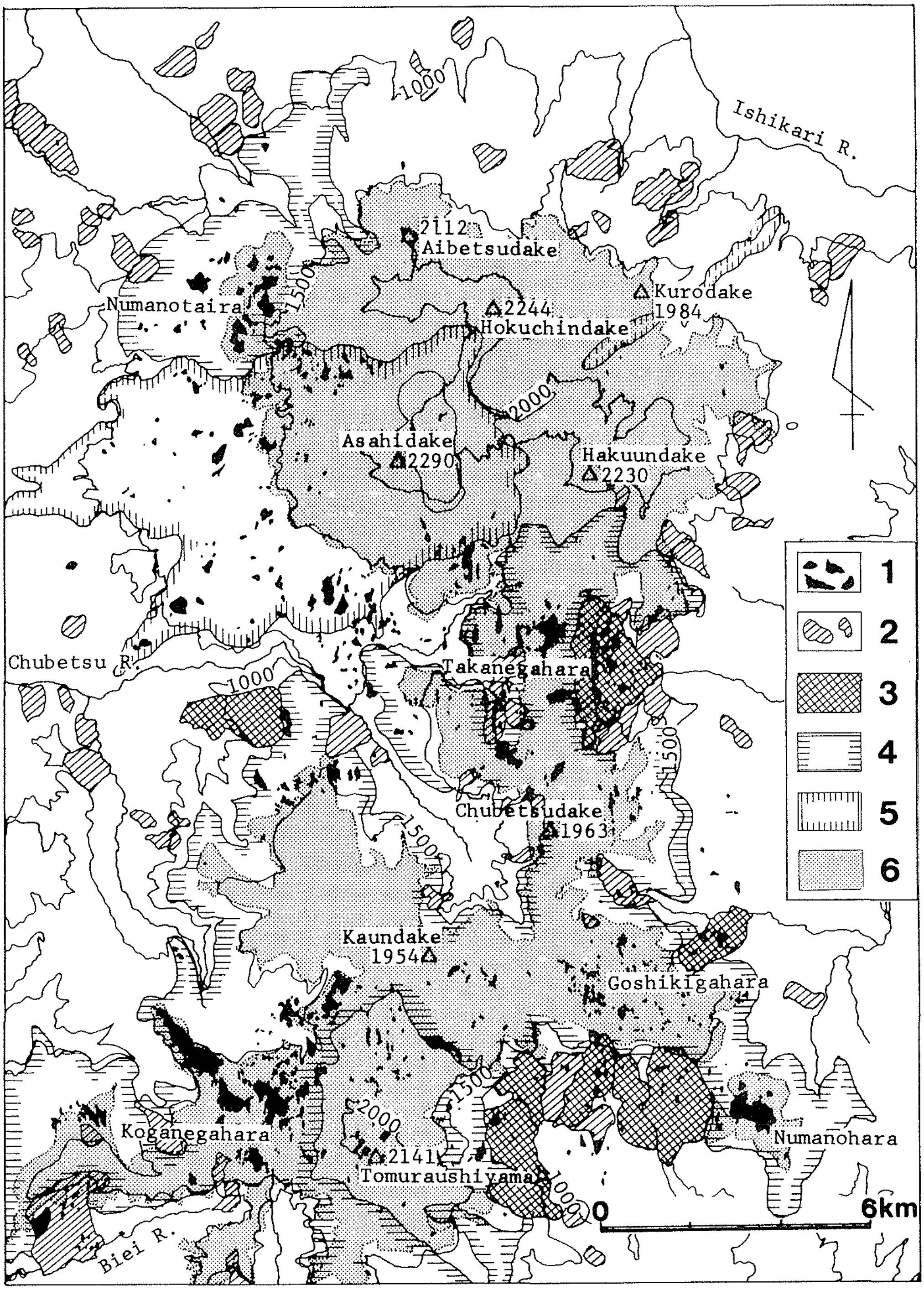

Figure 7 Distribution of mires, ejecta of Stages I and IV and landslide area.
1 : mire, 2 : landslide area (10 ha<, <100 ha), 3 : landslide area (100 ha<), 4 : ejecta of Stage I, 5 : ejecta of Stage IV, 6 : alpine zone.

Table 4. ^{14}C data from seven mires in the Daisetsuzan Mountains.

Locations	Altitude	Landforms around sampling locations	^{14}C ages	Codo No.	Materials	Depth of sampling horizon	Mean rate of peat accumulation**	References
1 Numanotaira (43° 41′ 34″ N, 142° 49′ 11″ E)	1453 m	Depression on the lava plateau	* 4060±140 y.B.P.	NUTA-198	Peat	95~100 cm	0.24 mm/y	Takahashi et al. (1988)
2 South of Hiragatake (43° 36′ 54″ N, 142° 54′ 6″ E)	1720 m	Broad col on the lava plateau	1390± 85 y.B.P.	NUTA-454	〃	29~ 31 cm	0.22 mm/y	〃
3 〃 (〃 , 〃)	〃	〃	* 4250±130 y.B.P.	NUTA-455	〃	58~ 60 cm	0.14 mm/y	〃
4 East of Ponchubetsudake (43° 36′ 3″ N, 142° 53′ 17″ E)	1735 m	Gentle slope on the lava plateau	3800± 40 y.B.P.	KSU-914	〃	128~133 cm	0.34 mm/y	Takahashi and Igarashi (1986)
5 〃 (〃 , 〃)	〃	〃	* 7540± 65 y.B.P.	KSU-915	〃	215~220 cm	0.29 mm/y	〃
6 Midorinonuma (43° 36′ 59″ N, 142° 55′ 5″ E)	1365 m	Depression resulted from landslide	* 1310±100 y.B.P.	TH-985	〃	135~140 cm	1.05 mm/y	Igarashi and Takahashi (1985)
7 Goshikigahara (43° 33′ 27″ N, 142° 55′ 19″ E)	1693 m	Gentle slope on the lava plateau	1590±350 y.B.P.	NUTA-453	〃	65~ 70 cm	0.43 mm/y	This study
8 Numanohara (43° 32′ 15″ N, 142° 57′ 33″ E)	1424 m	Flat-topped surface on the lava plateau	140± 50 y.B.P.	KSU-912	〃	14~ 19 cm	1.18 mm/y	This study
9 〃 (〃 , 〃)	〃	〃	1260±100 y.B.P.	TH-986	〃	50~ 55 cm	0.42 mm/y	Igarashi and Takahashi (1985)
10 〃 (〃 , 〃)	〃	〃	* $3620\pm^{140}_{120}$ y.B.P.	TH-987	〃	105~110 cm	0.30 mm/y	〃
11 Yutomuraushi (43° 31′ 27″ N, 142° 49′ 7″ E)	1635 m	Wide depression on the lava plateau	* 4620± 40 y.B.P.	KSU-913	〃	173~178 cm	0.38 mm/y	Takahashi and Igarashi (1986)

* Samples obtained at or near the base of peat layers
** From the sampling horizon to the surface

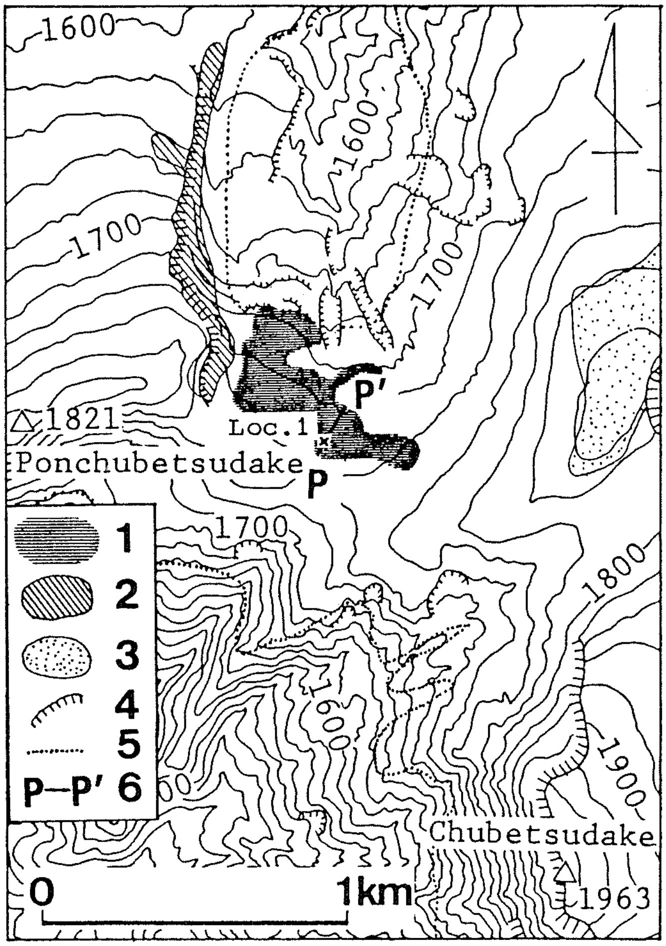

Figure 8 Topography around the mire on the east of Ponchubetsudake.
1 : mire, 2 : nivation hollow, 3 : wind-blowing gravel slope, 4 : scarp, 5 : timber line, 6 : location of the profile shown in Figures 9 and 27.
Loc. 1 is a sampling point of mire deposits for ^{14}C dating and pollen analysis.

3. Reconstruction of Paleoenvironment by Pollen Analysis

3.1 Introduction

In this chapter, the author reconstructs a paleoenvironment of the Daisetsuzan Mountains during the Holocene on the basis of palynological studies (Igarashi and Takahashi, 1985; Takahashi and Igarashi; 1986).

Borings were attempted at four mires: the mire on the east of Ponchubetsudake, the Yutomuraushi mire, the Numanohara mire and the Midorinonuma mire. At each locality,

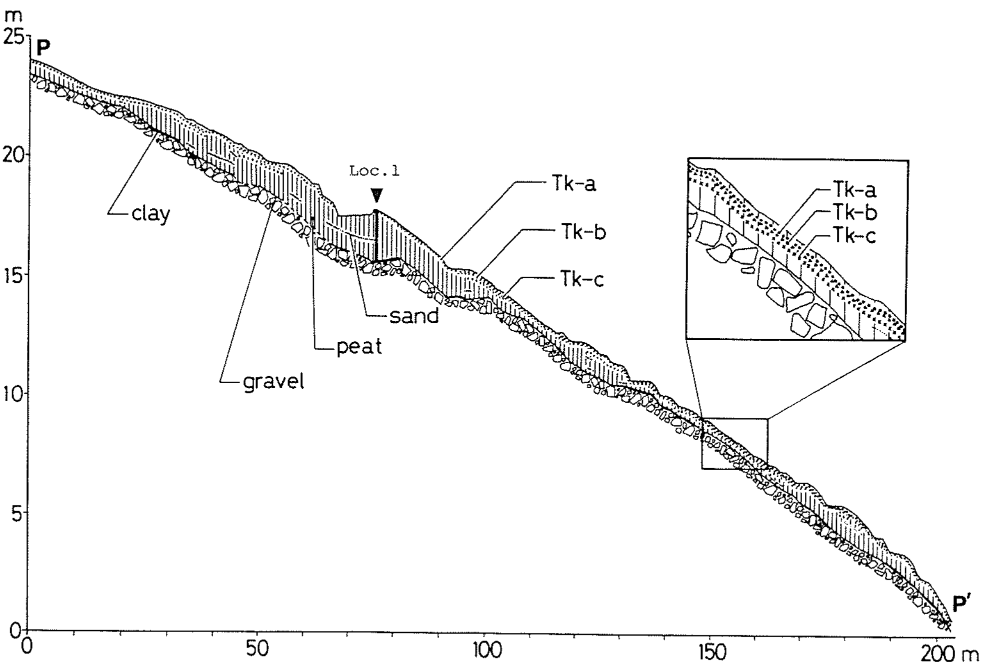

Figure 9 Profile (P-P') of topography and superficial deposits of the mire on the east of Ponchubetsudake. Location of the profile is shown in Figure 8.

1.2 to 2.3 m long core was taken by peat sampler in order to obtain samples for pollen analysis and ^{14}C dating. The results of ^{14}C dating are shown in Table 4. The pollen diagrams of each mire were zoned on the basis of the fluctuation of main arboreal pollen percentages.

3.2 Environmental settings and deposits of four mires

3.2.1 The mire on the east of Ponchubetsudake

The mire on the east of Ponchubetsudake is located in the central part of the Daisetsuzan Mountains. It ranges from 1,650 to 1,750 m a.s.l. on the northern gentle slope (5-6°) of the wide pass and occupies an area of about 32 ha (Figure 8). The longitudinal profile of the mire is rather convex (Figure 9). The mire is surrounded by *Pinus pumila* community except on the western side where it is bordered by a blocky slope (Figure 10). The elevation of the timber line around the mire is 1,600-1,700 m a.s.l. There are snow patches until late-August on the eastern blocky slope of Ponchubetsudake which receives much snowfall in winter. However, on the pass where the mire is located, snow is blown out by the wind and the mire is almost completely free from a snow cover by mid-July.

Several kinds of microtopography, including gully and bank and hollow complex, are found in the mire (Figure 10). Gully is generally less than 1 m both in width and depth and often accompanied with a pond or a depression at the head. Bank and hollow complex develops in the central part of the mire.

The thickness of peat layer in the mire ranges up to 220 cm (Loc.1 in Figure 9), but is

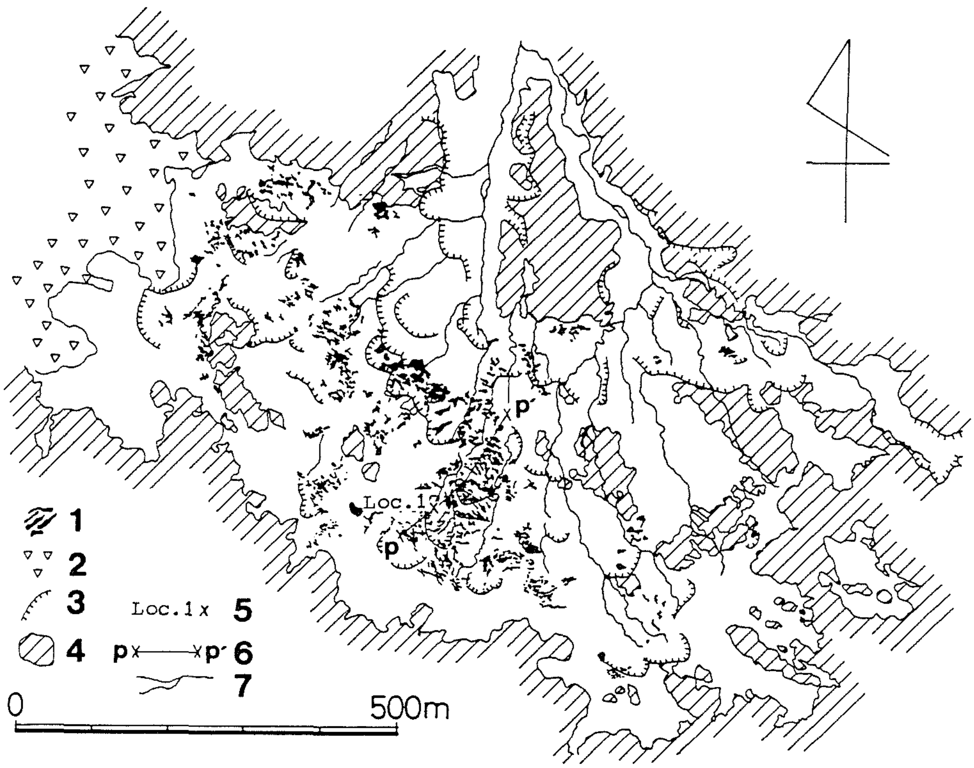

Figure 10 Mire on the east of Ponchubetsudake.
1 : hollow (Schlenke), 2 : block slope, 3 : minor scarp, 4 : Pinus pumila community, 5 : sampling point of peat for ^{14}C dating and pollen analysis, 6 : location of the profile shown in Figures 9 and 27, 7 : gully or stream

generally less than 100 cm. It is underlain by a gravelly layer with a thin silty or clayey layer at the top. The gravelly layer has a sandy matrix and consists of angular or subangular pebble and cobble ranging up to several tens centimeters. At Loc.1 where peat samples for ^{14}C dating and pollen analysis were taken (Figure 11), the peat layer is intercalated with a thin sandy layer at a depth of 130 cm, and three ash layers (Tk-a, Tk-b and Tk-c) at depth of 10-12 cm, 13-13.5 cm and 36-37 cm respectively. Peat samples taken from a depth of 128-133 cm and the bottom of the peat layer (215-220 cm) gave ^{14}C dates, 3,800-40 y.B.P. and 7,540±65 y.B.P. respectively (Table 4).

3.2.2 The Yutomuraushi mire

The Yutomuraushi mire is located in the source area of the Yutomuraushi River, on the south of Koganegahara in the southwestern part of the Daisetsuzan Mountains (Figure 12). It is in a cirque-like depression with an area of about 50 ha. The upper part (above 1, 650 m a.s.l.) of the depression is landslide origin. It is composed of a main scarp, many mounds and small hollows. The main scarp stretches along the southern margin of Koganegahara, and is up to 100 m high, and about 1 km long. The mounds are several tens meters wide, 100-200 meters long and several to ten meters high, and are arranged nearly

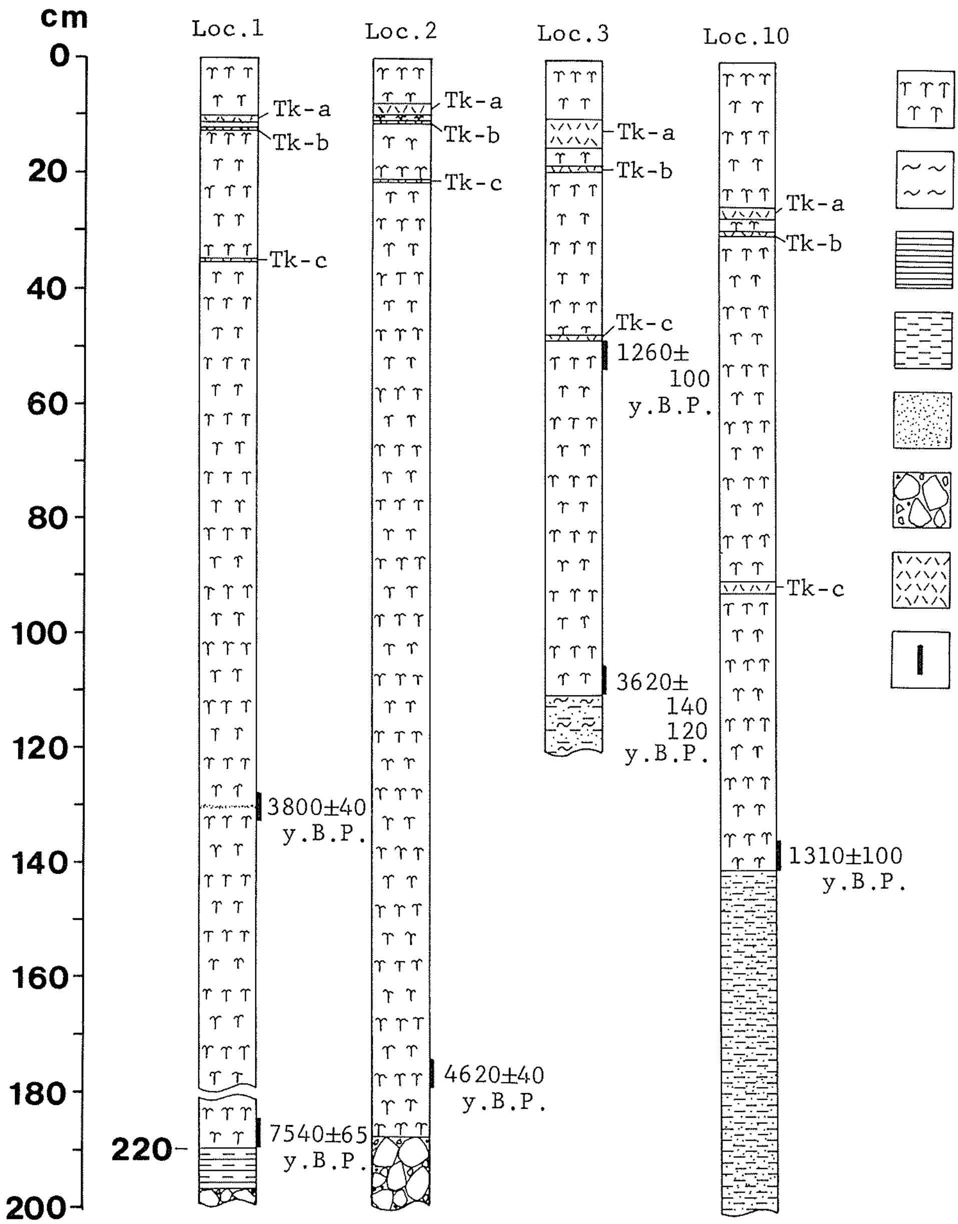

Figure 11 Deposits of the mires.
Loc. 1 : the mire on the east of Ponchubetsudake (Figures 8, 9 and 10), Loc. 2 : the Yutomuraushi mire (Figures 12 and 14), Loc. 3 : the Numanohara mire (Figure 15), Loc. 10 : the Midorinonuma mire (Figures 16, 17 and 18), 1 : peat, 2 : plant remains, 3 : clay, 4 ; silt, 5 : sand, 6 : gravel, 7 : ash, 8 : horizon of [14] C dating.

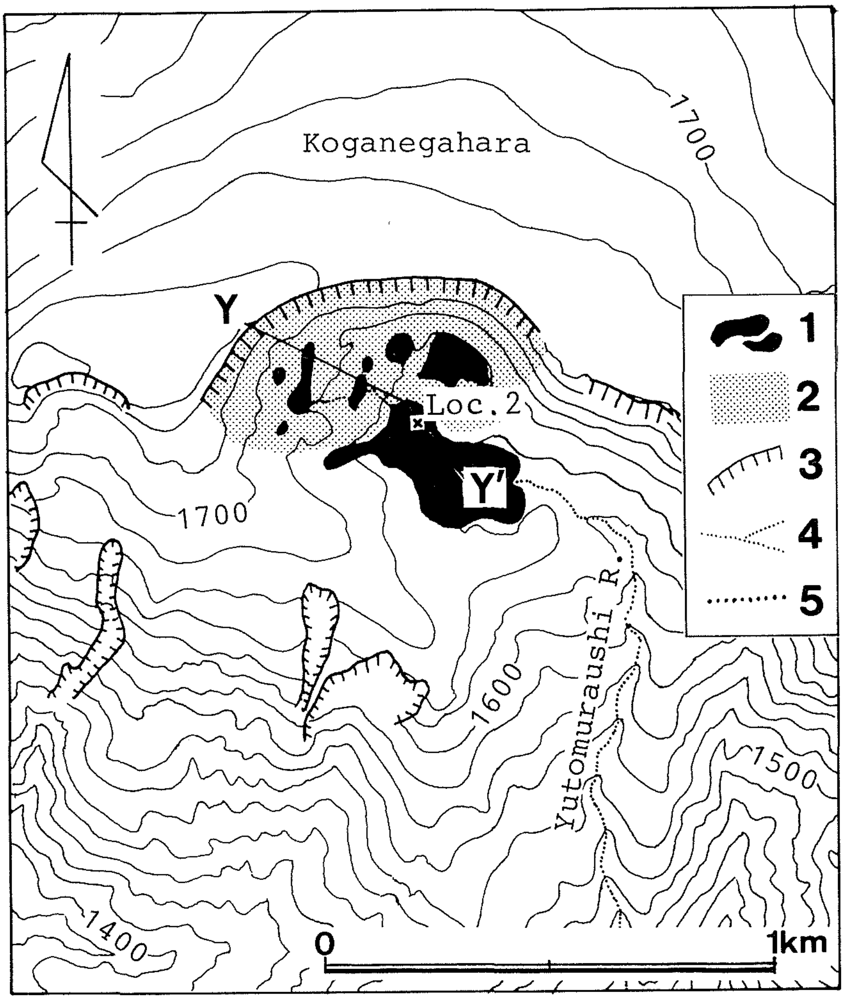

Figure 12 Topography around the Yutomuraushi mire.
1 : mire, 2 : landslide area, 3 : scarp, 4 : stream, 5 : timber line, Y-Y' : location of the profile shown in Figure 13, Loc. 2 : sampling point of mire deposits for ^{14}C dating and pollen analysis.

parallel to the main scarp. The hollows are located between the mounds and filled with mineral and organic materials. The studied mire is located on the gentle slope in front of the landslide blocks (Figure 13). The elevation of the timber line around the mire is 1,550-1,600 m a.s.l., and the surrounding area of the mire is mainly covered with *Pinus pumila* or *Sasa kurilensis*. Snow patches remain on the main scarp until late-August, because the scarp receive much snowfall in winter. Therefore, the mire is supplied enough water from the snow patches throughout summer.

Bank and hollow complex also develops in this mire. The thickness of peat layer ranges up to 190 cm (Loc.2 in Figure 14). The peat layer is underlain by a gravelly layer

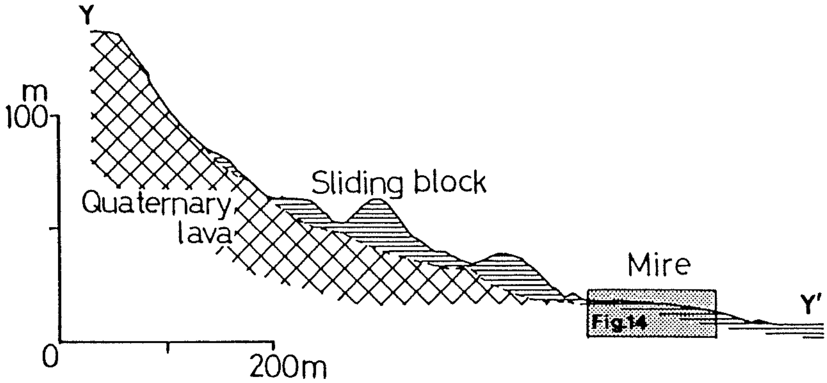

Figure 13 Geomorphological and geological Profile (Y-Y') around the Yutomuraushi mire.
Location of the profile is shown in Figure 12.

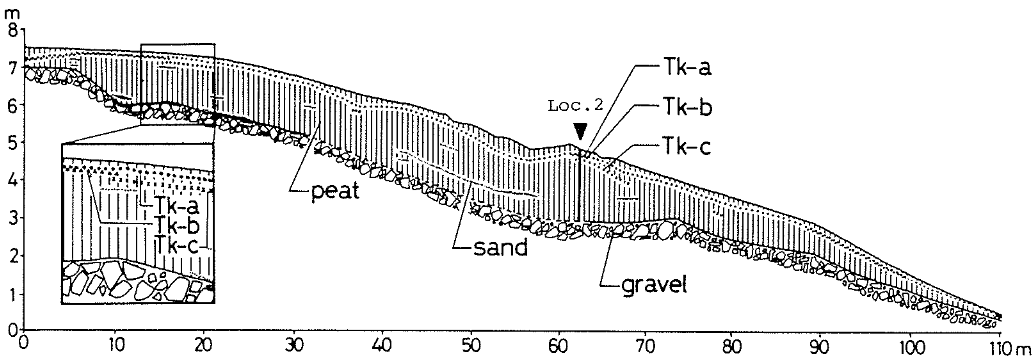

Figure 14 Profile of topography and superficial deposits of the Yutomuraushi mire. Location of the profile is shown in Figure 13. Loc. 2 is a sampling point of mire deposits for ^{14}C dating and pollen analysis.

which has a thin silty or clayey bed of several centimeters thick at the top. The peat is intercalated with three ash layers (Tk-a, Tk-b and Tk-c). Among them, Tk-a occurs continuously within a depth of 10 cm. No mineral layers are intercalated but these ash layers and several thin sandy layers at a depth of 70-150 cm. At Loc.2 where the peat samples for ^{14}C dating and pollen analysis were taken (Figure 11), Tk-a, Tk-b and Tk-c occur at depths of 8-10 cm, 11-11.5 cm and 21-21.5 cm respectively. The peat sample taken from a depth of 173-178 cm was dated 4,620±40 y.B.P. (Table 4).

3.2.3 The Numanohara mire

The Numanohara mire is located in the southwestern part of the Daisetsuzan Mountains. It extends on the nearly flat surface composed of andesitic lava of Stage I. It ranges from 1,420 to 1,430 m a.s.l., and occupies an area of about 280 ha (Figure 15). Numanohara lies on a divide between the basin of the Ishikari and that of the Tomuraushi which is one of the tributaries of the Tokachi. The northeastern margin of Numanohara is dissected by the Ishikari, the southwestern one is steepened by large-scale landslides

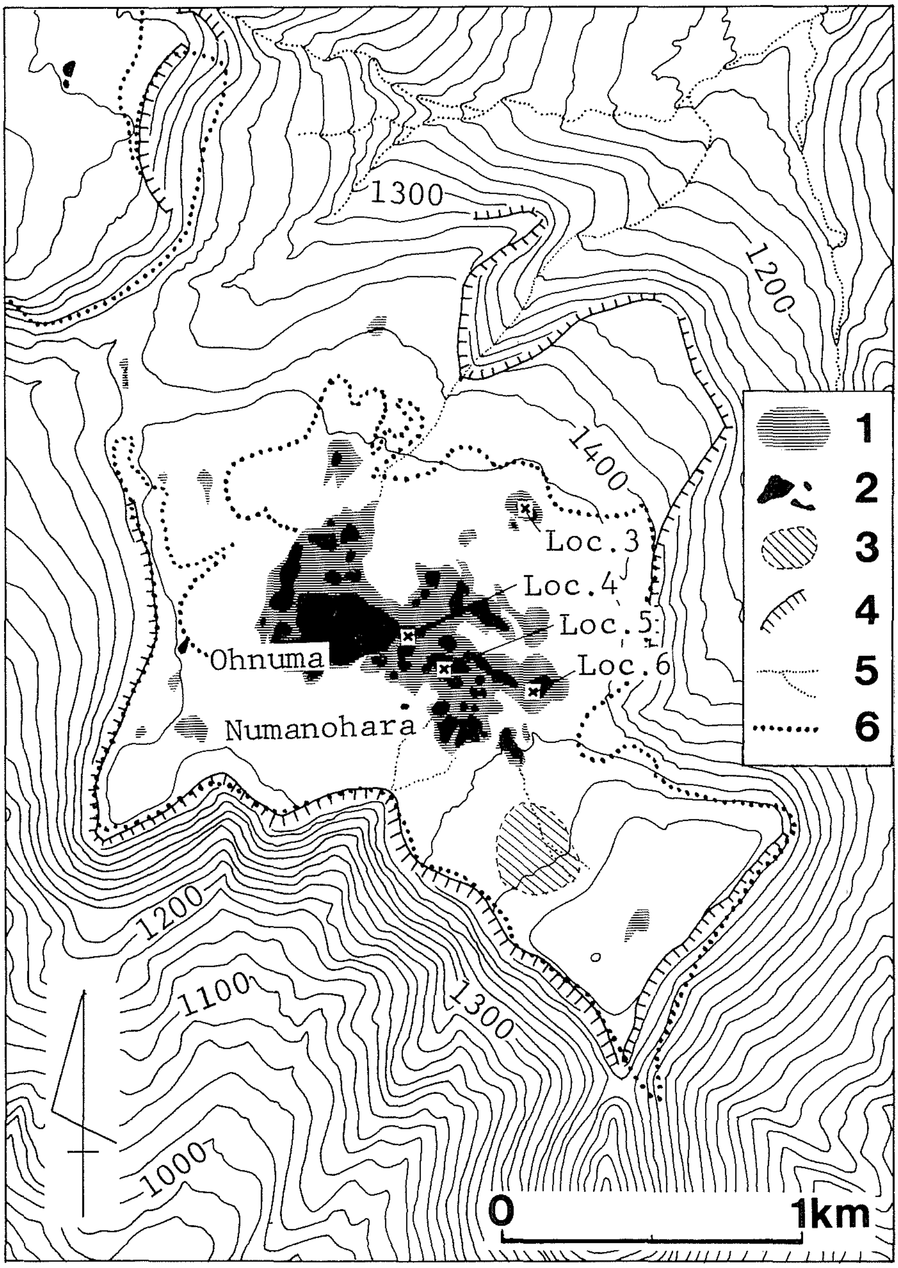

Figure 15 Topography around the Numanohara mire.
1 : mire, 2 : pond, 3 : shallow depression, 4 : scarp, 5 : gully or stream, 6 : timber line.
Loc. 3 is a sampling point of mire deposits for ^{14}C dating and pollen analysis.
Locs. 4, 5 and 6 are observation points of mire deposits shown in Figure 16.

extending over the sources of the Tomuraushi. The Numanohara mire is composed of many ponds including the Ohnuma (5.3 ha), the largest, and their surrounding peat bogs. It is drained by small streams to the north and the south. There is a shallow depression with gallies on the southeastern slope.

The elevation of the timber line around Numanohara ranges from 1,420 to 1,430 m a.s.l., while it is generally higher than 1,500 m a.s.l. around Goshikigahara locating on the northwest of Numanohara, in the eastern side of the Daisetsuzan Mountains. The area above the timber line is mainly occupied by *Sasa kurilensis* community and mire, but *Betula ermanii,* and *Picea glehnii* and *Pinus pumila* invade *Sasa kurilensis* community and mire, respectively.

Direction of wind-deformed trees indicates the prevailing northwesterly wind, and the height of *Pinus pumila* suggests the maximum snow depth as 1 - 2 m.

At Loc.3 in the northern part of Numanohara, the mire deposits are sampled for ^{14}C dating and pollen analysis (Figure 11), and at the other three points (Locs.4, 5 and 6), superficial deposits were examined (Figure 16).

The mire deposits at Loc.3 consist of a peat layer of 110 cm thick, which is underlain by a silty layer containing plant remains and intercalated with three ash layers (Tk-a, Tk-b and Tk-c) at depth of 10-15 cm, 18-19 cm and 47-48 cm respectively. The peat sample taken from a depth of 105-110 cm was dated $3,620\pm^{140}_{120}$y.B.P. (Table 4).

At Loc.4 on the east of the Ohnuma, the sediment to a depth of 76 cm is an unhumified peat intercalated with thin ash layers, Tk-a and Tk-b, at depths of 19 - 30 cm and 68 - 68.5 cm respectively, and contains wood fragments between 30 and 76 cm. Between 76 - 84 cm, the peat is moderately humified and, between 84 - 91 cm, well humified. Below that, the sediment underlying the peat layer consists of silt which contains sand, granule and fibrous plant remains between 91 - 113.5 cm, silty gravel between 113.5 - 125 cm and gravel below 125 cm.

At Loc.5, 230 m east of Loc.4, the upper 80 cm of sediment consists of an unhumified peat intercalating thin ash layers, Tk-a, Tk-b and Tk-c, at depths of 8 - 13 cm, 15 - 15.5 cm and 40.5 - 41 cm respectively. It is accompanied with many wood fragments at a depth of 51 - 59 cm. Between 80 and 112 cm, the peat is moderately to well humified and contains an intercalated thin sand layer at a depth of 104 - 106 cm. Below that, the sediment consists of silt, which contains sand, granule and fibrous plant remains, between 112 - 127 cm, silty gravel between 127 - 140 cm and gravel below 140 cm.

At Loc.6, 260 m east of Loc.5, the upper 117 cm of sediment consists of peat, which is intercalated with Tk-a, Tk-b and Tk-c at depths of 19 - 21 cm, 21.5 - 22 cm and 46 - 46.5 cm, respectively. It contains wood fragments between 38 and 97 cm, and 107 and 117 cm. The peat layer is unhumified at depths of 0 - 25 cm, 38 - 81 cm and 104 - 107 cm, moderately humified at depths of 25 - 38 cm and 81 - 104 cm, and well humified at a depth of 107 - 117 cm. The lower sediment consists of silt, which contains sand and fibrous plant remains, between 117 and 125 cm, silty gravel between 125 and 135 cm, and gravel below 135 cm.

At Locs.4, 5 and 6, the silty gravels, which are overlain by grayish-yellow-brown to grayish-brown silt, are reddish brown at the uppermost part (1 - 2 cm from the top) resulting from the accumulation of oxide iron.

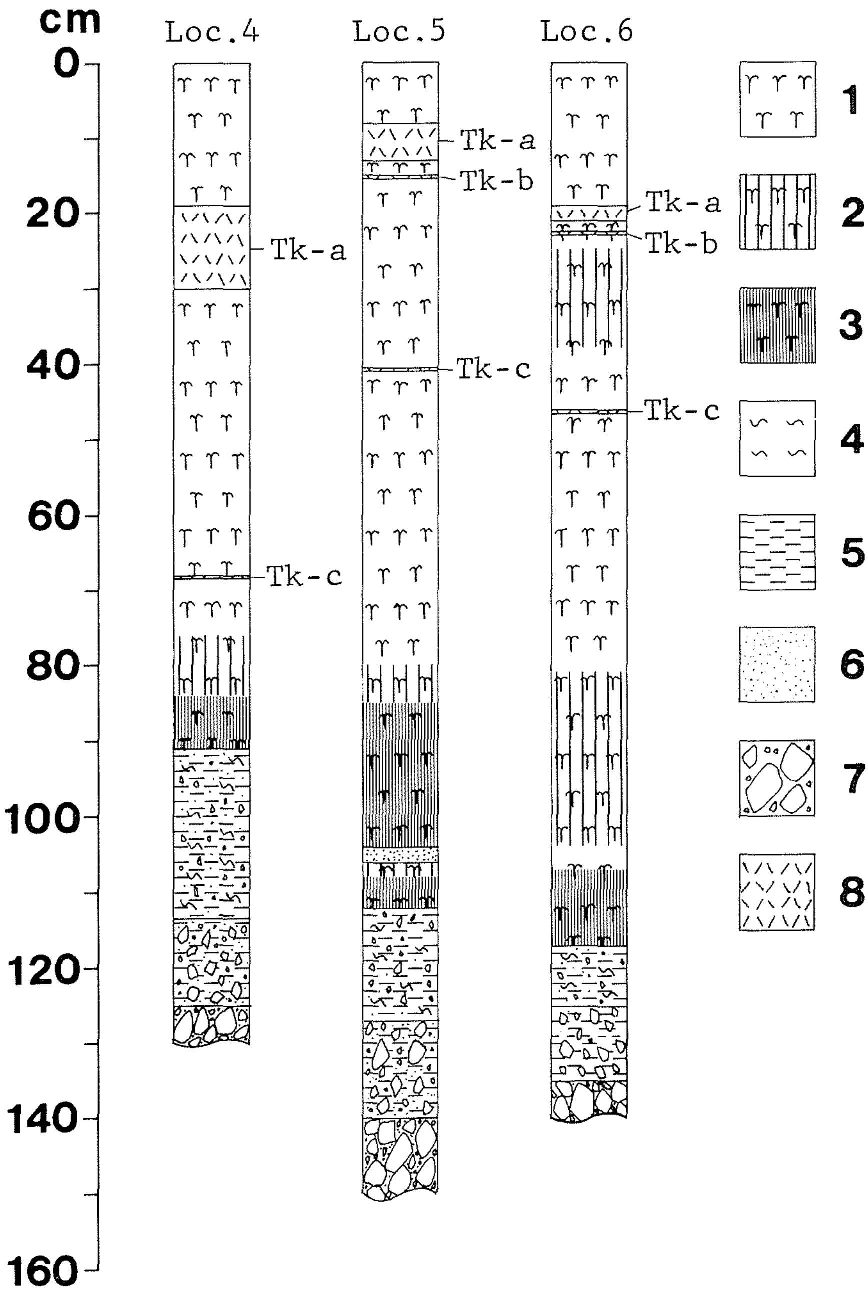

Figure 16 Deposits of the Numanohara mire.
1 : unhumified peat, 2 : moderately humified peat, 3 : well humified peat, 4 : plant remains, 5 : silt, 6 : sand, 7 : gravel, 8 : ash.
Locs. 4, 5 and 6 are shown in Figure 15.

3.2.4 The Midorinonuma mire

The Midorinonuma mire is located at 1,365 m a.s.l. within the Kogen landslide area, which occupies a total area of 358 ha and ranges from 1,760 to 1,190 m a.s.l. on the east of Takanegahara (Figure 17). The area below 1,500 m a.s.l. is under the forest. The Midorinonuma mire is surrounded by *Picea glehnii* forest. The main scarp, up to 200 m high, elongates over about 3.5 km along the eastern margin of Takanegahara. The landslide blocks are composed of mounds and depressions. In the upper part, the individual mound has a more distinct outline, and is 100-300 meters long and several tens meters wide and high. The flat surface which constitutes the upper-slope of the mound seems to be originated from the initial flat surface of Takanegahara. The mounds with these characteristics are arranged in a direction nearly parallel to the main scarp. These facts suggest that a primary landslide was slump-type mass movement. Below a range of minor scarps at an altitude of 1,400-1,450 m, the outline of an individual mound becomes less clear and its height becomes smaller. Furthermore, some of the mounds are arranged in a direction rectangular to the minor scarps. On the other hand, the depressions which are located between the mounds are almost closed and occupied with mires, including the Midorinonuma mire (Figure 18).

Several perennial snow patches, fed by westerly prevailing wind, are formed on the landslide scarp which borders the eastern margin of Takanegahara. The mires developing in the landslide area are, therefore, supplied sufficient water from these snow patches during the summer.

Thick alternating beds of silt and sand overlie the weathered gravel layer at the bottom of depressions (Locs.7, 8 and 9 in Figure 19) on the upper part, where sufficient water is supplied directly from the snow patches on the scarp. The peat layers in these depressions are thinner. At Loc.7, only a few plant remains are contained within the uppermost silty layer. At Loc.9, only a well-humified peat layer of 5 cm thick is found at the top.

In the depressions in the lower landslide area, the peat layers become much thicker than in the upper area, and the mineral layers become thinner. At Loc.10, however, a sandy silt layer of more than 60 cm thick still underlies the peat layer of 140 cm thick. The peat layers at Locs.10, 11 and 12 are intercalated with three to five thin ash layers, while at Locs. 8 and 9, only one or two are found in the mineral layers, and at Loc.7, no ash layer occurs in the deposits. The mire deposits were sampled at Loc.10 for ^{14}C dating and pollen analysis. A peat sample taken from a depth of 135-140 cm was dated 1,310$\pm$100 y.B.P. (Table 4).

3.3 Results of pollen analysis

3.3.1 The mire on the east of Ponchubetsudake

The pollen diagram (Figure 20) was divided into the following three zones, on the basis of the fluctuation modes of *Picea* and *Quercus* values: Po-III (230 - 152 cm), Po-II (152 - 70 cm) and Po-I (70 - 0 cm).

Zone Po-III: *Pinus* and *Juglans* have their highest values. *Picea* values are variable in the range from 10 to 35 %. *Quercus* values gradually increase toward the top with a reverse tendency to *Picea* pollen. The pollens of *Ulmus, Alnus* and *Phellodendron* are almost

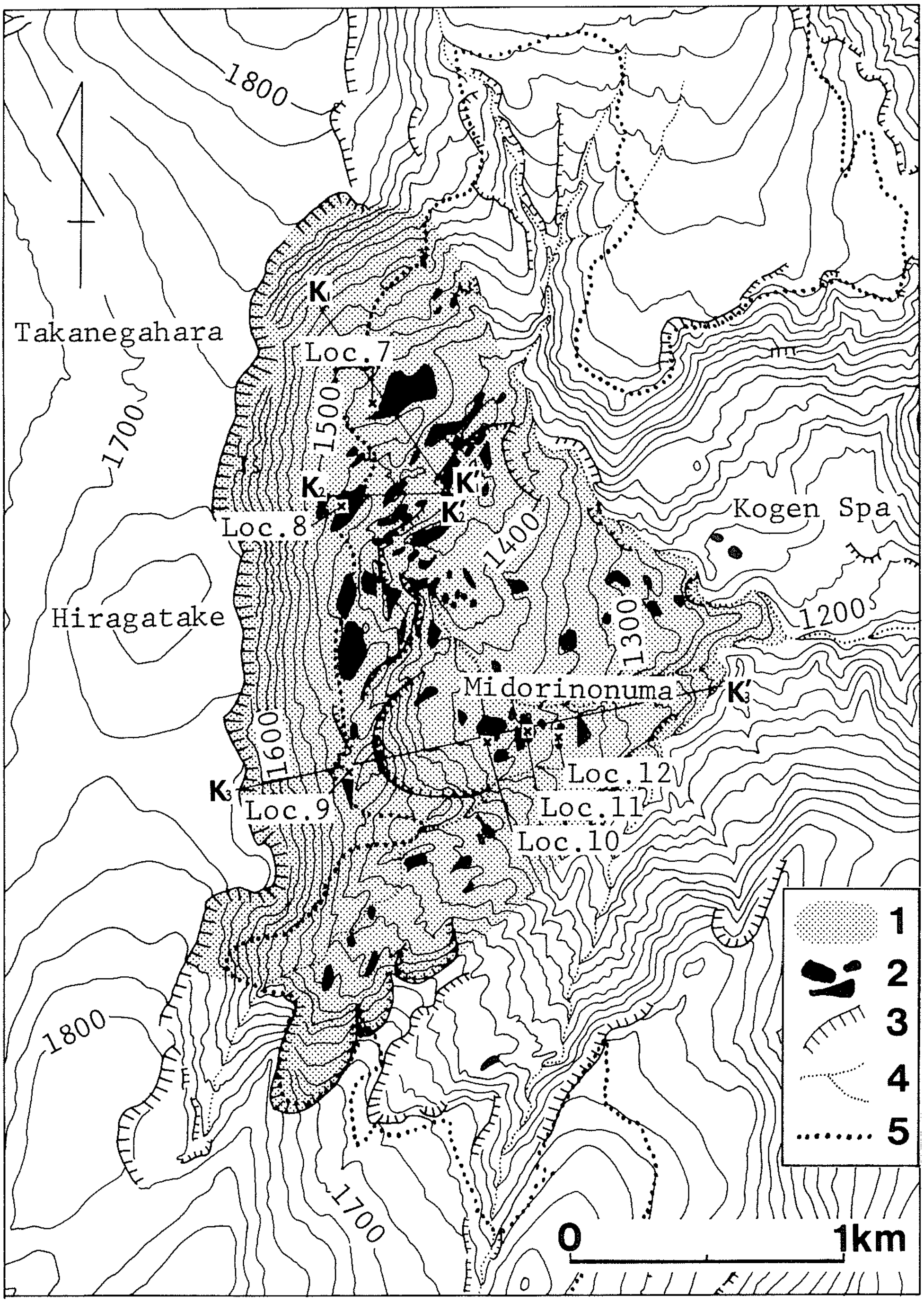

Figure 17 Topography around the Kogen landslide area.
1 : landslide area, 2 : mire, 3 : scarp, 4 : stream, 5 : timber line. K_1-K_1', K_2-K_2' and K_3-K_3' are the location of the profiles shown in Figure 18. Locs. 7-12 are the observation points or sampling point of mire deposit shown in Figure 19.

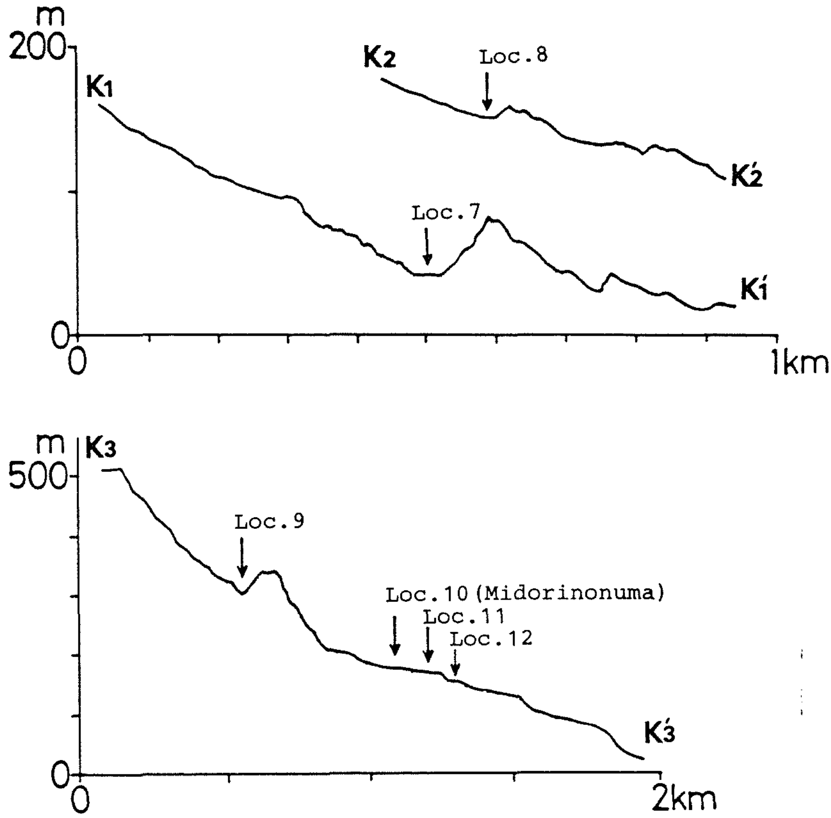

Figure 18 Topographic profiles of the Kogen landslide area.
Locs. 7-12 are the observation points or sampling point of mire deposits shown in Figure 19. Locations of the profiles are shown in Figure 17.

consistently represented but poor. Nonarboreal pollens have relatively high values (10-57%) in this zone. The pollens of *Menyanthes* represent an emerged plant, Umbelliferae, Gramineae, Cyperaceae and *Lysichiton* represent a wetland plant, and Rosaceae, *Artemisia,* Carduoideae and *Epilobium* represent an alpine meadow components. *Menyanthes* and *Epilobium* pollens are encountered only in this zone. The spores of monolete type and Osmundaceae have their highest values.

Zone Po-II: *Pinus* and *Juglans* percentages decline, and *Quercus* pollen is dominant in the range up to 50%. *Picea* and *Abies* pollens are almost consistently represented. *Betula* values are low as well as at the top of the previous zone but gradually increase toward the top of this zone. Although percentages of nonarboreal pollens and spores are generally much less than in Zone Po-III, Cyperaceae pollen has high values reaching about 10% and Umbelliferae and Liliaceae values are a little bit higher than in Zone Po-III.

Zone Po-I: *Picea* pollen is dominant with its highest value of more than 60%. *Abies* values are somewhat higher than in Zone Po-II, while *Quercus, Pinus* and *Juglans* values are lower. *Betula* pollen is consistently represented from the upper part of the previous

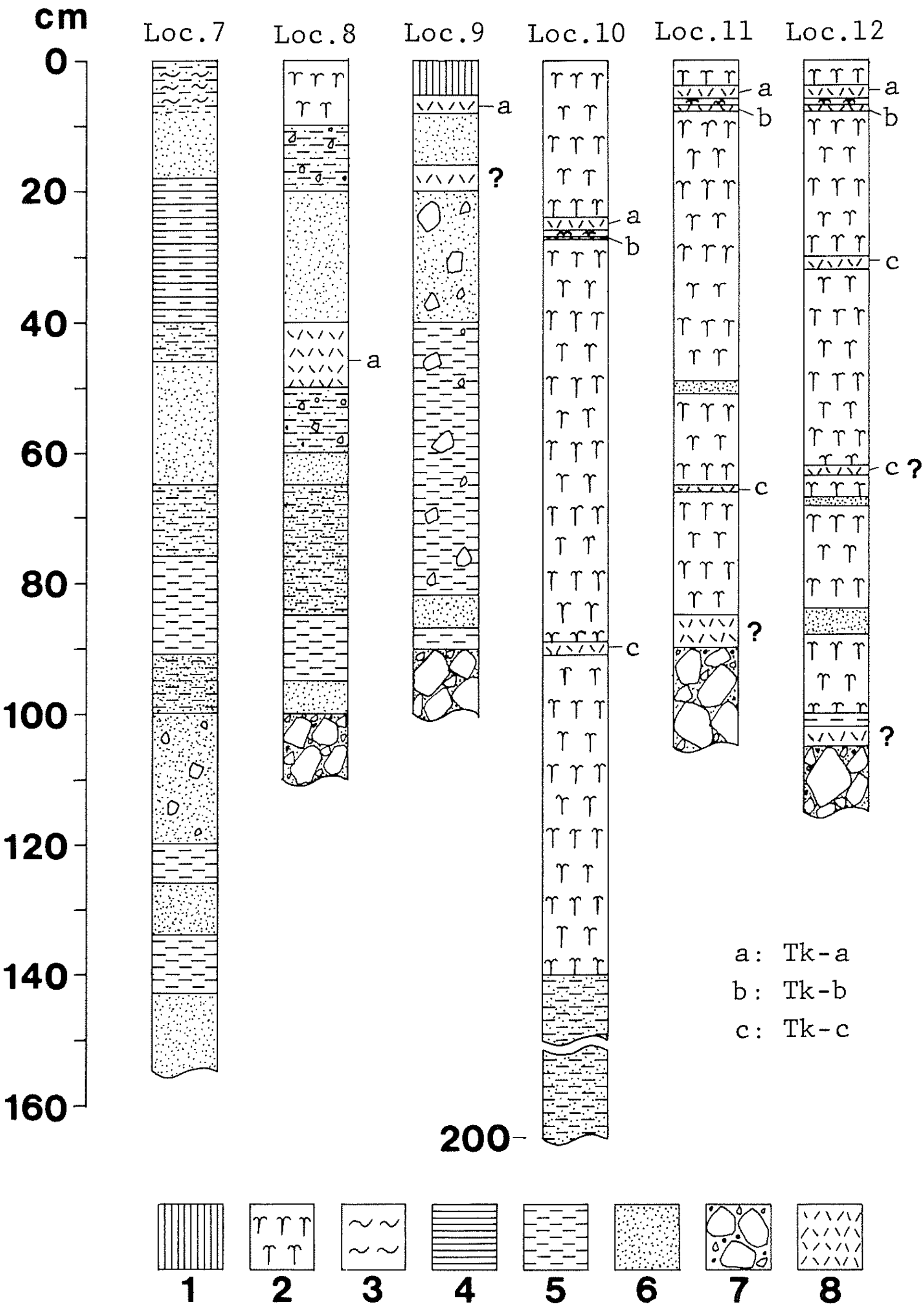

Figure 19 Deposits of the mires in the Kogen landslide area.
1 : humus, 2 : peat, 3 : plant remains, 4 : clay, 5 : silt, 6 : sand, 7 : gravel, 8 : ash.
Locs. 7-12 are shown in Figures 17 and 19.

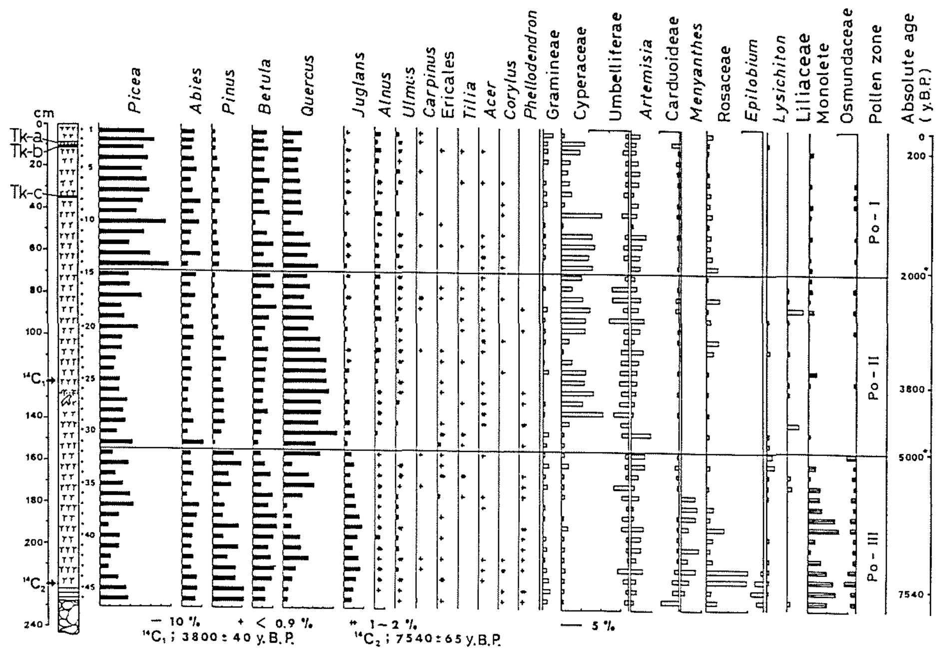

Figure 20 Pollen diagram from Loc. 1 in the mire on the east of Ponchubetsudake (after Takahashi and Igarashi, 1986).
*: estimated age.

zone. Cyperaceae and *Artemisia* values in nonarboreal pollens are almost as much as in Zone Po-II. Umbelliferae and Liliaceae pollens have their lowest values. Percentages of nonarboreal pollens and spores are further lower than in Zone Po-II.

3.3.2 The Yutomuraushi mire

The pollen diagram (Figure 21) was divided into the following two zones, on the basis of the fluctuation modes of *Picea* and *Quercus* values: Zone Yu-II (187 - 60 cm) and Zone Yu-I (60 - 0 cm).

Zone Yu-II: This zone is marked by high values (to 35%) of *Quercus* pollen, although it declines into the upper part. However, *Picea, Abies* and *Betula* increase gradually toward the top of the zone. The pollens of *Pinus, Juglans, Ulmus, Alnus, Carpinus* and *Fraxinus* are almost consistently represented, but in low values (less than 8%). Cyperaceae, Artemisia and Umbelliferae pollens are represented with variation throughout the zone. *Menyanthes* and Liliaceae pollens are represented in the range up to 5% in the lower and the upper parts, respectively.

Zone Yu-I: *Picea* pollen is dominant with its peak at the bottom (more than 30%), while *Quercus* values are lower than in previous zone. The percentage of *Betula,* except in sample 1, and that of *Pinus* in all samples are nearly as much as those in Zone Yu-II. *Abies* values are somewhat higher. Although Cyperaceae values are relatively high (about 10%) in nonarboreal pollens as well as in Zone Yu-II, *Artemisia* and Umbelliferae pollens are poorly represented and Liliaceae pollen is not encountered.

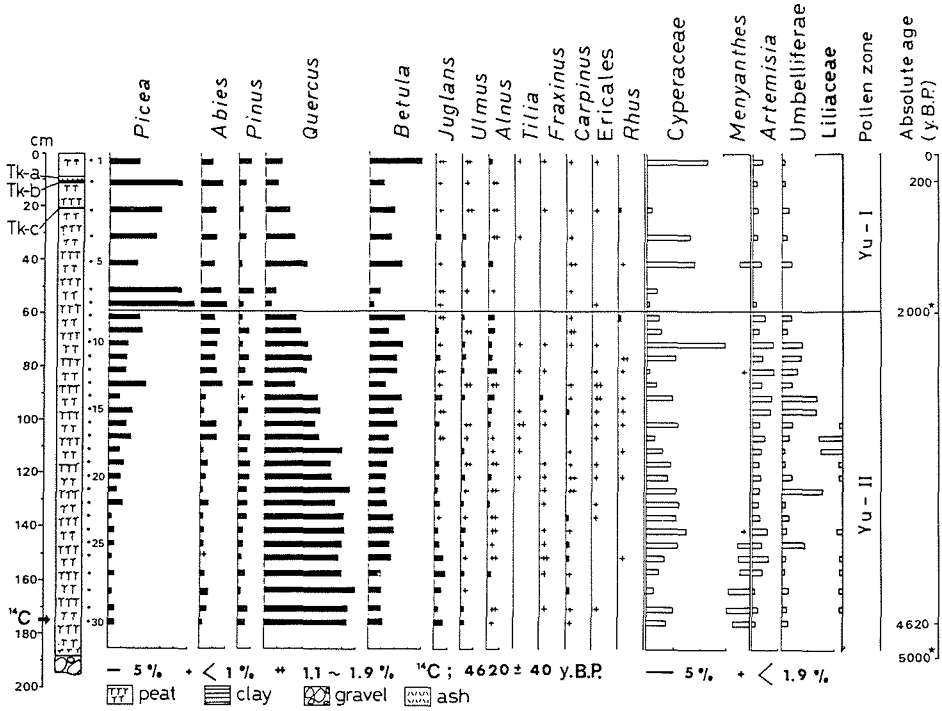

Figure. 21 Pollen diagram from Loc. 2 in the Yutomuraushi mire (after Takahashi and Igarashi, 1986).
*: estimated age.

3.3.3 The Numanohara mire

The deposits of the Numanohara mire are rich in arboreal pollen (86 - 98 %). The pollen diagram (Figure 22) was divided into the following three zones on the basis of the fluctuation mode of *Betula* and *Picea* percentages: Nu-III (120 - 70 cm), Nu-II (70 - 20 cm) and Nu-I (20 - 0 cm).

Zone Nu-III: This zone is marked by a high value of *Betula* (30 - 60 %), however, Betula percentage declines gradually from the bottom to the top of the zone. Contrarily, *Picea* and *Abies* values increase gradually. *Quercus* percentage is relatively high (more than 20 %) throughout the zone. *Pinus* and *Alnus* are minor components except *Alnus* value of sample 9. Each nonarboreal type is less than 2 % except Gramineae at the bottom of the zone.

Zone Nu-II: *Betula* and *Quercus* pollens have high values in the previous zone decline abruptly, while *Picea* pollen rises to about 60 %. *Abies* and *Pinus* percentages are higher than previous values. Ericales has its highest value in the diagram. *Sphagnum* is represented but poor.

Zone Nu-I: *Picea* percentage is lower than in Zone Nu-II, while *Betula* and *Quercus* return to relatively high values. Nonarboreal types are very poor except Cyperaceae of sample 2.

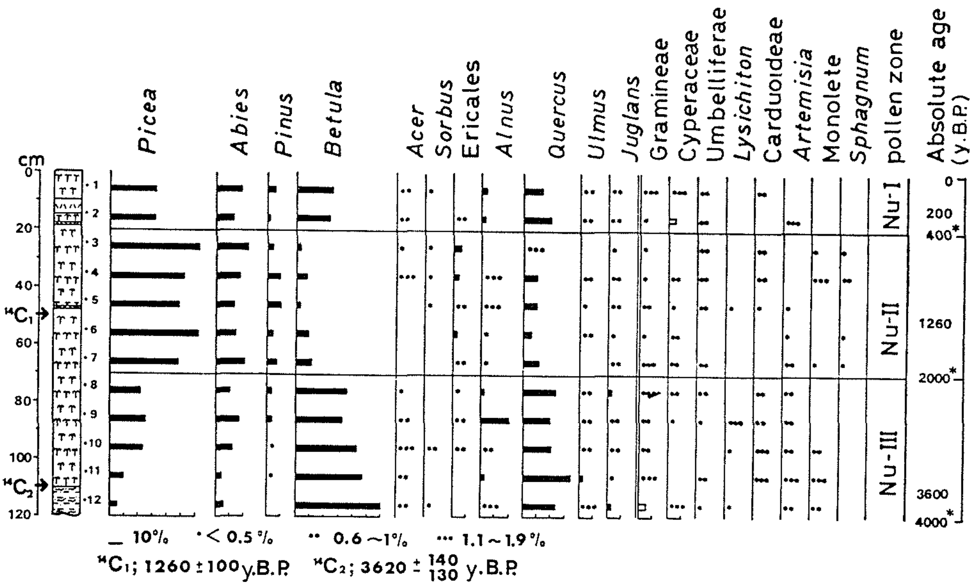

Figure 22 Pollen diagram from Loc. 3 in the Numanohara mire (after Igarashi and Takahashi, 1985).
*: estimated age.

3.3.4 The Midorinonuma mire

The pollen diagram (Figure 23) was divided into the following two zones, on the basis of the fluctuation of *Picea* and *Betula* values: Mi-II (190 - 150 cm) and Mi-I (150 - 0 cm). The values of arboreal pollens range from 63 to 90 % throughout the diagram.

Zone Mi-II: This zone is marked by the highest value of *Betula,* however whose percentage declines abruptly toward the top of the zone. Meanwhile, *Picea, Abies, Alnus* and *Quercus* increase gradually from the bottom to the top. *Pinus* value is lower than in Zone Mi-I. Arboreal types are very poor except monolete type spores which are represented with comparatively high values throughout the diagram. *Lysichiton* pollens are poor as well but have a higher value than in Zone Mi-I.

Zone Mi-I: *Picea* pollen is dominant, ranging from 30 to 50 %. *Abies* pollen is consistently represented with a value of about 20 %. *Pinus* percentage is variable, but always in a higher value than in Zone Mi-II, while *Betula, Alnus* and *Quercus* percentages are variable in a lower value. Cyperaceae and Umbelliferae values are somewhat higher than in Zone Mi-II.

3.4 Discussion

3.4.1 Reconstruction of paleovegetation

According to Nakamura (1968), the lowland vegetation during the glacial maximum to the late glacial at Chippubetsu, 40 m a.s.l., about 70 km WNW of the Daisetsuzan Mountains was a park land vegetation consisting mainly of *Pinus pumila* and *Betula.* It was

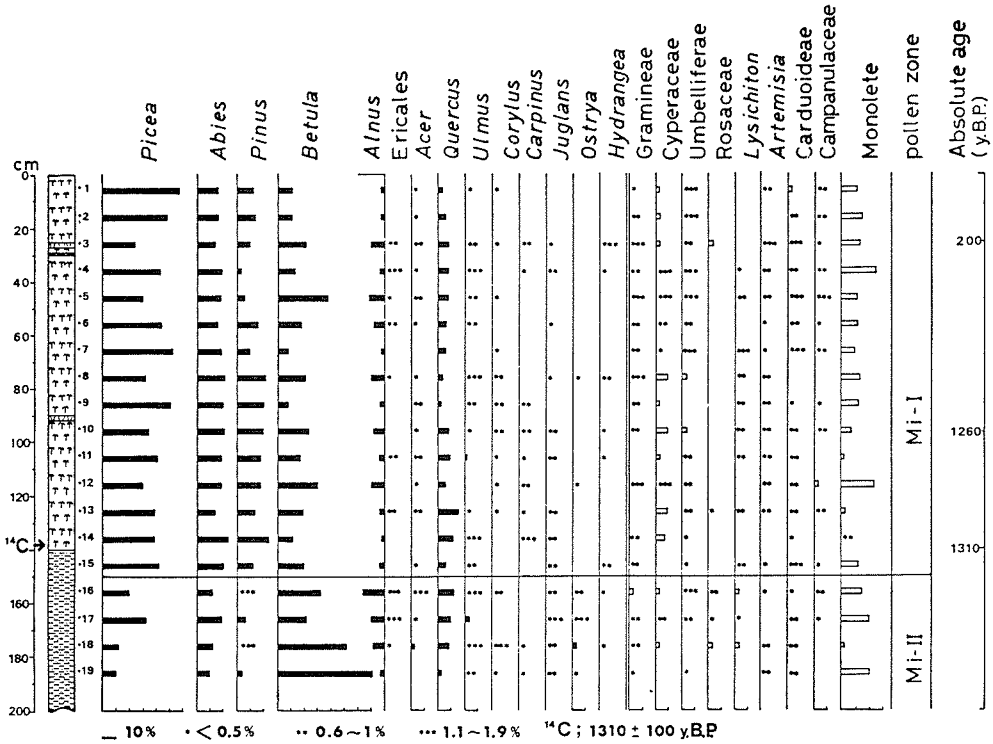

Figure 23 Pollen diagram from Loc. 10 in the Midorinonuma mire (after Igarashi and Takahashi, 1985).

replaced by a boreal forest consisting of *Betula, Picea jezoensis, Picea glehnii* and *Abies sacharinensis* at the late glacial time. In the Ishikari plain, about 90 km SW of Chippubetsu, the last glacial boreal forest consisting mainly of *Larix gmelini, Picea jezoensis* and/or *Picea glehnii* was replaced by coniferous forest consisting of *Picea jezoensis* and/or *Picea glehnii* and *Abies sacharinensis* at the late glacial time (Igarashi and Kumano, 1981).

Judging from the distribution of these lowland vegetations, the alpine zone during the last glacial time is thought to have spread much more than at present. Climatic amelioration after the late glacial time probably caused the retreat of alpine components from the lowland to the northern area or the highland.

In this study, the author obtained peat samples dated back to the early Holocene (about 7,500 y.B.P.). The vegetational succession after this age revealed by pollen analysis in three mires, except the Midorinonuma mire, is as follows:

1) ca. 7,500 - 5,000 y.B.P. (Zone Po-III)

On the upper slope, *Pinus,* most probably *P. pumila,* is the dominant tree, whereas on the lower slope, such trees as *Picea jezoensis* or *Picea glehnii* are well represented, although *Quercus* increases with climatic amelioration. In the case of *Abies*, the fluctuation is not recognized so remarkable as others throughout the whole period. On the eastern slope of Ponchubetsudake, an alpine meadow stretched in the early stage of this period. It was mainly composed of *Menyanthes,* Carduoideae, *Epilobium* and monolete type pteridophyta.

2) ca. 5,000 - 2,000 y.B.P. (Zone Po-II, Zone Yu-II, Zone Nu-III)

On the upper slope, as represented by the eastern slope of Ponchubetsudake, *Pinus pumila* had decreased its area to the present extent by about 2,000 y.B.P. On the lower slope, *Quercus* dominated in the first period, while *Picea jezoensis* or *Picea glehnii, Betula ermanii* and *Alnus* were comparatively remarkably represented later, between about 3,500 and 3,000 y.B.P. The vegetation of the mire usually comprised Cyperaceae, Umbelliferae, Liliaceae and *Artemisia.*

The vegetational succession around the Yutomuraushi mire was almost similar to that around the mire on the east of Ponchubetsudake. On the lower slope, in the early stage of this period, however, conifer was a very minor component and broad-leaved trees represented by *Quercus* were more dominant than around the mire on the east of Ponchubetsudake. In the mire, *Menyanthes* was dominant at first, and subsequently Cyperaceae, Umbelliferae, *Artemisia* and Liliaceae became dominant.

In the Numanohara mire, peat accumulation begun around 3,600 y.B.P., when *Betula* was the most dominant tree, while *Picea glehnii* was a minor component around the mire. Subsequently *Betula ermanii* was gradually replaced by *Picea glehnii. Pinus pumila* was somewhat represented in the latter half of this period.

The dominance of *Quercus* between about 5,000 and 4,000 y.B.P., represented in the diagrams of the mire on the east of Ponchubetsudake and the Yutomuraushi mire, indicates that this period was warmest during Holocene time. Subsequently, an increase in *Picea* and a decrease in *Quercus* represented in the diagrams of the three mires indicate that the climate became gradually cooler after 4,000 y.B.P.

3) ca. 2,000 y.B.P.- present (Zone Po-I, Zone Yu-I, Zone Nu-II,I)

In the Numanohara mire, the vegetational succession during this period is subdivided into two stages: Zones Nu-II and I. In all three mires, an increase in *Picea,* especially *Picea glehnii* in the Numanohara mire, and a decrease in *Quercus* are noted. This indicates that the lowering of air temperature since about 4,000 y.B.P. was accelerated. Besides, a remarkable lowering of humification of peats in the Numanohara mire suggests that the climate became comparatively wet. In the Numanohara mire, *Betula ermanii* decreased between ca. 2,000 and 400 y.B.P. much more than in the previous period. This tendency is different from that of the other two mires that the dominances of *Betula* forest and *Pinus pumila* zone were almost as same as in the previous period.

A vegetation map of the Daisetsuzan Mountains (Igarashi et al., 1981) shows that the Midorinonuma mire was located between the upper mixed forest and *Betula ermanii* forest. According to the observation by the author, the vegetation surrounding the Midorinonuma mire consists mainly of *Picea glehnii.*

The vegetational succession around the Midorinonuma mire is divided into two stages: Zones Mi-II and I.

In Zone Mi-II, *Betula ermanii* forest was established in the landslide area in the early stage of this period as an intolerant tree forest, and subsequently had been gradually replaced by *Picea glehnii.*

In Zone Mi-I, the vegetation around the mire reached the climax *Picea glehnii* forest.

It has been maintained until now since that time when *Pinus pumila* community extended more than in previous period.

3.4.2 Development of mires

The cross section of buried topography in the mire on the east of Ponchubetsudake revealed the existence of a step-shaped microtopography under the peat layers. This microtopography seems to be originated from the solifluction lobes which were formed before the onset of peat accumulation. It is overlain by a thin silty layer, which indicates that the fine materials were removed by a sheetwash before the onset of peat accumulation. The silty cover probably plays a part of impermeable layer. These conditions seem to have been favorable for the water stagnation leading to the mire development on the slope. The peat accumulation started at about 7,500 y.B.P. In the early stage of the mire development, the alpine meadow stretched and ponds were scattered. The peat layer does not contain any intercalated mineral layers except a very thin sandy layer at a depth of 130 cm (about 3, 800 y.B.P.) and three ash layers (Tk-a, Tk-b and Tk-c). The fact indicates that a remarkable mass movement did not occur in the period of peat accumulation. After about 200 y.B.P., some bank and hollow complexes were formed by slide-type mass movement of peat layer itself. *Sphagnum* value (not shown in the pollen diagram) is very poor but presents throughout the almost whole period (Takahashi and Igarashi,1986). This fact suggests that the mire has developed as a bog mire since the early stage.

In the Yutomuraushi mire, peat accumulation started at about 5,000 y.B.P. The topographical condition before the onset of it resembles to that of the mire on the east of Ponchubetsudake, namely , a step-shaped microtopography composed of gravels overlain by a thin silty layer. Ponds are scattered in the mire in the early stage as well. The mire is located in front of a landslide area, nevertheless the formation of the buried topography and the peat accumulation do not seem to be affected by landslide. Also in this mire, the peat layer contains three intercalated ash layers.

The Numanohara mire develops on a flat and nearly horizontal surface of lava plateau. The peat accumulation at Loc.1 started at about 3,600 y.B.P. As the peat deposits (91-117 cm thick) at Locs.2, 3 and 4 are almost as thick as that in Loc.1 (110 cm), the peat accumulations at these locations also seems to have started around 3,600 y.B.P. The silty layers (8-22 cm thick) underlain by basal gravel layers at these locations suggest that there was a pond with an extensive and shallow standing water before the onset of peat accumulation. The Ohnuma can be regarded as a remain of the ancient pond. Judging from the fact that the peat deposits of this mire do not contain any intercalated mineral layers without three ash layers as well as in the former two mires, a remarkable mass movement did not occur around the mire during the peat accumulation. *Sphagnum* represented in the pollen diagram after about 2,000 y.B.P. suggests that the mire was in the phase of a bog mire after that time.

In the Midorinonuma mire located in the Kogen landslide area, the peat accumulation started at about 1,300 y.B.P., however, the silty layer of more than 60 cm thick below the peat layer suggests that the mire experienced a pond phase for a while before the onset of peat accumulation. The silty materials are thought to have been carried by snow-melt water or rain wash from the surrounding slopes, which were unstable after the destruction of forest vegetation by landslide. The age of the transition from the silty to the peaty deposits coincides with the age of the vegetational succession from the dominance of *Betula* to that of *Picea*. This facts suggests that the supply of the mineral materials from the surrounding slopes ceased, and subsequently peat accumulation started with a stabilization of the surrounding slopes by the recovery of the climax forest. The depositional structure of the other mires in the landslide area is different from that of the Midorinonuma mire. In the mires (Locs.7, 8 and 9) in the upper part of the landslide area, where melting water is supplied directory from the upper slope, the mire deposits consist of mineral layers with thin organic layers. The mineral materials were probably carried by snow-melt water from the upper slope with poor vegetation cover. While, in the mires (Locs.11 and 12) in the lower part, a thick peat layer (90-100 cm) is found as well as in the Midorinonuma mire (Loc.10). However, a silty layer is hardly found under this peat layer. This fact suggests that the peat accumulation of the mires started soon after the occurrence of landslide without a pond phase. The peat accumulation at Loc.12 started around 5,000 y.B.P. (Igarashi and Takahashi,1985).

4. Development of Microtopography in Mire —— Bank (Kermi) and Hollow (Schlenke) Complex ——

4.1 Introduction

Several kinds of microtopography characterize the mires on the Daisetsuzan Mountains. Bank (Kermi) and hollow (Schlenke) complex and palsa are the most important. In this chapter the author describes the bank and hollow complex and discusses its genesis and development. It is a step-like microtopography which characterizes the sloping bogs.

According to Sakaguchi(1974), there are several views concerning with the genesis of bank and hollow complex. The first opinion is that the formation is based on the microrelief development due to the gravitational movement of peat layer itself. The second one is that the formation is attributed to a difference in water conditions for plant growing. The third one is a compromise between these two views. On the basis of the observation of the movement of needle leaves which formed a miniature of bank and hollow complex on the lawn surface after a heavy rain, Sakaguchi(1985) maintained that a gentle slope with adequate relief on ground surface, the supply of needle-shaped material in adequate size, and occurrence of sheetwash are likely to form the bank and hollow complexes.

In this chapter, the author shows several views related to the formation of bank and hollow complex, based on the observation of superficial deposits and topographies before and after peat accumulation in the Koganegahara mire and the mire on the east of Ponchubetsudake.

4.2 Environmental settings of two mires

The environmental settings of the mire on the east of Ponchubetsudake was already described in the preceding chapter.

The Koganegahara mire (Figure 24) is located in the southwestern part of the Daisetsuzan Mountains. It is situated on the gentle slope of andesitic lava of Stage I inclining to the north or the northwest, which ranges in altitude from 1,400 to 1,800 m. It

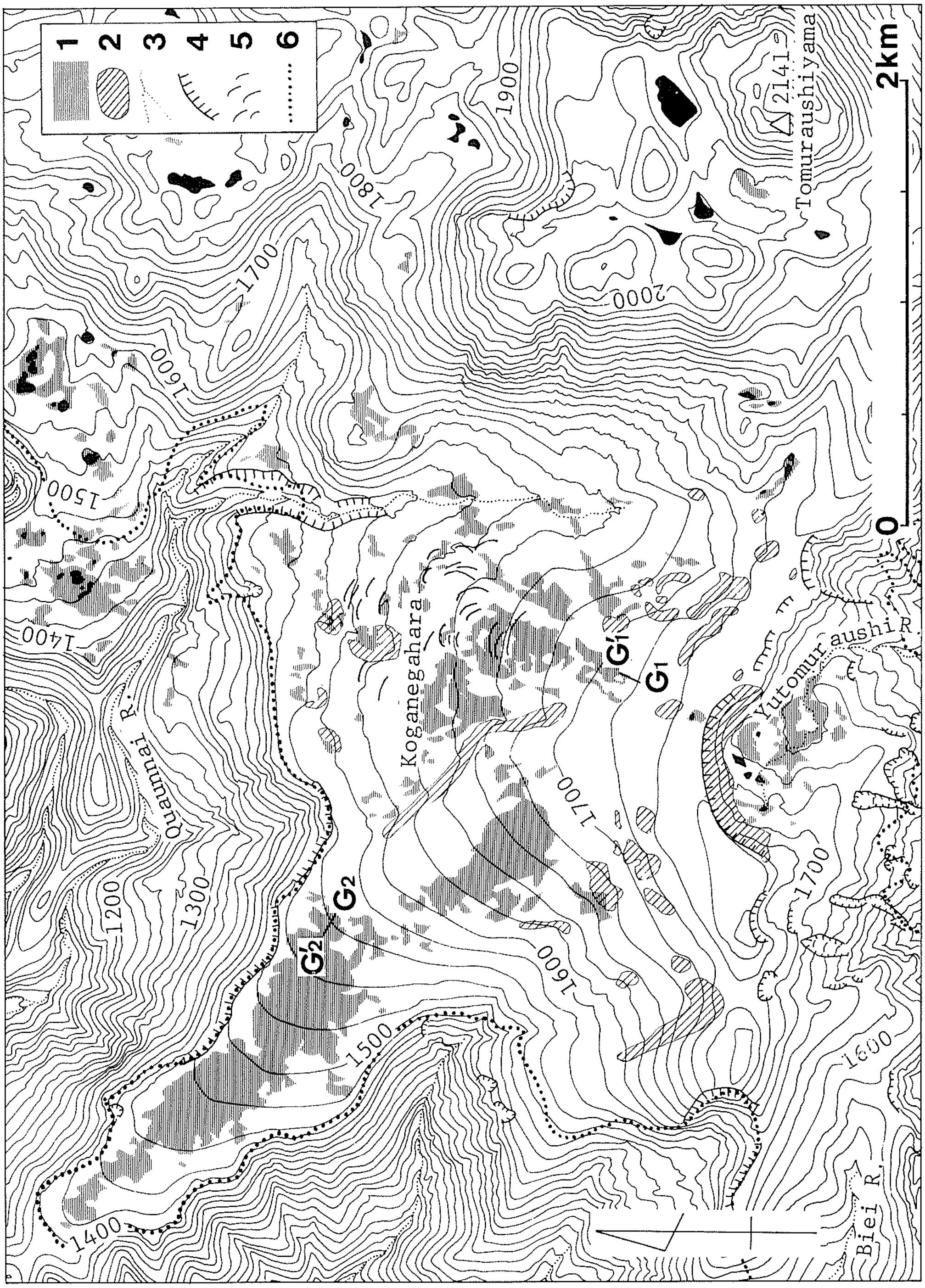

Figure 24 Topography and mire distribution around Koganegahara.
1 : mire, 2 : nivation hollow, 3 : stream, 4 : scarp, 5 : large-scale solifluction lobe, 6 : timber line.
G_1–G_1' and G_2–G_2' show the locations of the profiles shown in Figures 25 and 26 respectively.

occupies an area of about 640 ha. The eastern side of Koganegahara continues smoothly to the dome-shaped mountain slope of Tomuraushiyama, composed of andesitic lavas of Stages II and III. The other sides of Koganegahara are dissected by landslide or fluvial erosion. The timber line elevation around Koganegahara is 1,400 - 1,700 m. *Pinus pumila* community primarily occupies the space above the timber line, however, tall herbaceous community, *Sasa kurilensis* community and mire are dominant on Koganegahara where *Pinus pumila* community stretches only sporadically.

Air photograph interpretation revealed the occurrence of large-scale solifluction lobes in the northeastern part of Koganegahara and nivation hollows in the south and the center. Some of nivation hollows are covered with boulder deposits and herbaceous vegetation. Bank (Kermi) and hollow (Schlenke) complex develops most remarkably in the Koganegahara mire, especially in the northwestern part, among the mires of the Daisetsuzan Mountains.

The direction of wind-deformed trees suggests that southerly to southeasterly winds prevail on Koganegahara in winter. The distribution of the nivation hollows which are concentrated on the northern to northeastern slopes shows that there are much snow on these slopes, which correspond to the shade of prevailing wind. These facts suggest that the westerly wind, passing through the valley of the Biei River, comes to Koganegahara from southwest and sweeps snow over Koganegahara to the north.

4.3 Profiles and Superficial Deposits

The topography and the superficial deposits of bank and hollow complex were observed in detail at two locations in the Koganegahara mire and at one in the mire on the east of Ponchubetsudake.

4.3.1 Profile G_1 - G_1' in the Koganegahara mire

1) Topography

Profile G_1 - G_1' (Figure 25) is located at about 1,710 m a.s.l. on the upper slope of Koganegahara. An average surface inclination is 6°. A profile between a and d is characterized by a gentle relief with a wave length of about 20 m, however two small gullies cross the profile at b and c. The surface inclination becomes more than 10° between d and e, while a nearly straight profile between e and f has an inclination of 5°. Between f and g, and further downslope, the profile is rich in a microrelief due to the occurrence of bank and hollow complexes. The front of bank is 30 - 80 cm high and has an inclination of more than 10°. Besides, the hollow is 1 - 2 m wide (in the direction of profile) and has a horizontal bottom.

2) Superficial deposits

Superficial deposits (Figure 25) are composed of dark-brown peaty silt or brown to yellowish-brown silt containing plant remains. They cover the gravel layers which consists of pebble and cobble in size. The relief of the buried topography, formed by this gravel layer, has an average inclination of 6° as well as the present surface and is characterized by gentle steps in a relative height less than 1 m. Between b and c, and e and f, the profile of the buried topography is almost parallel to that of the present one. However, in the other sections, there are differences between these two profiles.

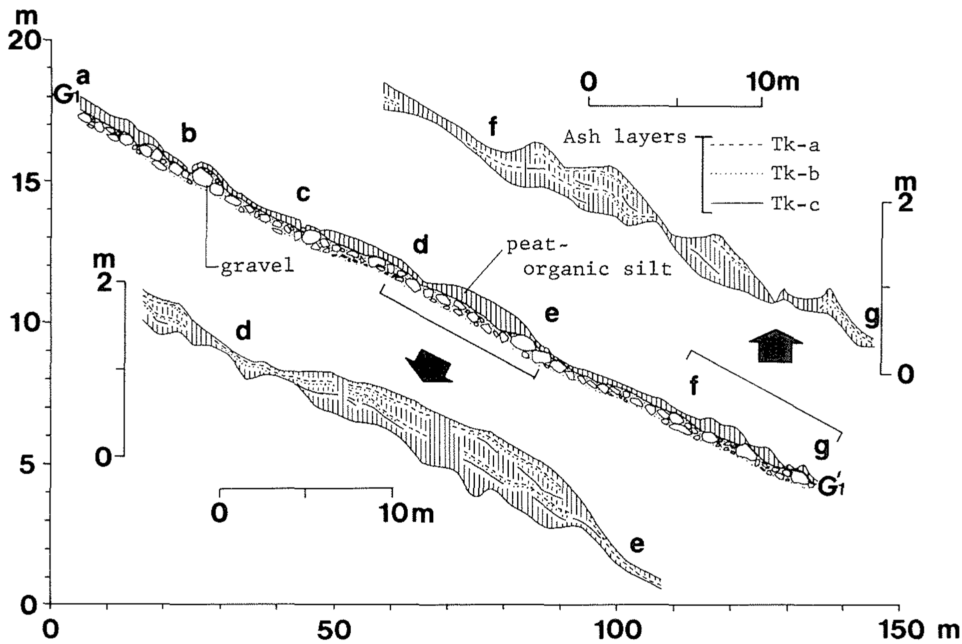

Figure 25 Profile (G_1-G_1') of topography and superficial deposits of the Koganegahara mire.
Location of the profile is shown in Figure 24.

Silty layer between a and e ranges in thickness from 7 to 82 cm. It is relatively thick between a and b, and c and e, since present profile is a convex while the buried one is concave. The lower part of the silty layer becomes clayey. In the gullies at b and c, the gravel layer exposes. It consists mainly of subangular gravel ranging in diameter from several to several tens centimeters. Subangular gravel also exposes on the ground surface, where the silty layer is thin.

Between e and f, the peat layer is about 10 cm thick, while it reaches 42 cm at one of banks between f and g. The silt layer overlain by the former also becomes thicker in the same section, particularly where the buried topography shows the concave profile (up to 22 cm thick). Between e and f, gravel of several tens centimeters in diameter exposes on the ground surface.

Silt and peat layers are intercalated with ash layers (Tk-a, Tk-b and Tk-c). Tk-a occurs almost continuously. Tk-b occurs intermittently at less than 1 cm below Tk-a. Tk-c occurs most fragmentarily. Between a and b, c and e, and f and g where the silt and peat layers are relatively thick, a set of these ash layers (Tk-a, Tk-a and Tk-b or Tk-a, Tk-b and Tk-c) is doubled with a normal order in each set. This superposition of ash layers will be discussed later.

4.3.2 Profile G_2 - G_2' in the Koganegahara mire

1) Topography

Profile G_2 - G_2' (Figure 26) is located at about 1,560 m a.s.l. in the north of Koganega-

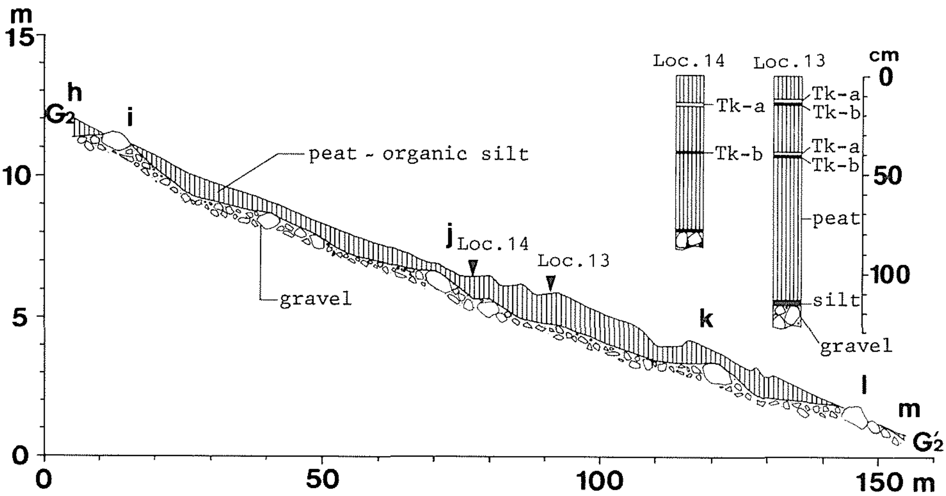

Figure 26 Profile (G_2-G_2') of topography and superficial deposits of the Koganegahara mire.
Location of the profile is shown in Figure 24.

hara. An average surface inclination is 4.3°. The mire with well-developed bank and hollow complexes spreads on the northwest of the profile. Between h and j, the topography has a straight profile with an inclination of 4.4°. Bank and hollow complexes are formed between j and l and the average inclination is 4.0°. Banks are about 50 cm in height and incline by 10° - 15° at front. Hollows are 1 - 5 m wide.

2) Superficial deposits

The peat layer (Figure 26) is thicker (up to 120 cm) between j and l, where the bank and hollow complex occurs. In other sections, it is less than 60 cm. There are differences of humification in the peat layer. The upper 20 - 70 cm is hardly humified, while the lower part is well humified. The peat layer is underlain by silt (or clay) layer containing plant remains, which covers the gravel underneath. The buried topography formed by gravel layer is characterized by a gentle step-shaped profile, which has an average inclination of 4.1° and is poorer in variation of relief than that of present land surface. The steps are 1 - 2 m high and 10 - 20 m wide except a step around j, and the front and the upper slopes are 6° - 10° and 0° - 4° respectively. Between j and k, the buried topography shows totally a concave profile contrary to a convex one of present land surface.

The peat layer is intercalated with ash layers (Tk-a, Tk-b and Tk-c). Tk-a is 1 - 4 cm thick, and it occurs in the range from 10 - 20 cm deep. Tk-b is less than 1 cm thick, and it occurs intermittently at less than 1 cm below Tk-a. Tk-c is less than 1 cm thick, and it occurs at a depth of 20 - 50 cm around j. At a part of banks (Loc.13) two sets of Tk-a and Tk-b occur at 12 - 15 cm and 39 - 42 cm deep respectively. The lower Tk-a is overlain by a humified peat, although the upper one is overlain by unhumified peat, which generally composes the superficial layer. At Loc.14, a very thick peat layer (22 cm) intervenes between Tk-a and Tk-b, although an intervening peat layer is ordinary less than 1 cm

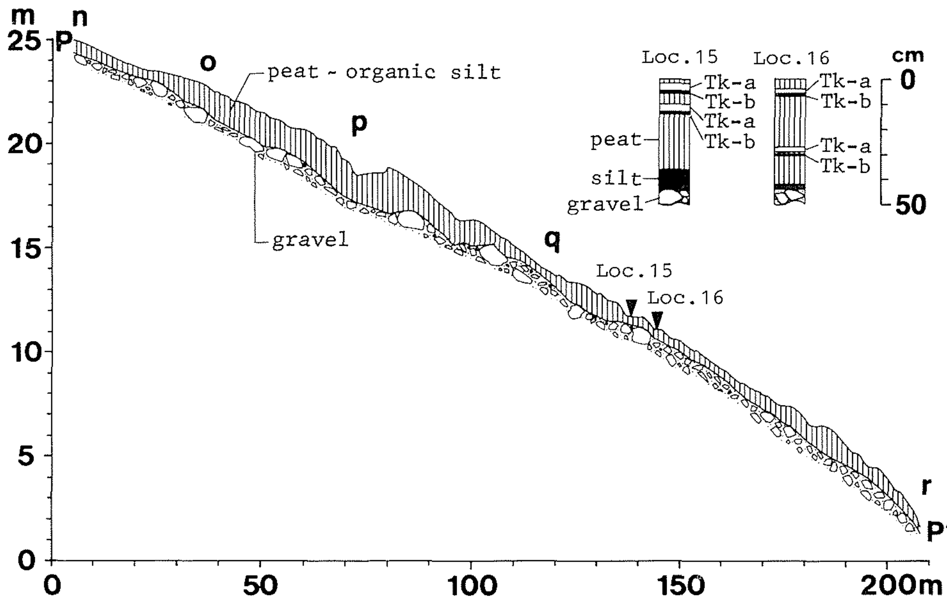

Figure 27 Profile (P-P') of topography and superficial deposits of the mire on the east of Ponchubetsudake. Location of the profile is shown in Figures 8 and 10.

thick.

4.3.3 **Profile P - P' in the mire on the east of Ponchubetsudake**

1) Topography

Profile P - P' (Figure 27), located around 1,730 m a.s.l., is convex as a whole and has an average surface inclination of 6.6°. Between n and o, the profile is nearly straight and 3° - 5° in inclination. Between o and p, the profile is convex and 6.9° in inclination, and is characterized by the occurrence of small-scale bank and hollow complex. The front of bank is 20 - 50 cm high and has an inclination up to 30°. Most of hollows are 10 cm - 2 m wide, although some of them reach 5 m wide. Pond at p is 30 cm deep and 8 m in diameter. The profile between p and q is 7.3° in inclination and consists of two nearly straight section and a pair of bank and hollow at the middle part. Between q and r, the profile is characterized by the development of bank and hollow complexes. It is 7.7° in inclination and convex as a whole except at the straight section in the middle part. The front of banks ranges from several tens centimeters to 1.3 meters in height and from 9° to 21° in inclination. Hollow is 1 - 4 m wide.

2) Superficial deposits

The peat layer (Figure 27) is relatively thicker (up to 220 cm) in the section of bank and hollow complex. The lower part of peat layer is more humified and grades to silty layer of less than 10 cm thick which sometimes contains organic materials. The silty layer is underlain by gravel layer which consists of mainly of angular to subangular gravels in a diameter of several tens centimeters. The profile of buried topography formed by gravel layer does not show a remarkable relief so much as that of present land surface. However, gentle steps occur on the profile as well as on Profiles G_1 - G_1' and G_2 - G_2'. The front of step ranges from several tens centimeters to 1.5 meters high and from 4 to 13 in inclination, and the upper slope is less than 3 and up to 15 m wide.

Peat layer is intercalated with ash layers (Tk-a, Tk-b and Tk-c). Tk-a is 2 - 4 cm thick, and occurs continuously from 0 to 15 cm deep. Tk-b is less than 1 cm thick, and occurs intermittently at less than 1 cm below Tk-a. Tk-c is less than 1 cm thick, and occurs intermittently from 20 to 40 cm deep. A set of Tk-a and Tk-b is doubled at bank and hollow complex between q and r (Locs.15 and 16), as well as in the profiles mentioned above.

4.4 Discussion

4.4.1 Topography before peat accumulation

The results of observation indicate that gravelly slopes or block fields had spread extensively on the Daisetsuzan Mountains before the onset of peat accumulation. At present, such slopes are subjected to strong wind or much snowfall in winter. Various kinds of periglacial landforms develop there. Solifluction lobes mainly develop in a nivation hollow or on the slope from which the water is supplied. Many of these lobes are several tens centimeter to one meter in height at their front.

Figure 28 shows a schematic profile of solifluction lobe in a nivation hollow. The lobe is about 70 cm high and the upper slope is about 2°. The lobe is composed mainly of subangular gravels ranging from several millimeters to several centimeters in diameter except the front composed of boulders up to 140 cm in diameter. Such lobes are similar in size and shape to the steps, composed of gravels below peat layer mentioned before.

Figure 29 shows a schematic cross section of a bank (Kermi) in the mire on Takanegahara. The bank is about 1 m high and is composed of boulders several tens centimeters in diameter at the front. The upper slope is about 2°. Behind the boulders, the gravels ranging from several millimeters to several centimeters in diameter are overlain by peat layer with a thin silt layer (1 - 2 cm) at the bottom. The similarity in shape and in depositional structure suggests that the steps below peat layers are solifluction lobes.

According to the mean rate of peat accumulation (0.43 - 0.14 mm/y) on the lava plateau, shown in Table 4, the beginning of peat accumulation in the three mires is inferred to be about 4,000 y.B.P., although, the peat accumulation started at about 7,500 y.B.P. in a part (around p) of the mire east of Ponchubetsudake. On the other hand, the decline of *Quercus* values which was represented in the pollen diagrams (Figure 20) suggests a deterioration of climate since about 4,000 y.B.P. Before the onset of peat accumulation, solifluction lobes might have occurred on the slopes. The microrelief of solifluction lobes, therefore, must have provided a preferable topographic condition for water stagnation, peat accumulation, and bank and hollow complex development.

4.4.2 Topographic changes after peat accumulation

The intercalated ash layers within peat layers indicate the topographic changes after the peat accumulation. As mentioned before, in all profiles, a set of ash layers sometimes repeats in different two horizons at one location, with a normal order in each set. Peat or organic silt layer is relatively thick in such place. Bank and hollow complex often develops

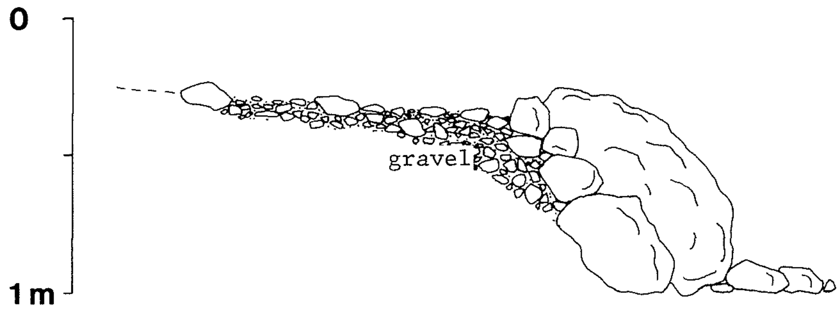

Figure 28 Schematic profile of solifluction lobe in nivation hollow.

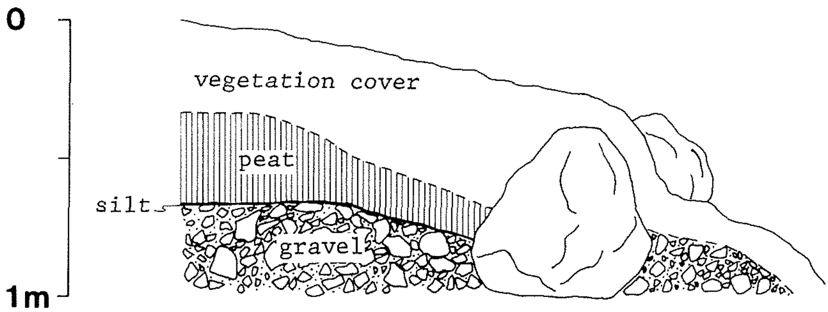

Figure 29 Schematic profile of bank (Kermi) in the mire on Takanegahara.

there. However, the upper slope often lacks ash layer, and the peat layer is very thin, as shown between e and f in Profile G_1 - G_1'. These facts suggest that the peat layer, which contains an upper set of ash layers, was displaced from the upper slope by slide-type movement. As a result of such displacement, the upper slope lacks ash layer at present.

At Loc.13 in Profile G_2 - G_2', the lower set of ash layers (Tk-a and Tk-b) is contained within unhumified peat layer of 15 cm thick, which generally composes a superficial layer. This fact indicates that the superficial peat layer containing the upper set of ash layers was moved from the upper slope after a fall of Tk-a. The extraordinary thickness (22 cm) of the intercalated peat layer between Tk-a and Tk-b at Loc.14 can not be explained by a difference in peat accumulation rate from the other locations. It is more reasonable to consider that the superficial peat layer containing Tk-a was moved from the upper slope onto the peat layer containing Tk-b.

It is concluded that some of bank and hollow complexes originate from slide-type mass movement of peat layer itself. This supports Sakaguchi's view that the formation of bank and hollow complexes is due to the gravitational movement of peat layer itself.

Ash layers intercalated in peat layers indicate that the mass movement occurred after 200 y.B.P.

5. Development of Microtopography in Mire —— Palsa ——

5.1 Introduction

In July 1986, the author discovered palsas first in Japan, They are located in the mire on the south of Hiragatake (43°37′N, 142°54′E; 1,720 m a.s.l.) in the central part of the Daisetsuzan Mountains.

According to the definition of palsas, proposed by Washburn (1983a), "palsas are peaty permafrost mounds, ranging from c.0.5 to c.10 m in height and exceeding c.2 m in average diameter, comprising (1)aggradation forms due to permafrost aggradation at an active -layer/permafrost contact zone, and (2)similar-appearing degradation forms due to disintegration of an extensive peaty deposit." "The term palsa was originally used by the Lapps and northern Finns and in their languages (Lappish and Finnish) means a hummock rising out of a bog with a core of ice" (Seppälä, 1972).

Palsas are reported mainly in a zone of discontinuous permafrost including Fennoscandia, Iceland, Soviet Union and Canada (Washburn,1983a), and are considered to be the only reliable indicator of permafrost in a zone of discontinuous permafrost (Brown,1974). Recently, however, palsas or palsa-like mounds are reported also in a zone of continuous permafrost (Washburn, 1983b). Svensson (1976) maintained that palsas and pingos are related through transitional forms. Collins et al. (1984) reported a fen-palsa located in the Beartooth Mountains, Wyoming (44°54′N, 109°27′W), at an altitude of 2,950 m. represents the southmost occurrence of palsa in North America.

According to Lundqvist (1969), the surface of palsa is rather dry and can be covered with a vegetation of low shrubs and lichens, or it can be a barren peat surface. Often it is traversed by open cracks in different directions. There is often free water immediately around a palsa. Zoltai and Tarnocai (1971), however, reported a wooded palsa in northern Manitoba, Canada. The occurrence of open cracks is usually restricted in the peat surface (Friedman et al., 1971) or in the seasonal thawing layer (Seppälä, 1976). There are three possible causes for the occurrence of cracks (Friedman et al.; 1971): (1) growth of the palsa core; (2) contraction in the frozen palsa in winter; and (3) desiccation of the peat cover in summer.

In Japan, the occurrence of permafrost has been reported at the summit of Mt. Fuji (above 3,500 m a.s.l.) (Higuchi and Fujii, 1971) and in the Daisetsuzan Mountains (above 2, 000 m a.s.l.) (Fukuda and Kinoshita, 1974; Sone and Takahashi, 1986). The discovery of palsas verifies geomorphologically the occurrence of permafrost on the Daisetsuzan Mountains. This proves that the permafrost in the Daisetsuzan Mountains occurred at least around 1,700 m a.s.l., which is 300 m lower than the previously known altitude of permafrost distribution.

In this chapter, the author describes the size, form and internal composition of the palsas in the Daisetsuzan Mountains on the basis of field investigation carried out in late September 1986. The areal changes of palsas during the period of 1955-82 are also illustrated, on the basis of air photograph interpretation, in order to relate them to the recent climatic changes.

5.2 The palsa mire on the south of Hiragatake

The palsa mire is located on a broad pass on the plateau, composed of the ejecta of Stage I at the south of Hiragatake, in the central Daisetsuzan Mountains (Figures 5 and 30). The altitude of the mire is 1,720 m a.s.l. The valley of the Chubetsu dissects the western side of the plateau, whereas the eastern margin is bounded by a steep scarp reaching about 200 m high which was formed by a large-scale landslide. The mire is located above the timber line whose elevation is about 1,600 m on the western slope and about 1,500 m on the eastern slope of the plateau.

The direction of wind-deformed trees around the mire suggests that the westerly wind prevails in winter. The wind seems to be strengthened at the mire, because the main valley of the Chubetsu, running from east to west, goes straight up to the mire. By the effect of blowing out, the snow depth on the mire is less than several ten meters, and ground surface partly exposes in winter. In summer, the westerly wind brings frequently low clouds or fogs onto the pass so that the amount of insolation onto the mire is much less than in its surroundings.

Although meteorological record has not been obtained in the mire, the mean annual air temperature at Hakuun hat (2,000 m a.s.l.) (Table 1), about 5 km north of the mire, was -3.8°C in 1985. With the laps rate of 0.6°C/100 m, the mean annual air temperature at the palsa mire is estimated as -2.0°C.

The length of the mire is about 650 m from east to west and about 350 m from north to south (Figure 30). The area totals about 10.3 ha. The mire is divided into two drainage systems by low watershed. The one is in a direction from north to southwest, and the other is in a direction from south to northeast. The surrounding vegetation of the mire is *Pinus pumila* community.

The mire has a peat of about 1 m thick, the bottom of which was dated $4{,}250 \pm 130$ y. B.P. by radiocarbon method.

Bank (Kermi) and hollow (Schlenke) complex develops well on a sloping bog. They stretch in harmony with the direction of drainage systems in the mire. There are also many depressions with standing water, some of which are evidently caused by thermokarst.

The vegetation in the mire is mainly composed of *Sphagnum*, *Carex* spp., *Drosera rotundifolia*, *Andromeda polifolia* and *Vaccinium oxycoccus* with *Menyanthes trifoliata* and *Eriophorum vaginatum*, however, the vegetation on the palsa mainly consists of *Diapensia lapponica v. obovata*, *Bryanthus gmelinii*, *Geum pentapetalum*, *Pinus pumila* and lichens. Palsa has often no vegetation cover on the surface.

5.3 Distribution, form and size of palsas

Fifteen palsas were identified on air photographs at scale of 1:2,000 to 1:2,500 taken in 1982 (Figure 30), and one small palsa (A in Figure 30) was found by field investigation. The identification was based on the form of palsas themselves, and the hue of color caused by a different water content in palsa. Palsa shows a lighter hue, suggesting the dryer surface condition. Ten of them are located within the eastern drainage basin, five are within the western one, and one is on the divide of two drainage basin. They are generally in round or elliptic shapes, whose diameter is up to 80 m except an irregular-shaped palsa on the

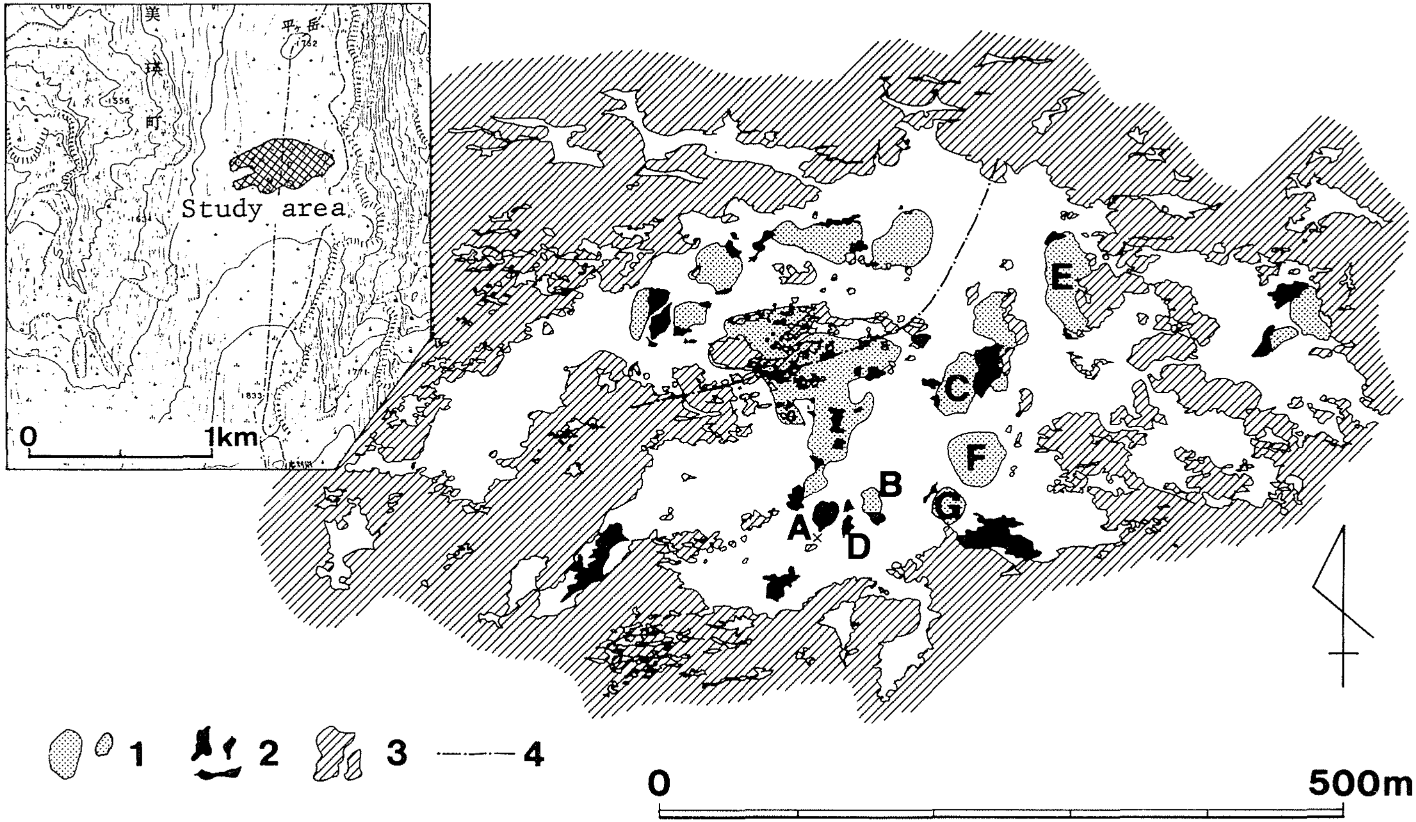

Figure 30 Distribution of palsas in the mire on the south of Hiragatake in 1982.
1 : palsas, 2 : ponds, 3 : *Pinus pumila* community, 4 : watershed, A–D : palsas described in the text.

divide whose length is 140 m from north to south, and 130 m from east to west. The height ranges from about 0.2 to 1 m. The palsas are generally characterized by flat upper surfaces and relatively steep side-slopes. They are often accompanied with ponds just around them. According to the definition of palsa and palsa plateau described before, some features in the studied mire can be called palsa plateau. However, the author will treat them as a palsa in this paper, because the distinction between palsa and palsa plateau is not sufficiently clear.

5.4 Internal structure of Palsas A, B and C

The internal structure of three palsas in different size, A, B and C, was examined by a boring stick in late September 1986. Palsa A (Figure 31) is located between two ponds in the south of the mire. It is 20 cm high and about 4m in diameter and the smallest of all. The surface of the palsa is somewhat dryer than its surroundings and is invaded by a young tree of *Pinus pumila.*

Palsa A is composed of peat layer of 60-150 cm thick, which becomes thinner toward the center of palsa. The peat layer contains sand and gravel at the lower part, and it is underlain by sandy-gravelly silt layer. The upper limit of a frozen core (permafrost) with segregated ice at a depth of 55-110 cm almost coincides with the boundary between the peat and the sandy-gravelly silt layers. The lower limit of frozen core ranges from 80 to 140 cm in depth, in the sandy-gravelly silt layer. The thickness of the frozen core is up to 90 cm at the center.

Palsa B (Figure 32), located in the south of the mire, is 80 cm high and about 15 m long with long axis running from north to south. The surface is nearly flat, and the side slope is steep except on the southern part which faces to a thermokarst depression with standing water. Several cracks occur on the peat surface. Except few patches of dwarf shrubs, including *Diapensia lapponica v. obovata, Bryanthus gmelinii* and *Geum pentapetalum,* and lichens, most of vegetation cover are stripped off from the top of the palsa by strong westerly wind in winter, so that the peat is widely exposed on the surface. Several gravels appear on the peat surface at the southern part. The trace of bank and hollow complex was identified on the surface of the palsa by air photograph interpretation.

Palsa B is composed of a peat layer of 60-110 cm thick which is underlain by sandy-gravelly silt layer. In the southern half, where the peat layer becomes thinner toward the depression with standing water, sand and gravel appears within the peat layer.

Although the permafrost table ranges in depth from 60 to 125 cm, it lies almost around 70 cm deep and is nearly parallel to the palsa surface. It almost coincides with the boundary between the peat and the sandy-gravelly silt layers, but in the southern half, it lies at a depth of 80-125 cm in the sandy-gravelly silt layer. The lower limit of the permafrost has not been known.

Palsa C (Figure 33) is located in the center of the mire. It is 80 cm high and 45 m long from north to south and 22 m long from east to west. The upper surface inclines toward the depression with standing water just on the east of the palsa, while the western side-slope is steep. Open cracks which range from several to 20 centimeters wide occur on the peat layer in the western side. Several peat blocks of several ten centimeters wide are

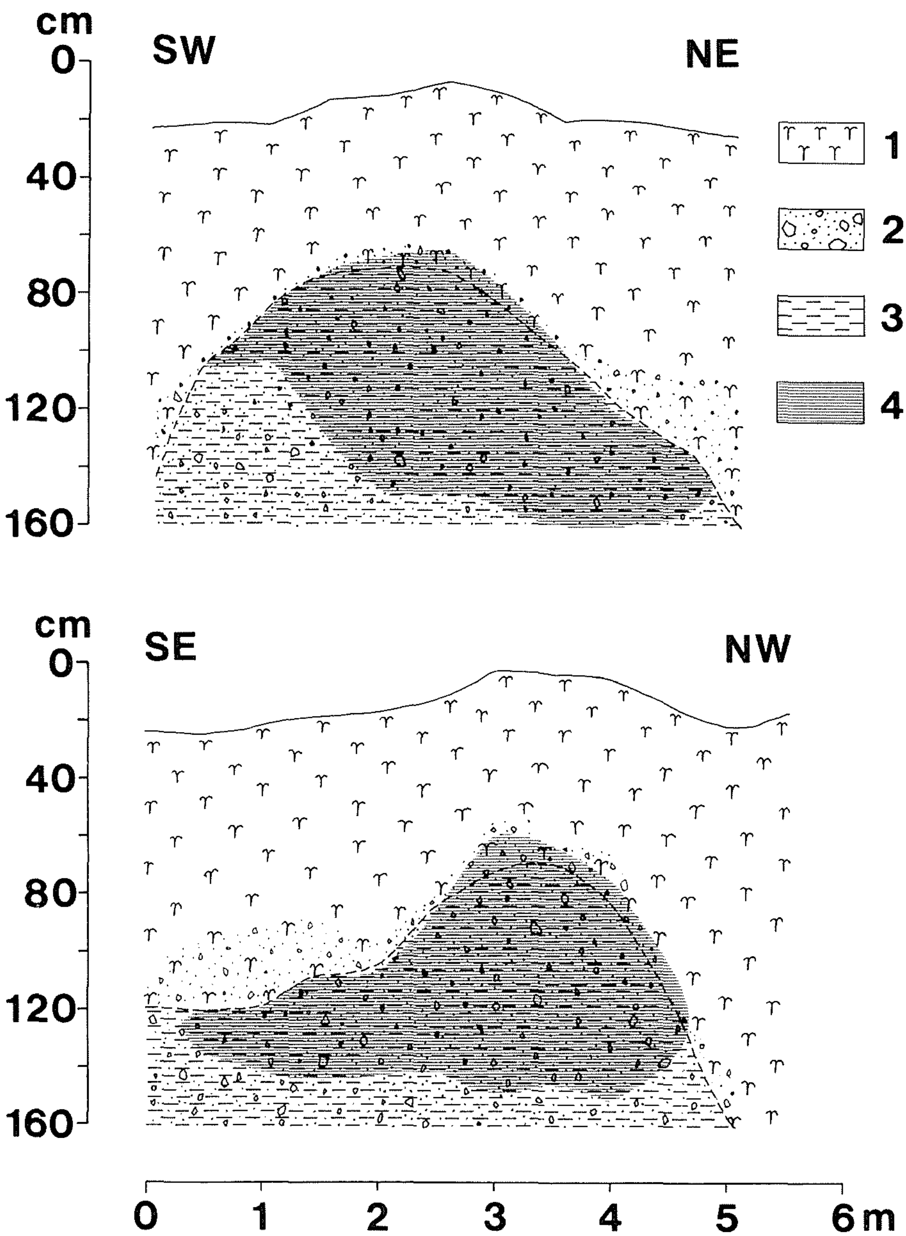

Figure 31 Cross sections of Palsa A.
1 : peat, 2 : sand and gravel, 3 : silt, 4 : frozen core. Broken line shows the boundary between peat layer and gravelly silt layer.
Location of Palsa A is shown in Figure 30.

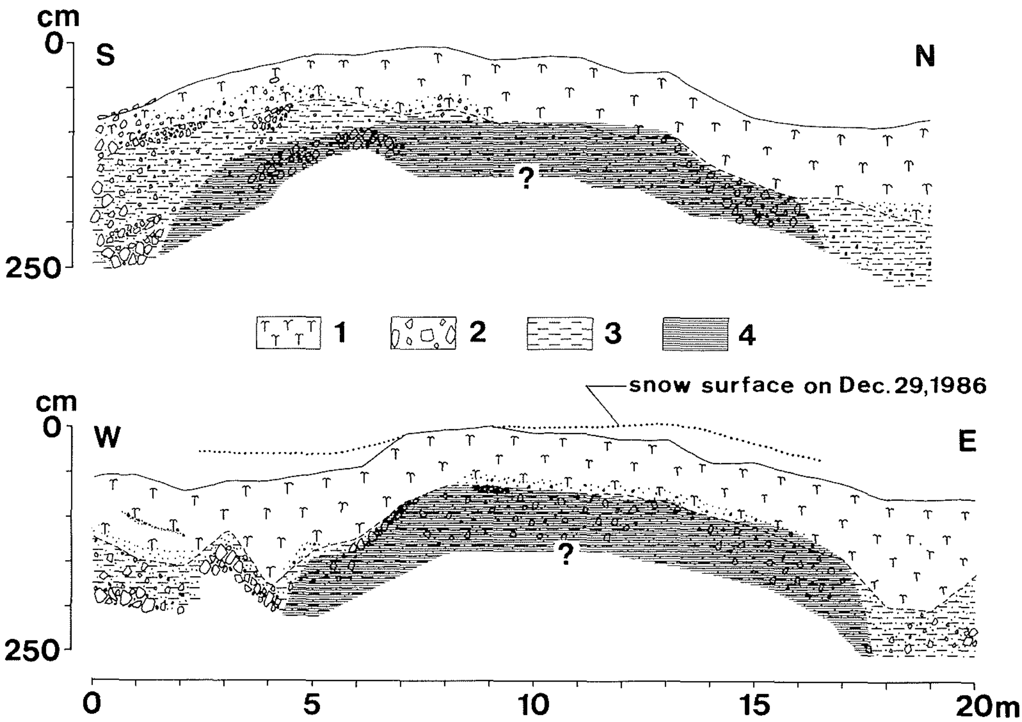

Figure 32 Cross sections of Palsa B.
Legend is shown in Figure 31.
Location of Palsa B is shown in Figure 30.

completely separated from the palsa along the open crack, while the surface slides of peat occur in the eastern side. The vegetation cover on the palsa is as poor as on Palsa B. Angular to subangular gravels of several centimeters in diameter are scattered on the surface in the eastern half.

Palsa C is composed of a peat layer of 10-75 cm thick which is underlain by sandy-gravelly silt layer. The thickness of the peat layer is variable, so that the boundary between the peat and the sandy-gravelly layers is undulating contrary to the nearly flat surface. Sand and gravel contents in the peat layer increases toward the bottom of the layer. In the eastern half, much sand and gravel is contained throughout the peat layer, and some gravels are exposed on the surface.

Permafrost table ranges from 75 to 90 cm in depth in the western half, but becomes more than 130 cm deep in the eastern half. It lies in the sandy-gravelly silt layer except at the point 5 m east from the western end of palsa, where it lies between the peat and the sandy-gravelly silt layers as well as in the case of Palsas A and B. The peat layer is 75 cm thick. The lower limit of permafrost has not been known.

5.5 Changes in size and areal extent of palsas during the period of 1955-82

On the basis of the air photographs at a scale of 1:2,000 - 1:2,500 taken in 1955, 1966,

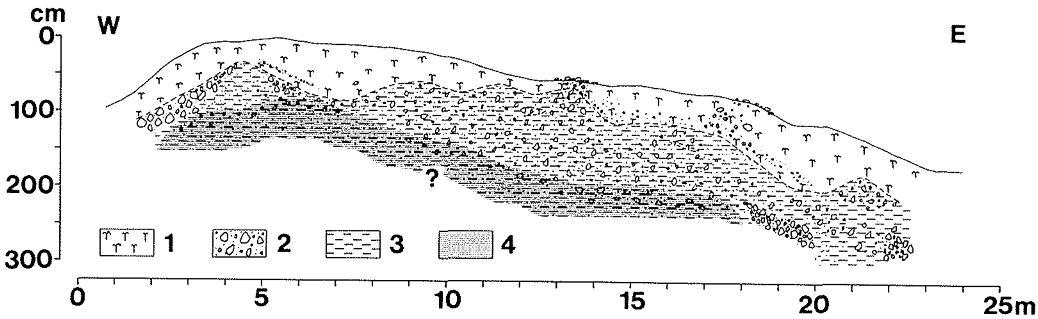

Figure 33 Cross section of Palsa C.
Legend is shown in Figure 31.
Location of Palsa C is shown in Figure 30.

1977 and 1982, the changes in size and areal extent of palsas during the period of 1955-82 were examined (Figure 34).

Comparison of air photographs revealed that the decay of palsas had occurred during this period. Table 5 shows the changes in the area of palsas, where the percentages of the area of palsas is calculated, basing on the total area of palsas in 1955. The reduction in the area of palsas for 27 years totals about 36%. The percentages of reduction in the area of palsas during each period are as follows : 1955-66, 17.2%; 1966-71, 1.4%; 1971-77, 9.4%; 1977-82, 8.2%.

Palsa D on the photograph taken in 1955 was replaced by a pond on the photograph in 1966. Palsa C which was about 120 m long in 1955 was also reduced and divided into two parts: 40 and 50 m long respectively. On the other hand, the pond around the palsa spread one and a half times. As shown in Palsas C and D, most of palsas tended to reduce. However, there are several palsas which were hardly reduced, such as Palsas E and F. On the contrary, Palsa G appeared on the photographs since 1971. It wasn't found on the photographs in 1955 and 66. This indicates that Palsa G grew since 1971. In addition, Palsa A which was found in the field survey seems to be in an early stage of development as mentioned below.

5.6 Discussion

5.6.1 Classification of palsas

On the basis of the field investigations and the air photograph interpretations, Åhman (1976) classified morphologically the palsas in northern Norway into the following five main types: palsa plateau, esker palsa, string palsa, conical palsa and palsa complex. Among them, palsa plateau is most common in northern Norway. It is normally 1.0-1.5 m high, and covers an area from 10,000 m² to 1 km². It has steep side-slopes and almost horizontal top surfaces, which is surrounded by thermokarst depressions.

Most of the palsas in the mire on the south of Hiragatake can be classified into palsa plateau, although the size is somewhat smaller than that in northern Norway. The increase in size of depressions with standing water which corresponds to the decay of palsa suggests

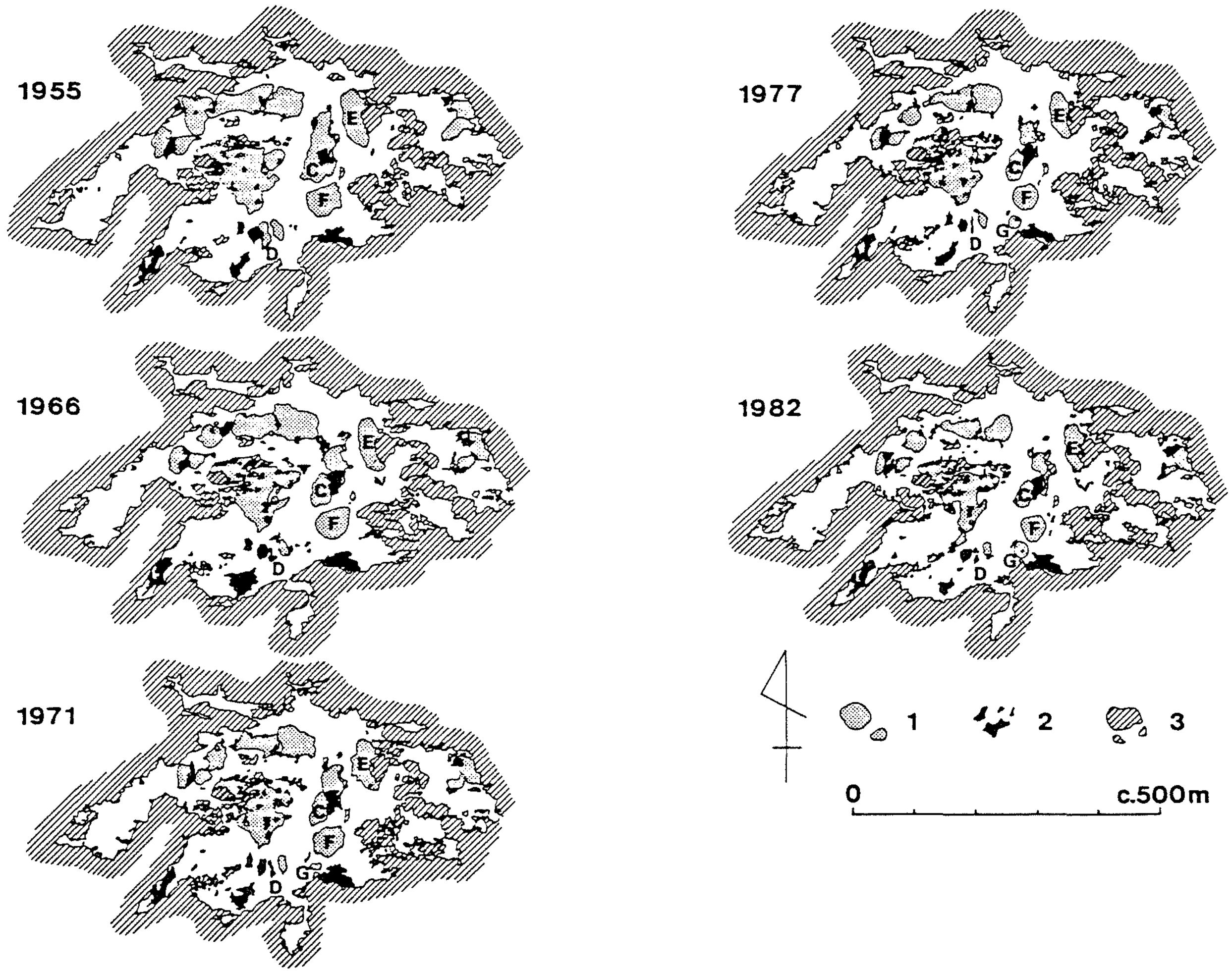

Figure 34 Changes of palsas in the mire on the south of Hiragatak during the period of 1955-1982. As palsas are traced directly from air photographs, the distortion is not corrected. 1 : palsas, 2 : ponds, 3 : *Pinus pumila* community.

Table 5 Changes in area of palsas in the mire on the south of Hiragatake during the period of 1955 - 1982.
1955 is a standard year for percentage of palsas' area.

Year	1955	1966	1971	1977	1982
Area	2.15 ha	1.78 ha	1.75 ha	1.55 ha	1.38 ha
Percentage	100 %	82 %	81 %	72 %	64 %

that the ponds around palsa are formed by thermokarst processes.

Washburn (1983a) classified palsas, by the internal structure, into organic palsas (peat -cored palsas), whose volume of peat exceeds that volume of mineral soil, and mineral palsas (mineral-cored palsas) whose volume of mineral soil exceeds that volume of peat. From this view point, the palsas shown in Figures 31, 32 and 33 are classified into mineral palsas. Other palsas in the mire are also considered to be mineral palsas, because they are situated under the same environmental conditions.

According to the record of air temperature in 1985 at elevation of 2,000 m a.s.l. (Table 1), the alpine zone of the Daisetsuzan Mountains is located around the boundary between the continuous and discontinuous permafrost zones. However, taking the snow cover into consideration, it is rather reasonable to consider that it belongs to the discontinuous permafrost zone (Sone et al.,1987). The existence of palsas verifies this idea.

The trace of bank and hollow complex remains on the surface of Palsa B. The complex develops in harmony with the present slope directions except on the palsa. This indicates that Palsa B is originated due to the permafrost aggradation. The surface of Palsa A is drier than the surrounding peat surface, and is invaded by a young tree of *Pinus pumila,* although *Sphagnum* has not died yet on the surface. These facts indicate that Palsa A is in the early stage of development, due to the permafrost aggradation. There is not a remarkable evidence suggesting a formation of degradation palsa.

5.6.2 Conditions for palsa development

Palsa development principally requires low temperature, thin snow cover, water supply and peat cover. Palsas occur commonly under the continental-climate where a mean annual air temperature is between 0 to −3℃ and a snow cover is thin (Karte,1983).

In Sweden, palsas occur "where the temperature is below 0℃ during more than 200 to 210 days a year", "....palsas are absent where the precipitation during November-April exceeds 300 mm" (Lundqvist,1962). "The palsa area in northern Norway is bounded by a mean annual air temperature between 0 and −1℃, a winter temperature of −10℃ for 120 days, a mean annual precipitation below 400 mm/year and less than 100 mm during the winter (December-March)" (Åhman,1977). The Finnish palsas occur in the southern part of the discontinuous permafrost zone where the mean annual air temperature is below −1℃ and the mean annual precipitations below 400 mm/year (Salmi, 1968). In Iceland, the southern limit of palsas is probably close to the 0℃ mean annual isotherm (Thorarinsson, 1951). In Quebec, Canada, the treeless palsas mainly develop in the area with a mean annual air temperature of −4 to −4.5℃; their southern limit is bordered by a mean annual air temperature of about −3℃, whereas the southern limit of palsas with tree is about −1℃.

From the result of an experimental study of the formation of palsas, Seppälä (1982) concluded that the thickness of the snow cover is the main factor controlling palsa formation in subarctic conditions.

At an elevation of about 2,000 m a.s.l. in the Daisetsuzan Mountains, a mean annual air temperature is −3.8℃, a mean daily air temperature is below 0℃ for 214 days and below −10℃ for 129 days (Table 1). Therefore, the air temperature conditions are probably enough for the occurrence of palsas in the studied mire, even if the difference in altitude about 300 m between the temperature observation site and the mire is taken into consideration. The thickness of the snow cover was less than 20 cm on Palsa B and less than 60 cm around it in December 1986. The top surface of the palsa was subjected to strong wind erosion. Consequently, the frost penetrated deeply into the earth in the mire, especially on the palsas, where the snow cover was thin.

Since a palsa grows by ice segregation (Washburn, 1983a,b), it requires a water supply. The study area is located on a flat plateau where the snow cover in winter is thin due to a strong westerly wind, so that a sufficient water supply cannot be expected from snow patches in summer. The palsa mire is thought to be maintained mainly by rainfall and/or moisture in the air.

A peat cover which protects a frozen core from thawing in summer is an indispensable factor for the palsa development. In the studied mire, the active layer involves the most of peat layer, and a frozen core is situated in the sandy-gravelly silt layer underneath. Permafrost table corresponds to the boundary between the peat and the sandy-gravelly silt layers, where the peat cover is more than 60 cm thick. However, it lies in the sandy-gravelly silt layer where the peat cover is less than 60 cm thick. The peat cover becomes thinner near a thermokarst depression. So the thin peat cover characterizes a collapsing palsa. Therefore the peat cover of more than 60 cm thick is considered to be necessary for the growth and persistence of palsas in the mire on the south of Hiragatake.

5.6.3 Sequence of palsa development

The concept of a cyclic development of palsa, from growing stage to collapsing stage through mature stage, has been reported by several researchers (Friedman et al., 1971; Seppälä, 1982; Washburn, 1979), and the palsas in various stages often occur together in the same mire (Friedman et al., 1971; Seppala, 1982; J. Lundqvist, 1969).

The palsas in various stages occur also in the studied mire. Considering the conditions for palsa formation mentioned above, the author proposes a following sequence of the palsa development in the study area:

1) initial stage

^{14}C age of the sample from the bottom of peat layer indicates that peat accumulation in the study area began around 4,200 y.B.P. As described before, a peat cover of more than 60 cm thick is required for the growth of palsas at present. According to the mean rate of peat accumulation above the timber line (0.2-0.3 mm/year), 2,000-3,000 years are necessary for the peat accumulation of 60 cm thick. If the thermal condition for growing palsas is constant, the palsa formation in the mire on the south of Hiragatake seems to be younger than 2,000-1,000 y.B.P.

The thickness of the snow cover is not uniform in the mire due to the wind and the occurrence of microtopographies such as bank and hollow complex. The frost penetrates deeply into the earth in winter only where the snow cover is thin. When the peat cover protects the winter frost underground from the summer heat, the permafrost occurs. The surface of the mire begins to rise due to the ice segregation and becomes drier. An experimental study of the formation of palsas (Seppälä, 1982) indicates that, after the first winter, the surface of the experimental site which was cleared of snow heaved some 10 cm above the surrounding level of the bog, and the grass (*Carex* and *Eriophorum*) on the surface died. Palsa A is thought to be in such an initial stage of development. The peat surface becomes drier than the surrounding surface and the death of *Carex* and the invasion of young *Pinus pumila* occurs.

2) mature and collapsing stages

As a result of the repetition of the same process year by year, the palsa grows gradually by the expansion of segregated ice. The growth of palsa caused the occurrence of cracks on the peat surface, which, however, does not mean directly the thawing of frozen core, because a remarkable thawing does not occur below the cracks.

Subsequently the palsa reaches the mature stage and enters to the collapsing stage. Palsa B is thought to be in a stage soon after the mature one or in an early collapsing stage. The decay of palsa is primarily resulted from the thawing of frozen core, which is mainly caused by the palsa development itself (Lundqvist, 1969; Seppälä, 1982; Friedman et al., 1971). With the growth of palsa, the surface becomes further exposed out of the snow cover and susceptible to wind erosion. In addition to this, at the edges of palsa, peat blocks collapse along the cracks and the surface slides of peat occur. Such a decrease of peat cover consequently leads to a deeper penetration of summer heat, which accelerates the thawing of frozen core. Moreover, the growth of palsa affects the distribution of snow depth around it. In the lee side of palsa, snow is piled more than before, so that in winter the frost cannot penetrate into the earth as deep as before, while in summer it thaws out completely. The penetration of water with high thermal conductivity causes the thawing of frozen core. In this respect, the occurrence of the crack on the peat surface and the thermokarst depression with standing water around the palsa further accelerates the thawing of frozen core which leads finally to the palsa collapse. Gravel which comes up into a peat layer and often scatters on the peat surface of Palsas B and C indicates a result of decay of peat cover and the penetration of active layer into the sandy-gravelly silt layer underneath.

Palsa C seems to be in a further collapsing stage. Most of the peat cover of the palsa are less than 60 cm thick, so that the active layer penetrates widely into the sandy-gravelly silt layer and much gravel is heaved into the peat layer by upfreezing. Some gravels appear on the peat surface. The expansion of the thermokarst depression at the east of palsa was verified on the air photographs since 1955.

The thermokarst depression with standing water occurred after the disappearance of Palsa D (Figure 34). This corresponds to the last stage of palsa development.

It takes several years to several millennia for the palsa formation (Karte,1983). According to Seppälä (1981), young palsas are rising at first by 10-20 cm annually and the mature palsas may stay 500-2,000 years at their maximum height. On the basis of the age

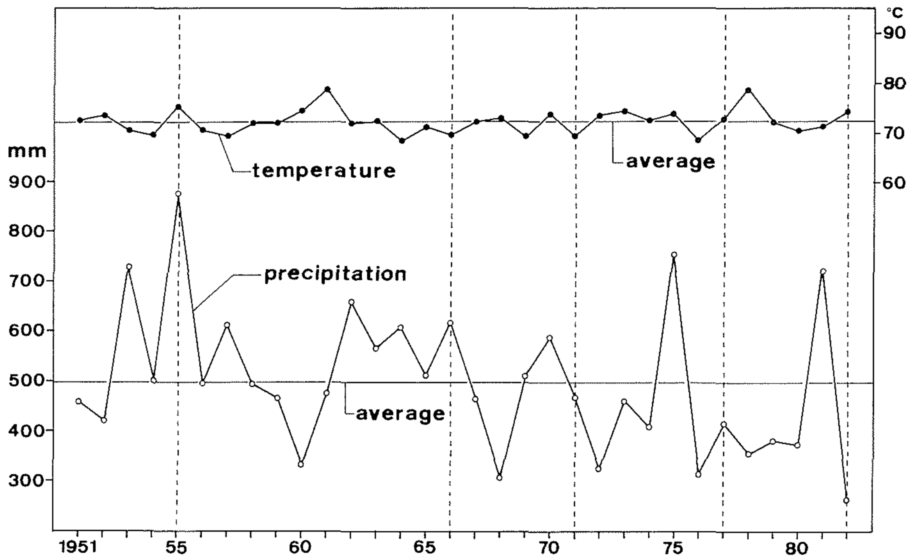

Figure 35 Accumulated mean monthly temperatures and precipitation at Asahikawa in summer (June-September) during the period of 1951-1982.
Broken lines show the years when air-photos were taken.

of ash layer overlain by peat, Kershaw and Gill (1979) inferred that the palsa and peat plateau complex in the Macmillan Pass, Canada, were formed since 1,220 y.B.P. The radiocarbon dates and the tephrochronological observation allowed to Hirakawa (1986) to infer that the development of permafrost in the bog in the central highland of Iceland started around 4,000 to 3,000 y.B.P. In the mire on the south of Hiragatake, the formation of palsas are inferred to have started around 2,000-1,000 y.B.P. Considering these ages of initiation and the time of persistence, it can be said that there have been one or a few cycles of palsa development in these mires.

5.6.4 Recent changes of palsas

Air photographs taken during the period of 1955-82 revealed that the total area of palsas in the study area was reduced by about 36% during this period. Among these palsas, Palsa D disappeared completely and was replaced by a thermokarst depression with water during a decade. The expansion by one and a half times of the thermokarst depression on the east of Palsa C indicates that the palsa decayed abruptly during a decade. A similar tendency of decay of palsas has been reported in Macmillan Pass and the north of Lake Winnipeg, Canada (Kershaw and Gill, 1979; Thie, 1974), and in Iceland (Thorarinsson, 1951). Such a decay of palsas is probably caused by regional climatic amelioration (Kershaw and Gill, 1979).

Air temperature and precipitation in summer mostly affect the thawing of permafrost. Figure 35 shows accumulated air temperature and precipitation in summer (from June to September) during the period of 1951-82 at Asahikawa, about 45 km WNW of the study area. Comparatively high air temperature and/or precipitation were recorded in the periods of 1955-66, 1971-77 and 1977-82, when the conspicuous reduction in total area of palsas (17.2%, 9.4% and 8.2% respectively) occurred. However, the period of 1966-71, with the areal reduction of only 1.4 %, shows a relatively low air temperature and precipitation. Therefore. also in the study area, the decay of palsas appears to be related to the change of regional climatic conditions, although the change of the snow cover conditions in winter has never been known during the periods mentioned above.

5.7 Conclusion

At present, palsas are found only in the mire on the south of Hiragatake in the Daisetsuzan Mountains. As far as the condition of air temperature is concerned, there is a possibility that palsas occur in other mires as well, but thick snow cover seems to prevent the occurrence of palsas in the mire except the studied one.

The sequence of palsa development in the study area was in harmony with that shown in the previous studies on palsas in the world. In general, the causes of decay of each palsa are to be found within the palsa itself, whereas a tendency of decay of many palsas is probably caused by a regional climatic amelioration. It is interesting that during the last several decades such tendency has occurred almost synchronously in several regions in the world. In order to examine the effect of regional climatic changes on the palsa sequence, the present environmental conditions surrounding palsas in each region must be clarified not only qualitatively but quantitatively.

6. Concluding Remarks

6.1 Topographic factors of mire development

In the Daisetsuzan Mountains, there is a difference in origin of mires between below and above the timber line.

The occurrence of the mires below the timber line was controlled by topographic factors, related to volcanic activities and landslides. They cause the destruction of forest vegetation and the unstabilization of slopes, although they provide a favorable topographic conditions for mire development, such as flat lava plateau or depressions in the landslide area.

In the landslide area, represented by the Midorinonuma mire, the pollen diagram and the sequence of mire deposit reflect the process of forest recovery and stabilization of slopes around the mire after the occurrence of landslide. The age (about 1,300 y.B.P.) of the transition from a pioneer vegetation (*Betula*) to a climax vegètation (*Picea*) coincides with that from the mineral deposit indicating an unstable slope condition around the mire to the peat deposit indicating a stable one. Although there are many mires around the Midorinonuma, their sequence of development is different each other according to a different topographic condition around each mire.

The Tennyogahara mire, on the western slope of Asahidake, at an altitude of 1,390 m, is inferred to have occurred around 600-500 y.B.P. resulting from a volcanic activity of Asahidake (Katsui et al., 1979).

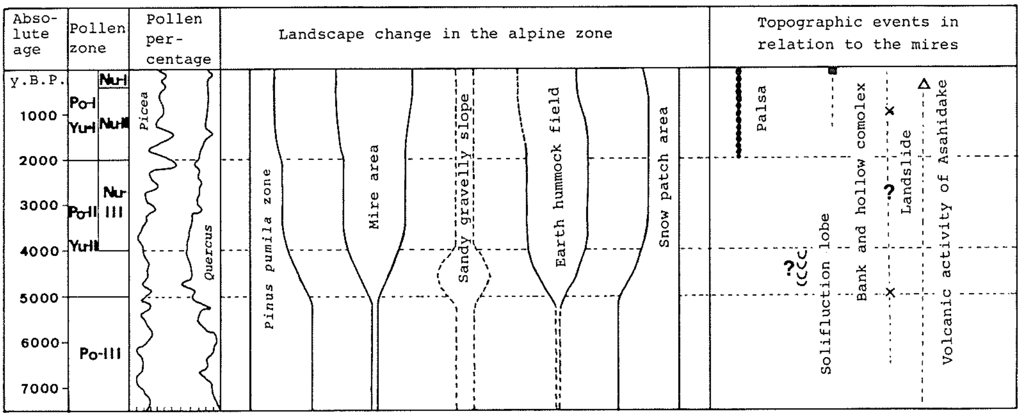

Figure 36 Fluctuation of pollen percentages of *Picea* and *Quercus,* landscape change in the alpine zone and topographic events in relation to the mires.

6.2 Climatic factors of mire development and environmental changes in the alpine zone of the Daisetsuzan Mountains

On the other hand, the occurrence of mires in the alpine zone was controlled by climatic factors. The space occupied by mires expanded through Holocene time, following the changes of the position of timber line, the extents of *Pinus pumila* community and snow patches.

The environmental changes in the alpine zone and its surroundings during the past 7, 500 years are summarized as follows (Figure 36):

1) 7,500-5,000 y.B.P.

Above the timber line of the Daisetsuzan Mountains, the mire formation in this period seems to have been almost limited to the slope on the east of Ponchubetsudake. However, this indicates that there was already a favorable climatic condition for the mire formation on the Daisetsuzan Mountains.

According to the pollen analysis of the deposit in the mire on the east of Ponchubetsudake, the climatic amelioration of the postglacial age did not affect the vegetation in the Daisetsuzan Mountains significantly until about 5,000 y.B.P. A frequent change of the ratio of *Picea* and *Quercus* in pollen diagram suggests an unstable climatic condition. During this time, the timber line did not probably reach its maximum height, and the upper slope is considered to have been still covered widely with boulders or rock fragments which had been produced by periglacial processes during the last glacial time. Accordingly, it was not easy for the forest vegetation to spread onto the upper slope, even if the slope became potentially a forest zone. As Okitsu (1985) indicated, only *Pinus pumila* could invade into such periglacial debris slopes. Therefore, *Pinus pumila* community likely occupied an extensive area above the timber line. The high percentage of its ratio in pollen diagram (Figure 20) supports this idea. In the mire on the east of Ponchubetsudake, many ponds with *Menyanthes* were scattered among the alpine meadow, composed of Rosaceae, *Artemisia,* Carduoideae, *Epilobium,* monolete type pteridophyta, etc. (Figure 20).

2) around 5,000-4,000 y.B.P.

The formation of mires gradually started as indicated by ^{14}C data from the Yutomuraushi mire (Table 4).

The dominance of *Quercus* which corresponds to the decrease in *Picea,* shown in the pollen diagrams of the mire on the east of Ponchubetsudake (Figure 20) and the Yutomuraushi mire (Figure 21), indicates that the effect of the climatic amelioration became remarkable. It led to the rising of the timber line up to the maximum height.

In the Ozegahara mire in the northern Kanto district, the forest zone in the postglacial warm period is inferred to have been at least by 300-500 m higher than at present (Nakamura, 1967). In Naebayama in the same district, the upper limit of *Fagus* forest is inferred to have been by 360 m higher at 3,000 y.B.P. than at present (Kaji, 1982). When the timber line in the Daisetsuzan Mountains rose up by 300 m higher than at present, the alpine zone would be reduced to about 20 % of the present area and be restricted to around Asahidake and Ohachidaira in the northern part and around Tomuraushiyama in the southern part (Figure 37). In this case, the major distribution area of mires, including the mire on the east of Ponchubetsudake, would be below the timber line.

The difference in elevation between the sampling point of peat for ^{14}C dating in the mire on the east of Ponchubetsudake and the surrounding present timber line is about 100 m. When the timber line rose up 100 m higher, the alpine zone would be reduced to about 63 %. In this case, not only the mire on the east of Ponchubetsudake but also the mires on Takanegahara and the upper parts of the Koganegahara and the Goshikigahara mires would be involved within the alpine zone (Figure 37). The pollen diagram (Figure 20) indicates that in the alpine zone, *Pinus pumila* community decreased but was still presented in this age. According to Okitsu (1985), even if the high mountain areas are forest zone under thermal condition, the areas become deforested by strong winds and heavy snows in winter, and finally *Pinus pumila* community extends there and forms the *P. pumila* zone. Taking this idea into consideration, it may be inferred that the timber line of the Daisetsuzan Mountains in the postglacial warm period did not rise up to the top of main ridge, and that the area above the timber line was mainly occupied by *Pinus pumila,* snow patches and wind-blown debris slope.

In the alpine zone, the area of *Pinus pumila* decreased conspicuously, while Cyperaceae increased remarkably around the mire on the east of Ponchubetsudake and the Yutomuraushi mire. At present, Cyperaceae often grows on the earth hummocks in the alpine zone, which are developed mainly in front of the snow patches where the ground surface is freed from the snow cover by mid to last June. Therefore, the increase in Cyperaceae suggests that the snow melting season became earlier, and the area of the snow patches was reduced leading to the expansion of the earth hummock field. This is in harmony with the climatic amelioration.

3) 4,000-2,000 y.B.P.

Many mires, including the Numanohara mire (Table 4), began to develop in the alpine zone.

The increase in *Picea* and the decrease in *Quercus* (Figures 20, 21 and 22) suggest that the climate became cooler and the elevation of the timber line was lower than the previous

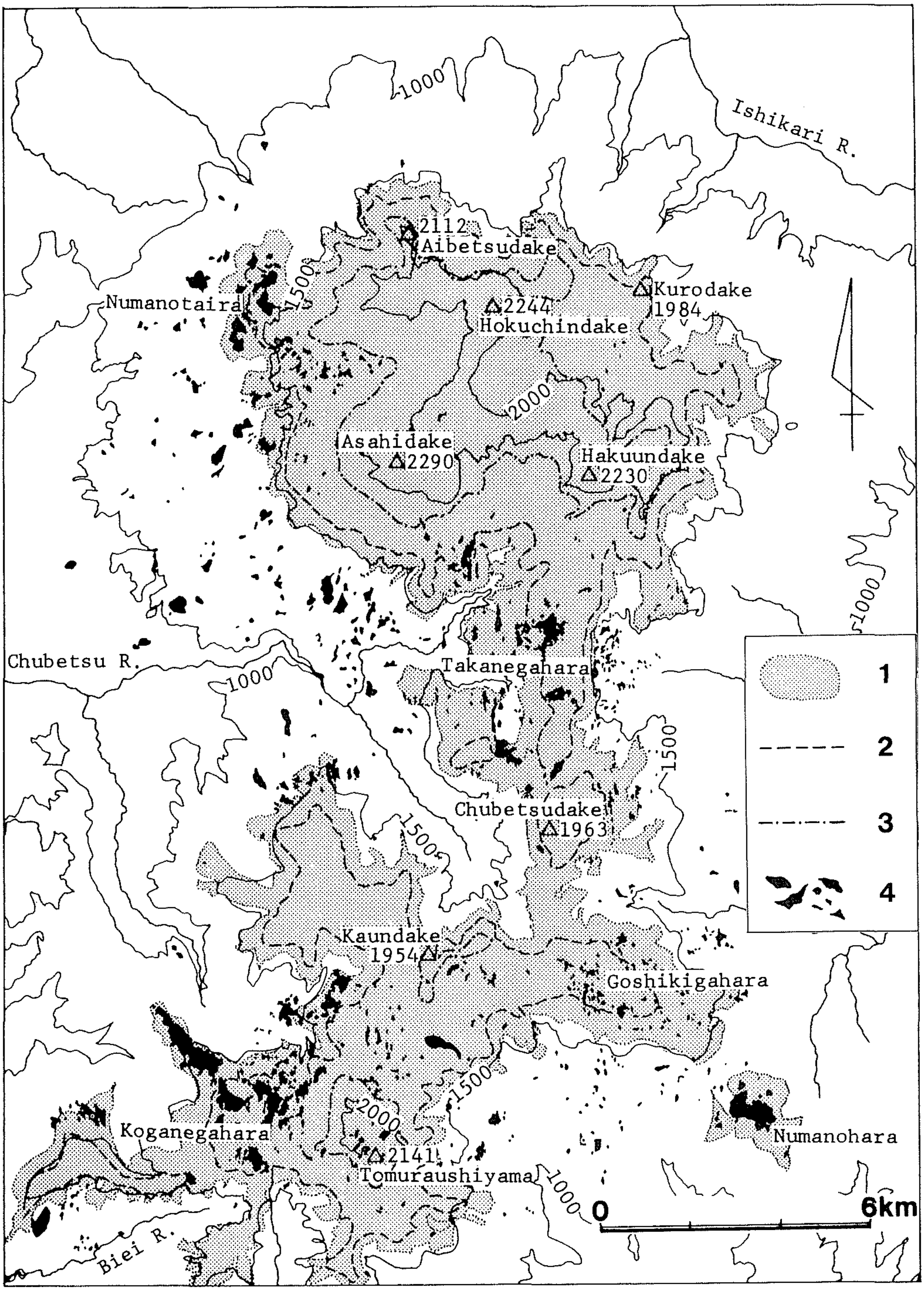

Figure 37 Distribution of mires, present alpine zone and estimated timber lines.
1 : present alpine zone, 2 : timber line 100 m higher than at present, 3 : timber line 300 m higher than at present, 4 : mires.

period. In the alpine zone, *Pinus* decreased further and Cyperaceae became dominant. These facts indicate a further reduction in *Pinus pumila* zone and the snow patches, which probably led to the expansion of the space for development of mires and earth hummock fields.

According to Okitsu and Ito (1983), *Pinus pumila* community exists where the snow depth ranges from about 30 to 300 cm. The prevailing westerly wind in winter affects the variation in the cover and height of *Pinus pumila* community. If the snow depth, covering *Pinus pumila* community in winter, becomes less than 30 cm, it will die by exposing to the blowing wind and the coldness. If *Pinus pumila* community in a critical condition, such as that on a windward slope of Takanegahara, dies, it is likely replaced by the mire where there is a favorable hydrological condition for water supply. However, the cause of the reduction in snow depth is unknown, and it must be studied in future.

4) after 2,000 y.B.P.

Around 2,000 y.B.P. the climate became coolest throughout the last 7,500 years.

Since 2,000 y.B.P., a cool climatic condition has been kept, but the pollen diagrams from the Numanohara and the Yutomuraushi mires (Figures 21 and 22) indicate a slightly warmer climate for the last several hundreds years. In the alpine zone, Cyperaceae decreased for a while, but a remarkable change of vegetation did not occur. The unhumified peat in the Numanohara mire (Figure 16) suggests that the climate became wetter than in the previous time.

6.3 The age of mire formation

Based on the result of ^{14}C datings, the ages of the onsets of peat accumulation in the Daisetsuzan Mountains except in the landslide area are grouped into about 7,500 and 4,600 -3,600 y.B.P. (Table 4). Koizumi (1982) pointed out that, in Honshu, the onsets of peat accumulation in the mountain oligotrophic bogs center in 12,000-7,000 and 4,100-3,300 y.B.P. He attributes the peat accumulation of the former age to the heavy snowfall and that of the latter to the delay of snow melting caused by a little lowering of the air temperature. The ages of peat accumulation of the study area almost coincide with those of Honshu. However, they are 500-300 years earlier than them. Furthermore, the peat in the Daisetsuzan Mountains has continued to accumulate since 4,600-3,600 y.B.P., while the peat bogs in Honshu are buried at present. This difference can be explained by the difference in the climatic conditions between Hokkaido and Honshu: the peat accumulation in the Daisetsuzan Mountains continued under a cooler climatic condition even after 2,000 y.B.P., while that in Honshu was ceased by a slight climatic amelioration.

6.4 Development of bank (Kermi) and hollow (Schlenke) complex

The geomorphological studies on the bank and hollow complex in the Daisetsuzan Mountains revealed that it was originated from solifluction lobes. Many sections (Figures 25-29) proved that solifluction lobes were formed before the beginning of peat accumulation. Although the age of the formation of solifluction lobes could not be determined, the author pointed out the possibility that the solifluction lobes were formed around 5,000 - 4,000 y.B.P.

However, the intercalated ash layers in the peat deposit indicated that some bank and hollow complexes were originated by slide-type mass movement of peat layer after 200 y. B.P.

6.5 Significance of palsa

The discovery of palsas indicates that a permafrost occurs at an altitude of 1,720 m in the Daisetsuzan Mountains. Most of palsas (Figure 30) are in round or elliptic shapes with flat upper surface. They range in height from about 0.2 to 1 m and up to 80 m in diameter. The frozen cores are situated in the silty layer overlain by peat (Figures 31, 32 and 33).

The occurrence of palsa requires a thinner or no snow cover, a peat cover and a low -temperature condition in the discontinuous permafrost zone. In the palsa mire of the Daisetsuzan Mountains, the mean annual air temperature is estimated about $-2^{\circ}C$; most of snow is blown away by the strong westerly wind in winter; and peat layer is generally about 1 m thick. The existence of palsas of different stages of development (Figures 31, 32 and 33) supports the concept of their cyclic development. An individual palsa grows up by the aggradation of permafrost and decays itself without any change of climate. However, judging from the meteorological data at Asahikawa (Figure 35), whole tendency of the decay of palsas in the mire during the period of 1955-82 (Figure 34, Table 5) seems to be due to a regional climatic amelioration. A peat cover of more than 60 cm thick is necessary for growth and persistence of the permafrost core which leads to the growth of palsas. According to the common rate of peat accumulation (0.2-0.3 mm/year) above the timber line of the Daisetsuzan Mountains, it takes about 2,000-3,000 years for the peat accumulation of 60 cm thick. The formation of palsas in the Daisetsuzan Mountains, therefore, most likely began at about 2,000 y.B.P. with a climatic deterioration after the warmest period in Holocene.

Acknowledgments

The author wishes to thank to Prof. Yugo Ono, Graduate School of Environmental Science, Hokkaido University, for his useful suggestions and revision of the manuscript. He is also indebted to the other staffs of Graduated School of Environmental Science, Hokkaido University for their friendly advices and encouragements. Gratitude is also expressed to Mr. Toshio Sone, Graduate School of Environmental Science, Hokkaido University, for his great help both in the field and discussion. He also thanks to Dr. Yaeko Igarashi, Department of Geology and Mineralogy, Hokkaido University, for her pollen analysis and kind cooperation, and to the members of Hakuun hut in the Daisetsuzan Mountains, especially to Mr. Yasuyuki Watanabe and Mr. Nobuki Yasuda, Curator of the Sounkyo Museum, for their friendly encouragements.

Finally, the author must not forget the constant encouragements and kind advices of Prof. Hiroshi Kadomura, Department of Geography, Tokyo Metropolitan University, a former professor of Graduate School of Environmental Science, Hokkaido University.

References

Åhman, R. (1976). The structure and morphology of minerogenic palsas in northern Norway. *Biul. Perygli.,* 26: 25−31.

Åhman, R. (1977). Palsar: Nordnorge. Medd. Lunds Univ., Geogr. Inst., 78, 165pp.

Brown, R.J.E. (1974). Some aspect of airphoto interpretation of permafrost in Canada. National Research Council of Canada, Division of Building Research, Technical Paper, 409, 20pp.

Collins, E.I., Lichvar, R.W. and Evert, E.F. (1984). Distribution of the only known fen-palsa in the contiguous United States. *Arctic and Alpine Research,* 16: 255−258.

Dionne, J.-C. (1978). Formes et phenomenes periglaciaires en Jamesie, Quebec subarctique. *Geogr. Phs. Quat.,* 32: 187−247.

Friedman, J.D., Johansson, C.E., Oskarsson, N., Svensson, H., Thorarinsson, S. and Williams, R.S.Jr. (1971). observations on Icelandic polygon surfaces and palsa areas. Photo interpretation and field studies. *Geogr. Ann.,* 53A: 115−145.

Fukuda, M. and Kinoshita, S.(1974). Permafrost at Mt. Taisetsu, Hokkaido and its climatic environment. *The Quaternary Research,* 12: 192−202. (JE)

Higuchi, K. and Fujii, Y. (1971). Permafrost at the summit of Mount Fuji, Japan. *Nature,* 230: 521.

Hirakawa, K. (1986). Development of palsa bog in central highland, Iceland. *Geogr. Rep. Tokyo Metropolitan Univ.,* 21: 111−122.

Igarashi, Y. and Fujiwara, K. (1984). Pollen analysis of upland bog deposits in the Teshio Mountains, northern Hokkaido. *The Quaternary Research,* 23: 213−218. (J)

Igarashi, Y. and Kumano, S. (1981). Vegetational changes during the last glacial age in Hokkaido. *The Quaternary Research,* 20: 129−141. (J)

Igarashi, Y. and Takahashi, N. (1985). Origin and vegetational succession of upland bogs in the Daisetsuzan Mountains, central Hokkaido (I). *The Quaternary Research,* 24: 99−109. (JE)

Ito, K. and Sato, K. (1981). Explanatory notes for actual vegetation map of the Daisetsuzan Mountains. Synthetic survey of the Daisetsuzan Mountains, Hokkaido, 23pp. (J)

Kaizuka, S. (1986). Mountainous country, Japan. in "Mountains of Japan" Kaizuka, S. and Chinzei,K. eds. . 1−27. Iwanamishoten, Tokyo.

Kaji, M. (1982). Studies on the ecological geography of subalpine conifers ——Distribution pattern of *Abies mariesii* in relation to the effect of climate in the postglacial warm period——. *The Bull. the Tokyo Univ. Forests,* No.72. 31−120. (JE)

Kanauchi, A. (1987). Pollen analysis of deposits in Kinu bog. *The Quaternary Research,* 26: 147−153. (J)

Karte, J. (1983). Periglacial phenomena and their significance as climatic and edaphic indicators. *Geo-Journal,* 7: 329−340.

Katsui, Y., Igarashi, Y., Gouchi, N., Johnson, K., Ikeda, T. and Ohse, N.(1985). Geology of the Onnebetsu-dake wilderness area and its environs, Shiretoko Peninsula, east Hokkaido. Conservation Rep. the Onnebetsu-dake Wilderness Area, Hokkaido,Japan, Nature Conservation Bureau, Environment Agency, Japan, 37−64. (JE)

Katsui, Y and Ito, T. (1975). Ohachi-daira caldera of the Daisetsuzan, central Hokkaido. *Bull. Volcanol. Soc. Japan,* Second Ser., 20: 113. (J)

Katsui, Y., Yokoyama, I. and Ito, T. (1979). Asahidake —— its volcanic geology, present state of activity and prevention of disaster. Committee for Prevention of Disaster of Hokkaido, Sapporo, 42pp. (J)

Kershaw, G.P. and Gill, D. (1979). Growth and decay of palsas and peat plateaus in the Macmillan Pass − Tsichu River area, Northwest Territories, Canada. *Can. J. Earth Sci.,* 16: 1362−1374.

Koaze, T., Nogami, M. and Endo, R. (1975). Ground temperature observation on the huge-scale polygons in the Daisetsuzan Mountains. *The Quaternary Research,* 14: 169−170. (J)

Koizumi, T. (1982). Increase in snowfall since Late Glacial Age in the mountainous region of Japan, viewed from fossil periglacial slopes, nivation hollows and mountain oligotrophic bogs. *The Quaternary Research,* 21: 245−253. (J)

Konoya, M., Kobayashi, T., Kim, C. and Kawachi, S. (1968). Geological Map of Japan "Asahidake" (1:50, 000). Hokkaido Development Agency. (JE)

Konoya, M., Matsui, K., Kawachi, S. and Kobayashi, T. (1966). Geological Map of Japan "Taisetsuzan" (1: 50,000). Hokkaido Development Agency. (JE)

Lundqvist, J. (1962). Patterned ground and related frost phenomena in Sweden. Sveriges Geol. Undersokning, ser. C583, 101pp.

Lundqvist, J. (1969). Earth and ice mounds: A terminological discussion. in "The Periglacial Environment" Péwé, T.L. ed. 203−215. McGill-Queen's Univ. Press. Montreal.

Miyagi, T., Morita, Y. and Daimaru, H. (1987). Environmental change of the Uryunuma mire in the Holocene. in "Changes in environments and geomorphological and hydrological characteristics of cold district in the Holocene" Kadomura,H. ed.. 31−42. (J)

Morita, Y. (1984a). The vegetational history of the subalpine zone in northeast Japan, I. The Azuma Mountains. *Jap. J. Ecol.,* 34: 347−356. (JE)

Morita, Y. (1984b). The relationship between the modern pollen spectra and vegetation on the subalpine zone in northeast Japan. *The Quaternary Research,* 23: 197−208. (JE)

Morita, Y.(1985). Palynological study of the deposits from the Uryu-Numa in Mt.Shokanbetsu, Hokkaido. *Ann. Tohoku Geogr. Assoc.,* 37: 166−172. (JE)

Morita, Y and Aizawa, S. (1986). Pollen-analytical study on the vegetational history of the subalpine zone in the northern Tohoku District. *Ann. Tohoku Geogr. Assoc.,* 38: 24−31. (JE)

Nakamura, J.(1967). "Pollen analysis". 232pp. Kokonshoin. Tokyo. (J)

Nakamura, J. (1968). Palynological aspects of the Quaternary in Hokkaido. V. —— Pollen succession and climatic change since the upper Pleistocene ——, *Res. Rep. The Kochi Univ.,* 17: 1− 13. (JE)

Okitsu, S. and Ito, K. (1983). Dynamic ecology of *Pinus pumila* community of Mts. Taisetsu, Hokkaido, Japan. *The Environmental Science, Hokkaido Univ.,* 6: 151−184. (JE)

Okitsu, S. (1985). Consideration on vegetation zonation based on the establishment process of a *Pinus pumila* zone in Hokkaido, northern Japan. *Jap. J. Ecol.,* 35: 113−121. (JE)

Ono, Y, Hirakawa, K. and Iwata, S. (1982). Meeting and field excursion of the International Geographical Union Co-Ordinating Committee for Periglacial Research, Hokkaido, Japan, August 1980. *Arctic and Alpine Research,* 14: 162−172.

Sakaguchi, Y. (1954). Uber die Entwicklungsgeschichte des Ozegahara-Moores. Scientific Report of the Ozegahara Moor, 45−67. (J)

Sakaguchi, Y. (1959). Old peat layers occurred in the Ozegahara Basin. *The Quaternary Research,* 1:155−164. (JE)

Sakaguchi, Y. (1974). "Geology of Peatland". 329pp. The University of Tokyo Press. Tokyo. (J)

Sakaguchi, Y. (1976). Characteristics of Ozegahara deposits and climatic changes since lateglacial in central Japan. Bull. Depart. Geogr. Univ. Tokyo, No.8, 1−24.

Sakaguchi, Y. (1979). Distribution and genesis of Japanese peatlands. *Bull. Dept. Geogr. Univ. Tokyo,* 11: 17−42.

Sakaguchi, Y. (1980). On the genesis of banks and hollows in peat bogs —— An explanation by a thatch line theory ——. *Bull. Dept. Geogr. Univ. Tokyo,* 12: 35−58.

Sakaguchi, Y. (1985). Some aspects of geology of peatlands. *Transactions Japanese Geomorphological Union,* 6: 333−350. (JE)

Sakaguchi, Y., Arai, F. and and Sohma, H. (1982a). On deposits of the Ozegahara basin —— A contribution to late Quaternary evolution of the largest raised bog in Japan and its paleoenvironment. in "Ozegahara, Scientific Researches of the Highmoor in Central Japan" Hara et al. eds. . 31−46.

Sakaguchi, Y., Saijo, Y., Yagi, A., Hibino, M. and Sohma, H. (1982b). Characteristics of deposits and genesis of pools. in "Ozegahara, Scientific Researches of the Highmoor in Central Japan" Hara et al. eds. . 75–90.

Sakaguchi, Y. and Sohma, H. (1982). Characteristics of bank and hollow complexes in the Ozegahara moor. in "Ozegahara, Scientific Researches of the Highmoor in Central Japan" Hara et al. eds. . 31–46.

Salmi, M. (1968). Development of palsas in Finnish Lapland. International Peat Congress, 3rd, Proc., 182–189.

Seppälä, M. (1972). The term 'palsa'. *Zeitsch. Geomorph., N.F.,* 16: 463.

Seppälä, M. (1976). Seasonal thawing of a palsa at Enontekio Finnish Lapland,in 1974. *Biul. Perygl.,* 29: 232–243.

Seppälä, M. (1981). Present-day periglacial phenomena in northern Finland. *Biul. Perygl.,* 29: 232–243.

Seppälä, M. (1982). An experimental study of the formation of palsas. in "Proceedings of the Fourth Canadian Permafrost Conference (The Roger J.E.Brown memorial volume)" French,H.M. ed. . 36–42. National Research of Canada. Ottawa.

Sohma, H. (1984). Changes in stability of mountain slopes of Yakushima Island analyzed by variation of inorganic content in peat deposits. *J. Geogr.,* 93: 25–35. (JE)

Sohma, H.(1985). Changes in natural environments in the Shiretoko Peninsula analyzed by deposits of peat bog. Conservation Rep. the Onnebetsu–dake Wilderness Area, Hokkaido, Japan, Nature Conservation Bureau, Environment Agency, Japan, 91–112. (JE)

Sone, T. and Takahashi, N. (1986). Winter field observation of the frost-fissure polygons on Hokkai-daira plateau, Daisetsu Volcanic Massif, Hokkaido. *Geogr. Rev. Japan,* 59: 654–663. (JE)

Sone, T., Takahashi, N. and Takahashi, H. (1987). Climatic environment and periglacial phenomena of the Daisetsuzan Mountains, Hokkaido, Japan. *Abstracts of the Annual Meeting of the Association of Japanese Geographers,* 31: 2–3. (J)

Sone, T., Takahashi, N. and Fukuda, M. (1988). Alpine permafrost occurrence at Mt. Taisetsu, central Hokkaido, in northern Japan. Proceedings of First International Conference on Permafrost, 1:253–258.

Svensson, H. (1976). Pingo problem in the Scandinavian countries. *Biul. Perygl.,* 26: 33–40.

Takahashi, N. (1983). Landslides around Takanegahara in the Daisetsuzan Mountains, Hokkaido, Japan. Abstracts of the *Annual Meeting of the Association of Japanese Geographers,* 24: 88–89. (J)

Takahashi, N. (1987). On the microtopography of upland bogs in the Daisetsuzan Mountains, Hokkaido. *Ann. Tohoku Geogr. Assoc.,* 37: 166–172. (JE)

Takahashi, N. and Igarashi, Y. (1986). Origin and vegetational succession of upland bogs in the Daisetsuzan Mountains, central Hokkaido (II). *The Quaternary Research,* 25: 113–128. (JE)

Thie, J. (1974). Distribution and thawing of permafrost in the southern part of the discontinuous permafrost zone in Manitoba. *Arctic,* 27: 189–200.

Thorarinsson, S. (1951). Note on patterned ground in Iceland. *Geogr. Annalar,* 33: 144–156.

Wakahama, G., Endo, Y., Yamada, T., Ushiki, H. and Naruse, R. (1968). Studies of firn on Mt. Daisetsu in summer, III. *Low Temperature Science,* 26: 215–235. (JE)

Wakahama, G., Shimizu, H., Akitaya, E., Narita, H., Tanuma, K., Yamada, T., Naruse, R., Kitahara, T., Sato, N., Ishikawa, N. and Kawamura, T. (1969). Studies of firn on Mt. Daisetsu in summer, IV. *Low Temperature Science,* 27: 181–196. (JE)

Washburn, A.L. (1979). "Geocryology. A survey of periglacial processes and environments". 406pp. Arnold. London.

Washburn, A.L. (1983a). What is a palsa?. in "Mesoformen des heutigen Periglazialraumes (Geomorphologisches Symposium, Kehr bei Göttingen, 1982), Proceedings, Göttingen Akademie der Wissenschaften" Poser,H. ed. . 34–47.

Washburn, A.L. (1983b). Palsas and continuous permafrost. Proceedings of the Fourth International Conference on Permafrost, 1372–1377. National Academy of Sciences Press, Washington, D.C.

Yamada, T. (1982). Studies on accumulation-ablation processes and distribution of snow in mountain regions, Hokkaido. *Low Temperature Science,* 31: 1−33.

Yamanaka, M. (1977). Palynological studies of Quaternary sediments in Northeast Japan. I.Gozaisho -Numa moor in the Hachimantai Mountains. *Ecol. Rev.,* 18: 251−262.

Yamanaka, M. (1978). Vegetational history since the Late Pleistocene in Northeast Japan. I.Comparative studies of the pollen diagrams in the Hakkoda Mountains. *Ecol. Rev.,* 19: 271−276.

Yoshii, R. and Fujii, S. (1981). Palynological study of the bog deposits from the Midagahala Plateau, Mt. Tateyama in Toyama prefecture, central Japan (preliminary report). *J. Phytogeogr. Taxonomy,* 29: 40−50. (JE)

Zoltai, S.C. and Tarnocai, C. (1971). Properties of a wooded palsa in northern Manitoba, *Arctic and Alpine Research,* 3: 115−129.

(J) : in Japanese

(JE) : in Japanese with English abstract