PERMAFROST ENVIRONMENT DURING THE LAST GLACIAL IN EAST AND NORTH HOKKAIDO, NORTHERNMOST JAPAN

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Abstract Permafrost environment during the Last Glacial in East and North Hokkaido was examined on the basis of monthly air temperature, the freezing and thawing indicies, and ice wedge casts, comparing them with fossil pollen evidence. The assumed annual mean temperature -8°C is in great disagreement with field evidence in East Hokkaido. The annual mean temperature *ca.* -2°C appears to be more reasonable. Continuous permafrost environment seems to have never occurred in East and North Hokkaido, or northernmost Japan, but discontinuous permafrost under the forest tundra occurred even in the coldest period of the Last Glacial. Ice wedge polygons could be formed under the discontinuous permafrost environment with extraordinarily cold winter, which characterized the climate of northernmost Japan.

Key words: permafrost environment, periglacial phenomena, pollen analysis, freezing and thawing indicies, forest tundra

1. Introduction

It is well known that there should be a close relationship between periglacial phenomena, particularly those relating to the permafrost, and climatic parameters. Therefore fossil periglacial phenomena in the Tokachi Plain and the Konsen Plain, East Hokkaido, northernmost Japan, have been always discussed in the last *ca.* 20 years for the reconstruction of the past environment during the Last Glacial in Japan. They contribute, in fact, to our understanding of the environment in the Last Glacial. However, interpretation of past environment using fossil periglacial phenomena will inevitably be speculative, as stressed by Williams (1975). Extreme caution is required in the reconstruction of past environment through fossil periglacial phenomena. Consequently it is strongly desirable to compare the periglacial evidence with that derived from other method. Palynological evidence should be one of the most reliable data to aid such interpretation.

In this note, firstly palynological evidence newly obtained in the Tokachi Plain will be presented, and secondly disagreement between the past environment reconstructed through periglacial phenomena and that by pollen data will be discussed. Finally permafrost environment of the coldest period of the Last Glacial in E and N Hokkaido will be examined in relation to assumed monthly and annual mean temperatures, and to the freezing and thawing indicies.

2. Previous Views and Problems

The past environment during the Last Glacial in E and N Hokkaido was reconstructed mainly on the basis of fossil periglacial phenomena, particuarly on the basis of extraordinarily well developed involutions and finds of ice wedge casts (Koaze *et al.*, 1974a, 1974b; Nogami *et al.*, 1980). Major conclusions postulated so far are as follows:

1. A rapid climatic deterioration began about 40,000 yeras ago, and a continuous permafrost environment spread about 32,000 years ago.
2. The annual mean temperature in this coldest period is estimated to have been -6°C to -8°C, that is 12°C-14°C colder than at present.
3. A discontinuous permafrost environment had expanded during the period just after 32,000 yBP to 28,000 yBP. The annual mean temperature is estimated to have been -1°C or less.
4. Another discontinuous permafrost environment having an annual mean temperature of -1°C or less should have prevailed around 15,000 years ago.

Could the continuous permafrost environment lasting relatively short duration, presumably few thousand years, have really occurred in E and N Hokkaido? If the continuous permafrost had prevailed, how can it be explained that ice wedge casts are so scaresely found, only at 3～4 localities in the whole E and N Hokkaido? Frost susceptible tephra has extensively covered the alluvial lowland (mainly alluvial fan) in the Last Glacial.

3. Palynological Evidence

Up to now very little is known about the vegetation of the coldest period of Last Glacial in East Hokkaido. Paleovegetational reconstruction for this region, therefore, chiefly depends on the pollen data from N Hokkaido (Nakamura, 1973).

Small, but significant outcrops of peat are found at three sites in the Tokachi Plain and pollen analysis was carried out. The chronology for these sections derives from radiocarbon dates of a buried branch of tree and marker tephra layers. Peat at the site Shibusan in the western Tokachi Plain, or in eastern foot of the Hidaka Range (Fig. 1−1) is underlain by fluvial terrace gravels, and intercalates the En-a pumice layer in the uppermost horizon. In the section at Toyonishi (Fig. 1−2) in the center of the Tokachi Plain, peat is overlain by the En-a pumice layer and underlain by the Spfa-1 pumice layer. A buried tree in the middle horizon has a radiocarbon date of 26,970 ± 1,490 yBP (Gak-5649). In the section at Toyoni (Fig. 1−3) in the southern Tokachi Plain, peat is overlain by the Spfa-1 pumice layer and underlain by the TBS scoriae. Radiocarbon dates of the En-a and Spfa-1 are 15,000 ± 400 yBP and 32,000 ± 2,000 yBP, respectively (Comm. Nomencl. Deposit, Hokkaido, 1972). New radiocarbon dates for En-a indicate

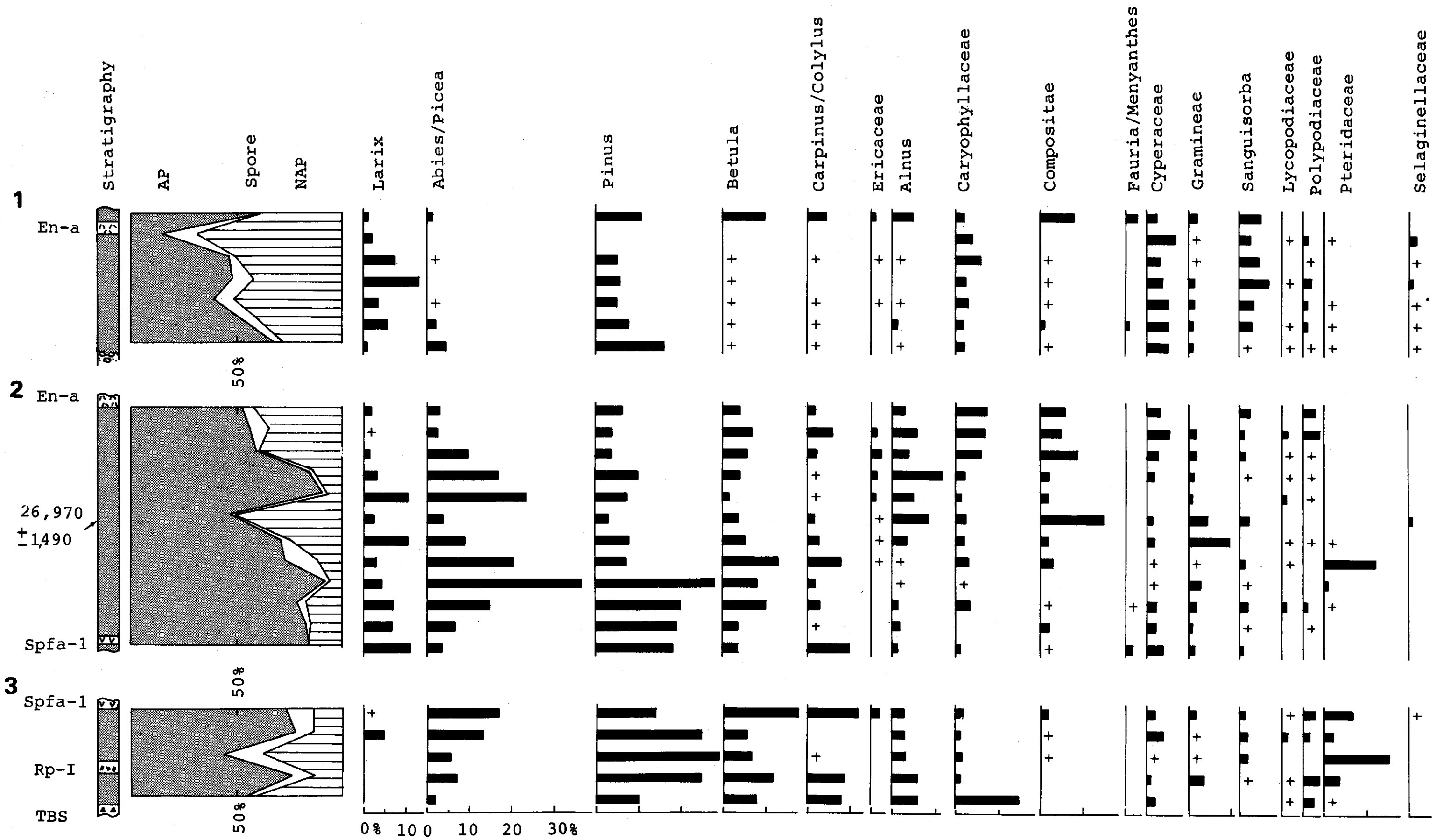

Fig. 1 Pollen diagrams for Tokachi Plain, east Hokkaido
1: Shibusan; 2: Toyonishi; 3: Toyoni; +: <1 %

16,000～19,000 yBP (Umezu, 1987). The lowest horizon indicated by the TBS scoriae is estimated to have a date *ca.* 40,000 yBP. Accordingly these three sections cover the period from *ca.* 40,000 yBP to 16,000 yBP.

Pollen analysis of these peat yealds significant information concerning the vegetation of the Last Glacial including the coldest period. Stratigraphic relations of the pollen and spores are diagrammed in Fig. 1. All percentage values are based on the sum of arboreal (AP) pollen, nonarboreal (NAP) pollen and spores.

Significant facts for the comparizon with periglacial evidence are recognized. General description of these pollen diagrams including pollen zonation will be made in the other oppotunity. The information to be noted is as follows:

1. It should be noted, as a whole, that total AP pollen comprises high value of more than 50～80 %, more than 90 % in two horizons (Fig. 1－2). These pollen grains are mostly composed of a combination of *Abies/Picea, Pinus, Larix and Betula.*
2. In particular, the section 3 having dates from *ca.* 40,000 yBP to 32,000 yBP is characterized by high value of AP pollen such as *Abies/Picea, Pinus, Betula, Carpinus/Corylus* and *Alnus.* Similar pollen assembladge is reported from southern Tokachi Plain by Tokachi Research Group (1978). It must be noted that this period was thought to have been coldest under the continuous permafrost environment, on the basis of the finds of ice wedge casts.
3. In the section 1 (Fig. 1－1), values of AP pollen are comparatively lower representing *ca.* 40～60 per cent (including a horizon with exceptionally low value of 15 %). These AP pollen grains are composed mainly of *Pinus* and *Larix,* and are characterized by almost complete lack of *Abies/Picea* as well as *Betula.* On the other hand, NAP pollen such as Caryophyllaceae, Cyperaceae and *Sanguisorba* indicating a grassland environment reach relatively higher values. Also in the section 2 (Fig. 1－2), NAP pollen such as Caryophyllaceae, Compositae and Cyperaceae significantly increase, in contrast to the decrease of *Abies/Picea* and *Larix,* in the corresponding horizons to those in the section 1.
4. Therefore it may be said from the decrease of *Abies/Picea* in the section 2, or almost completely lack of them in the section 1 as well as from relating high NAP values that a closed conifer forest did not exist around the time of the En-a pumice (approximately 16,000～19,000 yBP). These horizons should indicate a responce to the climatic deterioration, probably the presense of forest tundra environment, as suggested by Igarashi and Kumano (1981).
5. Except for this period, relatively closed conifer forest seems to have prevailed through the Last Glacial at least since 40,000 yBP.
6. It is safely said that low herbaceous tundra vegetation which is always associated with permafrost had never prevailed during the period of *ca.* 40,000～32,000 yBP at least in E Hokkaido.

4. Examination of Past Permafrost Environment

Monthly mean temperature

As described above, Nogami *et al.* (1980) proposed that the annual mean temperature

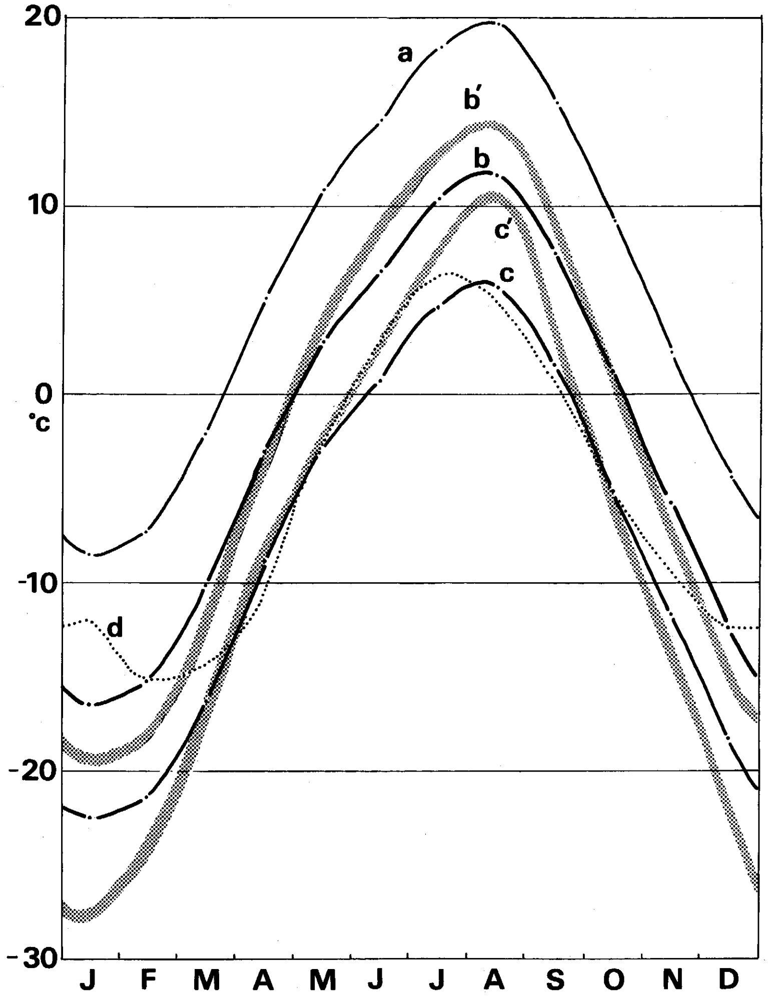

Fig. 2 Monthly temperatures for the examination of the coldest environment of the Last Glacial in east Hokkaido
Curve **a**: at present; Curve **b** and **c**: annual mean temperature -2°C and -8°C with the same range of temperature as at present, respectively; Curve **b'** and **c'**: conjectural curves of -2°C and -8°C, respectively; **d**: present monthly temperature in Longyearbyen of Svarbard as the region of active ice wedge development as well as the typical herbaceous tundra vegetation under continuous permafrost environment.

had been -6°C to -8°C in the coldest period of the Last Glacial, that is 12°C～14°C lower than at present. This interpretation depends on the finds of ice wedge casts. However, ice wedge casts were observed only at three localities in the whole E and N Hokkaido, one of which was reported in the tephra between TBS scoriae and Spfa-1 pumice layer in the

Tokachi Plain. Are these forms recognized as ice wedge casts by Koaze *et al.* (1974a, 1974b) without any doubt the fossil form of ice wedge? Why are the ice wedge casts so sparsely distributed in E and N Hokkaido, if the continuous permafrost had prevailed? How can we explain the noticeable disagreement between environmental reconstructions based on the periglacial and pollen evidence?

The present climate of the central Tokachi Plain shows mean temperature of about -7°C in winter, 17°~18°C in summer, and 6°C as annual mean. Air temperatures below 0°C are generally recorded from mid-October to early May.

Continuous permafrost environment

Curve **a** in Fig. 2 represents the present monthly mean temperature in Obihiro City, Tokachi Plain. Curve **b** and **c** are constructed assuming an annual mean temperature of -2°C (as a limit of discontinuous permafrost environment) and -8°C (as a continuous permafrost environment), and a range of temperatures now, respectively. Curve **d** (dotted line) represents the monthly mean air temperature of Longyearbyen in Svarbard, which will be used for the discussion on the relationship among vegetation, active continuous permafrost environment and climate. Svarbard is wholly covered by the continuous permafrost with the annual mean temperature of *ca.* -5°C, and lies beyond the northern forest line.

Comparing Curve **c** with Curve **d** of Svarbard as the continuous permafrost environment, temperatures in summer are very similar each other. The present vegetation of Svarbard in the condition of this summer warmth is that of an arctic tundra. The vegetation inferred from pollen data in the Tokachi Plain seems to have been mainly closed conifer forest intervening tundra forest for the short duration. Summer temperatures must have been enough high to allow the forest vegetation. Therefore the temperature of the warmest month must have attained to at least *ca.* 10°C.

The winter temperatures, on the other hand, represented by Curve **c** is already lower than that in Svarbard, where active ice wedge polygons are relatively well developed (Åkerman, 1980). Accordingly ice wedges are expected to have been so widely distributed as those at present in Svarbard , under such climatic environment with the annual mean temperature of -8°C. We have further problem to be considered in this connection. Assuming an annual mean temperature of -8°C, winter temperatures must have been lower in accordance with summer warmth mentioned above. Shadow Curve **c'** is such a conjectural curve. Climatic environment represented by Curve **c'** should be most favorite for the development of ice wedge polygons. Thus Curve **c** or **c'** is completely in disagreement with the vegetational and periglacial evidence obtained in the Tokachi Plain, not only with regard to summer temperatures, but also to winter temperatures.

Discontinuous permafrost environment

Next, Curve **b** assuming the annual mean temperature -2°C will be examined.

Summer temperatures in this condition may be enough high, 10°C or more in July and August, to allow a closed conifer forest, whereas winter temperatures are comparable with those at present in Svarbard. The degree of continentality in the Last Glacial in E and N Hokkaido is thought to have been higher than at present *(e.g.* Ono, 1984). Curve **b'** is, thus, conjecturally drawn, assuming higher and lower temperatures up to 3°C for the summer and winter temperatures, respectively.

Interestingly, even Curve **b'** still presents a sufficient environment for the formation of ice wedge polygons, as far as the present climate in Svarbard is taken into account. Consequently discontinuous permafrost environment represented by monthly mean temperature of Curve **b'** would help to explain the periglacial features as well as the pollen evidence in E and N Hokkaido.

Freezing and thawing indicies

Many attempts have been made to use the annual mean air temperature as a suitable climatic indicator. Climatic variables other than the annual mean air temperature, however, strongly expected to reconstruct the complex nature of past permafrost environment. Harris (1981) presented an interesting scheme for plotting the distribution of periglacial landforms in relation to annual mean air temperature, freezing anf thawing

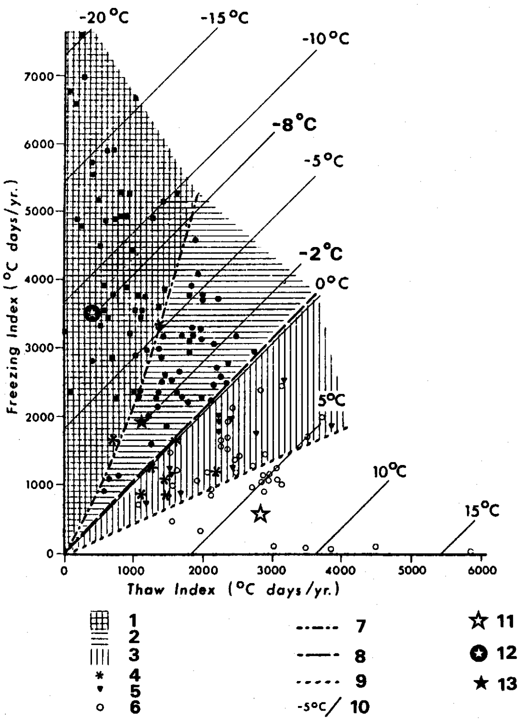

Fig. 3 Freezing and thawing indicies for the Tokachi Plain plotted on the graph by Harris (1981)
1: Continuous permafrost zone; 2: Discontinuous permafrost zone; 3: Sporadic permafrost zone; 4: Ice caves; 5: Ice beneath peat; 6: No permafrost; 7: Limit of continuous permafrost; 8: Limit of discontinuous permafrost; 9: Limit of sporadic permafrost; 10: Mean annual isotherm; 11: Freezing and thawing indicies of present Obihiro City, Tokachi Plain; 12: Freezing and thawing indicies assuming annual mean temperature of -8°C; 13°: Freezing and thawing indicies assuming annual temperature of -2°C.

indicies, and permafrost condition. On the basis of this scheme, he found a clear relationship between permafrost zonation and freezing and thawing indicies.

We will now discuss the past permafrost environment during the Last Glacial in E and N Hokkaido by means of the freezing and thawing indicies, which can be roughly calculated from the inferred monthly mean temperatures in Fig. 2.

The freezing and thawing indicies in the climate represented by Curves b, b', c and c' are as follows:

	Freezing index	Thawing index
Curve b (annual mean −2°C):	1900°C days/year	1200°C days/year
" b' (annual mean −2°C):	2250	1500
" c (annual mean −8°C):	3200	360
" c' (annual mean −8°C):	3600	700

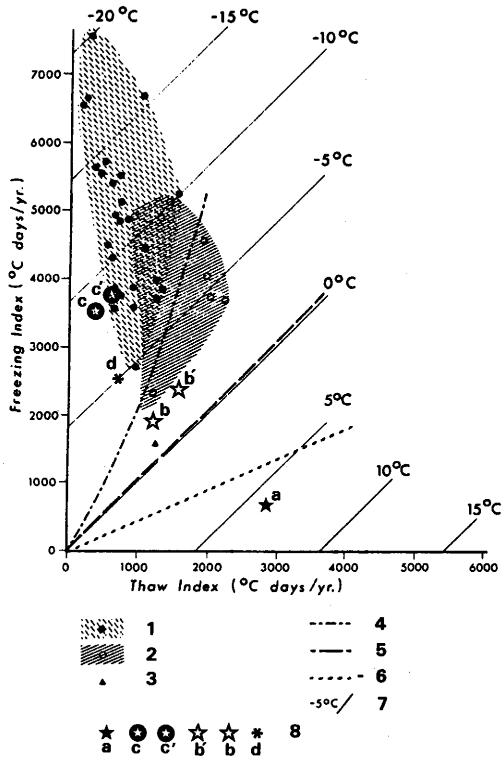

Fig. 4 Distribution of active ice wedge polygons with freezing and thawing indicies by Harris (1981), and freezing and thawing indicies in Obihiro City and Svarbard
1: Ice wedge polygons (mineral soil); 2: Ice wedge, "polygonal peat plateau"; 3: Ice wedges persisting under peat (Norway); 4: Limit of continuous permafrost; 5: Limit of discontinuous permafrost 6: Limit of sporadic permafrost 7: Mean annual isotherm; 8: a: present Obihio City; b, b', c and c': freezing and thawing indicies calculated from monthly mean temperature curve b, b', c and c' in Fig. 2, respectively; d: Present Longyearbyen, Svarbard

Each pair of freezing and thawing indicies is plotted on the graph made by Harris (1981), and permafrost environment is examined (Fig. 3).

Figure 4 represents the relationship between the freezing and thawing indicies and the distribution of ice wedge polygons. The freezing index, 3200～3600°C days/year is evidently included in the area where ice wedge polygons are extensively developed in the mineral soil. Therefore the climate having such amounts of freezing index is not in agreement with the very sparsely ditributed ice wedge casts in E and N Hokkaido.

Under the environment with the freezing index, 1900～2250°C daye/year, ice wedge can be formed, restricted in the peat.

In Svarbard, the freezing index amounts to 1944°C days/year at Isfjord facing the west coast or 2500°C days/year at Longyearbyen (Åkerman, 1987). These amounts of freezing index indicate nearly the limit of development of active ice wedge polygons, as shown in Fig. 4. In the Tokachi Plain, the freezing index could reach the amounts of 2500°C days/year, even though the annual mean temperature is -2°C. Accordingly it appears to be reasonable that the annual mean temperature had been approximately -2°C with the freezing index of 2000～2500°C days/year, even in the coldest period of the Last Glacial in E and N Hokkaido.

It is stressed by Williams (1975) that the thawing index should totalled 900°C days/year or more for extensively distributed involutions, such as those observed in E and N Hokkaido. The thawing index associated with the annual mean temperature of -8°C (Curve **c** or **c'** in Fig. 2) are only 360～700°C days/year, while the thawing index of -2°C annual mean 1200～1500°C days/year. The latter climatic condition seems to be in good agreement with the various periglacial features in E and N Hokkaido. Such permafrost environment characterized by high degree of continentality should have prevailed during the Last Glacial.

5. Concluding Remarks

Paleoenvironment in relation to permafrost during the Last Glacial in E and N Hokkaido was discussed on the basis of monthly mean temperature, freezing and thawing indicies and ice wedge cast as an indicator of past annual mean temperature, comparing them with pollen evidence. An examination of past permafrost environment using the freezing and thawing indicies based on assumed monthly temperature for the Last Glacial seems to have revealed the complex nature of past climatic environment and periglacial features of E and N Hokkaido during the Last Glacial.

It is most likely that E and N Hokkaido occupied the southern marginal region of discontinuous permafrost environment, where relatively closed coniferous forest has prevailed, intervening the short duration of open forest tundra. Herbaceous park tundra can not be reconstructed, as far as the pollen evidence in the Tokachi Plain are concerned.

The continentality had been considerably larger than that at present. Thermal cracking for the formation of ice wedge polygons could have occurred in a restricted place where frost susceptible materials were distributed or poorly drained area spread, even under the sporadic permafrost environment, because winter temperatures had been so low as inferred from the reconstructed curves of monthly mean temperatures.

Althogh the annual mean temperature had been *ca.* -2°C, it seems to have been enough cold to develop ice wedge polygons. Sudden drop of temperature reaching -30°C or -40°C in winter must have happened, because daily lowest temperature attaining -20°C to -30°C is relatively frequently recorded even at present. Thus, ice wedge polygons could have been very sparsely formed during the Last Glacial, even under such sporadic permafrost environment. It is essentially inadequate that the annual mean temperature of -6°C to -8°C is assumed to explain only a few ice wedge cast in E and N Hokkaido. It is to be emphasized that no present periglacial region provides an exact model of former permafrost environment in Hokkaido, Japan.

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