Nobuo Ooi*, Sei-ichiro Tsuji** and Mutsuhiko Minaki***:

Pollen Assemblages from Early Last Glacial Peat Sediments at Hiroo, Hokkaido, Japan

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北海道広尾における最終氷期初期の泥炭堆積物の花粉群

Abstract We present pollen assemblages of the early Last Glacial Biraotri Formation at the right bank of the Rakko River, Hiroo, in eastern Hokkaido. Nineteen tephra layers were recognized in the study section, and two of them are correlated to the widespread tephra Aso-4 and K-M, which have been dated to the early Last Glacial period. Eight local fossil pollen assemblage zones HRO-I to VIII are established based on the changes in the major arboreal pollen. The patterns of pollen assemblage change below and above the K-M pumice are similar and corresponding to two sedimentary cycles from gravel to peat. In each sequence, the characteristic pollen types change from *Alnus*, through *Larix*, *Picea*, to *Larix* from lower to upper. This pattern reflects succession linked to the bog development and increasingly cold climate. The pollen assemblage in the upper sequence indicates climatic fluctuation with a larger amplitude. The lower sequence suggests the smaller climatic fluctuation in oxygen isotope stage 5, and the upper one does larger change from the stage 5 to 4.
Key Words: Climatic change, Late Pleistocene, Pollen analysis, Succession, Widespread tephra

要　旨　北海道広尾の楽古川右岸に分布する初期最終氷期ビラオトリ層の花粉群の変遷を示す。調査した露頭断面で認識された 19 火山灰層のうち 2 層は最終氷期の広域火山灰 Aso-4 と K-M に対比される。この堆積物から得られた花粉群は、主要木本花粉組成の変化から 8 局地化石花粉群帯 HRO-I〜VIII に区分される。花粉群は K-M の上下で礫から泥炭への 2 回の堆積輪廻と対応して同じような変遷を繰り返す。それぞれの変遷は、下位より上位へ特徴的な花粉がハンノキ属から，カラマツ属，トウヒ属，そしてカラマツ属へと変わることで示される。この変化は湿原の発達と気候の寒冷化にともなう植物遷移を反映している。化石花粉群より復原される気候変動の振幅は上位の変遷の方が大きい。下位の変遷は酸素同位体ステージ 5 の中のより小さな変動を，上位の変遷は酸素同位体ステージ 5 から 4 へのより大きな変動を示している。
キーワード：花粉分析, 気候変動, 広域火山灰, 後期更新世, 遷移

Introduction

Early Last Glacial sediments in Hokkaido have been recognized in discoveries of widespread tephra. The Aso-4 ash derived from Kyushu, southern Japan is a significant widespread tephra layer in Japan (Machida *et al*., 1985). The date of this ash fall is estimated to be about 70,000-90,000 years ago, but is still not certain (Machida & Arai, 1992). In Hokkaido, the Aso-4 ash is found within the Biraotori Formation. This formation is distributed in fragments along the eastern foot of the Hidaka Mountains, the margin of the Toyokoro Hills, and the Pacific shoreline (Matsui *et al*., 1973, 1978). It mainly consists of peat or peaty silt. The present study site is the type locality of the Biraotori Formation, where there is thick peat sediment including 19 tephra layers. Two of them were correlated to the widespread tephra layers from the Last Glacial period: the Aso-4 ash, and K-M pumice. The pumice derived from the Kuttara Caldera, in central Hokkaido, and is dated to about

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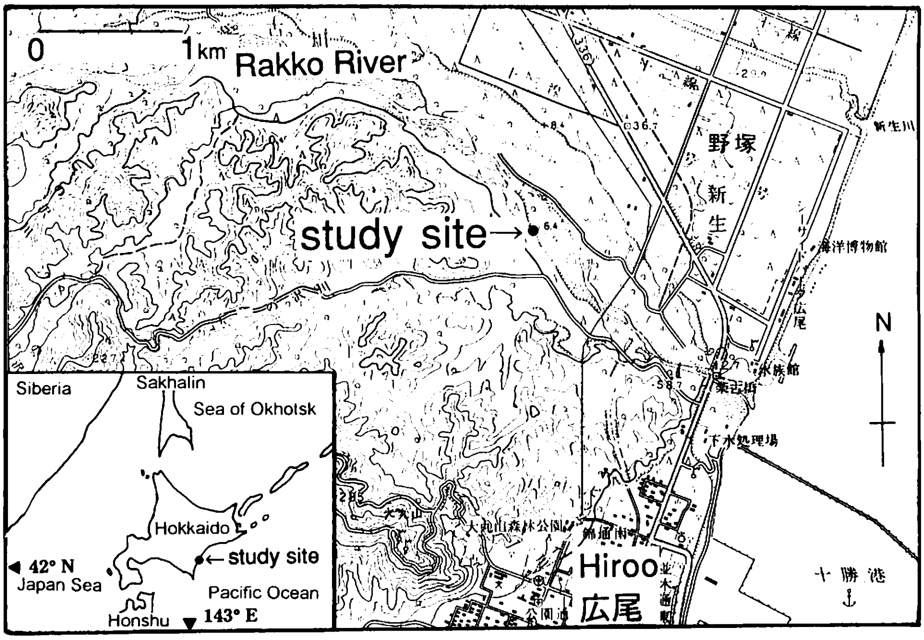

Fig. 1 Locality map of study site

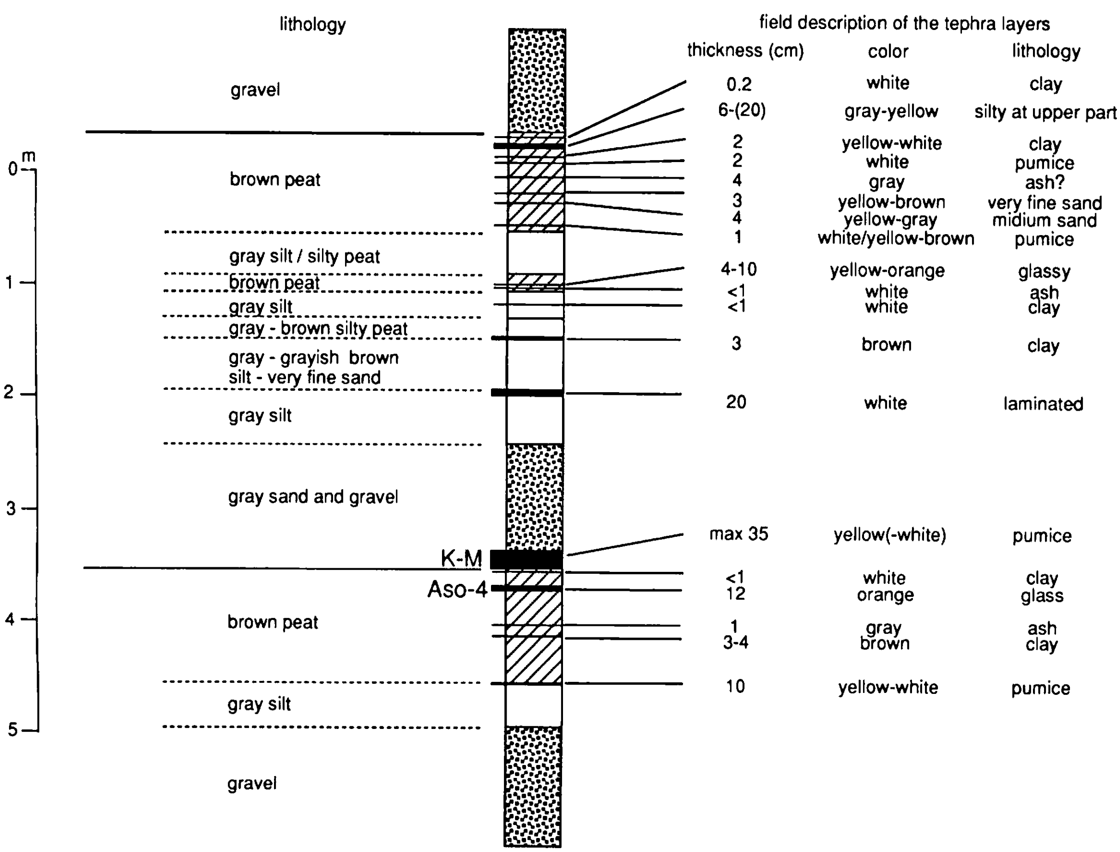

Fig. 2 Columnar section and lithology of study site

60,000- 70,000 years ago (Arai *et al.*, 1986). In this study we describe pollen assemblages from peaty sediments above and below the dated tephra layers, and reconstruct the environmental changes.

Study site and Stratigraphy

The study site is at 42° 19′N, 143° 16′E, on the right bank of the Rakko River, at Hiroo (Fig. 1). The Biraotori Formation in the study section unconformably overlies Tertiary sediments and is covered by terrace gravel from the Rakko River. Two sedimentary cycles are apparent, each beginning with gravel and ending with peat. The sequence of each cycle is as follows (Figs. 2-4):

The first cycle begin with more than 1 m of a gravel layer, followed by a gray silt 30 cm thick, and brown peat about 1 m thick. There are five tephra layers in this sequence. The lowermost tephra layer is composed of yellow to white volcanic sand and lies on top of the gray silt layer. Another four layers are within

Fig. 3 Entire view of study section

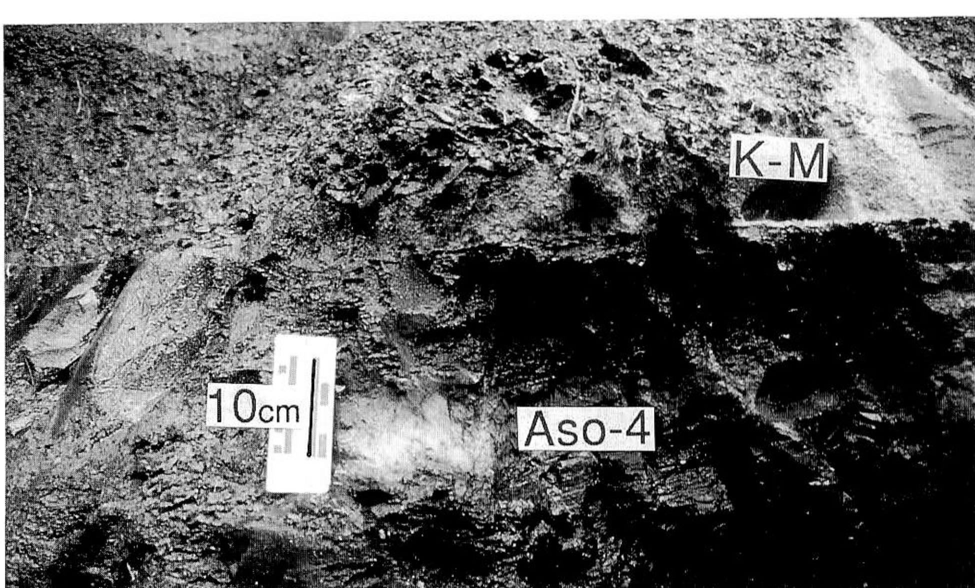

Fig. 4 Widespread tephra layers Aso-4 and K-M of study section

the brown peat (Fig. 2). One of these, an orange tephra layer, 12 cm thick, and 15 cm below the top of peat, is mainly composed of bubble wall type glass. This orange tephra can be correlated to the Aso-4, because the Aso-4 tephra was found from the Biraotori peat (Machida *et al.*, 1985) and there are no other thick glassy tephra layers in Biraotori Formation. Wood fragments concentrate below this ash.

The second and upper cycle is represented by the following lower to the upper; sand and gravel 1 m thick with a yellow pumice of about 35 cm in maximum thickness at the bottom, gray silt 40-45 cm thick with laminated white volcanic sand, gray to grayish brown silt 30 cm thick with reworked volcanic sand at the bottom, grayish brown silty peat 15 cm thick, gray silt 20 cm thick, brown peat 30 cm thick with two tephra layers in the lower part and wood remains in the upper part, alternation of gray silt and silty peat in a 30 cm layer, and brown peat 90 cm thick with 8 tephra layers. The yellow pumice layer at the bottom of this sequence mainly consists of fibrous pumice pieces about 5 mm in diameter. This tephra can be correlated to K-M, because K-M pumice known to lie above the Aso-4 (Arai *et al.*, 1986) and it was described as a thick orange pumice, named the Op-3 in the Biraotori Formation (Kasugai *et al.*, 1978).

The thickness, color and lithology of all the tephra layers detected in the field are described in Fig. 2. Further studies are necessary to identify many of these tephra layers.

Methods

Thirty-two samples, each of which is about 2 cm thick and 30 cm^3 were removed at the horizons about 5 to 20 cm intervals from the section. The intervals were determined by lithology and by the locations of tephra layers. About 2 cm^3 from each sample was used to extract pollen.

Samples for pollen analysis were treated with 10% KOH, sieved with a 0.5 mm mesh, decanted to remove sand, treated with 50% HF, dehydrated with acetic acid, and treated for 2 minutes by the acetolysis method. The residue was saturated in glycerin, and mounted. All pollen grains and spores on each slide were counted. Arboreal pollen counts in each sample exceeded 200.

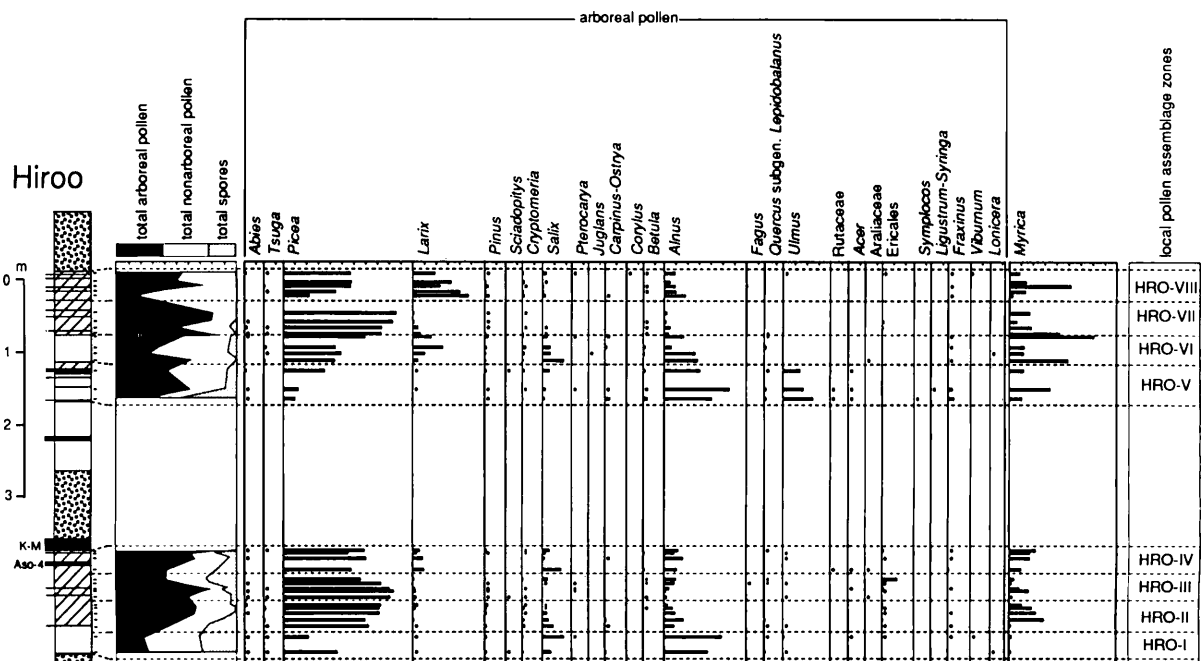

Fig. 5 Arboreal pollen diagram of Hiroo

The frequencies of arboreal pollen types were calculated from the total arboreal pollen counts, and these of other pollen and spore types were calculated from the total pollen and spore counts. *Myrica* pollen, which should be from *Myrica gale*, was excluded from the total of arboreal pollen grains, because of modern life form of mother plants.

Results

Seventy-six pollen and spore types are obtained. Eight local fossil pollen assemblage zones, HRO-I to VIII, are established by major arboreal pollen changes (Figs. 5, 6) and changes of other pollen and spore types almost correspond to these zones. HRO-I to IV correspond to the lower sedimentary sequence and HRO-V to VIII correspond to the upper one. The Aso-4 horizon is in the middle of the zone HRO-IV, and that of the K-M horizon is just above the HRO-IV. The characteristics of each zone are as follows:

HRO-I: *Alnus* contributes 40 to 50 % of the arboreal pollen, and this dominance characterizes the zone. It is also noteworthy that monolete spores contribute to about 30 % of the total counts.

HRO-II: A mixture of *Picea, Salix, Pinus*, and *Cryptomeria* pollen characterizes the zone. *Picea* makes up 70 to 80 %, *Salix* makes up 5 to 10 %, and *Pinus* and *Cryptomeria* exceed 1 % of the total arboreal pollen. *Myrica* contributes 10 to 30 % of total counts except at the bottom of the zone. It is noteworthy that *Lysichiton* pollen increases to 10 % of the total counts at top of this zone.

HRO-III: Dominance by *Picea* and Ericales pollen characterizes the zone. More than 90 % of arboreal pollen are made up of these two types. Ericales pollen increases towards the top. It is noteworthy that about 10 % of the total counts are trilete spores.

HRO-IV: *Larix* contributes 5 to 10 % of the total arboreal pollen, and this occurrence characterizes the zone. *Alnus* contributes more than 10 % and *Salix* contributes 2 to 15 % of the total arboreal pollen. *Myrica* occupies 10 to 25 % of the total counts.

HRO-V: Dominance by *Alnus* and *Ulmus* pollen characterizes the zone. *Alnus* makes up 30 to 50 %, and *Ulmus* makes up 15 to 25 % of the total arboreal pollen. Other deciduous types such as *Carpinus-Ostrya, Betula, Quercus*, and *Fraxinus* occur most frequently in this zone, particularly at the lower horizons. Saxifragaceae also occurs up to 8 % of the

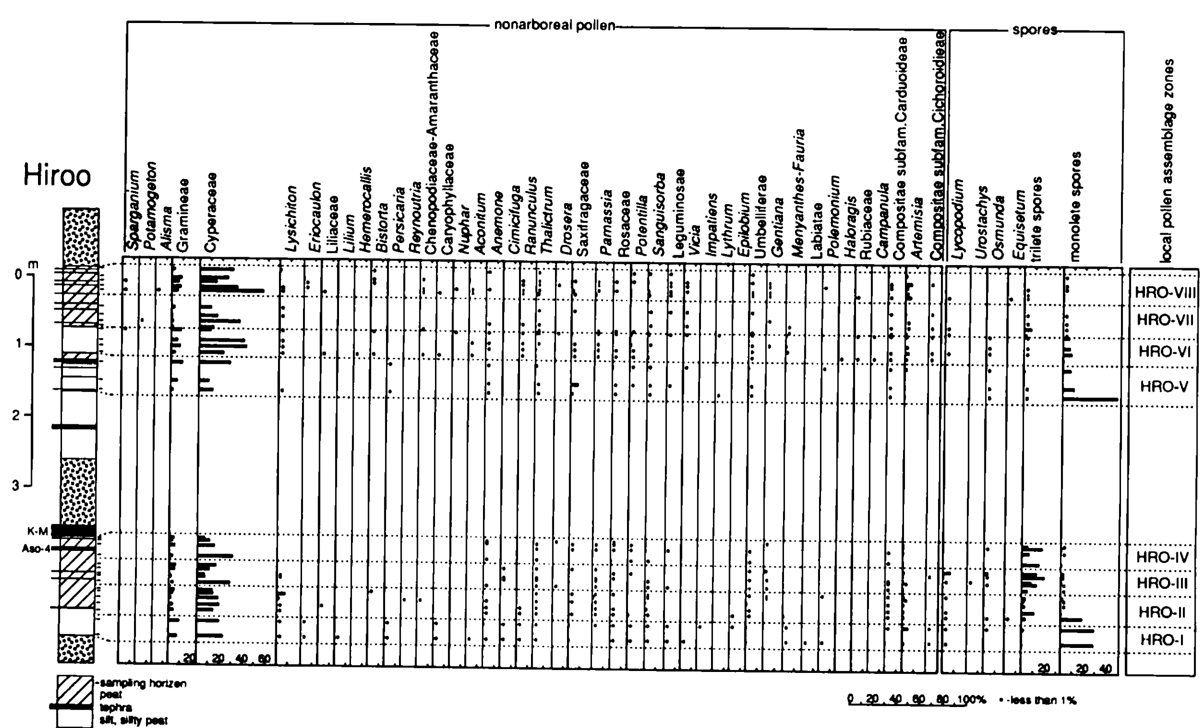

Fig. 6 Nonarboreal pollen and spore diagram of Hiroo

total counts in this zone. It is also noteworthy that 10 to 45 % of the total counts are monolete spores.

HRO-VI: *Larix*, which makes up 5 to 30 %, and this characterizes the zone. *Pinus* occurs more than 1 % of the total arboreal pollen. *Salix* and *Cryptomeria* pollen occur significantly at the lower part of the zone, and *Picea* increases to 80 % of the total arboreal pollen at the top of the zone. *Myrica* and herbaceous types such as *Thalictrum, Potentilla, Sanguisorba, Menyanthes-Fauria* and *Artemisia* occur significantly in this zone.

HRO-VII: *Picea* contributes 80 to 90 % of the total arboreal pollen, and this characterizes the zone. Ericales occurs more than 1% of the total arboreal pollen only in this zone of the upper sequence (HRO-V to VIII).

HRO-VIII: *Larix* contributes 20 to 50 %, and this characterizes the zone. *Picea* occupies 20 to 50 % of the total arboreal pollen. *Pinus* occurs about 1 % of the total arboreal pollen. Herbaceous types such as *Thalictrum*, Saxifragaceae, *Potentilla*, *Sanguisorba* and *Artemisia* occur significantly in this zone.

Discussion

Patterns of pollen change of the lower and the upper sequences, HRO-I to IV and HRO-V to VIII, resemble each other. The pollen spectra of both sequences seem to show following plant succession (stages 1 to 4) linked to the bog development and climatic change to cold:

Stage 1 (HRO-I and HRO-V) : Dominant types at the beginning of sequence are *Alnus* and monolete spores, which suggest an unstable and barren environment such as a river sandbank. Pollen of temperate broad leave trees such as *Ulmus* and *Fraxinus* dominated at the beginning of the upper sequence (HRO-V) suggesting a warm climate. In the lower sequence (HRO-I), a warm climate is implied by the small contribution of pollen by boreal conifers.

Stage 2 (HRO-II and HRO-VI) : *Picea*, *Larix* and *Myrica* pollen show relatively high occurrences. Cyperaceae, *Sanguisorba* and *Artemisia* pollen are accompanied with them. Increase of boreal conifers such as *Picea* and *Larix* suggest a climatic change to cold. *Myrica* which should be *Myrica gale* and Cyperaceae suggest a development of raised bog. *Sanguisorba* and *Artemisia* would be lived at the relatively dry habitat in and around the raised bog.

Salix and *Menyanthes-Fauria* pollen show relatively high occurrences in transition from stage 1 to 2. The horizons of peaks of these two taxa are different in the lower and the upper sequences; peak of *Salix* appears at the upper horizon of HRO-I while it does at the lowest horizon of HRO-VI, and peaks of *Menyanthes-Fauria* comes a bit later to those of *Salix*. This succession from *Salix* to *Menyanthes-Fauria* suggests the changes of water condition from riverine environment to raised bog.

Stage 3 (HRO-III and HRO-VII) : *Picea* and Ericales pollen dominate in the third zones. *Picea* pollen include pollen from *Picea glehnii* because cones of *Picea glehnii* obtained from peat of the Biraotri Formation (Matsui *et al.*, 1978). The increases of *Picea* pollen seem to inversely related to the decreases of *Larix* pollen and accompanies increases of Ericales pollen. This suggests that raised bog was temporarily or locally dried up, allowing the invasion of *Picea glehnii* and Ericales (Ericaceae and/or *Empetrum*) into the bogs.

Stage 4 (HRO-IV and HRO-VIII) : *Larix* and *Myrica* pollen dominate again in the last stage. The pollen assemblages suggest a cold climate and a development of peaty bogs as in the stage 2. Comparing with other stage, occurrences of *Larix* pollen show the highest peaks. Particularly, it reached to nearly 50 % of the total arboreal pollen in the upper sequence (HRO-VIII). The *Larix* pollen from the sediment would be *Larix gmelini* pollen judging from the macrofossil obtained from the Last Glacial in Hokkaido (Yano, 1970). Modern distribution of *Larix gmelini* spreads on colder and drier regions than Hokkaido, that is, Northeast China, Sikhote Alin Mountains, Sakhalin, Kuril Islands, and Kamchatka Peninsula (Shimizu, 1990). Thus, it seems reasonable to suppose that high frequency of *Larix* pollen indicate colder and drier, namely continental, environments than today.

It is remarkable that tephra layers concentrate at the upper part of the sequences. This implies volcanoes frequently erupted during cold phases, although this may be partly because we could easily detect thin tephra layers in the peat.

Although two sequences show the same trend of vegetation changes, there are striking differences between them. In the upper sequence, pollen of temperate deciduous broad leave trees such as *Ulmus*, *Fraxinus*, *Quercus* and *Carpinus-Ostrya* makes up to 20 % of the total arboreal pollen at the first zone (HRO-V). Whereas *Larix* pollen, which is the continental climate indicator, reached to nearby 50 % of the total arboreal pollen at its peak (HRO-VIII). In contrast, in lower sequence, temperate deciduous broad leave trees only slightly occurred at the first zone (HRO-I), and *Larix* pollen reaches up to 10 % of the total arboreal pollen at its peak (HRO-IV).

Our results described above do not conflict with other pollen sequences including the horizons of K-M and Aso-4 reported in Hokkaido. In Haboro, northwestern Hokkaido, the pollen assemblages were recording from the peat including three tephra layers by Yamazaki (1942). These three tephra layers were later correlated to Aso-4, Toya and Kc-Hb from the top by Machida *et al.* (1985). The pollen assemblages around the horizons of Aso-4 are dominated by *Picea* and *Larix*. In Ishikari Lowland, central Hokkaido, where Aso-4 ash is obscure but its horizon can be estimated by Mpfa-3 and Aafa-2, which are respectively correlated to K-M and Toya ash (Arai, *et al.*, 1986). The pollen assemblages between K-M (Mpfa-3) and Toya (Aafa-2) horizons consist mainly of *Picea* and *Larix* (Yamada *et al.*, 1981; Hoshino *et al.*,1982, 1986). Above the K-M (Mafa-3), the pollen assemblages include more *Larix* (Hoshino *et al.*, 1986). In Hidaka, south of Ishikari, pollen assemblages above the K-M have more *Larix* than around the horizon of Aso-4 (Sakaguchi & Katoh, 1993). That is to say, these studies did not represent pollen assemblages that include temperate tree pollen above the K-M horizon in Hokkaido as our study. The reason for a lack comparative assemblages is mainly due to the gap of the sediment corresponding to HRO-V.

In Tohoku District, northern Honshu, south of Hokkaido, there are some pollen diagrams including the Aso-4 horizon (Kanauchi, 1988; Suzuki & Takeuti, 1989; Takeuti & Kawamura, 1991). Their compositions around the Aso-4 differ with those of Hokkaido. They mainly consist of conifer such as *Picea*, *Pinus*, *Tsuga*, and including some *Cryptomeria* at Iwanosawa, Miyagi Prefecture (Suzuki & Takeuti, 1989) or *Fagus* and *Cryptomeria* at Onikobe, Miyagi Prefecture (Takeuti & Kawamura, 1991) and Yanohara, Fukushima Prefecture (Kanauchi, 1988). In spite of these differences, the climatic changes below and above the Aso-4 horizon would correspond to our studies. At Onikobe (Takeuti & Kawamura, 1991), a warm peak above the Aso-4 has more deciduous broad leave trees than the peak below the Aso-4. Unfortunately, a cold phase after this warm phase is not detected. At Yanohara (Kanauchi, 1988), a cold peak above the Aso-4 is colder than that around the Aso-4, whereas a warm peak above the Aso-4 shows a bit colder assemblage than that below the Aso-4. Small amplitude of difference between below and around the Aso-4 correspond to our studies, although a bit colder assemblage above the Aso-4 does not correspond to our studies.

Vegetation change in the lower sequence is small and may reflect the climatic change indicated by the oxygen isotope stage 5. The much greater vegetation change indicated by the upper sequence, may correspond to the change from stage 5 to 4 in the oxygen isotope stage. The cold climate of the upper sequence (HRO-VI to VIII) should correspond to the stage 4. On the contrary, the warm climate above the K-M should suggest that HRO-V is still in stage 5. If this idea is true, the horizon of Aso-4 at pollen sequences implies that Aso-4 fell after the coldest peak but before the warm stages, that is, at about the end of stage 5b. This assumption supports the idea that the horizon of Aso-4 is located about the oxygen isotope stage 5b (Machida & Arai, 1992).

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ドイツ植物学会 1994 年度大会は 9 月 11～19 日にバイロイトで開催されたが，本書はそのプレシンポジウムとして書名と同じテーマで行われた国際会議での 38 の講演を論文化して編集したものである。著者によって分類学に対する考え方がまちまちで各論文内容を直接比較しにくい面はあるが，キンポウゲ上目の木材解剖，師部，上クチクラ，花，雄蕊，花粉，種子，二次代謝産物，葉緑体 DNA，核 DNA 等様々な形質とそれらの解析法が示されていてためになる。特にキンポウゲ科，ケシ科，メギ科について詳しく言及されている。*Hydrastis* はキンポウゲ科に含めるかまたはこれと近縁とする見解が DNA 以外の形質の進化分類学的解析や葉緑体 DNA，核 DNA の解析により支持されているが，形態形質の分岐分類学的解析や木材解剖の特徴はこの見解を必ずしも支持していない。*Kingdonia, Circaeaster* の類縁については依然としてよくわかっていない。

論文の主著者は次の通り。Adachi, J., Aitzetmüller, K., Bandelt, H.-J., Barthlott, W., Behnke, H.-D., Blackmore, S., Blattner, F. R., Brückner, C., Carlquist, S., Dahlgren, G., Ehrendorfer, F., Endress, P. K., Engell, K., Hoot, S. B., Jensen, U., Johansson, J. T., Jork, K. B., Kadereit, J. W., Kim, Y. D., Kosuge, K., Kubitzki, K., Lang, J., Lidén, M., Loconte, H., Nickol, M. G., Nikolić, T., Oxelman, B., Ronse Decraene, L. P., Schwarzbach, A. E., Shneyer, V. S., Steinbach, K., Tamura, M., Weber, A. 中でも Hoot, S. B. は精力的で 4 本の DNA 関係の論文の主著者となっている。

（田村　実）