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Late-Quaternary Vegetation in the Lake of Korea

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영랑호, 월함지 및 방어진의 제 4 기 이후의 식피의 변천

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ABSTRACT

Pollen analysis from lake districts, Youngnangho, Wolhamji and Bangeojin, revealed vegetational patterns in Korea. The pollen stratigraphy was divided into five zones, zone L, Ⅰ, Ⅱ, Ⅲa and Ⅲb for the past 15,000 years. During zone L (earlier than 10,500 yr BP), late-glacial period, Youngnangho was vegetated with a coniferous forest dominated by spruce, larch, haploxylon pine and fir with considerable amount of herbs. Zone Ⅰ (10,500~7,500 yr BP) was predominantly herbaceous vegetation with significant amount of oak and diploxylon pine. It suggests that the overall environment became milder and drier than late-glacial period. Zone Ⅱ (7,500~4,000 yr BP), hypsithermal period, showed significant warming condition, indicated by high pollen concentrations of oak, diploxylon pine and hornbeam, and by more diverse flora of deciduous broad-leaved trees than before. Herbs were not an important part of vegetation. Zone Ⅲa(4,000~1,500 yr BP) had pine and oak as main elements. Birch increased slightly while hornbeam decreased in this time. It indicates cooling condition. Zone Ⅲb (1,5000-present) which can be called pine period showed obvious human interference. Following forest clearance, agriculture was intensified. The beginning of logging and agriculture was discernible by a sudden decline of arboreal species and by considerable amount of rice, buckwheat, sorrel and plantain. Numerous charcoal fragments were observed in zone Ⅰ and zone Ⅲb.

INTRODUCTON

Pollen analysis and other paleobotanical studies have provided the means for studying Quaternary vegetational and climatic history. Since the first pollen diagrams were described by Von Post in 1926, pollen analytical investigations have greatly increased both in number and complexity. Early studies revealed a sequence of pollen assemblages which succeeded one another following the close of the last glaciation and in this way a broad picture of changing vegetation was built up. This vegetational history has offered an opportunity for reconstructing the history of our climate, since the plants which produced the pollen have responded to the sequence of climatic changes during the Quaternary period.

Nevertheless, the study of late-Quaternary vegetational history and stratigraphy in Korea is still in its infancy. The first pollen study in Korea was made by Yamazaki (1940) with only a 15 cm peat sediments from Seseok-Pyungjeon on Mt. Jiri. Abundant pine and oak pollen in the surface sample are reflected by the present surrounding forest species. Other deciduous broad-leaved species showed a decrease on the surface as a result of man's deforestation.

Matsushima (1941) also has applied pollen analysis to reconstruct the past vegetation of the western coast of Korea, covering three sites from Icksan, Kimpo, four sites from Anju, Youngcheon and two sites from Pyunggang. All his diagrams showed that pine, oak, alder and willow shared 90% of the vegetation except in Youngcheon and Pyunggang where spruce occupied over 5%.

After Yamazaki and Matsushima presented their diagrams in early 1940's, there was a gap of 30 years until Oh (1971) reported the pollen diagrams of Pyungtaek. Subsequentlty Tsukada *et al.* (1977, 1978) reported the pollen diagrams from Youngnangho near Sokcho with three radiocarbon dates which were the first attempt in Korea. These diagrams showed that larch, spruce, fir and haploxylon pine were aboundant during the late-glacial and that oak and pine were the dominant species altenately in postglacial period.

Hong (1978) and Jo (1979) also showed great abundances of pine and oak in the postglacial period from their samples taken from several places. Jo divided the pollen zone into two stages and three substages, and considered that the changes of forest in the study area was controlled mainly by climate, partly by sea level change and human interference.

The aim of this study are to clarify the past vegetational and climatic change in the Korean Peninsula. The samples taken from Youngnangho, Wolhamji and Bangeojin were used for the pollen analysis (Fig. 1).

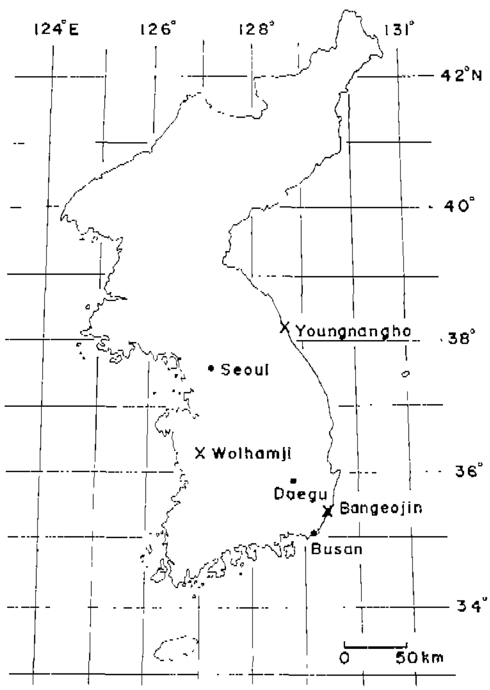

Fig. 1. Map showing three study sites marked with X.

VEGETATION AND CLIMATE

Vegetation. For the study, Yim's (1977) vegetation map was used to determine the present vegetation. Youngnangho is located between cool-temperate and warm-temperate deciduous zone, Wolhamji in warm-temperate deciduous zone and Bangeojin in warm-temperate evergreen zone. Three study areas show different vegetation type at present.

Climate. Temperature and precipitation records of study areas were obtained from the Central Meteorological Office at Seoul. Data from Sokcho (Youngnangho) had been recorded from 1968 through present, Buyeo(Wolhamji) from 1971, and Ulsan (Bangeojin) from 1958.

The overall climate of Korea is continental: winter is cold and dry, and summer hot and wet. These are controlled by northwest high pressure from Siberia in winter and by summer monsoon derived from south-Pacific low pressure.

Sokcho, of eastern coast, has the mean annual temperature 13.1°C, and −0.5°C in January and 23.9°C in August. Winter is comparatively mild because of Föhn wind from west of Mts. Taebaek, and the summer is hot. Average annual preciptation was 1302.3 mm for the last 11 years.

Buyeo, located in the western central part of Korea, has colder winter temperature and less precipitation than other two study sites. Mean temperature of January and August is −1.7°C and 23.5°C respectively. The mean annual temperature was 12.8°C and a mean annual precipitation 1174.9 mm.

Ulsan, faced southeast margin of the Korean Peninsula, is climatically similar to Sokcho. However, temperature was higher and preciptation less than Sokcho through the year.

STUDY SITES

Youngnangho (Fig. 2) lies at Sokcho city, Kangwon province, in the eastern coast of Korea (Lat. 38°12′55″ N, Long. 128°35′03″ E). The water of Youngnangho runs to Donghae (Sea of Japan) and Mt. Seorak (1708 m) is apart about 16 km from this lake. Youngnangho is approximately 750 m wide and 2,150 m long, and has a maximum water depth of 6.54 m.

Wolhamji (Fig. 3) lies in Buyeo city, in the western central part of Korea (Lat. 36° 17′03″ N, Long. 126° 55′34″ E). Baekma river is main water source of this area. According to historical record (Samkooksagi), Wolhamji was constructed for resort area for King Moo of Baekje period AD 638. Until this resort area was converted into rice paddy in 1947, it was left as it had been.

Bangeojin (Fig. 4) is located at Ulsan city in Kyungsang province, southeastern coast

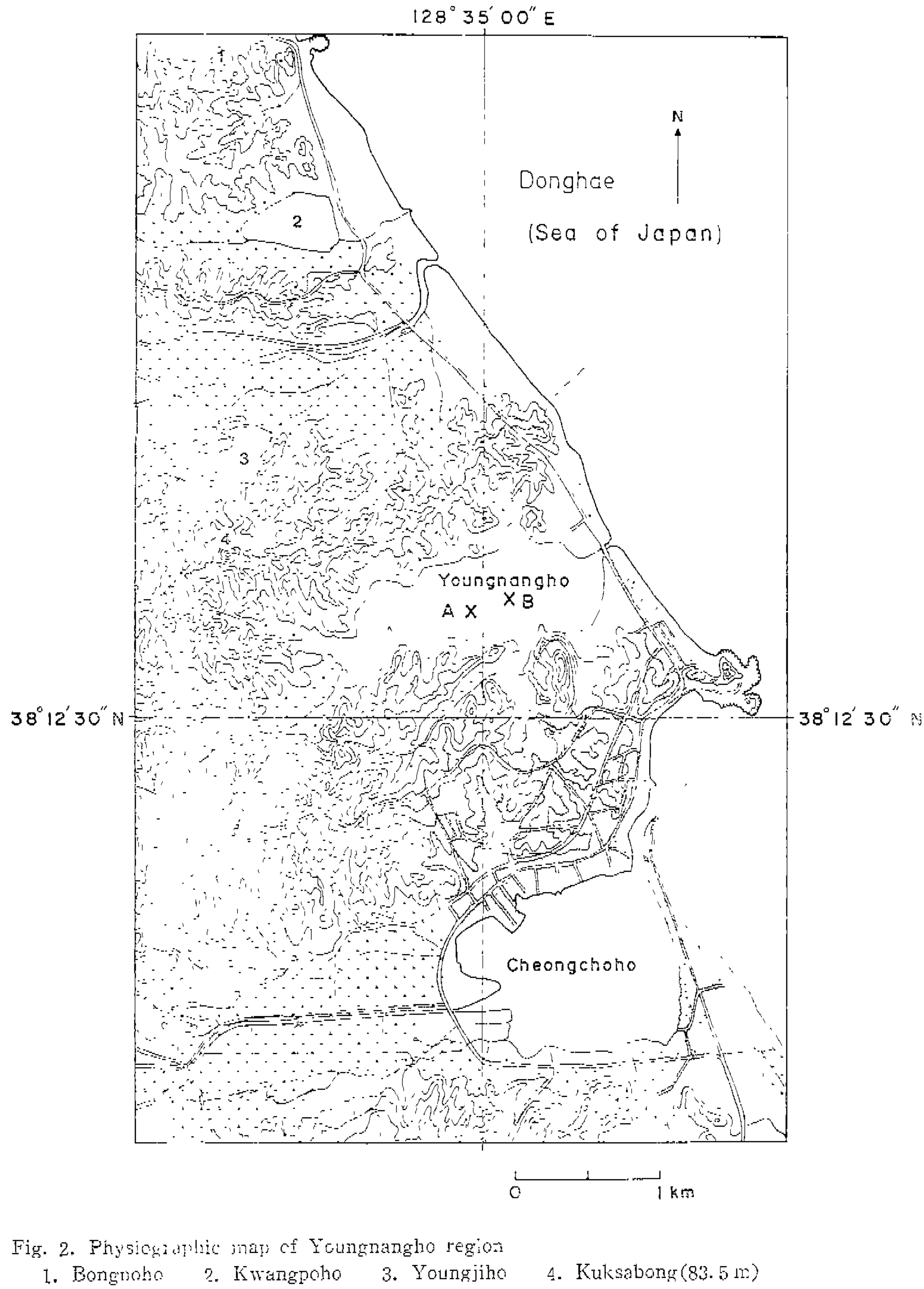

Fig. 2. Physiographic map of Youngnangho region
1. Bongpoho 2. Kwangpoho 3. Youngjiho 4. Kuksabong (83.5 m)
Samples were taken from A in 1977, B in 1978.

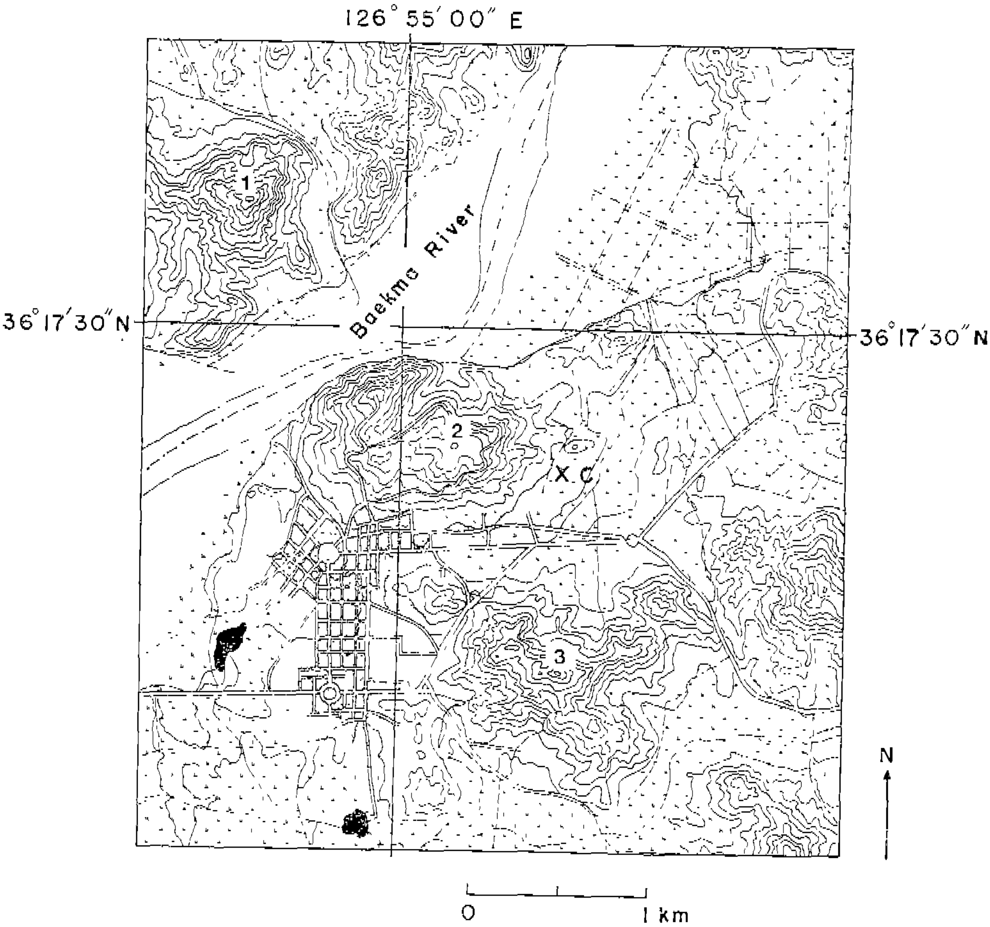

Fig. 3. Physiographic map of Wolhamji.
1. Deumujae(121.2 m), 2. Mt. Buso(100.2 m), 3. Mt. Keumseong(121.2 m), C indicates the study site.

of Korea (Lat. 35°29′02″N, Long. 129°25′48″E). The sample was taken at the margin of small pond which lay 125 m away from sea. Currently, this area is surrounded by mainly cultivated fields and partly a secondary forest composed of pine and herbs, such as *Artemisia*, *Polygonum*, Chenopodiaceae, *Symplocarpus*, *Setaria*, Umbelliferae, *Miscanthus* and Gramineae.

METHODS

Sediment samples for pollen analysis were obtained from Youngnangho and Wolhamji with modified Livingstone sampler, and sample from Bangeojin with Hiller sampler. Samples were processed for pollen counts by the standard pollen extraction techniques

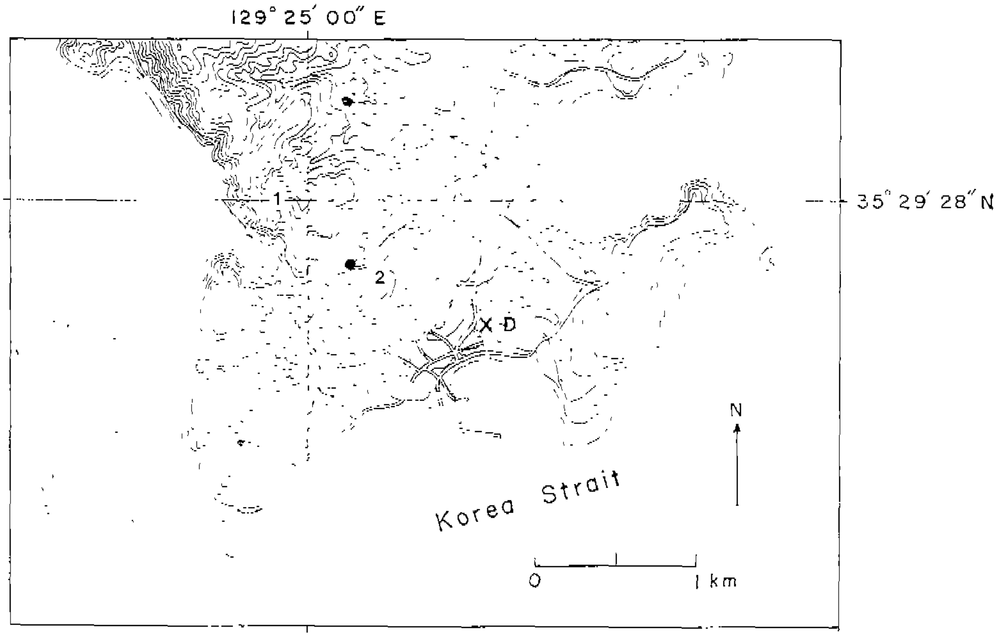

Fig. 4. Physiographicmap of Bangeojin.
1. Bonghwajae(116 m) 2. Munjae(78 m), D indicates study site.

(Faegri and Iversen, 1975). Exotic marker grain method by Benninghoff (1962) was used for determination of pollen concentration (absolute pollen frequency). The prepared residue was mounted with 50% glycerine; counting continued until at least 500 pollen grains of terrestrial taxa were tabulated.

Pinus koraiensis pollen was distiguished from *P. densiflora* pollen using the morphological criterion described by Ueno (1958). In order to identify *Oryza* type pollen from other Gramineae, the samples were mounted again using glycerine jelly as a mounting medium. *Oryza* type pollen whose characteristics were described by Nakamura (1974) was distingnished from other Gramineae at 1,000× magnification using a phase-contrast microscope.

RESULTS

Younangho.

The late-glacial and postglacial sequence at Yonngnangho was divided into four major pollen zones, L, Ⅰ, Ⅱ and Ⅲ. Zone Ⅲ was subdivided into rather older and younger subzones, Ⅲa and Ⅲb (Fig. 5).

Zone L: The oldest peat sediment was characterized by a dominance of boreal elements, *Picea*, *Larix*, *Pinus* (haploxylon) and *Abies*, *Betula*, *Carpinus*, *Castanea*, *Platycarya*, *Lepidobalanus* (deciduous oak), *Fraxinus* and *Corylus* were recorded in this time. Some herbaceous species, for example, *Artemisia*, Gramineae, Chenopodiaceae and Compositae were abundant in this zone. Especially Cyperaceae showed great amounts during late-glacial period. All species declined toward the end of this zone which was dated 15,300 ±115 yr BP.

Zone Ⅰ: In this transitional pollen zone Ⅰ, *Lepidobalanus* and *Carpinus* increased slightly while boreal elements, the main species in zone L, appeared sporadically with low pollen concentration. Other broad-leaved species, *Acer*, *Celtis*, *Juglans*, *Tilia*, *Ulmus*, *Alnus*, Leguminosae, Moraceae and *Salix* appeared from this zone. *Artemisia*, Chenopodiaceae and Compositae were still present. Gramineae, *Pteridium*, monolete and trilete spores reached maximum in the beginning of zone Ⅰ, then decreased. *Myriophyllum*, *Trapa* and *Lythrum* growing in wet area also appeared in this time. The bottom of this zone (11.6 m) is assumed to be ca. 10,500 yr BP.

Zone Ⅱ: This zone began to increase all pollen types. *Pinus* (diploxylon) and *Lepidobalanus* continued to increase with *Carpinus* as well as zone Ⅰ, then they decreased in pollen concentration. *Acer*, *Betula*, *Celtis*, *Juglans*, *Platycarya*, *Tilia*, *Ulmus*, *Alnus* and *Corylus* increassed steadily through the zone. *Artemisia*, Gramineae were abundant and Chenopodiaceae and Compositae consistently present in this zone. Other taxa were only of minor importance here. Some aquatic plants, *Myriophyllum*, *Typha*, *Lythrum* appeared sporadically and *Pediastrum* reached peak in this zone. The boundary between zone Ⅱ and zone Ⅲa dated ca. 4,000 yr BP. Charcoal fragments reached maximnm at the early stages of zone Ⅱ which was estimated ca. 6,700 yr BP.

Zone Ⅲ: Decrease of arboreal species and increase of herbaceous species were characterics of this zone. Subzone Ⅲa was characterized by decrease of most of the tree pollen except that of *Betula*, *Castanea*, *Corylus* and *Salix* which increased slightly. Among herbaceous species, *Artemisia* and Gramineae become up to a maximum near the upper boundary of the zone. *Oryza* type pollen started from 2 m level followed *Fagopyrum* and *Rumex*. Chenopodiaceae, Umbelliferae, Compositae and ferns also begin to rise slightly through this period and *Pediastrum* declined continually. Zone Ⅲa was estimated to be between ca. 4,000 and ca. 1,000 yr BP.

In subzone Ⅲb, since ca. 1,100 yr BP, all species decreased in the pollen concentration. But *Pinus* expanded drastically and herbaceous species also increased within a few hundred years. *Oryza* showed consistency through the zone Ⅲb, but *Fagopyrum* scattered appearance.

Wolhamji.

Zone Ⅲa: Wolhamji core consisted of two subzones, Ⅲa and Ⅲb. Zone Ⅲa was characterized by high percentage of pollen of arboreal species, mainly *Lepidobalanus* and *Pinus*. This indicated that this site was surrounded by a dense deciduous broad-leaved forest (Fig. 6). Other tree species, *Carpinus*, *Platycarya*, *Ulmus* and *Juglans*

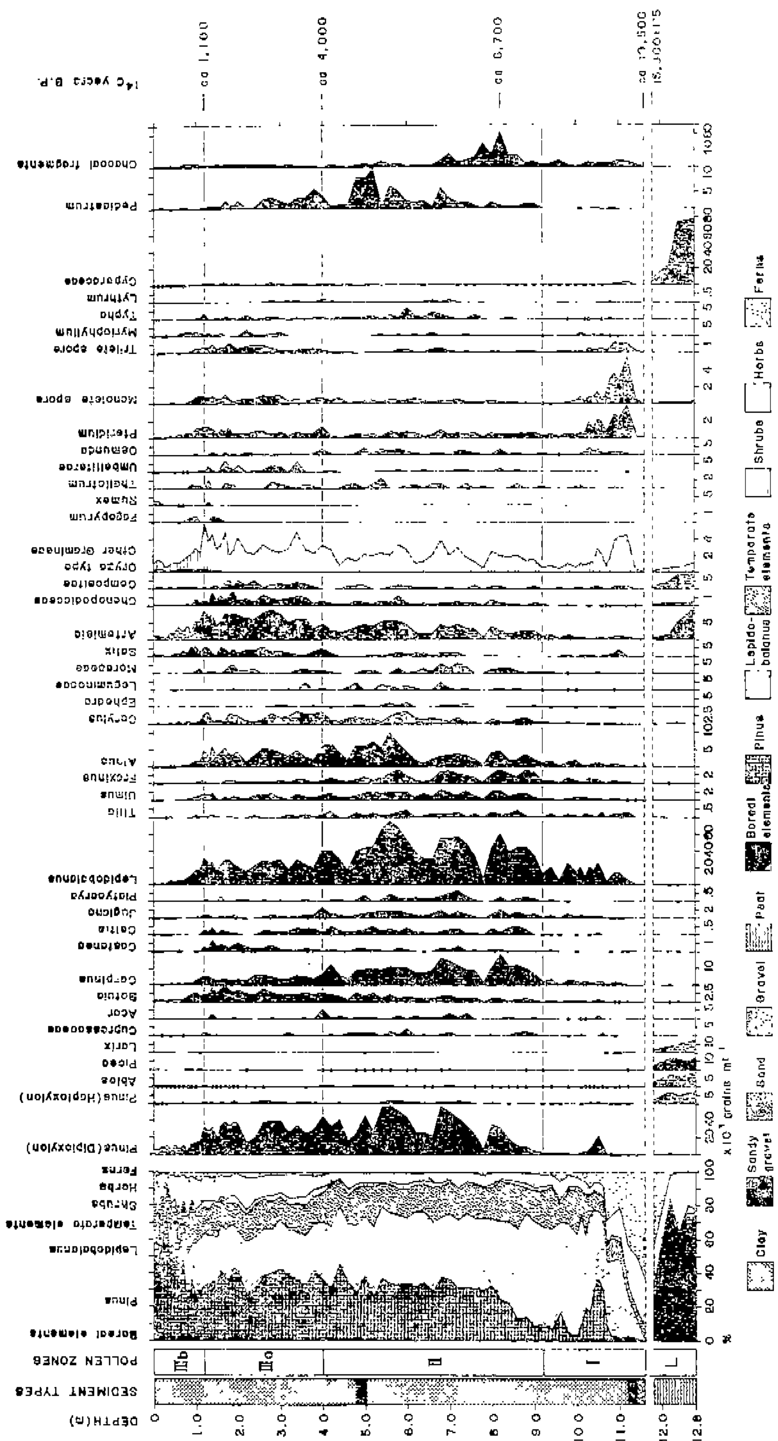

Fig. 5. Summary pollen diagram and pollen concentration(APF) curves for Youngnangho. Percentages are calculated on the basis of the total terrestrial pollen. Dots are values of less than 100 grains/ml except in case of Fagopyrum which dots are values of less than 20 grains/ml.

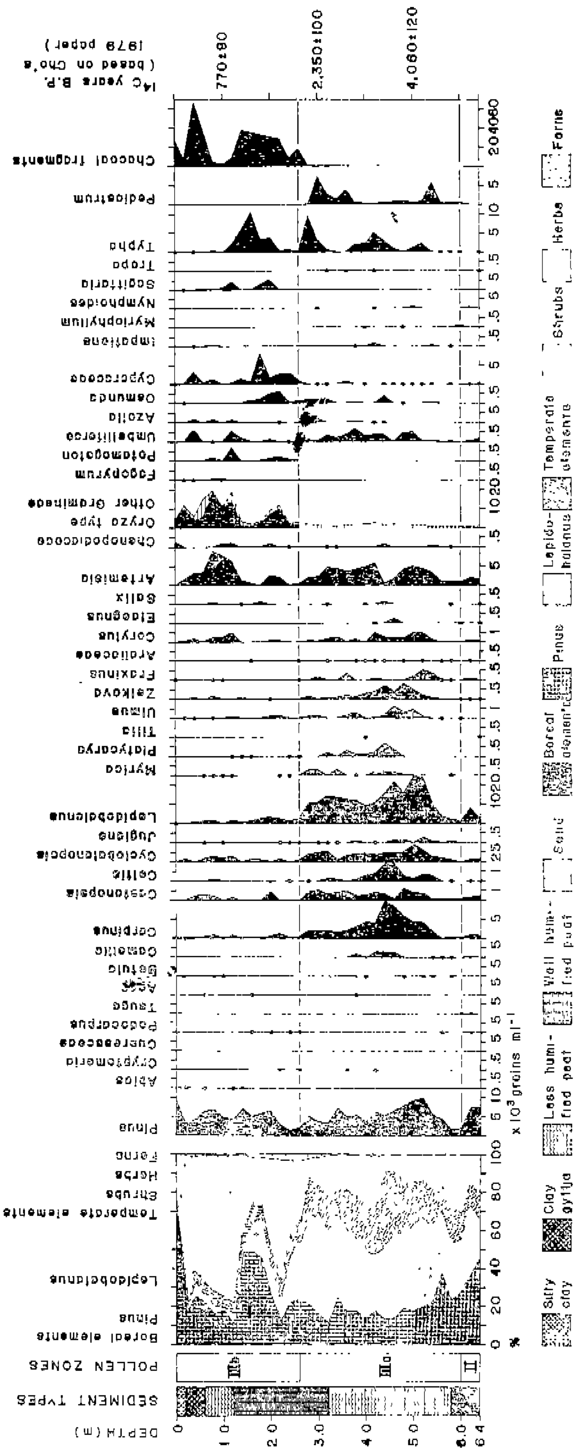

Fig. 6. Summary pollen diagram and pollen concentration curves for Wolhamji. Percentages are calculated on the basis of the total terrestrial pollen. Dots are values of less than 50 grains/ml except Cyperaceae (100 grains/ml).

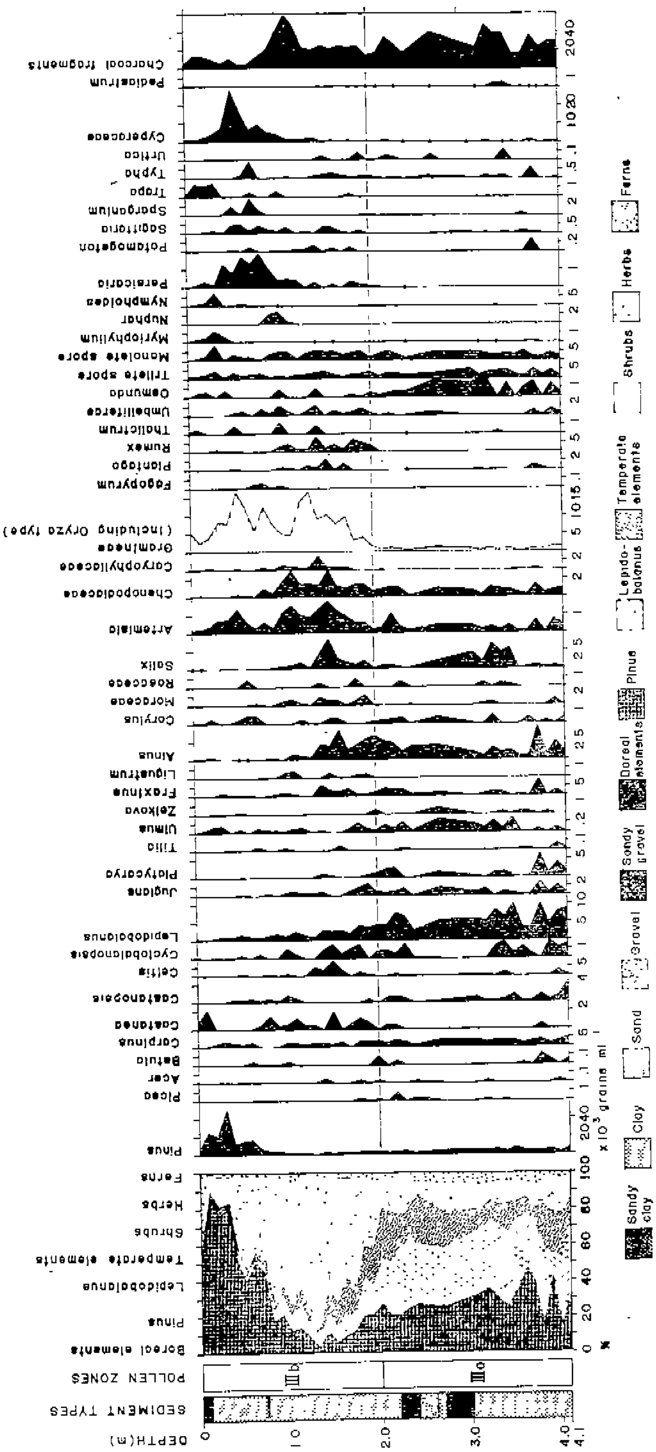

Fig. 7. Summary pollen diagram and pollen concentration curves for Bangeojin. Percentages are calculated on the basis of the total terrestrial pollen. Dots are valuse of less than 50 grains/ml.

were common in this zone. Among the non-arboreal species, the most common pollen types were Gramineae, Chenopodiaceae and *Artemisia*.

While *Carpinus* and *Juglans* occurred more or less steadily, frequencies of *Lepidobalanus*, *Cyclobalanopsis*, *Castanopsis* and *Platycarya* decreased in the early zone Ⅲa, then declined, and it increased again from the middle of zone Ⅲa. Gramineae, Chenopodiaceae and *Artemisia* were abundant. Charcoal fragments also were prevelent in this zone. Judging from the appearance of aquatic plants, *Myriophyllum*, *Nymphoides*, *Potamogeton*, *Sagittaria* and *Typha*, Wolhamji might be a natural pond.

No significant changes appeared in pollen composition and concentration of each taxon, although gravel and sandy gravel layers were shown in the stratigraphy of zone Ⅲa. It was probably related to the erosion of high land and redeposition of sediments. Presumably the time span between these layers would be short.

Zone Ⅲb: High percentages of Gramineae, Chenopodiaceae, *Artemisia* and herbaceous plants charcaterized zone Ⅲb. In the end of this zone *Pinus* increased drastically, while other arboreal species decreased. The pollen concentrations of Gramineae, Chenopodiaceae and *Artemisia* were large. *Oryza* type pollen appeared from 2 m level which was boundary of zone Ⅲa and Ⅲb.

The concentration of charcoal fragments was maximum in this zone together with the pollen of Gramineae (*Oryza* type), *Fagopyrum*, *Plantago*, *Rumex*, *Thalictrum* and Caryophyllaceae. In the uppermost part of zone Ⅲb, all pollen concentrations were low, caused by high sedimentation rate or less compaction of sediments. By the radiocarbon dates of Wolhamji, its bottom may be ca. 4,500 yr BP. and zone Ⅲa and zone Ⅲb boundary ca. 2,100 yr BP.

Bangeojin.

Zone Ⅱ: Pollen sequence of Bangeojin was divided into two pollen zones, Ⅱ and Ⅲ which belong to the postglacial period. Zone Ⅲ also subdivided into two subzones, Ⅲa and Ⅲb. Zone Ⅱ was not clearly distinguished for zone Ⅲa (Fig. 7).

Zone Ⅲa: Pollen assemblage of zone Ⅲa of Bangeojin was rather different from that of zone Ⅲa of Youngnangho and Wolhamji. The leading elements were *Lepidobalanus*, *Pinus*, and *Carpinus* at Youngnangho and Wolhamji, but *Cyclobalanopsis* and *Castanopsis* growing in warm-temperate evergreen lucidophyll forest zone were more abundant at Bangeojin. *Camellia* and *Elaegnus*, evergreen genera, appeared only at Bangeojin. *Cryptomeria*, *Podocarpus* and *Tsuga* were also present in this time, while neither Youngnangho nor Wolhamji had those genera. *Celtis*, *Ulmus* and *Corylus* reached maximum concentration in the middle portion of this zone, then declined. Gramineae and *Artemisia* occurred in great quantity, but Chenopodiaceae was rare. *Typha* was very abundant with other aquatic plants, *Impatiens*, *Myriophyllum*, *Nymphoides* and *Trapa*. *Pediastrum*, indicator of clear and oligotrophic water, occurred abundantly in the early and in the end of zone Ⅲa, but it did not appear any more. Charcoal fragments appeared from just below the boundary of zone Ⅲa and Ⅲb.

If Jo's (1979) radiocarbon dates in Bangeojin are applied to this zone, peat sediments at the 3 m level is estimated to be ca. 2,350±100 yr BP and 5 m level can be dated 4,060±120 yr BP.

Zone Ⅲb: This zone is dominated by *Pinus* and herbaceous taxa. Other arboreal taxa declined and *Camellia* and *Elaegnus* were absent during this period. Among herbaceous taxa, *Artemisia* and Cyperaceae occurred in greater amount with drastic increase of Gramineae, especially *Oryza* type pollen in zone Ⅲb than in zone Ⅲa. *Oryza* type pollen was recorded from the bottom of zone Ⅲb and *Fagopyrum* appeared later than *Oryza* in the middle portion of this zone. Umbelliferae presented in significant quanttity with occasional appearance of Chenopodiaceae and *Potamogeton*. *Typha* and *Sagitaria* which reflect local vegetation have maximum pollen concentration in this period. From the end of zone Ⅲb, the concentration of charcoal fragments started to appear and continued through the zone Ⅲb and had the peak at 40 cm level. Peat sediments at the 1 m level is assumed to be ca. 770±90 yr BP.

DISCUSSION

Pollen records of the late-glacial period (zone L) from Youngnangho showed high percentages of boreal species, *Pinus* (haploxylon), *Picea* and *Larix*. This was probably the result of the cold climate due to the last glaciation.

There was evidence that there has been two general glaciation in Asia (Brooks, 1922), of which the first was more severe, separated by a long interglacial during which in Japan at least the climate became appreciably warmer than present (Oseki, 1915; Simotomai, 1914). The first glaciation was related to elevation in the Arctic basin, which closed Bering Strait and united the New Siberian islands to the main land. It was almost certainly contemporaneous with the first glaciation (Gunz-Mindel) in Europe. The ice began to be a glacier on the mountains in Scandinavia, but, owing to the scanty supply of snow, it developed slowly and only reached the dignity of ice-sheets in northeast Siberia. Then followed subsidence below the present level, wider opening of the Bering Strait, warm ocean current and a long interglacial. After this there was again elevation and a re-development of ice-sheets, but apparently once only, and not twice in Europe. This glaciation probably correspond in point of time more or less with the Rissian.

In northeastern Korea, Mt. Kwanmo (2,540 m) at the northeast end of the Kaema Plateaus has had small glaciers which were possibly results of last glaciation, as inferred from 18 cirques occurring at about 2,000 m and moraines as low as 1,700 m. The low snowline resulted from large precipitation value was caused by the winter monsoon (Sasa and Tanaka, 1938). Although the glaciation didn't advance to Youngnangho, the vegetation has been affected by the cold climate accompanied by glaciation. Under this condition warm-temperate species could not develop in this time, except the boreal elements.

Cyperaceae's peak in zone L was accompanied by *Artemisia*, Gramineae, Chenopodiaceae and Compositae, which suggest that the condition was cold and dry. Toward the end of zone L dated 15,300±215 yr BP the climate became mild and still dry, consequently the vegetation was scant.

Around 10,500 years ago the initial vegetation at Youngnangho was replaced by a large amount of grasses and ferns. This means that the climate was warmer and drier than the late-glacial period. Boreal species which were the main elements during the late-glacial period decreased. Still some of them remained in high altitude at least over 1,000 m, however, and showed sporadic occurrence in this time. *Pinus* (diploxylon) had small peak in the middle of this zone and *Lepidobalanus* gradually increased. Trees except *Pinus* and *Lepidobalanus* were not an important part of vegetation. *Carpinus*, *Ulmus*, *Tilia* and *Juglans* appeared constantly. Rest of broad-leaved species began to start during this zone but these also were not important. Probably it was due to the combination of dry condition plus well-drained soil. The region was covered mainly with herbaceous plants, ferns, and some stands of deciduous oak and pine. It seemed that temperature increased gradually and the climate was fairly dry, so the vegetation became more open in zone I than in the end of zone L. However, declines of herbaceous species at the end of zone I indicated the increase of dense forest. Small amounts of charcoal fragments could be seen in this period.

Zone I corresponded to the zone IV (Birch-Pine zone) which is considered the opening of the postglacial period after the late-glacial in England and Wales (Godwin, 1940), and to the zone A (Birch-Pine zone) of New England in North America (Deevey, 1951).

The zone II ended ca. 4,000 years ago at Youngnangho. Oak-pine forest has developed considerably during this period with other broad-leaved species, especially *Carpinus*, which means temperature was increased and moisture was enough for tree species. Most of arboreal species have maximum pollen concentration during this time.

Continuous occurrence of Moraceae indicates warm temperature and the peak of *Platycarya* (*P. strobilacea*) in the middle of this zone, now having the limited distribution to only the southern Korea, the southern Japan and the part of China, is also a good evidence of mild condition. Judging from the above, zone II estimated to be 9,500 and 4,500 years ago which was the interval now widely recognized as "Hypsithermal" (Deevey and Flint, 1957), during this time the forest probably reached climax under the best climatic environments. Oak and pine were the leading elements with great abundance and decreased toward the end of zone II.

Alnus and *Corylus* increased toward the end of this time, when oak and pine began to decrease. Probably in some area oak and pine stands were replaced by *Alnus* and

Corylus which are elements of secondary forest. Drop in herbaceous species also points to forest expansion. Among the herbaceous species, *Artemisia* and Gramineae were important part of vegetation. *Pediastrum* was very abundant, so the lake was clear and few organisms survived in the water through the zone Ⅱ. At the margin of the lake, some aquatic species, such as *Typha*, Cyperaceae, *Myriophyllum* and *Lythrum* grew.

It can be seen three peaks of concentration of charcoal fragments in zone Ⅱ. The contemporaneous increase in the number of charcoal fragments suggested an increase of fire frequency. Following every peaks of charcoal fragments, pine reached high concentration. Charcoal study at the lake of Minnesota showed good relationship between fire and pine, especially *Pinus banksiana* which requires periodic fire for adequate reproduction (Swain, 1973; Davis, 1967). In Korea, however, it seemed that *Pinus densiflora* correspond to the fire instead of *Pinus banksiana* in North America.

Zone Ⅲa of Youngnangho showed cooling condition. However, the boreal species did not develop fully, but *Betula* gradually replaced *Carpinus* which perhaps was not able to tolerate the cooling climate in zone Ⅲa. Other temperate elements, such as *Lepidobalanus, Juglans, Platycarya, Tilia, Ulmus* also decreased through this time. This zone Ⅲa corresponds to the subatlantic zone in Europe, and to the period in which *Tsuga heterophylla* and *Pseudotsuga* increased in North America 4,000 years ago. All these indicate the worldwide falling of temperature.

Castanea increased toward the uppermost of zone Ⅲa although it can't grow under the cool climate. However, *Castanea* was related to human disturbance (Davis, 1968), probably by the reason of the edibility of its nut, so that *Castanea* might be grown at the hilly district in this time. While most of arboreal species declined during zone Ⅲa, herbaceous species, particularly *Artemisia* and Gramineae showed sudden increase due to the cool climate.

Pediastrum decreased in zone Ⅲa. Perhaps more organisms lived in the water of this zone than zone Ⅱ, so that the lake was changed from oligotrophic to eutrophic condition.

Pine and oak were main species in zone Ⅲa of Wolhamji and other temperate elements existed through this period. Especially *Cyclobalanopsis*, which grows under 11.5 ± 2.86 °C of the annual mean temeperature, and *Castanopsis*, its distribution is limited to 13.1 ± 2.45°C of annual mean temperature (Yim, 1977), show significant amount. Although zone Ⅲa was posthypsithermal period, the climate of Wolhamji was not too cold to kill the warm-temperate evergreen trees.

Some aquatic species, for instance, *Myriophyllum, Potamogeton, Sagittaria* and *Typha* appeared from the beginning of this zone. According to historical records (Samkooksagi), Wolhamji was constructed for resort area of King Moo of Baekje dynasty (AD 638), but pollen sequence was not consistent. Perhaps it was a good place in which there was a small pond and some plants grew around the pond, and artificial decoration was added for King. Pollen diagram of Wolhamji showed that it was a natural pond.

Wolhamji core has no radiocarbon dates, but if dates of other two study sites apply to this core, the date of the boundary between zone Ⅲa and Ⅲb is approximately 2,000 years ago.

In case of Bangeojin, located at the southeast of the Korean Peninsula, oak was more abundant than pine (almost twice as much as pine), which is shown neither at Youngnangho nor at Wolhamji. Probably climatic conditions were more suitable for the oak at Bangeojin. *Podocarpus* and *Cryptomeria*, exotic species in Korea, appeared only in Bangeojin core. It seems that their pollen grains were transported from Japan by wind, because they were very abundant in Japan during this time (Tsukada, 1974).

Bangeojin had similar vegetation to that of Wolhamji, because both had significant amount of warm-temperate species during the cooling period. Warm-temperate evergreen species such as *Cyclobalanopsis* and *Castanopsis* showed fairly large amount of pollen concentration than other two study sites. Particularly *Camellia* and *Elaegnus* which can grow under $13.1\pm1.71^{\circ}C$ of annual mean temperature (Yim, 1977) at least appeared only here. Although the zone was in cooling period, the climate was the mildest among three sites.

Herbs were not important elements in the vegetation, but *Artemisia* was common here. Fairly large amount of *Typha* and sporadic occurrence of other aquatic species reflected the damp condition around the pond. *Pediastrum* appeared with large concentration in this zone, but it was absent at the end of zone Ⅲa and became extinct completely. This boundary estimated to be $2,350\pm100$ yr BP and approximately 300 years later rice cultivation has begun. Therefore, sudden disappearance of *Pediastrum* and drastic increase of charcoal fragments should be related to the human impact. Presumably the bottom of the pond has filled gradually with sediment and eventually became rice paddy.

Zone Ⅲb could be called a pine period; most of its pollen was *Pinus densiflora* judged by characteristics which were established by Ueno (1958) and by its dominance in present forest. Zone Ⅲb was obviously a disturbed period. Through this period, forest was cleared by human interference, especially agricultural activites. Continuous burning of forest was clearly shown by numerous charcoal fragments. In the tropical area slash-and burn techniques have been used for agriculture, and this evidence was also shown by charcoal fragments (Tsukada and Deevey, 1967). All three study sites showed that appearance of rice pollen (*Oryza sativa*) coincides with pine expansion together with increase of herbaceous species. The prime indicator of agriculture, *Rumex*, *Plantago* and *Thalictrum* increased appreciably in this time. At Youngnangho all species dropped in their pollen concentrations probably because of the increase of sedimentation rate or less compaction of sediments.

In case of Wolhamji aquatic species were more abundant. Especially *Nuphar*, very common species to decorate the pond these days, are shown here. It suggests that *Nuphar* was probably planted around the pond for ornamenting 1,300 years ago when Wolhamji was constructed. *Trapa* living in the water showed high pollen concentration at the end of zone Ⅲb, but it fell suddenly at the surface. This was the evidence that Wolhamji was left until it was converted to rice paddy in 1947.

Zone Ⅲb at Bangeojin was also pine period together with great amount of herbaceous species. Charcoal fragments were the most abundant among three study sites. This corresponds very well with the highest pollen concentration of *Oryza* type at Bangeojin. Therefore, rice would be proceeded the most intensively in Bangeojin area by the good climatic condition for rice.

摘 要

영랑호, 월함지, 그리고 방어진에서 실시한 화분분석은 한반도에서 제 4기 이후의 식피변천을 보여준다. 이에 의하여 지난 15,000년 동안 한반도에서 5개의 다른 화분대를 구별할 수 있다. 후빙기인 화분대 L(~10,500 yr BP)동안에 한반도의 식피는 침엽수림으로 덮여 있었고, 주수종은 가문비나무, 낙엽송, haploxylon 소나무, 전나무이며 초본류도 상당량 나타났다. 화분대 Ⅰ(10,500~7,500 yr BP)에서는 초본류가 우점종을 이루면서 참나무와 diploxylon 소나무도 공존하는데 이것은 환경조건이 후빙기보다 따뜻하면서 다소간 건조하였을 것을 시사한다. 화분대 Ⅱ(7,500~4,000 yr BP)는 화분대 Ⅰ보다 더 따뜻해지는데 이것은 참나무와 diploxylon 소나무, 그리고 서나무가 더욱 증가하며, 낙엽활엽수가 더욱 다양해지는 것으로 보아 유럽에서나 미국에서와 마찬가지로 기후가 가장 따뜻했던 hypsithermal period로 여겨진다. 화분대 Ⅲa (4,000~1,500 yr BP)에서는 소나무와 참나무가 역시 주수종이고, 자작나무가 조금씩 증가하는 반면에 소나무가 감소하는데 이러한 현상은 이 시기에 기후가 다시 한냉해졌음을 뜻한다. 화분대 Ⅲb(1,500 yr BP~)는 소나무대로 간주되며 인간간섭의 결과가 뚜렷이 나타나기 시작한다. 벌목후에 농경이 시작되었고, 이 농경의 시작은 수종의 급격한 감소와 더불어 벼, 메밀, 여뀌와 질경이의 증가를 수반한다. 화분대 Ⅰ과 Ⅲb에서 목탄조각이 상당량 나타나는데, 전자는 산림화재 때문으로 추측되며, 후자는 인간의 간섭, 특히 농경의 결과로 해석된다.

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REFERENCES

Benninghoff, W. S. 1962. Calculation of pollen and spores density in sediments by addition of exotic pollen in known quantities. *Pollen et Spore* 4 : 332~333.

Brooks, C. E. P. 1922. The evolution of climate. Benn Brothers, London.

Davis, M. B. 1967. Pollen studies of near-surface sediments in Main lakes. *In* Quaternary Paleocology, E. J. Cushing and H. E. Wright, Jr. eds., pp. 147~173. Yale. Univ. Press, New Haven.

_____. 1968. Climate changes in southern Connecticut recorded by pollen deposition at Rogers lake. *Ecology* **50** : 409~422.

Deevey, E. S. Jr. 1951. Late-glacial and postglacial pollen diagrams from Maine. *Amer. J. Sci.* **249** : 177~207.

_____ and R. F. Flint. 1957. Postglacial hypsithermal interval. *Science* **125** : 182~184.

Faegri, K. and J. Iversen. 1975. Textbook of pollen analysis 3rd Ed. Hafner Press, New York. 295 pp.

Godwin, H. 1940. Pollen analysis and forest history of England and Wales. *New Phytol.* **39** : 370~400.

Hong, S. 1978. Palynological studies of Koonja county, Korea. M.S. thesis Seoul National Univ.

Jo, W. 1979. Palynological studies on postglacial age in esatern coastal region, Korean Peninsula. *Tohoku-Chiri* **31** : 23~35.

Matsushima, M. 1941. 花粉統計にする朝鮮の森林變遷の考察. 日本林學會誌 **23** : 441~450.

Nakamura, J. 1974. Some palynological notes on grass pollen, with special references to *Oryza sativa*. *Quat. Res. Japan* **13** : 187~193.

Oh, C. Y. 1971. A pollen analysis in the peat sediments from Pyungtaek county, *Kor. J. Bot.* **14** : 126~133.

Oseki, K. 1915. Some notes on the glacial phenomena in the north Japanese Alps. Ediburgh, Scot. Geogr. Mag., No. 31.

Sasa, Y. and K. Tanaka 1938. Glaciated topography in the Kanbo Massif, Korea. Hokkaido Imperial Univ. *J. Fac. Sci., ser.* 4 : 194~212.

Simotomain, H. 1914. Die diliviale Eiszeit in Japan. Berlin, Zs. Ges. Erdkunde.

Swain, A. M. 1973. A history of fire and vegetation in northern Minnesota as recorded in lake sediments. *Quat. Res.* **3** : 383~396.

Tsukada, M. 1974. Paleoecology Ⅱ. Kyoritsu-shuppan, Tokyo. 231 pp.

_____. 1978. Environmental history of the Korean Peninsula Ⅱ. *Ecol. Japan Hiroshima* **24** : 168.

_____ and E. S. Deevey. 1967. Pollen analysis from four lakes in the Southen Maya area of Guatemala and El Salvador. *In* Quaternary Paleoecology, E. J. Cashing and H. E. Wright, Jr. eds. pp. 30~331. Yanle Univ. Press, New Haven.

_____ and Y. Yasuda 1977. Environmental history of the Korean Peninsula Ⅰ. *Jap. Associ. Quat. Res. Congr. Sendai* **5** : 21.

Ueno, J. 1958. Some palynological observations of Pinaceae. *J. Inst. Polytechnics Osaka City Univ., ser.* D **9** : 163~186.

Yamazaki, S. 1940. 花粉分析にする朝鮮南部の 樹種變遷に關する考察. 日本林學會誌 **22** : 73~85.

Yim, Y. J. 1977. Distribution of forest vegetation and climate in the Korean Peninsula. Ⅳ. Zonal distribution of forest vegetation in relation to thermal climate. *Jap. J. Ecol.* **27** : 269~278.

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