Geosciences Journal
Vol. 10, No. 4, p. 423 − 431, December 2006

Vegetation and climate changes during the Late Pleistocene to Holocene inferred from pollen record in Jinju area, South Korea

Chull-Hwan Chung* *Faculty of Earth Systems and Environmental Sciences, Chonnam National University, Gwangju 500-757, South Korea*
Hyoun Soo Lim
Ho Il Yoon } *Korea Polar Research Institute, KORDI, Incheon 406-840, KOREA*

ABSTRACT: The pollen record from paleo-swamp deposits spanning the last ca. 26,000 yr reveals a detailed history of vegetation and climate changes of the Jinju area, South Korea. From ca. 26.2 to 23.9 cal. kyr BP, xerophytic *Artemisia*-dominated grassland and mixed subalpine coniferous and deciduous broadleaved forests occupied the study area, indicating a cool and dry condition during interstadial stage of the last glacial period. The period between ca. 23.9 and 14.7 cal. kyr BP exhibits the expansion of grassland and subalpine coniferous forest and the retreat of deciduous broadleaved forest, reflecting a cold and dry condition during the Last Glacial Maximum (LGM). During the period of ca. 14.7–11.2 cal. kyr BP, climatic amelioration comparable to the Boelling-Alleroed Event induced an enlargement of temperate deciduous broadleaved forest and a shrink of subalpine coniferous forest and grassland. Vegetation changes controlled by human impact occurred from ca. 4.7 to 0.7 cal. kyr BP, as indicated by an increase in *Pinus* and Gramineae pollen.

Key words: Late Pleistocene to Holocene, palaeovegetation, palaeoclimate, pollen, Jinju in South Korea

1. INTRODUCTION

The last deglacial period during the Late Pleistocene to the Holocene has been considered to be important in understanding present climate evolution and vegetation history (Traverse, 1988; Whitlock and Bartlein, 1997; Rioual et al., 2001). Various high resolution paleoclimate records show that abrupt environmental changes including sea-level change and vegetation shift occurred in many parts of the world during this period (Bond et al., 1993; Dansgaard et al., 1993; Grootes et al., 1993; Schulz et al., 1998; Allen et al., 1999; Nakagawa et al., 2003), and provide useful information on climate changes.

The difference in climatic conditions between glacial and interglacial periods might have induced a drastic vegetation change and was expected to be well preserved in pollen record. Among various terrestrial paleoclimate proxies, pollen has proven to be one of the most useful tools (Birks and Birks, 1980; Traverse, 1988). Pollen is well suited to examine the impact of rapid climate fluctuations on terrestrial ecosystems since the response of vegetation to climate change is pronounced and can occur on a decadal time scale (Tinner and Lotter, 2001).

Comparing with other terrestrial sequences, paleo-swamp deposits are relatively untouched, and thus provide a long record of climate and vegetation changes (Chamber and Charman, 2004).

Although a number of palynological studies on the Late Quaternary deposits in Korea have been carried out (Yoon, 1996, 1997; Yoon and Jo, 1996; Choi, 1998; Chung et al., 2004; Park and Oh, 2004; Yi et al., 2004), most of them were focused on the Holocene deposits, and thus the detailed information on palaeovegetation and/or paleoclimate covering the deglacial period during the Late Pleistocene to the Holocene is rarely known.

In this paper we explored a long pollen record spanning Late Pleistocene to Holocene from a paleo-swamp in the Jinju area, South Korea. The result is expected to provide useful information on the history of vegetation and climate in the central part of the southern Korean Peninsula during the Late Pleistocene and Holocene.

2. LOCATION AND SETTING

Korea is situated at the eastern end of the Asian continent adjacent to the West Pacific and belongs to the temperate zone with four distinct seasons. During the winter, from December to February, it is cold and dry under the dominant influence of the northwesterly Siberian air mass. Meanwhile, the summer, from June to August, is hot and humid with frequent heavy rainfalls associated with the East Asian monsoon.

The Jinju area is located in the central part of southern Korea, about 300 km southeast of Seoul (Fig. 1). This area is surrounded by hills with elevations of 100–300 m a.s.l., and is bordered on the north by the Sobaek Mountains at a distance. The mean annual temperature of the study area during the last 30 years is 13.1°C, and the mean temperatures in August and in January are 25.6°C and 0.1°C, respectively (Korea Meteorological Administration, 2003).

---

*Corresponding author: chungch93@hanmail.net

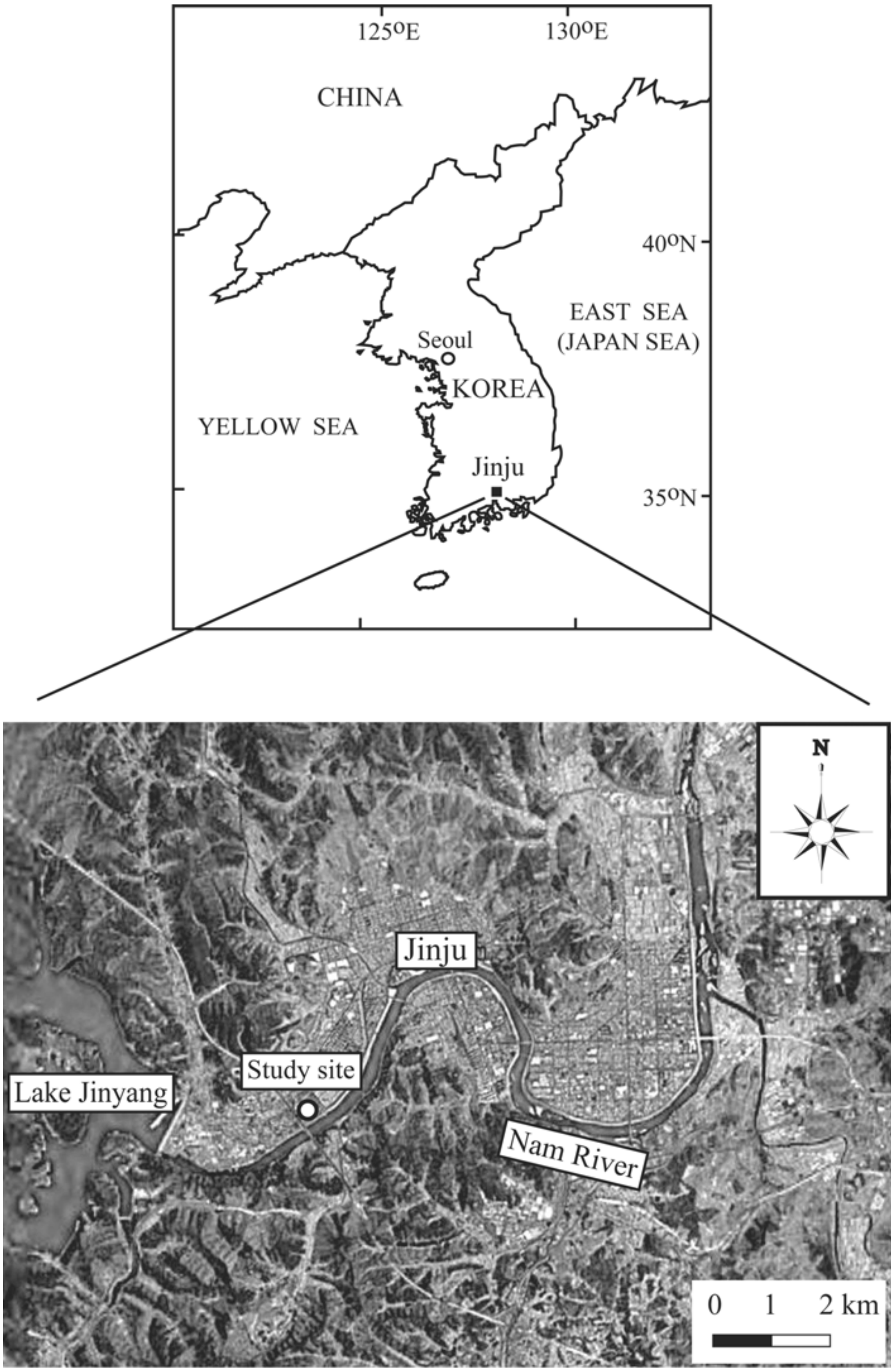

Fig. 1. Map showing location of study area.

Precipitation is relatively high, averaging 1,489.9 mm per year, and about 60 % of the annual precipitation falls in the summer (June-August). The Pyonggeodong archaeological site (35°10′07″N, 128°03′43″E) is situated in the western part of Jinju City, adjacent to Jinyang Lake, and is on the floodplain of the Nam River. The Quaternary paleo-swamp deposits studied were exposed by archaeological excavations in 2005 and are estimated to exceed 3 m in thickness. The deposits consist of fine sand, silty mud, peat and mud (Fig. 2). The lowermost 80 cm is a homogeneous grey mud layer containing plant rootlets. The overlying layer consists mainly of peat and sandy peat with intercalation of a 15-cm-thick yellowish grey mud layer, and appears to be swamp deposits. The overlying 60 cm is a well sorted grey fine sand layer. The uppermost layer is a 50-cm-thick dark brown silty mud.

The modern natural vegetation of the study area, especially in the lowlands, was destroyed or greatly modified by cultivation and urbanization. The neighboring vegetation

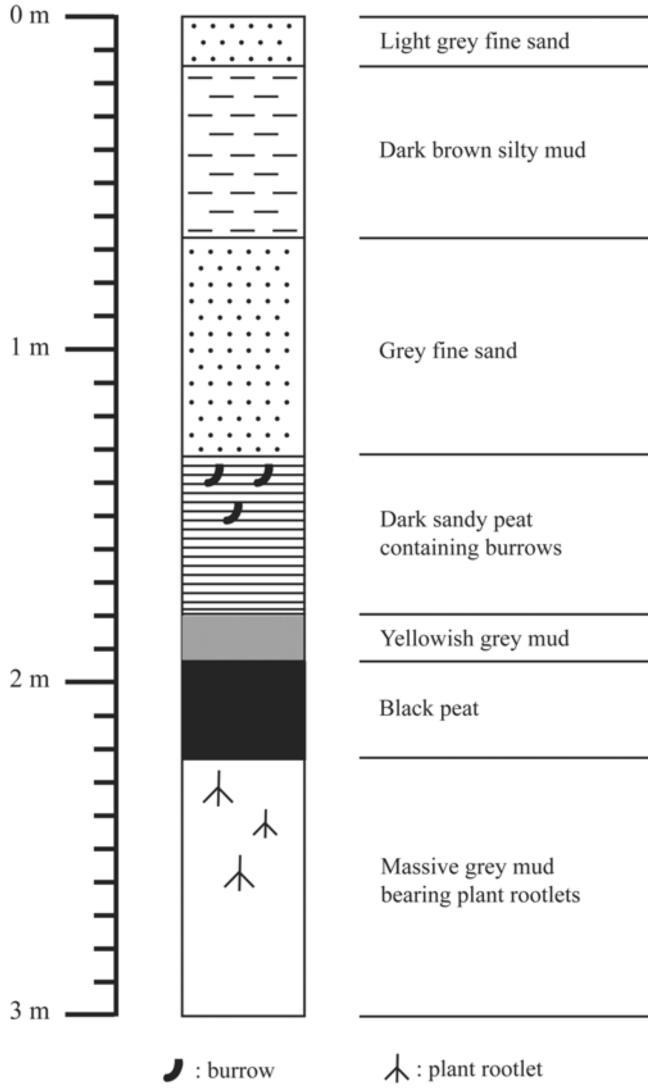

Fig. 2. Lithology of archaeological trench studied.

reservations such as national park, nevertheless, are keeping the natural vegetation which belongs to the southern temperate deciduous broadleaved forest (Uyeki, 1933; Yim and Kira, 1975). This forest includes diverse deciduous broadleaved trees such as *Quercus variabilis, Q. acutissima, Q. aliena, Q. serrata, Q. mongolica, Betula ermanii* var. *saitoana, Carpinus laxiflora, Corylus heterophylla, Salix glandulosa, Prunus sargentii, Fraxinus rhynchophylla*, etc. and some coniferous taxa such as *Pinus densiflora* and *Juniperus chinensis* (Kim, 1988; Lee and Yim, 2002).

3. MATERIALS AND METHODS

For this study a 3.0-m-deep trench was excavated and thirty samples were taken at 10 cm intervals from the vertical section of the trench. 2 g of each sample was processed for extraction of pollen and spore using standard pollen preparation techniques, which included treatments with 10% KOH and 45% HF, mineral separation with a $ZnCl_2$ solution (sp. gr., 2.0), acetolysis, and mounting in glycerin jelly. *Lycopodium* spore tablets (batch #483216, mean= 18,583±764 spores per tablet) were added to each sample prior to preparation to estimate pollen concentration (Stockmarr, 1972; Maher, 1981).

Pollen and spores were identified and counted with a light microscope at 400× magnification, but a magnification of 1,000× was used for some critical determinations. Taxonomic identification was based upon Chang and Rim (1979), Nakamura (1980a, b) and Wang et al. (1995). Over 250 pollen grains of trees and herbs were counted for each sample. Considering that any taxon is over-represented throughout the pollen record, for the calculation of the percentages only indeterminable grains have been excluded from total sum of pollen and spores. Only the principal pollen and spores were included in the percentage pollen diagram. The percentages of arboreal pollen (AP) and non-arboreal pollen (NAP) were calculated from total sum of pollen and spores.

The chronology of the site is based on the radiocarbon dating of bulk soil samples. Six soil samples taken from the vertical section were dated using a conventional method with the extended counting time at Geochron Laboratories, USA.

4. RESULTS

4.1. Chronology

Chronological control is of course crucial to the successful use of any palaeoclimate proxy. In this study, we performed six radiocarbon dating and the results are shown in Table 1 and Figure 3. Radiocarbon dates were calibrated to calendar years using the terrestrial INTCAL98 dataset from Stuiver et al. (1998) by means of the CALIB program 5.0 (Stuiver et al., 2005) (Table 1).

Calendar age errors are generally small and this permits the construction of a reliable age-depth model (r^2=0.99). The age determinations reveal that this 3 m-thick soil horizon was formed from Late Pleistocene to Late Holocene. Based on sedimentation rate interpolations between radiocarbon dates the average accumulation rate is roughly calculated to be about 0.11 mm/yr (Fig. 3).

4.2. Pollen Zonation

Diverse assemblages of palynomorphs occurred from paleo-swamp deposits of the Pyonggeodong archaeological site. Principal components include trees of *Pinus, Picea, Abies*, Taxodiaceae-Cupressaceae-Taxaceae (T-C-T), *Salix*, *Alnus, Betula* and *Quercus (Lepidobalanus),* and herbs of *Artemisia*, Compositae, Chenopodiaceae, Gramineae, Cyperaceae and Umbelliferae. Five local pollen assemblage zones including

Table 1. Radiocarbon ages from the Jinju archaeological site, South Korea.

Sample Code	Material	Depth below surface (cm)	$\delta^{13}C$ (‰)	^{14}C Age (yr BP)	Calibrated age ranges, 2σ (yr BP)	Calibrated age ranges, 2σ (BC/AD)
RB-1	soil	20-30	−22.7	2140±80	1950-2332	BC 383-AD 0
RB-2	soil	40-50	−23.1	2200±80	2003-2346	BC 397-BC 54
RB-3	soil	60-70	−24.3	4200±80	4448-4957	BC 3008-BC 2499
RB-4	soil	160-170	−25.9	11040±150	12808-13226	BC 11277-BC 10859
RB-5	soil	190-200	−26.5	14560±200	16783-18475	BC 16526-BC 14834
RB-6	soil	270-280	−25.6	20160±1300	21211-26000	BC 24051-BC 19262

*Calibrated using CALIB 5.0 (Stuiver et al., 2005)

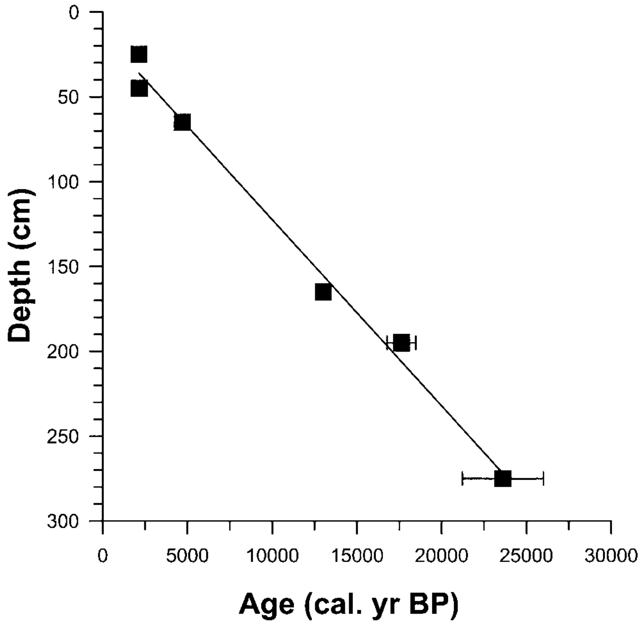

Fig. 3. The age-depth plots of six radiocarbon ages.

one barren zone were identified based on variations of percentages of the principal components and conspicuous fluctuation in pollen concentration (Fig. 4). The characteristics of the local pollen assemblage zones are described in ascending order.

4.2.1. Pollen zone I *(300 – 280 cm, ca. 26.2-23.9 cal. kyr BP)*

This zone is dominated by AP of *Picea*, *Salix, Alnus* and *Quercus (Lepidobalanus)*, and NAP of *Artemisia* and Compositae. Arboreal pollen, mainly derived from *Quercus (Lepidobalanus)* (11–13%), *Salix* (6–8%), *Picea* (4–6%) and *Alnus* (4–6%), account for 51–53% of the total palynomorph sum. Conifer pollen such as *Pinus* (2–3%) and *Abies* (1–2%) show relatively low values, but occur persistently. Other common arboreal pollen taxa are T-C-T (4–5%), *Betula* (3–4%) and *Castanea/Castanopsis* (3–4%). Among herbaceous taxa, *Artemisia* is the predominant component attaining up to 18–21% of the total palynomorph sum. Other common herbs are Compositae (7–8%), Cyperaceae (3–5%) and Chenopodiaceae (3–4%). The pollen concentration is relatively high reaching 90,000–120,000 grains/g.

The pollen assemblage suggests a mixed coniferous and deciduous broadleaved forest in company with open grassland on the riverside of the Nam River.

4.2.2. Pollen zone II *(270–180 cm, ca. 23.9-14.7 cal. kyr BP)*

This pollen zone begins with an apparent increase in *Artemisia* and *Picea*, and a decrease in *Quercus (Lepidobalanus)* and T-C-T, and is characterized by a predominance of herbaceous pollen. Herbaceous pollen represented by *Artemisia* (23–30%), Compositae (6–12%) and Gramineae (3–9%) account for 51–63% of the total palynomorph sum. Arboreal pollen, mainly derived from *Quercus (Lepidobalanus)* (7–12%), *Picea* (5–12%), *Betula* (4–8%) and *Salix* (3 –7%) decrease to 36–47%. The percentages of T-C-T (<2%) and *Alnus* (1–4%) pollen are reduced, but that of *Abies* (2–4%) is slightly increased. Other common components are *Pinus*, *Carpinus* and *Castanea/Castanopsis* of AP, and Umbelliferae, Cyperaceae and Chenopodiaceae of NAP. Fern spores, particularly the monolete type, are rare (1–3%) and occur sporadically. The pollen concentration is slightly increased to 100,000–200,000 grains/g.

The palynomorph assemblage of this zone indicates the expansion of grassland vegetation and subalpine coniferous forest, and the retreat of deciduous broadleaved forest, which is an evidence of climatic deterioration.

4.2.3. Pollen zone III (*170–140 cm, ca. 14.7-11.2 cal. kyr BP*)

This zone is marked by apparent decrease in *Artemisia* and *Picea* pollen and by remarkable increase in *Quercus (Lepidobalanus)* pollen and Polypodiaceae spores. The total AP is increased, but the total NAP is reduced. This zone is contains high percentages of AP, including *Quercus (Lepidobalanus)* (10–15%) and *Salix* (6–8%), NAP referable to *Artemisia* (11–19%), and Polypodiaceae spores (5–8%). *Picea* pollen decreases to 2–4%, and Compositae to 3–6% of the total palynomorph sum. Other common components are T–C–T, *Betula*, *Alnus* and *Castanea/Castanopsis* of AP, and Gramineae, Umbelliferae and Chenopodiaceae of NAP.

Thermophilic *Quercus (Cyclobalanopsis)* pollen shows relatively low values of 1–3%, but occurs persistently throughout

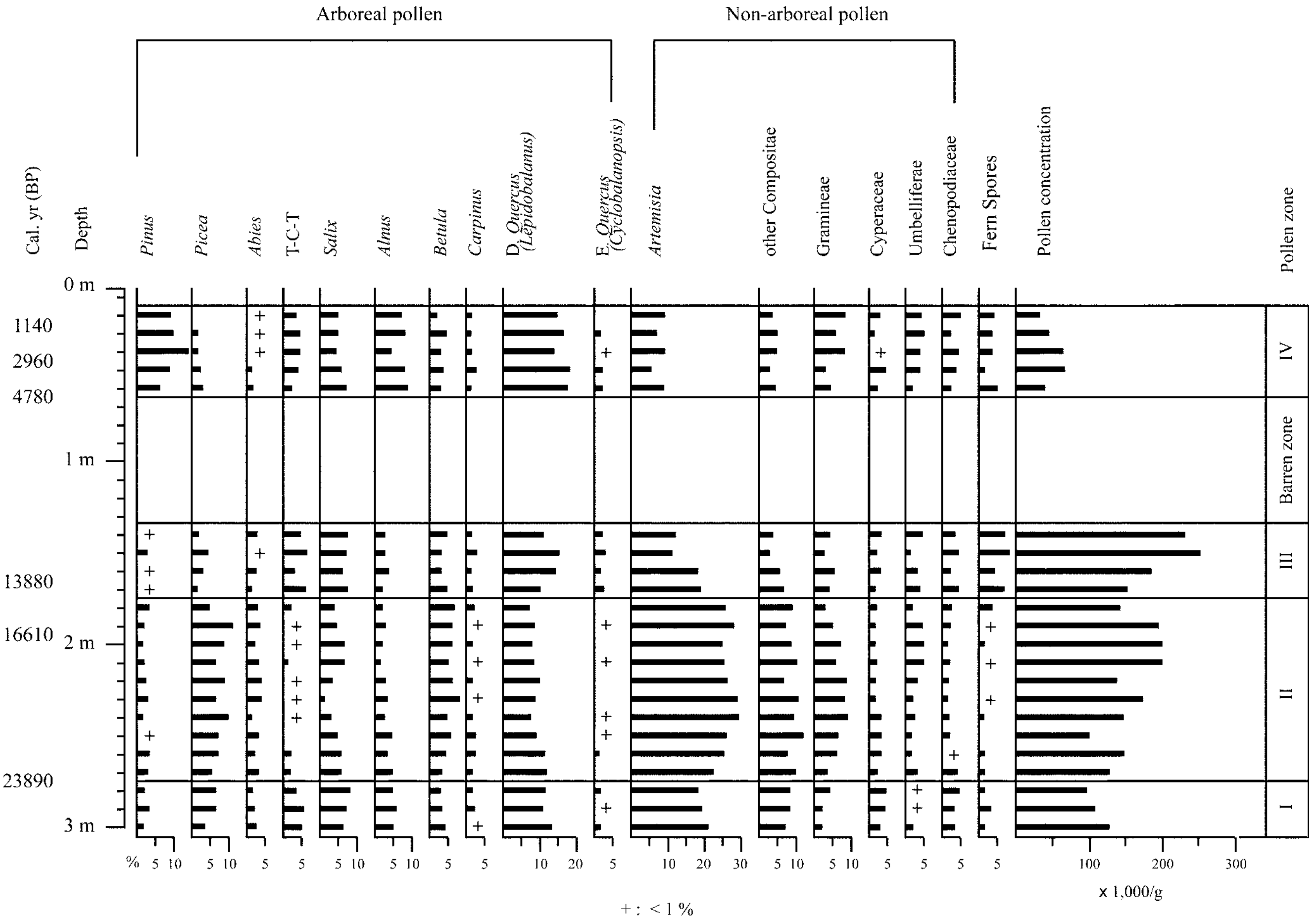

Fig. 4. Percentage diagram of the principal palynomorph taxa. T-C-T in figure is an abbreviation for Taxodiaceae-Cupressaceae-Taxaceae.

this pollen zone. The pollen concentration attains its highest values reaching 160,000–260,000 grains/g.

The palynomorph assemblage of this zone designates the expansion of deciduous broadleaved forest and the retreat of grassland vegetation and subalpine coniferous forest, implying climatic amelioration.

4.2.4. Barren zone (*130–70 cm, ca. 11.2-4.7 cal. kyr BP*)

No palynomorphs are recovered from the grey fine sand of which this interval of the sedimentary succession is composed. As a result, palynological analysis on this interval is leaved out.

4.2.5. Pollen zone IV (*60–20 cm, ca. 4.7-0.7 cal. kyr BP*)

This zone shows a continued increase in AP and a sharp decrease in pollen concentration (30,000–70,000 grains/g). Arboreal pollen, mainly derived from *Quercus (Lepidobalanus)* (14–18%), *Pinus* (6–14%) and *Alnus* (4–9%), account for 50–65% of the total palynomorph sum. The percentages of *Quercus (Lepidobalanus), Pinus* and *Alnus* pollen attain their highest values. The percentages of *Picea* and *Abies* pollen decrease upward. The total NAP is slightly reduced, but Gramineae pollen increases, especially in the upper part of this pollen zone, up to 8%. *Artemisia* pollen decreases to 5–9%, and Compositae to 2–5% of the total palynomorph sum. Other common components are T–C–T, *Salix, Betula* and *Alnus* of AP, Umbelliferae and Chenopodiaceae of NAP, and Polypodiaceae spores. The percentage of thermophilic *Quercus (Cyclobalanopsis)* pollen is maintained.

The palynomorph assemblage of this zone indicates deciduous broadleaved forest in company with open grassland on the lowland and coniferous forest in the highlands of the hinterland, and appears to be similar to modern vegetation of the study area.

5. DISCUSSION

5.1. Vegetation history

The pollen record from paleo-swamp deposits in the Jinju area reveals a detailed vegetation history during the Late Pleistocene to Holocene. Remarkable fluctuations in the percentages of principal palynomorph taxa between pollen zones indicate that the vegetation changes were distinct and extensive.

The palynomorph assemblage of Pollen Zone I (*300–280 cm, ca. 26.2-23.9 cal. kyr BP*) is composed mainly of deciduous broadleaved trees and grasses. The predominance of cool temperate taxon, *Quercus (Lepidobalanus),* and xerophytic herb *Artemisia* and Compositae suggests the development of grassland vegetation on the lowland along the riverside of the Nam River in company with cool temperate deciduous broadleaved forests. Significant proportions of subalpine coniferous and deciduous broadleaved trees such as *Picea, Abies* and *Betula*, are considered to reflect the montane vegetation of the hinterland. The subalpine coniferous taxa, *Picea* and *Abies* are now growing at altitude of about 1,000–2,000 m in Korea and central Japan (Miyoshi et al., 1999; Lee and Yim, 2002). Considering the low topography of the Jinju area with elevations of 100–300 m a.s.l., considerable occupancy of subalpine taxa implies the expansion of the subalpine forest belts to the lowland due to a climatic deterioration.

A further lowering of the subalpine forest belts is recognized in the palynomorph assemblage of Pollen Zone II (*270–180 cm, ca. 23.9-14.7 cal. kyr BP*), as indicated by an increase in the proportion of the subalpine taxa such as *Picea, Abies* and *Betula*, and a decrease in that of deciduous broadleaved taxa (Fig. 5). Along with the expansion of the subalpine forest, a rise in representation of NAP such as *Artemisia*, Compositae and Gramineae, reflects the continued climatic deterioration. This pollen zone represents grassland vegetation on the lowland with patches of cool temperate deciduous broadleaved forests, and mixed subalpine coniferous and deciduous broadleaved forests in the montane of the hinterland. Together with the preceding Pollen Zone I, this pollen zone reflects the vegetation favored by cool and dry climatic conditions during the last glacial period.

The vegetation reconstructed from Pollen Zone III (*170–140 cm, ca. 14.7-11.2 cal. kyr BP*) is clearly discriminated from those from pollen zones I and II. The palynomorph assemblage of Pollen Zone III is characterized by a predominance of *Quercus (Lepidobalanus), Salix* and Polypodiaceae. A remarkable decrease in the proportions of conifers

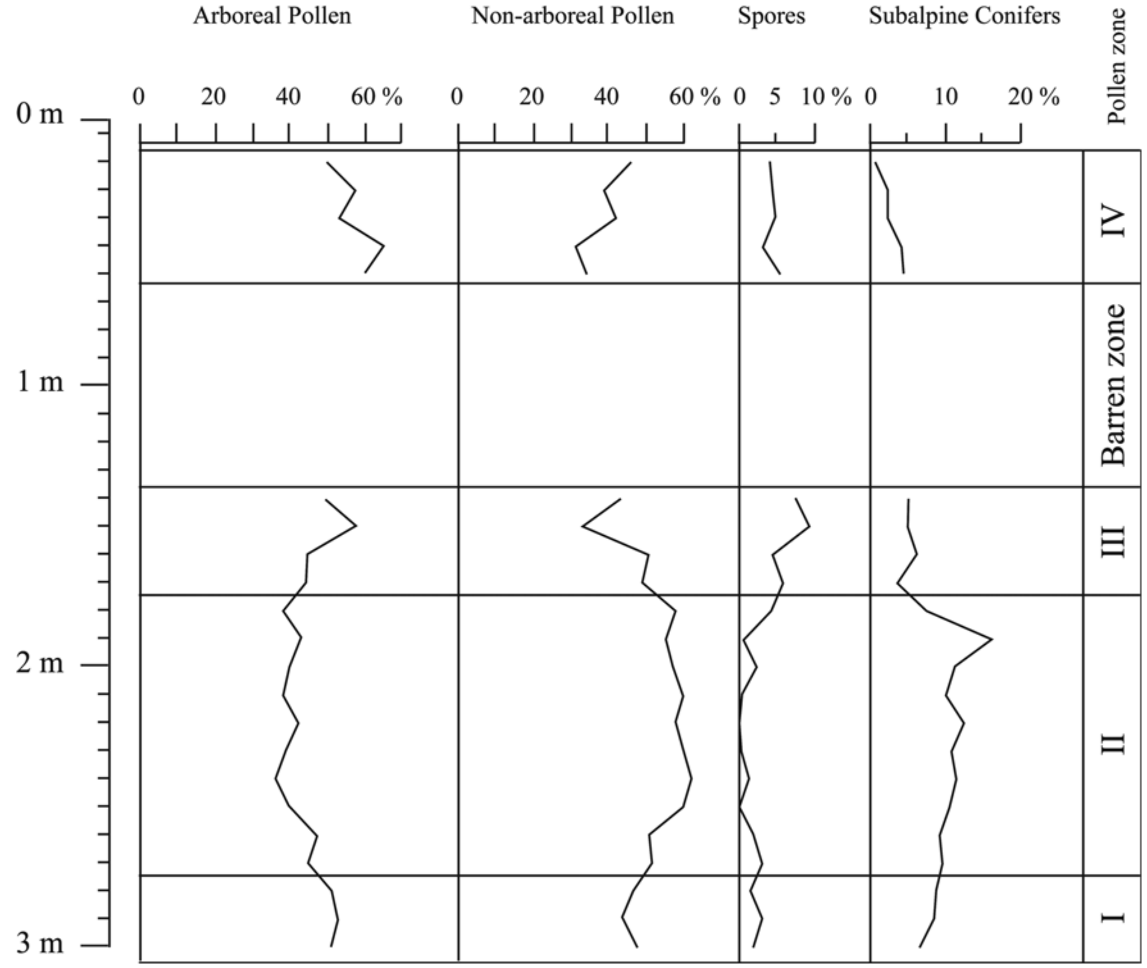

Fig. 5. Fluctuation in proportions of arboreal pollen, non-arboreal pollen, fern spores, and subalpine coniferous pollen.

and herbs, and an increase in that of deciduous broadleaved trees imply that a significant vegetation shift occurred. An abrupt increase in Polypodiaceae spores is known as a sign of vegetation transition during the last deglacial period in Korea (Yasuda et al., 1980; Lee and Yim, 2002; Chung et al., 2004). *Artemisia*-dominated grassland was gradually replaced by deciduous broadleaved forests comprising Polypodiaceae and the subalpine conifers of mixed coniferous and deciduous broadleaved forest in the montane began to disappear. The high pollen concentration indicates that vegetation cover was dense during the periods from 14 to 12 cal. kyr BP. The palynomorph assemblage of this pollen zone appears to represent transitional vegetation from glacial type to postglacial, resulted from a climatic amelioration.

The reconstructed vegetation of Pollen Zone IV (*60–20 cm, ca. 4.7-0.7 cal. kyr BP*), dominated by *Pinus, Alnus* and *Quercus (Lepidobalanus)* indicates the expansion of deciduous broadleaved forest and the development of *Pinus* forest. *Pinus* took the place of the subalpine conifers, *Picea* and *Abies.* The apparent decline in the proportion of herbaceous taxa such as xerophytic herb *Artemisia* implies the retreat of grassland vegetation. However, the total NAP is slightly increased in the upper part of this pollen zone, as a result of rise in representation of Gramineae pollen (Figs. 4 and 5). Mixed pine and broadleaved deciduous forests reconstructed from this pollen zone are comparable to the modern vegetation in and around the study area, and are typical vegetation in the temperate zone of Korea during the late Holocene (Choi, 1998; Yi and Yu, 2001; Fujiki and Yasuda, 2004).

5.2. Paleoclimatic Implications

The distinct difference in vegetation between pollen zones is the result of climate changes, and thus an investigation on vegetation shift can provide the climatic conditions over the Jinju area during the last ca. 26 kyr. The rise and decline in deciduous broadleaved forest, subalpine forest and grassland must be intimately associated with climate changes.

The reconstructed vegetation of Pollen Zone I (from ca. 26.2 to 23.9 cal. kyr BP) characterized by predominance of xerophytic herb *Artemisia* and significant occupancy of subalpine taxa indicates that the climatic condition was cooler and drier than today. However, the climatic deterioration was not great, as indicated by the relatively high proportion of temperate deciduous broadleaved trees. Therefore, this vegetation appears to reflect an interstadial condition during the last glacial period.

The period between ca. 23.9 and 14.7 cal. kyr BP corresponding to Pollen Zone II was marked by a cold and dry climate, as indicated by the expansion of grassland and the subalpine forest (*Picea, Abies* and *Betula*) and the retreat of deciduous broadleaved forest. The reconstructed vegetation of Pollen Zone II is considered to be the result of response to a cold and dry climate during the Last Glacial Maximum (LGM). During the LGM a variety of environmental changes occurred in and around the Korean Peninsula. The continental shelves of the East China Sea and the Yellow Sea which surround the Korean Peninsula at the south and west respectively, were extensively exposed (Emery et al., 1971; Park et al., 1994; Ijiri et al., 2005; Kong et al., 2006). The exposure of the continental shelves around the Korean Peninsula must have affected the albedo and resulted in a more arid condition (Sun et al., 2000). The vegetation during the LGM in Korea is characterized by the expansion of *Artemisia*-dominated grassland and subalpine forest (Yasuda et al., 1980; Choi, 1998; Chung et al., 2004), same as in other parts of the world. Therefore, *Artemisia*-dominated grassland vegetation combined with subalpine coniferous forest of Pollen Zone II is interpreted to reflect a cold and dry climate during the LGM.

Climatic amelioration is detected at ca. 14.3 cal. kyr BP, as indicated by an increase in the proportions of deciduous broadleaved trees (*Quercus (Lepidobalanus), Salix* and T-C-T) and ferns. This climatic warming event is also supported by a remarkable decrease in the proportions of subalpine conifers and herbs. The reconstructed vegetation of Pollen Zone III (from ca. 14.7 to 11.2 cal. kyr BP) exhibits a continuous occurrence of thermophilous *Quercus (Cyclobalanopsis),* one of important constituents in warm temperate broadleaved evergreen forests, and the high pollen concentration as a possible evidence of dense vegetation cover, implying a warm and humid condition. This vegetation reflects not only the global warming but also the geographical change in and around the Korean Peninsula during the deglacial period. The continental shelves of the East China Sea and the Yellow Sea experienced the postglacial marine transgression and submerged (Kim and Kennett, 1998; Wang, 1999; Liu et al., 2004; Kong et al., 2006). A combination of the strengthening of the East Asian summer monsoon and submergence of the shelves must have brought about an increase in humidity as well as temperature. This warm and humid period is comparable to the Boelling-Alleroed Event recorded in the North Atlantic region.

The history of vegetation and climate of the period between ca. 11.2 and 4.7 cal. kyr BP are punctuated by barren zone.

The vegetation reconstructed from Pollen Zone IV (from ca. 4.7 to 0.7 cal. kyr BP) dominated by *Pinus, Alnus* and *Quercus (Lepidobalanus)* is the closest and most direct ancestor of the modern flora of the study area. The predominance of temperate deciduous broadleaved forest and *Pinus* forest is a typical feature in Korea during the late Holocene (Choi, 1998; Yi and Yu, 2001; Fujiki and Yasuda, 2004). After ca. 2.5 cal. kyr BP, climatic cooling is recognized by a rising frequency of herbaceous and *Pinus* pollen. The increase of herbaceous pollen in this interval (40–20 cm, from ca. 2.5 to 0.7 cal. kyr BP) is attributed mainly to a rise in representation of Gramineae pollen. Remarkable increase in Gramineae pollen in the late Holocene is regarded as an evidence of rice cultivation, although part of the Gramineae pollen can be originated from wild grasses. And according to Jiang and Piperno (1999) and Yi et al. (2003), the high proportion of *Pinus* pollen during the late Holocene possibly resulted from deforestation by humans and, soon after, the growth and spread of a secondary pine forest. Moreover, several archaeological artifacts including pottery shards, agricultural tools and wooden tools, which correspond to the Bronze Age and the period of the Three States (BC 18–AD 660) were found in the interval. Therefore, the vegetation change from ca. 2.5 to 0.7 cal. kyr BP is considered to reflect human impact.

6. CONCLUSIONS

To investigate a detailed history of vegetation and climate changes during the late Pleistocene to Holocene a palynological study on paleo-swamp deposits at an archaeological site of the Jinju area, South Korea, was carried out. Five local pollen assemblage zones including one barren zone represent well-defined evolutionary stages of vegetation and climate.

The vegetation reflecting a cold and dry climate during the last glacial period occurred from ca. 26.2 to 14.7 cal. kyr BP and is characterized by a predominance of *Artemisia*-dominated grassland and a significant occurrence of subalpine taxa such as *Picea, Abies* and *Betula.* A climatic amelioration during the period of ca. 14.7–11.2 cal. kyr BP, is indicated by an increase in temperate deciduous broadleaved taxa and thermophilic *Quercus (Cyclobalanopsis),* and by a decrease in xerophytic herbs and subalpine taxa. The predominance of temperate deciduous broadleaved forest and *Pinus* forest from ca. 4.7 to 0.7 cal. kyr BP indicates mixed pine and broadleaved deciduous forests which consist of similar floral composition to that of modern vegetation in and around the study area. A rising trend of *Pinus* and Gramineae after ca. 2.5 cal. kyr BP is interpreted as the result of human impact such as deforestation and cultivation.

ACKNOWLEDGEMENT: This research was supported by the Korea Polar Research Institute Project (PE06010) and partly by the Korea. Science and Enineering Foundation (R01-2003-000-10592-0). We appreciate two anonymous reviewers on their valuable comments to improve our manuscript.

REFERENCES

Allen, J.R.M., Brandt, U., Brauer, A., Hubberten, H.-W., Huntley, B., Keller, J., Kraml, M., Mackensen, A., Mingram, J., Negendank, J.F.W., Nowaczyk, N.R., Oberhansli, H., Watts, W.A., Wulf, S. and Zolitschka, B., 1999, Rapid environmental changes in southern Europe during the last glacial period. Nature, 400, 740–743.

Birks, H.J.B. and Birks, H.H., 1980, Quaternary Palaeoecology. Edward Arnold, London, 289 p.

Bond, G., Broecker, W., Johnsen, S., McManus, J., Labeyrie, L., Jouzel, J. and Bonani, G., 1993, Correlations between climate records from North Atlantic sediments and Greenland ice. Nature 365, 143–147.

Chambers, F.M. and Charman, D.J., 2004, Holocene environmental change: contributions from the peatland archive. *The Holocene* 14, 1–6.

Chang, N.K. and Rim, Y.D., 1979, Morphological studies on the pollen of flowering plants in Korea. Seoul National University Press, Seoul, 62 p with 137 plates (in Korean).

Choi, K.R., 1998, The Post-glacial vegetation history of the lowland in Korean Peninsula. Korean Journal of Ecology, 21, 169–174.

Chung, C.H., Yoon, H.I. and Lee, S.H., 2004, Paleoclimatic Implications of Palynoflora from the Quaternary Sediments at Seogwipo, Jeju Island, Korea. Journal of the Korean Earth Science Society, 25, 377–385 (in Korean with English abstract).

Dansgaard, W., Johnsen, S.J., Clausen, H.B., Dahl-Jensen, D., Gundestrup, N.S., Hammer, C.U., Hvidberg, C.S., Steffensen, J.P., Sveinbjörnsdottir, A.E., Jouzel, J. and Bond, G., 1993, Evidence for general instability of past climate from a 250-kyr ice-core record. Nature 364, 218–220.

Emery, K.O., Niino, H. and Sullivan, B., 1971, Post-Pleistocene sea level of East China Sea. In: Turekian, K.K. (Ed.), The Late Cenozoic Glacial Age. Yale University Press, New Haven, 380–390.

Fujiki, T. and Yasuda, Y., 2004, Vegetation history during the Holocene from Lake Hyangho, northeastern Korea. *Quaternary International*, 123–125, 63–69.

Grootes, P.M., Stuiver, M., White, W.C., Johnsen, S. and Jouzel, J., 1993, Comparison of oxygen isotope records from the GISP2 and GRIP Greenland Ice cores. Nature 366, 552–554.

Ijiri, A., Wang, L., Oba, T., Kawahata, H., Huang, C.-Y. and Huang, C.-Y, 2005, Paleoenvironmental changes in the northern area of the East China Sea during the past 42,000 years. Palaeogeography, Palaeoclimatology, Palaeoecology, 219, 239– 261.

Jiang, Q. and Piperno, D.R., 1999, Environmental and archaeological implications of a Late Quaternary palynological sequence, Poyang Lake, Southern China. Quaternary Research 52, 250–258.

Kim, J.M. and Kennett, J.P., 1998, Paleoenvironmental changes associated with Holocene marine transgression, Yellow Sea (Hwanghae). Marine Micropaleontology, 34, 71–89.

Kim, J.S., 1988, Vegetation of Jinju, Jinyang and Haman. In "Survey of nationwide natural environment (1-3)." Ministry of Environment (in Korean).

Kong, G.S., Park, S.-C., Han, H.-C., Chang, J.H. and Mackensen, A., 2006, Late Quaternary paleoenvironmental changes in the southeastern Yellow Sea, Korea. Quaternary International, 144, 38–52.

Korea Meteorological Administration, 2003, Annual Meteorological Report (1971–2000).

Lee, W.C. and Yim, Y. -J., 2002, Plant Geography. Kangwon National University Press, Chuncheon, 412 p (in Korean).

Liu, J.P., Milliman, J.D., Gao, S. and Cheng, P., 2004, Holoecene development of the Yellow River's subaqueous delta, north Yellow Sea. Marine Geology 209, 45–67.

Maher, L.J., 1981, Statistics for microfossil concentration measurements employing samples spiked with marker grains. Review of Palaeobotany and Palynology 32, 153-191.

Miyoshi, N., Fujiki, T. and Morita, Y., 1999, Palynology of a 250-m core from Lake Biwa: a 430,000-year record of glacial-interglacial vegetation change in Japan. Review of Palaeobotany and Palynology, 104, 267-283.

Nakagawa, T., Kitagawa, H., Yasuda, Y., Tarasov, P.E., Nishida, K., Gotanda, K., Sawai, Y. and Yangtze River Civilization Program Members, 2003, Asynchronous Climate Changes in the North Atlantic and Japan During the Last Termination. Science, 299, 688–691.

Nakamura, J., 1980a, Diagnostic characters of pollen grains of Japan. Part I. Osaka Museum of Natural History, Special publication, 12, 91pp (in Japanese).

Nakamura, J., 1980b, Diagnostic characters of pollen grains of Japan. Part II. Osaka Museum of Natural History, Special publication, 13, 91pp (in Japanese).

Park, J.-H. and Oh, K.-J., 2004, Palynological Study of Organic Clays in Unjeon-ri, Cheonan-city, Korea. Journal of the Korean Geomorphological Association, 11, 105–112(in Korean with English abstract).

Park, Y.A., Khim, B.K. and Zhao, S., 1994, Sea level fluctuation in the Yellow Sea Basin. Journal of the Korean Society of Oceanography, 29, 42–49.

Rioual, P., Andrieu-Ponel, V., Rietti-Shati, M., Battarbee, R.W., de Beaulieu, J.L., Cheddadi, R., Reille, M., Svobodova, H. and Shemesh, A., 2001, High-resolution record of climate stability in France during the last interglacial period. Nature 413, 293–296.

Schulz, H., von Rad, U. and Erlenkeuser, H., 1998, Correlation between Arabian Sea and Greenland climate oscillations of the past 110,000 years. Nature 393, 54–57.

Stockmarr, J., 1972, Tablets with spores used in absolute pollen analysis. Pollen et Spores, 13, 615–621.

Stuiver, M., Reimer, P., Bard, E., Warren-Beck, J., Burr, G.S., Hughen, K.A., Kromer, B., McCormac, G., van der Plicht, J. and Spurk, M., 1998, INTCAL 98 Radiocarbon age calibration, 24,000-0 cal BP. *Radiocarbon,* 40, 1041–1083.

Stuiver, M., Reimer, P.J. and Reimer, R., 2005, CALIB 5.0. Radiocarbon calibration program. (http://www.calib.qub.ac.uk/).

Sun, X., Li, X., Luo, Y. and Chen, X., 2000, The vegetation and climate at the last glaciation on the emerged continental shelf of the South China Sea. Palaeogeography, Palaeoclimatology, Palaeoecology, 160, 301–316.

Tinner, W. and Lotter, A.F., 2001, Central European vegetation response to abrupt climate change at 8.2 ka. Geology, 29, 551–554.

Traverse, A., 1988, Paleopalynology. Unwin-Hyman, Boston, 600 p.

Uyeki, H., 1933, On the forest zone of Korea. Acta Phytotaxanomy Geobotany, 2, 73–85.

Wang, F.S., Chien, N.F., Zhang, Y.L. and Yang, H.Q., 1995, Pollen Flora of China, 2nd Edition. Science Press, Beijing, 461 p (in Chinese).

Wang, P., 1999, Response of western Pacific marginal seas to glacial cycles: paleoceanographic and sedimentological features. Marine Geology, 156, 5–39.

Whitlock, C. and Bartlein, P.J., 1997, Vegetation and climate change in northwest America during the past 125 kyr. Nature, 388, 57–61.

Yasuda, Y., Tsukada, M., Kim, J.M., Lee, S.T. and Yim, Y.J., 1980, The environment changes and the agriculture origin in Korea. Japanese Ministry of Education Overseas Research Reports, 1–19.

Yi, M.-S. and Yu, K.-M., 2001, Late Pleistocene pollen records of vegetation history and inferred climatic changes in the Yellow Sea and environs. Journal of the Geological Society of Korea, 37, 365–374 (in Korean with English abstract).

Yi, S., Saito, Y., Oshima, H., Zhou, Y. and Wei, H., 2003, Holocene environmental history inferred from pollen assemblages in the Huanghe (Yellow River) delta, China: climatic change and human impact. Quaternary Science Reviews 22, 609–628.

Yi, S., Nam, S.-I., Chang, S.-W. and Chang, J.H., 2004, Holocene environmental changes in the tidal sediments of west coast of south Korea inferred from pollen records. Journal of the Geological Society of Korea, 40, 213–225 (in Korean with English abstract).

Yim, Y.-J. and Kira, T., 1975, Distribution of forest vegetation and climate in the Korean Peninsula: I. Some indices of thermal climate. Japanese Journal of Ecology, 25, 77–88.

Yoon, S.-O., 1996, The Geomorphic Development and Environmental Changes on the Samcheonpo Area in the later Half of Holocene. Journal of the Geomorphological Association of Korea, 3, 36–55 (in Korean with English abstract).

Yoon, S.-O., 1997, The Holocene Environmental Changes and Reconstruction of the Palaeogeography at Ilsan Area with the Special Reference to Pollen Analysis. Journal of the Korean Geographical Society, 32, 15–30 (in Korean with English abstract).

Yoon, S.-O. and Jo, W., 1996, The late Quaternary Environmrntal Change in Youngyang Basin, Southeastern Part of Korea Peninsula. Journal of the Korean Geographical Society, 31, 447–468 (in Korean with English abstract).

Manuscript received March 21, 2006
Manuscript accepted August 18, 2006