Late-Holocene palaeoclimatic change at the Dongnimdong archaeological site, Gwangju, SW Korea

Hyoun Soo Lim, Chull-Hwan Chung, Cheong-Bin Kim, Yong Il Lee, Heon Jong Lee and Young Chul Lee

The Holocene 2007 17: 665
DOI: 10.1177/0959683607078997

Late-Holocene palaeoclimatic change at the Dongnimdong archaeological site, Gwangju, SW Korea

Hyoun Soo Lim,[1,*] Chull-Hwan Chung,[2] Cheong-Bin Kim,[3] Yong Il Lee,[4] Heon Jong Lee[5] and Young Chul Lee[6]

([1]Korea Polar Research Institute, KORDI, Incheon 406-840, Korea; [2]Faculty of Earth Systems and Environmental Sciences, Chonnam National University, Gwangju 500-757, Korea; [3]Department of Science Education, Sunchon National University, Chonnam 540-742, Korea; [4]School of Earth and Environmental Sciences, Seoul National University, Seoul 151-747, Korea; [5]Division of History and Culture, Mokpo National University, Chonnam 534-729, Korea; [6]Honam Cultural Property Research Center, Gwangju 506-498, Korea)

Received 10 June 2005; revised manuscript accepted 28 December 2006

A HOLOCENE RESEARCH PAPER

Abstract: A late-Holocene swamp sediment record is presented from the Dongnimdong archaeological site in SW Korea. Pollen analysis, geochemical analyses and radiocarbon dating have been used to reconstruct the vegetation and climatic changes. According to the pollen records, temperate deciduous broadleaved trees combined with herbs predominated in the study area ecology. Reduction of deciduous broadleaved trees with the spread of herbaceous taxa found in the middle part (*c*. 3300–2600 yr BP) indicates climatic change toward cooler and drier conditions. Significant increase in sand content and concomitant decrease in TOC content may suggest the occurrence of a period of drought. Vegetation changes recorded in the pollen sequence indicate the destruction of lowland deciduous forests and an accompanied expansion of grasses resulting from the climate changes. However, the increase of cultivation-accompanied herbs and excavated wooden tools for agriculture suggest the significant anthropogenic influence on the vegetation changes.

Key words: Holocene, swamp, pollen analysis, palaeoclimate, human impact, geoarchaeology, Korea

Introduction

Understanding climate change in the Holocene is important for prediction of future climate change and understanding of human history. Early palaeoclimate studies suggested that a remarkably stable climate prevailed during the Holocene (Dansgaard *et al.*, 1993). However, subsequent works on both ice cores and ocean sediments (O'Brien *et al.*, 1995; Bond *et al.*, 1997) have shown that the climate of the Holocene is more variable than previously thought. Long-term trends indicate an early to mid-Holocene climatic optimum, with a cooling trend in the late Holocene (deMenocal *et al.*, 2000). Recent studies on environment and vegetation changes during the Holocene also suggest the influences of significant anthropogenic factors (eg, Stevenson *et al.*, 2001; Vincens *et al.*, 2003; Dull, 2004; Faust *et al.*, 2004; Makohonienko *et al.*, 2004; Sadori *et al.*, 2004).

Compared with terrestrial palaeosol sequences, swamp deposits have been relatively untouched, and thus have a long record of vegetation change and human impact (Chambers and Charman, 2004). Here, we present multiproxy records of environment and climate changes obtained from the swamp deposits at the Dongnimdong archaeological site, SW Korea (Figure 1), and intend to differentiate between anthropogenic and climatic impacts on environmental and vegetation changes during the late Holocene. This study is expected to provide a good example of how swamp deposits can be used for palaeoclimate studies.

Climate and site description

Korea is located in the mid-latitude of the Northern Hemisphere (Figure 1) having a temperate climate with four distinct seasons. Geographically, it lies on the eastern coast of

*Author for correspondence (e-mail: tracker@kopri.re.kr)

10.1177/0959683607078997

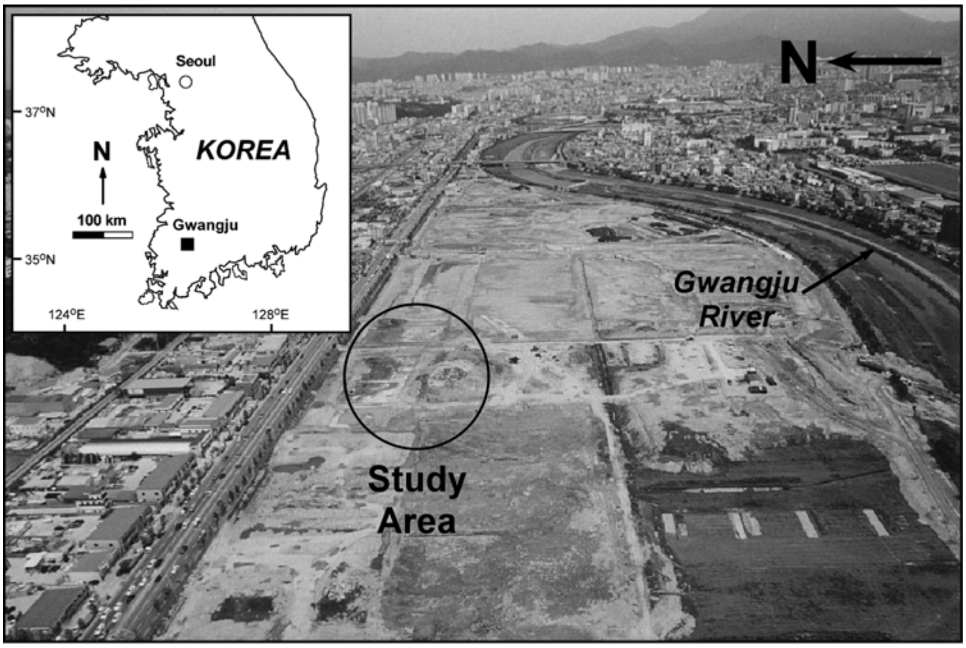

Figure 1 Location map and a bird's-eye view of the Dongnimdong archaeological excavation site, Gwanju, SW Korea

the Eurasian continent adjacent to the West Pacific. 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 average temperatures of the study area during the 30 years between 1971 and 2000 are 0.4°C and 26.1°C in the coldest and warmest months, respectively (Korea Meteorological Administration, 2003). Precipitation is relatively high (up to 1400 mm annually). About 60% of the annual precipitation falls in the summer, while the winter precipitation comprises less than 10%.

Pollen and palaeoclimatic studies on the Holocene sediments in Korea have been carried out in various environments, including continental shelf (Chung *et al.*, 1998; Yi and Yu, 2001; Yi *et al.*, 2004), lake (Chang and Kim, 1982; Fujiki and Yasuda, 2004) and swamp (Choi, 1998; Yi *et al.*, 1999; Yi and Saito, 2003). According to these pollen data, a striking vegetation change from *Quercus-Alnus* deciduous broadleaved forests to *Pinus* coniferous forests occurred during the late Holocene. This vegetation change is known to have resulted from climate deterioration and sea-level fluctuations in the late Holocene (Choi, 1998; Chung *et al.*, 1998; Yi and Yu, 2001; Yi *et al.*, 2004).

Gwangju Metropolitan City is surrounded by high mountains and forms a natural basin, which is a fertile and warm area with many tributary streams of the Youngsan River. Because of such natural environments, this region is believed to have been an area of first human settlement. Many archaeological remains (Palaeolithic~Chosun Dynasty) found in Gwangju area support this hypothesis. The Gwangju region also has been the granary of Korea from ancient times, and thus natural vegetation of the study area has been transformed by cultivation and urbanization. The neighbouring vegetation reservations such as national parks, nevertheless, retain the natural vegetation belonging to the southern temperate deciduous broadleaved forest (Uyeki, 1933; Yim and Kira, 1975). This forest includes diverse deciduous broadleaved trees such as *Quercus aliena, Q. variabilis, Q. serrata, Q. mongolica, Carpinus tschonoskii, C. laxiflora, Zelkova serrata, Castanea crenata*, *Platycarya strobilacea* and some broadleaved evergreen taxa such as *Q. acuta, Castanopsis cuspidate* and *Camellia japonica* (Lee and Yim, 2002; Kil *et al.*, 2000).

Dongnimdong archaeological site is located in the central part of Gwangju City (Figure 1). The site studied is situated on the bank of the Gwangju River. Following the archaeological surface survey in 1999, the full-scale excavation began in 2003. By the end of 2004, about 100 000 m^2 were excavated, and many archaeological artefacts were found. The items include pottery shards, stone axes, axe handles, stone blades, wooden tools, fishing tackle, porcelain fragments (Figure 2) and ancient tombs. Several cultural horizons from the Bronze Age to the Chosun Dynasty (AD 1392–1926) were identified based on the archaeological assemblages.

Sampling and methods

The stratigraphy of the Dongnimdong section records the sedimentary environmental change of the study area from an oxbow lake to a freshwater swamp during the late Holocene. The lateral migration of the meandering Gwanju River gave rise to abandonment of the channel, and resulted in the formation of an elongated oxbow lake. This oxbow lake was changed into swamp, and then infilled with fine-grained sediments under a very low-energy condition. Soil samples were collected from the vertical sections of two adjacent excavation trenches, 20 m apart. Forty samples were obtained at 5 cm intervals through the palaeosol sequence for magnetic susceptibility, particle size and total organic carbon analyses (A section; Figure 3a). The 2.0 m sediment section studied here excludes the topmost disturbed horizon of 50 cm thick. Magnetic susceptibility (MS), total carbon (TC) and total nitrogen (TN) contents were measured using Bartington Instruments MS2 and elemental analyzer (FlashEA 1112).

Chronological control is provided by ^{14}C and optically stimulated luminescence (OSL) dating. Radiocarbon analyses were carried out for the excavated wooden tools and bulk soils samples taken from A-section (Figure 3a). Eight soil samples,

Figure 2 Excavated artefacts from the Dongnimdong site. (a) A wooden tool with unknown usage (GD-1; Bronze Age), (b) a long-handled wooden rake (GD-2; Bronze Age), (c) pottery shards and fishing sinkers (Iron Age), and (d) various pottery and porcelain shards (Chosun Dynasty). Each square on the scale is 1 cm long

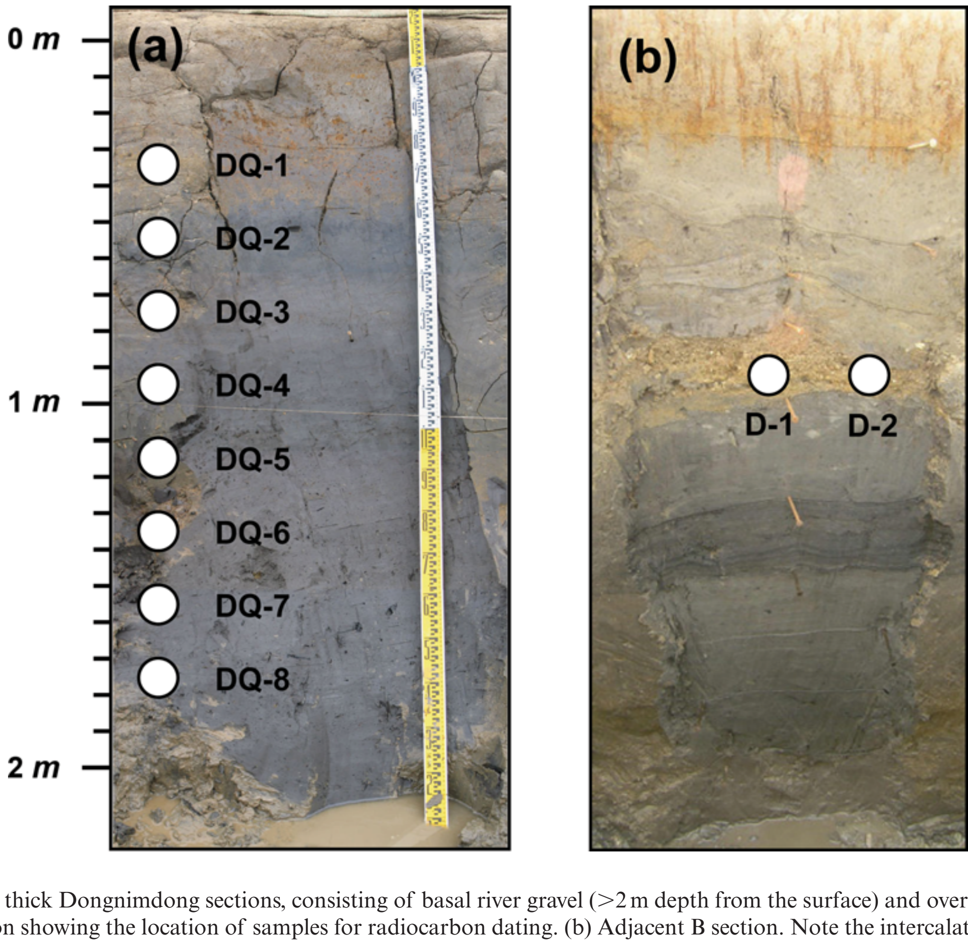

Figure 3 The 2 m thick Dongnimdong sections, consisting of basal river gravel (>2 m depth from the surface) and overlying Holocene sediments. (a) A section showing the location of samples for radiocarbon dating. (b) Adjacent B section. Note the intercalated sand body in the middle part where two samples for OSL dating were collected

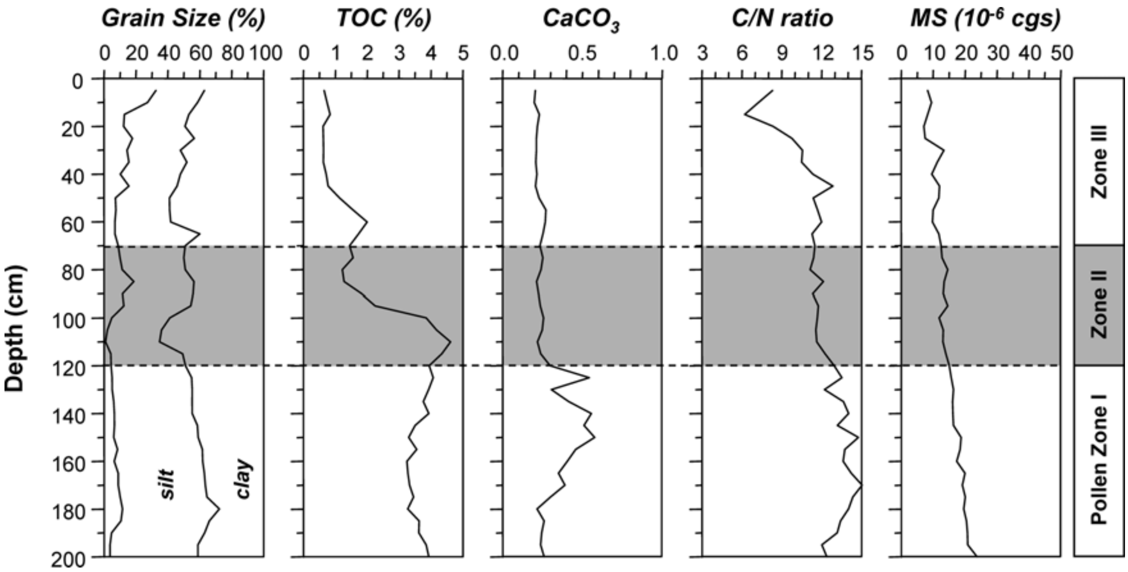

Figure 4 Vertical variations of grain size, total organic carbon (TOC), $CaCO_3$, C/N ratio and magnetic susceptibility of the Dongnimdong palaeosol at A section. Note the abrupt change in grain size and TOC content at around 110–80 cm depth

collected at 20 cm intervals from 30 cm to 180 cm at A section, were dated using a conventional method with the extended counting time at Geochron Laboratories, USA. Two wooden tools were dated using accelerator mass spectrometry (AMS) at Seoul National University. Two sand samples for OSL-age dating were obtained from the middle part (about 90 cm from the surface) of the palaeosols in the adjacent B section (Figure 3b). OSL dating was carried out at the Korea Basic Science Institute.

For pollen analysis, 20 samples were taken at 10 cm intervals from a 2 m long columnar section of the A trench (Figure 3a). Pollen were identified and counted with a light microscope at 400× magnification, but a magnification of 1000× was used for some critical determinations. Over 300 pollen grains of trees and herbs were counted for each sample. For the calculation of the percentages only indeterminable grains have been excluded from total sum of pollen and spores.

Results

Stratigraphy

There are three principal sediment types found at the Dongnimdong excavation site (Figure 3). The basal unit is a gravel layer with light grey sand matrix, reflecting fluvial origin. Overlying this unit is a 150 cm thick organic-rich, dark grey to black mud (silt and clay) layer, which appears to be swamp deposits. An upper unit is a 50 cm thick reddish brown mud layer. The colour of this upper unit and the presence of root traces (Figure 3) indicate that this horizon has undergone alteration by pedogenic processes.

The results of particle size analyses are shown in Figure 4. The Dongnimdong sediment is dominated by clay (30–65%) and silt (30–60%), with a minor amount of sand (mostly less than 20%). Because sand fractions are small, mean grain size is controlled by clay and silt contents. They can be classified as clay, silty clay or silty clay loam by soil classification. In the depth interval between 180 cm and 110 cm, the size distribution shows a fining-upward trend with an increase in clay content. However, the sand content is abruptly increased in the 110–80 cm interval (up to ~20%), suggesting a significant change in physical environment such as water depth and/or precipitation. This interval can be correlated with a 10–20 cm thick intercalated sand layer at section B (Figure 3b).

Chronology

In this study, we performed ten radiocarbon datings (eight soil samples and two wood samples), and two OSL datings (Tables 1 and 2). Radiocarbon dates were calibrated to calendar years using the terrestrial INTCAL98 data set by means of the CALIB program 5.0 (Stuiver and Reimer, 1993; Stuiver *et al.*, 1998). Calendar age errors are generally small and this permits the construction of a reliable age–depth model, though two radiocarbon ages (DQ-3 and DQ-8) deviate somewhat from the

Table 1 Radiocarbon ages from the Donglimdong excavation site, SW Korea

Sample code	Sample	Depth below surface (cm)	$\delta^{13}C$ (‰)	^{14}C age (yr BP)	Calibrated age ranges, 2σ (yr BP)	Calibrated age ranges, 2σ (BC/AD)
DQ-1	soil	30–40	−23.5	2170 ± 110	1876–2428	BC 479–AD 79
DQ-2	soil	50–60	−25.4	2270 ± 70	2067–2464	BC 515–BC 118
DQ-3	soil	70–80	−24.9	3190 ± 80	3217–3611	BC1662–BC1268
DQ-4	soil	90–100	−24.9	2970 ± 70	2954–3345	BC1396–BC1005
DQ-5	soil	110–120	−27.3	3030 ± 70	3005–3381	BC1432–BC1056
DQ-6	soil	130–140	−28.1	3190 ± 70	3254–3577	BC1628–BC1305
DQ-7	soil	150–160	−27.9	3500 ± 80	3573–3980	BC2031–BC1624
DQ-8	soil	170–180	−28.1	3230 ± 70	3275–3635	BC1686–BC1326
GD-1	wood	*c*. 180	−28.2	3880 ± 30	4084–4522	BC2573–BC2135
GD-2	wood	*c*. 150	−28.3	3210 ± 40	3359–3555	BC1606–BC1410

Table 2 OSL dating results of the sand samples from the Donglimdong site, SW Korea

Sample code	Dose rate (Gy/ka)	Equivalent dose (Gy)	Water content (%)	Aliquots used (*n*)	OSL Age (ka)
D-1	2.34 ± 0.05	6.99 ± 0.41	34.8	18	2.99 ± 0.19
D-2	2.48 ± 0.05	6.96 ± 0.41	21.1	18	2.81 ± 0.17

age–depth path obtained by linear regression ($r^2 = 0.71$; Figure 5). The OSL ages of two sand samples taken from section B also show a good agreement with other radiocarbon ages (Figure 5). The age determinations reveal that the sediments are of late Holocene age, with the basal sediment overlying a gravel layer having been deposited around 4500 yr BP. Because the age of the top section can be interpolated to be *c*. 1500 yr BP, this 2 m thick swamp deposit is interpreted to have been formed during a period of about 3000 years. Based on sedimentation rate interpolations between ^{14}C and OSL dates the average accumulation rate is roughly calculated to be about 0.7 mm/yr (Figure 5).

Organic concentration (TOC, $CaCO_3$ and C/N ratio) and magnetic susceptibility (MS)

Total organic carbon (TOC) contents of the Dongnimdong sediments range from 0.6 to 4.6%. Based on the TOC contents, the Dongnimdong sediments can be roughly divided into three intervals. The lower part (200–120 cm) has relatively high TOC contents in the range of 3.3–4.6%. Then, the TOC content abruptly decreases by about 3.0% in the 120–70 cm interval and remains low, less than 2.0%. It shows an abrupt decrease at around 50 cm depth, and the top 50 cm interval has the lowest TOC content, less than 1.0%. Except for the upper 50 cm interval, vertical variation of TOC content shows a strong positive correlation with that of clay contents (Figure 5). This indicates that the TOC content of the Dongnimdong sediments are closely related with the amount of clay fraction.

$CaCO_3$ contents show relatively constant values of *c*. 0.2%, except in the 180–120 cm interval (up to 0.6%). TN contents of

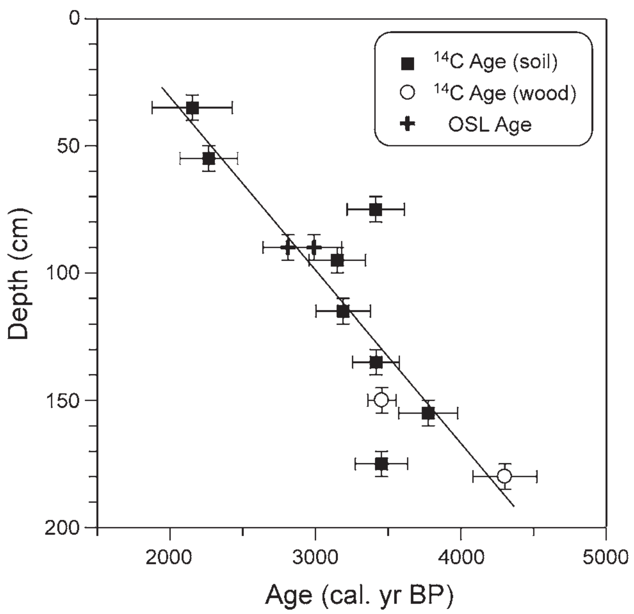

Figure 5 Age–depth relationship based on radiocarbon and OSL dating from the Dongnimdong palaeosol section A

the sediments reaches 0.4% by weight, and vertical variation of TN contents is exactly the same as that of TOC content ($r^2 = 0.96$). The C/N ratios range from 6 to 15, and are variable to some extent throughout the profile. From 200 to 120 cm interval, the C/N ratios are relatively high (12–15), then show constant values of 11–12 in the middle part (110–50 cm). In the upper 50 cm interval, however, the C/N ratios abruptly decrease down to 6. The magnetic susceptibility (MS) values of the Dongnimdong sediments decrease gradually from bottom to top without any significant fluctuation (Figure 5).

Pollen analysis

Diverse types of pollen and spores are recognized in the Dongnimdong succession. On the whole, broadleaved deciduous taxa *Alnus* and *Quercus* (*Lepidobalanus*), broadleaved evergreen taxa *Quercus* (*Cyclobalanopsis*), and herbaceous Gramineae and Compositae are dominant components. Three local pollen assemblage zones (LPAZ), reflecting three phases in the vegetation development during the late Holocene, have been distinguished on the basis of significant changes in the proportion of the major taxa (Figure 6).

Pollen zone I (200–120 cm, c. 3300–4400 cal. yr BP)

This zone is characterized by a predominance of arboreal pollen, including *Alnus*, deciduous *Q.* (*Lepidobalanus*) and evergreen *Q.* (*Cyclobalanopsis*). *Pinus*, *Abies*, Taxodiaceae-Cupressaceae-Taxaceae, *Carpinus* and *Pterocarya* are common constituents. Among herbaceous taxa, Gramineae and Cyperaceae are most common, and aquatic taxa such as *Typha, Myriophyllum* and *Nymphoide*s occur consistently. Herbaceous pollen grains are relatively low in this zone. Pteridophytic spores are dominant throughout the zone.

Zone II (120–70 cm, c. 2600–3300 cal. yr BP)

The major components are *Alnus*, deciduous *Q.* (*Lepidobalanus*) and Gramineae. Other common taxa are *Pinus*, Taxodiaceae-Cupressaceae-Taxaceae, *Carpinus*, evergreen *Q.* (*Cyclobalanopsis*), Cyperaceae and *Artemisia.* Compared with zone I, percentage frequencies of *Alnus* and evergreen *Q.* (*Cyclobalanopsis*) decrease, whilst those of *Pinus* and xerophytic *Artemisia* increase to the contrary, which suggests a possibility of climate deterioration. Another significant feature is that within this zone deciduous *Q.* (*Lepidobalanus*) distinctly decreases upward, and Gramineae and Cyperaceae increase.

Zone III (70–0 cm, c. 1500–2600 cal. yr BP)

This zone is dominated by evergreen *Q.* (*Cyclobalanopsis*) and Gramineae in asociation with common occurrence of Taxodiaceae-Cupressaceae-Taxaceae, *Alnus, Pterocarya*, deciduous *Q.* (*Lepidobalanus*), *Castanea*/*Castanopsis*, Cyperaceae and *Artemisia.* However, *Alnus* and deciduous *Q.* (*Lepidobalanus*) occur at remarkably lower percentages than in the underlying zones. Herbaceous pollen occurs most abundantly among three zones and Gramineae is the most dominant taxa in this zone. Increased or more regular occurrences of thermophilic taxa such as evergreen *Q.* (*Cyclobalanopsis*),

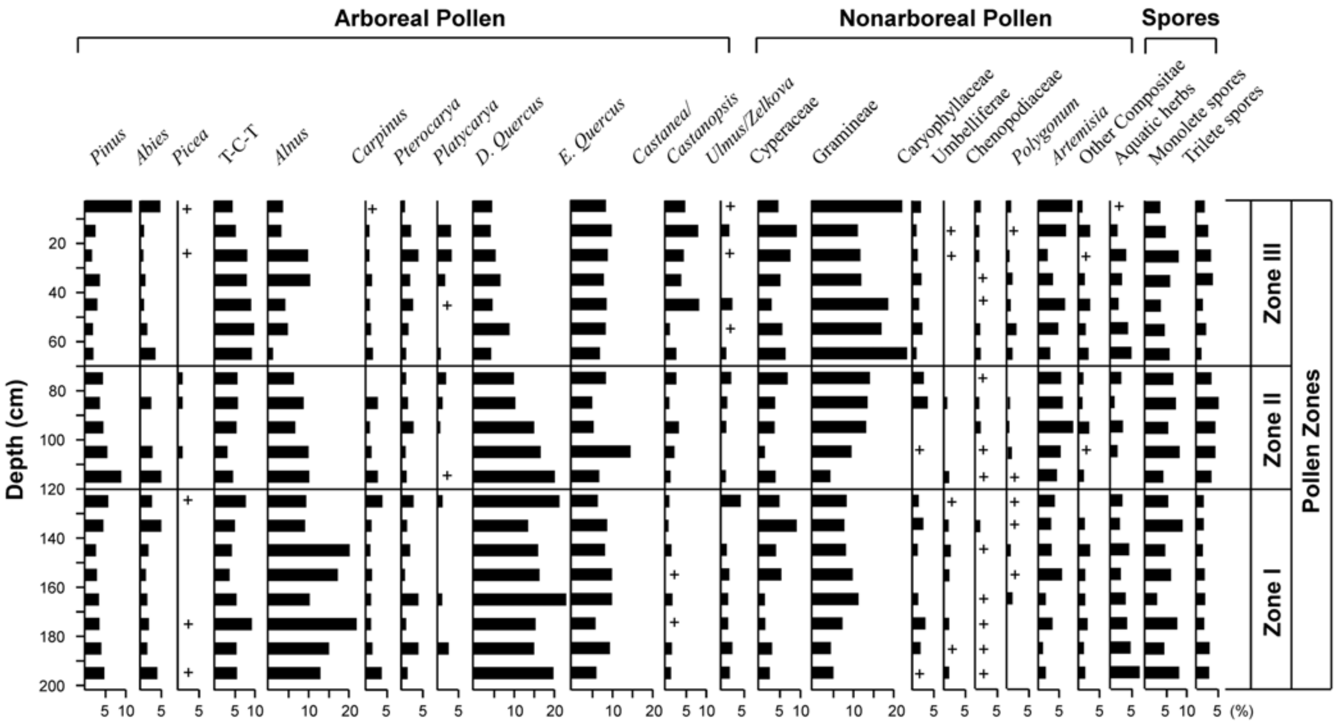

Figure 6 Diagram of selected pollen and spore percentage frequency and pollen zones for Dongnimdong site. T-C-T, Taxodiaceae-Cupressaceae-Taxaceae; and +, <0.5%

Castanea/*Castanopsis, Pterocarya* and *Platycarya* indicate that this zone represents the warmest period.

Interpretation and discussion

The abrupt decrease of TOC content and C/N ratio in the upper 50 cm interval (Figure 4) is thought to have been caused by decomposition of organic matter, which is supported by the reddish brown colours and the presence of root traces in this horizon (Figure 3). However, the vertical variations of grain size, TOC and $CaCO_3$ contents indicate environmental and/or climatic changes in *c.* 3300–2600 cal. yr BP (120–70 cm interval). The clay, TOC and $CaCO_3$ contents decrease within this interval, and the C/N ratios also decrease down to less than 12 (Figure 4). Those changes are thought to have been caused by the decrease of water depth, and climatic change can be considered as a possible cause of water depth change. Such palaeoclimatic changes are also observed in pollen data. In general, pollen of temperate deciduous broadleaved trees such as *Alnus* and deciduous *Quercus*, combined with herbs, are predominant in the study area (Figure 6). The general trends of decrease in pollen of deciduous broadleaved trees and increase in herbaceous pollen in LPAZ II seem to be the result of gradual cooling and drying. Thermophilic taxa such as evergreen *Q.* (*Cyclobalanopsis*), *Castanea*/*Castanopsis, Pterocarya* and *Platycarya* are rather enriched in the uppermost zone (LPAZ III). Such vegetational changes seem to have been mainly controlled by climatic changes.

Recent palaeoclimate studies showed that Holocene climate was variable, having been interrupted by several significant, millennial-scale cooling events (O'Brien *et al.*, 1995; Bond *et al.*, 1997; Bianchi and McCave, 1999). Lim *et al.* (2005) suggested the aridity maximum at *c.* 3100 cal. yr BP based on the data of aeolian quartz flux (EQF) variations in Cheju Island, south of the study area. This maximum in EQF corresponds to the lowest lake level in the Lake Yiema, NW China (Chen *et al.*, 1999). O'Brien *et al.* (1995) also suggested that concentrations of sea salt and terrestrial dusts increased in Summit snow, Greenland during the period 2400–3100 yr BP. Using the reconstructed sea surface temperature (SST) variations, furthermore, deMenocal *et al.* (2000) suggested that one of the Holocene cooling events was centred at 3000 yr BP. These previously reported studies imply that the abrupt changes observed in the Dongnimdong sediments might have been caused by palaeoclimatic changes.

However, it is difficult to attribute such environmental and vegetation changes only to climatic change. Alternatively, the influence of anthropogenic factors should also be considered. Human impact on vegetation and/or environmental changes has lately attracted considerable attention (eg, Stevenson *et al.*, 2001; Vincens *et al.*, 2003; Dull, 2004; Faust *et al.*, 2004; Makohonienko *et al.*, 2004; Sadori *et al.*, 2004). Because of the interaction between human activity and nature, both human impact and climate changes must be considered simultaneously. The destruction of lowland deciduous forests and accompanied expansion of grasses can be caused by human impacts (Berglund, 1985; Okuda *et al.*, 2003; Dull, 2004; Kerig and Lechterbeck, 2004). The increase of herbaceous pollen, such as Gramineae, Chenopodiaceae and Polygonum may suggest expansion of cultivation. At the Dongnimdong section, a long-handled wooden rake (Figure 2b) used to level the ground was found at 150 cm depth, and has a radiocarbon age of *c.* 3500 cal. yr BP (GD-2 in Table 1), approximately the same time as the beginning of rice cultivation in Korea (Kim, 1982; Nelson, 1982). The presence of agricultural tools suggests intensive land use for agriculture at this period. Therefore, the environmental changes observed at the Dongnimdong site appear to have been affected by an anthropogenic factors.

Significant variations are recognized in the middle part of LPAZ II, in which the retreat of deciduous broadleaved trees and the expansion of herbaceous taxa become apparent. Then, the accelerated human impacts on the vegetation resulted in intensive lowland deforestation and the spread of herbaceous taxa including cultivation-accompanied herbs, Gramineae and Chenopodiaceae. Each LPAZ seems to reflect the stepwise influences of human activities on the vegetation. LPAZ I represents the natural vegetation before human interference. Evident human impacts appear in LPAZ II, showing the transition from *Alnus*-deciduous *Quercus* forest to herbaceous open landscape. LPAZ III is the phase that increasing human interference resulted in the reduction of deciduous broadleaved forest and the development of open herbaceous lowland. Abundant Gramineae pollen grains may be the result of rice cultivation, although part of the Gramineae pollen grains originate from wild grasses. LPAZ III is also marked by the regular occurrence of Chenopodiaceae and Polygonum, which have been used as cultivation indicators in many parts of the world (Bottema and Woldring, 1990; Dull, 2004). Accordingly, the increase of herbaceous pollens including Gramineae in the Dongnimdong pollen record seems to have been caused by climate change to warmer conditions and cultivation. This interpretation is coincident with the vertical variations of grain size distribution and TOC contents. The abrupt decrease of clay fraction and TOC contents occurs at a depth of *c*. 110 cm, which corresponds to the middle part of LPAZ II. Increased influx of sandy and silty sediments in LPAZ II might result from changes in the landscape by deforestation and resulting soil erosion. Thus, the environmental and vegetational changes found in the Dongnimdong area are interpreted to have been controlled by climate change, coupled with human impact.

Conclusions

At the Dongnimdong archaeological site, the palaeoenvironmental and palaeoclimatic changes during the late Holocene were reconstructed by a multiproxy record. Three local pollen assemblage zones, reflecting vegetation and climate changes for 3000 years, are distinguished on the basis of significant changes in the proportion of the major taxa. Pollen records suggest a relatively cold and dry period in LPAZ II (*c*. 2600–3300 cal. yr BP), and such palaeoclimatic changes are also found in vertical variations of grain size and TOC contents. Abrupt decrease in clay and TOC contents at a depth of 110 cm suggests a water-depth decrease, resulting from arid condition during this period. The retreat of deciduous broadleaved trees and the expansion of herbaceous taxa, including cultivation-accompanied herbs in LPAZ II reflect the increased human impacts on the vegetation changes. In conclusion, the environmental and vegetation changes in the Dongnimdong area are interpreted to be the results of both climate change and human impact, although climate is considered to have exerted the major control.

Acknowledgements

This study was supported by a grant from the Korea Science and Engineering Foundation (R01-2003-000-10592-0) and the Korea Polar Research Institute (PE07010). The authors would like to thank Kaoru Kashima and the Associate Editor C. Neil Roberts for their critical reviews and constructive comments.

References

Berglund, B.E. 1985: Early agriculture in Scandinavia: research problems related to pollen analytical studies. *Norwegian Archaeological Review* 18, 77–105.

Bianchi, G.G. and **McCave, I.N.** 1999: Holocene periodicity in North Atlantic climate and deep-ocean flow south of Iceland. *Nature* 397, 515–17.

Bond, G., Showers, W., Cheseby, M., Lotti, R., Almasi, P., De Menocal, P., Priore, P., Cullen, H., Hajdes, I. and **Bonani, G.** 1997: A pervasive millennial-scale cycle in North Atlantic Holocene and glacial climates. *Science* 278, 1257–66.

Bottema, S. and **Woldring, H.** 1990: Anthropogenic indicators in the pollen record of the Eastern Mediterranean. In Bottema, S., Entjes-Nieborg, G. and van Zeist, W., editors, *Man's role in the shaping of the Eastern Mediterranean landscape*. Balkema, 231–64.

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

Chang, C.H. and **Kim, C.M.** 1982: Late Quaternary vegetation in the lake of Korea. *Korean Journal of Botany* 25, 37–53.

Chen, F.H., Shi, Q. and **Wang, J.M.** 1999: Environmental changes documented by sedimentation of Lake Yiema in China since the late glaciation. *Journal of Paleolimnology* 22, 159–69.

Choi, K.R. 1998: The post-glacial vegetation history of the lowland in Korean Peninsula. *Korean Journal of Ecology* 21, 169–74.

Chung, C.H., You, H.S., Choi, D.K. and **Kim, J.Y.** 1998: Paleoenvironmental interpretations of Holocene palynomorphs from the continental shelf, southern part of the East Sea. *Journal of the Korean Earth Sciences Society* 19, 461–66.

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, 218–20.

deMenocal, P., Ortiz, J., Guilderson, T. and **Sarnthein, M.,** 2000: Coherent high- and low-latitude climate variability during the Holocene warm period. *Science* 288, 2198–202.

Dull, R.A. 2004: An 8000-year record of vegetation, climate, and human disturbance from the Sierra de Apaneca, El Salvador. *Quaternary Research*, 61, 159–67.

Faust, D., Zielhofer, C., Escudero, R.B. and **Olmo, F.D.D.** 2004: High-resolution fluvial record of late Holocene geomorphic change in northern Tunisia: climatic or human impact? *Quaternary Science Reviews* 23, 1757–75.

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

Kerig, T. and **Lechterbeck, J.** 2004: Laminated sediments, human impact and a multivariate approach: a case study linking palynology and archaeology (Steisslingen, southwest Germany). *Quaternary International* 114, 67–86.

Kil, B.-S., Kim, J.-U. and **Kim, Y.-S.** 2000: Forest vegetation of southern area of Mt. Naejang National Park, Korea. *Korean Journal of Ecology* 23, 231–40.

Kim, W.-Y. 1982: Discoveries of rice in prehistoric sites in Korea. *Journal of Asian Studies* XLI, 513–18.

Korea Meteorological Administration 2003: *Annual meteorological report* (1971–2000).

Lee, W.C. and **Yim, Y.-J.** 2002: *Plant geography*. Kangwon National University Press, 412 pp.

Lim, J., Matsumoto, E. and **Kitagawa, H.** 2005: Eolian quartz flux variations in Cheju Island, Korea, during the last 6500 yr and a possible Sun-monsoon linkage. *Quaternary Research* 64, 12–20.

Makohonienko, M., Kitagawa, H., Naruse, T., Nasu, H., Momohara, A., Okuno, M., Fujiki, T., Liu, X., Yasuda, Y. and **Yin, H.** 2004: Late-Holocene natural and anthropogenic vegetation changes in the Dongbei Pingyuan (Manchurian Plain), northeastern China. *Quaternary International* 123–125, 71–88.

Nelson, S.M. 1982: The effects of rice agriculture on prehistoric Korea. *Journal of Asian Studies* XLI, 531–43.

O'Brien, S.R., Mayewski, P.A., Meeker, L.D., Messe, D.A., Twickler, M.S. and **Whitlow, S.I.** 1995: Complexity of Holocene climate as reconstructed from Greenland ice core. *Science* 270, 1962–64.

Okuda, M., Sato, Y., Tang, L.H., Takahashi, M., Toyama, S., Yano, A., Kitagawa, H. and **Yasuda, Y.** 2003: Late Holocene vegetation

and environment at Cauduntou, west of Yangtze Delta, SW Jiangsu Province East China. *Quaternary International* 105, 39–47.
Sadori, L., Giraudi, C., Petitti, P. and **Ramrath, A.** 2004: Human impact at Lago di Mezzano (central Italy) during the Bronze Age: a multidisciplinary approach. *Quaternary International* 113, 5–17.
Stevenson, J., Dodson, J.R. and **Prosser, I.P.** 2001: A late Quaternary record of environmental change and human impact from New Caledonia. *Palaeogeography, Palaeoclimatology, Palaeoecology* 168, 97–123.
Stuiver, M. and **Reimer, P.** 1993: Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program. *Radiocarbon* 35, 215–30.
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, 1041–83.
Uyeki, H. 1933: On the forest zone of Korea. *Acta Phytotaxonomica et Geobotanica*. 2, 73–85.
Vincens, A., Williamson, D., Thevenon, F., Taieb, M., Buchet, G., Decobert, M. and **Thouveny, N.** 2003: Pollen-based vegetation changes in southern Tanzania during the last 4200 years: climate change and/or human impact. *Palaeogeography, Palaeoclimatology, Palaeoecology* 198, 321–34.
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, 365–74.
Yi, S. and **Saito, Y.** 2003: Palynological evidence for late Holocene environmental change on the Gimhae Fluvial Plain, Southern Korean Peninsula: reconstructing the rise and fall of Golden Crown Gaya State. *Geoarchaeology* 18, 831–50.
Yi, S., Chun, H.Y. and **Yun, H.** 1999: Paleoecological aspect using palynology since 4,000 year B.P. in the lowland of Western Central Korea. *The Korean Journal of Quaternary Research* 13, 1–23.
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, 213–25.
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.