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Climate and environmental changes for the past 44 ka clarified by pollen and algae composition in the Ulleung Basin, East Sea (Japan Sea)

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ABSTRACT

The pollen and algae records derived from core KCES-1 in the East Sea (Japan Sea) reveal vegetation and climate changes during the past 44 ka. From 44 to 36 cal ka BP, forest vegetation in the coastal regions of Ulleung Basin was composed predominantly of subalpine conifer forest, open grassland covered the exposed continental shelves, indicating a cool and dry climate. During the period of 36–28.3 cal ka BP, a warmer and wetter climate caused the contraction of subalpine conifer forest in the coastal regions of Ulleung Basin, and the expansion of marsh in the exposed continental shelves. From 28.3 to 17.6 cal ka BP, the sea-level decline restricted the herbs pollen originates in the exposed shelf of East China Sea and Yellow Sea inflow into the East Sea (Japan Sea), and caused the reduction of herbs pollen in the site location. During the time interval of 17.6–15.1 cal ka BP, a great expansion of subalpine conifer forest can be regarded as the consequence of enhanced East Asian winter monsoon (EAWM). The obvious increase in temperate deciduous broadleaved trees, spores and algae can be attributable to the rising of sea level and the warming of climate from 15.1 to 12.1 cal ka BP. During the period of 12.1 to 5.3 cal ka BP, broadleaved taxa increased, especially during the time period of 9.5–5.3 cal ka BP, evergreen broadleaved trees pollen reach the highest values throughout the core, as a result of the Holocene climate optimum condition. Vegetation changes controlled by humid impacts occurred at the late Holocene, as indicated by an increase in *Pinus* pollen.

1. Introduction

The East Sea (Japan Sea), a semi-isolated marginal sea lying between the Japan archipelago and Asian continent, has experienced large environmental changes during the late Quaternary under glacio-eustatic sea-level changes (Oba et al., 1991). During the last glacial maximum (LGM), the East Sea (Japan Sea) was almost isolated from the neighboring seas as the global sea level was lowered by approximately 130 m (Ishiwatari et al., 2001). This inhibited the Tsushima Warm Current (TWC) inflow and caused anoxic conditions in the East Sea (Japan Sea) (Lee, 2007). As the sea-level rose in the deglaciation, the oceanographic circulation pattern in the East Sea (Japan Sea) substantially changed with the stop of water column stratification and start of the ventilation (Koizumi et al., 2006). In the past decades, many researchers have focused on the Quaternary paleoenvironmental evolution of the East Sea (Japan Sea) (Oba et al., 1991; Ikeda et al., 1999; Ikehara and Itaki, 2007; Yokoyama et al., 2007; Lee et al., 2008; Ryu et al., 2008; Choi et al., 2012; Bahk et al., 2016; Lim et al., 2015). Based on the lithology (Bahk et al., 2001; Nishida and Ikehara, 2013; Khim and

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Bahk, 2014), marine micropaleontology (Gorbarenko and Southon, 2000; Itaki et al., 2004; Hoshiba et al., 2006; Koizumi et al., 2006; Minoura et al., 2012; Ishihama et al., 2014), and organic geochemical analysis (Hyun et al., 2007; Kido et al., 2007; Khim et al., 2008; Bae et al., 2014), the hydrography and sea-bottom conditions (oxygen levels) of the East Sea (Japan Sea) during the Late Quaternary were well understood. However, the impact of sea level and ocean current changes on neighbouring land environment has remained uncertain.

Among the various environmental proxies of marine sediment cores, pollen and spores are unique in providing information about the evolution of vegetation from the neighboring land, and bridging paleoenvironmental studies between land and sea (Sun and Li, 1999). The primal marine pollen studies in East Sea (Japan Sea) had begun in the 1980s, but most of the works had poor age-control (Morley et al., 1986; Takahara and Takeoka, 1992; Igarashi, 1994). In the recent years, some high resolution researches concerning the late Quaternary pollen analysis were carried on, but which were concentrated in north and central of the East Sea (Japan Sea) (Tsoy and Vagina, 2008; Ikehara and Oshima, 2009; Gorbarenko et al., 2014, 2015). In this study, we present a well-dated pollen and algae record over the past 44 ka from core KCES-1 in the southwestern part of the East Sea (Japan Sea). The results are expected to provide useful information on the history of vegetation and climate, and the influence of sea level and current changes on the environment of the southern East Sea (Japan Sea) area over the late Quaternary.

2. Study area

2.1. Oceanographic setting

The East Sea (Japan Sea) is a semi-enclosed marginal sea in the northwestern Pacific. It is connected to the East China Sea, the Okhotsk Sea, and the North Pacific by four shallow and narrow straits with sill depths less than 140 m. The average water depth of the East Sea (Japan Sea) is 1350 m and the maximum water depth is about 3700 m. The deep part of the East Sea (Japan Sea) is subdivided into three deep basins: the Ulleung Basin, the Yamato Basin, and the Japan Basin, by the topographic highs of the Korea Plateau, the Oki ridge, and the Yamato Rise (Fig. 1) (Khim et al., 2008). The Ulleung Basin, a bowl-shaped basin in the southwest of East Sea (Japan Sea), is connected to the steep continental slope of the eastern Korean Peninsula at the west and bounded by the gentle slope and relatively broad shelf of the Japanese Arc to the southeast (Hyun et al., 2007).

The only oceanic water entering the East Sea (Japan Sea) at present is the TWC, a branch of the Kuroshio Current (KC), which flows into the East Sea (Japan Sea) through the Tsushima Strait and flowing out through the Tsugaru and Soya Strait (Fig. 1) (Yoshiki et al., 2007). It occupies the upper 150 m of the Ulleung Basin and Yamato Basins and flows northward along the western margin of the Japanese islands (Fujine et al., 2009), and is thought to be the main source of heat and salt in the surface and middle water of the East Sea (Japan Sea), especially the southern part of East Sea (Japan Sea). The temperature and salinity of the TWC are affected by river discharge from the adjacent land and changed seasonally, with low temperature and high salinity in winter, and high temperature and low salinity in summer (Lee, 2007).

2.2. Vegetation types

Modern vegetation in the east coast of Korea and western Japan, the two potential pollen source areas for the Ulleung Basin, is briefly introduced as follow.

The vegetation in the east coast of Korea is dominated by warm temperate evergreen broadleaved forest and temperate deciduous broadleaved forest (Yim and Kira, 1975; Yi and Kim, 2011). The warm temperate evergreen broadleaved forest mainly consists of *Castanopsis cuspidate*, *Quercus acuta*, *Q. myrsinaefolia*, *Q. glauca*, *Camellia japonica*, *Pittosporum tobira* and *Machilus thunbergii* (Chung, 2011). The temperate deciduous broadleaved forest includes diverse deciduous broadleaved trees such as *Quercus acutissima*, *Q. variabilis*, *Q. serrata*, *Q. mongolica*, *Carpinus tschonoskii*, *C. coreana*, *Corylus heterophylla*, *Zelkova serrata*, *Castanea crenata*, etc. and coniferous taxa such as *Pinus densiflora* and *Juniperus chinensis* (Chung et al., 2006, 2014).

The present vegetation in western Japan consists of warm temperate evergreen broadleaved forest, temperate deciduous broadleaved forest and conifer forest (Nakagawa et al., 2002). The warm temperate evergreen forest mainly consists of *Cyclobalanopsis*, *Castanopsis, Camellia* and Lauraceae (Tsukada, 1985). Temperate deciduous broadleaved forest composed of *Fagus crenata* and *Quercus crispula* (Takahara et al., 2010). *Cryptomeria japonica* is distributed in the temperate forests of snowy regions in the coastal areas of the East Sea (Japan Sea) (Hayashi et al., 2010). Conifer forest is represented by *Abies firma*, *Picea polita* and *Tsuga sieboldii* (Tsukada, 1985; Heusser and Morley, 1990).

However, the modern natural vegetation of Korea and Japan, especially in the lowlands, have changed largely to pine (*Pinus densiflora*) and oak (*Quercus serrate*) secondary forest due to human activity (Park et al., 2012; Demske et al., 2013).

3. Materials and methods

The piston core KCES-1 (35°56.150′N, 130°41.915′E, 10.15 m long) was provided by the Korean Ocean Research and Development Institute. It was extracted from the southeastern Ulleung Basin in 2005. The water depth is 1463.8 m (Fig. 1). The lithology of core KCES-1 has been described by Zou et al. (2012). Briefly, the upper section (0–400 cm) of the core is dominated by clayey silt and silt. A thick laminated layer is present at the middle section (400–730 cm). The lower portion displays irregular structures possibly resulting from the turbidities. In addition, the sediments contain four layers of volcanic ash with different thicknesses (Fig. 2). We select the upper 679 cm portion for study in the present work.

3.1. Age model and sedimentation rates

One AMS^{14}C date was measured on 10 mg shells of planktonic foraminifera (*Neogloboqudrina pachyderma*) from 156 to 160 cm of core KCES-1 at the NOSAMS, Woods Hole Oceanographic Institution, USA. The AMS^{14}C age was corrected for reservoir age (400 years) and calibrated into the calendar age by using the CALIB 5.0.1 program (Table 1) (Stuiver and Becker, 1993).

Based on the AMS ^{14}C dating, marker tephra layers and laminated layers, 7 age control points were obtained (Table 1), as also published by Liu et al. (2010). The depth-age relationship of core KCES-1 is well constrained by the 7 age control points. An age model was obtained by linear interpolation between calendar ages. The 679 cm core contains a continuous record of the past 44 ka with sedimentation rates ranging from 5.9 to 28 cm ka^{-1}.

3.2. Palynoflora analysis

A total of 101 samples were taken for palynoflora analysis and were processed according to a procedure slightly modified from Moore et al. (1991). The samples were successively treated with HCl, KOH, HF and heavy liquid flotation, and slides were made after