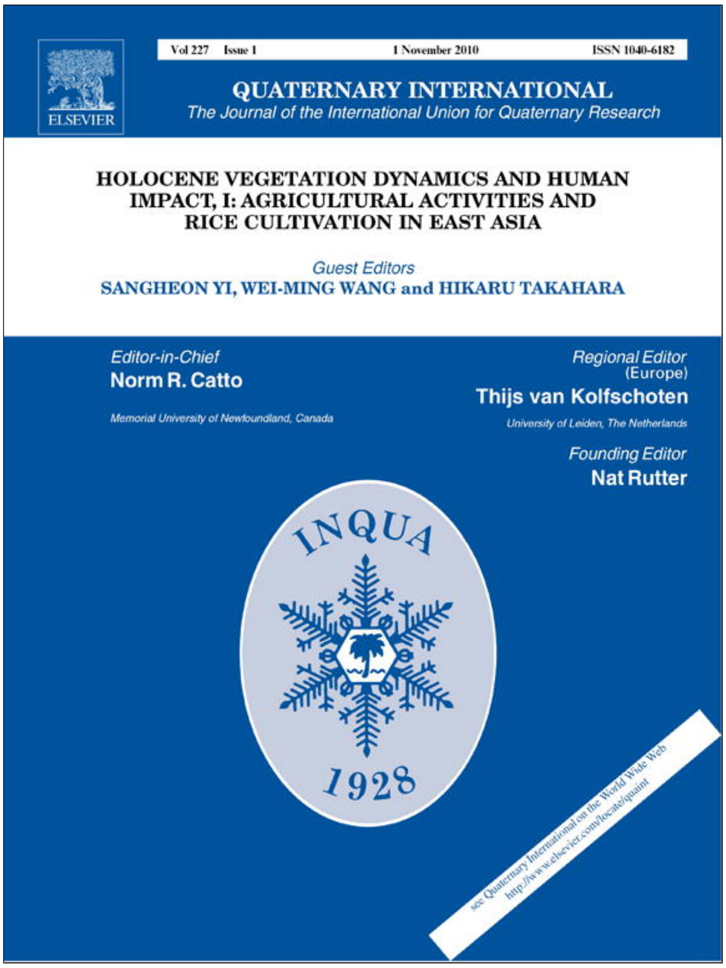
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30 000-Year vegetation and climate change around the East China Sea shelf inferred from a high-resolution pollen record

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ABSTRACT

A high-resolution pollen record derived from DG9603 core reveals vegetation and climate changes on the East China Sea Shelf (ECSS) during the past 30 000 years. From 29.8 to 26.6 cal ka BP, the ECSS was covered by warm temperate forest-steppe and wetland, indicating a relatively temperate and moist environment. During the period of 26.6–14.8 cal ka BP (including the Last Glacial Maximum), wetland and temperate forest-steppe developed around the ECSS. From 14.8 to 5.3 cal ka BP, sea-level continuously rose, and the ECSS was gradually submerged. In some exposed areas of the ECSS and lower reaches of the Yangtze River, northern subtropical forest (with plants of *Quercus*-evergreen, *Castanopsis*–*Lithocarpus* and *Tsuga*) developed instead of temperate forest-steppe and wetland. The pollen record shows that the rainfall and temperature increased continually during the period of 14.8–12.8 cal ka BP. At the end of this period, subtropical forest expanded and even reached the level of "Holocene Optimum period" (early-mid Holocene). IN the Younger Dryas period (12.8–11.1 cal ka BP), a rapid increase in the proportion of arboreal taxa especially *Quercus*-deciduous tree, and a slight decrease in *Quercus*-evergreen, *Tsuga* and herbs component indicates a mild climate with higher precipitation. From 11.1 to 5.3 cal ka BP, the northern subtropical forest was widely distributed around the ECSS region, suggesting a relative warm and humid condition in the early Holocene. The subtropical forest component declined slightly and herbaceous taxa increased, reflecting a relatively drier and cooler climate during the period of 9.0–7.0 cal ka BP. In the past 5.3 cal ka BP, forest vegetation in the lower reaches of the Yangtze River was deforested severely, possibly caused by human activity.

1. Introduction

Accurate reconstruction of global vegetation history during the Last Glacial Maximum (LGM) period must include vegetation successions in exposed continental shelves around the world (Ray and Adams, 2001; Sun et al., 2000; Wang et al., 2007). The East China Sea Shelf (ECSS), one of the largest continental shelves, was widely exposed at the LGM (26.5–19.0 cal ka BP) (Clark et al., 2009; Saito et al., 1998). There are some studies focused on the history of vegetation and climate changes around the ECSS during the LGM depending on pollen data from the Okinawa Trough, ECSS, and Taiwan Island (Deng et al., 2005; Kawahata and Ohshima, 2004; Lu et al., 2002a,b; Wang et al., 1987; Xu et al., 2009). Some research demonstrates that the ECSS area was widely covered by grassland during the LGM (Deng et al., 2005; Liew et al., 1998; Sun et al., 2000; Wang et al., 1987; Xu et al., 2009). However, biomization results indicate forest vegetation was widely distributed around the ECSS in the same period (Harrison et al., 2001; Zheng et al., 2003, 2007). Thus, vegetation successions in this region and its surrounding areas are still contentious. The controversy is mainly due to lack of a high-resolution and well dated pollen record (Kawahata and Ohshima, 2004).

This study presents a well dated and high-resolution pollen record of the past 30 000 years from DG9603 core drilled in the Okinawa Trough. The results provide new evidence to address the history of vegetation evolution and environmental changes around the ECSS during the past 30 000 years.

2. Environmental setting

The East China Sea (ECS) is a marginal sea with one of the widest continental shelves in the world and is about 770 000 km^2 (Wang, 1985). The ECS receives huge amounts of riverine water

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(1×10^{12} m^3/y) mainly from the Yangtze River, and sediments (about 2×10^9 tonnes/y) from coastal region transported by the Yangtze River and Yellow River (Hu et al., 1998). During the LGM, sea-level was 120–150 m lower than present in the ECS, and most of the present shelf was exposed (Saito et al., 1998; Wang, 1992) (Fig. 1). The Okinawa Trough, which was close to the shelf edge and continually submerged during the glacial–interglacial cycles, maintained continuous deposition. Therefore, the sedimentary record from the Okinawa Trough is able to provide a high-resolution environmental and climatic record for reconstructing vegetation changes in the ECSS area.

3. Materials and methods

DG9603 core (28°08.869′N, 127°16.238′E, water depth 1100 m), located in the west margin of the Okinawa Trough (Fig. 1), was drilled during the Chinese–French joint DONGHAI cruise of R/V L'Atalante in 1996. This core is 5.92 m in length, and mainly composed of hemipelagic gray silty clay with thin volcanic ash layers. No disturbance was observed in the whole core.

The core was sampled at 2~3 cm intervals from 0 to 3.02 m, with each sample about 3.0 ± 0.3 g, to which was added one *Lycopodium* tablet (27 637 N/tablet). 10% hydrochloric acid and 40% hydrofluoric acid were added to remove carbonates and silicates respectively, and then samples were heated with 10% KOH to dissolve organic matters. The remained materials after acid–alkaline reactions were sieved through a 7-μm mesh in an ultrasonic instrument in order to concentrate pollen. The residue was suspended in glycerine and mounted on slides for microscopic examination at 400× magnification. Each sample was counted for pollen and spores over 450 grains (average 510 grains). A total of 69 481 grains of pollen and spores have been obtained from the 136 samples. In addition, charcoal particles with length greater than 50 μm were counted, and their concentrations were calculated with the ratio of *Lycopodium*.

A cluster analysis (CA) improved the reliability of pollen zonation. CA was executed by PAST software (Hammer et al., 2010).

The chronological sequence for DG9603 has been established by Liu et al. (2001). Materials for AMS ^{14}C dating were foraminifera, such as *Globorotalia menardii* and *Globigerinoides sacculifer*. Fig. 2 shows the calendar ages of 9 samples from the upper 3.02 m (Table 1). The ages were calculated by using CALIB 4.1 (Stuiver et al., 1998). Linear interpolation of calendar ages provides age controls of the samples from bottom to top respectively. The upper 3.02 m covers the past 30 000 years with an average sampling resolution of 220 years, and 175 years especially for the LGM.

4. Results

4.1. Pollen taxa

A total of 178 pollen types were identified including 118 arboreal taxa, 40 herbaceous taxa and 20 fern taxa. In reference to previous classifications (Wang et al., 2009; Xu et al., 2009), and taxa ecological types, vegetation groups are as follows:

Tropical high montane forest group: *Phyllocladus*, *Dacrydium*;
Subtropical high montane forest group: *Podocarpus*, Taxodiaceae, *Tsuga*;
Cool montane forest group: *Abies*, *Picea*, *Larix*;
Tropical forest group: *Ficus*, *Altingia*, *Liquidambar*, *Elaeocarpus*, Palmae, Rhizophoraceae, Myrtaceae, etc.;
Subtropical forest group: *Quercus*-evergreen, *Castanopsis*–*Lithocarpus*, Myrsinaceae, Melastomataceae, Leguminosae, Euphorbiaceae, *Cycas*, etc.;
Temperate and subtropical forest group: *Ginkgo*, Moraceae, *Ulmus*, *Zelkova*, Araliaceae, Celastraceae, Rutaceae, Oleaeceae, Rosaceae, Sapindaceae, *Ilex*, *Fagus*, etc.;
Temperate-deciduous-forest group: *Quercus*-deciduous, *Castanea*, *Betula*, *Alnus*, *Carpinus*, *Corylus*, *Juglans*, *Pterocarya*, *Tilia*,

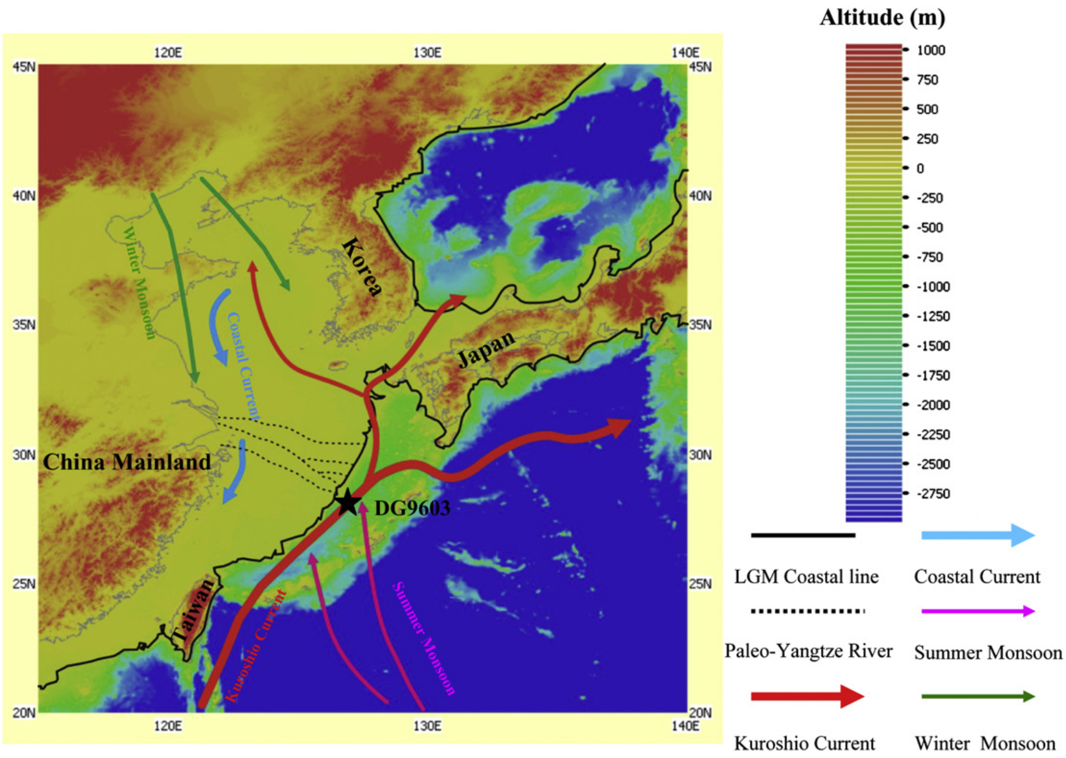

Fig. 1. Location of the studied area and DG9603 core. Paleo-Yangtze River from Xiao et al. (2003) and paleo-monsoon direction after Zhou et al. (2008).

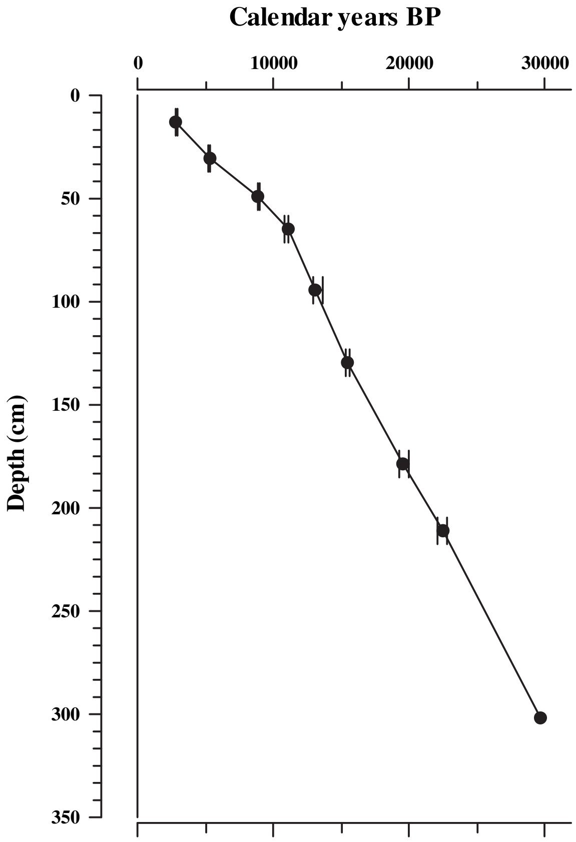

Fig. 2. Age-depth relationship in DG9603 core.

etc.; Aquatic group: *Typha*-Sparganiaceae type, *Myriophyllum*, *Alisma*, *Sagittaria*, *Nymphoides*, etc.;
Herb group: *Artemisia*, Gramineae, Cyperaceae, Compositae, Chenopodiaceae, *Polygonum*, Cruciferae, Caryophyllaceae, Plantagoaceae, *Sanguisorba*, Umbelliferae, Ranunculaceae, Liliaceae, Labiatae, Rubiaceae, *Ephedra, Humulus*, *Thalictrum*, Plantagoaceae, *Urtica,* Solanaceae, Umbelliferae, etc.;
Fern taxa: *Lycopodium*, Polypodiaceae, *Hicriopteris*, *Pyrrosia*, *Selaginella*, *Hymenophyllum*, *Pteris*, *Osmunda*, *Microlepia*, *Cibotium*, *Cyathea* etc..

4.2. Pollen assemblages

Pollen assemblages of DG9603 core can be divided visually into 4 pollen zones from bottom to top according to the changes of pollen percentage and CA results (Fig. 3 and Fig. 6).

Table 1
AMS ^{14}C ages of DG9603 core (Liu et al., 2001).

Depth(cm)	AMS ^{14}C age[a]	Calendar years BP	1σ age errors	Species
11–13	2740 ± 50	2840[b]	+80/−70	*G.menardii*
26–31	4500 ± 50	5300[b]	+120/−50	*G.menardii*
47–49	8080 ± 60	8950[b]	+50/−50	*G.sacculifer*
63–65	9690 ± 50	11090[b]	+70/−260	*G.sacculifer*
89–94	11 230 ± 50	13140[b]	+590/−130	*G.sacculifer*
128–130	12 980 ± 50	15510[b]	+200/−210	*G.sacculifer*
174–179	16 580 ± 60	19640[b]	+320/−310	*G.sacculifer*
209–211	19 070 ± 80	22510[b]	+370/−350	*G.sacculifer*
300–302	26 350 ± 190	29790[c]	–	*N.dutertrei*

[a] A 400-year correction is applied for the reservoir age of sea water.
[b] Converted to calendar age using CALIB 4.1 (Stuiver et al., 1998).
[c] Converted to calendar age following Laj et al. (Laj et al., 1996).

4.2.1. Zone I: 302 cm~262 cm, 29.8–26.6 cal ka BP (late MIS 3)

Herbaceous pollen (HP) is more than 60.0% in which *Artemisia* (average 29.0%,) and Cyperaceae (19.0%) are predominant. The subtropical-evergreen-broadleaved component is 17.2% including *Quercus*-evergreen (13.0%) and *Castanopsis–Lithocarpus* (2.0%). In addition, this zone contains a lower percentage of temperate-deciduous-broadleaved taxa (8.2%), which is composed of *Quercus*-deciduous (6.0%) and Betulaceae (2.0%). The main component of coniferous taxa is *Pinus* (7.0%), while the minor is *Tsuga* (1.5%), subtropical-montane-conifers. Pollen grains of *Phyllocladus* and *Dacrydium* occur sporadically. Charcoal concentration, about 350 N/g (number/gram), shows relatively low abundance.

4.2.2. Zone II: 262 cm̃119 cm, 26.6–14.8 cal ka BP (MIS 2, including LGM)

This zone is characterized by an increase of percentage of herbs (average 65.0%) such as *Artemisia* (31.0%), Cyperaceae (17.0%), Gramineae (4.5%), Chenopodiaceae (4.3%), *Thalictrum* (0.8%), Ranunculaceae (0.7%) and Cruciferae (0.9%). In addition, herbaceous species are very diverse, and their total component reaches 70% in some samples. A comparatively low proportion of arboreal pollen (AP, 35.0%) is represented by temperate arboreal taxa (16.5%), composed of *Quercus*-deciduous (12.0%) and Betulaceae (2.5%). There is an abrupt and remarkable decrease in the percentage of subtropical AP (6.0%), especially *Quercus*-evergreen (3.6%) and *Castanopsis–Lithocarpus* (1.0%). A slight increase in Taxodiaceae (1.0%) is present, and pollen grains of *Phyllocladus* and *Dacrydium* occur frequently. Charcoal concentration rises to 757 N/g on average, and its maximum value reaches 2414 N/g.

4.2.3. Zone III: 119 cm~31 cm, 14.8–5.3 cal ka BP (last Deglacial to the early-mid Holocene)

AP increases to 67.0% and tropical taxa reach 1.0%. Subtropical arboreal taxa are marked by a predominance of *Quercus*-evergreen (15.6%), *Castanopsis–Lithocarpus* (3.2%) and *Tsuga* (7.0%). Temperate-deciduous pollen is characterized by low percentages of *Quercus*-deciduous (7.5%) and Betulaceae (2.4%). The proportion of HP (33.0%) composed of *Artemisia* (11.0%) and Cyperaceae (11.0%) declines to the minimum value (20.0%) at about 10.0 cal ka BP, whereas percentage of *Pinus* increases to 30.0%. Charcoal concentration indicates a remarkable declining trend ranging from 1701 N/g to less than 100 N/g. Three subzones are divided based on the changes of pollen assemblages and CA results.

4.2.3.1. Zone III-1: 119 cm ~ 92 cm: 14.8–12.8 cal ka BP (bølling-allerød period, BA). *Quercus*-evergreen recovers from 7.0% to 20.0%, in combination with an increase in the percentage of *Castanopsis–Lithocarpus* (vary between 1.0% and 4.0%) and *Tsuga* (from 1.0% to 9.0%), associated with a decline in the proportion of *Quercus*-deciduous, ranging from 19.0% to 6.0%. This subzone is marked by dramatic reductions in the proportion of *Artemisia* (between 25.0% and 10.0%) and Cyperaceae (from 15.0% to 10.0%).

4.2.3.2. Zone III-2: 92 cm~65 cm, 12.8–11.1 cal ka BP (Younger Dryas period). There is a slight decrease in the percentage of *Quercus*-evergreen (14.0%), *Tsuga* (7.0%) and *Artemisia* (6.0%), whereas *Quercus*-deciduous (10.0%) exhibits a sharp increase.

4.2.3.3. Zone III-3: 65 cm ~ 31 cm, 11.1–5.3 cal ka BP (early-mid Holocene). This subzone is dominated by *Quercus*-evergreen (16.0%) and an apparent decrease in the proportion of *Quercus*-deciduous (from 10.0% to 4.5%) and *Pinus* ranging from 30.0% to 15.0%. The percentages of *Quercus*-evergreen (14.0%) and *Tsuga* (5.0%) show relatively low values during 9.0–7.0 cal ka BP. There is

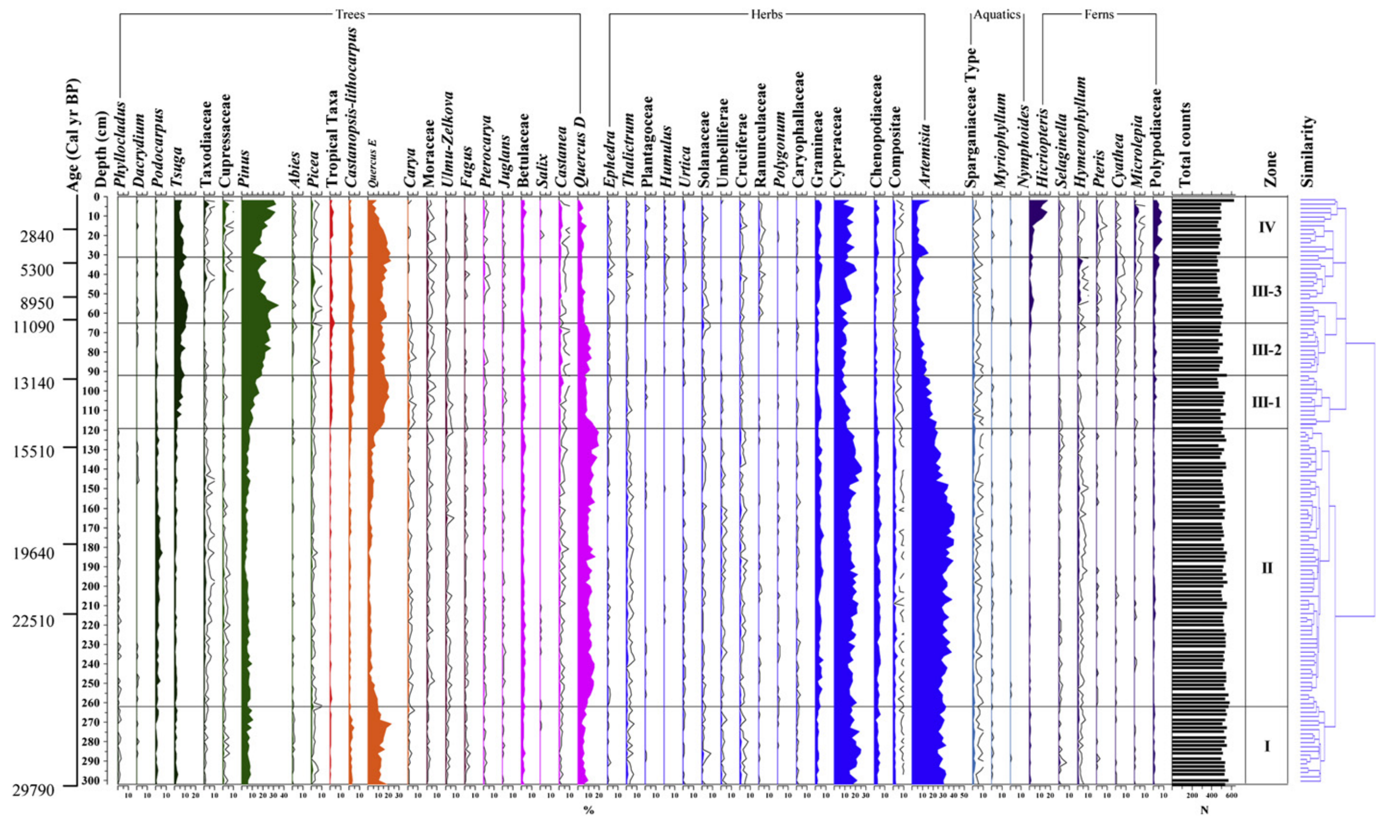

Fig. 3. Analysis of pollen and spore percentage diagram of DG9603 core for the past 30 000 years.

a slight increase in proportion of *Artemisia* (7.0%) and Cyperaceae (12.5%), and frequent occurrences of fern spores.

4.2.4. Zone IV: 31 cm~0 cm, 5.3–0.4 cal ka BP (late Holocene)

There is a gradual decrease in the percentage of *Quercus*-evergreen (ranging from 18.0% to 4.0%) and *Tsuga* (the values vary between 7.0% and 2.0%), whereas *Pinus* component increases remarkably from 14.0% to 30.0%. Herb pollen taxa such as *Artemisia*, Caryophyllaceae, Chenopodiaceae, Cruciferae, Gramineae, Plantagoaceae, *Polygonum*, Ranunculaceae, Compositae and *Urtica* are present more frequently. The total proportion of fern spores reaches its maximum value of 40.0%.

4.3. Results of principal component analysis (PCA)

PCA analysis of pollen data further improved paleoclimatic interpretation for the established pollen zones. Thirty two pollen types with concentrations exceeding 0.5% were selected, except for fern spores, *Pinus*, and other pollen including *Phyllocladus*, *Dacrydium* and *Podocarpus* probably transported by the Kuroshio Current. Fig. 4 shows a PCA biplot of pollen percentages. The first principal component, axis 1, has a 0.75 eignvalue and axis 2 a 0.09 eignvalue. Subtropical-evergreen-taxa, especially *Quercus*-evergreen, *Castanopsis–Lithocarpus* and *Tsuga*, have the highest positive loadings on axis 1, whereas temperate taxa *Quercus*-deciduous and HP including *Artemisia*, Cyperaceae, Gramineae, Chenopodiaceae and Compositae have negative loadings. Positive loadings suggest a warmer climate and negative ones represent a cooler condition on axis 1.

Factor scores on axis 1 (Fig. 5) clearly show relatively low values, suggesting a temperate climate for pollen Zone I. Zone II, indicated by significant lowest scores, represents the coldest climate. Zone III is characterized by an increase in values of axis 1, and then scores increase gradually, implying continuous rising in temperature from 15.0 to 10.0 cal ka BP. Slightly lower values at 10.0–5.0 cal ka BP show a warm climate in the late part of Pollen Zone III.

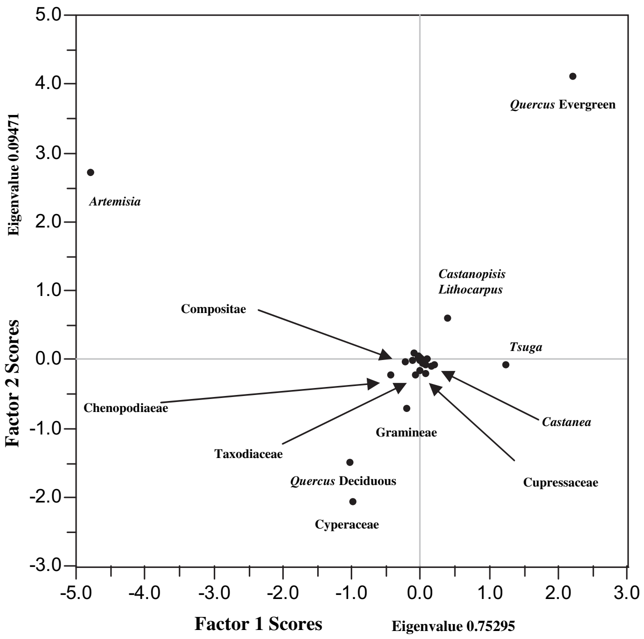

Fig. 4. Principal component analysis of pollen taxa from DG9603 core.

5. Discussion

5.1. Paleovegetation reconstruction and its climate significance

The pollen record from DG9603 core reveals a detailed vegetation history in the past 30 000 cal BP.

Between 29.8 and 26.6 cal ka BP, the HP component exceeds 60%, marked by a predominance of *Artemisia* and Cyperaceae associated with Chenopodiaceae, Compositae and Gramineae. A total proportion of broadleaved AP is less than 26%, characterized by a high proportion of evergreen and deciduous arboreal taxa such as *Quercus*-evergreen, *Castanopsis–Lithocarpus*, *Quercus*-deciduous and Betulaceae. *Artemisia* and Chenopodiaceae are the main components of steppe vegetation (Li et al., 2005). Previous studies (Xu et al., 2005) based on palynological analysis from forest and steppe soil in Northern China reported that the AP component accounts for more than 30%, and the HP proportion is lower than 50% in forest regions. In steppe regions, HP is generally more than 90% and AP is less than 5%, whereas in forest marginal areas, AP is not more than 15% (Li et al., 2005). The ECSS was covered by forest-steppe during late MIS 3 according to the characteristics of modern pollen assemblages from forest-steppe area in Inner Mongolia, Ningxia and Shaanxi province (Xu et al., 2005). Cyperaceae cannot tolerate saline conditions, but favor a stable wetland (González and Dupont, 2009). At present, a sedge and reed community is widely distributed around wetland of the Yangtze River estuary and Taihu Lake (Tang and Lu, 2003; Tian et al., 2008). Thus, it can be speculated that freshwater lakes and marshes probably presented around the ECSS region (Kawahata and Ohshima, 2004). The ECSS area was covered by forest-steppe and wetland during 29.8–26.6 cal ka BP, characterized especially by evergreen and deciduous trees reflecting a relatively temperature and moist condition. Factor scores on axis 1 are slightly lower during this period and also indicate a temperate climate.

During the LGM, the pollen assemblage is characterized by an increase of HP percentage (65%) associated with a high proportion of Cyperaceae and *Artemisia*, which reach 70% in some samples. Broadleaved trees decline to 23%. Additionally, the whole proportion of deciduous taxa including *Quercus*-deciduous and Betulaceae increases, while evergreen component decreases abruptly. Thus, dry steppe vegetation might be distributed around plain areas inferred from predominant steppe pollen component. A high proportion of sedge and grass pollen probably indicates wetlands existed in low-lying land. A certain AP component implies some deciduous trees growing in the ECSS, or might be derived from the middle and upper reaches of the Paleo-Yangtze River. Han et al. (1989) considered that forest-steppe existed on the ECSS and in the Yangtze River estuary during the LGM. Thus, these tree pollen grains were more likely derived from the ECSS itself. Wetland and temperate forest-steppe were still present around the ECSS during the LGM, although dry steppe plants were distributed there. This vegetation type with the lowest values on axis 1 of PCA suggests a relatively colder climate than that of late MIS 3. An expansion of *Artemisia* and highest abundance of charcoals may indicate a dry climate at the LGM. High percentage of cold and dry phytolith types from the same DG9603 core during this period also supports this interpretation (Lu et al., 2002a, 2002b).

Stalagmite records from East and South China (Fig. 6) revealed a weakened summer monsoon (Wang et al., 2001; Yuan et al., 2004), while the winter monsoon became more strengthened in East Asia during the LGM (Sun et al., 2000; Zheng et al., 2003). The Yellow Sea and Bohai Sea shelf was widely exposed owing to global sea-level lowering, and covered mainly by desert or desert steppe (Yu et al., 1997; Harrison et al., 2001; Zheng et al., 2003, 2007). In winter, the cold and dry air mass from Siberia through the Bohai Sea and Yellow Sea became drier and was pushed to the ECSS (Yu et al., 1997) (Fig. 1). Hence, significant lower temperature and rainfall indicated by temperate forest-steppe and wetland may be related to strengthened winter monsoon and weakened summer monsoon. However, it is difficult to know these vegetation types of paleogeographic distribution at that time around the ECSS.

From 14.8 to 12.8 cal ka BP (BA), broadleaved AP proportion constantly exceeded 30%, and the HP component is below 50%. The pollen assemblage reflects a marginal condition of forest vegetation, indicating that woodlands gradually replaced temperate forest-steppe and wetland. A general increase in the percentage of subtropical-evergreen AP is combined with a significant decrease in temperate-broadleaved AP components. Northern subtropical-evergreen-broadleaved forest and subtropical-montane-coniferous forest gradually predominated. This result suggests that subtropical forest started to expand at about 14.8 cal ka BP. Additionally, this subtropical forest had a large expansion at about 13.0 cal ka BP, and its vegetation type was similar to that of the "Holocene Optimum period" (early-mid Holocene). Higher PCA scores on axis 1 and a decrease of charcoal concentration are consistent with the vegetation changes, suggesting a growing trend in both temperature and precipitation. The time of significant climate warming reflected by subtropical forest expansion is at least 2 ka earlier than previously reported in core PC-1 and MD982195 from the north Okinawa Trough (Wang et al., 2009).

Nowadays, the northern subtropical-evergreen-broadleaved forest is distributed in a narrow belt of mid-east China monsoon region with mean annual precipitation of 800–1200 mm, of which 50%–60% rainfall brought by summer monsoon is concentrated in April to September (Yang and Yang, 1992). This rapid rising in rainfall and temperature indicated by expansion of subtropical forest is mostly probably related to the strengthened summer monsoon at about 14.8 cal ka BP. Warm and humid climate in the BA period has previously been identified in marine and terrestrial studies. Records from DG9603 and DG9604 core in the Okinawa Trough indicate a remarkable temperature increase at about

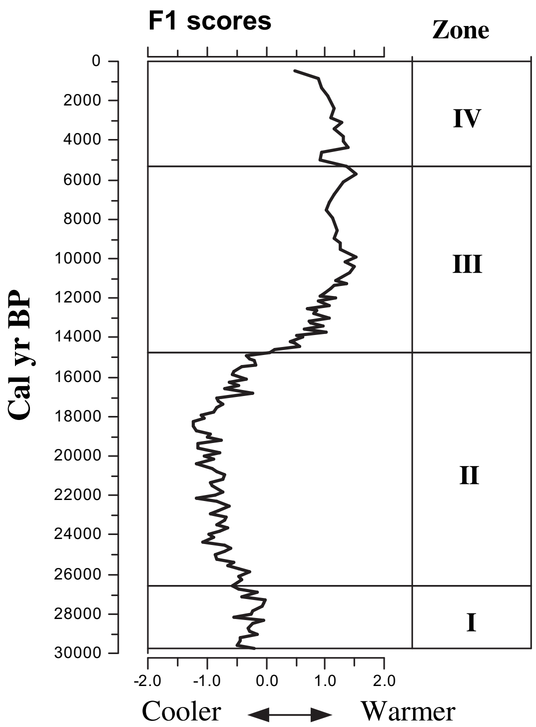

Fig. 5. Variations of factor scores in PCA axis 1.

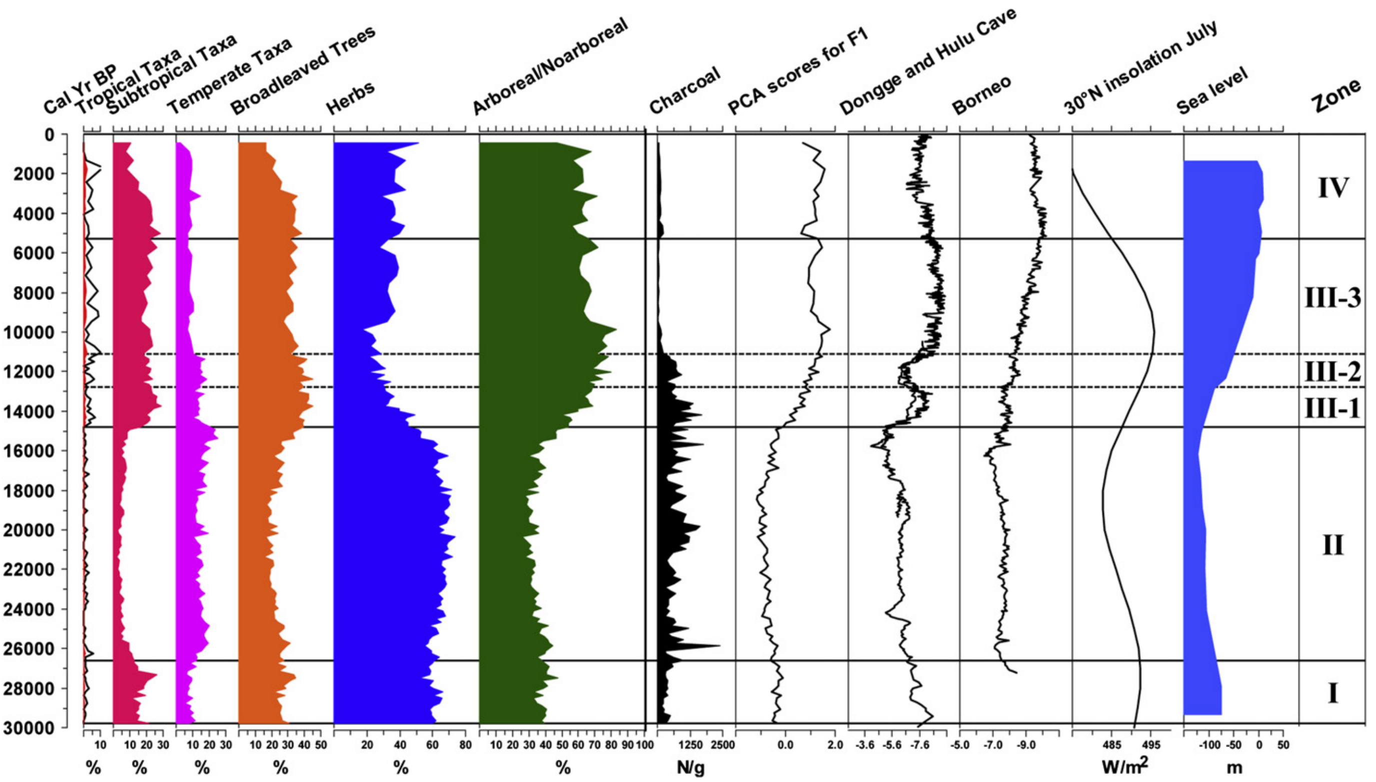

Fig. 6. Multiple records from DG9603 core compared with those of stalagmites and sea-level curve. Stalagmite oxygen isotopic records of Borneo, Dongge Cave and Hulu Cave are from Partin et al. (2007), Wang et al. (2001), and Yuan et al. (2004), respectively. The record of sea-level change in the East China Sea is from Saito et al. (1998).

14.8 cal ka BP (Li et al., 2001; Lu et al., 2002a, 2002b; Yu et al., 2009). Increases in both temperature and precipitation in the same period are also shown in some terrestrial records especially palynological and phytolith results in the South China Sea (Wang et al., 2009). Results of phytoliths and terrestrial molluscs from the Chinese Loess Plateau (Wu et al., 2002; Lu et al., 2007) and stalagmite records from South and East China (Wang et al., 2001; Yuan et al., 2004) also show the same conditions.

Four probable impacting factors: northern hemispherical summer insolation, meridional overturning circulation, atmospheric CO_2, and sea surface temperature (SST) (Clark et al., 2009; Liu et al., 2009), may contribute to the regional climate changes observed from the DG9603 pollen record. These results indicate the expansion of northern subtropical forest and the intensifying of summer insolation were synchronous during the BA period. Although the influences of increases in atmospheric CO_2, tropical Pacific SST, and intensifying meridional overturning circulation cannot be excluded, the northern hemispherical summer insolation was a primary trigger that drove this rapid climate change (Ruddiman, 2006a, 2006b).

The initiation of the BA in East Asia (14.8 ka BP) (Wang et al., 2001) and central Europe (13.9 ka BP) (Litt et al., 2001) is asynchronous. Regional solar insolation might cause the earlier Bölling origin in the Far East area (Nakagawa et al., 2003), if it is not caused by dating errors.

During the YD (12.8–11.1 cal ka BP), AP percentage increased gradually, while HP proportion declined continually. The deciduous AP component, especially *Quercus*-deciduous, showed a slight increase, but subtropical AP percentage such as *Quercus*-evergreen and *Tsuga* decreased to some extent. Therefore, this vegetation change implied a relatively cooler and wetter climate in the YD period.

From 11.1 to 5.3 cal ka BP, northern subtropical-broadleaved forest and subtropical-montane-coniferous forest were widely distributed around the ECSS and in mountains of lower reaches of the Yangtze River, respectively, which were indicated by a higher component of *Quercus*-evergreen and *Tsuga*, suggesting a relative warm and humid condition in the early Holocene. This condition has also been identified through previous phytolith studies (Lu et al., 2002a, 2002b). During the period of 9.0–7.0 cal ka BP, *Quercus*-evergreen and *Tsuga* percentage declined slightly, and the HP component increased. This vegetation change reflects a drier-milder stage.

From 5.3 to 0.4 cal ka BP, a general change in vegetation indicated by pollen assemblage is an increase in the proportion of pioneer plants such as *Pinus* and ferns and a gradual decrease in the original forest component, especially *Quercus*-evergreen and *Tsuga*. Furthermore, herbs more frequently occurred during the late Holocene. This kind of vegetation pattern might be caused by human activity during this period. A similar phenomenon has been reported previously from the lower reaches of Yangtze River and southeastern China, where the broadleaved components were reduced and secondary forest increased. Especially, pine increased remarkably at about 5.0 cal ka BP, which had been attributed to human impacts (Wang et al., 2010; Xu et al., 1996; Zheng et al., 2004).

5.2. Pollen origin in DG9603 core

DG9603 core is located in the western part of the Okinawa Trough, about 150 km from Ryukyu archipelago and 530 km from the modern East China coast. A long distance exists presently between the core and coast. However, it was close to the source area of the ECSS as its large area was exposed at the LGM (Fig. 1). The Okinawa Trough captured the materials mainly from the ECSS region owing to enhanced denudation during that time (Dou et al., 2010; Jin et al., 2006). In particular, more terrigenous plant fragments including pollen and spores were input into the Okinawa Trough region during the LGM than in the Holocene (Ujiie et al., 2001; Zheng et al., 2009). Even at present, a period with relatively high sea-level, a mass of terrigenous materials in the Okinawa Trough mainly comes from the drainage area of the Yangtze River (Hu et al., 1998; Jin et al., 2006). Pollen grains from the continent are transported by the Yangtze River and other rivers to the shelf, slope and trough of the ECS, consequently influencing pollen assemblages of surface sediments in the ECS including the Okinawa Trough (Wang et al., 1987). A small amount of pollen grains may be from middle reaches of the Yangtze River, other rivers and coastal current also can contribute some pollen to the Okinawa Trough (Zheng et al., 2009). These pollen grains may interfere with determination of vegetation in the ECSS and the lower reaches of the Yangtze River.

During the LGM, sea-level was 120~150 m lower than at present (Saito et al., 1998; Wang, 1992), and the position of DG9603 core was closer to coastline (Fig. 1). Thus, pollen in the DG9603 core might largely come from the exposed ECSS. During 18.0–5.0 cal ka BP, the ECSS was continuously submerged as sea-level rose (Saito et al., 1998). Pollen might mainly represent vegetation communities of exposed shelves and the lower reaches of Yangtze River. At about 5.0 cal ka BP, the ECSS was completely submerged (Saito et al., 1998), and the pollen assemblage should principally reflect vegetation changes in the lower reaches of Yangtze River.

5.3. Occurrence of tropical-montane-coniferous pollen and their implication

At present, *Dacrydium* is distributed in Hainan, and *Phyllocladus* originates from South-East Asia (New Guinea, Indonesia and the Philippines; Chang and Ren, 1998). These tropical-montane-coniferous pollen grains appear continuously with a low proportion in the pollen assemblages during 30.0–15.0 cal ka BP, which implies that the Kuroshio Current may play some role in carrying tropical pollen to that area, apart from wind transportation. It might be possible that the Kuroshio Current still flowed through the Okinawa Trough during that time, because the same result has also been found in MD982195 and PC-1 core (Kawahata and Ohshima, 2004; Xu et al., 2009).

6. Conclusion

Vegetation and climate changes around the ECSS and lower reaches of the Yangtze River have been reconstructed for the past 30 000 cal BP based on studies of pollen assemblages, PCA, and CA of DG9603 core.

From 29.8 to 26.6 cal ka BP, the pollen assemblages show a high proportion of AP including *Quercus*-evergreen, *Castanopsis–Lithocarpus*, *Quercus*-deciduous and *Pinus,* and HP like *Artemisia* and Cyperaceae. Evergreen-deciduous-mixed forest-steppe and wetland was dominant in the ECSS during this period, indicating a temperate and moist climate.

During 26.6–14.8 cal ka BP (including the LGM), HP percentage increases to the maximum value, and AP component declines apparently. The ECSS was covered mainly by temperate forest-steppe and wetland composed of *Quercus*-deciduous, *Artemisia*, Cyperaceae, Chenopodiaceae, Compositae, Gramineae, *Thalictrum*, Ranunculaceae and Cruciferae, while tree components, especially *Quercus*-evergreen, declined remarkably. Cold and dry climate prevailed in this area in response to intensifying of winter monsoon and weaken summer monsoon during the LGM.

During 14.8–5.3 cal ka BP, an abundant appearance of arboreal taxa such as *Quercus*-evergreen, *Castanopsis–Lithocarpus* and *Tsuga,* associated with a general decrease in the percentage of deciduous trees and herbs, indicates a remarkable recovery in subtropical forest community. At this interval, the ECSS was gradually submerged. Northern subtropical forest was developed around the exposed ECSS and in the lower reaches of the Yangtze River. Both temperature and rainfall showed an increasing trend since 14.8 cal ka BP. At about 13.0 cal ka BP, subtropical forest expansion reached the level of the "Holocene Optimum period" (early-mid Holocene). The time of significant climate warming reflected by subtropical forest expansion was at least 2 ka earlier than indicated by former studies. A mild climate with higher rainfall reflected by an increase in AP component especially *Quercus*-deciduous pollen was present 12.8–11.1 cal ka BP in response to the YD event. From 11.1 to 5.3 cal ka BP, the recovery of subtropical forest indicated increases of humidity and temperature.

In the past 5.3 cal ka BP, pollen assemblages were marked by a continuous decrease in the proportion of *Quercus*-evergreen and *Tsuga*, and a gradual increase in the percentage of *Pinus* and ferns, implying forest degradation that might be related to human activities.

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