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Palaeoenvironmental changes from pollen record in deep sea core PC-1 from northern Okinawa Trough, East China Sea during the past 24 ka

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A pollen record of core PC-1 from the northern Okinawa Trough, East China Sea (ECS), provides information on vegetation and climate changes since 24 cal. kaBP. A total of 103 samples were palynologically analyzed at 8 cm intervals with a time resolution of 230 a. Four pollen zones are recognized: zone I (812—715 cm, 24.2—21.1 cal. kaBP), zone II (715—451 cm, 21.1—15.2 cal. kaBP), zone III (451—251 cm, 15.2—10.8 cal. kaBP), zone IV (251—0 cm, 10.8—0.3 cal. kaBP), corresponding to Late MIS 3, Last Glacial Maximum (LGM), deglaciation and Holocene, respectively. The LGM is characterized by the dominance of herbs, mainly *Artemisia*, and high pollen influx, implying an open vegetation on the exposed continental shelf and a cool and dry climate. The deglaciation is a climate warming stage with *Pinus* percentage increased and *Artemisia* percentage decreased and a rapid sea-level rise. The Holocene is characterized by predominance of tree pollen with rapid increase in *Castanea-Castanopsis* indicating the development of mixed evergreen and deciduous broad-leaved forest and a warm, humid climate. Low pollen influx during the Holocene probably implies submergence of the continental shelf and retreat of the pollen source area. The vegetation indicated by pollen assemblage found in this upper zone is consistent with the present vegetation found in Kyushu, Japan. Originating from the humid mountain area of North Luzon of the Philippines, Tasmania and New Zealand, *Phyllocladus* with sporadic occurrence throughout PC-1 core probably suggests the influence of Palaeo-Kuroshio Current or intense summer monsoon. The observed changes in *Pinus* and Herbs percentage indicate fluctuations of the sea level, and high *Pinus* percentage corresponds to high sea level. Spectrum analysis of the pollen percentage record reveals many millennial-scale periodicities, such as periodicities of 6.8, 3.8, 2.2, 1.6 ka.

East China Sea, Okinawa Trough, palynology, Kuroshio, palaeoenvironment, MIS

The topography of the East China Sea (ECS) is characterized by wide continental shelf area, extending up to 500 km. The total area of the ECS is about 770 000 km^2[1]. Water depth is <150 m in the continental shelf and >800 m in the Okinawa Trough. Sea level during the last glacial maximum (LGM) was 120—130 m lower than the present[2], consequently most of the continental shelf changed into land. However, the Okinawa Trough was always below the sea level, so it was a good place to research the palaeoenvironmental changes and palaeoclimatic evolution. There are controversies over the Pa-

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laeo-Kuroshio Current in previous palynological and foraminiferal studies[3–7]: one opinion is that during the LGM the Kuroshio Current was not present in the Okinawa Trough but shifted to a position east of the Ryukyu Islands[3–5] because of the land bridge between Ryukyu Islands and Taiwan Island[3]; the other is just contrary[6,7]. Kawahata et al.[6] and Deng et al.[8] revealed that it was grassland on the exposed continental shelf of the ECS during the MIS 2. Lü et al.[9] considered during the last 20 ka oceanographic changes of the ECS lagged behind the epicontinent climate changes by 1000 a through palynology and phytolith, diatom and foraminifera data.

In this paper, we present the palynological record of gravity core PC-1 from the northern end of the ECS, and discuss the floral evidence of terrestrial environmental changes around the ECS continental margin and Kyushu Island. An emphasis of our discussion will be laid on the paleoceanographic and terrestrial environmental changes since 24 cal. kaBP in the region.

1 General situation of study areas

PC-1 core (31°27.50′N, 128°24.80′E) is located at the continental slope zone in the northern Okinawa Trough at a site to the east side of Tsushima Warm Current, a branch of Kuroshio Current (Figure 1). The core site is 150 km away from Kyushu Island of Japan, 600 km from the mainland of China. The Kuroshio Current originates from western equatorial Pacific, flows northward off the Philippines, enters the Okinawa Trough, flows northeastward along the edge of the ECS continental shelf, and finally offsets into several branches around 29°—30°N. The mainstream then turns eastward across the Tokara Strait and flows along the southern sea of the main islands of Japan. The branch with the ECS surface water together constitutes the Tsushima Warm Current, which enters the Sea of Japan through the Tsushima Strait and runs along the northern Japanese coast. The Kuroshio Current carries a huge amount of thermal energy from the equatorial to mid-latitudinal regions, directly influences the oceanographic setting and the distribution of ocean sediments and palaeoclimatic changes of the ECS.

The terrigenous materials at PC-1 core mainly come from Japan[1]. The natural vegetation on Kyushu Island is characterized by evergreen and deciduous broad-leaved forest. Evergreen broad-leaved forest mainly Fagaceae, Theaceae and Lauraceae grows below 1000 m a.s.l., with the major species of *Castanopsis*, *Quercus*-evergreen and *Machilus*. Above 1000 m a.s.l. grows deciduous broad-leaved forest dominant by *Fagus*, incidental by *Quercus*-deciduous, *Acer*, *Betula*, *Carpinus*. Man-made conifers mainly *Larix leptolepis*, *Cryptomerica japonica*, *Chamaecyparis obtuse*, *Pinus densiflora*, *Abies firma*, *Tsuga sieboldii*, etc. develop in areas where deciduous broad-leaved forest had been destroyed[10,11].

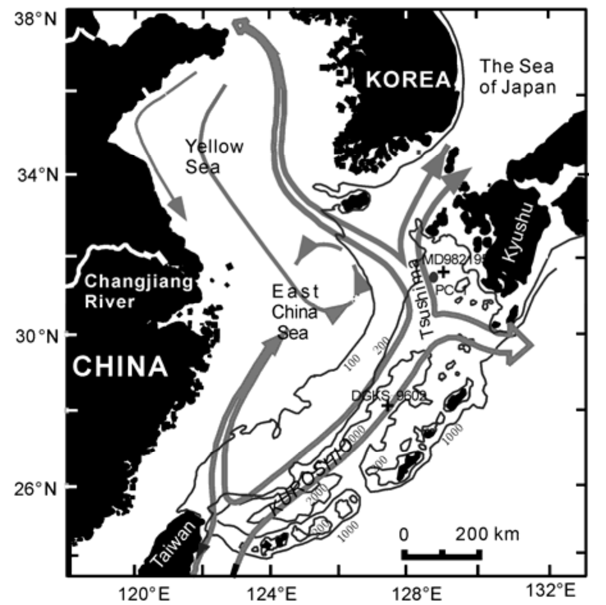

Figure 1 Map showing the present Kuroshio Current in the East China Sea and the location of PC-1 core site (according to ref. [12]). Also shown in “+” are sites of cores MD982195 (31°38.33′N, 128°56.63′E) and DGKS-9602 (28°07.491′N, 127°22.13′E).

2 Materials and methods

Gravity core PC-1 was obtained by the Institute of Oceanology, Chinese Academy of Sciences in March 1990 from a water depth of 590 m (Figure 1). The core is 812 cm in length. The lithology is characterized by silty clay ooze (0—165 cm), clayey silt (165—410 cm), silty clay (410—610 cm) and fine silt (610—812 cm). Foraminifers and bioclasts occur throughout the core, while volcanic glass and detritus are mainly confined to 123—130 cm, 315—330 cm, 735 cm and 746—748 cm.

A total of 103 samples were palynologically analyzed at 8 cm intervals, with 4—6 cm intervals individually with heavy-liquid separation. First, 4—8 g dry material from each sample was added with a piece of *Lycopodium* spore (University of Lund, batch 483216) standard containing 18583 spores as additional spore for calculating the total influx in the sample. Then dilute hydrochloric acid was added to remove calcareous materials and hydrofluoric acid was used to dissolve siliceous ingredient. Finally, floral ingredients were separated using heavy liquid with the density of 2.0 g/cm^3 before identified with an Olympus CX31 microscope. About 200 or more pollen grains were identified for each sample, and the pollen percentage of each species was calculated on a cardinal number that is the sum of all pollen from seed plants on land. Pollen percentage and influx diagrams were drawn with Tilia software.

Foraminifers including *Neogloboquadrina dutertrei* or mollusk shells with the diameter >250 μm were picked for ^{14}C dating using the National Ocean Sciences AMS Facility, Woods Hole Oceanographic Institution. The results show that two ages are reverse among the eleven dataset (405 cm: 9360 ± 50 ^{14}C aBP; 809 cm: 13 650 ± 80 ^{14}C aBP) and may not be reliable. Age calibration was carried out by using the Calib5.1.0 software[13,14] after considering an adopted AMS ^{14}C reservoir effect of −400 years (Table 1, Figure 2). Linear interpolation and extending of radiocarbon dates indicate 351 cal aBP at the core top and 24280 cal. aBP for bottom sediments, respectively. The time resolution of palynological samples is 230 a and the sedimentation rate is 33 cm/ka on average. Two ash layers with ages of 6.1 ^{14}C ka BP (123—130 cm) and 11.5 ^{14}C kaBP (315—330 cm) are very close to that of the K-Ah (6.3 ^{14}C kaBP) and U-Oki (9.3 ^{14}C kaBP) tuffs[15], respectively. The calibrated ages for the two ash layers are 6.5 cal. kaBP, 12.8 cal. kaBP, respectively.

3 Results of pollen analysis

3.1 Pollen species

Total 103 genera or family of sporopollen were identified and 56 genera or family of pollen belong to woody plant, 19 belong to herbaceous plant and 4 belong to aquatics and 22 genera or family of spore belong to ferns. The dominant species are *Pinus* and *Artemisia*. Pollen of *Picea*, *Abies*, *Betula*, *Castanea-Castanopsis*, *Quercus*, Gramineae, Cyperaceae, Compositae and Chenopodiaceae occur quite often, while others occur rather rare, particularly some of the tropical-subtropical taxa and ferns. For easier interpreting the pollen diagram, several groups of taxa are presented according to their plant ecology and modern distribution except *Pinus* as follows:

Montane conifers: *Abies*, *Picea*, *Tsuga* and *Larix*.

Tropical montane conifers: *Podocarpus*, *Phyllocladus* and Taxodiaceae.

Temperate broad-leaved taxa: *Quercus*-deciduous, *Betula*, *Alnus*, *Carpinus*, *Corylus*, *Fagus*, *Juglans*, *Ulmus*, *Salix*, *Acer*, *Tilia*, *Pterocarya*, Rosaceae, etc.

Tropical and subtropical taxa: *Quercus*-evergreen, *Castanea-Castanopsis* are main species, others quite rare, such as Euphorbiaceae, *Altingia*, *Ilex*, *Carya*, *Platycarya*, *Engelhardtia*, *Mallotus*, Palmae, Moraceae, Myrtaceae, Proteaceae, Rutaceae, Theaceae, Anacardiaceae, Araliaceae, Sapindaceae, etc.

Aquatics: *Alisma*, *Typha*, *Myriophyllum* and Sparganiaceae.

Herbs: *Artemisia*, Gramineae, Cyperaceae, Compositae, Chenopodiaceae, *Polygonum*, Cruciferae, *Thalictrum*, *Sanguisorba*, Umbelliferae, Ranunculaceae, *Anemone*, Liliaceae, Labiatae, Geraniaceae, etc.

Ephedra and *Nitraria* represent very dry climate, so they are specially grouped together.

Ferns: *Polypodium*, *Hicriopteris*, *Pyrrosia*, *Selaginella*, *Pteris*, *Lycopodium*, *Dicranopteris*, *Osmunda*, *Cibotium*, *Cyathea*, Davaliaceae, Dryopteridaceae, The-

Table 1 Radiocarbon dating and sedimentation rate of PC-1core

Depth (cm)	Species	AMS ^{14}C age (aBP)	Cal. age (cal. aBP)	Sedimentation rate (cm/ka)
10	*N. dutertrei*	1290 ± 30	836 (793—883)*	
66	*N. dutertrei*	3880 ± 30	3851 (3806—3905)	18.6
150	*N. dutertrei*	7000 ± 50	7496 (7452—7546)	23.1
222	*N. dutertrei*	9160 ± 40	9965 (9885—10072)	29.2
351	*N. dutertrei*	12150 ± 70	13600 (13501—13695)	35.5
500	*N. dutertrei*	13850 ± 50	15978 (15781—16153)	62.7
598	Mollusc	17000 ± 60	19693 (19578—19694)	26.4
708	Mollusc	18100 ± 60	20888 (20695—21055)	92.1
752	*N. dutertrei*	19200 ± 95	22340 (22251—22428)	30.3

* showing the data with 1δ error range.

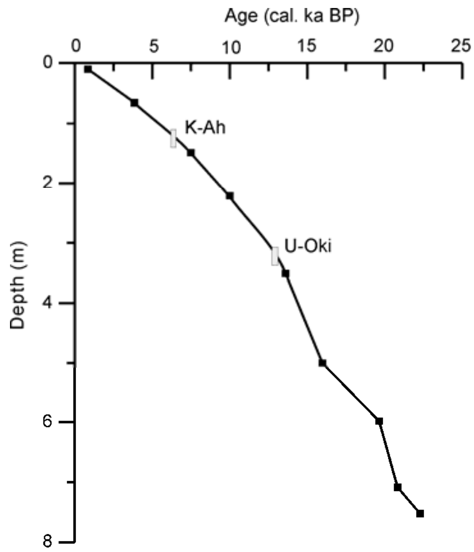

Figure 2 Map showing sample age and sedimentation rate of PC-1 core.

lypteridaceae, etc. Most of them are difficult to identify which genera or family belongs to, so just grouped to Monolete-spores or Trilete-spores respectively.

What's more, *Concentricystes*, *Zygnema* and *Anthoceros* are rarely seen in several samples.

3.2 Pollen assemblage zones

Based on the pollen percentage and influx diagrams (Figures 3 and 4), the core could be divided into 4 zones from bottom to top. Zones I, II and III are characterized by high herbaceous pollen percentage; whereas arboreal pollen predominates in zone IV.

Zone I: 812—715 cm, 24.2—21.1 cal. kaBP (Late Marine Oxygen Isotope Stage 3). Herbaceous pollen percentage is rather high (39.6%—56.5%) with an average value 46.5%, *Artemisia* (32.3% on average, the same below), Chenopodiaceae (4.8%), Cyperaceae (3.2%), Compositae (2.5%), Gramineae (1.3%) and *Thalictrum* (1.1%) are predominant species. Arboreal pollen such as *Pinus* (18.6%), montane conifers (16.4%), temperate broad-leaved taxa (14%) and tropical and subtropical taxa (3.9%) are major ones, such as *Tsuga* (3.2%), *Abies* (1.6%), *Quercus*-deciduous (7%), *Betula* (1.6%), *Alnus* (2.1%), *Corylus* (1%), *Quercus*-evergreen (1.4%) and *Castanea*-*Castanopsis* (1.6%). Another character is high percentage of *Picea* (11.7%) and spo- radic occurrence of *Phyllocladus*. Other groups like aquatics (0.6%), *Ephedra* and *Nitraria* (0.1%) and tropi- cal montane conifers (0.5%) are quite low. Ferns (3.3%) are at low abundance. The total pollen flux is up to 174.7 grains·$(g/cm)^{-1}\cdot a^{-1}$, with herbaceous pollen influx 80.7 and arboreal 91.4 grains·$(g/cm)^{-1}\cdot a^{-1}$, respectively.

Zone II: 715—451 cm, 21.1—15.2 cal. kaBP (MIS 2, LGM). Herbaceous pollen increases to the dominance (39.6%—64.9%) with average 54.5% and *Artemisia* 36.1%. Arboreal pollen such as *Pinus* (10.1%), *Picea* (6.8%) and *Tsuga* (2.5%) decreases, while *Quercus*-deciduous (12%), *Castanea*-*Castanopsis* (4%) and *Ulmus* (1.1%) increases. Ferns are 4.9%. Other groups change little and are still at low abundance. Montane conifers (9.9%) decrease, but pollen influx increases up to sesquialter (276.4 grains·$(g/cm)^{-1}\cdot a^{-1}$), herbaceous pollen influx 147.1 and arboreal 117.2 grains·$(g/cm)^{-1}\cdot a^{-1}$, respectively), the sedimentary quantity is as high as zone I.

Zone III: 451—251 cm, 15.2—10.8 cal. kaBP (Deglaciation). Herbaceous pollen decreases to 37.7% (28.6%—48.6%), lower than zones I and II, with main species like Chenopodiaceae (2.2%), Compositae (1.6%) and *Artemisia* (28.4%). Arboreal pollen increases, such as *Pinus* (24.6%), temperate broad-leaved taxa (22.3%) like *Quercus*-deciduous (15.9%) and tropical and subtropical taxa (10%) like *Castanea*-*Castanopsis* (5.1%) and *Quercus*-evergreen (2%). While montane conifers gradually decreases to 4.8%, such as *Picea* (2.3%) and *Tsuga* (1.6%). Ferns gradually increase to 7.2%. Total pollen influx reaches to an climax (343.7 grains·$(g/cm)^{-1}\cdot a^{-1}$), and herbs' (123.5 grains·$(g/cm)^{-1}\cdot a^{-1}$) decrease while trees' (195.4 grains·$(g/cm)^{-1}\cdot a^{-1}$) increase.

Zone IV: 251—0 cm, 10.8—0.3 cal. kaBP (Holocene). The most obvious change is arboreal pollen (69.7%—95.2%) increases to an absolute dominance at an average of 86.3%. Herbaceous pollen decreases to 13.7% like *Artemisia* (9.8%) and Chenopodiaceae (1.2%), and ferns grow up to 12.7% like *Polypodium* (1.6%). Arboreal pollen such as *Pinus* (37.4%) and *Quercus*-evergreen (4%) increase and *Castanea*-*Castanopsis* sharply increases to 23.6%. While temperate broad-leaved taxa (16.8%) and montane conifers (2.9%) decrease. Total pollen influx decreases to 172.8 grains·$(g/cm)^{-1}\cdot a^{-1}$ with herbaceous pollen influx 20.8 and arboreal 132.4 grains·$(g/cm)^{-1}\cdot a^{-1}$ respectively.

4 Discussion and conclusions

4.1 Pollen indication of palaeoenvironmental changes

Pollen assemblage in ECS surface sediments near PC-1

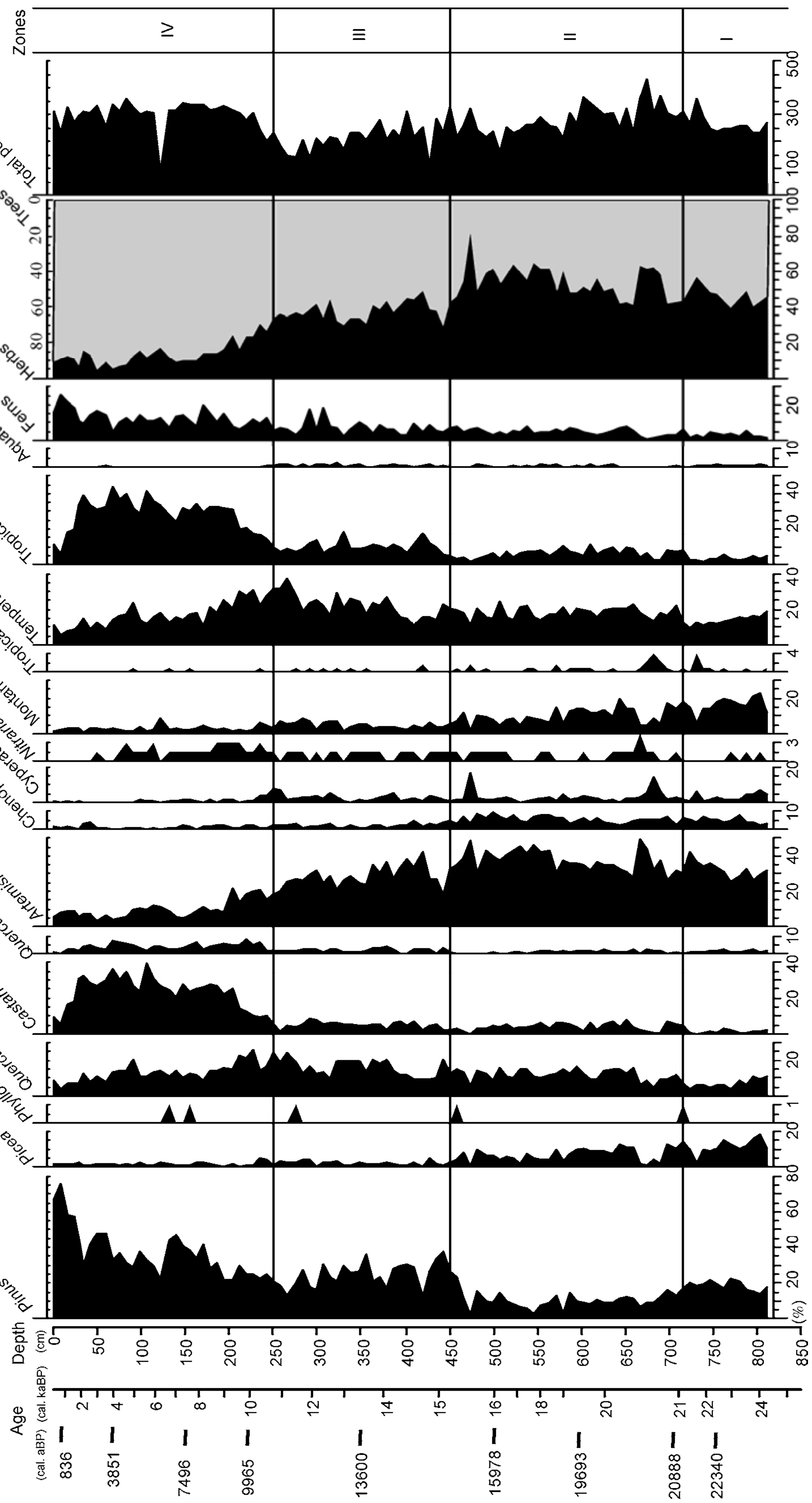

Figure 3 Pollen percentage diagram of PC-1 core.

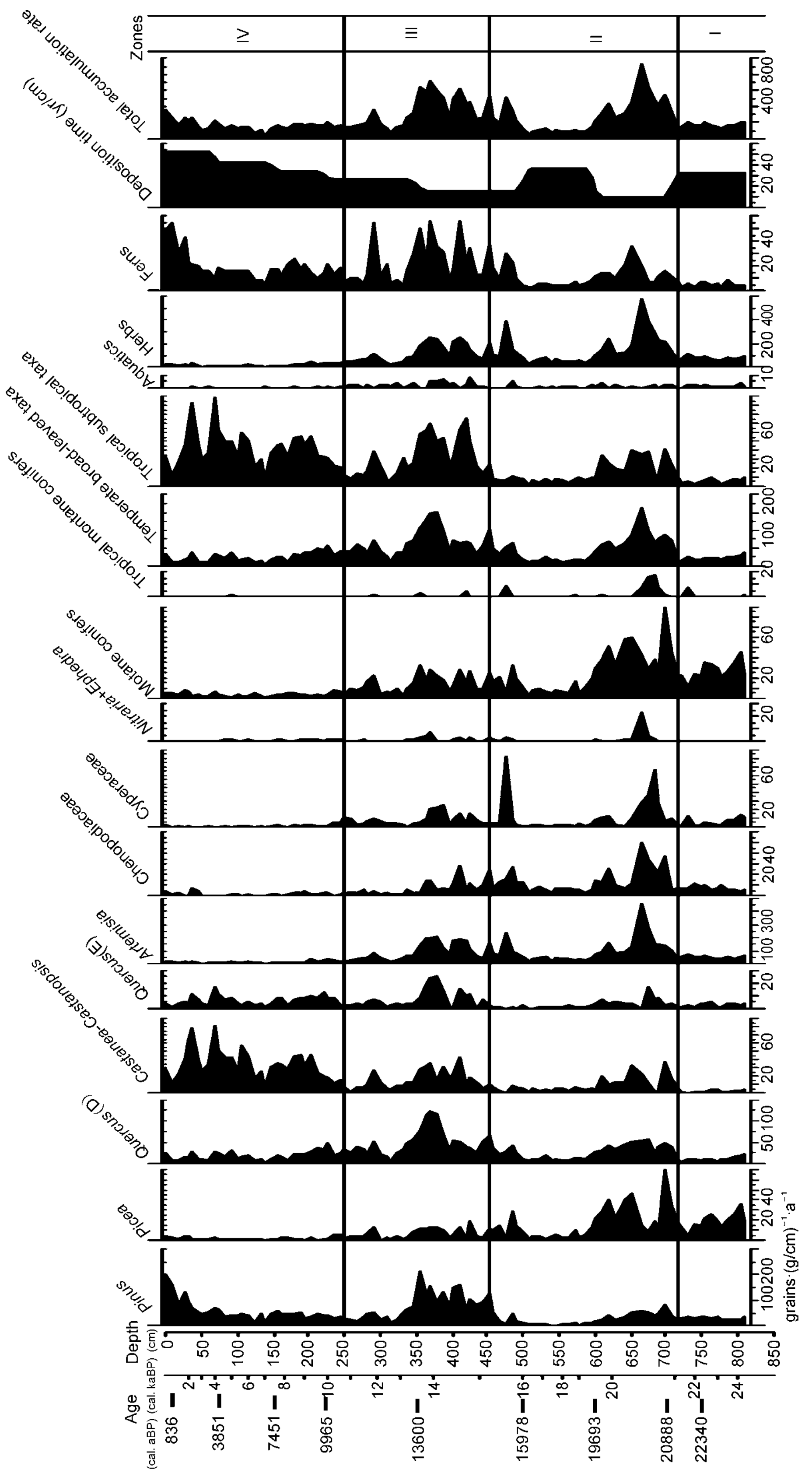

Figure 4 Pollen influx diagram of PC-1 core.

core site is predominant by *Pinus*, *Quercus* and *Castanopsis*. The abundance of evergreen broad-leaved taxa like *Castanopsis* (11%) and *Quercus glauca* (>10%) is high, while herbaceous pollen is very low[16]. This floral assemblage is consistent with the vegetation found in Kyushu and the pollen assemblage zone IV at PC-1 site and provides a reference for paleoenvironmental interpretation of the pollen zones in the core.

Zone I (812—715 cm, 24.2—21.1 cal. kaBP) corresponded to Late MIS 3 with an average sedimentation rate of 31 cm/ka. The predominant are arboreal pollen (53.5%), including montane conifers (16.4%) and temperate broad-leaved taxa (14%). *Artemisia* is the main taxon in nonarboreal pollen. Sea level at that time was about 80 m lower than today[2] and the distance from the mainland of China to PC-1 core site would be shortened by about 400 km, with a large area of the continental shelf becoming silty land. The pollen assemblage indicates that the exposed shelf was covered with grassland mainly *Artemisia*, and temperate needle-broad leaved mixed forest developed at higher altitude areas around the area.

Zone II (715—451 cm, 21.1—15.2 cal. kaBP) corresponded to the LGM with an average sedimentation rate of 45 cm/ka. Herbaceous pollen such as *Artemisia* shows higher abundance and arboreal pollens such as *Pinus* has the lowest percentage in the core, implying wider extension of grassland even onto the coastal region. It is quite interesting that the percentage of temperate broad-leaved taxa and tropical and subtropical taxa increases while montane conifers decreases although its sedimentary quantity stays almost the same as before. These palynologic characteristics imply that sparse deciduous broad-leaved forest might develop around the grassland and needle-broad leaved mixed forest might grow at high altitude areas such as Kyushu Island and upper-middle reaches of the Yangtze River. As sea level was about 120 m lower than today at LGM[2], the continental shelf was entirely exposed, resulting in the coastal line 500 km away from the mainland of China. More denudated substance from the exposed continental shelf was deposited at the PC-1 site because of shorter distance, so did the pollen influx.

Palynological analysis of DGKS-9602 core in the middle of Okinawa Trough also indicates the development of grassland on the exposed continental shelf at the LGM[8]. The biome reconstruction of China at the LGM based on palynological data displays that steppe and desert expanded southwards and eastwards reaching the northern margin of the present evergreen broad-leaved forest; evergreen broad-leaved forest retracted southwards to the present tropical zone and needle-broad leaved mixed forest retracted to the evergreen broad-leaved forest zone[17,18]. These results imply that grassland developed in the middle-lower Yangtze area. Another pollen study has shown that even the Japanese Archipelago was almost entirely covered with coniferous forests during the LGM, and Kyushu was covered by temperate coniferous-deciduous broad-leaved forests including *Picea polita*, *Abies firma*, *Tsuga sieboldii*, *Pinus*, *Fagus*, *Ulmus* and *Quercus* and over 95% of arboreal pollen[19]. High percentage of herbaceous and temperate broad-leaved taxa pollen in zone II of PC-1 might reflect different sources of pollen: herbs from the exposed continental shelf and arboreal pollen from vegetations on Kyushu.

Zone III (451—251 cm, 15.2—10.8 cal. kaBP) corresponded to the Last Deglaciation with an average sedimentation rate of 46 cm/ka. With the decrease of montane conifers and herbaceous pollen, *Pinus*, tropical and subtropical taxa, temperate broad-leaved taxa and ferns increase, implying warmer and moister climate and higher sea level during this period. But grassland still grew on the rest exposed continental shelf and temperate deciduous broad-leaved forest grew in its surrounding areas. High pollen influx and sedimentation rate were ascribed to increased rainfall. Foraminiferal study of KH82-4-14 core (31°44.4′N, 129°02.1′E) and RN80-PC3 core (29°04.1′N, 127°22.6′E) revealed that during 19.5—10.5 cal. kaBP high abundance of foraminifer species preferring low sea-surface salinity and temperate water conditions was due to increased river and sediment discharge[20].

Zone IV (251—0 cm, 10.8—0.3 cal. kaBP) corresponded to the Holocene with an average sedimentation rate of 24 cm/ka. *Pinus* and ferns continually increase and *Castanea-Castanopsis* increases sharply; herbaceous pollen decreases and pollen influx and sedimentation rate decrease significantly. Due to the continuous rise in sea level, the exposed continental shelf was submerged again, and the distance between PC-1 site and the mainland of China increased, resulting in low pollen influx and low sedimentation rate in the core. Pollen at PC-1 core mainly comes from Kyushu Island, and evergreen and deciduous broad-leaved forests were now better developed there with main species of *Quercus* and *Castanopsis*. From a nearby core B-3GC, palynological analysis also shows that evergreen and deciduous broad-leaved forests developed alternately in the Holocene on land[10].

To sum up, during glacial times high pollen influx and sedimentation rate were due to shorter distance between material sources and the core site, and high percentage of herbaceous pollen implies grassland grew on the exposed continental shelf, while pollen of montane conifers and temperate broad-leaved taxa indicates needle-broad leaved mixed forests probably developed on Kyushu Island. During the Holocene, however, sea level rise led to the submergence of the exposed continental shelf, resulting in low sedimentation rate and pollen influx, when Kyushu Island was inhabited mainly by evergreen and deciduous broad-leaved forests.

4.2 Sea level fluctuations indicated by herbs/*Pinus* ratio

The *Pinus* percentage curve overall is in a consistent changing trend with the oxygen isotopic curve from core MD982195 (Figure 5). During glacial times *Pinus* is low, and oxygen isotopic value is high, indicating cold climate. From deglaciation to Holocene *Pinus* gradually rises and the oxygen isotopic value decreases, indicating a warming stage. As discussed above, the alternation of herbs/*Pinus* (H/P) indicates the comparative distances between the PC-1 site and coastal line due to the sea level changes, and H/P variation is comparable with the oxygen isotopic curve. Similar conclusions have been reported from palynological analyses of core DGKS-9602 and cores in the South China Sea[8,21,22]. The H/P ratio has been considered by Sun[23] to indicate the distance changes between study sites and the coastline: rise of H/P values is related to marine regression, exposure of the continental shelf and inland shifting of the coastline, while falling of H/P values indicates marine transgression, submergence of the continental shelf and offshore shifting of the coastline. And during a glacial and interglacial cycle, the more the amplitude of H/P values changed, the wider the continental shelf was[23]. In core PC-1, the average H/P values are 2.5 for Late MIS 3, 5.4 in the LGM which is the highest, 1.7 in Deglaciation and 0.4 during the Holocene, indicating the wide continental shelf of the ECS broadly exposed during the glacial times.

4.3 *Phyllocladus* pollen

Phyllocladus has never occurred in the Quaternary-Tertiary sediments in Japan. In modern conditions, *Phyllocladus* vegetation is distributed in the humid mountain area of North Luzon of the Philippines, Tasmania and New Zealand, and is not distributed in Taiwan Island[24]. The *Phyllocladus* pollen is about 35 μm with two small airsacs (Figure 6). The sporadic occurrence of *Phyllocladus* in the whole PC-1 core (Figure 3, Table 2) might

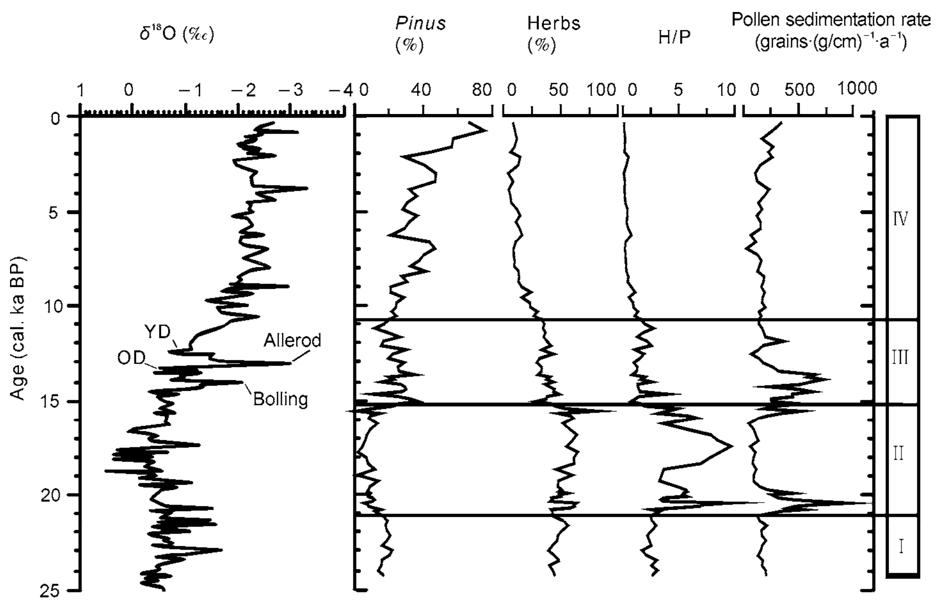

Figure 5 Comparison of pollen percentage, H/P ratio and influx of PC-1 core with δ^{18}O curve of MD982195 core[12] (YD and OD indicate Younger and Older Dryas periods, respectively).

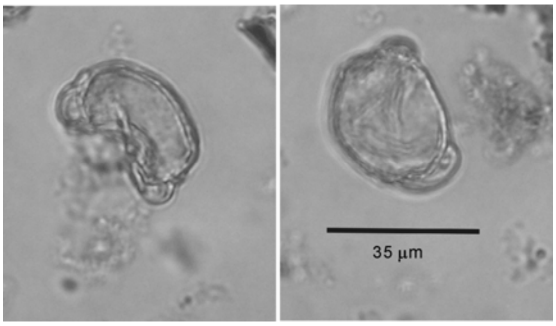

Figure 6 Pollen morphology of *Phyllocladus*.

Table 2 Pollen percentage and influx of *Phyllocladus* in PC-1 core

Depth (cm)	Cal. Age (cal. a BP)	Density (grains/g)	Percentage (%)	Pollen influx (grains·(g/cm)$^{-1}$·a^{-1})
131	6670	15	0.3	0.3
155	7667	16	0.3	0.4
275	11458	36	0.7	1.3
459	15323	18	0.5	1.1
715	21119	12	0.3	0.4

be mainly ascribed to ocean current. They are transported to the coastal region by large amounts of river water and then to the hemipelagic region and/or open ocean by ocean current. The Kuroshio Current could play an important role in transporting *Phyllocladus* to the ECS, which implies that the Kuroshio Current influenced the sedimentation environment of North Okinawa Trough since 24 cal. kaBP. The same conclusion was found in the MD982195 core[6] and supported by foraminiferal research[7,12,20]. However, another factor ascribed to the occurrence of *Phyllocladus* might be intense summer monsoon.

4.4 Spectrum analysis

Percentage of different pollen species fluctuates obviously in different stages (Figure 3), especially alternating lifting of *Pinus* and *Artemisia* in the last deglaciation and the fluctuations of *Pinus*, *Quercus*-deciduous and *Castanea*-*Castanopsis* in Holocene. With univariate spectrum analysis from the SPECTRUM program[25] spectrum analyses of *Pinus*, *Artemisia*, *Quercus*-deciduous, temperate broad-leaved taxa and tropical and subtropical taxa percentages are performed, which show the similar periodicity. Figure 7 shows the millennial climatic fluctuations reflected by *Pinus* percentage: the cycle of 6.8 ka might correspond to the cycle of Heinrich events found in the northern Atlantic deep-sea sediments[26–28], while the 3.8 ka and 2.2 ka cycles might correspond to the cycle of Dansgaard-Oscheger (D-O) events found in Greenland iceberg[29,30]; the 1.6 ka cycle might be correlated with the 1.5 ka cycle found in some areas of the tropical ocean[5,31]. 0.7 ka cycle is less credible because of 230 a of sample resolution. Millennial-scale climatic fluctuations have been testified by many researches, might be ascribed to the monsoon periods and correlated with the sun activity, atmospheric circulation and instability inside the ocean, etc. Its origin, mechanism and paleoclimatic significance are still unclear, and need further research.

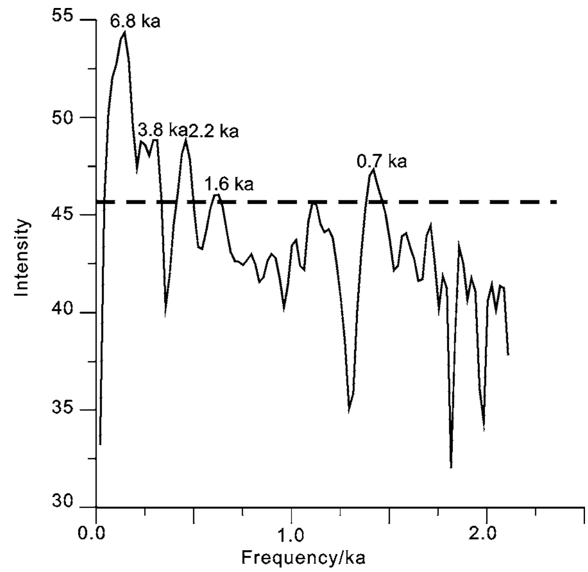

Figure 7 Spectrum analysis of *Pinus* pollen percentages showing periodicity at millennial scales (Dashed line represents 95% level of significance).

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