AMS RADIOCARBON DATING AND POLLEN ANALYSIS OF CORE KS0412-3 FROM KASHIBARU MARSH IN NORTHERN KYUSHU, SOUTHWEST JAPAN

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ABSTRACT. We performed pollen analysis and accelerator mass spectrometry (AMS) radiocarbon dating on cored sediments (KS0412-3) from Kashibaru Marsh, located in the western part of the Sefuri Mountains in northern Kyushu, southwestern Japan, to investigate environmental change around the marsh. Sediment accumulation began in this marsh around cal AD 1200 and continued with an estimated average sedimentation rate of about 4 mm/yr. Human rice cultivation at this location began around cal AD 1300 and was abandoned due to the deposition of a thick sand layer at around cal AD 1400. Since this event, the area has been maintained as a "natural" marsh.

INTRODUCTION

Pollen analytical studies have been conducted in the lowland area of northern Kyushu, southwestern Japan, providing information to reconstruct past climate (Hatanaka 1978, 1985; Kuroda and Hatanaka 1979). Regarding the mountainous area, Okuno et al. (2001) reported micro- and macrofossils in landslide deposits (500 m asl) of the Sefuri Mountains and discussed the middle Holocene paleoenvironment. Unfortunately, the landslide deposits can provide only limited information for a short period. In contrast, marsh deposits are expected to preserve a continuous paleoenvironmental record. Therefore, Okuno et al. (2006, 2011) studied sediments in Kashibaru (also known as Kashinokibaru) Marsh (Figure 1) extracted with a hand auger sampler and with an estimated basal dating of about cal AD 1200.

Pollen analysis is a useful tool for revealing the dynamics of plant communities. Poaceae pollen grains are important because an increase in their relative abundance implies a decrease in forest density. The appearance of the fossil pollen of rice (a Poaceae species) is considered to be a major indicator for the beginning of rice cultivation. Poaceae pollen grains have a relatively simple morphology consisting of a spheroidal shape with a single pore (monoporate type). Although Poaceae pollen is easily identifiable at the family level, it is often difficult to identify at the genus or species level with a light microscope. Nakamura (1974) conducted a study of the fine surface structure of 68 species of Poaceae pollen distributed throughout Japan with a transmission electron microscope using a "replica method" and recognized 3 characteristics of Poaceae pollen ornamentation.

To provide key elements to reconstruct the past environment in Kyushu, we reconstructed paleoenvironmental and land-use changes in and around the Kashibaru Marsh using pollen analysis as well

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Proceedings of the 21st International Radiocarbon Conference edited by A J T Jull & C Hatté
RADIOCARBON, Vol 55, Nr 2–3, 2013, p 1693–1701

as accelerator mass spectrometry (AMS) radiocarbon dating of the cored samples. Furthermore, to identify the cultivation type of Poaceae and to demonstrate evidence of the previous existence of a paddy field in this area, we also determined the surface type of the fossil Poaceae pollen with a scanning electron microscope (SEM) based on the characteristics described by Nakamura (1974).

SAMPLES AND ANALYTICAL METHODS

Geological Settlement

Kashibaru Marsh (591 m asl) is located in the western part of the Sefuri Mountains in northern Kyushu, southwestern Japan (Figure 1). The mountains consist of Cretaceous plutonic rock with a roof pendant of Sangun metamorphic rock (Karakida et al. 1992).

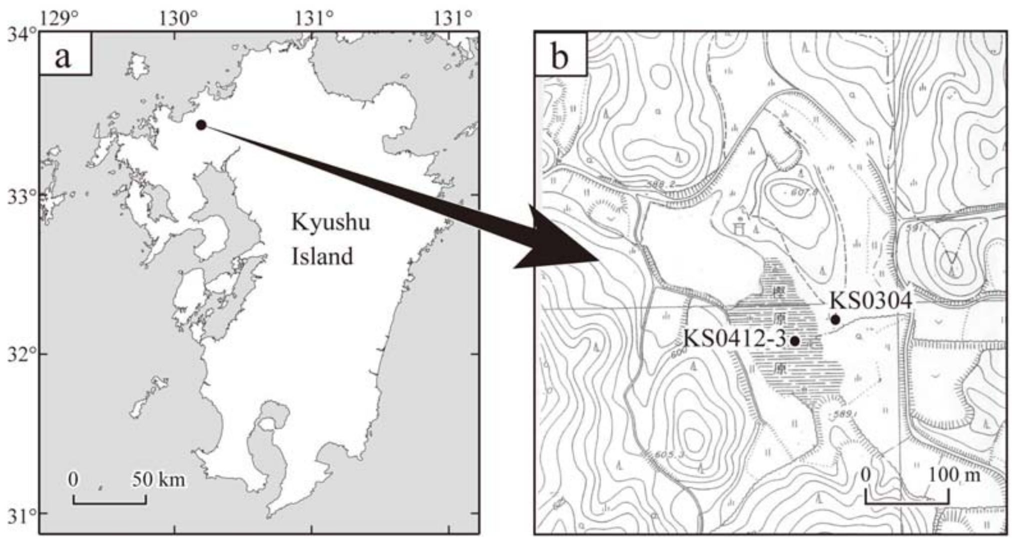

Figure 1 (a) Index map showing the location of the Sefuri Mountains on Kyushu Island. (b) Locations of the coring sites (KS0412-3 and KS0304) in Kashibaru Marsh.

Location of the Drilling Site

Whereas Okuno et al. (2006, 2011) studied sediments in core KS0304 obtained by a hand auger sampler, we collected core samples (KS0412-3) from the bottom to the top of the marsh deposits in December 2004 using a drilling machine. Core KS0412-3 was taken in the central part of the marsh, where the thickest deposits were expected (Figure 1; 33°24′54″N, 130°9′26″E). About 90 species of native plants were recognized in the marsh, including *Scirpus nipponicus*, *Utricularia multispinosa*, and *Menyanthes trifoliata* (Iwamura and Kuranari 1972). The surrounding vegetation is a secondary forest of *Pinus densiflora* and plantations of Japanese cedar (*Cryptomeria japonica*). The average annual rainfall in this area is about 2500 mm (Ando and Yoshimori 2007), with a mean annual temperature of about 13 °C (Iwamura and Kuranari 1972).

Stratigraphy

The 400-cm KS0412-3 core was retrieved in 100-cm intervals (86 mm in diameter). The stratigraphy of the core samples is shown in Figure 2. The cored sediments can be divided into 4 facies: i.e. silt (400–377, 348–313, 300–227, 200–159, 141–89, 64–21, and 10 cm to surface); sandy silt (377–

348 cm); fine sand (227–219 cm); and medium to coarse sand (313–300, 219–200, 159–141, 89–64, and 21–10 cm). Sand grains appear to have been derived from nearby granite badlands around the marsh as a debris flow. No tephra layer was recognized within this core.

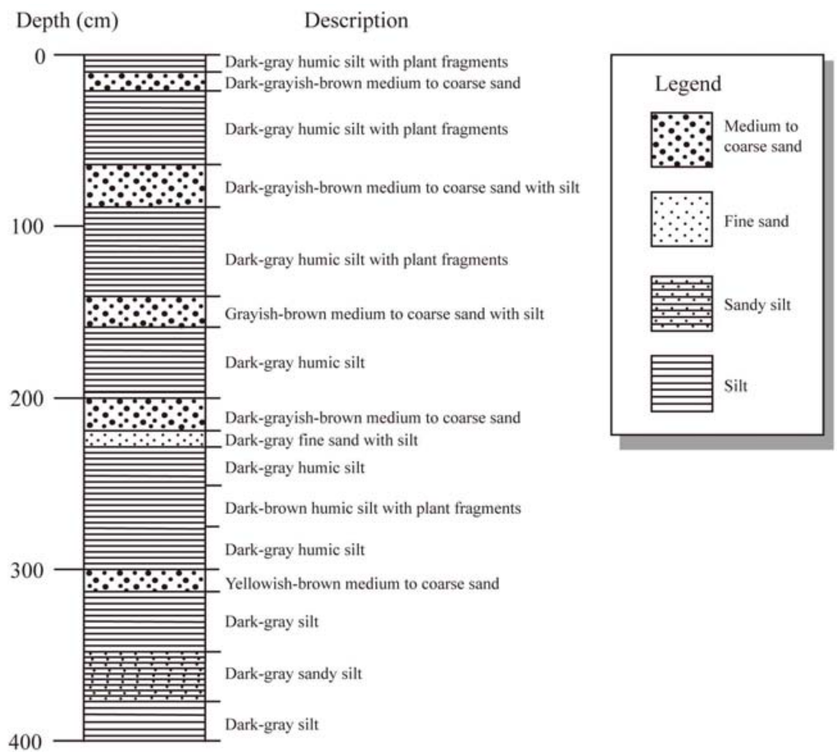

Figure 2 Columnar section showing the stratigraphy of the KS0412-3 core

AMS Radiocarbon Dating

The plant fragments were collected from 3 horizons immediately after coring. Unfortunately, suitable samples for ^{14}C dating were limited in these horizons. In addition, we could not identify plant species or parts. Samples were purified by routine acid-alkali-acid (AAA) treatments using 1.2N HCl and 1.2N NaOH, respectively, followed by washing with distilled water and drying. Each purified sample was sealed in a quartz tube together with CuO and then heated to 850 °C for 4 hr. The produced gas was cryogenically purified to CO_2 gas using a vacuum line, and then reduced catalytically to graphite on Fe powder with H_2 gas (Kitagawa et al. 1993). Prepared samples were measured by the HVEE Tandetron AMS system (model 4130-AMS) at Nagoya University (Nakamura et al. 2000). All 3 carbon isotopes in both the samples and the NIST oxalic acid (HOxII) standard were measured with the AMS system. The $^{13}C/^{12}C$ ratios ($^{13}C_{PDB}$) obtained by the AMS system were used to correct carbon isotopic fractionation when calculating conventional ^{14}C ages. The ^{14}C age errors were estimated by machine errors evaluated by the ^{14}C reproducibility of repeated measurements on standard targets and errors in ^{14}C background removal calculations (Nakamura et al. 2007).

Pollen Analysis

A few grams of sample were collected from the core every 5 cm for pollen analysis. Fossil pollen and spores were extracted by 10% KOH treatment, $ZnCl_2$ solution treatment, and Erdtman's acetolysis method (Erdtman 1934). To determine pollen assemblages, samples were dehydrated with an ethanol series (30%, 60%, and 99.5%) and then treated with xylene after acetolysis. The samples were mounted in Eukitt for observation under a light microscope. Five hundred or more pollen grains (excluding spores) were counted, including at least 300 arboreal pollen grains, in each sample. The percentage of each taxon (arboreal and non-arboreal pollen, and fern spores) was based on the total arboreal pollen count.

To observe the morphology of the fossil Poaceae pollen by SEM, a sample from 348 cm depth was fixed and treated for conductive coating with 2% osmium tetroxide solution after acetolysis, dehydrated with an ethanol series, then treated with xylene. The sample was set on stands and spattered with gold-palladium for ~5 min. The JSM-6300 SEM by JEOL Ltd., Japan was used for observation.

RESULTS AND DISCUSSION

Depositional Age

The results of AMS ^{14}C dating are shown in Table 1 and Figure 3. Since the Sefuri Mountains consist of plutonic and metamorphic rocks containing no carbonaceous material, a hardwater effect on water plants grown in the marsh could be small, even though degradation of old organic matter contained in the sediments in and around the marsh may produce a certain degree of hardwater effect. The marsh is located more than 50 km from active volcanoes existing in northern Kyushu; thus, the effect of volcanic CO_2 depleted in ^{14}C on the photosynthesis of plants and trees around the marsh is negligible. Thus, the calibration of the obtained ^{14}C dates we assume a constant reservoir age along the sequence and equal to 0. It is noteworthy that the obtained ^{14}C dates do not show any inversion, and this corroborates that our assumption of constant and even zero reservoir age is not misleading.

Table 1 Results of AMS ^{14}C dating.

Depth (cm)	$\delta^{13}C_{PDB}$ (‰)	^{14}C date (BP)	Lab nr (NUTA2-)	Age range (cal AD) (2σ, probability %)
51	–29.0	110 ± 25	8622	1682–1736 (28.6%)
				1804–1935 (70.7%)
				1951–1954 (0.07%)
278	–28.5	390 ± 25	8621	1442–1522 (79.3%)
				1574–1584 (1.6%)
				1590–1624 (19.2%)
375	–30.2	795 ± 25	8620	1209–1276 (100%)

^{14}C dates were calibrated to calendar age ranges with the IntCal09 data set (Reimer et al. 2009) using the CALIB v 6.0 software (Stuiver and Reimer 1993; Stuiver et al. 2010). Although the calibrated age spanned a wide range (~70 to 270 yr with 2σ probability), the sedimentation rate of the marsh deposits was estimated to be ~4 mm/yr based on modal points of the lower 2 dates. Because sand layers can be deposited rapidly by debris flows, these layers can be disregarded when estimating the sedimentation rate. The result indicates that the marsh deposits have accumulated since about cal AD 1200. This age is similar to a previous age obtained from the KS0304 core. In addition, as discussed below, human rice cultivation existed here around cal AD 1300, according to the obtained ^{14}C dates. This age is consistent with the global Medieval Warm Period (10th–14th century).

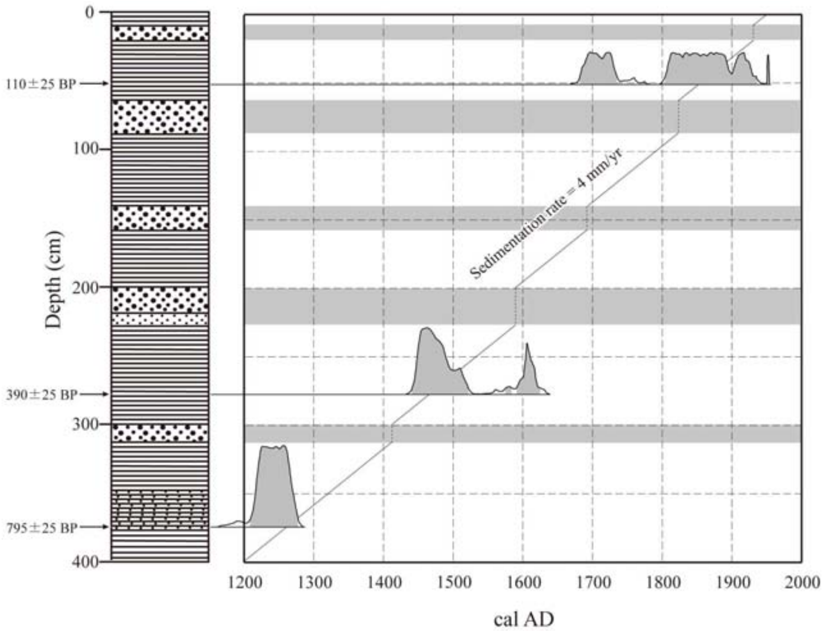

Figure 3 Histogram of the probability distribution for calibrated ^{14}C dates of the plant fragments from the KS0412-3 core. Sandy horizons are shown by shading.

Pollen Assemblages

The analyzed pollen data are plotted in Figures 4 and 5. Trends in the appearance of the main pollen types are as follows. The occurrence of *Pinus* pollen of the secondary forestelement was very low below 370 cm depth but suddenly increased to 50% to 80% above 200 cm. *Carpinus* and *Betula* pollen grains of the cool temperate deciduous broad-leaved forest element were abundant below 200 cm. *Quercus* subgenus *Lepidobalanus* pollen of the cool temperate deciduous broad-leaved forest element comprised <10% of pollen throughout all layers. *Quercus* subgenus *Cyclobalanopsis* pollen of the warm temperate evergreen broad-leaved forest element was dominant below 350 cm, exhibiting high percentages ranging from 50% to 90%. However, this pollen decreased to <10% of pollen content below 100 cm (Figure 4). Herb pollen grains such as Poaceae, Cyperaceae, *Haloragis*, and *Artemisia* dominated from 350 to 150 cm (Figure 5). No evidence of human impact on the natural vegetation was observed in the lowest part of the core, where pollen of a potential natural vegetation element, *Quercus* subgenus *Cyclobalanopsis*, dominated. *Quercus* subgenus *Cyclobalanopsis* pollen rapidly decreased, whereas secondary forest elements such as *Pinus* (e.g. *P. densiflora*) pollen showed a rapid increase, indicating a more pronounced human impact on natural vegetation. Japanese cedar was introduced around this marsh ~200 yr ago, as reflected in the increase in *Cryptomeria japonica* pollen in the upper part of the core. Poaceae pollen increased from 360 to 320 cm, and the pollen of lowland weed elements such as *Sagittaria* and *Alisma* increased slightly at the same time. It is quite possible that rice (Poaceae) was cultivated at this site. *Fagopyrum* pollen was also detected in the core sample and increased slightly from 240 to 160 cm. It is likely that buckwheat was also cultivated at this site. Pollen grains of swamp elements, including *Typha* and *Lythrum*, increased from about 250 cm. This finding indicates that the wetland environment regained its natural vegetation and that rice cultivation never occurred again at this site.

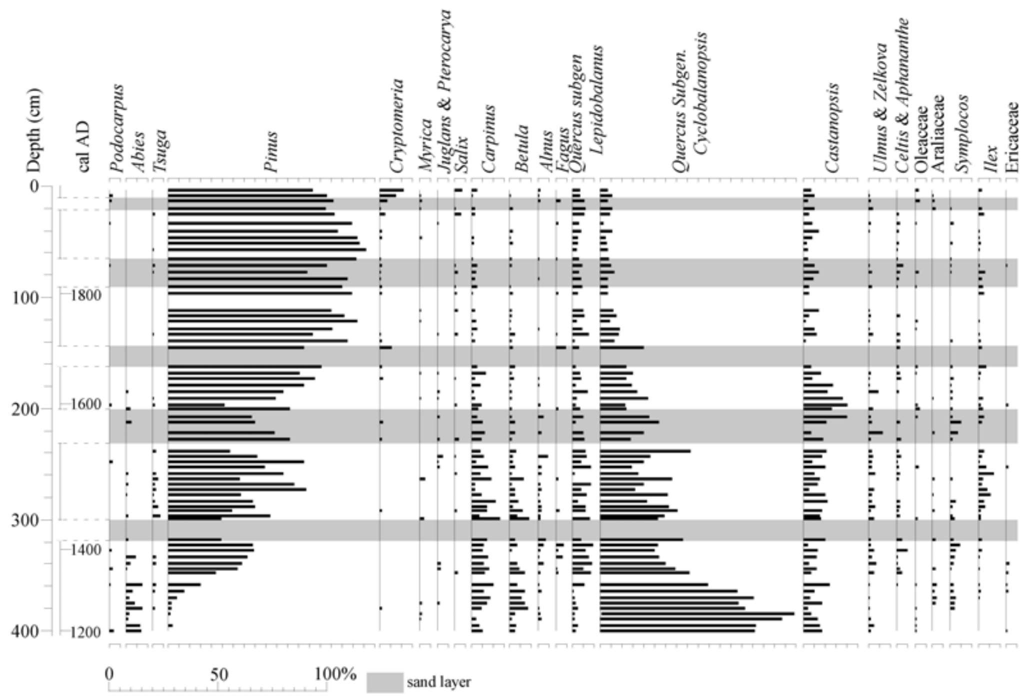

Figure 4 Arboreal pollen diagram for the KS0412-3 core

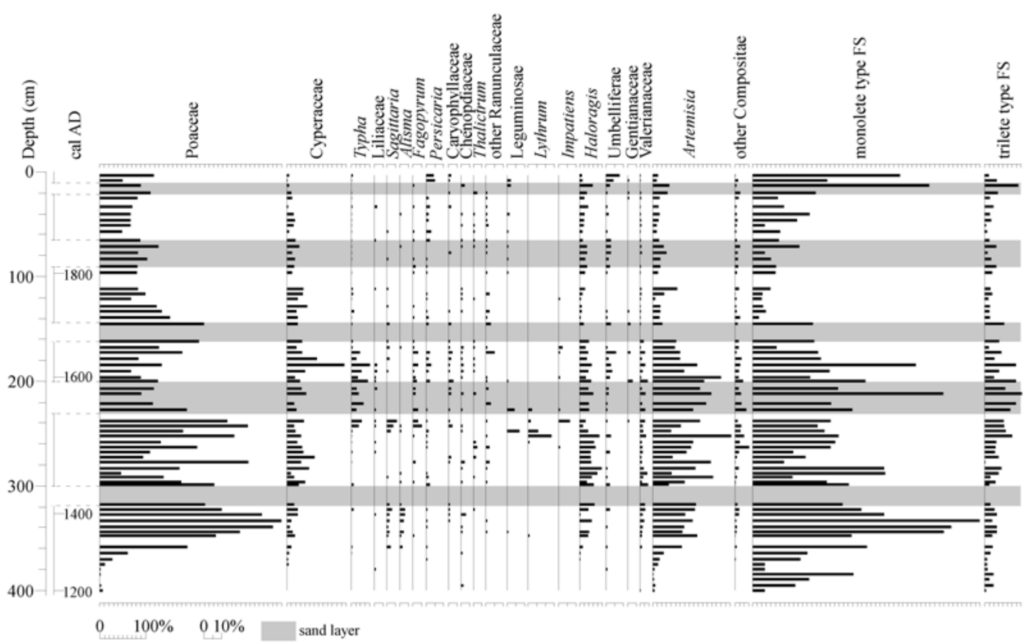

Figure 5 Non-arboreal pollen diagram for the KS0412-3 core

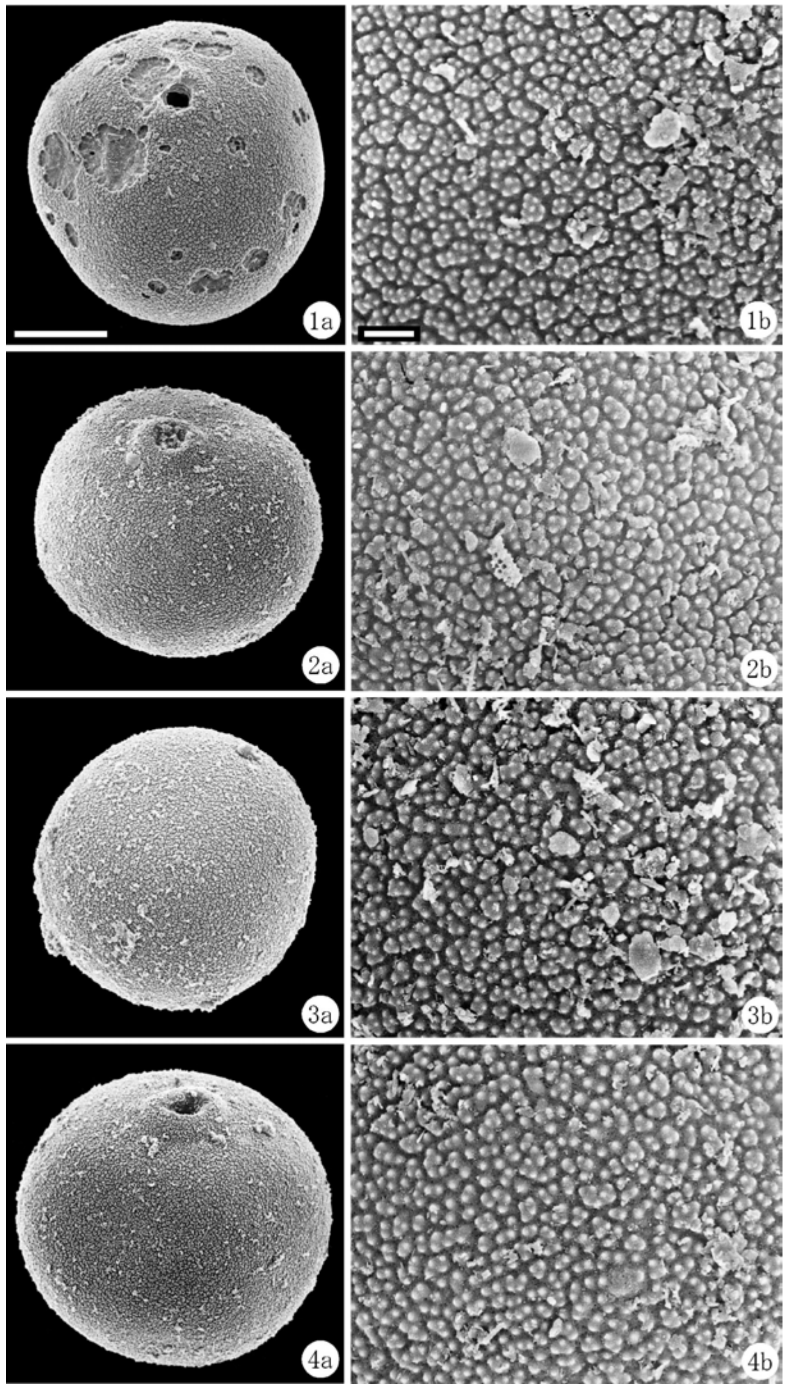

Figure 6 Selected SEM microphotographs of the fossil Poaceae pollen found at 348 cm depth in the KS0412-3 core. Scale bars are (a) 10 µm and (b) 1 µm. Photograph 1 is type III, and other specimens are type II, the cultivated type.

These data indicate that humans used the site and surrounding area as a rice field, and rice cultivation is considered to have started around cal AD 1300. The marsh was subsequently buried by a medium to coarse sand layer at cal AD 1400, after which time the paddy field was abandoned. The marsh has been preserved since its burial in about cal AD 1400. Although the wetland recovered sufficiently to be used again for rice cultivation, this has not occurred. This result is consistent with insect and diatom assemblages in the KS0304 core (Okuno et al. 2006, 2011). According to Okuno et al. (2011), index diatoms for the paddy field, such as *Rhopalodia gibberula*, *Aulacoseira ambigua*, and *Navicula elginensis*, appeared at a high rate below 300 cm (corresponding to about cal AD 1350–1550), and remains of the rice pest *Donacia provostii* also appeared. These diatoms inhabit current paddy fields (Mori 1999, 2002). Many remains of *D. provostii* have been discovered in the soil layers of paddy fields since the early Yayoi period (~500 cal BC) in Japan (Mori 1996, 2002). These diatoms and insects are indicative of a paddy field layer in this marsh (Okuno et al. 2011). In contrast, none of these indicators were present above 300 cm in the KS0304 core. Instead, taxa such as *Plateumaris sericea*, which inhabit shallow wetlands, and *Donacia clavareaui*, which inhabit the sedge community of wetlands with less open water, appeared in high abundance. Therefore, data from the KS0304 core suggest that rice cultivation was abandoned around cal AD 1400. The results of the pollen analysis conducted in this study are consistent with those of the diatom and insect analyses of the KS0304 core.

Morphology of Fossil Poaceae Pollen

The ornamentations of Poaceae pollen grains are divided into the following 3 types: type I is composed only of microgranules; type II is a mixture of microgranules and insulae; and type III is composed only of insulae (Nakamura 1974). The fine surface structures of pollen grains of cultivated Poaceae (rice) are often of type II. The fine surface structures of fossil rice pollen grains from 348 cm depth are shown in Figure 6. These grains were analyzed following the classification of Nakamura (1974) and showed a high amount of type II ornamentation, suggesting that many fossil rice pollen grains were from cultivated rice. The presence of such fossil pollen grains strongly indicates that rice was cultivated.

CONCLUSIONS

Pollen analysis and AMS ^{14}C dates revealed the origin of Kashibaru Marsh and subsequent environmental changes in the marsh. Sediment accumulation in this marsh started around cal AD 1200. The marsh was used as a rice field as early as cal AD 1300 and was subsequently buried by a medium to coarse sand layer around cal AD 1400. Cultivation was abandoned as a result of a geological hazard, as evidenced by the sand layers deposited by a debris flow. Since the burial of the rice field, the marsh has remained in a “natural” state.

ACKNOWLEDGMENTS

We would like to thank Dr Kiyofumi Yoshimori of the Saga Prefectural Government for granting permission to core at the Kashibaru Marsh. We also thank Dr Kazuyuki Matsusue of OYO Corporation for his support and assistance with core sample collection. The authors are very grateful to anonymous reviewers, the editors, and Dr Ma Hannah T Mirabueno for their detailed and constructive comments and suggestions that helped to improve our paper. This work was partly supported by a Grant-in-Aid (14380031 and 15068206, 21101002) for Scientific Research from the Japan Society for the Promotion of Science (JSPS) and the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan.

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