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VEGETATION CHANGES VIEWED FROM POLLEN ANALYSIS IN RAROTONGA, SOUTHERN COOK ISLANDS, EASTERN POLYNESIA

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ABSTRACT. This study presents accelerator mass spectrometry (AMS) radiocarbon dates and pollen assemblages of 400-cm core sediments collected from the Karekare Swamp in Rarotonga, Southern Cook Islands, to investigate vegetation changes on the island, in particular those induced by human impacts. Eight ^{14}C dates of charcoal and higher plant fragment samples indicate that the sediments accumulated since ~6.0 cal kBP, with an apparent interruption of deposition (hiatus) from 130 to 132 cm in depth, corresponding to ~2.8 to 0.7 cal kBP. The appearance of Chenopodiaceae pollen from upland weeds, and Cucurbitaceae and *Vigna* pollen grains from cultivated plants suggest that human influence existed in core sediments above 130 cm in depth. The increased abundance of *Pandanus* pollen and monolate-type fern spores also implies the existence of human activity.

INTRODUCTION

Pollen analysis is a useful tool for reconstructing the dynamics of plant communities. Previous studies of vegetation changes in Polynesia (South Pacific Ocean) include Ellison (1994), Kirch and Ellison (1994), Kirch (1996), and Peters (1998). Kirch and Ellison (1994) and Kirch (1996) focused on the decrease of *Ficus* and Arecaceae, and the increase of *Pandanus tectorius*, *Cyclosorus interruptus*, and *Dicranopteris lineari* that appeared between 2.5 and 1.8 kBP (~2 cal kBP) in the pollen record from Mangaia, Cook Islands (Figure 1). They connected these vegetation changes with the settlement of Polynesians on the island.

To reveal vegetation changes on Rarotonga, Southern Cook Islands, we obtained a 400-cm sediment core from Karekare Swamp (1.65 m asl; 0.114 km^2), on the northeastern part of the island (Figure 1) in August 2009. Accelerator mass spectrometry (AMS) radiocarbon dates were conducted of charcoal and higher plant fragments samples collected from the sediments. We also examined the pollen assemblages in these sediments. This article presents these data and discusses the past vegetation environment in Rarotonga.

STUDY SETTING AND MATERIAL

Outline of Geology and Palynology in Rarotonga

The island of Rarotonga is a Pliocene-Pleistocene volcanic complex (Thompson et al. 1998) with a maximum height of 652 m and a circumference of 32 km, surrounded by a coral reef (Figure 1). A reef flat extends several hundred meters to the reef, and then slopes steeply into the deep water that

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surrounds the island (Moriwaki et al. 2006).

The island's interior is densely forested (jungle of ferns, creepers, and towering trees). Many endemic species are distributed on this island. The forests of Rarotonga are divided into three principal types (Merlin 1985): (1) the *Homalium* mountain forest; (2) the *Fagraea–Fitchia* ridge forest; and (3) the *Metrosideros* cloud forest. However, the coastal lowland and lower slope vegetation have been completely changed by human activities, and the secondary vegetation is composed mostly of species introduced from different areas. The lowland vegetation includes coconut plantations, secondary thickets and forests, and *Dicranopteris* fernland (Mueller-Dombois and Fosberg 1998).

Karekare is a back swamp, originated from doline (Moriwaki et al. 2006), bearing thick peaty deposits. *Barringtonia asiatica*, *Pandanus tectorius*, *Hibiscus tiliaceus*, and *Cocos nucifera* grow around the swamp. Herbaceous plants of Poaceae and Cyperaceae are flourishing in the swamp.

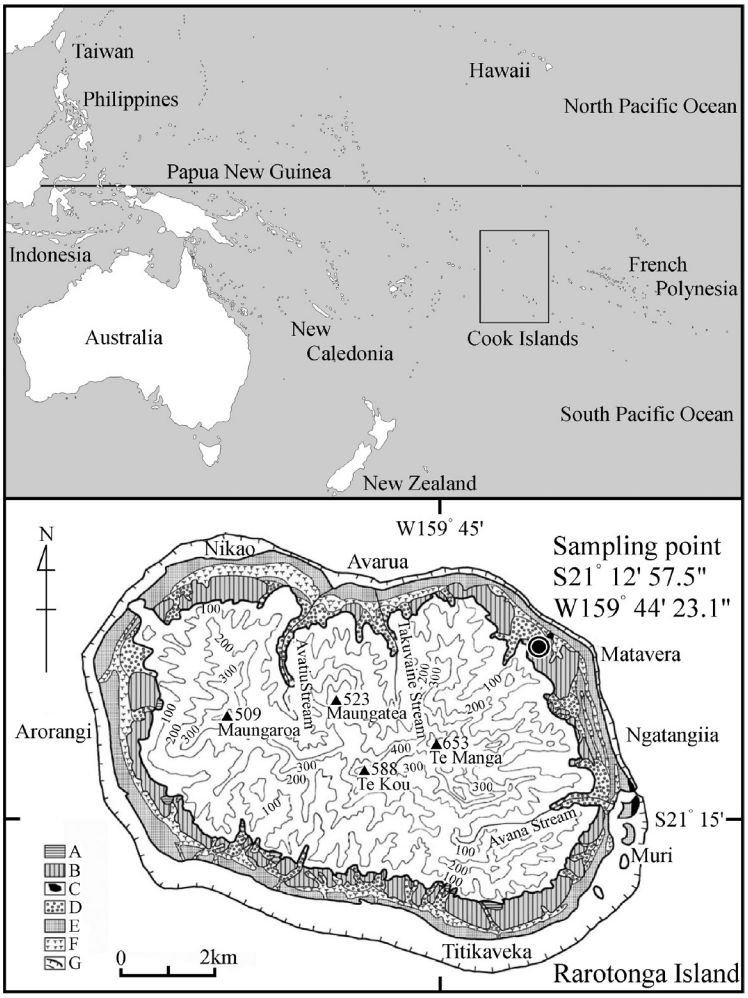

Figure 1 Index map showing the location of the Cook Islands (above). Geomorphologic map of Rarotonga (after Moriwaki et al. 2006) (below). A: Pleistocene upper terrace, B: Pleistocene lower terrace, C: Pleistocene coral reef, D: alluvial fan, E: sand ridge, F: swale and swamp, G: present coral reef. Counter lines in the mountain area are elevation in meters. The coring site in the Karekare Swamp is also indicated by the closed circle.

Study Site and Stratigraphy

A 400-cm long sediment core was obtained at the location of Karekare Swamp (21°12′57.5″S, 159°44′23.1″W) using a hand auger sampler. On the basis of sediment facies, the core can be divided into four layers: clayey peat from 0 to 137 cm depth below the ground surface; nondecomposed peat from 137 to 170 cm; peat from 200 to 350 cm; and clay from 350 to 400 cm (Figure 2).

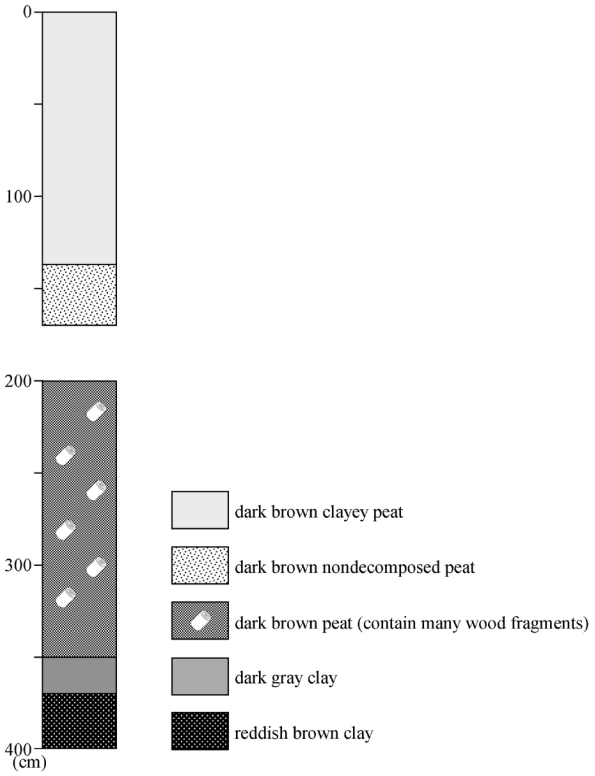

Figure 2 Columnar section showing the stratigraphy of Karekare Swamp core.

ANALYTICAL METHODS

AMS Radiocarbon Dating

Two charcoal and six higher plant fragment samples were collected from eight horizons immediately after coring. Ages of six samples (from depths of 60, 130, 132, 137, 140, 315 cm below surface) were measured by a HVEE tandetron accelerator mass spectrometry (AMS) system at Nagoya University (NUTA2; Nakamura et al. 2000) and ages of four samples (from depth of 130, 137, 200, 340 cm below surface) were obtained at the Institute of Accelerator Analysis Ltd. (IAAA), Japan. Samples suitable for ^{14}C dating could not be found in the sediments at the depth from 350 to 400 cm below the surface. The plant fragments could not be identified for all samples.

Samples were cleaned by routine acid-alkali-acid (AAA) treatments using 1.2N HCl and 1.2N NaOH, respectively, to remove carbonates and secondary organic acids. After washing with distilled water and drying, each pretreated sample was sealed in a quartz tube together with CuO and then heated. The gas product 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). The three carbon isotopes in the samples and the NIST oxalic acid (HOxII) standard were measured with the AMS

systems. The $^{13}C/^{12}C$ ratios ($\delta^{13}C_{PDB}$) obtained by the AMS were used to correct carbon isotopic fractionation when calculating conventional ^{14}C ages. To estimate and remove the ^{14}C background level, the ^{14}C concentration of commercial graphite powder (dead carbon) was also measured in the same analytic sequence of sample and standard measurements.

Pollen Analysis

A few grams of sample were collected for pollen analysis from approximately every 10 cm of the core. 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 medium (O. Kindler GmbH & Co, Freiburg, Germany) for observation under a light microscope (Kershaw et al. 1993; Coimbra et al. 2009). 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.

RESULTS AND DISCUSSION

Depositional Age

The results of AMS ^{14}C dating are shown in Table 1 and Figure 3. The ^{14}C dates were calibrated to a calendar age range with the SHCal04 data set (McCormac et al. 2004) using the computer program CALIB 6.0 (Stuiver and Reimer 1993; Stuiver et al. 2010). The obtained calendar ages are consistent with the stratigraphy of this core. However, a significant age gap is recognized at the depth between 130 and 132 cm below surface, likely due to an interruption in sedimentation (hiatus) at the site. The sedimentation rates of both parts were estimated to be 2.5 mm/yr for 340 to 137 cm depth, 1.3 mm/yr for 130 to 60 cm depth, respectively, based on modal points of calibrated probability distributions.

Regarding the causal mechanism for the interruption of sedimentation at this depth, some causes due to anthropogenic and environmental changes can be considered. The most plausible reason might be due to human impact. We suggest that the production of organic matter decreased for this reason, and the interruption of sedimentation occurred.

Pollen Assemblages

Forty-four varieties of fossil pollen grains and spores were detected. These were divided into AP (arboreal pollen; Figure 4), NAP (non-arboreal pollen; Figure 5), and FS (fern spores), as listed below:

> AP: *Pinus*, Casuarinaceae, *Ficus*, other Moraceae, *Castanopsis*, Proteaceae, *Elaeocarpus*, Myrtaceae, Oleaceae, *Barringtonia*, Apocynaceae, *Glochidion*, *Crtton*, other Euphorbiaceae, Malvaceae, *Wikstroemia*, *Gardenia*, *Mussaenda*, other Rubiaceae, *Erythrina*, other Fabaceae, Araliaceae, *Tristellateia*, Rhizophoraceae, Arecaceae, *Pandanus*.
>
> NAP: Poaceae, Cyperaceae, *Urtica*, Chenopodiaceae, *Vigna*, *Cardiospermum*, Onagraceae, Cucurbitaceae, Umbelliferae, *Epilobium*, *Pharbitis*, Valerianaceae, Campanulaceae, *Artemisia*, other Compositae, Nymphaeaceae.
>
> FS: monolete type, trilete type.

Barringtonia, Arecaceae, and *Pandanus* pollen grains dominated in arboreal pollen. *Barringtonia* pollen is dominant in the cored sediments deeper than 140 cm, and the abundance of this fossil

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

Depth (cm)	Material	$\delta^{13}C_{PDB}$ (‰)	^{14}C date (BP)	Lab code	Age range (cal BP) (2σ probability %)
60	Charcoal	−23.1	365 ± 25	NUTA2-19299	315–465 (100.0%)
130	Charcoal	−23.1	640 ± 20	IAAA-120416	546–570 (30.0%) 592–637 (69.7%)
		−23.4	680 ± 25	NUTA2-19302	559–654 (100.0%)
132	Higher plant fragment	−25.4	2795 ± 25	NUTA2-19301	2762–2887 (96.3%) 2907–2922 (3.7%)
137	Higher plant fragment	−26.1	3740 ± 30	IAAA-120417	3903–4095 (94.4%) 4118–4154 (5.6%)
		−25.4	3745 ± 25	NUTA2-19301	3916–4095 (94.0%) 4118–4146 (6.0%)
140	Higher plant fragment	−24.9	3705 ± 25	NUTA2-19303	3877–3882 (0.8%) 3886–4084 (99.2%)
200	Higher plant fragment	−29.2	3990 ± 30	IAAA-120418	4246–4444 (92.4%) 4481–4513 (7.6%)
315	Higher plant fragment	−26.6	4825 ± 25	NUTA2-19304	5333–5346 (3.8%) 5352–5372 (3.3%) 5463–5589 (92.9%)
340	Higher plant fragment	−27.9	5240 ± 30	IAAA-120419	5768–5787 (1.3%) 5792–5805 (0.9%) 5890–6004 (96.8%) 6085–6097 (0.8%) 6163–6167 (0.2%)

pollen is 10–89%. However, the amount of this pollen suddenly decreases in the sediments above 140 cm, where the abundance ranges between 0.2 and 9%. Arecaceae pollen is dominant with an abundance of 25–80% throughout all layers.

The abundance of *Pandanus* pollen is about 25% in the bottom layer of the core, but appears only sporadically between 315 and 147 cm depth. This pollen becomes more prevalent above 147 cm, and the abundance is about 25%. However, the abundance ratio of this pollen decreases again at the top of the section.

Casuarinaceae pollen appears only in the sediment shallower than 130 cm, and Myrtaceae pollen appears only at the depth below 200 cm. The abundance of *Erythrina* pollen is 2–9% at ~250 cm and from 130 to 50 cm, and this pollen appears sporadically at other depths.

The percentage of the herbaceous fossil pollen grains, such as Poaceae and Cyperaceae, are high. The percentages of monolete-type and trilete-type fern spores are also high. The percentages of Poaceae and Cyperaceae pollen grains increase slightly above 220 cm. Monolete-type fern spores increase slightly above 220 cm, and then rapidly increase above 157 cm. Chenopodiaceae, *Vigna*, and Cucurbitaceae pollen grains appear only in the upper 130 cm of the core. Onagraceae, Compositae, and Nymphaeaceae pollen grains show a tendency to increase in the upper part of the core.

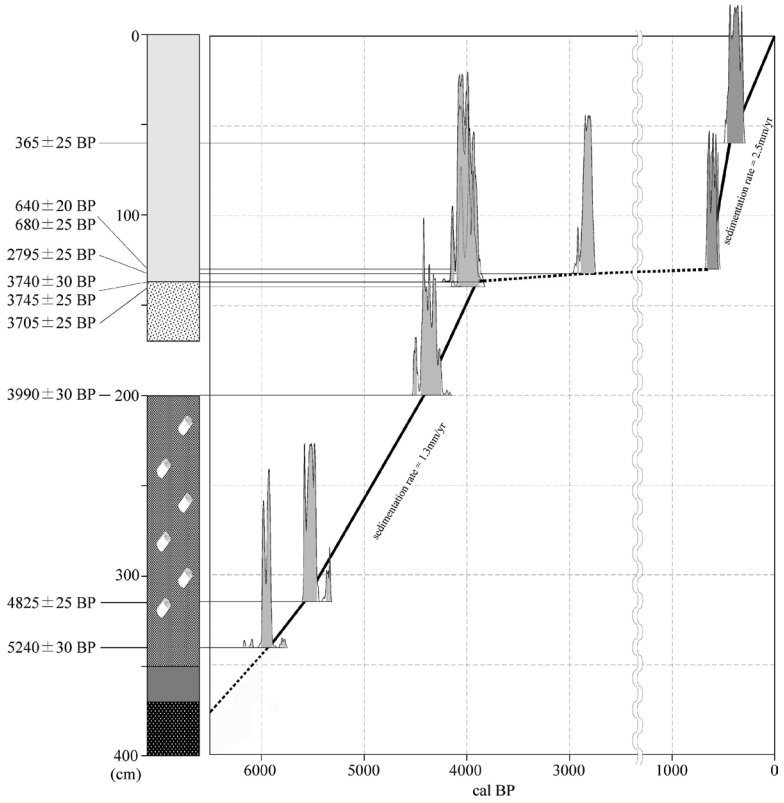

Figure 3 Age-depth profile of Karekare Swamp core. Histograms of the probability distribution for calibrated ^{14}C dates of the plant fragments from the swamp core are included.

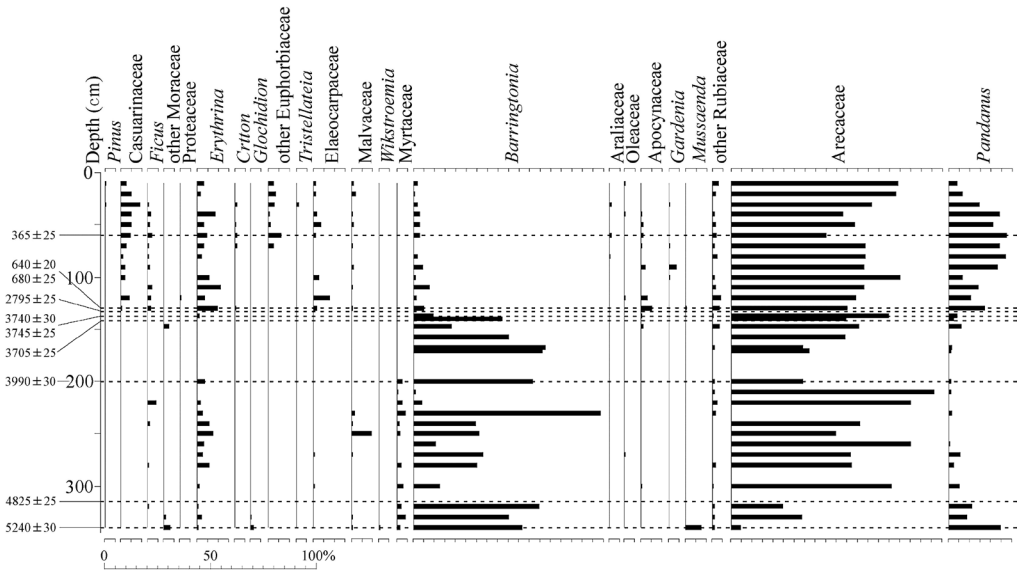

Figure 4 Arboreal pollen (AP) diagram for the Karekare Swamp core

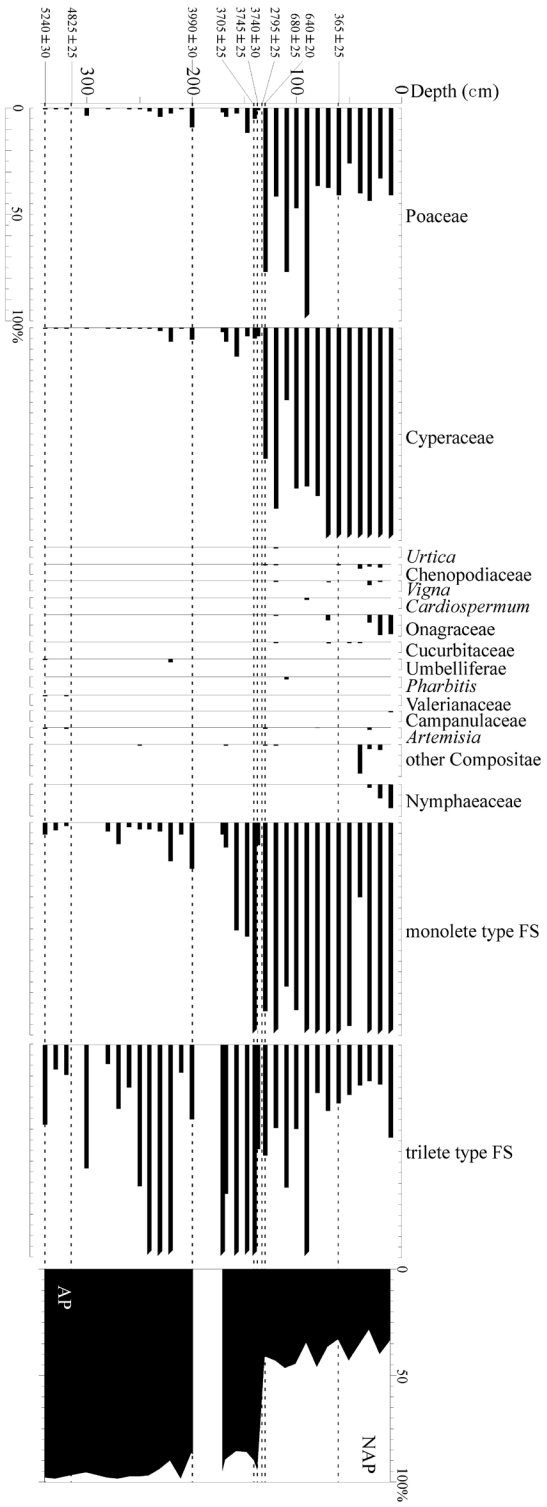

Figure 5 Non-arboreal pollen (NAP) diagram for the Karekare Swamp core.

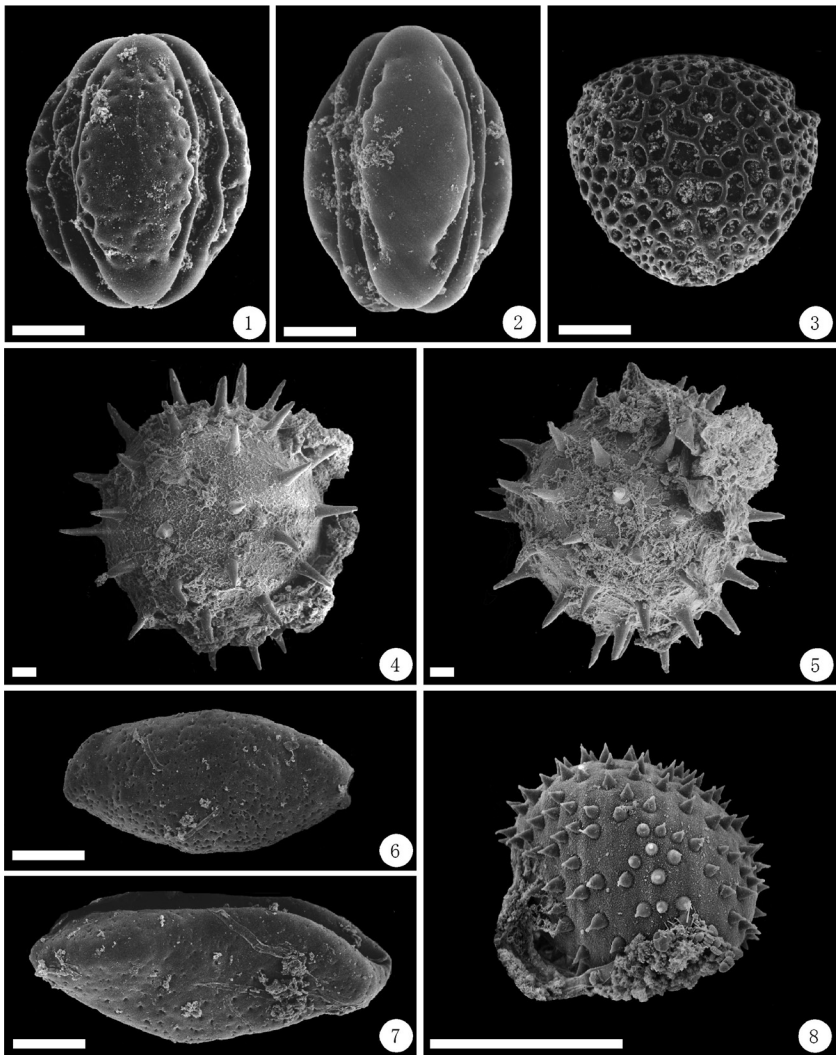

Figure 6 Selected SEM microphotographs of the fossil pollen found from Karekare Swamp core: 1–2: *Barringtonia*, 3: *Erythrina*, 4–5: *Hibiscus*, 6–7: Arecaceae, 8: *Pandanus*. Scale bar is 10 µm.

Barringtonia pollen decreases from 150 cm, and decreases rapidly at 137 cm. The dry field weed pollen grains, such as Chenopodiaceae, and the cultivated plant pollen grains, such as *Vigna* and Cucurbitaceae, are detected from 130 cm.

Based on this evidence, humans seem to have been active there since about 0.7 kBP (~0.6 cal kBP). *Barringtonia asiatica* is dominant along the coast of the Southern Cook Islands, including Rarotonga, Mangaia, and Atiu (Merlin 1985, 1991; Franklin and Merlin 1992). Thus, it is inferred that the *B*. *asiatica* forest was destroyed, after which herbaceous species, such as Poaceae, Cyperaceae, and fern, flourished. The grasslands and fernlands accompanied by *Pandanus tectorius* spread as the secondary vegetation.

Tonga, Samoa, and other western Polynesian islands were colonized until ~1000 BC and the eastern Polynesian islands were settled until about AD 600 from the archaeological evidence (Kirch 2001). However, the paleoenvironmental evidence from Mangaia Island may indicate human impacts from 2.5 to 2.0 kBP (~2.5 to 1.9 cal kBP) (Kirch 2001). The percentage of *P. tectorius* pollen and *Dicranopteris linearis* and *Cyclosorus interruptus* spores increased, and this phenomenon is associated with the settlement of Polynesians on this island (Kirch and Ellison 1994; Kirch 1996). Regarding the paleoenvironmental evidence from Rarotonga Island, the percentage of monolete-type fern spores increased from 157 cm, and the percentage of *Pandanus* pollen increased above 147 cm (~4.0 cal kBP). This vegetation change can be attributed to human impact. Therefore, there is a possibility that Polynesians settled in this island at ~3.7 kBP (~4.0 cal kBP). In the future, we plan to conduct further dating and study the pollen analysis in greater detail, in order to better estimate the arrival date of Polynesians to Rarotonga.

CONCLUSIONS

This article investigated the vegetation changes on Rarotonga, in particular, those induced by human impacts, using AMS ^{14}C dates and pollen analysis results of 400-cm core sediments from the Karekare Swamp. The dry field weeds pollen grains, such as Chenopodiaceae, and the cultivated plant pollen grains, such as *Vigna* and Cucurbitaceae, are detected from 130 cm. Thus, Polynesians reliably had been active there since ~0.6 cal kBP. *Barringtonia* pollen decreases from 150 cm, monolete-type fern spores increased from 157 cm, and *Pandanus* pollen increased from 147 cm. *B. asiatica* forest was destroyed, after which the grasslands and fernlands accompanied by *P. tectoriu*s were established as the secondary vegetation in ~4.0 cal kBP.

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REFERENCES

Coimbra S, Costa M, Jones B, Mendes MA, Pereira LG. 2009. Pollen grain development is compromised in Arabidopsis agp6 agp11 null mutants. *Journal of Experimental Botany* 60(11):3133–42.

Ellison J. 1994. Palaeo-lake and swamp stratigraphic records of Holocene vegetation and sea-level changes, Mangaia, Cook Islands. *Pacific Science* 48(1):1–15.

Erdtman G. 1934. Über die verwendund von essigsäureanhydrid bei pollenuntersuchungen. *Svenska Botanica Tiddskrift* 28:354–61.

Franklin J, Merlin M. 1992. Species-environment patterns of forest vegetation on the uplifted reef limestone of Atiu, Mangaia, Ma'uke and Miti'aro, Cook Islands. *Journal of Vegetation Science* 3(1):3–14.

Kershaw AP, McKenzie GM, McMinn A. 1993. A Quaternary vegetation history of northeast Queensland from pollen analysis of O.D.P. Site 820. *Proceedings of the Ocean Drilling Program Scientific Results* 133:107–14.

Kirch PV. 1996. Late Holocene human-induced modifications to a Central Polynesian island ecosystem. *Proceedings of the National Academy of Sciences of the USA* 93:5296–300.

Kirch PV. 2001. *On the Road of the Winds: An Archaeological History of the Pacific Islands before European Contact*. Berkeley: University of California Press. 424 p.

Kirch PV, Ellison J. 1994. Paleo-environmental evidence for human colonization on remote Oceanic Islands. *Antiquity* 68(259):310–21.

Kitagawa H, Masuzawa T, Nakamura T, Matsumoto E. 1993. A batch preparation method for graphite targets with low background for AMS ^{14}C measurements. *Radiocarbon* 35(2):295–300.

McCormac FG, Hogg AG, Blackwell PG, Buck CE, Higham TFG, Reimer PJ. 2004. SHCal04 Southern Hemisphere calibration 0–11.0 cal kyr BP. *Radiocarbon* 46(3):1087–92.

Merlin M. 1985. Woody vegetation in the upland region of Rarotonga, Cook Islands. *Pacific Science* 39(1):81–99.

Merlin M. 1991. Woody vegetation on the raised coral

limestone of Mangaia, southern Cook Islands. *Pacific Science* 45(2):131–51.

Moriwaki H, Chikamori M, Okuno M, Nakamura T. 2006. Holocene changes in sea level and coastal environments on Rarotonga, Cook Islands, South Pacific Ocean. *The Holocene* 16(6):839–48.

Mueller-Dombois D, Fosberg FR. 1998. *Vegetation of the Tropical Pacific Islands*. New York: Springer-Verlag. 733 p.

Nakamura T, Niu E, Oda H, Ikeda A, Minami M, Takahashi H, Adachi M, Pals L, Gottdang A, Suya N. 2000. The HVEE Tandetron AMS system at Nagoya University. *Nuclear Instruments and Methods in Physics Research B* 172(1–4):52–7.

Peters C. 1998. Human settlement, vegetation history and landscape change on Rarotonga, southern Cook Islands. *Documenta Naturae* 121:1–200.

Stuiver M, Reimer PJ. 1993. Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program. *Radiocarbon* 35(1):215–30.

Stuiver M, Reimer PJ, Reimer RW. 2010. CALIB 6.0. Available online at http:/calib.qub.ac.uk/calib. Accessed 2 April 2013.

Thompson GM, Malpas J, Smith IEM. 1998. Volcanic geology of Rarotonga, southern Pacific Ocean. *New Zealand Journal of Geology and Geophysics* 41(1): 95–104.