Katsuhiko Kimura*, Nobuo Ooi** and Shigeru Suzuki***:

# Evidence of Vegetation Recovery on Yakushima Island after the Major Holocene Eruption at the Kikai Caldera, as Revealed by the Pollen Record of Buried Soils under the Old-Growth *Cryptomeria japonica* Forest

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# 屋久島のスギ林内で得られた埋没土壌の花粉分析によって明らかにされた完新世の鬼界カルデラ火砕流噴火後の植生回復

**Abstract** Pollen analysis was applied to a buried soil underlying the natural *Cryptomeria japonica* forest on Yakushima Island, in southern Japan. This soil developed above the Koya pyroclastic flow, which was deposited by an eruption from the Kikai Caldera, in 6300 y. BP. Pollen assemblages from the buried soil showed three different successional stages of vegetation recovery following the eruption, which were not reported in previous studies. 1: Grassland vegetation, dominated by Gramineae and ferns, indicating early successional stages following damage by pyroclastic flow materials. The age of this vegetation was estimated to be between 5170 and 6300 y. BP. 2: Mixed grassland and forest vegetation with high species diversity, characterized by the presence of *Haloragis* and *Myrica*. 3: Forest vegetation dominated by *Cryptomeria* and *Trochodendron*, corresponding to present surrounding vegetation, but having different species composition.
**Key Words**: *Cryptomeria japonica*, Holocene, Koya pyroclastic flow, Pollen analysis, Vegetation recovery

**要 旨** 屋久島は6300年前の鬼界カルデラの噴火で噴出した幸屋火砕流によって植生が大きな影響を受けたとされているが，花之江河湿原とその周辺で行われた過去の花粉分析ではそれを示唆するような結果は得られていなかった。本研究ではスギ自然林を通る林道脇の露頭に見いだされた火砕流堆積物の上に発達した埋没土壌の花粉分析を行い，火砕流噴火後の植生の回復過程を示すと考えられる3つの異なる花粉組成を得た。即ち，1)イネ科花粉とシダ胞子が圧倒的に優占する遷移初期の草原植生を示す組成，2)イネ科とシダの優占は変わらないものの，草本，木本ともに種数が多く特に草本ではアリノトウグサが，木本ではヤマモモが目立ち，先駆樹種が定着を始めた状態を示す組成，3)スギやヤマグルマなど木本花粉が優占し，現在の周辺植生に対応するものの，現在の森林では希な種や，より標高の低いところに分布する種を多く含む組成である。1)の堆積物の年代は5170〜6300 y. BPの間であると推定され，噴火後早い時期に埋没した土壌であると考えられた。
キーワード： 花粉分析，完新世，幸屋火砕流，植生回復，スギ

## Introduction

Yakushima Island (Fig. 1) has a famous old-growth natural forest of *Cryptomeria japonica*, including trees more than 3000 years old. The island is known to have been affected by a huge pyroclastic flow that erupted from the Kikai Caldera 50 km northwest of the island about 6300 years ago (Machida & Arai, 1978). The eruption must have destroyed much of the vegetation of the island because thick pyroclastic flow deposits are found everywhere, even around the highest moun-

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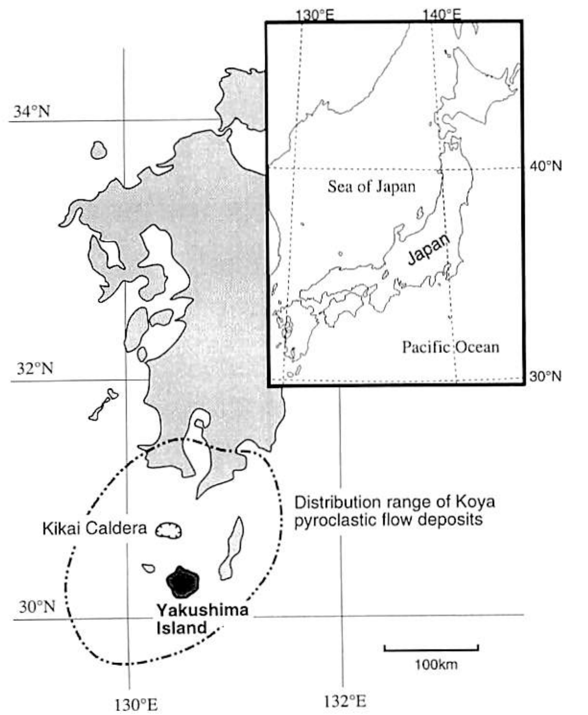


Fig. 1 Location of Yakushima Island and Kikai Caldera

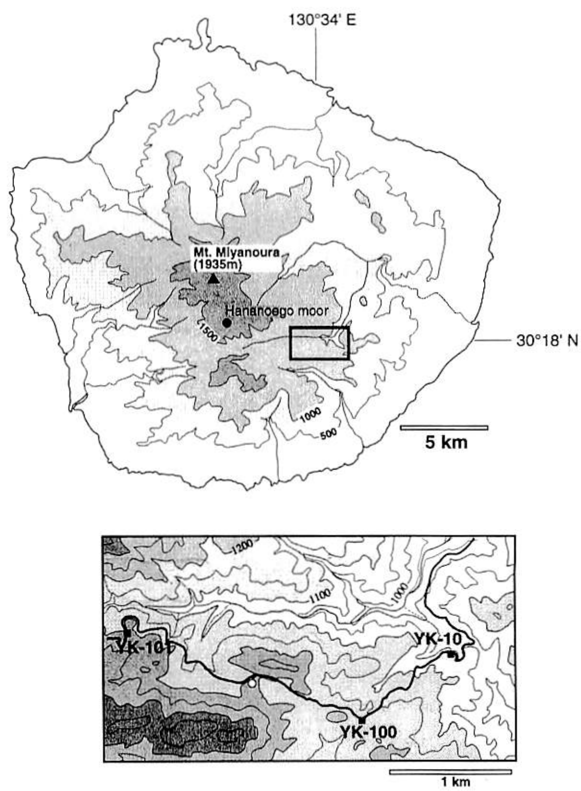


Fig. 2 Topography of Yakushima Island and location of sampling sites. The open circle in the lower figure indicates the location of the ecological study plot of Suzuki & Tsukahara (1987).

tain (1935m a.s.l.) of the island.

There are some palynological studies at and around Hananoego moor (Fig. 2), which developed in a gentle valley at an altitude of 1600m on Yakushima Island (Miyai 1938, Takeoka 1971, Takeoka & Torii 1982, Yasuda 1991). However, all of these data show pollen assemblages very similar to present forest vegetation, that is characterized by the dominance of *Cryptomeria*, and no indications of the eruption have been reported to date.

When examining the pyroclastic flow along a roadside soil section we found there were pockets of buried soil established above the pyroclastic flow deposit. Palynological analysis of the buried soils revealed the existence of vegetation which was not known there before.

Part of this study was published as a project research report for the Japan Environment Agency (Kimura & Suzuki, 1994).

## Study site and Methods

### Study site

Yakushima island (30°20′N, 130°30′E) is located 100km south of Kyushu, Japan (Fig. 1). Although small (500km$^2$ in area), Yakushima is a mountainous island, with a highest peak of 1935m. This mountain, along with the Kuroshio warm current, produces high precipitation on the island. The mean annual rainfall at the Yakushima weather station on the island's east coast is 3820 mm/y, but much more rain is recorded for hillside areas. Annual precipitation in 1982 at the Arakawa dam (670m a.s.l.), near the study site, was 8693mm, while at the weather station it was 4725mm (Eguchi, 1984).

Kikai Caldera, which erupted in 6300 y. BP, lies 50km NNW of the island. This was one of the largest eruptions in the world during the Holocene, and created a huge pyroclastic flow (Koya pfl, Fig. 1) together with a well known and widespread tephra, the Akahoya ash (Machida & Arai, 1978). The pyroclastic flow extended across the sea, reached Yakushima Island, and even deposited at the top of its' highest mountain. The thickest deposit we observed on the island was about 2m. The total volume of ejecta,

**Table 1** Vertical distribution of forest vegetation in Yakushima Island expressed by basal area (sum of cross section area of stems). Data modified from Tagawa *et al.* (1984), Suzuki & Tsukahara (1987), Kimura (unpablished), Kohyama *et al.* (1984) and Irikura (1984).

| Altitude (m)<br>Species | 1500 | 1200 | 950 | 600 | 300 |
|---|---|---|---|---|---|
| | Basal Area ($m^2$/ha) | | | | |
| *Paula coreana* | 1.3 | | | | |
| *Eurya yakushimensis* | 1.0 | | | | |
| *Acer sieboldianum* | 0.4 | | | | |
| *Cornus kousa* | 0.5 | | | | |
| *Rhododendron metternichii* | 5.2 | 0.0 | | | |
| *Clethra barbinervis* | 0.3 | 0.7 | | | |
| *Cryptomeria japonica* | 32.8 | 31.0 | 11.1 | | |
| *Trochodendron aralioides* | 15.1 | 12.4 | 7.0 | | |
| *Symplocos myrtacea* | 1.9 | 1.0 | 0.4 | | |
| *Pieris japonica* | 4.3 | 0.4 | 0.0 | | |
| *Stewartia monadelpha* | 5.6 | | 1.8 | | |
| *Tsuga sieboldii* | | 20.4 | 2.1 | | |
| *Abies firma* | | 2.6 | | | |
| *Daphniphyllum macropodum* | | 0.5 | | | |
| *Kalopanax pictus* | | 3.4 | 2.7 | | |
| *Dendropanax trifidus* | | 0.5 | 0.0 | | |
| *Quercus (Cyclobalanopsis) acuta* | | 0.4 | 2.2 | | |
| *Quercus (Cyclobalanopsis) salicina* | | 4.2 | 7.5 | 3.2 | + |
| *Illicium religiosum* | | 3.6 | 5.4 | 2.0 | |
| *Rhododendron tashoi* | | 5.9 | 4.6 | 0.4 | 4 |
| *Cletera japonica* | | 2.1 | 2.4 | 3.7 | 2 |
| *Camellia japonica* | | 0.5 | 1.1 | 0.2 | 2 |
| *Camellia sasanqua* | | 0.5 | 0.4 | 1.1 | |
| *Eurya japonica* | | 0.2 | 0.7 | 0.9 | 1 |
| *Distylium racemosum* | | | 12.4 | 25.0 | 6 |
| *Symplocos tanakae* | | | 0.0 | 0.8 | |
| *Symplocos prunifolia* | | | 1.1 | 0.3 | + |
| *Litsea acuminata* | | | 0.5 | 2.3 | |
| *Persea japonica* | | | 0.7 | 3.7 | |
| *Ternstroemia gymnanthera* | | | 0.3 | 0.0 | + |
| *Pasania edulis* | | | 0.3 | 0.0 | 6 |
| *Myrsine seguinii* | | | 0.0 | 1.5 | 2 |
| *Acer morifolium* | | | 0.4 | 0.0 | 1 |
| *Myrica rubra* | | | | 7.4 | |
| *Ilex rotunda* | | | | 1.8 | |
| *Torreya nucifera* | | | | 1.5 | |
| *Mallotus japonicus* | | | | 0.6 | |
| *Podocarpus nagi* | | | | 0.5 | |
| *Neolitsea aciculata* | | | | 2.8 | 2 |
| *Syzygium buxifolium* | | | | 0.1 | 2 |
| *Castanopsis cuspidata* | | | | | 25 |
| *Styrax japonica* | | | | | 1 |
| *Daphniphyllum teijsmannii* | | | | | 1 |
| *Elaeocarpus japonicus* | | | | | 1 |

+ less than 1

including ash, pfl and pumice, is estimated to be over 170km³ (Machida & Arai, 1992).

The present natural vegetation of Yakushima Island is composed mostly of evergreen forests, except for dwarf bamboo scrub at the island's summit. Areas lower than 500m are dominated by *Castanopsis cuspidata* (var. *sieboldii*), those between 500m and 1000m by *Distylium racemosum* and those higher than 1000m by *C. japonica* (Table 1). *Trochodendron aralioides*, which often exhibits a strange epiphytic form on Yakushima, and the two conifers *Tsuga sieboldii* and *Abies firma* are common in the zone where *Cryptomeria* dominates. *Quercus acuta, Quercus salicina, Illicium religiosum* and *Rhododendron tashiroi* are common at 1200m and below. Vegetation data in Table 1, from 1200m, were obtained from a 4770m² ecological study plot (Suzuki & Tsukahara, 1987) near the sampling sites for this study (Fig. 2).

## Samples and Methods

Buried soil samples were collected from roadside cuts at 3 locations, YK-10, YK-100 and YK-101, at

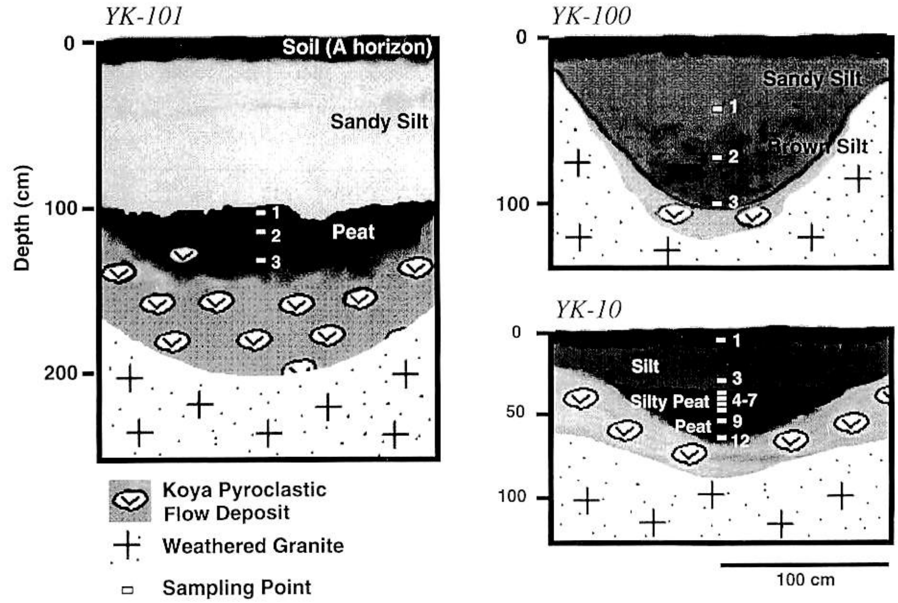


**Fig. 3** Geological sections of sampling sites

altitudes of 1050m, 1150m and 1200m respectively (Fig. 2). All are located near a ridge, so that geologically they have not been greatly affected by material from the upper slope. Geological sections of the 3 sites are shown in Fig. 3. At each site, buried soil was found in small concave pockets above the Koya pyroclastic flow. The pyroclastic flow deposit directly covers a weathered granite, which also has a concave surface.

At YK-10, the Koya pfl has a thickness of 20 cm, and black peat and dark brown silty peat, both with thickness of 20 cm, and contain pfl pumice and gravel, fill the depression. The peat is covered by silt with thickness of 30 cm, and top of it is dark brown A horizon soil of present vegetation. Twelve samples were taken in a column from the top soil to the bottom of depression. Eight of these samples were used for pollen analysis. A block of peat was taken from the bottom of the deposit for radiocarbon analysis.

At YK-100, Koya pfl is found only in the bottom of the ditch, with a maximum thickness of 20 cm. Brown silt-sandy silt, of 60 cm thickness, fills the ditch and is covered by light-brown silt with thickness of 40 cm. Samples were taken from the brown silt at 3 points.

At YK-101, the Koya pfl has a maximum thickness of 60 cm, and a black peat is developed on it with a maximum thickness of 25 cm. The peat clearly originates from vegetation which was established on the pfl. The top surface of the peat is clear, but has a rather irregular shape. Gray-brown sandy silt with thickness of 100 cm covers it. Samples were taken from 3 points in the peat layer. A block of peat was taken from the bottom of the layer for radiocarbon dating.

Collected samples were treated with 10% KOH, sieved through a 0.5mm mesh, decanted to remove sand, treated with 50% HF, dehydrated with acetic acid, and treated by the acetolysis method. The residue was saturated in glycerin, and mounted on a slide. All pollen grains and spores on each slide were counted. Frequencies of pollen and spore types were calculated based on total identified pollen and spore counts. Single-grain pollen preparations were preserved for further morphological and taxonomic studies.

Peat samples obtained from YK-10 and YK-101 were radiocarbon dated, using the methanol-LSC method, at the Research Institute for Advanced Science and Technology, Osaka Prefectural University. For the YK-101 sample, acid pretreatment by HCl was used to remove carbonates, possible contaminants from ancient inorganic carbon materials.

**Table 2** Counts of pollen and spores for each taxon at each sampling point

| site no. | YK-10 | | | | | | | | YK-100 | | | YK-101 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| sample no. | 1 | 3 | 4 | 5 | 6 | 7 | 9 | 12 | 1 | 2 | 3 | 1 | 2 | 3 |
| arboreal pollen | | | | | | | | | | | | | | |
| *Podocarpus* | | | 8 | 8 | 14 | 5 | 9 | | | 1 | 4 | | | |
| *Abies* | 14 | 10 | 6 | 10 | 3 | 7 | | 7 | 2 | 16 | 38 | 5 | | |
| *Tsuga* | 9 | 3 | 1 | 1 | 4 | 2 | 1 | 2 | 1 | 2 | | 2 | | |
| *Pinus* | | | 1 | 4 | 7 | 3 | | 1 | 3 | 1 | 1 | | | |
| *Cryptomeria* | 84 | 102 | 37 | 6 | 2 | 5 | 3 | 2 | 362 | 126 | 157 | | | |
| Taxaceae-Cephalotaxaceae | | | | | | | | | 8 | 6 | 14 | | | |
| *Salix* | | | | 2 | | | | | | | | | | |
| *Myrica* | 4 | 23 | 58 | 103 | 72 | 45 | 18 | 4 | 15 | 9 | 8 | 4 | 1 | |
| *Carpinus-Ostrya* | 4 | 5 | 2 | 9 | 2 | | | | 1 | 83 | 54 | 7 | | 3 |
| *Alnus* | | 2 | 3 | 6 | 2 | 1 | | | 7 | 8 | 6 | | | |
| *Quercus* subgen. *Cyclobalanopsis* | 67 | 50 | 59 | 31 | 39 | 30 | 6 | 8 | 263 | 181 | 149 | 52 | 14 | 22 |
| *Quercus* subgen. *Lepidobalanus* | | | | | 1 | | | | 2 | 1 | 1 | | | |
| *Castanopsis* | | 12 | 9 | 5 | 1 | 4 | 3 | 1 | 11 | 3 | 1 | 1 | | |
| *Ulmus-Zelkova* | | 2 | | | 2 | 1 | | | 1 | 1 | 1 | | 1 | |
| *Trochodendron* | 57 | 41 | 37 | 18 | 10 | 8 | | 1 | 167 | 103 | 268 | 91 | | 1 |
| *Illicium* | 13 | 7 | 19 | 18 | 3 | 5 | | | 8 | 9 | 6 | | 1 | 1 |
| *Corylopsis* | | | | | | | | | 1 | 1 | 1 | | | |
| *Distylium* | | | 4 | 4 | 1 | 3 | | 1 | 14 | 2 | | | | |
| cf. *Prunus* | | | | | | | | | | | | 21 | | 1 |
| *Daphniphyllum* | 34 | 34 | 42 | 17 | 13 | 9 | 7 | 3 | 15 | 22 | 12 | 2 | | |
| *Zanthoxylum* | | | 5 | 6 | 1 | 3 | | | 2 | | | | | |
| *Rhus* | | | | | | 2 | | | | | | | | |
| *Ilex* | 3 | | | | | | | | 1 | 1 | 1 | | | |
| *Acer* | 4 | 5 | 4 | 13 | 9 | 6 | 1 | | 1 | | 1 | | | |
| *Vitis* | | | | | | | | | 1 | | | | | |
| *Camellia* | | | 4 | 3 | 3 | 2 | | | | | 1 | | | |
| Araliaceae | | | | | | | | | | 1 | 1 | 2 | | |
| Ericaceae | 31 | 118 | 134 | 30 | 13 | 19 | | | 15 | 36 | 27 | 6 | | |
| *Symplocos* | 99 | 121 | 123 | 4 | 4 | 4 | | 1 | 169 | 268 | 147 | 16 | 3 | 4 |
| *Ligustrum* | | 1 | | | 1 | 1 | | | | | | | | |
| *Viburnum* | | | 2 | 2 | 3 | 2 | | | | | | | | |
| nonarboreal pollen | | | | | | | | | | | | | | |
| Gramineae | 25 | 63 | 255 | 919 | 590 | 616 | 566 | 566 | 6 | 18 | 28 | 699 | 724 | 627 |
| Cyperaceae | 2 | 2 | | | | 1 | | | | | | | | |
| *Heloniopsis* | | | 3 | 3 | | | | | | | | | | |
| Moraceae | | | | | | | | | | 2 | 1 | | | |
| Chenopodiaceae-Amaranthaceae | | | | | | 1 | | | 1 | | 1 | | | |
| Ranunculaceae | | | | | | | | | | | 1 | | | |
| *Clematis* | | | | 28 | | | | | | | | | | |
| *Thalictrum* | | | 2 | | | | | | | | | | | |
| *Drosera* | | | | | 1 | | | | | | | | | |
| Rosaceae | | 1 | 6 | 6 | 5 | | 1 | | 2 | 4 | 2 | 1 | | |
| Leguminosae | | 2 | | | | 1 | | | 11 | 13 | 9 | 1 | 1 | 1 |
| *Haloragis* | | 6 | 70 | 261 | 203 | 144 | 19 | 1 | 1 | 2 | 2 | | | |
| Crusiferae | | | | | | 2 | | | | | | | | |
| Umbelliferae | 3 | 2 | 1 | 2 | 1 | | | | | | | | | |
| Labiatae | | | | 3 | | | | | | | | | | |
| Compositae subfam.Carduoideae | | 5 | 20 | 52 | 61 | 29 | 7 | | 1 | 1 | 1 | 2 | 1 | 2 |
| *Artemisia* | 6 | 2 | 5 | 20 | 12 | 8 | 5 | | 4 | 5 | 5 | 3 | 2 | 4 |
| Compositae subfam.Cichorioideae | | | 4 | 12 | 1 | 2 | 2 | 3 | | | | 17 | 10 | 14 |
| fern spores | | | | | | | | | | | | | | |
| *Lycopodium* | 8 | 89 | 227 | 445 | 423 | 303 | 171 | 154 | 1 | 10 | 20 | 15 | 8 | 1 |
| *Osmunda* | 2 | | 1 | | | | 14 | 6 | | | | | | |
| Trilete spore | | 12 | 52 | 52 | 15 | 58 | 28 | 15 | 3 | 6 | 13 | 39 | 7 | 10 |
| Monolete spore | 8 | 73 | 198 | 583 | 545 | 326 | 472 | 339 | 10 | 23 | 23 | 203 | 396 | 831 |
| unknown | 128 | 75 | 102 | 84 | 60 | 54 | 10 | 18 | 87 | 82 | 56 | 32 | 23 | 21 |
| total arboreal pollen | 423 | 536 | 558 | 300 | 210 | 167 | 48 | 31 | 1070 | 881 | 899 | 209 | 20 | 32 |
| total nonarboreal pollen | 36 | 83 | 366 | 1306 | 874 | 804 | 600 | 570 | 26 | 45 | 50 | 723 | 738 | 648 |
| total fern spores | 18 | 174 | 478 | 1080 | 983 | 687 | 685 | 514 | 14 | 39 | 56 | 257 | 411 | 842 |
| total identified pollen and spores | 477 | 793 | 1402 | 2686 | 2067 | 1658 | 1333 | 1115 | 1110 | 965 | 1005 | 1189 | 1169 | 1522 |
| total pollen and spores | 605 | 868 | 1504 | 2770 | 2127 | 1712 | 1343 | 1133 | 1197 | 1047 | 1061 | 1221 | 1192 | 1543 |

## Results

### Pollen assemblages

Pollen and fern spore samples from three sites, including morphological groups, included 31 arboreal pollen types, 18 nonarboreal pollen types and 4 fern spore types (Table 2). The vertical distributions of major pollen and spore types are shown in the pollen diagram (Fig. 4). This diagram plots the different

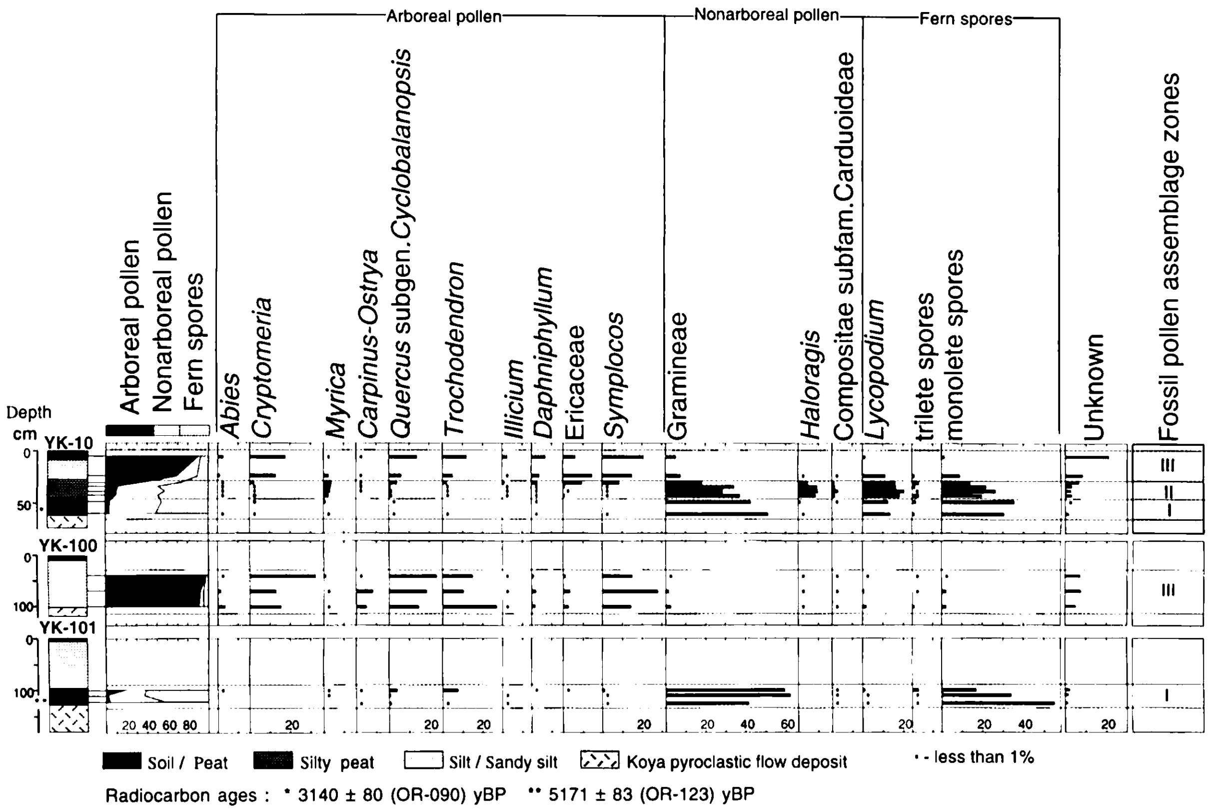


**Fig. 4** Pollen diagrams for the three sampling sites, showing major taxa, with proportions higher than 2% for any of the sampling points. Proportions are shown as percentages of the total number of pollen and spores.

species as percentages of total pollen and spores. Moraceae, Rosaceae (excluding cf. *Prunus*) and Leguminosae are considered nonarboreal pollen although they might originate from both trees and herbs. Many of the pollen grains and spores, especially in the top soil of YK-10, were not identified because of bad preservation.

The results show two very contrasting pollen assemblages. Arboreal pollen dominates in YK-100 and the upper samples of YK-10, indicating forest vegetation, whereas, in YK-101 and lower samples of YK-10, nonarboreal pollen and fern spores dominate. The following observations may be made for the three locations sampled.

YK-10: Three local pollen assemblage zones, YK-10-I to YK-10-III are identified. YK-10-I: Samples 12 and 9 show a high occurrence of Gramineae (50.8 to 42.5 %) and monolete spores (30.4 to 35.4). Other pollen and spore types, except *Lycopodium* (ca. 13 %) are rare or absent. YK-10-II: Samples 7 to 4. Arboreal pollen comprises about 10 to 40 % of the total identified pollen and spores. In particular, *Myrica* (2.7 to 4.1 %) and *Quercus* subgen. *Cyclobalanopsis* (1.2 to 4.2 %) exceed 1% for every sample. Gramineae (18.2 to 37.2 %), monolete spores (14.1 to 26.4 %) and *Lycopodium* (16.2 to 20.5 %) are still common. Arboreal pollen types that characteristically occur in this zone are *Podocarpus, Pinus, Distylium, Zanthoxylum, Camellia* and *Viburnum*. Among the nonarboreal pollen types, *Haloragis* (5.0 to 9.8 %) and Compositae subfam. Carduoideae (1.4 to 3.0 %) are characteristic. YK-10-III: Samples 3 and 1. Arboreal pollen proportions are high, making up 67 % of 10-3, and increasing to 89 % in 10-1. Among arboreal types, *Symplocos* (15.3 to 20.8 %), *Cryptomeria* (12.9 to 17.6 %), *Q.* Subgen. *Cyclobalanopsis* (6.3 to 14.0 %), *Trochodendron* (5.2 to 11.9 %), *Daphniphyllum* (4.3 to 7.1 %) and Ericaceae (14.9 to 6.5 %) are characteristic, and all except Ericaceae increase towards the top of the column. *Tsuga* (0.4 to 1.9 %) and *Abies* (1.3 to 2.9 %) have the same tendency although they only increase by a few percent. One fifth of the pollen grains cannot be identified because of bad preservation.

YK-100: Arboreal pollen comprises more than 90 % of the total pollen and spores. *Cryptomeria* (13.1 to 32.6 %), *Q.* subgen. *Cyclobalanopsis* (14.8 to 23.7 %), *Trochodendron* (10.7 to 26.7 %) and *Symplocos* (14.6 to 27.8 %) are dominant throughout 3 samples. The most dominant types in 100-3, 100-2 and 100-1 are *Trochodendron, Symplocos* and *Cryptomeria* respectively. In the lower two samples, *Abies* (0.2 to 3.8 %) and *Carpinus-Ostrya* (0.1 to 8.6 %) are relatively common. *Daphniphyllum* (1.2 to 2.3 %) and Ericaceae (1.4 to 3.7 %) are higher than 1 % throughout the samples. Nonarboreal types are rare, except Gramineae (0.5 to 2.8 %) and monolete spores (0.9 to 2.4 %).

YK-101: This site is characterized by high occurrences of Gramineae pollen and fern spores. Arboreal pollen comprises 17.6 % of sample 101-1, but only 1.7 and 2.1 % in the lower two samples. Among arboreal pollen types, *Q.* subgen. *Cyclobalanopsis* dominates, showing an occurrence of 1 % in lower samples and attaining 4 % in 101-1. In 101-1, *Trochodendron* (7.7 %), cf. *Prunus* (1.8 %), and *Symplocos* (1.3 %) are common trees. Nonarboreal pollen are almost exclusively Gramineae (41.2 to 61.9 %) and monolete spores (17.1 to 54.6 %), followed by some Compositae types such as *Artemisia* (0.2 to 0.3 %) and subfam. Cichorioideae (0.9 to 1.4 %).

### Radiocarbon dates

The radiocarbon dates for the peats taken from YK- 10 (corresponding to pollen zone YK- 10-I) and YK- 101 are 3410±80 y. BP (OR-090) and 5171±83 y. BP (OR-123). The former sample was taken from a rather shallow depth (ca. 50 cm) and contains many visible roots, so it would be younger than the actual age of deposition. As the latter sample is from a deeper depth (ca. 120 cm), and acid pre-treatment with HCl has been applied to remove carbonates, the date should be more accurate, but there are still a few rootlets visible in the sample.

## Discussion

### Successional stages reconstructed from pollen assembleges

Although all the buried soil samples developed above the Koya pyroclastic flow deposit, pollen assemblages obtained from three sites differ, probably because of different ages of deposition. This illustrates the course of vegetation recovery after the eruption.

General vegetation change in this region seems to proceed from a grassland community, composed of Gramineae and ferns (namely, stage 1 : pollen assemblage zone I, YK-10-I & YK-101) through mixed vegetation of grass and trees (stage 2 : pollen assemblage zone II, YK-10-II) to a forest community composed of *Cryptomeria, Trochodendron, Q.* subgen. *Cyclobalanopsis* and *Symplocos* (stage 3 : pollen assemblage zone III, YK-10-III & YK-100). However, it is very difficult to arrange pollen assemblages obtained here on an absolute time scale, as the deposits are not continuous.

Stage 1: The pollen assemblages of YK-10-I and YK-101 indicate that there was a grassland vegetation around the sampling locales. The number of identified taxa from this zone is much smaller than the number from the other zones, and is dominated by Gramineae and ferns. To identify the species of Gramineae, plant opal analysis was carried out on the YK-101 sample after washing it through a 10$\mu$m mesh screen. However, no plant opal was obtained, suggesting that it was not a *Miscanthus sinensis* grassland, the most common volcanic vegetation type in Japan. This grassland might be composed of other Gramineae species which did not produce plant opal larger than 10 $\mu$m.

Among the tree taxa, *Q.* subgen. *Cyclobalanopsis* seemed to establish earlier than others, in both YK-10- I and YK-101. In YK-10-I, *Myrica* and *Daphniphyllum* are also dominant. Since *Q.* subgen. *Cyclobalanopsis* and *Daphniphyllum* are not typical pioneer species, the source of pollen from these trees could be remote forest fragments which survived the eruption.

The radiocarbon ages of YK-10-I and YK-101 are quite different (3410±80 and 5171±83 y. BP) in spite of the similarity in their pollen assemblages. As already mentioned, the former age may to be too young because of modern root contamination. However, the latter date also seems too young, since it is 1100 years after the eruption. In Krakatau Island, Indonesia, dense forests were re-established only 100 years after a catastrophic eruption (Tagawa *et al.*

1985). As the YK-101 sample contains a few roots and carbonates have been removed by HCl pre-treatment, 5171 y. BP is thought to be the minimum age. Thus, the correct age would be between 5171 and 6300 y. BP, but it is difficult to tell when this vegetation was established and how long it lasted.

Stage 2: This zone corresponds to YK-10-II, and is characterized by high diversity but low occurrence (10%) of arboreal pollen taxa. The number of taxa is greater than in zone I, and almost all the taxa occurring in YK-10 are represented in this zone. The vegetation seems to have still been predominantly grassland, but many of the tree taxa characterize this zone, such as *Podocarpus, Pinus, Myrica, Distylium, Zanthoxylum, Acer, Camellia* and *Viburnum*. All of these are minor taxa in the present forest around the site, but some are common in lower elevation forest areas, such as *Distylium* and *Myrica* (see Table 1). Among these, *Pinus, Zanthoxylum* and possibly *Myrica* are pioneer species.

The dominant tree taxa in this zone is *Myrica*, which would be *M. rubra*, a nitrogen fixer. *Myrica* is thought to be a typical pioneer species in volcanic areas in the tropics (Flenley, 1979). In Hawaii, an exotic pioneer *M. faya*, which is also a nitrogen fixer and has seeds dispersed by birds, is reported to expand into areas covered with volcanic ash (Vitousek & Walker, 1989).

Species diversity of nonarboreal taxa is also high and *Haloragis*, *Artemisia* and Compositae subfam. Carduoideae are typical in this zone. *Haloragis micrantha*, the only possible species of the genus, which is a small herb growing on wet but open places, might have grown in the small ditch where the buried soil was formed. The local vegetation would have been an open grassland, composed of many herbaceous species, with many tree species, including pioneers, invading the surrounding area. *Cryptomeria* was still a minor species even among tree taxa.

One of the problems associated with this kind of buried soil sample is the possibility of mixing of two or more different pollen containing soils that originated in completely different times. This could produce a fake flora. However, in YK-10 some taxa, such as *Haloragis*, Compositae subfam. Carduoideae and *Myrica*, characterize zone II and decrease in both the upper and lower zones, suggesting that the assemblage of pollen and spores in this zone is not a mixture of soils from zones I and III, but reflects the actual flora that existed at a specific time in the past.

Stage 3: High occurrence of arboreal pollen in zone III clearly indicates that the vegetation has already changed to forest. This zone includes samples YK-10-III and YK-100. YK-10-III is the top soil from the present forest, but YK-100 is buried 40-100 cm and thus might have been protected from the effects of sub soil animals. Pollen assemblages from this zone correspond to the present vegetation around the study area, but there are three interesting discrepancies between them.

1. Some of the pollen taxa found in this zone are very rare, or even not recorded in the present flora of Yakushima. *Carpinus-Ostrya* is relatively abundant in YK-100, but it is very rare in the present flora (only *C. laxiflora* is recorded for this taxa in the flora list of Mitsuta & Nagamasu (1984)). *Alnus* (only *A. firma* is in the list) and *Quercus* subgen. *Lepidobalanus* (*Q. acutissima*) are found in this zone, although not frequently, are also rare in the present flora. *Ulmus-Zelkova* is not recorded in the present flora list. Takeoka & Torii (1982) detected pollen of *Zelkova*. It is interesting that some of the species that survived the catastrophic eruption and expanded after it, were extinguished or almost extinguished in the process of vegetation recovery. This implies that species extinction does not always occur due to the catastrophic event itself.

2. Many of the taxa in the pollen flora are distributed in lower elevation areas in the present forest vegetation. *Q.* subgen *Cyclobalanopsis*, one of the dominant taxa in YK-100, is distributed mainly below 1000m a.s.l. and is not a dominant species in the forest around YK-100 (Table 1). The pollen taxa *Myrica*, *Castanopsis-Pasania*, and *Podocarpus* would correspond to the species *Myrica rubra*, *C. cuspidata* / *P. edlus* and *P. nagi* /*P. macrophyllus*. Their present vertical distribution is centered in elevations below 500 m and usually never goes higher than 1000m. A similar phenomenon is reported for pollen records from the Hananoego moor (Fig. 2). Takeoka (1971) ascribed this to wind transport from lower elevation areas, but it is possible that these species were actu-

ally distributed around the site.

3. The low occurrence of *Tsuga* and *Abies*. As *T. sieboldii* and *A. firma* are dominant tree species in the present forest near the sampling points (Table 1), the occurrences of the two species in the pollen record appear to be rather low. The highest occurrence of *Abies*, found at the bottom of YK-100, is 3.8%, and that of *Tsuga*, in the top soil of YK-10, is only 1.5%. Takeoka & Torii (1982) reported a significant increase of *Tsuga* in the surface sample. Expansion of *Tsuga* and *Abies* seems to have taken place rather recently. In general, *Tsuga* more often grows on ridges with shallow soil than on slopes with deep soil. So, expansion of *Tsuga* might not have started until the pyroclastic flow deposit was eroded and bare rocks emerged on the surface. Extensive cutting of *Cryptomeria* trees during the Edo era (100-350 years ago) might have accelerated this erosion process.

**Comparison with previous studies**

The pollen assemblages of Zones I and II in this study are completely different than previously studied pollen assemblages from the *Sphagnum* peat bog in Hananoego moor (Miyai, 1938; Takeoka, 1971; Takeoka & Torii, 1982; Yasuda, 1991). The earlier data are much like the pollen assemblage of zone III, which shows forest vegetation. These differences may result from different sample ages rather than different sampling locations.

As the Hananoego moor is located in a gentle valley, pyroclastic flows might have deposited much deeper than in other areas. Erosion would likely have started soon after deposition and continued down to the surface of the bed rock, because no thick pfl deposit was observed under the bog (Sohma, 1984: Fig. 5). Radiocarbon ages of peat samples obtained from the bottom of Hananoego moor are 3380 y. BP (Takeoka & Torii, 1982), 2600 y. BP (Sohma, 1984) and 2460 y. BP (Yasuda, 1991) indicating that initiation of the deposition was rather late. Sohma (1984) ascribed this late start of deposition to unstable slope conditions caused by heavy rainfalls which started around 2000 y. BP.

On ridges and upper slopes erosion would have been stopped by the relatively early recovery of the surrounding vegetation, and some soils of this age, especially those in gully like microtopography, might have been buried by occasional small scale slope failures. This would be the origin of buried soils in YK-10 and YK-101. This kind of buried soil is useful because it is commonly found in other volcanic areas.

**Features of soil pollen analysis**

In the case of pollen analysis of soils, as opposed to *Sphagnum* peat bog samples, surface soil on which pollen falls is not a newly produced pollen free material, but an aged material that always contains pollen from former vegetation, except when it is in very early successional stages. So, pollen assemblages of upper soils would be more or less of a mixture of different ages. Also, vertical transport by soil animals, or leaching and preservation of pollen, would be important considerations in the soil analysis.

We haven't discussed the preservation of pollen in the soil, however, great differences in preservation among species are known. Havinga (1984) studied deterioration of pollen and fern spores in different fill materials and showed differences in preservation rate among species and fill materials. In the extreme case, all the *Lycopodium* spores survived in river clay for 10 years, whereas 99 % of *Myrica* deteriorated within a few years. The differences were greater in river clay and leaf mould than in peat. Thus the actual dominance of *Myrica* in YK-10-II might have been much greater than we observed.

In spite of these problems, however, buried soil provides an advantage in pollen analysis, because peat bogs develop in very restricted locations, especially in steep mountain areas as on Yakushima.

**The effects of erruption to the vegetation**

This study found that vegetation around the study sites became grassland some time after the pyroclastic eruption in Kikai Caldera. However, some portion of forest must have survived the catastrophe since Yakushima has a rich flora including many endemic plant species. Mitsuta & Nagamasu (1984) noted that on Yakushima, there were many primitive plant species which could only survive in stable natural forest conditions.

Effects of the eruption still exist in the present forest vegetation because there are extensive pyroclastic flow deposit remnants on the island. These are important as a source of mineral nutrients for plants and as mother material for the present forest soil. However, they are being gradually eroded by rainfall, which will make the species composition of the forest change in the future.

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**書評(新刊紹介)：地球環境問題への国際的取り組みの特集**

今年3月に社団法人環境情報科学センターから，環境情報科学の25巻1号として「環境の四半世紀－地球環境－」と題した特集号が刊行された。ひじょうに多岐にわたる地球環境問題への国際的な取り組み方およびその歴史が概括的，かつ今日的問題をもふんだんに含むかたちで特集されている。総ページ150のうち113が特集記事に当てられており，量的にも圧巻である。この特集は「環境の四半世紀」と銘打った通年特集企画の第1弾「地球環境編」であり，続いて「環境のデザイン編」が5月に刊行される予定である。

この特集は，編集委員の袴田共之の巻頭言にあるように「環境問題，とくに地球環境問題のむずかしさのひとつは，そこに包含される問題群の個々の現象の認識から政策実現までの全段階において，広範でかつ深い科学的知見を要求されるという点にある。(中略)わが国民各階層の関心を上滑りの，いわゆるブームに終わらせてしまうのでなく，問題解決のうねりとして実体化していくためには，広範で深い科学的知見を全体として整理して把握しておく必要がある」という認識を背景として企画された。前半では，この四半世紀におけるおもな流れと現時点の主要な側面をそれぞれの分野の専門家が概説し，その構成は，地球環境の四半世紀(橋本)，わが国の環境政策(森島)，地球環境問題－地球科学と国際政治との融合(米本)，気候変動に関する政府間のパネルの活動と今後(西岡)，国連気候変動枠組条約の制定経緯と取り組みの現状（松村)，地球環境問題の意識の変遷（石)，南北問題からみた地球環境－グローバル化における環境と貧困（勝俣)，NGOの活動と地球環境問題－「マングローブ植林行動計画」のベトナム・プロジェクトを事例として（向後）の8論説と，「地球環境はいま」と題する7論説すなわち，地球温暖化研究の過去と現在(松野)，オゾン層の破壊（富永)，酸性雨－これまでとこれから（原)，熱帯林の消失と劣化はいつまで続くか(熊崎)，砂漠化－新たな対応への期待（門村)，生物多様性のもつ意味（安野)，海洋汚染（宮崎）からなる。

後半の構成は，日本学術会議の地球環境研究へのかかわり－第14期・第15期の地球環境関連特別委員会の活動（吉野)，第16期の地球環境と人間活動特別委員会の活動状況（平田)，地球環境に関する研究体制（北村）の3つの日本学術会議における地球環境研究の概要，学術審議会建議「地球環境科学の推進について」(平川)，地球環境研究遂行の見取り図（西岡）の2つの概説，および3つの大きなプログラムであるIGBP（地球圏－生物圏国際協同研究計画)，HDP(地球環境変化の人間次元の研究計画)，WCRP（気候変動国際協同研究計画）の個々のプログラムの国際動向に関する次のような25の概説からなっている。IGBPでは，IGBPの国際動向，日本におけるIGBP研究の概要，IGAC, JGOFS, LOICZ, GCTE, BAHC, GAIM, IGBP-DIS, PAGES, LUCC, HDPでは，HDPの国際動向，地球環境問題の「人間的次元」とは何であったか，DEPS, HDP-GIS, ED, EMA, WCRPでは，WCRPの国際動向，日本におけるWCRP, TOGA, WOCE, GEWEX-CLIVAR, GEWEX-GAME, ACSYS, SPARCが取り上げられている。これらにSTART（解析・研究・研修システム）とGCOS（全地球気候観測システム）の2つの大きなプロジェクトの概説が加えられている。最後に年表地球環境の四半世紀が8ページにわたってまとめられている。

どの論説・概説をとってみても簡潔でコンパクトにまとめられているので，興味のある項目について調べるにも便利であるし，研究体制の構造や各プロジェクトの関わり方，これまでの経緯が分かり易い図・表にまとめられているので理解し易い。

地球環境問題は地球社会が抱える深刻な問題である。これまでの取り組みと現状を理解し，これからのわれわれの関わり方を考えるのに，この特集は大いに役立つものと思われる。

なお，この特集は一部2575円で購入することができる。環境情報科学センターは☎03-3265-3916, FAX 03-3234-4307，振替00190-3-75900である。

（辻　誠一郎）