Analysis of Plant Microfossils in Archaeological Deposits from Two Remote Archipelagos: The Marshall Islands, Eastern Micronesia, and the Pitcairn Group, Southeast Polynesia[1]

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Abstract: Pollen and starch residue analyses were conducted on 24 sediment samples from archaeological sites on Maloelap and Ebon Atolls in the Marshall Islands, eastern Micronesia, and Henderson and Pitcairn Islands in the Pitcairn Group, Southeast Polynesia. The sampled islands, two of which are "mystery islands" (Henderson and Pitcairn), previously occupied and abandoned before European contact, comprise three types of Pacific islands: low coral atolls, raised atolls, and volcanic islands. Pollen, starch grains, calcium oxylate crystals, and xylem cells of introduced non-*Colocasia* Araceae (aroids) were identified in the Marshalls and Henderson (ca. 1,900 yr B.P. and 1,200 yr B.P. at the earliest, respectively). The data provide direct evidence of prehistoric horticulture in those islands and initial fossil pollen sequences from Pitcairn Island. Combined with previous studies, the data also indicate a horticultural system on Henderson comprising both field and tree crops, with seven different cultigens, including at least two species of the Araceae. Starch grains and xylem cells of *Ipomoea* sp., possibly introduced *I. batatas*, were identified in Pitcairn Island deposits dated to the last few centuries before European contact in 1790.

During the late Holocene settlement of the eastern Pacific, agricultural practices combining tropical Asian-Pacific and American crops were adapted to a diversity of island environments (Yen 1973, Spriggs 1982, Ayres and Haun 1990, Kirch 1994, Bellwood 2005). This involved starch staples produced through a variety of "wet" and "dry" field-cropping methods (Kirch 1994) and tree cropping (Yen 1973). The extension of these practices to remote islands of often very small area with barren soil, unreliable groundwater supply, unpredictable rainfall, and frequent marine inundation was one of the most challenging accomplishments of this diaspora.

The starch staples include four species of the Araceae, *Colocasia esculenta* (*taro*), *Alocasia macrorrhiza* (elephant ear *taro*), *Cyrtosperma merkusii* (syn. *chamissonis*, giant swamp *taro*), and *Amorphophallus paeoniifolius* (elephant yam); and *Dioscorea* spp. (yams), *Musa* spp. (bananas), *Artocarpus altilis* (breadfruit), and *Ipomoea batatas* (sweet potato). In total, there are approximately 30 species of subsistence plants listed (see, e.g., Kirch 1989, Loy et al. 1992, Matthews 1996). Many of these originated in Asia and, recent research suggests, also in the Sahul continental region (Haberle 1995, Lebot 1999, Denham et al. 2003, Matthews 2003, Bellwood 2005). They were introduced throughout the Pacific by early human colonizers. *Ipomoea batatas* (sweet

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[1] The Marsden Fund administered by the Royal Society of New Zealand provided support for M.H. Funding from the Wenner Gren Foundation for Anthropological Research, the United Nations, the U.S. National Park Service, the Australian South Pacific Cultures Fund, and the Historic Preservation Office (Republic of the Marshall Islands) provided support for M.I.W. Manuscript accepted 2 June 2005.

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Pacific Science (2006), vol. 60, no. 2:261–280

potato) and *Lagenaria siceraria* (bottle gourd) originated in South America, their introductions a result of Polynesian contact (Hather and Kirch 1991, Green 2000).

Research on the age, development, and diversity of early agriculture in the Pacific has been hindered by transformation of traditional cropping systems after European contact and archaeological scarcity of crop fossils. However, recent advances have been made with regard to the latter at sites across the Pacific by the identification of plant macrofossils and especially by the application of a range of microfossil techniques, namely pollen, starch residues, and phytoliths. In Micronesia, prehistoric pollen (and macrofossils) of the Araceae and *Artocarpus altilis* has been reported in the Mariana, Caroline, and Marshall Islands (Beardsley 1994, Athens et al. 1996, Athens and Ward 2002, 2004). In Melanesia, Araceae starch residues have been identified at Lapita settlements in the Bismarck Archipelago (Crowther 2005) and Vanuatu (Horrocks and Bedford 2005). Similarly, Lentfer and Green (2004) identified *Musa* phytoliths at a Lapita site in the Bismarcks. In Polynesia, starch residues, phytoliths, and pollen of a suite of introduced cultivated plants have been identified in New Zealand, comprising *Ipomoea batatas*, *Colocasia esculenta*, *Lagenaria siceraria*, and *Broussonetia papyrifera* (paper mulberry) (Horrocks 2004*a*). In the Society Islands, Parkes (1997) reported pollen of *Ipomoea batatas*, *Colocasia esculenta*, and *Cordyline fruticosa* (syn. *terminalis*, Pacific Island cabbage tree). Athens and Ward (1997) reported pollen of *Colocasia esculenta*, *Cordyline fruticosa*, and *Aleurites moluccana* (candlenut tree) in Hawai'i, and Cummings (1998) reported pollen of *Ipomoea batatas* and starch granules of *Colocasia* on Easter Island. Macrofossils identified in Polynesia include *Ipomoea batatas* root (commonly referred to as tuber) from Hawai'i (Rosendahl and Yen 1971), the Cook Islands (Hather and Kirch 1991), and New Zealand (e.g., Yen and Head 1993); *Aleurites moluccana* endocarp from the Cooks and Henderson Island (Kirch et al. 1992, Weisler 1995); and Araceae and *Musa* leaf also from Henderson (Weisler 1997, Hather and Weisler 2000). Despite this growing body of evidence, however, major gaps in the Pacific record remain. In addition, human settlement of atolls is extremely underresearched (Weisler 1999).

Although ethnographic accounts are valuable sources of information, we would like to know which species were introduced where and when. The so-called "mystery islands" are particularly problematic in this respect because they were uninhabited at the time of Western contact. There are more than a score of these, typically small targets at some distance from their nearest neighbors (Irwin 1992). Given the isolation, small size, and especially resource-poor nature of these habitats (including low-nutrient soils and unpredictable water resources), it is uncertain if horticulture was practiced at all.

During an archaeological expedition to the Pitcairn Group in Southeast Polynesia in 1991–1992, sediment samples from deposits thought to be prehistoric gardening areas were collected (Weisler 1995). The project was investigating the survival of small human groups on isolated, marginal landfalls, and an island-wide archaeological survey and extensive excavations in habitation sites were conducted (Weisler 1995, 1997). In another project samples were collected in 1993–1997 from the Marshall Islands in eastern Micronesia (Weisler 1999, 2001*a*). That project was investigating the timing and nature of Araceae horticulture across the rainfall gradient in the Marshalls. Extreme remoteness is a common feature of these two distant archipelagoes. The sites presented the opportunity to test different tropical soil types in a range of environmental settings for preservation of plant microfossils and to look for direct evidence of prehistoric horticulture near the outer margins of both Polynesia and Micronesia. The outer Pacific archipelagoes were among the last habitable places on Earth to be colonized by people. These islands are ecologically fragile and often small, providing microcosms for the study of human adaptation to diverse, extreme environments. Presented here are results of recent analyses of pollen and starch residues in the sediment samples from archaeological sites in these archipelagoes.

The Study Areas, Sites, and Sample Context

MARSHALL ISLANDS. Situated in eastern Micronesia, the Marshall Islands comprise 29 atolls and five coral islands without a central lagoon aligned in two roughly parallel alignments. The climate is tropical, with the archipelago traversing a rainfall gradient from ~1,000 mm in the north to ~4,000 mm in the south. Mean annual temperature is ~27 °C. Most of the atolls and islands are currently inhabited; the two northernmost and driest atolls, Taongi (Pokak) and Bikar, are uninhabited but are visited occasionally to collect birds and turtles. Samples from two atolls were analyzed in this study: Maloelap in the center of the archipelago and Ebon in the far south. The 71 islets composing Maloelap Atoll have a total terrestrial area of 9.8 km^2. Samples from one of these islets, Kaven (2.3 km^2), were analyzed. The 22 islets of Ebon Atoll total 5.6 km^2. Samples from two of these, the largest, Ebon (2.7 km^2), and Enilok (0.4 km^2), were analyzed. Low coral atolls such as the Marshalls, usually only ca. 2–3 m above sea level, are prone to marine inundation during storms. Soils are typically humus-poor and porous, with potable subterranean water restricted to the largest islets of an atoll. Radiocarbon evidence suggests occupation from ca. 2,000 yr B.P. (Weisler 1999). Detailed site descriptions and stratigraphic context are given in Weisler (2001*a*, 2002*a*).

All samples are from prehistoric habitation or suspected horticultural areas (see Appendix). The Kaven islet (Maloelap Atoll) samples comprise samples 1–3. Samples 1 and 2 are from MLMl-3, TP9, feature 1, a suspected storage pit for *Artocarpus altilis* (breadfruit) paste. Small pits, <1 m wide and ~0.5 m deep (Weisler 2001*b*), were often used to store *Artocarpus* paste to extend the availability of this seasonal crop. Especially on drought-prone islands, food storage was an important buffer against famine, a strategy well documented in the Marquesas Islands (Handy 1923, Linton 1925). Our Marshall Islands sample 1 from Kaven islet (Maloelap Atoll) was taken from inside the pit and sample 2 outside the pit, both at 53 cmbs (centimeters below surface). The samples are stratigraphically below a 1,580 ± 80 yr B.P. date (Beta-69516 [Weisler 2001*a*]). The pit, 73 cm in diameter, had subparallel sides to a depth of 54 cm. Sample 3 is from MLMl-3, TP19, 21, and 24, buried A horizon dating to 1,910 ± 70 yr B.P. (Beta-79576 [Weisler 1999]). Because the buried A horizon was thin, sediment was taken from the sidewall of three contiguous test pits. This sample is associated with the construction of an adjacent pit currently used for cultivation of *Cyrtosperma merkusi*.

The Ebon and Enilok islet (Ebon Atoll) samples comprise samples 4–8. Samples 4–7 are from MLEb-2I, TP2 layers I, II, III, and IV, which correspond to samples 4–7 (Figure 1*A*). A 4-m-long trench was excavated through the rim of a suspected horticultural pit, and stratigraphic samples were taken from all four layers; layer III was the buried A horizon dated to 1,930 ± 40 yr B.P. (Beta-92123 [Weisler 2002*a*]), layer I the near-surface A horizon, layer II a prehistoric habitation layer, and layer IV the sterile subsoil. Sample 8 is from MLEb-38, TP2, 65 cmbs within a large pit feature measuring at least 132 cm wide and ~33 cm deep, below a date of 1,560 ± 70 yr B.P. (Beta-92134 [Weisler 2002*a*]).

PITCAIRN GROUP. The Pitcairn Group, located in Southeast Polynesia, comprises the raised coral island of Henderson, two coral atolls (Oeno and Ducie), and the Pleistocene volcanic island of Pitcairn. Only Pitcairn Island is currently inhabited. The climate is subtropical, with meteorological records from Pitcairn showing a mean annual rainfall of 1,716 mm but with considerable interannual variability, and a mean annual temperature of ~21 °C (Spencer 1995). Samples from Henderson and Pitcairn Islands, both "mystery islands" and therefore uninhabited at European contact, were analyzed in this study. Soils throughout Henderson (37.2 km^2), as on low atolls, are humus-poor, porous, and undeveloped, although at 30 m above sea level, the island is not subject to inundation. Potable water is found as cave drips following ample rains. Radiocarbon dating of all major habitation sites suggests a 600-yr Polynesian occupation sequence commencing

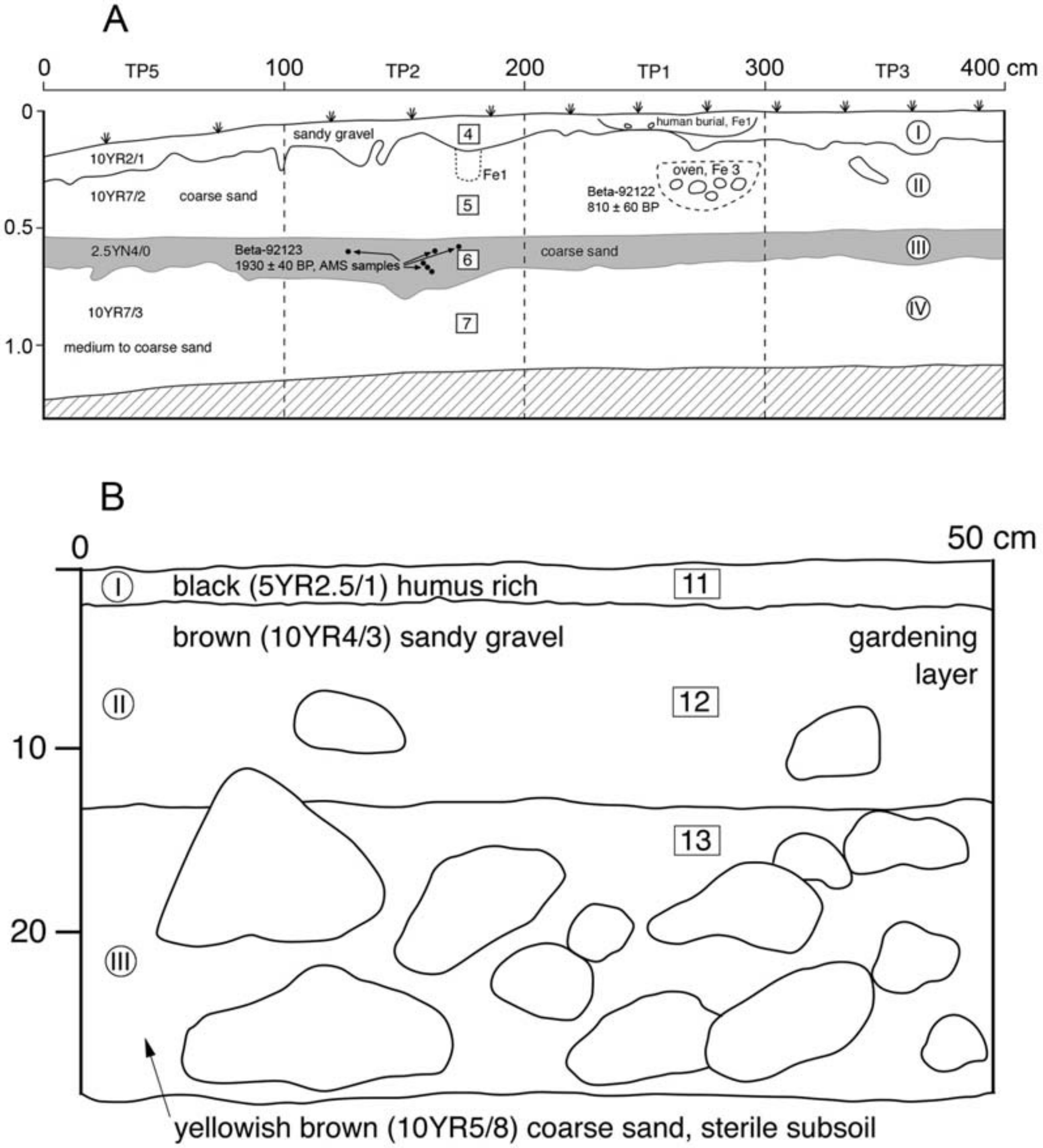


FIGURE 1. Sampled profiles from the Marshall Islands and Henderson Island in the Pitcairn Group. Sample numbers and positions are shown in boxes (see Appendix for descriptions). *A*, North profile of MLEb-2I trench, Ebon Islet, Ebon Atoll, Marshall Islands (from Weisler 2002*a*). The darkened layer III is a buried A horizon. *B*, A typical profile (TP1 North profile) showing the suspected gardening layer at site HEN-23, Henderson Island.

1,100 yr B.P. (Weisler 1995). Suspected horticultural soils in the northern and northeastern part of the island are associated with relic stands of the Polynesian introduced shrub *Cordyline fruticosa* and were sampled. The sample areas consist of soil pockets, up to 3 m across, between bedrock outcrops and stone mounds. The archaeology of Henderson Island is discussed by Weisler (1995, 1997, 1998).

Pitcairn Island (4.5 km^2) is much smaller than Henderson, although it is higher (ca. 330 m) with well-developed soils and a greater variety of habitats. There are few springs on Pitcairn, and water flows down some of the valleys after rain. Radiocarbon evidence from Pitcairn is minimal, but occupation should be similar to that at Henderson at ca. 1,100 yr B.P.; the earliest date associated with human activity is 615 ± 105 yr B.P. (Weisler 1995). Two soil profiles were sampled on Pitcairn. The first comprised stratigraphic samples taken from the east side of a small drainage at Down Fence (8 m from a walking track and bridge), thought to be the result of landscape disturbance upslope on the plateau, the main gardening area today. The second profile comprised stratigraphic samples taken at The Landing, situated at the base of a slope, ca. 3.5 m above sea level and <10 m from the water. This sequence records upland landscape change. Further details of Pitcairn Island archaeology are discussed by Gathercole (1964) and Weisler (1995).

The Henderson Island samples comprise samples 9–13. Samples 9 (layer I) and 10 (layer II) are from a suspected prehistoric gardening area (site HEN-20 [Weisler 1997]) on the north end of the plateau, just inland from site HEN-3. Samples 11–13 are from a suspected prehistoric gardening area (site HEN-23) near the northwestern edge of the plateau between rock shelter sites HEN-11 and 12 in the cliff face below (Weisler 1997) (Figure 1*B*). Layer I is recent humus, II a suspected gardening layer, and III is sterile subsoil.

The Pitcairn Island samples comprise samples 14–24. Samples 14–17 (layers I–IIIB) are from Down Fence, just inland from the northeastern coast of Pitcairn Island in a small gulch that drains from the plateau at Flatlands (Weisler 1997) (Figure 2). Layer I is an historic A horizon and II is possibly historically deposited upland clay. IIIA and IIIB are very late prehistoric or very early historic layers with dispersed macroscopic charcoal. Samples 18–24 (layers I–VII) are from The Landing, located on the west side of Bounty Bay (Figure 3). Layer I is the A horizon, layers II–IV are colluvial with minor amounts of dispersed macroscopic charcoal, layer V is a cultural deposit, layer VI has minor amounts of dispersed charcoal, and layer VII has no macroscopic charcoal.

MATERIALS AND METHODS

A total of 24 sediment samples, eight from the Marshall Islands (samples 1–8), five from Henderson Island (9–13), and the remainder (14–24) from Pitcairn Island, were taken directly from sections and examined for evidence of plant microfossils (pollen and starch residues). Descriptions and provenance of the samples are given in the Appendix. Starch residue analysis was carried out on all samples. Pollen analysis was carried out on all samples except 2, 7, and 13.

Pollen (and spores) was recovered using the standard acetylation and hydrofluoric acid method (Moore et al. 1991). The sum comprised 200 pollen and spores, and slides were scanned for types not found in the count. Relative concentrations of fragments of microscopic charcoal, recovered along with pollen, were noted subjectively.

Starch residues were recovered by density separation using the method given in the work of Horrocks (2004*b*). Presence or absence of starch residues was noted. Identification of starch residues was carried out with the aid of a modern reference collection, which includes the starch staples (see beginning of article), minor starch crops, and many of the remaining plants known to have been cultivated in the prehistoric Pacific. The many studies available on starch grain morphology were also consulted (Reichert 1913, Seidemann 1966, Hoover 2001).

The radiocarbon age determinations were carried out by Beta Analytic Inc. using standard procedures for conventional sample analysis (Weisler 1995).

RESULTS

Palynology

All except one of the samples analyzed for pollen has high concentrations of micro-

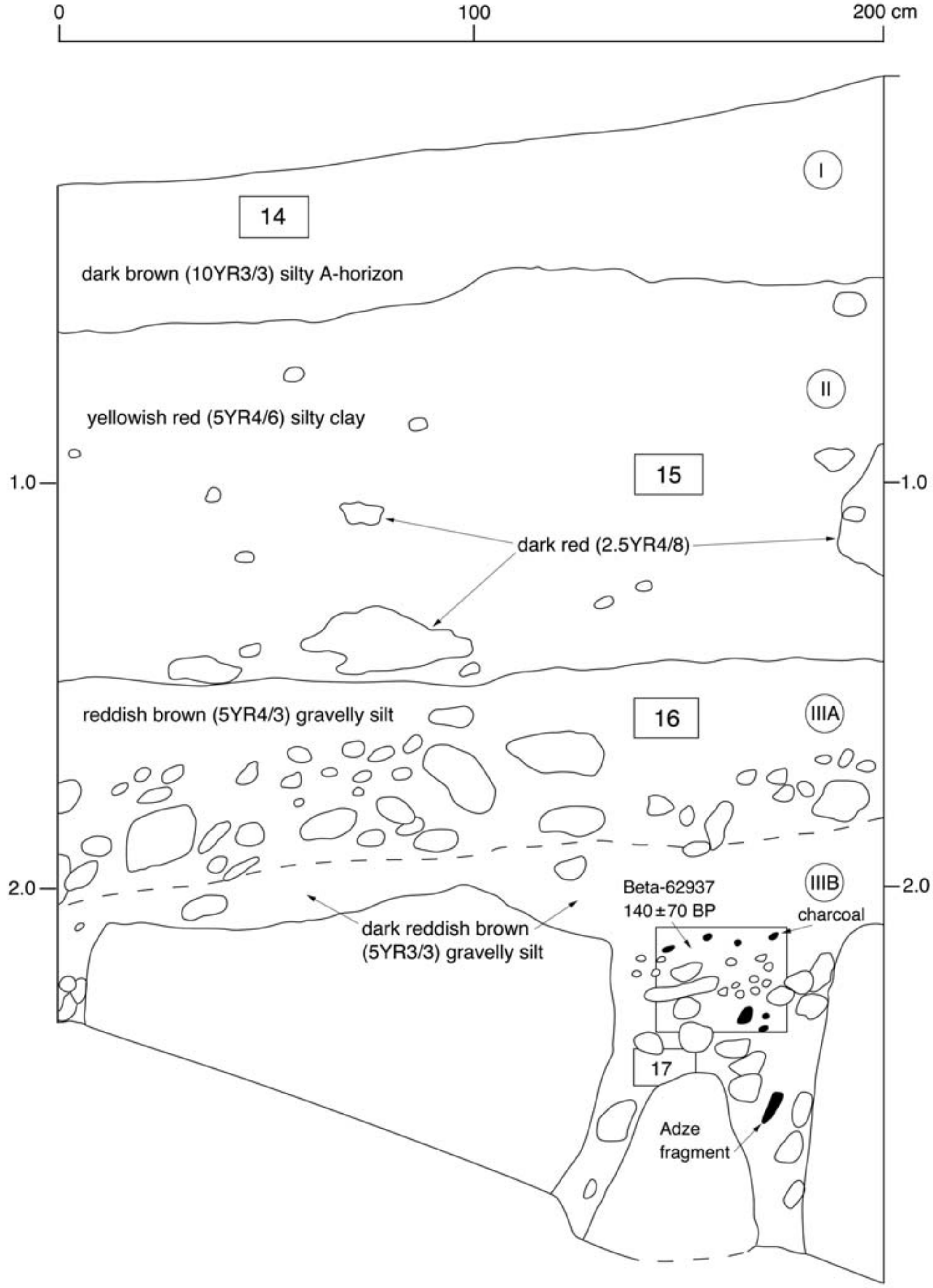


Figure 2. Sample from the East profile at Down Fence, Pitcairn Island. Sample numbers and positions are shown in boxes (see Appendix for descriptions). The late radiocarbon age determination for layer IIIB suggests rapid accumulation of overburden.

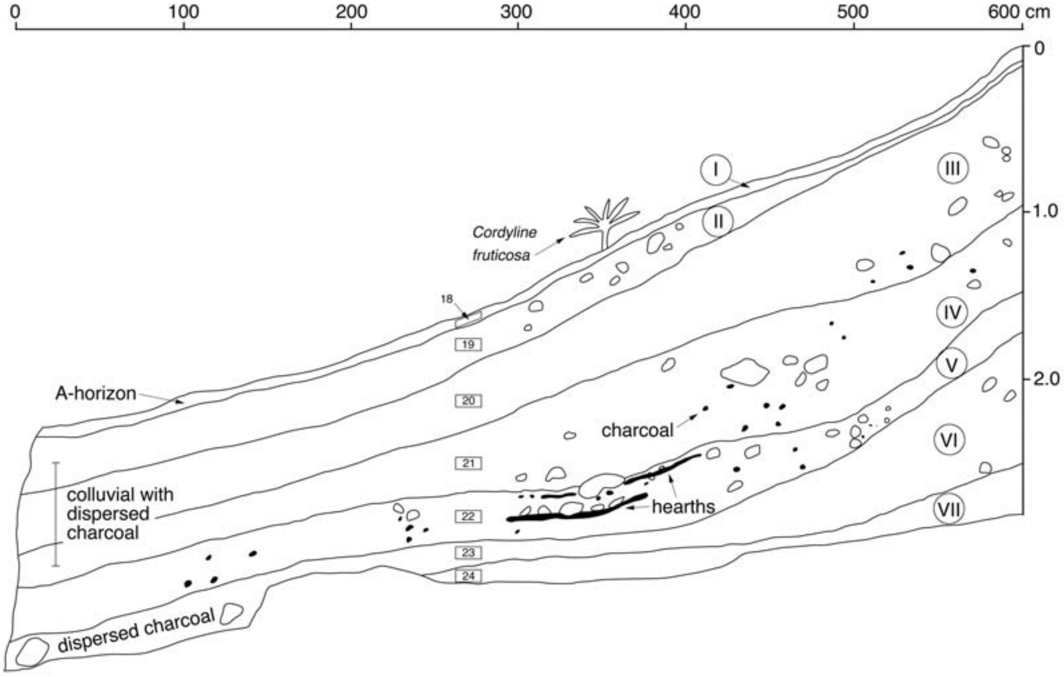


FIGURE 3. Sample from The Landing, Pitcairn Island. Sample numbers and positions are shown in boxes (see Appendix for descriptions). Much of the profile material is colluvium from upslope.

scopic charcoal. The exception, the lowermost sample of The Landing profile from Pitcairn (sample 24, Figure 3), has a relatively very low charcoal concentration. Preservation of pollen ranged from moderately good to poor. None of the samples from the Marshall Islands had sufficient palynomorphs for counting, although a few types were noted during scanning (Figure 4). Samples 9, 10, and 12 from Henderson Island contain abundant pollen, the assemblages of which are overwhelmingly dominated by monolete fern spores (both 95% psilate and 5% patterned). The monolete spores in sample 12 were too degraded to differentiate. Traces of a few other types palynomorphs were found in the Henderson samples, notably pollen consistent with *Alocasia/Amorphophallus* in sample 9 (Figure 5) and pollen of *Pandanus* in samples 9 and 10. Because the former is first reported here, modern examples are shown in Figure 6. Pollen of woody trees was not found in any of the Henderson samples.

All of the Pitcairn Island samples contained sufficient pollen for analysis (Figure 4). Like the Marshall Island samples, monolete fern spores (55–80%) dominated the palynomorph assemblages in the shorter Pitcairn profile (Down Fence), although Myrtaceae shrub (up to 25%) and *Pandanus* tree (10–15%) pollen and trilete fern spores (up to 15%) also had substantial values. In the longer Pitcairn profile (The Landing), assemblages were dominated by both monolete fern spores (30–60%) and *Pandanus* (20–55%) pollen. Small amounts of Asteraceae shrub pollen (long spine) were noted in the uppermost two samples. Pollen of several disturbance-related herbaceous taxa, notably Chenopodiaceae, Poaceae (grasses), and Cichorieae (a tribe of Asteraceae with distinctive pollen), occurs in the upper part of the profile. Cyperaceae (sedges) pollen was noted in the lowermost sample (sample 24 [Figure 3]). In addition, pollen slides of this sample show a high concentration of other plant

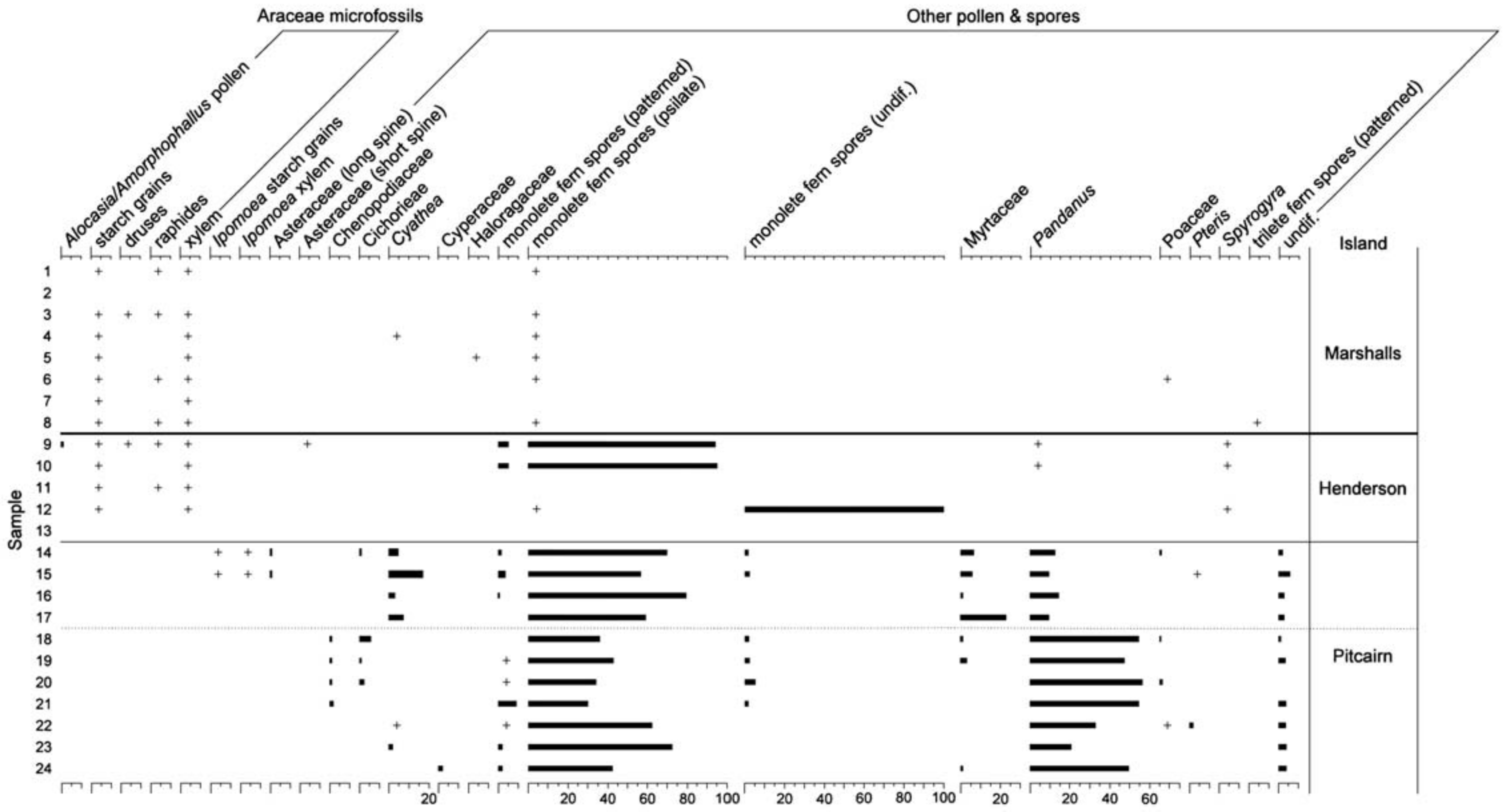


FIGURE 4. Pollen and starch residue diagram from the Marshall Islands and the Pitcairn Group (see Appendix for sample descriptions). Bars represent pollen percentages in samples with sufficient pollen for counting, + represents pollen noted after count or starch residues noted during scanning of slides, dotted line separates the shorter Down Fence profile from that of The Landing.

material, which although degraded appears to comprise mainly sclerenchyma cells (not found in any of the other pollen samples in this study). Pollen of woody trees was not found in any of the Pitcairn samples.

Starch Residue Analysis

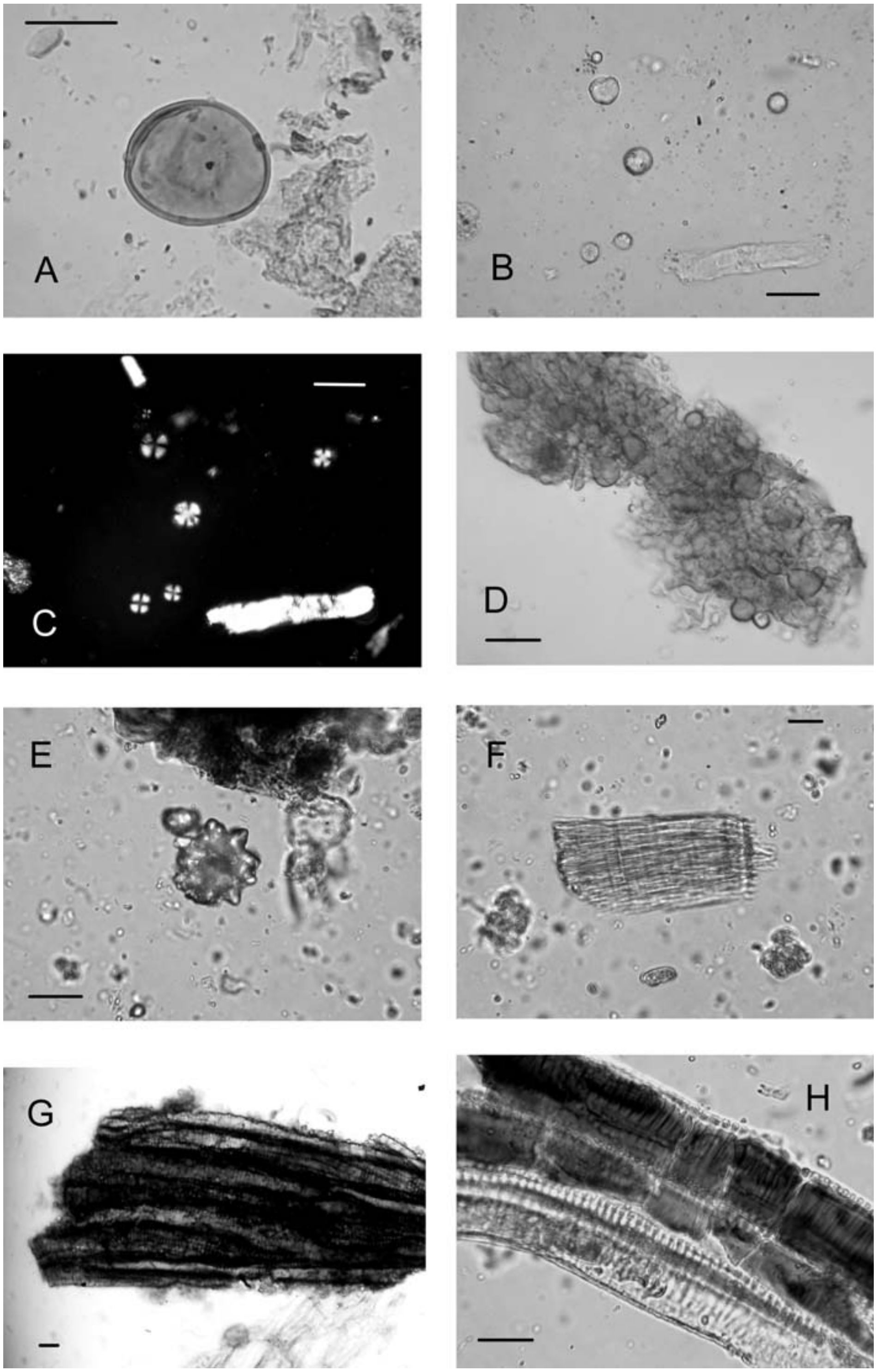
In 13 of the samples examined for starch residues we identified a range of starch residue types (Figure 4). Two of the samples not yielding starch residues, samples 2 (outside pit, Marshalls) and 13 (sterile subsoil, Henderson [Figure 1*B*]), were virtually devoid of any organic material. In the Marshalls and Henderson samples, starch residues comprise spherical to subspherical starch grains, calcium oxylate crystals (raphides and druses), and xylem vessels with helical walls (Figures 5 and 7). Residues in the Pitcairn samples are different, comprising ovate to subtriangular, often bell-shaped starch grains, with a vacuole at the central hilum, fissured in larger grains, and xylem vessels with slitlike pits (Figure 8). Calcium oxylate crystals were not found with the starch grains and xylem in the Pitcairn samples.

Preservation of the starch residues ranged from good to poor. The starch grains were present individually or attached to cellulose tissue and many showed signs of gelatinization: discoloration, swelling, and loss of birefringence. The color change is from colorless to shades of amber or brown (Horrocks et al. 2004*a*). Most xylem vessels were also discolored. Xylem was present as bundles of vessels or fragments of vessel elements. Raphides were present mostly embedded in cellulose tissue and occasionally in bundles and as individual fragments.

The starch residues in the Marshall Islands–Henderson Island samples have a combination of attributes that occur in the Araceae, a family of mainly herbaceous plants with aerial or underground stems or rhizomes, often swollen as an adaptation for starch storage (e.g., corms, rhizomes [all commonly referred to as tubers]). [Photomicrographs and descriptions of microparts of modern reference samples of Araceae are given in the works of Loy et al. (1992), Horrocks (2004*a*), and Horrocks et al. (2004*b*)]. This is based on starch grain and xylem vessel morphology, and raphide concentration. (Starch grains are highly concentrated in the tubers, whereas calcium oxylate crystals and xylem are found throughout the plant, with raphides in particular often in very high concentrations.) Although xylem with helical wall thickening may be found in other taxa, this was virtually the only type of xylem found in the samples. However, xylem vessels (and druses) of the four cultivated Pacific Araceae are difficult to distinguish between species.

The following rationale for Araceae microfossil identification is from the work of Horrocks and Bedford (2005). Of the four Araceae, *Colocasia esculenta* can be differentiated from the other three on the basis of size of starch grains (Loy et al. 1992). The former has a mean grain size of <5 μm (most grains are <3 μm) whereas *Alocasia macrorrhiza*, *Cyrtosperma merkusii*, and *Amorphophallus paeoniifolius* have mean grain sizes of 10–14 μm. However, overlap in standard deviations within this "non-*Colocasia*" group, together with degradation and possible swelling of fossil grains due to gelatinization, makes differentiation to species on this basis in our case unreliable.

The four Pacific Araceae each have several types of raphide. However, the types produced in the most abundance, "whisker raphides" (Loy et al. 1992), are difficult to distinguish between species. Fragmentation and degradation exacerbate the problem of raphide differentiation. Types distinctive to species are produced in relatively far lower amounts, and none of these was identified with certainty in either the Marshall Islands or Henderson Island samples. Thus, on the basis of morphology of microfossils found in the samples, we cannot confidently distinguish between the four Araceae species. However, notwithstanding swelling of grains, *Colocasia esculenta* can almost certainly be ruled out for the starch grains shown in Figures 5 and 7, typical of those found in the samples, on the basis of size. Although some of the very large, discoloured grains we classify as swollen (Figure 7*D*) are within the size range of several *Dioscorea* species (mean grain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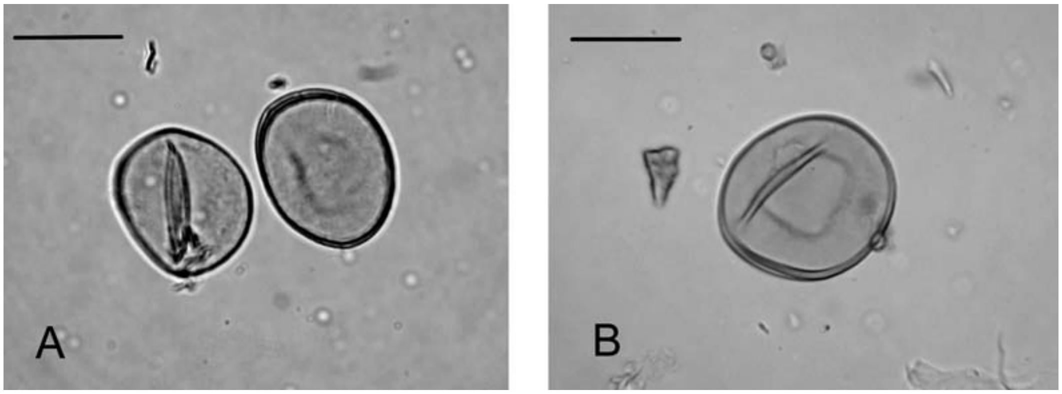

Figure 6. Pollen grains (acetylized) of *A*, *Alocasia macrorrhiza* and *B*, *Amorphophallus paeoniifolius* from modern reference samples. Acetylized pollen grains of these two species of Araceae are difficult to differentiate from each other but usually can be differentiated from those of the remaining two Pacific aroids: *Colocasia esculenta* and *Cyrtosperma merkusii.* Both of the former are inaperaturate, spherical to subspherical, 32–42 μm in diameter, exine <2.5 μm thick, and psilate. Because Araceae pollen in general does not resist acetolysis (Thanikaimo 1969), acetylized grains can appear different than untreated grains. Although acetylized and untreated grains of *C. esculenta* are echinate and those of *C. merkusii* monosulcate, *un*acetylized grains of *A. macrorrhiza* are echinate; the spines are destroyed by acetolysis.

size of >30 μm), we can also rule these out because we did not find any grains with the characteristic eccentric Maltese cross of this genus.

The starch residues in the Pitcairn samples have a combination of attributes that occur in *Ipomoea*, a genus of twining prostrate or scrambling herbs, often lianoid. Starch residues of different species of *Ipomoea* are difficult to differentiate. [Photomicrographs and descriptions of microparts of modern reference samples of *Ipomoea* are given in the works of Loy et al. (1992), Horrocks (2004*a*), and Horrocks et al. (2004*a*)]. Although other taxa have xylem vessels similar to those of *Ipomoea* (slitlike pits), this was the only type of xylem vessel found in the samples. Several species of indigenous and introduced *Ipomoea* are found throughout the Pacific. The latter includes *Ipomoea batatas*, introduced in prehistoric times and cultivated for its tuberous roots.

DISCUSSION

The microfossil data from the Marshall Islands and Henderson Island provide direct evidence of introduced Araceae crops. The Araceae have a long history throughout the tropics and subtropics as a subsistence starch food, with many species cultivated. The four introduced Pacific Araceae (*Colocasia esculenta*, *Alocasia macrorrhiza*, *Cyrtosperma merkusii*, and *Amorphophallus paeoniifolius*) originated in the Indo-Malayan region (Croat 1979, Hay 1990). The natural distribution of terrestrial Araceae in Oceania extends east as far as Vanuatu, and one widespread *Rhaphidophora*

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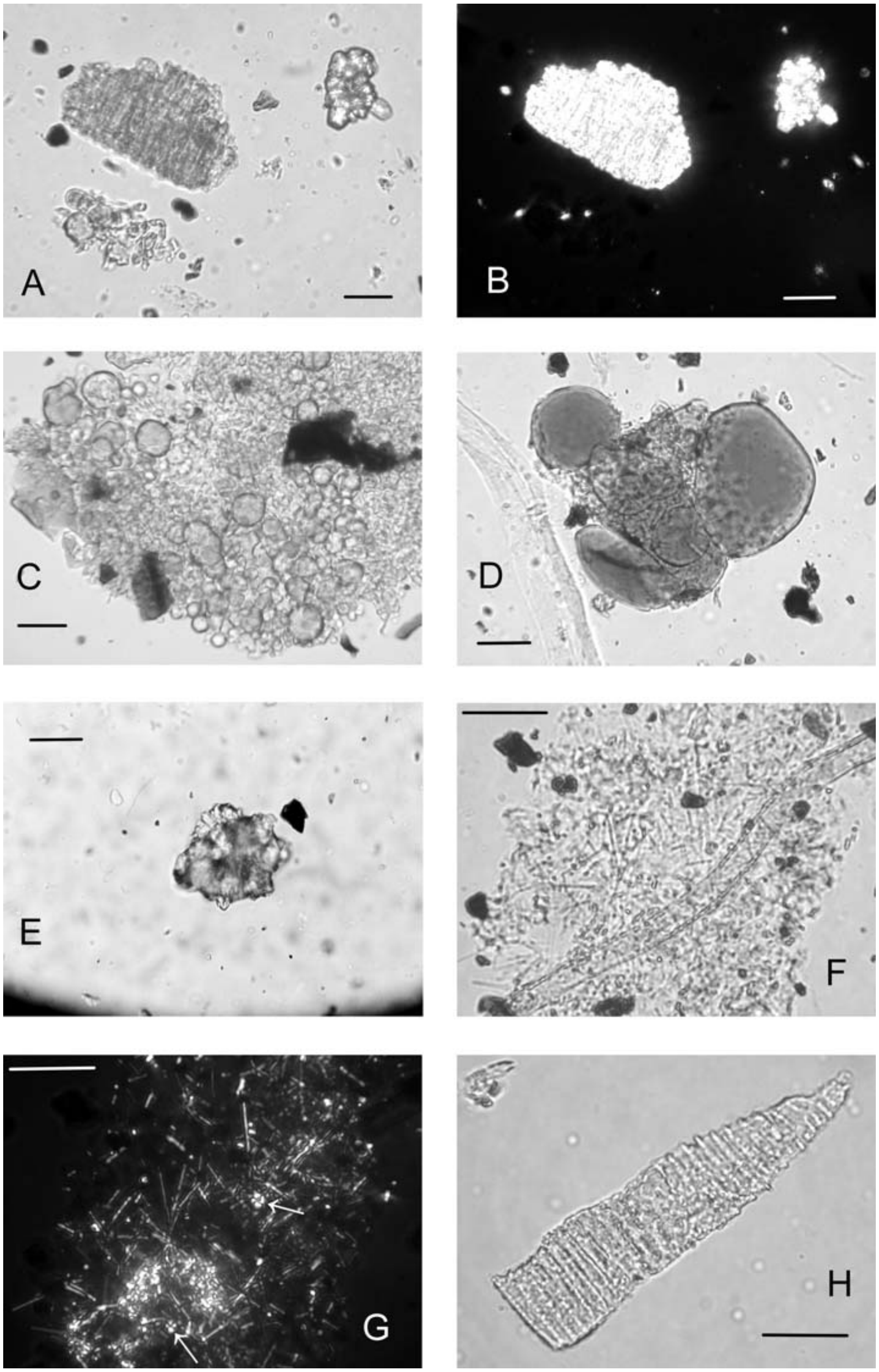
Figure 5. Prehistoric microfossils consistent with introduced Araceae from Henderson Island (*B*, *C* mounted in Caedex, a resinous mounting agent; remainder mounted in glycerol jelly, an aqueous agent). *A*, Pollen grain (acetylized) of *Alocasia macrorrhiza* or *Amorphophallus paeoniifolius* from sample 9 (cf. Figure 6). *B*, Spherical to subspherical starch grains from sample 10. *C*, Spherical to subspherical starch grains from sample 10 (those in *B*) viewed under cross-polarized light, showing Maltese crosses due to birefringence (a feature of all starch grains). The elongated objects are fragments of other plant material. *D*, Gelatinized spherical to subspherical starch grains in cellulose tissue from sample 9. *E*, Druse (starlike) from sample 9. *F*, Bundle of raphides (hundreds) from sample 11. *G*, Large bundle of degraded xylem vessels from sample 10. *H*, Bundle of degraded xylem vessels from sample 9, showing helical wall thickening. Scale bars, 20 μm.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climber extends to Samoa (A. Hay, pers. comm.). All other Pacific islands have introduced Araceae.

The starch-residue evidence from the Marshalls and Henderson indicates that the Araceae crops were non-*Colocasia* (i.e., *Alocasia macrorrhiza*, *Cyrtosperma merkusii*, or *Amorphophallus paeoniifolius*) and for Henderson the pollen evidence allows this to be further narrowed down to *Alocasia* or *Amorphophallus*. Associated radiocarbon dates suggest first settlement of Henderson Island ca. 1,200 yr B.P., at the earliest (Weisler 1999). As reported by Thompson (1982), the modern distribution of *Alocasia* and *Amorphophallus* places their farthest east occurrence in the Marquesas Islands. We know from the previous identification of macrofossil leaf material (ca. 500 yr B.P.) from a rock shelter that *Cyrtosperma* was also present on Henderson (Hather and Weisler 2000). As suggested by Hather and Weisler (2000), the presence of fossil Araceae on Henderson suggests agrarian practices in the Pacific that may now be only locally isolated but may have been of considerable importance in the past. *Cordyline fruticosa* was also introduced by early Polynesians for cultivation; relic plants are found on the island today, rare on the plateau ridge (Florence et al. 1995, Waldren et al. 1999). With the addition of *Aleurites moluccana*, reported growing on Henderson in 1912 and 1922 (Paulay and Spencer 1989) and recovered from prehistoric habitation sites dated to as early as 700 yr B.P. (Weisler 1997), *Musa* sp. dated to 600 yr B.P. (Weisler 1997), *Cocos nucifera* (coconut) dated to 1,000 yr B.P. (Weisler 1997), and *Pandanus tectorius* (see later in this section), there is combined evidence of a horticultural system comprising both field and tree cropping, with seven different cultigens, five of which are unequivocally introduced, including at least two species of the Araceae. Horticultural diversity would almost certainly have been advantageous in such a marginal, barren habitat.

The identification of Araceae microfossils in the ancient small pit (sample 1) from the Marshall Islands was unsuspected because similar pits are routinely used today for preserving *Artocarpus* paste. (Araceae tubers can probably be stored in subterranean pits for short periods of time, but the identification of Araceae macrofossils inside but *not outside* the pit provides strong evidence for the presence of the latter.) Although *Cyrtosperma* is the dominant aroid cultivated in the Marshalls today, we cannot rule out the possibility that other non-*Colocasia* species of the Araceae were present in the pit; the microfossil evidence in our case cannot differentiate between the three members of this group, *Cyrtosperma*, *Alocasia*, and *Amorphophallus*. The combined micro- and macrobotanical evidence from Henderson indicates local cultivation of both *Alocasia* and *Cyrtosperma* or at least transport of leaves (for wrapping parcels) and tubers. The lack of starch residues of other carbohydrate crops such as *Dioscorea* and *Ipomoea* in the Marshall Islands samples suggests that Araceae was the common cultigen. Pollen of another cultivated member of the Araceae, *Colocasia esculenta*, has been reported elsewhere in the Marshall Islands, west of Maloelap on Kwajalein Atoll (ca. 1,900–1,600 yr B.P. [Beardsley 1994]). Virtual absence of organic material from the sample from the sterile subsoil on Henderson (sample 13, Figure 1*B*), which is overlaid by layers of high organic matter content, sug-

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FIGURE 7. Prehistoric microfossils consistent with introduced Araceae from the Marshall Islands (mounted in glycerol jelly). *A*, *Clockwise from lower left:* gelatinized spherical starch grains in cellulose tissue, fragment of degraded xylem vessel element showing helical wall thickening, and druse from sample 3. *B*, Fragment of degraded xylem vessel element (*left*) showing helical wall thickening and druse from sample 3 (those in *A*), highly visible under cross-polarized light. The starch grains are not visible, having lost their birefringence due to gelatinization. *C*, Spherical to subspherical starch grains in cellulose tissue from sample 6. *D*, Clump of gelatinized starch grains from sample 3 showing extreme swelling. *E*, Druse from sample 3. *F*, Raphides (needlelike) in cellulose tissue from sample 1. The thick elongated object is a fungal hypha. *G*, Raphides (needlelike) in cellulose tissue from sample 1 (those in *F*) highly visible under cross-polarized light. Note also small starch grains showing Maltese crosses (arrows). *H*, Degraded fragment of xylem vessel element from sample 7. Scale bars, 20 μm.

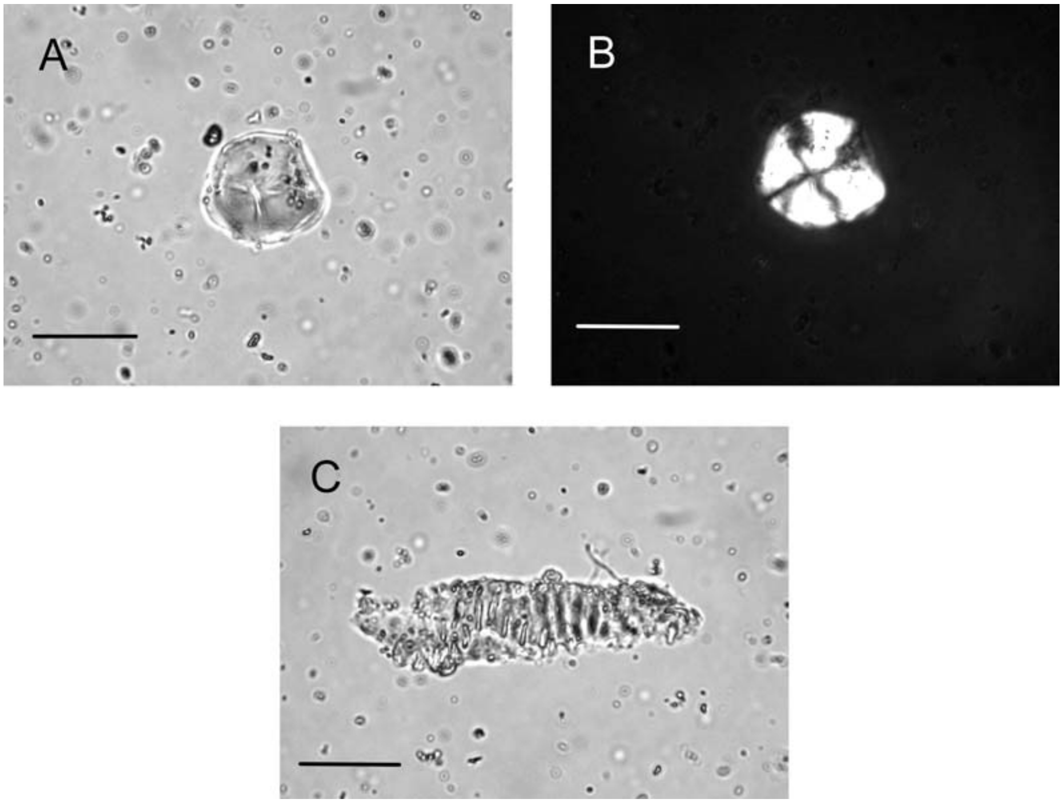

Figure 8. Microfossils consistent with *Ipomoea* from Pitcairn Island (mounted in glycerol jelly). *A*, Ovate to subtriangular starch grain from sample 15, showing central vacuole, fissure at the central hilum, and flattened pressure facets. *B*, Ovate to subtriangular starch grain from sample 15 (that in *A*) viewed under cross-polarized light, showing Maltese cross. *C*, Degraded fragment of xylem vessel element from sample 15, showing alternate slitlike pits. Scale bars, 20 μm.

gests that downward movement of microfossils in these soils by percolating rainwater has been minimal.

Unlike the Araceae microfossils on the Marshalls and Henderson, the *Ipomoea* microfossils in the Down Fence profile from Pitcairn are equivocal regarding Polynesian cultivation of introduced *Ipomoea batatas* because of indigenous species of this genus. Cummings (1998) reported possible *Ipomoea* starch granules at a site on Easter Island thought to be agricultural. *Ipomoea macrantha*, which occurs throughout the Pacific near sea level or at low elevations on beaches, arid shores, lagoon cliffs, and in thickets (Smith 1991), is indigenous to Pitcairn (and Henderson) Island (Florence et al. 1995). Its current distribution is rare at one coastal station at Bounty Bay (on Henderson it is moderately common in coastal *Argusia* scrub). However, given that *I. macrantha* does not have tuberous roots, is not reported as being cultivated by early Polynesians, is found in only the two upper layers of a five-layer profile, and would possibly have found the elevation of the site unsuitable (Down Fence is >100 m above sea level), the presence of *Ipomoea* starch residues in heavily disturbed anthropogenic soils points to the cultivation of *I. batatas*. A single radiocarbon age determination suggests that anthropogenic landscape disturbance was well under way by late prehistory (i.e., 300 yr B.P. [Weisler 1995]). However, we do not know if the *Ipomoea* starch horizons extend into prehistory. The upper of the two layers in which the starch was found (layer I, sample 14; Figures 2 and 4) also contains historic artifacts but the lower layer (layer II, sample 15) does not and therefore may be prehistoric. Microfossil starch of *I. batatas* has been identified at a number of prehistoric Polynesian sites in New Zealand (Horrocks 2004*a*), as have macrofossils (e.g., Yen and Head 1993). Other direct, unequivocal prehistoric evidence of this crop in Polynesia is the pollen from the Society Islands (ca. 1,150 yr B.P. [Parkes 1997]) and Easter Island (ca. 700–300 yr B.P. [Cummings 1998]) and the macroremains from the Cook Islands (ca. 1,000 yr B.P. [Hather and Kirch 1991]) and Hawai'i (ca. 500 yr B.P. [Rosendahl and Yen 1971]). Lack of starch residues in The Landing profile from Pitcairn suggest that if that area was gardened, starch crops did not feature.

The lack of pollen in the samples from the Marshall Islands is presumably a result of poor pollen preservation. Compared with silt or clay soils, coarser-textured soils such as coral sands and gravels are typically pollen-poor. The three Henderson Island samples that contained sufficient pollen for counting were from coralline sediments and had relatively high levels of organic matter.

The extremely high values of fern spores coincident with microscopic charcoal and the apparent absence of pollen of woody trees in the Henderson Island samples (Figure 4) suggest at least a partially deforested, disturbed landscape, at least near the sampled sites, with extensive areas of fernland. Henderson has nine indigenous species of ferns, comprising epiphytic, epilithic, and terrestrial forms (Florence et al. 1995). Some *Pandanus* trees would have grown or perhaps been cultivated in the vicinity of the site of samples 9 and 10, which, along with at least two species of Araceae, may have been part of a mixed cropping system. Two forms of *P. tectorius* (possibly involving Polynesian cultivars) occur on the island and are very common throughout, often forming small groves (Florence et al. 1995). As with other taxa known to be used by Polynesians, it is not clear whether it is indigenous, introduced, or (perhaps most likely) both. The Asteraceae pollen in sample 9 would have come from the indigenous *Senecio stokesii*, one of two shrub species of this family on the island, now common in open communities (although see later in this section regarding Polynesian introductions to Pitcairn). Pollen of the other species, the endemic *Bidens hendersonensis* var. *hendersonensis*, has longer spines (Florence et al. 1995), allowing the two to be differentiated.

As with Henderson Island, the pollen assemblages from Pitcairn (Figure 4) also suggest a disturbed landscape with extensive fernland, deforested by fire. The late radiocarbon age determination for layer IIIB, Down Fence, at 140 ± 70 yr B.P., from ~2.25 m below surface (Figure 2), suggests a rapid accumulation of the overburden, and the colluvial nature of The Landing profile (Figure 3) also indicates large-scale erosion, consistent with human modification of the uplands. Pitcairn Island has 16 or 17 indigenous and two endemic species of ferns, including epiphytic, epilithic, and terrestrial forms (Florence et al. 1995). As well as plentiful ferns, abundant *Pandanus* trees were also present near the two Pitcairn sites, especially The Landing, and as on Henderson, perhaps cultivated. There are currently no radiocarbon age determinations for The Landing profile. However, assuming that Pitcairn was abandoned at a similar time as Henderson (ca. 500 yr B.P.), prehistoric artifacts (basalt flakes) in layer V (sample 22 [Figure 3]) are at least several centuries old. Today *Pandanus tectorius* is found on Pitcairn along the strand line at West Harbour (Waldren et al. 1995). Along with ferns and *Pandanus*, the vegetation in the vicinity of the Down Fence site also would have comprised Myrtaceae shrubs and *Cyathea* tree ferns. There are two indigenous Myrtaceae species on Pitcairn: *Metrosideros collina* and *Eugenia reinwardtiana* (Florence et al. 1995). The often poor preservation of the Mytaceae pollen in the samples did not allow confident differentiation between these two taxa. Today the former occurs occasionally on dry crests and slopes in open communities; the latter is rare on coastal cliffs at Bounty Bay. *Syzygium malaccensis* (Malay apple), a cultivated tree introduced by humans throughout the Pacific, should also be considered as a possible source of the fossil

Myrtaceae pollen. The indigenous *Cyathea medullaris* is the only tree fern in the Pitcairn Group flora (Florence et al. 1995). Today it is rare below the summital crest in a disturbed *Metrosideros/Homalium* forest and very rare elsewhere on Pitcairn.

The relatively low concentration of charcoal and high concentration of plant material (sclerenchyma cells) in the lowermost sample of The Landing profile from Pitcairn (sample 24 [Figure 3]) suggests initial human impact on the island. The plant material in that layer may be from vegetation growing on the soil at the time, which was subsequently buried by upslope erosion. The presence of pollen of the disturbance indicators Chenopodiaceae, Poaceae, and Cichorieae in the upper part of the profile (Figure 4) suggests vegetation succession, a result of progressive increase in the frequency or intensity of the disturbance regime. Cichorieae in particular is a universally common pollen indicator of human disturbance of vegetation. Only one indigenous species of Poaceae is recorded for Pitcairn: *Lepturus repens*, today rare in coastal vegetation at Bounty Bay (Florence et al. 1995).

The Chenopodiaceae, Cichorieae, Cyperaceae, and *Pteris* pollen evidence from Pitcairn is interesting because indigenous species of these taxa were not recorded in a recent vegetation survey of the island (Florence et al. 1995), suggesting Polynesian introduction, probably accidental. *Atriplex* and *Chenopodium* species are likely candidates for Chenopodiaceae; *Cyperus*, *Mariscus*, and *Fimbristylis* for Cyperaceae; *Woolastonia biflora* for Cichorieae; and *P. tripartita* and perhaps *P. vittate* for *Pteris* (Smith 1991; J. Braggins, pers. comm.). Another possibility is that taxa of these pollen types were native to Pitcairn, becoming extinct during Polynesian occupation. This could be the case for Cyperaceae, pollen of which was found only in the earliest, lowermost sample. However, Chenopodiaceae, Cichorieae, and *Pteris* are typically disturbance related and therefore would presumably not be adversely affected by human activity. A pollen study from Norfolk Island in the Southwest Pacific showed that some putative exotics were part of the native flora long before the earliest recorded Polynesian settlement (Macphail et al. 2001). At this stage we cannot determine this for Pitcairn, because neither of our pollen profiles appears to include prehuman times.

CONCLUSIONS

The identification in this study of microfossils of cultigens (at least for the Marshalls and Henderson) in soils of all three Pacific island types (atolls, raised atolls, and volcanic islands) and in two far-distant archipelagos in Micronesia and Polynesia shows the potential for this type of analysis in Oceania and elsewhere. Araceae evidence is unequivocal because of absence of indigenous members of this family from most of the Pacific. However, at this stage it is difficult to differentiate the non-*Colocasia* Pacific Araceae preserved in the types of deposits analyzed in this study. The problem of differentiating individual species within the same group also applies to *Ipomoea*, indigenous species of which are widespread in the Pacific. A possible solution would be analysis of plant DNA preserved in soils. Extremely low pollen concentrations in some coral sediment samples, in our case from the Marshalls, could probably be overcome by analyzing larger-volume samples (e.g., by using a 10- to 15-cm^3 sample instead of the standard 1- to 3-cm^3 volume). The identification of starch residues of cultigens in these pollen-poor samples shows the value of combining the different types of microfossil analysis.

The geographically marginal and environmentally depauperate islands of the eastern Pacific challenged human colonists to their limits. Although previously uninhabited islands, with their pristine stocks of fish, shellfish, turtles, and seabirds, would have attracted colonists, sustained occupation required some level of horticulture or regular contact with larger, more diverse islands for needed resources (Weisler 1997, 2002*b*). The documentation of a mixed cropping regime on Henderson Island in Southeast Polynesia implies a more permanent and sustained presence on the island. The Marshall Islands of eastern Micronesia, although permanently occupied for about two millennia (Weisler 1999), were nevertheless precarious landscapes for sustained human settlement.

ACKNOWLEDGMENTS

We thank C. Salvador, Leng Guan Saw, E. Cameron, and B. Sykes for plant reference material.

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Appendix

Description and Provenance of Samples

Marshall Islands

1: Kaven Islet, Maleolap Atoll, inside small pit. A dark gray (5Y4/1) medium to coarse sand with abundant prehistoric artifacts.

2: Kaven Islet, Maleolap Atoll, outside small pit. A dark gray (5Y4/1) medium to coarse sand with abundant prehistoric artifacts.

3: Kaven Islet, Maleolap Atoll, buried A horizon. A very dark grayish brown (10YR3/2) to very pale brown (10YR8/3) slightly gravelly sand to sand with rare charcoal flecks.

4: Ebon Islet, Ebon Atoll, layer I. A black (10YR2/1) sandy gravel, organic-rich cultural layer with historic and prehistoric artifacts.

5: Ebon Islet, Ebon Atoll, layer II. A light gray (10YR7/2) coarse sand.

6: Ebon Islet, Ebon Atoll, layer III buried A horizon. A dark gray (2.5YN4/0) coarse sand with dispersed charcoal flecks. This layer was dated to 1,930 ± 40 yr B.P. (Beta-92123 [Weisler 2002*a*]).

7: Ebon Islet, Ebon Atoll, layer IV. A very pale brown (10YR7/3) medium to coarse sand.

8: Enilok Islet, Ebon Atoll, within large pit. A black (2.5YN2/0) sandy sediment. A radiocarbon age determination of 1,560 ± 70 yr B.P. (Beta-92134 [Weisler 2002*a*]) caps the sample.

Henderson Island

9: Layer I, suspected gardening area. A very dark brown (10YR2/2) humus-rich, silty A horizon with very little sand and dense roots.

10: Layer II, suspected gardening area. A dark yellowish brown (10YR3/4) gravelly silt with rare charcoal flecks.

11: Humus (layer I). An A horizon consisting of a black (5YR2.5/1) humus-rich sand and decomposed coral gravel layer.

12: Suspected gardening layer (layer II). A brown (10YR4/3) sandy gravel with dispersed charcoal.

13: Sterile subsoil (layer III). A yellowish brown (10YR5/8) coarse-sand sterile subsoil with very little coral.

Pitcairn Island

14: Layer I, Down Fence. A dark brown (10YR3/3) silty A horizon with historic artifacts.

15: Layer II, Down Fence. A yellowish red (5YR4/6) silty clay with dark red (2.5YR4/8) saprolites, few cobbles, and minor amounts of dispersed charcoal.

16: Layer IIIA, Down Fence. A reddish brown (5YR4/3) gravelly silt with dispersed charcoal and abundant cobbles.

17: Layer IIIB, Down Fence. A dark reddish brown (5YR3/3) gravelly silt with minor dispersed charcoal and abundant cobbles.

18: Layer I, The Landing. A brown (10YR4/3) silty clay A horizon with no charcoal.

19: Layer II, The Landing. A yellowish red (5YR4/6) silty clay with cobbles and no charcoal.

20: Layer III, The Landing. A brown (10YR4/3) silty clay with dispersed charcoal and few cobbles.

21: Layer IV, The Landing. A reddish brown (5YR4/4) silty clay with dispersed charcoal and cobbles.

22: Layer V, The Landing. A brown (10YR4/3) silty clay prehistoric cultural layer with dispersed charcoal, basalt flakes, and combustion features.

23: Layer VI, The Landing. A yellowish red (5YR4/6) silty clay with rare dispersed charcoal and cobbles.

24: Layer VII, The Landing. A reddish brown (5YR4/4) clay.