Ballard et al. (2005) have recently reviewed the dispersal and impact of the sweet potato (*Ipomoea batatas* (L.) Lam.) in the Pacific Islands. Contributors to the volume note the huge impact that this plant had on a number of islands in Near and Remote Oceania. With regard to Polynesia, Green (2005) reviewed the evidence for sweet potato before and at the time of early European contact and proposed that it was a secondary introduction to central East Polynesia, arriving some time around the 11th to 12th centuries A.D. For Hawai‘i, the earliest direct date for sweet potato until recently was some time in the late 15th to late 17th centuries. Charcoal fragments that appear to derive from a piece of carbonised sweet potato and excavated from an inland area of the Kohala Field System date to an earlier time period centred in the 14th century. These results have implications for ascertaining when the crop was first introduced to Hawai‘i and for understanding its rapid dispersal into interior leeward areas of the archipelago.
sweet potato was recovered. The lower layer produced a calibrated date range of 988-1155, and the upper layer produced a calibrated date range of 1409-1440. The sweet potato sample from unit F10 is bracketed by calibrated date ranges of 1162-1280 and 1327-1438. These dates would suggest a conservative estimate for the earliest sweet potato remains in Mangaia of c.1000 to 1440, or perhaps an estimate of 1200 to 1300 if the dates from above and below the sweet potato remains are interpolated. Green (2005:50) cites Kirch (pers. comm. 2002) for additional not yet published 14C dates from the site as indicative of a 1000 estimate for the sweet potato remains in unit E10, level 11, and maintains that a date of 1000-1100 is a good estimate for the introduction of sweet potato to Mangaia. Green (2005) suggested the sweet potato

Figure 1. The Kohala Field System and the location of sweet potato remains found in the area.
was transferred from the “central ellipse region” to Rapa Nui via Mangareva no earlier than 1100 (cf. Wallin et al. 2005, who suggested a date of 1200-1300), to New Zealand via Mangaia with the original colonists around 1150 to 1250 and to Hawai’i via the Marquesas by 1100 to 1200.

Hommon (1976) and Kaschko and Allen (1978) were among the earliest to suggest that sweet potato was a secondary introduction to the Hawaiian archipelago and did not come with the first colonists. Rosendahl and Yen (1971:283) reported the charred remains of a sweet potato found in a fireplace feature of a field shelter in Lapakahi in the Kohala Field System (Fig. 1). The tuber was embedded in an ash layer that contained charcoal, which produced a $^{14}$C age of 295 ± 90 b.p (Table 1, Fig. 2). Calibrating the date produces a 2-sigma calendar date of 1400 to 2000 A.D. and a 1-sigma calendar date with a 65.7% probability within the 1470 to 1670 A.D. range. Allen (1981:81, 150) tentatively identified with a “confidence” level of “poor” a piece of sweet potato “tuber skin” from the upper layers (I, II and II/III) of Ko‘oko‘olau Rockshelter on Mauna Kea near the adze quarry at an elevation of 3780m. The layer (IV) below the layer containing the tentatively identified sweet potato skin dates to a 2-sigma calibration range of 1400 to 1700 A.D. (93.7%) and 1750 to 1800 A.D. (1.7%) (see Table 1 and Fig. 2). A charred fragment of sweet potato (identification based on unspecified criteria) was found during excavations of residential sites in the Waimea area, South Kohala, Hawai’i Island (Clark 1983a). This fragment came from Site 50-10-06-8803, Feature A, which is a large U-shaped structure that is part of a residential complex located nearly 16km from the coast and at an elevation of nearly 800m above sea level. Within Feature A there was an “oven” (Feature A.5) that extended from 22 to 47cm below ground surface and contained charcoal, Chenopodium seeds, shellfish, bird and fish remains, and a carbonised sweet potato fragment. An uncorrected date of 300 ± 80 b.p. (BA-3584) was returned on the charcoal from the oven (Clark 1983b:320), which has a 2-sigma calibration range of 1400 to 1850 A.D. (92.1%) and 1900 to 2000 A.D. (3.3%) (see Table 1 and Fig. 2).

![Figure 2](image_url)

Figure 2. Calibrations of radiocarbon dates associated with sweet potato remains in Hawai’i. Brackets below probability curves show 2-sigma calendar age ranges.
Table 1: Radiocarbon determinations associated with sweet potato remains in Hawai‘i

<table>
<thead>
<tr>
<th>SHPD Site Number</th>
<th>Provenance</th>
<th>Sample number*</th>
<th>$^{14}$C BP</th>
<th>$^{13}$C adjusted</th>
<th>2 sigma calibration (all dates are A.D.)</th>
<th>Dated material/association</th>
<th>Location</th>
<th>Citation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trench 50</td>
<td></td>
<td>B-208143</td>
<td>580+/-40</td>
<td>580+/-40</td>
<td>1290 to 1430 (95.4%).</td>
<td>cf. Ipomoea fragment</td>
<td>Kahua 1, Hawai‘i</td>
<td>Allen 1981, Table 8</td>
</tr>
<tr>
<td>50-Ha-G28-14-R1</td>
<td>Layer IV</td>
<td>HRC-279</td>
<td>355+/-80</td>
<td></td>
<td>1400 to 1700 (93.7%); 1750 to 1800 (1.7%).</td>
<td>Charcoal from layer below Ipomoea fragment</td>
<td>Mauna Kea, Hawai‘i</td>
<td>Rosendahl and Yen 1971</td>
</tr>
<tr>
<td>Feature 4727</td>
<td></td>
<td>I-4400</td>
<td>295+/-90</td>
<td></td>
<td>1400 to 2000 (95.4%).</td>
<td>Charcoal from layer containing Ipomoea fragment</td>
<td>Lapakahi, Hawai‘i</td>
<td>Clark 1983a-b</td>
</tr>
<tr>
<td>Site and feature</td>
<td></td>
<td>B-3584</td>
<td>300+/-80</td>
<td></td>
<td>1400 to 1850 (92.1%); 1900 to 2000 (3.3%).</td>
<td>Charcoal from layer containing Ipomoea fragment</td>
<td>Waimea, Hawai‘i</td>
<td>Clark 1983a-b</td>
</tr>
<tr>
<td>8803-A.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trench 12</td>
<td></td>
<td>B-210381</td>
<td>170+/-40</td>
<td>190+/-40</td>
<td>1640 to 1710 (22.4%); 1720 to 1820 (48.3%); 1830 to 1880 (7.0%); 1910 to 1960 (17.7%).</td>
<td>Ipomoea fragment</td>
<td>Kahua 1, Hawai‘i</td>
<td></td>
</tr>
<tr>
<td>MAW-339</td>
<td>TU 2, feature 2</td>
<td>B-179678</td>
<td>100+/-30</td>
<td></td>
<td>1680 to 1740 (27.2%); 1800 to 1940 (68.2%).</td>
<td>cf. Ipomoea fragment</td>
<td>Kahikinui, Maui</td>
<td>Coil and Kirch 2005</td>
</tr>
</tbody>
</table>

*Beta (B), Isotopes (I), or Bishop Museum (HRC)
Until our recent findings, only one carbonised piece of Hawaiian sweet potato had been identified and directly dated. In Kahikinui on Maui (Kirch et al. 2004, Kirch et al. 2005) a piece of carbonised tuber excavated from site MAW-339 produced a direct AMS date of 100 ± 30 b.p., which has two possible 2-sigma calibrations, 1680 to 1740 A.D. (27.2%) and 1800 to 1940 A.D. (68.2%) (see Table 1 and Fig. 2). On the basis of archaeological evidence, Coil and Kirch (2005) rejected the later date and accept the earlier one. Five additional samples identified as sweet potato were recovered from sites in Kahikinui, but none of these have been directly dated. Additional archaeological and radiocarbon evidence from the area does, however, suggest that Kahikinui was developed in two phases, an earlier phase of cultivation dating from about 1400 to 1600 A.D., and a later more intensive phase dating to after 1640.

Other researchers in Polynesia have used microfossils, including pollen (Bennett 1983, Scott-Cummings and Puseman 1998, Tuggle 1997, also see Haberle and Atkin 2005), starch granules (Horrocks 2004a, 2004b; Kolb et al. 1997) and xylem cells (Horrocks 2004a, 2004b), to infer the presence of *Ipomoea batatas* in archaeological contexts, including agriculture terraces, stone mounds and coprolites thought to come from dogs or humans. With any of these lines of botanical evidence, however, there are potential problems in distinguishing *Ipomoea batatas* from other members of the same genus (often termed “morning glories”) that are indigenous to various parts of Polynesia. In Hawai‘i, for example, there are 14 native or naturalised species of *Ipomoea* (Wagner et al. 1990:553), at least six of which have Hawaiian names or are thought to be indigenous to Hawai‘i. These species occur mainly in coastal settings, but one or two also have more upland distributions.

On the whole, there are insufficient modern reference studies of these plants to produce solid evaluations of the degree to which tuber anatomy or microfossil characteristics can truly allow an archaeobotanical separation of sweet potato from other related, naturally occurring plants. Horrocks (2004b:153) reported, for example, that “starch grains and xylem of sweet potato are not easily differentiated from those of the single indigenous [New Zealand] species (*Ipomoea cairica*)”, although on ecological grounds he considers starches in his study to represent the cultivated *Ipomoea*. McCormick (1916:388) implies anatomical similarities in tuber anatomy in the family Convolvulaceae and notes that many members have, like sweet potato, “unusual structure in…[their]…thickened roots”. The problematic nature of this situation is compounded because some *Ipomoea* species have reported uses as famine foods in Hawai‘i and elsewhere (e.g., Whistler 1994:55), and as such may appear in contexts such as hearths or coprolites where sweet potato remains would also be expected.

**RECENTLY RECOVERED SWEET POTATO REMAINS FROM KOHALA**

Recent work in the Kohala Field System on Hawai‘i Island has focused on documenting agricultural developments (Ladefoged et al. 1996, Ladefoged et al. 2003, McCoy 2000, Vitousek 2004), changes in residential (Graves et al. 2002, O’Connor 1998) and religious (Mulrooney 2004, Mulrooney and Ladefoged 2005) structures, paleodemographic trends (Ladefoged and Graves in press a), and the implications of these processes for socio-political transformations (Ladefoged and Graves 2000), territoriality (Ladefoged and
Graves in press b) and human ecodynamics (Ladefoged and Graves 2005). This 20km by 3km agricultural complex developed over a 550 year period (perhaps as early as the late 13th century to the early 19th century) from swidden gardens to a 60km² highly intensified system of earthen and rock embankments and trails (see Fig. 1).

During our investigations in Kohala we excavated botanical remains, including carbonised wood and seeds, from a series of trenches placed across the earthen and rock embankments (known as field borders) within the field system. In two trenches located in the southern ahupua‘a ‘land unit’ of Kahua-1, fragments of charred material thought to be sweet potato were recovered (see Fig. 1). Agriculture in this area would have been restricted by the amount of annual rainfall and nutrient availability (see Ladefoged et al. 1996 and Vitousek et al. 2004), and it is notable that one of the botanical samples came from a trench located near the lower elevation (and lower rainfall) boundary for dryland agriculture in this area.

Figure 3. Profile drawing of south face of Trench 50, Kohala Field System, showing A-horizon (dark brown, loam, organically enriched, unconsolidated), B-horizon (light brown, silt and clay, alternating hard and soft packed) and location of charred materials including fragment of sweet potato, 18-30cmbs.
The first sample we discuss here was excavated from a stratigraphic context beneath one of the field border walls that are so typical of the Kohala Field System. In this case, the backhoe Trench 50 was excavated to perpendicularly bisect a low, rocky field border wall near the seaward edge of the field system. Trenches throughout the field system often reveal intact stratification, with the wall’s rock and mounded earth fill overlying a clear soil sequence of anthropogenically modified A-horizon with an underlying B-horizon. Often ash or charcoal lenses are visible at the interface between the two horizons. The sample was hand-excavated from under the wall’s rock fill in a small, scattered deposit of buried charcoal fragments (n=4) visible near the interface of the anthropogenically modified A and upper B-horizons (18-30cmbs). Given the context, it is likely that this charcoal was burned at some point before, possibly just before, the field wall was built. The other two charcoal fragments collected as part of this trench sample were identified as *Chenopodium cf. oahuense*, a disturbance-tolerant native shrub whose charcoal is common in both Hawaiian firewood assemblages and in agricultural contexts. Surrounding trenches that bisected nearby field walls contained very little in the way of recoverable charcoal remains.

Figure 4. Profile drawing of north face of Trench 12, Kohala Field System, showing A-horizon, B-horizon, and location of flotation bulk sample that produced charred materials including fragment of sweet potato, 17-28cmbs.
Figure 5. Photomicrographs of Trench 50 and Trench 12 samples.

a. Larger fragment of Trench 50 sample showing parallel vesicles, reflective surfaces, and lack of post-cambial tissues (scale=1mm).
b. SEM image showing advanced “glassy” fusion of most cell walls in Trench 50 sample (at top and bottom), with some preserved parenchyma cells running left to right across centre (scale=200 microns).
c. Parenchyma cell casts preserved in Trench 50 sample (scale=100 microns).
d. Parenchyma cells preserved in Trench 12 sample. Also note similar overall appearance of charred tissues to those seen in b above (scale=100 microns).
e. Camera lucida drawing of *Ipomoea batatas* parenchyma cells (modified from McCormick 1916:396) (scale=100 microns). Note similar appearance to cells seen in b,c,d.
f. Transverse section of Trench 12 sample, showing radially-oriented vesicles. Rounded outer circumference of tuber is seen at top (scale=5mm).
g. SEM image of transverse section of Trench 12 sample. Tissues with radially-oriented vesicles can be clearly contrasted with tangentially-oriented post-cambial tissues at top (scale=1mm).
Trench 50 is close to the seaward edge of the field system. Three additional trenches excavated at elevations below the seaward edge of the field system yielded no charcoal or other visibly preserved evidence of burning. This lack of charcoal below the system’s lower elevation boundary in Kahua-1 suggests that the Trench 50 sample was created during horticultural or agricultural activities, rather than as the result of wider landscape burning before the field system’s construction.

The second sweet potato sample was recovered from Trench 12. This trench was located in the higher elevations of the field system in Kahua-1 ahupua’a. This trench bisected two rock and earthen field borders as well as the adjoining field plot between these walls. During excavation of a bulk sediment sample for flotation analysis, several large fragments of charcoal were hand-collected from the lower A-horizon/Upper B-horizon of the field plot, at a depth of 17-28cms (Fig. 4). Two wood types, identified as Chenopodium cf. oahuense and cf. Dubautia sp. (both shrubby taxa that may have grown in fallow agricultural fields) were contained in this sample, as well as four fragments of carbonised parenchyma tissue that was identified as probable sweet potato. Criteria relevant to identification of both samples are reviewed below.

Archaeobotanical identification of the sweet potato

The Trench 50 carbonised sweet potato sample comprised two small fragments, weighing a total of 0.18grams; the Trench 12 carbonised sweet potato sample comprised four fragments, weighing a total of 0.42grams. Microscopic anatomy of the samples was first examined using two reflected light microscopes—a Wild M5a stereoscopic (12-50x) and an Olympus BHS metallurgical (50-500x)—followed by further examination and imaging using Environmental Scanning Electron Microscopy (ESEM) (Fig. 5). Observable anatomical characteristics were compared with published descriptions of sweet potato tuber anatomy (Esau 1960, Hather and Kirch 1991, Hayward 1938, McCormick 1916), as well as with modern reference collection materials of Pacific Island root and tuber crop plants, curated at the University of California-Berkeley Oceanic Archaeology Laboratory.

Hather and Kirch (1991) outlined some of the diagnostic anatomical characteristics useful in distinguishing carbonised sweet potato remains from other Pacific Island root and tuber crops, such as taro or yams. The larger Trench 12 sample fragments contained distinctive features corresponding to a sweet potato identification, including the presence of radial fissuring (see Fig. 5) and periclinaly oriented tissue exterior to the tuber’s primary cambium (cf. Coil and Kirch 2005, Hather and Kirch 1991). Other diagnostic features such as vessel arrangements, cell wall pitting or cell mineral inclusions could not be observed in this sample.

Because the Trench 50 fragments were smaller and appear to derive from a tuber interior rather than edge, diagnostic characteristics related to the presence of post-cambial tissues have not been preserved. At a more intermediate level of microscopic analysis, however, the sample compares favourably with reference samples of carbonised sweet potato as well as with the Trench 12 sample. Much of the tissue in both samples, which is dominated by parenchyma cells, has been melted into a “glassy” mass of relatively solid carbon with only limited visibility of individual cell outlines, a condition often seen in carbonised sweet potato. Parenchyma cells, where partially preserved in the Trench 50 sample, also correspond with the proper
size and shape range for *Ipomoea batatas*. Importantly, carbonised tissues in the Trench 50 fragments also show a marked tendency towards formation of parallel, elongated vesicles, suggesting a radial orientation in underlying cell structure such as that seen in sweet potato and absent in taro and yams. Observable trending towards radial arrangement in surviving blocks of cells also suggests the presence of this diagnostic anatomical structure. At the most detailed level of inspection the extreme degradation and distortion of much of the tissue during charring (probably while wet) has unfortunately obscured the visibility of other useful characteristics, such as cell wall pitting and mineral contents, which was also the case with the trench 12 sample. Vascular tissue seems to be very poorly preserved, but there is no indication of arrangement of such cell types into distinct “bundles”, such as those found in monocotyledonous taxa (Hather 2000).

In sum, the charcoal fragments examined appear to derive from the cultivated sweet potato, *Ipomoea batatas* (L.) Lam. In the case of the Trench 12 sample, the identification of *Ipomoea batatas* (L.) Lam. is relatively secure because the sample is larger and contains diagnostic external tissues. In the case of the Trench 50 sample, however, more room for uncertainty must remain, because of the small size of the sample fragments and lack of preservation of some diagnostic structures and details. Also, as discussed above, it may be possible that the roots of the related native morning glory plants in Hawai‘i, also from the genus *Ipomoea*, produce charcoal similar to that of the cultivated sweet potato. However, we believe that the archaeological contexts of our samples, which are clearly associated with the Kohala Field System, argue in favour of these remains representing a cultivated crop.

An AMS radiocarbon determination (Beta-208143) on the Trench 50 charred sweet potato fragment produced a date of 580 ± 40, which at 2-sigma calibrates to 1290 to 1430 A.D., and an AMS radiocarbon determination (Beta-210381) on the trench 12 sample produced a date of 190 ± 40, which at 2-sigma calibrates to 1640 to 1710 A.D., 1720 to 1820 A.D., 1830 to 1880 A.D. and 1910 to 1960 A.D. (see Table 1 and Fig. 2).

DISCUSSION

We have outlined some of the technical and botanical considerations that are important in deciding the degree to which identifications of sweet potato can be considered reliable. Preliminary research has established the possibility that native *Ipomoea* plants related to sweet potato can produce macrofossils or microfossils that are difficult to separate from the cultivated crop plant. Taphonomic issues involving loss of diagnostic characteristics seen in fresh reference material can also affect the security of identifications. Further research on establishing sound criteria for identifying sweet potato should help lead to more secure identification efforts in the future.

The directly dated remains of probable sweet potato fragments from Kohala demonstrates that sweet potato is likely to have been introduced to Hawai‘i as early as the late 13th century and certainly by the early 15th century. The early end of this estimate is within a century of the later end of the 1100-1200 estimate by Green
(2005:52) for the secondary introduction of sweet potato to Hawai‘i (the archipelago having been colonised by c. 800). By the late 13th century to early 15th century, sweet potato was being grown in an upland area of the leeward portion of Hawai‘i Island, some 6.5km from the coast. While the chronology of residential settlement along the Kohala coast and in the uplands has not been firmly established, the presence of gardening activities in the upland areas would suggest that populations were living along this leeward coast at this time. The sweet potato remains are not directly associated with the intensive agricultural walls and trails, and it seems likely that the remains of the sweet potato are the result of initial swidden horticulture in the area, where, from an ecological perspective, this plant would have been a primary cultivar.

The additional evidence of sweet potato in Hawai‘i reviewed here all comes from leeward contexts. A cursory search of sources that report archaeobotanical (Allen 1989, Kirch 1992) or pollen records (Athens 1997; Athens and Ward 1993, 1997; Athens et al. 1992, 2002) from windward O‘ahu did not turn up any identifications of sweet potato or its genus, Ipomoea. The distribution of archaeologically identified remnants of sweet potato or its pollen are currently limited to leeward environments, and apparently none have been found in windward locations. Most of the evidence for sweet potato comes from upland leeward areas of the volcanically younger islands of the archipelago (e.g., Kohala, Kahikinui, Kula). This substantiates the suggestion of Vitousek et al. (2004) that only the younger volcanic islands contained zones of soils with sufficient nutrient levels and climatic conditions for dryland agriculture. It is probably no coincidence that Kula is the one area on Maui that is said to have the closest thing to a “field system” similar to those on Hawai‘i Island. We might expect to find further evidence of sweet potato production in Kona and Kā‘u in Hawai‘i Island and in Honua‘ula in Maui, since these are upland areas with younger substrates that would have been optimal for sweet potato cultivation. Given the dates associated with the sweet potato starch grains from Kula and the dated sweet potato tuber from our work, the expansion of dryland agriculture into these uplands occurred relatively soon after the sweet potato arrived. The secondary introduction of this cultigen differentially benefited populations in leeward as opposed to windward areas, as it opened up large tracts of highly productive land that were previously underused.

While we are unable to say with certainty that sweet potato did not arrive with the original colonists of Hawai‘i, all available evidence suggests it was a later introduction. The 13th century is within the estimated duration of periodic long-distance voyaging between the islands of central East Polynesia and Hawai‘i (Cachola-Abad 1993), and it is possible that the sweet potato was introduced to Hawai‘i during these long-distance voyages. Our earlier probable sweet potato fragment from Kohala dates between 1290 and 1430, and demonstrates that people were using this upland interior area relatively early. The other sweet potato sample and the extensive archaeological evidence in the area indicate that the field system continued to be used into the historic period. It was the introduction of the sweet potato into Hawai‘i that enabled the establishment and development of dryland agriculture in areas such as leeward Kohala. Over subsequent centuries this area became one of the most productive zones of dryland agriculture in the archipelago.
NOTE

1. All dates cited in this article are A.D. unless specified as b.p.

2. All dates were calibrated with the OxCal 3.10 program (Bronk 1995, 2001) that uses the Intcal04 (Reimer et al. 2004) and Marine04 (Hughen et al. 2004) calibration curves.

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