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A Millennium of Human Activity at Makauwahi Cave, Māhā`ulepū, Kaua`i

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A cave system in the eolianite deposits of the Māhā`ulepū/Pā`ā area of Kaua`i, Hawai`i, contains a rich fossil record of prehuman Holocene conditions and also preserves a thousand-year record of human activity. Details concerning pre-Contact Polynesian life have been extracted from subaqueous middens and artifacts, including perishable materials such as wood, gourd, and cordage. Oral traditions concerning the cave and vicinity generally show good agreement with the archaeological and paleoecological record and provide rich stories said to derive from as early as the fourteenth century A.D. *Fossil evidence highlights biotic and landscape changes before, during, and after initial Polynesian and subsequent European settlement. The approximate temporal coincidence of evidence for human arrival and last occurrence of some now-extinct species is too great to ignore the possibility that humans played a role in some extinctions of native taxa before European colonization. Old maps, an 1824 sketch, records of the Land Court Awards, and old photographs confirm stratigraphic inferences and oral accounts concerning demographic and ecological conditions of the early historical period. Feral livestock proliferated in the nineteenth and early twentieth centuries, with loss of vegetative cover to overgrazing, decline of most of the native flora, and subsequent dune reactivation. Sedimentation rates reach their peak later in the twentieth century after the establishment of agricultural and mining operations nearby.*

KEY WORDS: Hawai`i; human settlement; ecological change; prehistoric diet; perishable artifacts.

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INTRODUCTION

The first Polynesians to see the island of Kaua`i saw a world that has almost completely disappeared. Dry leeward lowlands, now almost entirely without native forest, hosted a diverse assemblage of trees comparable to the most pristine interior highlands (Burney *et al.*, 2001). Birds were the only terrestrial vertebrates, some quite large and many now extinct, like the turtle-jawed *moa-nalo* (*Chelychelynechen quassus*), a flightless duck (Olson and James, 1991). We can only guess at the workings of ecosystems in which bird-catching owls (*Grallistrix auceps*) were the top carnivores, large flightless geese and ducks were the grazers and browsers, rats and ants were absent, and land snails of many types, mostly unique to this island, were ubiquitous.

Likewise, we know almost nothing about the first people on Kaua`i, and only a little more about their descendants in the earliest centuries of occupation (Kirch, 1985; Masse and Tuggle, 1998). Subsequent generations of Hawaiians we know better, through their own rich oral traditions and the glimpses of their lives from archaeological finds. Most of the latter serve only as murky "snapshots" of past lifeways, however, derived mostly from artifacts of stone and shell and fragmentary evidence for past meals. Until recently (see Burney *et al.*, 2001), no sites had been described for Kaua`i that contained in a single stratigraphic sequence an encapsulated view of the full span of human occupation, including the millennia preceding human arrival, earliest human evidence, subsequent population increase and cultural change, European contact, and modern transformation. Here we wish to examine in more detail the human-related components of the Makauwahi Cave system, and to relate these findings to other interdisciplinary studies of historical ecology and human impact on Pacific island landscapes and elsewhere in the world.

On the island's south coast, along the boundary between the *ahupua`a* (traditional land units) of Māhā`ulepū and Pā`ā, a site with an unprecedented richness of paleontological and archaeological information has come to light. Stratigraphy and radiocarbon dating reported for the caves and sinkhole there in Burney *et al.* (2001) provide a more detailed picture of a Hawaiian landscape before and after human arrival than previously available. Nearly 10,000 years of sedimentary record from a sinkhole paleolake has been analyzed for vertebrate bones, invertebrate shells, plant macrofossils, pollen, diatoms, sedimentology, and in the upper layers, human artifacts. This is a story already familiar in outline from islands worldwide, of an island transformed. Here we detail the human material culture and ethnohistory from the millennium that witnessed a decline from an avifauna of more than 40 species, plus over a dozen endemic land snail species and a botanically diverse forested environment, to a modern biota missing nearly all native elements and dominated by a handful of cosmopolitan plants and animals—weed species from around the world. The Kaua'i case provides a chronicle of the human transformation of an ancient environment in the isolated setting of a mid-Pacific microcosm. The trends described are comparable to events of recent millennia throughout the globe (Redman, 1999; Burney and Flannery, 2005).

Although Burney *et al.* (2001) and Burney and Burney (2003) chronicle the changes that have occurred at the site over the last ten millennia or more, and focus on reconstructing the details of the prehuman ecosystem and subsequent transformation, we provide here a more detailed account of human events at the site over the last approximately one thousand years. Owing to the unusual configuration, i.e., a prehistoric lake completely enclosed by a sinkhole in the midst of the most extensive limestone cave system known from the mid-Pacific, the site provides some extremely well-preserved evidence of human life in the vicinity at various times in the past. Most importantly, however, the nearly continuous nature of sedimentation and the excellent preservation of even perishable artifacts and food items provide an ongoing record of human activity near the site. The information reported here can be thought of as not just an "album of snapshots" of past life, but perhaps, in combination with the oral histories and early documents, maps, and pictures presented, a sort of epic movie of human ecology stretching over a thousand years.

SITE AND METHODS

The eolianite deposits at Māhā`ulepū formed on top of the island's ancient lava in the late Pleistocene. It is generally accepted that deposits of this type are created by rapidly rising sea level at the beginning of an interglacial. As the ocean rises, the offshore reef material (mostly coralline algae in this case (Blay and Longman, 2001)) is ground up and deposited onshore as calcareous sand. Prevailing winds blow this material farther up the beach, forming large dune fields. Over subsequent millennia, the grains may be partially dissolved by rain water and recrystallize, gradually converting the softer aragonitic calcium carbonate to a harder and less soluble calcite. Later in the Pleistocene, strong groundwater flow between the porous limestone and the underlying basalt resulted in the formation of solution hollows in the limestone, ultimately producing a large cave system.

In the early Holocene, this big cave had a dry floor (Burney *et al.*, 2001). As sea level rose to within a few meters of the present level, however, the sea breached the site. Around 7000 years ago, the ceiling of the central

Table I. Chronology of Significant Geological, Ecological, and Human Events at Makauwahi Cave, Māhā`ulepā, Kaua`i (after Burney *et al.*, 2001)

Date	Event (stratigraphic unit given in parentheses)
a previous interglacial	Rising sea produces dune deposits; diagenetic processes solidify calcareous sands to eolianite (I), perhaps 300-400 kyr B.P.
late Pleistocene	Cave passages form in eolianite deposits.
ca. 9500 cal yr BP	Cave present, floor relatively dry (II).
ca. 7000 cal yr BP	Marine incursion at site (III), parts of cave roof collapse.
mid- to late Holocene	Sinkhole paleolake occupies site. Fossils of diverse community of birds, land snails, and plants deposited (IV).
1039–1241 AD	First evidence for Polynesians at the site (upper part of Unit V).
1300's AD	Story of chief Kūkona, attributed to this period, recounts interisland warfare beginning at Māhā`ulepū.
1430–1665 AD	Sometime during this interval, a marine overwash event, probably a tsunami, leaves debris and human artifacts in the sinkhole (VI).
late 18th century	Sedimentation of thin sand and clay lenses (VII). First evidence for European livestock. Cook's First Voyage explores this coast in 1778.
19th century	Native population of valley decreases due to disease and emigration. Much of remaining coastal forest removed by sandalwood exploitation. Plantation era begins. Feral livestock proliferate. Overgrazing results in dune reactivation, with thick sand unit deposited on portions of site (VIII).
1950s	Drainage of Kapunakea Pond, agricultural development, and quarrying activities accelerate deposition of silty clay on site (IX).
1992	Sediment coring project begins on site, verifying Holocene record with preservation of wide array of fossils. Hurricane `Iniki hits Kaua`i. Site receives storm overwash (X).
1997	Large-scale multidisciplinary project begins on site. Subphreatic excavation reveals rich deposits of fossils and artifacts.
2000	Excavation program leads to initiation of cultural and ecological restorations in vicinity (Burney, 2002b; Burney *et al.*, 2002).

portion collapsed, producing a large sinkhole. Collapse in the back of the South Cave apparently sealed the site off from direct ocean incursion. Fresh or slightly brackish water, primarily derived from groundwater, formed a lake in the sinkhole at this time. Over subsequent millennia, a neutral peat-like material, formed from plant remains, grains of calcareous sand, and millions of shells and bones of indigenous creatures, built up over the cave floor beneath this lake, accumulating nearly 10m of sediment in the central part of the sinkhole. (See Table I for a summary of the site chronology; Appendix to Burney *et al.,* 2001, for complete stratigraphic descriptions).

Twenty cores (three with Livingstone sampler, the remainder with bucket auger) were collected, distributed over the entire site. Ten stratigraphic units were described on the basis of sedimentology, dating, fossils, and artifacts. Excavations were carried out in three pits to depths of up to 5m below the water table (see Burney *et al.*, 200l, for coring locations and stratigraphic sections). Stratigraphic control above the water table employed a one-meter horizontal grid system, with three-dimensional piece-plotting of key artifacts and features. These dry units were excavated by natural layers. At the water table and below, layers were dug on the same grid system but in 10 cm lifts, using the water surface as the primary leveling device (Burney and Robinson, in press). This was accomplished by surveying the top of the water table to the surface datum, then using small gas-powered water pumps to create a cone of depression by pumping out a casing-lined sump hole in the corner of the excavation, temporarily lowering the water to the base of the 10 cm layer being excavated. This allows quite precise vertical control and careful excavation in sediments that would otherwise be under water. (For other examples of the use of this technique, see Burney, 1993, 1999; Burney and Robinson, in press). Natural layers below the water table were generally level and massive, characteristic of a subaqueous sedimentation regime. Fresh water refilled the pit within ca. one hour after cessation of pumping, due to rapid groundwater recharge at the site.

To date, over 200 m^3 of sediment have been excavated from three pits. Sediments containing fossils and artifacts have been sifted in nested screen boxes down to a mesh size of 1.5 mm, producing thousands of specimens. Perishable artifacts and fossils are stored in watertight containers under refrigeration to prevent drying and decay. Each specimen has complete provenance information recorded on a waterproof tag. Additional stratigraphic information was recorded on excavation forms and in digital photographs. Chronological control for these studies has been obtained from over 50 radiocarbon dates on a wide array of organic materials, including plant macrofossils, bone collagen, acid/base/acid-pretreated sediments, and etched shells (see Appendix, Burney *et al.*, 2001). For determining earliest evidence for humans on the island, additional dates were obtained from diagnostic materials in other sites around the island for comparison to the results from Makauwahi (Table II; see Burney, 2002a, and Burney and Burney, 2003, for additional details). In post-European contact layers (late eighteenth century to present), which are too young for sufficiently precise ^{14}C dating, additional chronological insights were derived from earliest occurrence of fossils and artifacts whose dates of introduction are historically known. Old maps and photos, historical documents, oral traditions, and informal interviews were also employed in detailing the history of the past two centuries.

RESULTS AND DISCUSSION

The First Evidence for Humans

At present, the oldest published date for direct human evidence from Makauwahi is a collagen date on a pelvis of the Pacific rat (*Rattus exulans*) of 822 ± 60 yr B.P. (1039–1241 cal yr A.D..) (Burney *et al.*, 2001). Less direct evidence from charcoal particles in sediment cores from the sinkhole and elsewhere on the island (Burney and Burney, 2003) suggests a human presence in the form of a sudden drastic rise in charcoal at some sites beginning about a millennium ago. One of these, a small rise in charcoal detected at 381 cm in Core 20 from the sinkhole (Table II; Appendix, Burney *et al.*, 2001), dates to 970 ± 40 yr B.P. (1000–1170 cal yr A.D.).

Limahuli Bog on the north coast was the only site out of synch, (Table II; also see Burney and Burney, 2003) showing a charcoal rise as early as 1470 ± 60 yr B.P. (440–670 cal yr A.D.), but resolution is poor in the upper part of this core and it cannot be assumed that charcoal is a human indicator. Indeed, there is evidence from several sites around the island that prehuman fires occurred occasionally during the mid-Holocene (Burney and Burney, 2003), most notably during an inferred dry phase at ca. 3800 yr B.P. (ca. 4200 cal yr B.P.). A stratigraphic event we interpret as likely to have been an extreme marine overwash of the site (e.g., a tsunami or storm surge) unfortunately disturbs the Limahuli site at 1470 yr B.P., so that sediments are mixed with gravel and whole tree trunks. It therefore remains an open question whether, as some authors have suggested (e.g., Kirch, 1985), the wet windward valleys of the Hawaiian Islands were settled several centuries before the other parts of the islands.

In spite of the large number of archaeologists working in the Hawaiian Islands there is not yet a strong consensus for the date of initial colonization of the archipelago. For recent discussions, see Athens (1997), Masse and Tuggle (1998), Athens *et al.* (2002), and Burney and Burney (2003). Estimates from archaeologists run from slightly more than two millennia (e.g., Beggerley, 1990) to about one millennium (e.g., Athens, 1997). The latter dates first evidence for humans on O‘ahu, based on charcoal particles in sediment cores, at ca. 800 cal yr A.D..

Although a few early dates obtained from sites on Kaua‘i's north shore in past decades, from presumed agricultural horizons and charcoal thought

Table II. Early Dates for Human Evidence on Kaua`i.

Lab No	Site/Material	^{14}C yr BP[a] ± 1 σ	Calibrated age range[b] at 2 σ	Source	Remarks
NZA 10058	Makauwahi/bone (*Rattus exulans*)	822 ± 60	A.D. 1039–1241	Burney *et al.*, 2001	Introduced Pacific rat is direct evidence for human arrival.
β-164910	Makauwahi/sediment	970 ± 40	A.D. 1000–1170	This paper	Dates a moderate increase in charcoal at 381 cm depth in Core 20.
β-142807	Kekupua/sediment	830 ± 50	A.D. 1050–1280	Burney, 2002a	Dates large increase in charcoal, and inferred date of fishpond construction.
β-141060	Alekoko/wood	580 ± 30	A.D. 1305–1420	Burney, 2002a	Dates large increase in charcoal, but moderate increase begins earlier.
β-142808	Limahuli/wood	1470 ± 60	A.D. 440–670	Burney, 2002a	Dates large increase in charcoal, but layer is disturbed by a marine overwash.

[a]Corrected for isotopic fractionation ("conventional radiocarbon age").
[b]Based on Stuiver *et al.* (1998).

to be associated with forest clearance, pointed to arrival by the seventh or eighth century , reexamination of the sites has called some of these dates into question (discussed in Kirch, 1985, p. 87). Regardless of the exact date for human arrival, the approximate temporal coincidence of evidence for human arrival and last occurrence of some now extinct bird species is too great to ignore the possibility that humans played a role in some extinctions of native taxa before European colonization (Olson and James, 1982; James *et al.*, 1987; Burney *et al.*, 2001). Analysis of land-snail occurrences in the Māhā`ulepu sediments suggests that some large snail taxa, such as *Carelia* sp. and *Cyclomastra cyclostoma*, may disappear from the site about the time of human arrival as inferred from other evidence. This is followed by a decline and disappearance of other, smaller taxa over subsequent centuries, and a final third wave of extirpation of even the smallest endemic species after European arrival (Burney *et al.*, 2001). This three-tiered pattern is of course derived from the disappearance of snails from a single site, but it is consistent with the few dated occurrences of extinct land snails from other sites on the island as well (Dixon *et al.*, 1997; Burney, 2002a). It remains to be seen whether extinct birds may show a similar three-tiered pattern.

We know little about the activities of the earliest people in Hawai‘i, believed to have arrived from the Marquesas Islands (reviewed in Joesting, 1984). Significantly, there are legends associated with the Maha`ulepu area of the south coast that are said to reach back perhaps as far as the fourteenth century , but this date is based exclusively on genealogical reconstruction. Recent authors have questioned whether early dates determined by genealogy in the Hawaiian Islands may have utilized average generation times that are inappropriately long, thus pushing back traditional dates for events that predate written history of the islands too far (see discussion in Masse and Tuggle, 1998). In any case, early stories from the area suggest substantial human populations along this coast many centuries ago, since they involve interisland warfare, in which Kaua‘i is victorious, and a resource conflict, in which a chief’s fishing rights are usurped and poachers are punished.

The first of these stories, traditionally thought to have occurred in the 1300s, concerns a battle that began at Maha`ulepu between the forces of Kauai’s ruling chief, K*ū*kona, and Kalaunuiohua of Hawai`i, who had already conquered the chiefs of Maui, O`ahu, and Moloka`i. Kukona defeated him by continually retreating into the interior until the invading forces were quite weary and spread out (Kalakaua, 1888).

The second story, said to be of great antiquity, tells of a giant crab in the caves at Māhā`ulepū and implies a conflict over scarce food resources:

> Waiopili was another food altar. It was located at the source of the stream of Mahaulepu. It was an altar for the purpose of multiplying food plants, dedicated to the god Kanepuaa.
>
> Kailiili was a fish altar that stood on the beach at Paa. Near this spot is a long cave with a hole just above it. A famous legend is told in the olden days of the big crab, Kiakala, who belonged to the land of Paa. He took the octopus of the sea at Paa and carried them secretly to the shore for his keepers who lived in the cave. The octopus was prohibited for the use of the chief of that place, who was named Keakianiho.
>
> The crab was a red one. He seized the chief's octopus to feed his people with. Kaneakalau was the kahuna at that time. The chief was puzzled at the lack of octopus when it was time to go spearing them.
>
> When Kaneakalau ascended till he came to the place where he could look down into Kipu, he rested on a mound and fell into a trance. He saw a crab take the chief's octopus and give them to his people. When he came to, he saw that he had been in a trance. He went to tell the chief and when they went to investigate, they found the cave and the crab's people. They were all killed but the crab was never caught.
>
> This was one of the famous legends of this district of Koloa in the olden days. (Papers by Lahainaluna students, 1885)

The Waiopili Heiau mentioned here (also see Bennett, 1931) is located in the limestone quarry adjacent to the cave.

Polynesian Artifacts

Above the depths containing earliest human evidence (ca. 3.1 m below datum in the East Pit, in the upper part of Unit V; Burney *et al.*, 2001; Burney and Burney, 2003) the sediments at Māhā`ulepū show an increasing abundance and diversity of artifacts—fishhooks and other fishing gear, picks, abraders, lithics, ornaments, cordage, gourds, and worked wood. Table III summarizes these finds. Significant types and examples are pictured in Figures 1–6, and discussed below.

Fishhooks and Other Fishing Gear

A total of 89 fishhooks have been catalogued for the site (Kikuchi *et al.*, 2003). These include 60 small and medium-sized pearl shell (*Isognomon perna*) hooks and 28 medium-sized and large hooks of bone, some in two parts. Several barb styles are represented, and some are barbless (Fig. 1). One large handworked iron fishhook was also found in the post-Contact Unit VIII.

Also present are parts of octopus lures, including large drilled cowrie shells, stone weights, and a bone object that is probably a toggle device (Fig. 1C). Only a few hooks are from near the top of Unit V; many more are from Unit VI, which dates to cal A.D. 1425–1660, and subsequent layers.

Table III. Summary of Artifact Inventory from Excavations at Makauwahi Cave, Māhā`ulepū, Kaua‘i. For details, see Kikuchi *et al.*, 2003

Type	Total No	Provenance	Remarks
Fishhooks, shell	60	From upper Unit V to Unit VIII.	Hooks in all phases of completion especially prevalent in Unit VII, South Cave.
Fishhooks, bone	28	Same.	Same.
Fishhook, iron	1	Unit VIII.	Large, hammered-wire construction.
Octopus lures	4	Units VI through VIII.	1 sinker, 2 large drilled cowries, and a bone toggle.
Picks	10	Units VI through VIII.	Made from chicken and shearwater bone.
Abraders, coralline	37	Units VI through VIII.	Coral files of all sizes, including large types.
Abraders, urchin spine	66	Units VI through VIII.	Urchin spine files numerous in association with evidence for fishhook manufacture in South Cave.
Lithics (blades, scrapers, debitage)	70	From upper Unit V to Unit VIII.	Stone flakes of basalt, chert, and obsidian, some with retouch.
Adze	1	Unit VIII.	1 complete, several fragmentary.
Hammerstones	12	Units VI through VIII.	Also 2 pumice polishers.
Sling stones	4	Unit VIII.	
Game stones	2	Units VI through VIII.	Discoidal objects of *ulu maika* type.
Drilled shell ornaments	43	Units V through surface.	Mostly cowries (*Cypraea moneta*) and *Strombus maculatus.*
Drilled bone ornament	1	Unit VII.	Unusual grooved object. See Figure 4.
Drilled stone mirror	1	Unit VII.	See Figure 4. Also fragments.
Cordage	7	Units VI through VIII.	OlonÄ (*Touchardia latifolia*) and coconut fiber.
Wooden artifacts	22	Top of Unit V through VIII.	Includes canoe fragments, adze handles, and points.
Gourds	3 large	Same.	Some show decoration. Hundreds of smaller pieces.

In Units VII and VIII from the South Cave excavation, material of post-Contact age shows that traditional fishhook manufacture was carried out on a sand bar on the south edge of the lake under the cave overhang. This material consists of shell and bone debitage, and fishhooks in all stages of manufacture, from cut pig bones and roughly shaped pearl shell to partially filed blanks. Many coralline and urchin-spine abraders occur in association (see below).

Ten post-holes were excavated in the South Cave pit that trace to these layers. These may have been holes for posts that held up a platform erected

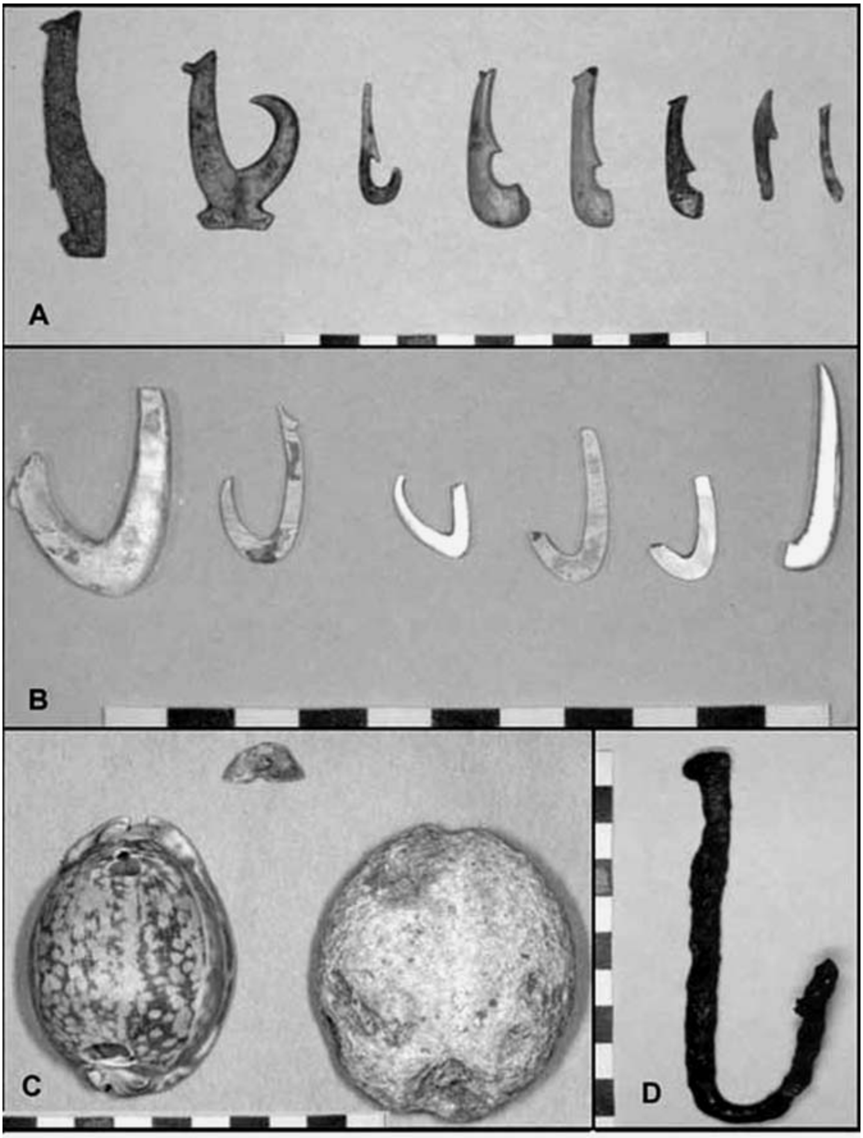

Fig. 1. Polynesian fishing gear from Makauahi Cave. (**A**) Carved bone fishbooks. (**B**) Pearl shell fishhooks. (**C**) Octopus lure parts: (left), drilled cowrie shell; (right) grooved stone weight; (above) carved stone toggle. (**D**) Hammered iron fishhook (post-contact Unit VIII).

Fig. 2. Carved bone picks from Makauwahi Cave. First two picks from left are probably made from chicken bone. Others are likely to be from wing bones of shearwaters or other small pelagic birds. Hawaiians used bone picks to remove small edible marine invertebrates from their shell.

over the wet sandy substrate. Also found was a *noho* (stone stool) that would have been useful for the same purpose. Both types of seating could have been used for ritual or utilitarian purposes.

The very large size of a few of the fishhooks also suggests that manufacture was carried out nearby, since large hooks would have been suitable only for offshore fishing for tuna and other large fish. Some smaller hooks may have been used for fishing in the sinkhole pond or the larger pond adjacent to the entrance. This might explain the large number of smaller hooks with broken points.

Picks and abraders

Numerous objects with points or beveled edges, fashioned from bone, coral, and urchin spines, were found in the site. Ten picks (Fig. 2), perhaps for removing the meat of small marine invertebrates (Kirch, 1985) that are prevalent in the midden materials (see below), were unearthed. Two were apparently fashioned from chicken bone; most of the rest are made from

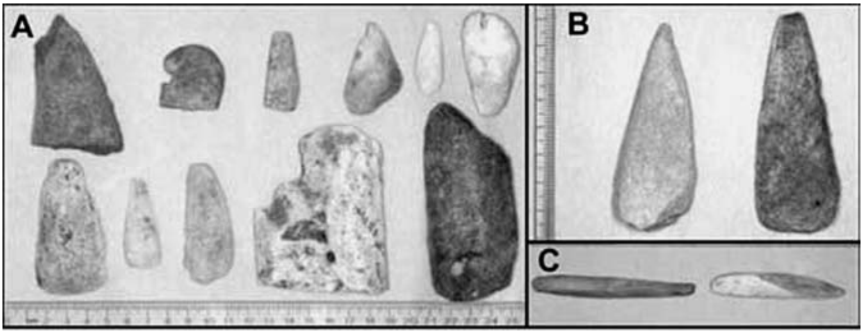

Fig. 3. Abraders from Makauwahi. (**A**) Sandstone (first on upper left) and coral files and saws. (**B**) Large pointed saws made from coral. (**C**) Small files made from sea-urchin spines.

wing elements of a seabird, probably Newell's Shearwater (*Puffinus auricularis newelli)* (Storrs Olson, pers. comm.).

Abraders or files were quite numerous (Fig. 3), including 37 of coral, some quite large, and 66 of spines of the large sea urchin *Heterocentrotus mammillatus*. Although these undoubtedly had many purposes, their association with fishhook manufacture is well-known and is confirmed by their great abundance in squares and levels containing the evidence for fishhook manufacture cited above.

Lithics

In addition to large amounts of basalt and chert debitage, the site also yielded cutting blades, scrapers, adzes, hammerstones, sling stones, and game stones. The last are discoidal objects of the type known as *ulu maika.* Although basalt and chert are available very nearby, small flakes of black and gray volcanic glass also occur, especially in the upper layers (Units VII and VIII). This material would probably have been transported from the high interior of Kaua'i or imported from O'ahu or elsewhere in the archipelago.

Ornaments

Small cowrie shells (*Cyprea moneta*) drilled lengthwise for necklaces, as well as other drilled shells, were found in all the layers of the human period. In addition, a finely polished black basalt mirror, perfectly circular and drilled as a pendant, was found near a carved bone bead of large size and peculiar construction (Fig. 4), and many drilled cowries. Several thin

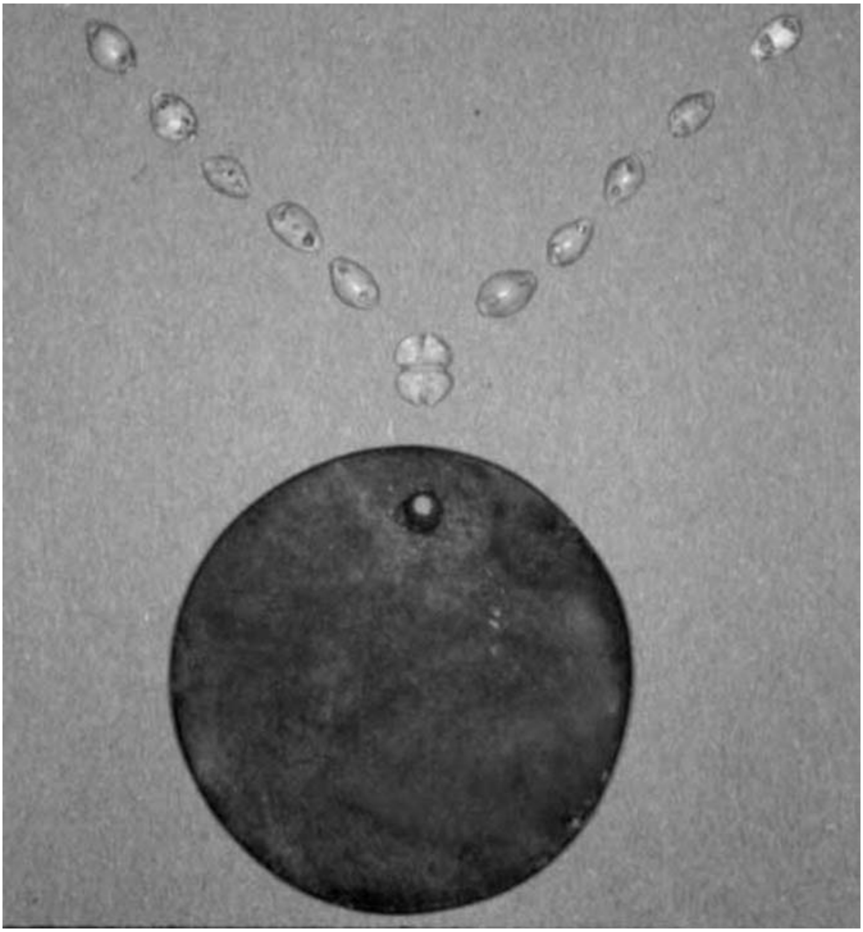

Fig. 4. Ornaments from South Cave excavation. Arrangement is conjectural only. **Bottom**, polished black basalt mirror drilled as pendant. **Center**, carved bone bead, with single lengthwise hole and incised grooves around both axes. **Top**, cowrie shells drilled lengthwise.

pieces of polished black basalt were also found that are probably fragments of other mirrors.

Cordage

Pieces of flat-braided cordage (Fig. 5) were found in the site, probably made from the fibers of coconut (*Cocos nucifera*) and *olonā* (*Touchardia latifolia*). The former are generally thicker, and were in some cases laced through wood fragments that may have been parts of canoes (Fig. 6). The

Fig. 5. Examples of cordage from the site, probably from olonā fiber (*Touchardia latifolia*). These are flat-braided in strands of three or more. Note that pieces on right are knotted.

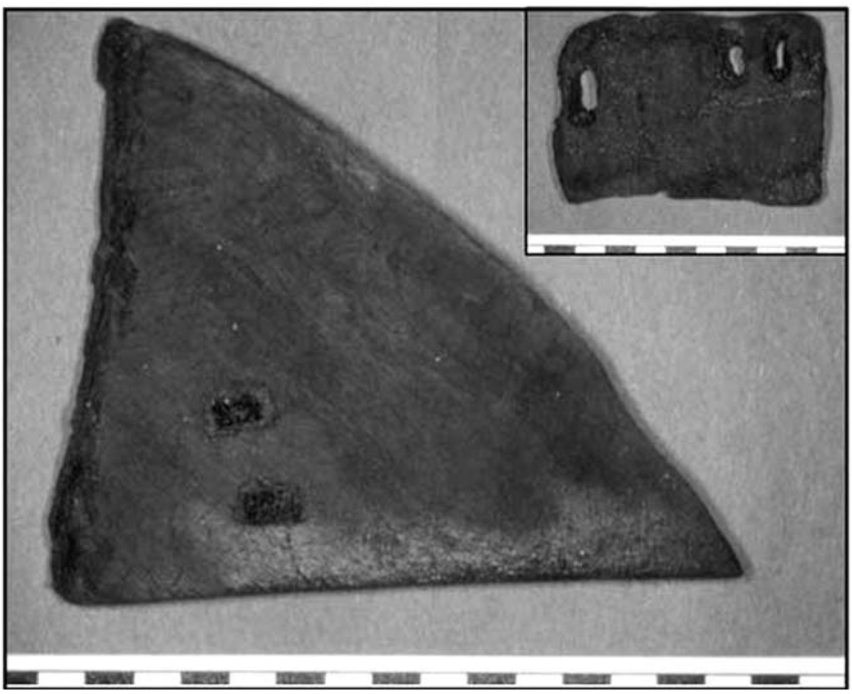

Fig. 6. Wooden artifacts, probably parts of a canoe, from the subphreatic excavations. Note oval holes for fastening parts together with cordage.

olonā found was much smaller in diameter (<2 mm) and was sometimes found in proximity to fishing gear and, in one case, with the skeleton of a small pig. A small piece of woven mat, probably made from *makaloa* (*Cyperus laevigatus*) or some other sedge, was recovered from Unit VII in Core BAC-20.

Wooden Artifacts

Fragments of canoes (Fig. 6) and paddles, adze handles, and points were recovered in good condition from pre-Contact layers. Also present were thin objects that may be bamboo tattoo needles, and an abundance of rectangular and trapezoidal wood chips with the type of beveling and scalloping characteristic of debitage produced by working a large piece of wood with a stone adze, as in canoe making.

Gourd

Gourd pieces, all probably derived from *Lagenaria siceraria*, the Polynesian-introduced bottle gourd, occur in all the layers containing human evidence except those of the twentieth century. Some of these may be kitchen refuse, since the gourd was both eaten and used for containers (Kirch, 1985). Associated large pieces, some comprising more than half of a single large gourd, were found in Unit VI. This extraordinary preservation is a consequence of rapid subaqueous burial. This layer is believed to have been deposited in a single overwash episode, probably a tsunami, about 400 years ago (Burney *et al.*, 2001). Gourds were probably swept in, along with many other artifacts, and buried instantly under stones, gravel, and sand.

Dietary Evidence

The sinkhole lake at Māhā`ulepū was essentially a huge midden during Polynesian times, in which food refuse accumulated below the water surface in anoxic mud—an ideal opportunity to see what was on the menu in the vicinity for centuries. Remains of species thought to have been utilized as food items that have been found in the human layers at Makauwahi include marine and terrestrial invertebrate shells, bones of marine fish and introduced mammals and birds, and the seeds, fruit capsules, and pollen of Polynesian-introduced plants (Table IV).

Table IV. Annotated list of inferred dietary remains from Makauwahi Cave.

Type	Item	Remarks
Vertebrate	Pig	Common from top of Unit V (human arrival) to the surface. Bones used to make fishhooks.
	Dog	Occasional, most common in Units VII–VIII.
	Chicken	Occasional throughout Units VI to surface. Bones used to make picks.
	Rat[a]	Common from top of Univ V (human arrival) to the present. In Unit IX (20th century), *R. exulans* replaced by *R. rattus/norvegicus*.
	Goat/Sheep	Earliest stratigraphic evidence for European contact is appearance of abundant remains (Unit VII).
	Cow	Abundant in Unit VIII (19th century) (also equids).
	Fish[b]	Many types, from small freshwater to very large marine; among most conspicuous is *Mugil cephalus* (mullet).
Invertebrate (marine)	Opihi (*Cellana exarata*)	Among most common shells from top of Unit V to surface.
	Pipipi (*Nerita picea*)	Among most common shells from top of Unit V to surface.
	Sea urchin (*Heterocentrotus mammilatus*)	Present from top of Unit V to surface.
	Others (13 types, listed in descending order of total weight)	*Cypreaea moneta, Strombus maculatus, Drupa morum, Brachidontes crebristriatus, Littorina pintado, Conus nanus, Turbo petholatus, Isognomon perna, Nerita polita, Musculus aviarius, Periglypta edmondsoni, Harpa conoidalis, Trochus intextus.*
(fresh/brackish)	Hapawai (*Theodoxus vespertinus, T. cariosus*	Abundant before humans. Used throughout Polynesian occupation, not present after Unit VII (18th century).
(terrestrial)	Land crab (*Geograpsus* aff. *geayi*)	Abundant before humans. Size decreases after human arrival, not present after Unit VI (AD 1425-1660).
Plant	Gourd (*Lagenaria siceraria*)	Abundant from top of Unit V (human arrival) to Unit VIII (19th century). See Appendix for ^{14}C results.
	Coconut (*Cocos nucifera*)	Common from top of Unit V (human arrival) to surface. Many large pieces from lower units are *niu hiva* (small bitter variety).
	Yam (*Dioscorea bulbifera*)	One tuber recovered, from Unit VII. See Figure 7.
	Kukui nut (*Aleurites mollucana*)	Extremely abundant from top of Unit V (human arrival) to surface. See Appendix for ^{14}C results.

[a] *Rattus exulans* was both a human commensal and a food item in pre-European Hawaii.
[b] *Mugil cephalus* is present in prehuman deposits as well. Mullet enter brackish and fresh waters from the ocean to feed. Their prehuman presence confirms the site's connection to the pond on the outside of the North Cave entrance (Kapunakea). Most other marine fish are present only in the human midden layers.

Polynesian-introduced animal remains include pig, dog, chicken, and Pacific rat. European contact is clearly demarcated (see below) by the advent of goat, sheep, cow, and horse remains (Burney *et al.*, 2001). To date, no direct evidence for human predation on an extinct bird, such as cut-marks on bones, has been recognized from the site (H. James, pers. comm.).

A large diversity of marine fish remains is present, including vertebral discs of large elasmobranchs (ray or shark) and a great many remains of mullet or *`ama `ama (Mugil cephalus).* Work is underway to identify the many fish remains from the site (Storrs Olson, unpublished data).

Shells of edible marine shellfish, most of them absent or rare in pre-human layers, were quite numerous, especially *pipipi (Nerita picea)* and *opihi (Cellana exarata).* Layers of Polynesian age contained shells of at least 16 marine species, presumably food items (Ryan Ly, pers. comm.). The presence of these marine shells only in layers from the Polynesian period strongly implies their utilization for food or some other human purpose.

The shells of indigenous brackish-water univalves, the *hapawai* (*Theodoxus vespertinus* and *T. cariosus*), occur in prehuman layers, continue through Polynesian times, and disappear from the site after European contact (Burney *et al.*, 2001). In the Polynesian layers, many of the shells have apices broken off in a characteristic way associated with consumption. This is a food item fondly remembered by many older residents, and occasionally still indulged in areas where they have survived on Kaua`i's north shore.

An extirpated land crab (*Geograpsus* aff. *geayi*) occurs for thousands of years before human arrival as a fossil at the site. After human arrival, it persists through Unit VII, shows a decline in mean size over this time interval, then disappears (Alec Burney, unpublished data). No evidence was found to discern whether it was used as a food item, but a gradual size decrease prior to extirpation is consistent with a pattern of overexploitation of an animal resource, especially for species whose body size increases throughout life (Flannery, 1994).

In addition to the bottle gourd discussed above, shells of coconut and *kukui* (*Aleurites moluccana*) are extremely abundant from human advent in Unit V up to the twentieth century. A rare find was a single small tuber (Fig. 7) of the Polynesian-introduced yam (*Dioscorea bulbifera*).

The Contact Period

Māhā`ulepū, like nearly all locations along Kaua`i's south shore except Waimea (where British Captain James Cook made the first documented European landfall in the Hawaiian Islands in 1778), does not figure prominently in the earliest annals of European contact. This is probably owing to

Fig. 7. Unique "mummified" yam (*Dioscorea bulbifera*) from subaqueous sediments of Makauwahi Cave. This was a root-crop grown by prehistoric Polynesians in dry sandy localities.

the scarcity of suitable anchorages in the vicinity. In 1792 Captain George Vancouver sighted the plains of Māhā`ulepū and noted numerous campfires (Vancouver, 1801). This relatively remote area of the coast most likely changed little in the first few decades after contact except for the impacts of European diseases and livestock introductions.

The upper part of Unit VII and all of Unit VIII at Māhā`ulepū contain evidence, including many shell and bone fishhooks, for a traditional Hawaiian diet and lifeway well into the nineteenth century. These layers also contain increasing amounts of European-derived material, however, starting with bits of iron and abundant remains of goats and/or sheep, and soon following with the other introduced European livestock. Other types of European goods, including a small piece of cloth that looks like sailcloth, occur in the top of Unit VIII, considered to be late nineteenth or early twentieth century (Burney *et al.*, 2001). The persistence of pre-Contact fishhook-making traditions here for a century or more after the beginning of European influence may reflect either the poverty of local natives, or their cultural conservatism, or both (see Bayman, 2003).

Historical Documents

Other sources of information about the Māhā`ulepū area in the nineteenth century are of course available from historical documents. An 1824 sketch by Hiram Bingham (Fig. 8) depicts a small village, labeled "Mahaulepu," in which 34 man-made structures are clearly pictured. The line of mountains in the background matches well the present view looking inland from the seashore just east of the cave. Interestingly, only one tree is shown.

Old maps, such as one dated 1886 (Fig. 9), confirm that a large pond, Kapunakea, existed on the landward north side of the sinkhole, forming a large crescent adjacent to the ground-level entrance to the North Cave. This pond, which was probably connected tenuously to the sea over a sand bar, was partially drained by channelization in the 1950s (Adena Gillin, pers. comm.). Excavation at this entrance (Burney *et al.*, 2001) showed that Kapunakea was probably integral with the pond inside the sinkhole until it was drained. The pond's original alignment is apparent in aerial imagery, such as the near-infrared false color image rendered in greyscale in Fig. 10.

It is clear from the Land Court Award (LCA) records that at the time of the Great Mahele (first colonial land division) in 1848 many people lived in the area. Land-use activities included cultivation, pastoralism, and salt ponds.

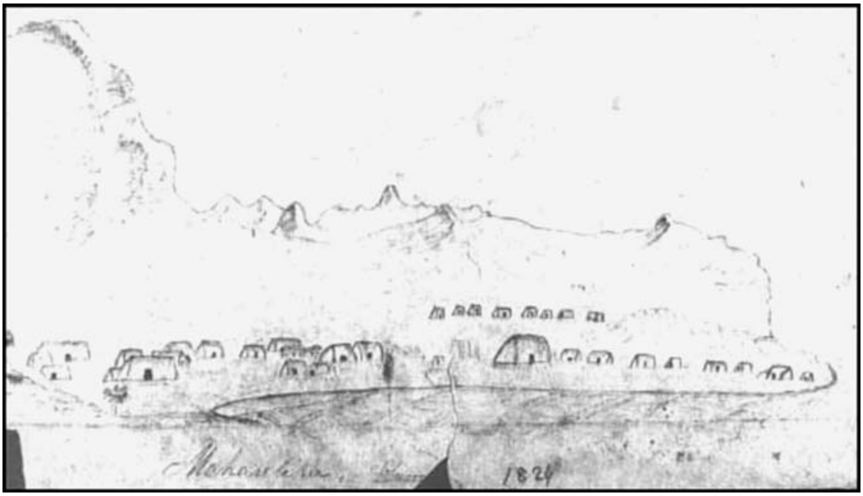

Fig. 8. Sketch of lower Māhā`ulepū Valley, dated 1824, drawn by Hiram Bingham. At least 34 human structures are visible, suggesting dense occupation at this time. A single tree is clearly visible in the lower left. The outline of Haupu Ridge spans the background. (Courtesy of Missionary Children's Museum, Honolulu, and Kaua`i Historical Society, Lihue).

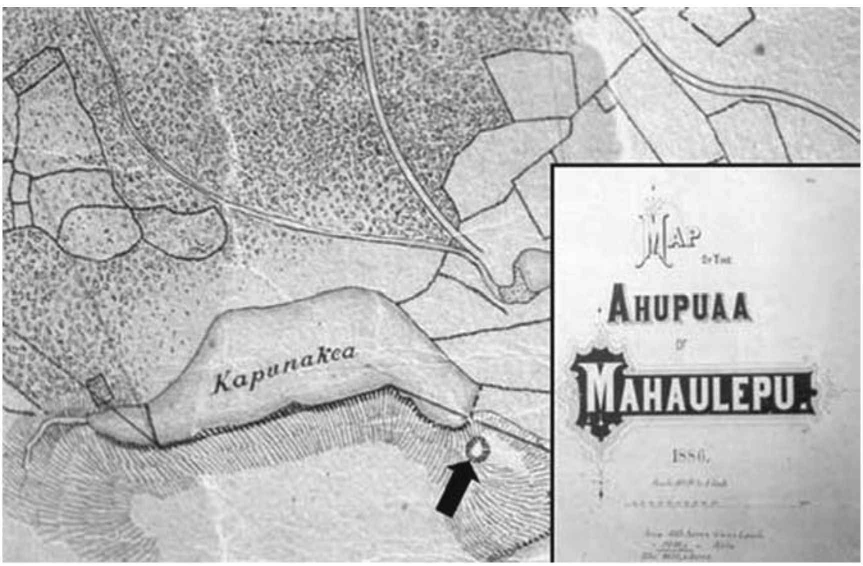

Fig. 9. Excerpt from 1886 map showing Kapunakea Pond and the sinkhole (indicated by arrow, added by authors). Map aligned to geographic north. Inset not to scale (map courtesy of Grove Farm Homestead Museum).

Oral History

One of the denizens of this valley from the mid-nineteenth century was Keahikuni Kekauonohi, the original LCA awardee of the cave (1848) and the great-great-great-grandfather of LaFrance Kapaka-Arboleda (pers. comm.). Ms. Kapaka is regarded as the "traditional owner" of the Makauwahi Cave (Grove Farm Company is the owner in current legal sense). Her ancestor, who is interred in a remote place closed to all visitation and protected by State and Federal laws, was a *kahuna* (shaman) who used the cave as a place of divination. Supplicants would come to him inside the cave. He would kindle a fire then put it out and read the answers to their questions in the patterns created by the smoke and ashes.

This ritual practice is consistent with excavated findings on the high sandy area near the entrance to the South Cave (see Fig. 1, Burney *et al.*, 2001) where there are large amounts of partially burned charcoal in the upper part of Unit VIII. Ten postholes are present in Unit VIII, intrusive into VII, and an *imu* or earth oven, containing a cooked pig, appears to have been ritually buried in grid O35. This was a practice carried out at the boundary between two *ahupua`a.* The sinkhole is on the boundary between Māhā`ulepū on the east and Pa‘a to the west.

William Kikuchi rediscovered the name Makauwahi, not previously in use in the twentieth century to our knowledge, in the Lahainaluna papers:

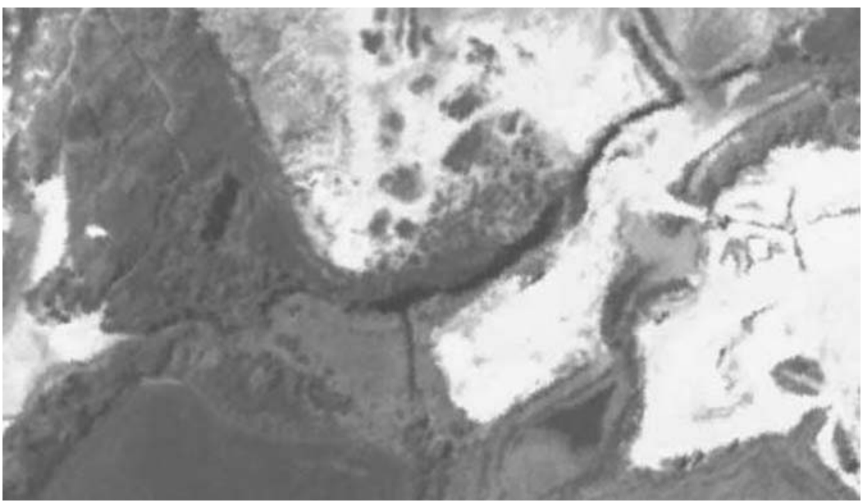

Fig. 10. Aerial view of Makauwahi vicinity ca. 1998, taken by NASA in connection with the Pathfinder program. Outline of Kapunakea Pond basin (now mostly drained) is clearly visible. Compare to Figure 9, rendered with same scale and orientation. (Digital infrared photo courtesy of NASA and Pacific Missile Range Facility, Barking Sands, Kaua`i).

> Kua is a fishing ground. When Maona appears above Kioea that is the lower land mark. When Makauwahi, a long cave at Paa seems to appear at the brow of Makaihuena, that is the upper land mark. (Papers by Lahainaluna students, 1885)

It may be that the name derives from *maka uahi,* which could be translated "eye smoke," "in the smoke," or "source of the smoke," perhaps referring to smoke in the eyes or seeing through smoke, as in Ms. Kapaka's description of her ancestor's fire divining.

The Plantation Era

By the late nineteenth century Hawaiians had declined greatly in numbers due to introduced disease and emigration, the last remnants of coastal forest had been leveled in the quest for sandalwood trees for export to China, and the era of large-scale plantation agriculture (e.g., sugar cane and pineapple) was underway (Joesting, 1984). Stratigraphic evidence from upper Unit VIII, as well as historical documents and photographs, indicate that the lower Māhā`ulepū Valley and adjacent areas were heavily utilized at this time by feral and domestic livestock. A virtually entire horse skeleton was excavated from the upper Unit VIII sands in the EP excavation. Cow and equid bones are a frequent occurrence there and also in the SC excavations at the same level. A photograph (Fig. 11) taken NE of the cave system, looking back toward Kapunakea pond probably sometime between 1890–1920, shows a virtual "moonscape" of rocky terrain almost entirely devoid of any vegetation except short grass. Sedimentological evidence suggests that the removal of ground cover nearby resulted in the reactivation of the dune field adjacent to the sinkhole. Along the east side of the sinkhole, Unit VIII consists almost entirely of rounded grains of wind-driven dune sand. Pollen and plant macrofossil evidence from the site at this time likewise confirm that vegetation was no longer diverse, and the only trees present were European-introduced "weed" trees such as Java plum, banyan fig, and woody legumes (Burney *et al.*, 2001).

By the 1950s, Māhā`ulepū Valley was under cane cultivation, a limestone quarry was operating near the cave on the site of the adjacent Waiopili Heiau, and a channel was constructed that drained Kapunakea to the sea. This is the "stream" that flows by the cave entrance on the outside, called variously Waiopili Stream, Kapunakea, or Mill Ditch. Since then, periodic flood events have carried a mixture of old pond sediments, loamy clay soil from cane-fields, and overwash debris (marine sand and woody material) into the cave, building up Unit IX above the water table in the North Cave, sinkhole, and front of the South Cave. Sedimentation rates in the late twentieth century have been the highest recorded in the sinkhole in

Fig. 11. Old photo, looking SW, of limestone escarpment (Keahikea Cliff) containing entrance to North Cave (on left end). Much of the hill on the right side of the picture has subsequently been quarried away. Note the lack of woody vegetation and closely grazed appearance of the landscape. Kapunakea Pond is the strip of water extending across the middle ground of the photo, up against the escarpment. Picture was probably taken between 1890–1920. (Courtesy of Bernice P. Bishop Museum).

the entire Holocene (Burney *et al.*, 2001), and other sites around the coast show a similar increase at this time (Burney, 2002a).

Recent Decades

The caves have been a popular spot for picnics, sightseeing, and contemplation for local visitors and tourists for decades. Many stories have been told (some are almost certainly modern concoctions) about the site. Modern graffiti have been added to the walls, including a large face in the North Cave. The place is referred to by many names, including Limestone Quarry Cave (Howarth, 1973), Grove Farm Sinkhole System (Halliday, 1991), Grove Farm Cave (Ashbrook, 1994), and the Māhā`ulepū Caves (Kikuchi and Burney, 1998). It is referred to as "the natural amphitheatre" in various tourist brochures, and merely as "the sinkhole" among locals today. We recommend the adoption of the name Makauwahi, since this name almost certainly has historical priority (Papers by Lahainaluna Students, 1885) and the etymology may carry rich connotations regarding previous ritual use.

SUMMARY AND CONCLUSIONS

Evidence from a full millennium of human activity chronicles the details of life nearby and its considerable impact on the island environment. The Makauwahi Cave site provides a rich record of life before and after human arrival, and preserves many artifacts and food remains, including perishable cultural items. Oral traditions said to extend back as far as the fourteenth century in some cases show good agreement with the archaeological and paleoecological record. Following European contact, additional environmental impacts, including a drastic increase in erosion and many additional biological invasions, are documented from the site.

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Appendix. ^{14}C Dates for Makauwahi Cave.

Site/Lab #	Material	Type	Depth[a]	^{14}C yr BP[b] $\pm$ 1σ	Calibrated age range[c] at 2σ	d^{13}C	Provenance
β-122587	*Aleurites* seed	radiometric	275–285	modern	too recent for calibration	–22.6	J34, South Cave excavation.[h]
β-110270	*Aleurites* seed	AMS	142–146	10 $\pm$ 40	too recent for calibration	–25.4	N35, South Cave excavation.[h]
β-67394	humic silty clay	AMS	112–113	[2145 $\pm$ 55][d]	not applicable (date rejected)	–26.4	Cone 3.[h]
β-122586	*Aleurites seed*	radiometric	305–315	20 $\pm$ 60	A.D. 1685–1955 +	–24.3	J34, South Cave excavation.[h]
β-110271	*Aleurites* seed	AMS	225–235	90 $\pm$ 40	1675–1955 cal A.D.	–24.5	LL49, East Pit excavation.[h]
β-122588	*Aleurites* seed	radiometric	245–255	100 $\pm$ 50	1665–1955 cal A.D.	–25.8	J34, South Cave excavation.[h]
β-116527	*Aleurites* seed	radiometric	155–160	160 $\pm$ 60	1645–1955 cal A.D.	–21.9	O33, South Cave excavation.[h]
β-122585	*Lagenaria* rind	AMS	325–335	180 $\pm$ 50	1645–1950 cal A.D.	–28.2	J34, South Cave excavation.[h]
β-134127	*Aleurites* seed	radiometric	275–285	190 $\pm$ 60	1530–1955 cal A.D.	–23.7	S50, Middle Pit excavation.[i]
β-116526	*Aleurites* seed	radiometric	150–155	220 $\pm$ 60	1515–1950 cal A.D.	–24.5	N33, South Cave excavation.[h]
β-134126	*Aleurites* seed	radiometric	265–275	230 $\pm$ 70	1490–1950 cal A.D.	–25.1	S50, Middle Pit excavation.[i]
β-110272	*Aleurites* seed	AMS	245–255	340 $\pm$ 40	1450–1650 cal A.D.	–25.4	LL49, East Pit excavation.[h]
β-110273	*Aleurites* seed	AMS	275–285	300 $\pm$ 40	1480–1660 cal A.D.	–25.4	LL49, East Pit excavation.[h]
β-116189	*Aleurites* seed	AMS	235–245	380 $\pm$ 50	1430–1645 cal A.D.	–24.1	KK47, East Pit excavation.[h]
β-115789	*Lagenaria* rind	AMS	285–295	410 $\pm$ 40	1425–1625 cal A.D.	–25.9	JJ46, East Pit excavation.[h]
NZA 10058	bone (*R. exulans*)	AMS	305–315	822 $\pm$ 60[e]	1039–1241 cal A.D.	–13.2	LL49, East Pit excavation.[h]
β-164910	sandy peat	AMS	381–382	970 $\pm$ 40	1000–1170 cal A.D.	–20.8	Core 20.[j]
NZA 10056	bone (*Grallistrix*)	AMS	245–255	2328 $\pm$ 60	2485–2157 cal B.P.	–16.0	KK46, East Pit excavation.[h]
β-67395	humic sandy clay	AMS	296–297	2705 $\pm$ 55	2910–2745 cal B.P.	–24.4	Core 3.[h]
NZA 10057	bone (*Buteo*)	AMS	245–255	3416 $\pm$ 60	3830–3475 cal B.P.	–15.9	KK46, East Pit excavation.[h]
β-110275	sandy peat	radiometric	305–315	3670 $\pm$ 60	4155–3845 cal B.P.	–25.8	LL49, East Pit excavation.[h]

Site/Lab #	Material	Type	Depth[a]	^{14}C yr BP[b] $\pm$ 1σ	Calibrated age range[c] at 2σ	d^{13}C	Provenance
β-128626	sandy peat	AMS	356–358	3760 ± 70	4380–3915 cal B.P.	−20.2	Core 6.[h]
β-151833	humic sand	AMS	469–473	3800 ± 40	4290–4080 cal B.P.	−8.4	Core 6.[i]
β-110274	sandy peat	radiometric	365–375	4310 ± 60	5035–4820 cal B.P.	−24.3	LL49, East Pit excavation.[h]
β-56647	humic sandy clay	AMS	398–399	4470 ± 70	5315–4860 cal B.P.	—	Core 3.[h]
β-149721	*Cordia* fruit	AMS	530	4610 ± 60	5470–5060 cal B.P.	−27.2	Core 20.[i]
β-115788	*Cordia* fruit	AMS	265–275	4680 ± 50	5580–5305 cal B.P.	−23.8	KK46, East Pit excavation.[h]
β-115786	*Cordia* fruit	AMS	375–385	4700 ± 50	5585–5310 cal B.P.	−23.9	KK47, East Pit excavation.[h]
β-64124	sandy peat	radiometric[f]	477–481	4780 ± 110	5730–5300 cal B.P.	−27.2	Core 3.[h]
β-115790	*Cordia* fruit	AMS	305–315	4960 ± 50	5875–5600 cal B.P.	−24.5	KK47, East Pit excavation.[h]
β-115785	*Cordia* fruit	AMS	495–505	4980 ± 50	5890–5605 cal B.P.	−23.7	KK46.5, East Pit excavation.[h]
β-115787	*Cordia* fruit	AMS	355–365	5010 ± 50	5900–5620 cal B.P.	−23.4	JJKK46, East Pit excavation.[h]
β-128627	*Cordia* fruit	AMS	672–673	5020 ± 70	5920–5605 cal B.P.	−24.3	Core 6.[h]
β-115783	*Cordia* fruit	AMS	475–485	5030 ± 50	5910–5645 cal B.P.	−23.5	KK46.5, East Pit excavation.[h]
β-115784	*Cordia* fruit	AMS	425–435	5120 ± 50	5945–5740 cal B.P.	−24.1	KK46.5, East Pit excavation.[h]
β-93000	sandy peat	AMS	832–836	5860 ± 50	6760–6545 cal B.P.	−28.4	Core 6.[h]
β-128625	marine bivalve	AMS	600–630	6550 ± 90[g]	7190–6660 cal B.P.	−0.3	II45, East Pit excavation.[h]
β-128629	silty clay	AMS	944–946	8490 ± 80	9560–9320 cal B.P.	−24.3	Core 6.[h]
β-128628	clay	AMS	899–901	8520 ± 80	9580–9425 cal B.P.	−24.7	Core 6.[h]

[a]Depth in cm below datum in excavations, and cm below surface in cores.
[b]Corrected for isotopic fractionation.
[c]Based on Stuiver *et al.* (1998).
[d]Date rejected. Sediments in this unit contain old carbon derived from erosion of channelized lake basin. See Burney *et al.* (2001) for details.
[e]Gelatin fraction of *Rattus exulans* pelvis. Insoluble residue (probably sediment-derived organic acids) dated to 3038(60 yr BP (NZA 10132), δ^{13}C-23.9.
[f]Small sample, given 4 X normal counting time.
[g]Applied local reservoir correction for marine samples (Stuiver and Braziunas, 1993) of 115 ± 50 yr.
[h]Date previously reported and discussed in Burney *et al.* (2001).
[i]Date previously reported and discussed in Burney (2002a).
[j]This new result dates a marked increase in charcoal at Makauwahi that may be the first evidence for humans at the site.

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