"Preceded by Forest": Changing Interpretations of Landscape Change on Kaho'olawe

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Man is everywhere preceded by forest, followed by desert
—Anonymous graffito, Paris, May 1968

THE ISLAND OF KAHO'OLAWE is the smallest of the eight major islands of the Hawaiian chain and is located 18 km southeast of Maui and in the rainshadow of its highest mountain, Haleakalā (3055 m [10,023 feet]). It is roughly 17 by 10 km and is 117 km^2 in area, with its highest point at 450 m.

Despite being such a relatively small island, Kaho'olawe has been the center of controversy for much of this century. The initial controversy was over how to rehabilitate the devegetated and rapidly eroding island, with ranchers and foresters the protagonists in the debate. But this early conservation issue was rendered academic when the island was taken over in 1941 by the U.S. military for use as a target island, and all conservation measures ceased. Kaho'olawe soon gained the reputation as "the most shot at island in the Pacific" (*Honolulu Star-Bulletin*, 16 August 1946, p. 19, c. 1–2). Military control continued after World War II and the use of the island for target practice and other military manoeuvres continues to the time of writing, much to the chagrin of various citizen groups and international peace organizations.

Although efforts were made by Inez Ashdown, the daughter of a former rancher, the County of Maui, and the Territorial and (after 1959) State Government, to have the island returned to civilian use, it was only in 1976 that the island's military status was seriously challenged. It was the Protect Kaho'olawe 'Ohana (PKO), a grass-roots Hawaiian native rights organization, that took the U.S. Navy on, this time in the Federal courts. The PKO filed a class-action suit claiming that "continued use of live ordnance on Kaho'olawe pollutes the environment, endangers lives, interferes with religious practices and destroys historical sites" (*Honolulu Advertiser*, 14 October 1976, p. A6), and that in failing to file an environmental impact statement describing the impact of military use on the island's archaeological sites, the Navy had violated the National Environmental Protection Act.

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When Hawaiian protests started in January 1976, archaeological knowledge of the island was limited to a short monograph by McAllister (1933). In response to PKO charges of destruction of historic sites by bombing, the State Historic Preservation Officer recommended, and the Navy agreed to, an archaeological survey of the island. This took place between 1976 and 1980. The PKO eventually won the lawsuit but failed to get the military off the island. Conflicts arose during and as a result of the survey between Hawaiians and archaeologists over the significance and interpretation of the archaeological sites on the island, and over the causes of the devastation of its vegetation and landscape (detailed in Spriggs 1989).

In 1980 the entire island was placed on the National Register of Historic Places as an archaeological district. Although military use continues, targets are now placed away from archaeological sites and the PKO is allowed monthly access to the previously restricted island for religious and cultural purposes. For several years the Navy has been preparing a Cultural Resource Management Plan for the island and is following a number of procedures of interim management policy. These included an interim site protection program involving data recovery and stabilization of those archaeological sites that are immediately threatened by erosion.

The project with which I was associated in 1982–1983 was a second phase of the interim site protection program. For the aims and results of the 1982–1983 project see the two-volume report by Rosendahl et al. (1987).[1] My own objective was to examine landscape change on the island in the prehistoric and historic periods. This involved a short program of field work and a reconsideration of historic sources and previous theories about how Kaho'olawe had come to present its current eroded and windswept appearance. The basic question to be addressed was when had this degradation of the landscape occurred, whether historically (post–1778) or predominantly in the prehistoric era.

Based on the results of the 1976–1980 survey (to be discussed below), Kaho'olawe has been held up as a classic case of prehistoric land degradation and subsequent population collapse. In the literature this view has come to replace the earlier one that its degradation was caused by overgrazing in the nineteenth and twentieth centuries, exacerbated by later military use. The revised interpretation has been generally publicized by the writings of Kirch (1982*a*:10, 1982*b*:4, 1983:30, 1984:108–109, 1985:153–154; see also Barrera 1984 [written in 1980]), and to an audience outside the Pacific by J. M. Diamond, among others (see for instance Keegan and Diamond [1987:79]). But was this bad press for Kaho'olawe justified?

HISTORIC DESCRIPTIONS

The first written references to Kaho'olawe start in 1779; it was an island often sailed past but rarely visited. In fact, the first significant account of a visit to the island by a literate observer is from 1841, more than 60 years later.[2] The historic descriptions of the island usually quoted are those by early explorers such as James King of Cook's expedition and the artist Jacques Arago of Freycinet's voyage, who viewed only the south and west sides of the island from a distance of several miles offshore (see for instance, King in Cook [Beaglehole] 1955–1974:III:I:582; Arago 1840:229–230). Table 1 summarizes the comments on Kaho'olawe's appearance by explorers (none of whom landed) from 1779 to the 1820s.

In all cases where the exact route of their ships can be established, it has been

TABLE 1. EXPLORERS' DESCRIPTIONS OF KAHO'OLAWE, A.D. 1779 TO C. 1825

YEAR	REFERENCE	DESCRIPTION
1779 (Feb.)	Clerke 1779 (unpaged)	The East point of an island named Tah'hoo'row'a [Kaho'olawe] lying on the south side of Mow'wee [Maui] N12°E distant about four leagues. We now stood in for the land, at 8 bore away and run along the South side of Tah'hoo'row' a which makes in high barren cliffs; the S.W. point of it is moderately low but very barren, we could see nothing at all about it but a few shrub bushes.
1779 (Feb.)	King in Cook [Beaglehole] 1955–1974 111:1:582	. . . Tahowrowe [Kaho'olawe], the western part of which we saw look'd very desolate, neither houses, trees, nor any cultivation that we saw: It is of a mod height, and has a sandy appearance.
1779 (Feb.)	Anderson 1784:595	A small barren island
1779 (Feb.)	Anderson 1784:601; cf. Cook, Clerke, and Gore 1818:119	It is destitute of wood, and its soil seems to be sandy and infertile
1779 (Feb.)	Bayly n.d. (unpaged)	This is one continued bed of lava, without any water on it consequently without inhabitant.
1779 (Feb.)	Burney 1776–1780:37	This island looks ragged and bare of trees making much such an appearance as Neehow [Ni'ihau].
1779 (Feb.)	Law 1779 (unpaged) cf. Edgar 1778–1779 (unpaged)	Looks rather Barren—like Oneehow [Ni'ihau]—tho' probably a good Yam Island.
1779 (Feb.)	Samwell 1778–1779 (unpaged)	A small low Island without any trees or any Inhabitants upon it—we saw Lava upon it
1779 (Feb.)	King in Cook [Beaglehole] 1955–1974: 111:1:609	It has no wood on it, seems a sandy poor soil, and is altogether a poor island.
1792 (March)	Chatham (Armed Tender) n.d.:123–124	As we passed Tahoorowa [Kaho'olawe], we observed large fires made on the side of the hills running in different directions that had the effect of a grand illumination, and was either intended as a compliment to us, or for purpose of clearing away the ground for a new crop of the grass used by the natives for covering their houses with.
1816 (Nov.)	Kotzebue 1967:1:318; cf. Chamisso 1970:11	Sailed so close to the island of Tahoorowa [Kaho'olawe], that we saw a number of fires along the shore [west end of island]
1817–1820	Freycinet n.d.:43; cf. Freycinet 1978:47	This island, not very elevated, and beaten on the southern shores (falaises) by the sea, is steep (escarpée) at that point, and is formed with horizontal layers of lava.
1818 (Oct.)	Golovnin 1979:218	Uninhabited because of its unproductive rocky soil . . . countless numbers of sea birds dwell there
1819 (Aug.)	Arago 1971:11:118	A barren island, flat, and moderately elevated, on which was not the slightest appearance of vegetation. The soil is reddish and furrowed at intervals. The island is desert and uninhabited.
1819 (Aug.)	Arago 1840:229–230 (trans. by Silva)	Reddish on the sides, black at her base, copper at her summit; Taouroe [Kaho'olawe], island of rock, embattled, notched, at the peak in pointed ridges, similar to a decrepit wall of lava chiselled by the centuries.

continues

TABLE 1. *Continued*

YEAR	REFERENCE	DESCRIPTION
		Who, then, has touched this ground barren of any greenery, who then has tried to scale these formidable ramparts on which the waves thunder and crash with such violence? No one. And yet the long and perilous reefs surround Taouroe [Kaho'olawe], as if the crags had to fear the conquest of man, as if they wanted to defend themselves against all greediness the wealth that is hidden perhaps in its sides. Taouroe will be eternally uninhabited, for life there is impossible.
1823 (June)	Ellis 1827: 9	It is low, and almost destitute of every kind of shrub or verdure, excepting a species of coarse grass.
1823–1825	Stewart 1970:91	A mass of uninteresting and barren rock

Note: Data from Silva 1983.

found that early explorers passed south of the island, in particular giving the western end a wide berth because of a dangerous reef or shoal off the southwest point. No early descriptions exist of the north and east (windward) coasts. The channel between Kaho'olawe and Maui was rarely used when sailing between Hawai'i and Lahaina or O'ahu, and when this route was used it appears the ships kept close to the Maui coast. Vancouver passed between Kaho'olawe and Maui on 10 March 1793 but did not comment on the island, and Ellis passed the same way in 1823 en route to O'ahu but at night (Vancouver 1984:851; Ellis 1827:454).

In Wilkes' sailing directions to Lahaina (1861:293), the merits of these two alternative routes are discussed. It is clear why the southern route was preferred:

> If a vessel wishes to anchor in Lahaina Roads, coming from the eastward, she ought, after leaving Hawaii, to steer so as to clear the west end of Kahoolawe. There is a passage to the north of Kahoolawe, between it and Maui, through which a vessel may sail. The islet of Molokini lies in the middle, between the two, and is the only danger; but I cannot recommend this route to any vessel. The land of both islands is high, and a vessel may be becalmed in passing through, and experience much detention from baffling airs from all points of the compass, and not infrequently be struck by heavy squalls, which from their suddenness as well as violence, would be very apt to cause the loss of light-sails and spars.
>
> The southwest point (Kealaikahiki Point) lies at 156° 42′ west longitude, latitude 20° 31′ north. A berth of five miles should be given to this point; off it lies Kuia Shoal, $1\frac{1}{2}$ miles distance, on which there is but $1\frac{1}{2}$ fathoms water.
>
> A vessel may pass close to the shore within this shoal, but it is advisable to go outside further to the south. The more room a vessel gives the west point of Kahoolawe the better; the breeze will be stronger, and cause the least delay in reaching the roadstead of Lahaina. When to the west of Kealaikahiki Point some six miles, the easterly breeze will be lost. Then the most western peak of West Maui will bear north 25° east (true); steer directly for it. About noon the sea-breeze sets in daily towards Maui, which will carry a vessel onward to the anchorage.

In assessing the early descriptions of the island it should be remembered that much of the southern coastline consists of high cliffs and that the western end is the driest and most agriculturally marginal area of Kaho'olawe. Apart from occupation of the coastal fringe, there is very little archaeological evidence of utilization of the western third of the island.

Although the missionary William Richards probably visited Kaho'olawe several times beginning in summer 1827, he left no detailed accounts of his visits (*Missionary Herald* 1828:II:53, Richards letter 14 April 1828; Annual Reports A.B.C.F.M:I:50 [1828] as quoted in Silva 1983). The first detailed account is from Wilkes, referring to a journey across the island from the western end to Kaulana on the north coast undertaken by Lieutenant Budd in March 1841:

> In passing over the island, the walking had been found very tedious; for they sunk ankle-deep at every step. The whole south part is covered with a light soil, composed of decomposed lava; and is destitute of vegetation, except a few stunted shrubs. On the northern side of the island, there is a better soil, of a reddish colour, which is in places susceptible of cultivation (1844:260–262).

Judd (1916:120) uses this description to suggest that aeolian erosion was already underway on the island at this time. The next important description of the island, by Perkins in about 1850, includes this description of the southwestern part of the island:

> The general aspect of the land was desolate in the extreme; the reddish sterile soil being unrelieved by either tree or shrub, and everything seemed parched up by the burning rays of the sun (1854:163).

These descriptions are of the driest part of the island, the western third, exhibiting less than 10 inches of rainfall each year, an area of shrubs, and, at best, annual grassland. Without sufficient rainfall the grass would have died back, revealing the underlying soil but not necessarily representing an eroded landscape. Indeed, this is not the eroded hardpan area of the island even today. Menzies in 1793 had described a similar vista for the ecologically comparable west end of Moloka'i, observing

> a naked dreary barren waste without either habitation or cultivation; its only covering is a kind of thin, withered grass, which, in many parts, is scarcely sufficient to hide its surface apparently composed of dry rocky and sandy soil (1920:22).

Early accounts by ships passing Kaho'olawe remarked on its "sandy appearance" (Cook [Beaglehole] 1955–1974:III:I:582). Also "its soil seems to be sandy and infertile" (Anderson 1784:601, referring to Feb. 1779) and "the soil is reddish and furrowed at intervals" (Arago 1971:2:118, referring to August 1819) appear to refer in particular to the dry west end that the ships coasted round and where vegetation of any kind was often scant. These accounts should not be misunderstood to refer to the island in general, particularly the inland plateau, which was clearly not in an eroded state before the establishment of the first sheep ranch in 1859

This is made clear by Perkins' description of the eastern and central portions of the island, which consisted of grassland and savannah (Perkins 1854:158–168). Further excerpts from Perkins' account are given below in the discussion on pre-Contact vegetation. His is the first direct mention of goats on the island, noting their damage to *'akoko* trees *(Euphorbia multiformis).*

There are two other important descriptions of the island in the 1850s, before the introduction of sheep and the beginning of the ranching period (Nahaolelua and Richardson, December 1857; Allen, May 1858). It is clear from these accounts that the inland plateau, which is now largely eroded hardpan devoid of vegetation, was

TABLE 2. REFERENCES TO ANIMALS ON KAHO'OLAWE, A.D. 1841–1918

DATE	PIGS/DOGS	GOATS	SHEEP	HORSES	CATTLE	REFERENCE
1841	"many tracks" (pigs)	—	—	—	—	Wilkes 1844:260–262
1850	"traces" (pigs)	present, damaging vegetation	—	—	—	Perkins 1854:158–168
1858 (May)	wild pigs and dogs present	wild goats present	—	—	—	Allen 1858: island suitable for 20,000 sheep
1859 (Jan.)	—	—	2000 ready to go to island	—	—	Hawaii State Archives, R. C. Wyllie Private Collection
1859 (June)	dog tracks seen, but no pigs	no goats seen	2075 sheep	—	—	Hawaii State Archives, R. C. Wyllie Private Collection; suitable for 10,000 sheep and 5000 goats
1875	2 dogs (domestic)	a few hundred	20,000	10	—	*Ka Lahui Hawaii*, 12/30/1875, p. 4, c. 2: suitable for 100,000 sheep
1876	—	—	16,000	—	—	Bowser (1880:576)
1880	—	—	"a few"	—	—	Bowser (1880:576)
1881	—	2000 to be removed	1000 to be removed	—	island being stocked with cattle	*Hawaiian Gazette*, 8/17/1881 p. 3, c. 2
1884	—	9000	2000	40	200	McKenney L. M. and Co. 1884:337
1888	—	—	1000	100	800	McKenney Directory Co. 1888:497
1890	—	—	12,000	—	900	Judd 1916:119
1892	—	—	present	—	no cattle	*Pacific Coast Commercial Record*, 5/1/1892, p. 22, c. 5

1896	—	—	—	—	cattle ranch recently established	Finney 1896:496
1899–1900	—	—	—	—	present	Olivares 1899–1900:426
1901–1902	—	—	present	—	no cattle	Dillingham papers, in Bishop Museum
1903 (May)	—	—	7000	—	—	*Maui News*, 5/23/1903 p. 4, c. 3
1903 (July)	—	—	—	—	present	*Maui News*, 7/18/1903 p. 2, c. 3
1903 (Dec.)	—	—	5000	a few	a few	*Pacific Commercial Advertiser*, 12/22/1903 p. 3, c. 2
1904 (Jan.)	—	—	5000	a small band	60	*Maui News*, 1/16/1904 p. 3, c. 3
1906 (Jan.)	—	5000	3200	—	—	Judd 1916:124
1909 (Feb.)	—	—	—	—	the few cattle removed to Moloka‘i	*Maui News*, 2/6/1909 p. 5, c. 1
1909	—	5000	3200	40	40	Judd 1916:121–124
1910	—	c. 1500	c. 1500	—	present	*Hawaiian Forester and Agriculturalist*, 9/1910
1912	—	1400–1500, 50 shot	—	—	—	*Sunday Advertiser*, 1/14/1912, Feature Section, p. 1, c. 1–6
1912	—	—	c. 1000 removed, 40–50 remain	—	—	Low 1982:3
1913	—	present	300	—	—	Forbes 1913:4
1916 (May)	—	286 killed	—	—	—	*Maui News*, 5/26/1916 p. 1, c. 1
1916	—	4300 killed in 10 years	150 remain	—	—	Judd 1916:124
1917 (April)	—	700	—	—	—	*Maui News*, 4/6/1917 p. 5, c. 3
1918 (April)	—	800–1000	—	—	—	*Maui News*, 4/12/1918 p. 3, c. 4

Note: Data from Silva 1983 and various primary sources.

then a savannah of grassland, shrubs, and small trees and was considered to have excellent potential as sheep pasture. A few months after the ranch was started, the island was visited by Webster (May 1859) who gave an equally favorable opinion of its potential. The laudatory comments of Allen and Webster, with talk of the pasture being sufficient for 10,000–20,000 sheep, suggest a very different landscape than today.

From the first ranching period (1859 to 1910) there exist some records of numbers of sheep, and later cattle, stocked on Kaho'olawe, as well as estimates of the number of wild goats (Table 2). Early accounts also noted wild pigs and dogs, but these appear to have been eradicated by 1860. The 1875 account of 20,000 sheep may be an exaggeration, but other accounts mention maximum numbers of 12,000–16,000 sheep and 900 cattle being on the island at particular times. Goat numbers are only rough estimates but their population was clearly in the thousands by the 1880s. The severe effects of overgrazing by feral and domestic arrivals were first noted in 1880, based on information from Walter Murray Gibson:

> It was at one time a flourishing sheep ranch, owned by Judge Elisha H. Allen, but owing to being overstocked and to severe droughts the land became utterly denuded of vegetation, and the constant violent tradewinds blowing over its unprotected plain have been for years carrying off the loosened soil in red clouds of dust, that are blown 30 or 40 miles out to sea. When visited in 1879 not a sheep was to be seen on the plains, all of a stock of about 16,000 that existed in 1876 had apparently perished. But it is said that a few sheep have been found in 1880 on the island, some that may have sustained life in the recesses of sheltered ravines. Of the surface about 35,000 acres is an utter unreclaimable desert, and there are about 5000 acres of good pasture land in the western, or lee side of the island (Bowser 1880:576).

Elisha Allen transferred his lease to Courtney and Cummings in March 1880, and in 1881 Cummings is described as beginning efforts to control erosion:

> To prevent the soil from the upper part of the island being blown away, Mr Cummings has planted a large hedge of prickly pears, and he has every hope that the plan will succeed (*Hawaiian Gazette*, 17 August 1881, p. 3, c. 2).

Gibson's account of the eroded acreage is certainly exaggerated, and the "few sheep" that he mentioned as being found on the island in 1880 are given as 1000 sheep (as well as 2000 goats) in the account of Cummings' improvements. What is clear, however, is that by 1879 severe erosion had already set in, and the period 1876–1879 in which drought and overstocking took place may have been the time that major erosion was initiated.

From 1903 onwards erosion was clearly appreciated as a major problem (*Pacific Commercial Advertiser*, 22 December 1903, p. 3, c. 2; *Maui News*, 16 January 1904, p. 3, c. 2) so that by June 1910, Superintendent of Forestry Ralph Hosmer could write:

> [as a] result of long continued overgrazing this little island, once a valuable asset to the Territory, has become almost worthless through erosion and loss of soil. . . . In recent years soil denudation has gone on so rapidly that now large areas have been eroded down to hardpan (State Dept. of Forestry Files: 23 June 1910; see also Judd 1917).

In 1910 the island was declared a Forest Reserve, the stock was removed, and efforts were made to eradicate the goats. In 1918 the island became a ranch again but efforts into the 1930s to keep down the wild goat and sheep population and to revegetate the eroded areas were never entirely successful. *Kiawe (Prosopis pallida)* was introduced at some point and by 1904 was well established. Australian salt bush *(Atriplex senibaccata)* was introduced about 1918 and made some inroads in the hardpan area (Stearns 1940:125). By the time of the geologist Stearns' visit in March 1939, nearly 15 square miles of land had been stripped to hardpan, the upper two to eight feet of soil having been lost (1940:125). At that time, there were 500 cattle, 200 wild sheep, 25 wild goats, 500 wild turkeys, and a few mules and horses on the island.

While stressing wind erosion, Stearns also noted:

> The bare surface and loose dust are everywhere the easy prey of running water. A few times a year heavy rains beat down on Kaho'olawe and wash into the sea immense quantities of red soil which has taken centuries to form (1940:127).

Stearns' monograph ends in dramatic tone:

> Goats were brought to the island about 1788 [sic], and in a few years the cover of vegetation was nearly destroyed and Kaho'olawe was transformed into a great desert of drifting red dust. Here in the short span of 152 years the soil accumulation of a million or more years was blown away forever and the former green little island became a bare bald forbidding land (1940:147).

In 1941 all conservation efforts ceased and the island was taken over by the U.S. military as a bombing range. Although further damage to the vegetation was doubtless caused by bombing and associated fires, the wild sheep and goat population was no longer controlled and increased rapidly again, preventing any significant revegetation. Comparing Stearns' map (1940:123) with the 1979 vegetation map (Environmental Impact Study Corporation 1979:Figs. 2–9) reveals little change in the area of eroded hardpan. More recently conservation efforts have been renewed. Scudder (1972) came to essentially the same conclusions as Stearns in regard to the history of vegetation and landscape change on the island.

1976–1980 ARCHAEOLOGICAL SURVEY

An examination of historical sources strongly suggests that the major period of erosion occurred during the early ranching period, 1859–1910. However, this view was strongly challenged in 1980 on the basis of archaeological data recovered during the 1976–1980 comprehensive archaeological survey of Kaho'olawe, and a completely different scenario was put forward suggesting that large-scale erosion had been initiated during the prehistoric occupation of the island (Hommon 1980*a*, *b*). Thus initial evidence for erosion was said to date to A.D. 1348 ± 17 on the basis of volcanic glass dating, with massive erosion and subsequent depopulation of the island underway by A.D. 1500–1550 (Hommon 1980*a*:7:60–61), such that population was reduced from a high of about 723 in A.D. 1500 to about 72 by A.D. 1750, and to 61 persons by A.D. 1800 (Hommon 1980*a*:7:55a).

By the late 1970s the prehistoric impact of Oceanic peoples on their island environments was beginning to be appreciated. The creation of anthropogenic grasslands or fern deserts on many Pacific islands in prehistory and human-accelerated erosion of hillsides had been well documented (Golson 1977; Hughes et al. 1979; Kirch 1975; Kirch and Kelly 1975; McLean 1980; Yen et al. 1972). Although many saw this accelerated erosion as landscape degradation, a case can be made that in many areas the productive environment was actually enhanced by the creation (from the products of erosion) of fertile alluvial plains suitable for intensive agriculture and human settlement (Spriggs 1981: Chapter 6, 1985). On an island like Kaho'olawe, however, with no extensive fringing reef or shallow embayments to act as sediment traps, run-off would tend to occur into deep water and therefore no such benefits would accrue.

In the Kaho'olawe survey research design (Hommon 1978, quoted in Hommon 1980*b*) various hypotheses concerning landscape change were formulated. The final report of the survey (Hommon 1980*b*) gives preliminary results of the testing of these hypotheses as they appeared in 1980. The relevant hypotheses are given and the results summarized below.

Hypotheses 9a–c (quoted in Hommon 1980*b*: 35):

> 9a) The large-scale erosion of the interior of Kaho'olawe was initiated and had affected a large portion of the island before contact.
> 9b) The large-scale erosion of the interior of Kaho'olawe was initiated prior to contact but most of its presently visible effects resulted from post-contact activities.
> 9c) The large-scale erosion of the interior of Kaho'olawe is totally a post-contact phenomenon.

The data used to consider these alternatives were "the dated chronology of the burn layers, the depositional history of the Ahupū Formation which overlies them, and the stratigraphic relationship between both these layers and archaeological features" (Hommon 1980*b*: 35). The burn layers will be considered further in relation to Hypotheses 10a–d, but first some discussion is necessary of the Ahupū and underlying Kaho'olawe formations. These two soil horizons were identified in all zones of the island with the Kaho'olawe Formation as a buried palaeosol. Hommon (1980*a*: 7: 60) quotes the geologist Morgenstein's definition of the Kaho'olawe Formation:

> Montmorillonitic, blocky B-horizon reducing, isothermic (Typic) chromustert vertisol developed from sedimentary fans originating in the higher elevations and from alluvium and colluvium on the lower slopes.

Hommon notes that it is usually brown to dark brown (7.5YR 4/2) in color. The Ahupū Formation as described by Morgenstein (quoted in Hommon [1980*a*: 7: 60]) is

> a reddish Kaolinitic weak granular A-horizon, oxidizing, denuded aeolian to aeolian-alluvial ferrigenous low humic latosol (Typic Torrix Oxisol) derived during hot dry climatic conditions.

Hommon gives the color as typically reddish-brown (5YR 5/4).

Sites were identified in both the Kaho'olawe and Ahupū Formations, indicating that the massive erosion represented by the aeolian-derived Ahupū Formation had begun during the prehistoric period. Seventy-six archaeological features (dated using volcanic glass) were identified as to soil formation association: 57 in the Kaho'olawe Formation and 19 in the Ahupū Formation. Nine of these 19 were dated by volcanic glass to the period A.D. 1500–1550

> indicating that the extensive erosion of the island began about this time. The nine features are distributed through seven sub-zones in all three settlement zones. At present it appears that the four features in Ahupu formation contexts that predate the 16th century may evince erosion of a limited scale (Hommon 1980*a*: 7: 61).

The four features referred to gave dates of A.D. 1348 ± 17 (Feature 228A), 1348 ± 39 and 1450 ± 35 (Feature 665B), 1485 ± 43 (Feature 665C), and 1503 ± 42 and 1522 ± 40 (Feature 657A) (Hommon 1980*a*:7:61a). A major contribution to the erosion was identified as removal of vegetation cover by burning, suggested by the presence of burn layers (charcoal layers) at the boundary between the Kaho'olawe and Ahupū Formations. These occur in many parts of the island and "usually measure between 0.5 and 2 centimetres in thickness and consist of charred grass stems and small fragments of charcoal" (Hommon 1980*a*:7:61). None of these burn layers were dated directly by radiocarbon, but dates from archaeological features associated with the Ahupū Formation suggested that they would date to the fifteenth century.

In the final report of the archaeological survey, Hommon suggests that Hypothesis 9a is supported, while noting that "descriptions of Kaho'olawe in the mid-nineteenth century suggest that the denuded hardpan may have been less extensive than at present, and that overgrazing was a major contributor to the most recent phase of degradation" (1980*b*:36).

Hypotheses 10a–d, as quoted in Hommon (1980*b*:36), are given below:

10a) The Kaho'olawe charcoal layers were primarily the result of the preparation of agricultural plots by the slash-and-burn method.
10b) The Kaho'olawe charcoal layers were primarily the result of burning to increase the growth of *pili* grass, a material used in thatching.
10c) The Kaho'olawe charcoal layers were primarily the result of fires that were accidental or naturally-caused.
10d) The Kaho'olawe charcoal layers were primarily the result of burning as a weapon of war.

Hommon concluded that none of the original hypotheses were strongly supported but suggested that a mix of 10a and 10c is likely; that is, large accidental fires started during clearance for agriculture (Hommon 1980*b*:37). Hommon's general conclusions concerning landscape change on the island are worth quoting at length.

> It is assumed that the large sections of virgin land being brought under cultivation were cleared of their natural vegetation cover by means of slash and burn techniques. After abandonment of agricultural plots and during fallow periods, grass and herbaceous weeds would grow on them. The replacement of forests and shrub vegetation by grassland probably extended far beyond the boundaries of the agricultural plots as the inhabitants collected wood as fuel for their fireplaces and earth ovens. This process probably proceeded rapidly as the inland population grew. . . .
>
> The following hypothetical sequence could have initiated the large-scale erosion of Kaho'olawe, particularly if it were repeated for several years:
>
> Just before the end of a severe drought large sections of the inland zone were cleared of vegetation cover in preparation for planting of crops. Large areas of grassland including fallow fields in the vicinity of the agricultural plots were accidentally burned. The drought was broken by a series of severe rainstorms. Substantial gullies were formed and grew rapidly in the cleared agricultural areas, and together with sheetwash, removed large amounts of soil from the lands in a relatively short period of time. Portions of the burned over grasslands on the fringes of the agricultural area were buried in the sediment carried by sheetwash (thus sealing in a "burn layer"). The gullies made inroads into the grasslands where the erosion protection afforded by the grass had been temporarily reduced by the burning of the grass stalks and leaves (Hommon 1980*a*:7:62–63).

Hommon concludes that from a maximum population of 725 at about A.D. 1500, a 90 percent reduction had occurred 250 years later in A.D. 1750 with a population at that time of only 72 people. This was directly associated with the destruction of the agricultural soil of the inland plateau through erosion and the fouling of the nearshore marine environment by the deposition of erosional products at major gulch mouths and along the shore. Differential effects in the Hakioawa and Honokoa catchments, the latter suffering much less erosion, are said to have led to a shift in population from the former to the latter site in the late prehistoric period (Hommon 1980*a*:60–67; 1980*b*:38–39; cf. Barrera 1984 [written in 1980]).

1981 EXCAVATIONS

The next project on Kaho'olawe involved the salvage excavation of 10 fireplaces endangered by erosion (Hommon 1983). Landscape change was again addressed in the research design, in terms of detailed stratigraphy, chronology, and soil associations of the individual features, as well as analyses to determine the nature of the pre-Contact vegetation. A similar stratigraphy was encountered at all sites. It consisted of an underlying *in situ* sediment, equivalent to the previously identified Kaho'olawe Formation, cultural features on top of or cut into this sediment, and overlying these the Ahupū Formation deposits. Some features had suffered erosion prior to the deposition of this latter soil. No cultural features were observed within the Ahupū Formation and the only artifacts within it were occasional stone flakes thought to be in secondary context, metal fragments, and a fragment of goat bone. It was suggested that parts of the Ahupū Formation were only a few decades old. None of the sites excavated had previously been assigned to a specific soil formation (see Hommon 1980*a*: Appendix A).

Volcanic glass dating was said to support the contention of a reduction in inland zone occupation by about A.D. 1650, but in regard to radiocarbon dates from the same features Hommon states that they "neither support nor contradict" this hypothesis (1983:147). Botanical analyses included charcoal identification and recovery and identification of carbonized seeds and other plant macrofossils. These analyses suggested that a substantial variety of woody taxa had existed on Kaho'olawe during the period of human occupation represented at the investigated sites. The identified genera implied a dry forest or savannah-parkland habitat, and the abundance of fireplaces on the inland plateau suggested that woody species were readily available during the pre-Contact occupation (1983:151).

Hommon addressed in some detail the doubts that had been raised, beginning about 1980, concerning the accuracy, indeed the utility, of volcanic glass dating in Hawai'i (cf. Olson 1983). Halbig (1987) has considered the validity of this technique in relation to the chronology of Kaho'olawe (see also Rosendahl et al. 1987:V12–V37).

1982–1983 DATA RECOVERY PROJECT

One of the major objectives of the project in which the author was involved was to investigate Hommon's model of prehistoric environmental modification. This was to be accomplished by integrating various sedimentological, palaeobotanical, and dating analyses of on-site and off-site soil formation exposures to investigate the erosional and depositional history of the island. Consideration was given to prehistoric agricultural practices used on the island and their effects on the environment.

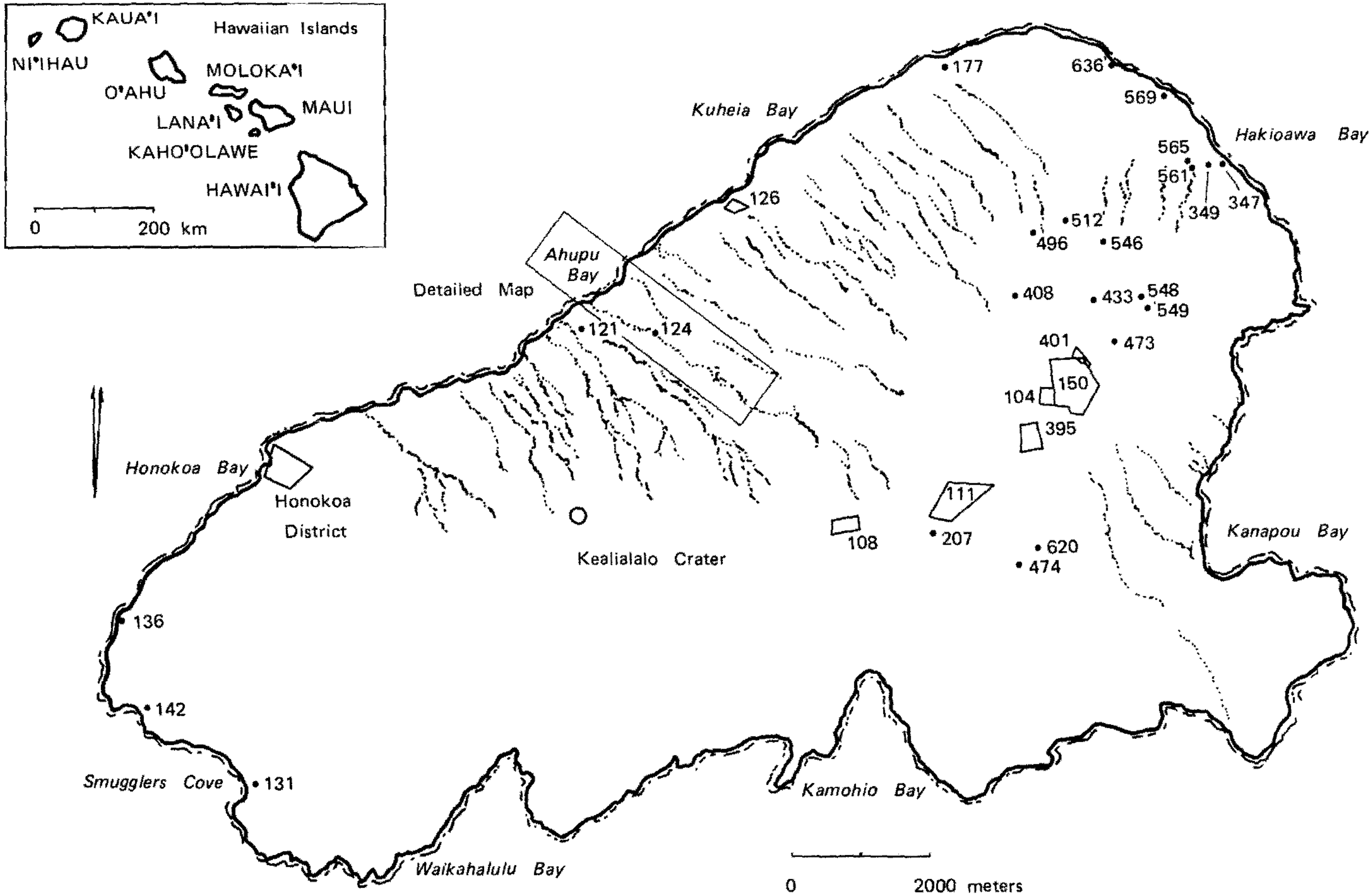

Fig. 1. Project area and site location map.

Direct dating of the burn layers between the Kaho'olawe and Ahupū Formations was considered to be of particular importance for this investigation.

Three kinds of locations were analyzed to test Hommon's model: cultural sites, valley bottom alluvial sequences, and other palaeoenvironmental sites such as burn layer exposures and land snail concentrations (Fig. 1). These locations will now be discussed, followed by a consideration of the issues raised in relation to Hommon's model of Kaho'olawe landscape change. An alternative model will then be presented.

Cultural Sites

As part of the 1982–1983 project six site features were salvaged and 43 features that had previously been identified as associated with the Ahupū Formation were resurveyed (Hommon 1980*a*: Appendix A). Details of the cultural site excavations are given in the project report (Rosendahl et al. 1987). The 43 cultural site features were components of Sites 111 (2 features), 121 (1), 126 (37), 142 (1), and 150 (2). Not one case was found where prehistoric cultural remains were associated with the Ahupū Formation. Thus at least 49 site features appear to have been misidentified as to soil formation association during the 1976–1980 survey. On the basis of this study it is suggested that in fact no prehistoric sites truly belong within the Ahupū Formation, which dates to a period after the abandonment of sites identified as prehistoric. This would affect a further 78 site features. It is also worth noting that none of the sites investigated by Hommon in 1981 were found to be associated with the Ahupū Formation. The misidentification appears to have resulted from two factors:

1. The original survey techniques did not usually involve facing-off the eroding hummock edges or other sites where stratigraphy was observed. Stratigraphic details are often not clear without excavation and so the original survey designations should be regarded as tentative. The problem is compounded by the nature of deposition of the Ahupū Formation. It is generally aeolian in origin and thus can be blown in among the stones of structures and oven features giving the impression that such cultural features are *on top of* the Ahupū Formation rather than that this sediment has blown in around the features and covered them.
2. The original survey involved many different field workers at different times, and many of them were not experienced in geomorphological matters and/or did not clearly understand exactly what was meant by the concepts of Ahupū and Kaho'olawe Formations. At the time of the survey (1976–1980), landscape change was only just becoming a significant concern of archaeological studies in Hawai'i.

Alluvial Sequences

Alluvial sequences were examined in Ahupū and Hakioawa gulches, and a test pit was dug into the floor of Kealialalo Crater to determine the age and rates of alluvial deposition. Soil and color designations (except for Sections D and A in Ahupū Gulch and Section 1 at Hakioawa Gulch) are tentative field identifications. Munsell colors are recorded from dry samples. Section locations are given in terms of the Department of Defense "Kaho'olawe Training Area" photo map (scale 1:25,000) grid coordinates ("GC-").

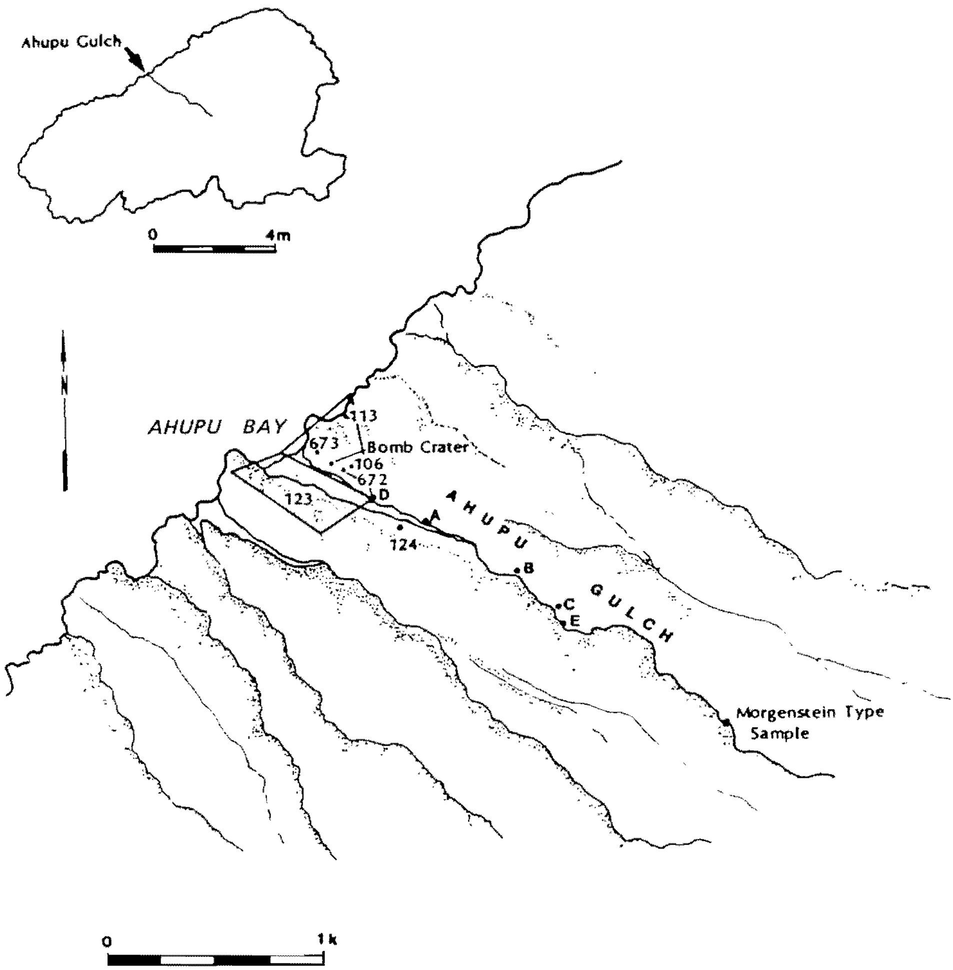

Fig. 2. Alluvial section locations.

Ahupū Gulch

Various terraces on the alluvial valley flats suggest agricultural plots but this interpretation has not yet been confirmed by excavation. Alluvial sections in the dry gulch bank were examined and the profiles were faced-off to enable sediment and charcoal samples to be collected (see Fig. 2 for locations). Also, on the valley floor 200 m inland on the east side of the gulch, a bomb crater was briefly examined. At about 65 cm below surface and covered by alluvially transported Ahupū Formation sediment, a gray marine sand layer with charcoal was revealed extending to the base of the crater at 2 m below surface. All of the alluvial sections examined in detail were inland of this crater. They are discussed in more detail below, beginning with the most seaward section and moving inland.

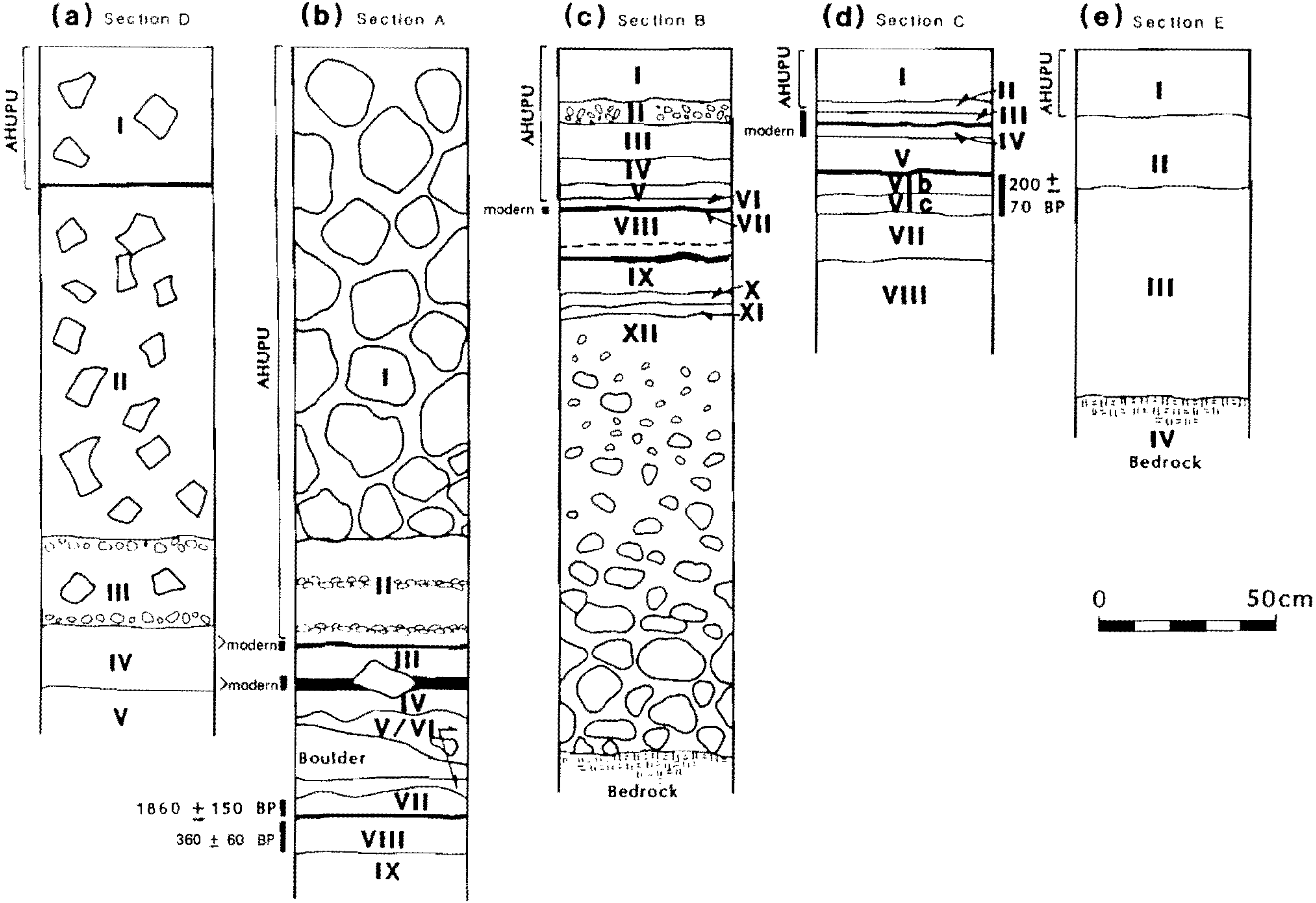

Fig. 3. Ahupū Gulch alluvial sections.

SECTION D

(Approximate GC-467/8, -767) (Fig. 3). 100 m downstream of Site 124, a "volcanic glass mine" and on the opposite (east) bank of the gulch approximately 400–500 m inland. At this point the gulch cuts into a gentle talus slope.

Stratigraphy

L1 c. 0–40 cm. Ahupū Formation silt loam (dark reddish-brown, 5YR 3/4) with subangular talus boulders. Lower contact distinct and regular.

L2 c. 40–140 cm. At top of layer a thin charcoal layer representing an *in situ* burning of grass is present, about 2 cm thick (Layer IIa). The rest of this layer consists of large subangular talus boulders. Matrix is a gravelly loam (very dark greyish-brown, 10YR 3/2). Lower contact distinct and regular.

L3 c. 140–165 cm. Dark brown (10YR 3/3) sandy clay loam with subangular blocky structure. Lens of small subangular cobbles at upper contact, also at base. Occasionally larger rounded to subangular boulders throughout. Very common white, orange, and grey mottles. Lower contact distinct and regular.

L4 c. 165–183 cm. Dark reddish-brown (5YR 3/4) sandy silt loam. Large granular to subgranular structure when dry. Grades to a coarser sand at base. Very common orange, gray, and white mottles. Contact distinct and regular.

L5 c. 183–190 cm. Dark reddish-brown (5YR 3/3) sandy silt loam. Fine granular structure. Extended to base of exposed section.

Apart from the "burn layer" at the Layer I to II contact no charcoal was visible in this section. There is a clear change in depositional mode below Layer II with mass movement of talus material occurring above and lower energy alluvial deposition below. Layers IV and V probably represent an in *situ* differentiation into an A- and B-horizon. Identification of Layer III as a former topsoil is very uncertain. The change in depositional mode suggests increasing hillslope instability with time, which might have resulted from vegetation clearance exposing the slopes adjacent to the location to erosion. The *in situ* "burn layer" of grass stems suggests burning prior to deposition of Ahupū Formation materials, but slope instability clearly predates this deposition.

SECTION A

(GC-471, -766) (Fig. 3*b*). Slightly upstream of Site 124 and on the opposite (east) bank of the gulch, about 200 m downstream of a large creek joining the main gulch from the east. The cliff is 15 m to the east of the creek at this point. On the opposite bank of the gulch (west side) the plain is starting to widen out. About 220 m upstream a "burn layer" was noted on the west bank at the contact between the Ahupū Formation and underlying alluvium that grades into large boulder alluvium. Seaward of this, and opposite Section A, on the plain only Ahupū Formation sediments were revealed in the gulch bank.

Stratigraphy

L1 c. 0–140 cm. Unconsolidated boulder deposit with Ahupū Formation sandy clay loam in the interstices (reddish-brown, 5YR 5/4). Lower contact distinct and regular.

L2 c. 140–170 cm. Ahupū Formation sandy clay loam (reddish-brown, 5YR 5/4). Small rounded cobble lens at 152 cm and 165 cm. Lower contact distinct and regular.

L3a 170–172 cm. "Burn layer." Radiocarbon date (Beta-8130) 105.7 ± 1.1% modern, showing atom bomb effect, post-A.D. 1950.

L3b 172–179 cm. Sandy clay loam to clay loam (reddish-brown 5YR 5/4). Poorly developed crumb-subangular structure. Charcoal throughout. Lower contact distinct and regular.

L4a 179–183 cm. "Burn layer," very fibrous in feel with many charred grass rhizomes and dense charcoal. A sandy clay loam. Radiocarbon date (Beta-8131) 106.8 ± 0.8% modern, showing atom bomb effect, post-A.D. 1950.

L4b 183–188/192 cm. A clay (reddish-brown, 5YR 5/3). Medium subangular blocky structure, fine white mottles. Dense charcoal throughout. Lower contact distinct and irregular.

L5/6 188/192–211/213 cm. A clay (reddish-brown, 5YR 5/3). Medium subangular blocky structure, with orange, white, grey mottles very common. Distinguishable in field from *L4b* and *L7* on basis of color and dryness. Upper part (*L5*) separated from lower, moist part (*L6*) by a large angular boulder extending across the section. Lower contact gradual and irregular.

L7 211/213–218 cm. A clay (reddish-brown, 5YR 5/4) with white mottles, and charcoal flecking. Radiocarbon date (Beta-8108) 1860 ± 150 B.P. (calibrated B.C. 10–A.D. 338, highest probability B.C. 30–A.D. 270 at .84), from scattered charcoal.[3] Lower contact distinct and regular.

L8a 218–220 cm. "Burn layer" with carbonized grass rhizomes. Sandy clay loam. Concentration at top of *L8b*.

L8b 220–229 cm. Clay loam (reddish-brown, 5YR 5/3) with dense charcoal throughout. Radiocarbon date from *L8a* and *L8b* combined (Beta-8105) 360 ± 60 B.P. (calibrated A.D. 1448–1636). Lower contact distinct and regular.

L9 229–240 cm +. Sandy clay loam to sandy loam (reddish-brown, 5YR 4/3) with charcoal flecking and orange, white, and gray mottles very common. Base of section at 240 cm.

The mode of deposition is primarily alluvial. Radiocarbon dates suggest that the catastrophic erosion represented by the Ahupū Formation deposits has occurred entirely in the historic period, primarily since 1950 A.D. Some alluvial deposition (and hence erosion) had begun during or after the period A.D. 1448–1636). This earlier erosion was of soil aggregates rather than subsoil as in the case of the Ahupū Formation. The early date from *L7* is hard to explain. It possibly represents redeposition of an eroded earlier deposit or burning of old wood (possibly driftwood of continental American origin, cf. Murakami 1987: H-12). Given the presence of charcoal throughout the alluvium and the three *in situ* "burn layers," the pre-Ahupū Formation erosion is probably associated with vegetation clearance by use of fire for agriculture within the catchment. Further it is suggested that in the vicinity of the site forest had been replaced by grassland by A.D. 1448–1636. This site would repay more investigation as charcoal continued to the base of the exposed section, and so pre-human strata had presumably not yet been reached.

Section B

(Approximate GC-475, -763) (Fig. 3*c*). 150–200 m inland of a large creek joining the main gulch from the east. The section is at the inland end of an alluvial terrace remnant on the east side of the creek. One meter upstream bedrock is revealed at 1m below the surface and dips seaward.

Stratigraphy

L1 c. 0–15 cm. Ahupū Formation, slightly humic reddish-brown loam. A-horizon. Lower contact gradual and regular.

L2 c. 15–22 cm. Ahupū Formation, semirounded coarse gravels and cobbles. Lower contact distinct and regular.

L3 c. 22–32 cm. Ahupū Formation, reddish-brown silt loam. Lower contact distinct and regular.

L4 c. 32–39 cm. Ahupū Formation, coarse angular small cobbles. Lower contact distinct and regular.

L5 c. 39–43 cm. Ahupū Formation, reddish-brown silt loam. Lower contact distinct and regular.

L6 c. 43–45 cm. Grey slightly gravelly sand lens. Lower contact distinct and regular.

L7 c. 45–47 cm. "Burn layer," mainly finely divided ash with some carbonized grass rhizomes. Radiocarbon date (Beta-8133) 101.2 ± 1.2% modern. Lower contact distinct and regular.

L8 c. 47–60 cm. Gray sandy loam grading with depth to coarser sands and gravels. At 56 cm is a thin lens of ash. Lower contact distinct and regular.

L9 c. 60–69 cm. Gray clay loam with concentration of charcoal at upper contact. Lower contact gradual and regular.

L10 c. 69–73 cm. Sands and fine gravels. Lower contact distinct and regular.

L11 c. 73–75 cm. Gray clay loam with charcoal flecking. Lower contact distinct and regular.

L12 c. 75–100 cm +. Coarser grades with depth through to cobbles and boulders. No charcoal present. Bedrock was encountered at 200 cm depth.

The dominant mode of deposition is alluvial, with perhaps some colluvial transport occurring within the Ahupū Formation layers. This section confirms the results from Section A that the catastrophic erosion represented by the Ahupū Formation is late in the occupation of the island. Again there is evidence that some erosion within the catchment occurred during the prehistoric period, represented by ash lensing and charcoal concentrations below the contact with the Ahupū Formation. This represents erosion of soil aggregates rather than subsoil and saprolitic parent rock. Vegetation at this time appears to have been grassland. Agricultural activities are suggested to be the cause of the erosion. *L7* and *L9* perhaps represent *in situ* A-horizon development. *L11* on the other hand appears to rest unconformably on *L12* boulder alluvium whose upper horizons appear to have been scoured prior to deposition of *L11*.

SECTION C

(GC-477, -762) (Fig. 3*d*). Approximately 300 m inland of Section B on the same side of the gulch. Approximately 1.45 km inland. The section is part of an alluvial terrace remnant.

Stratigraphy

L1 c. 0–15 cm. Ahupū Formation, reddish sandy clay loam. Lower contact gradual and regular.

L2 c. 15–18 cm. Ahupū Formation, fine gravel. Lower contact distinct and regular.

L3 c. 18–21 cm. Yellowish-gray loam with charcoal flecking. Lower contact distinct and regular.

L4a c. 21–22 cm. "Burn layer" of ash. Lower contact distinct and regular.

L4b c. 22–25 cm. Yellowish-gray loam with charcoal flecking. Radiocarbon date collected from 20–25 cm (*L3, L4a, L4b*) (Beta-8132) 100.9 ± 0.8% modern. Lower contact gradual and regular.

L5 c. 25–35 cm. Grades to coarser reddish-brown sands and gravel. Some charcoal flecks at base. Lower contact distinct and regular.

L6a c. 35–37 cm. "Burn layer" of ash. Lower contact distinct and regular.

L6b c. 37–42 cm. Yellowish-gray loam with charcoal flecking. Lower contact gradual and regular.

L6c c. 42–47 cm. Darker gray loam with reddish-brown lensing. Radiocarbon date collected from *L6a* to *L6c* (35–47 cm) (Beta-8107) 200 ± 70 B.P. (calibrated A.D. 1645–1955*, highest probability A.D. 1723–1820 at .50). Lower contact distinct and regular.

L7 47–60 cm. Coarse sand grading to gravel. Lower contact distinct and regular.

L8 c. 60–80 cm +. Gray "gleyed" firm clay, with orange and white mottles. Base of section 80 cm. Boulder alluvium is revealed below.

L1 might be either aeolian or alluvial. Other layers are alluvially transported sediments. Dating results confirm those of Sections A and B. Vegetation before Ahupū deposition appears to have been grassland. Prehistoric or early historic erosion of soil aggregates in the catchment, dating to the period after A.D. 1645, again is evidenced. *L4a, L4b, L6a,* and *L6b* appear to represent *in situ* formation of A-horizons during the late prehistoric or early historic period when the vegetation at this locality was probably grassland.

SECTION E

(GC-477, -761) (Fig. 3*e*). Approximately 50 m inland of Section C, on the opposite bank. Land snails were observed in the gulch bank at this location.

Stratigraphy

L1 c. 0–20 cm. Ahupū Formation, reddish sandy clay loam. Lower contact distinct and regular.

L2 c. 20–40 cm. Gray-brown clay with blocky structure. Charcoal and land snails present. Lower contact gradual and regular. B-horizon.

L3 c. 40–100 cm. Weathered basalt C-horizon. Lower contact gradual and regular.

L4 c. 100 cm +. Basalt bedrock R-horizon.

Apart from the aeolian or alluvially transported Ahupū Formation, the section appears to result from *in situ* weathering of the basalt substrate. *L1* rests unconformably on *L2*, suggesting scouring of the original A-horizon at this point, perhaps by sheetwash erosion of the hillside. Land snail analysis of samples from *L2* (Christensen 1987) identified six species: *Pleuropoma sandwichiensis*, which is known to be from a broad range of environments; *Leptachatina* (*Angulidens*) cf. *subcylindracea* and *Lyropupa (Mirapupa) costata*, which are xerophilic species (arid environments); and *Cookeconcha* cf. *thwingi* and unidentified species of *Amastra* and *Leptachatina*, which are too poorly known to be of use in ecological analysis.

Morgenstein's type section for the Ahupū and Kaho'olawe Formations was considerably further upstream at GC-484, -757 (Morgenstein 1977). The stratigraphy becomes simpler as one moves inland along the gulch. As one moves west from Ahupū Gulch, the drainages become less defined and the alluvial floors become less developed, and therefore less suitable for prehistoric agriculture. Gulches on the north coast with sections useful for reconstructing depositional history are likely to be confined to areas east of Ahupū Gulch.

Hakioawa Gulch

This study consisted of traversing the north gulch entering Hakioawa Bay. Near the gulch mouth only Ahupū Formation deposits are visible in the bank sections. About 250 m inland, the north bank section reveals mixed marine sand and alluvium underlying boulder alluvium. Three hundred meters inland on the north bank adjacent to the Site 560 area, a *heiau,* or Hawaiian religious site, is a bank section (Section I) with a complex stratigraphy of 14 layers. It may well represent the previously recorded Site 565, Section B, which was described on the National Register of Historic Places (NRHP) Form for Hakioawa Archaeological District (Site 356) as "a stratigraphic section exposed on the side of a streambed. It measures approximately 10 m in length and 1.5 m in height. Several dark humic layers, possibly of cultural origin, are present. The only definite indication of cultural material consists of several basalt rocks visible in the face, which might represent a structure."

SECTION I

(GC-544, -794) (Fig. 4*a*). Vicinity of Site 565B.

Stratigraphy

L1 c. 0–30 cm. White aeolian dune sand, darker and coarser at base. Lower contact distinct and regular.

L2 c. 30–65 cm. Ahupū Formation, dark brown (7.5YR 3/4) sandy clay loam with angular-blocky to columnar structure. Lower contact distinct and regular.

L3 c. 65–100 cm. Ahupū Formation, boulders, cobbles, and gravels. Lower contact distinct and regular.

L4 c. 100–115 cm. Ahupū Formation, reddish-brown silt loam. Lower contact gradual and regular.

L5 c. 115–167 cm. Grades to coarse Ahupū gravels, matrix is a gravelly sandy clay loam, dark reddish-brown (5YR 3/4). Lower contact distinct and regular.

L6 c. 167–172 cm. Friable sandy clay loam, dark brown (7.5YR 3/4). *In situ* "burn layer" of ash at upper contact. Lower contact gradual and regular. A basalt flake was found at the top of this layer.

L7 c. 172–180 cm. Dark yellowish-brown (10YR 3/4) sandy clay loam. Lower contact distinct and regular.

L8 c. 180–183 cm. Friable sandy loam, dark brown (7.5YR 3/4). Very thin "burn layer" of ash at the upper contact. Lower contact gradual and regular. An *'opihi* shell was found at the base of this layer.

L9 c. 183–193 cm. Dark reddish-brown (5YR 3/4) sandy clay loam. Ash lens at 188 cm. Lower contact distinct and regular.

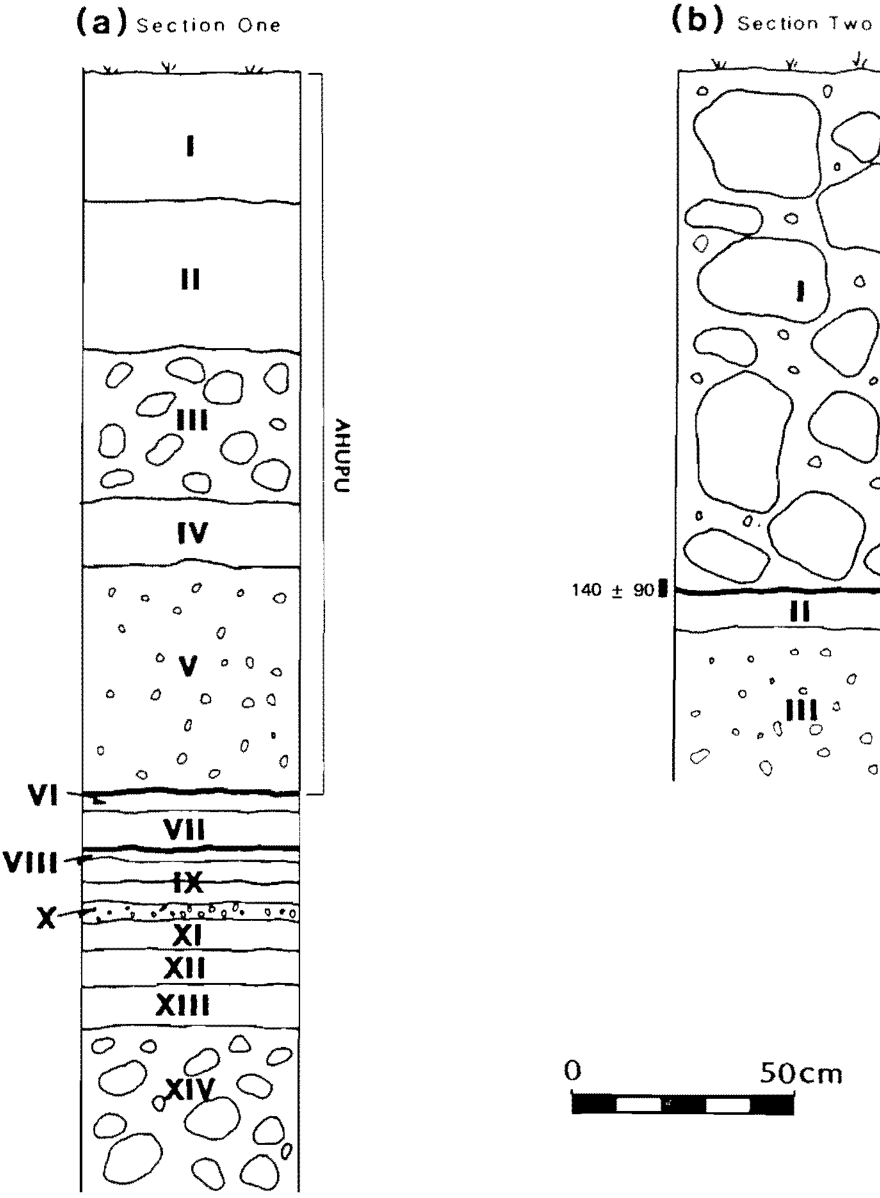

Fig. 4. Hakioawa Gulch alluvial sections.

L10 c. 193–197 cm. Alluvial gravels, dark reddish-brown (5YR 3/4). Finer fraction presumably scoured. Lower contact distinct and regular.

L11 c. 197–204 cm. Dark reddish-brown (5YR 3/4) sandy clay loam. Lower contact distinct and regular.

L12 c. 204–212 cm. Dark reddish-brown (5YR 3/4) firm loam of alluvial origin. Sea urchin exoskeleton fragments were present in this level. Lower contact gradual and regular.

L13 c. 212–222 cm. Dark reddish-brown (5YR 3/4) very firm loam of alluvial origin with some weathered basalt cobbles, and occasional ash lensing. Lower contact distinct and regular. Charcoal flecking present in *L6–L13*.

L14 c. 222–320 cm +. Boulder alluvium to riverbed at 320 cm below surface. No charcoal present.

This section is a complex mixture of alluviation and aeolian deposition of marine sand. As at several of the Ahupū sections there is a "burn layer" between the recent Ahupū Formation deposits and the older sediments, and other earlier ash lenses. The lowest layers are an alluvial deposit showing *in situ* development of A- and B-horizons (*L12* and *L13*). The presence of charcoal in these layers suggests that burning in the catchment may have led to erosion of soil aggregates from higher elevations. The dominant transport mechanism for *L6–L11* appears to be aeolian transport of dune sand and subsequent A-horizon development as dunes stabilized (*L6* and *L8*). Dune instability at this time would appear to relate to periodic burning of the vegetation holding the dunes in place. The Ahupū Formation deposits, representing catastrophic erosion in the catchment are themselves overlain by drifting dune sand, dune instability probably being caused by recent increased visitation to the nearby *heiau*. The presence of a basalt flake in the top of *L6* suggests a prehistoric date for this layer. Immediately downstream of this section, a shift in stream course prior to deposition of *L2* has removed earlier deposits.

SECTION 2

(GC-544, -793) (Fig. 4*b*). This occurs 50 m inland of Section 1 in an area of braided channels on the north bank of the stream braid nearest the south bank of the gulch. It is opposite the area of Site 561 and represents a partially eroded site remnant now isolated by changes in stream course.

Stratigraphy

L1 c. 0–120 cm. Ahupū Formation large boulder-alluvium, interstices filled with smaller gravel. Lower contact distinct and regular.

L2 c. 120–130 cm. Reddish-brown sandy loam, with "burn layer" of ash at top. A cultural layer with dense charcoal throughout, shell midden, and volcanic glass. Radiocarbon date on dispersed charcoal (Beta-8106) 140 ± 90 B.P. (calibrated A.D. 1657–1955*, highest probability 1672–1887 at .82). Lower contact gradual and regular.

L3 c. 130–160 cm +. Grades to coarser alluvial sand and gravel. No charcoal present. Base of section at 160 cm.

The radiocarbon date supports the evidence from Ahupū Gulch that the Ahupū Formation is a recent, almost certainly entirely historic, formation representing catastrophic erosion within the Hakioawa and other catchments. Although no dates were obtained from Hakioawa Section 1, one can assume that this conclusion can be extended to that nearby site.

Two other sites in the Hakioawa catchment have provided evidence of the depositional history of the area. They were investigated as part of the 1976–1980 survey of Kaho'olawe by Streck during 1978. Site 347 is immediately behind the beach at the southern end of Hakioawa Bay. Ahupū Formation alluvium (43–48 cm thick) overlay marine beach sand with associated prehistoric cultural deposits extending to 100 cm below the surface. It is worth quoting Streck's conclusion:

> The natural stratigraphy shows an apparent abrupt change in depositional environments at this location through time. . . . This probably represents either an abrupt change in the sediment load carried by the streams discharging at Hakioawa Bay (an increase) or a change in the manner of stream discharge, such as increased or intensified flash-flooding. Regardless, this Ahupū sediment overlay certainly represents a period of heavy inland erosion and coastal deposition on Kaho'olawe Island continuing to the present time (NRHP Site Form for Kaho'olawe Site 347).

Site 349 is located on the north bank of the south gulch emptying into Hakioawa Bay, about 200 m inland. A test pit adjacent to the stream revealed Ahupū Formation deposits overlying cultural layers. A date from a cultural layer, at 43 cm depth, was obtained by Streck, 310 ± 75 B.P. (Isotopes-10,586), which is calibrated to A.D. 1471–1656, with a second date obtained from 78 cm below surface, 395 ± 75 B.P. (I-10,587), which is calibrated to A.D. 1434–1630, highest probability 1435–1521 at .66. The suggestion at this site is that Ahupū Formation sediments could not have been deposited until the late prehistoric or historic period.

KEĀLIALALO CRATER

(GC-735, -460). A test pit was excavated near the center of the crater to investigate the depositional history of the alluvial infilling of the crater floor. At the time of excavation (March 1983) there were three pools of standing water on the crater floor. Stearns, after noting that a few feet of water stood in Keālialalo for six months or more during the year, reported that "[a]t one time it was planned to build collection ditches and store additional water in Keālialalo, but the plan was abandoned because the depression would have filled too rapidly with silt" (1940: 130). During excavation, no seepage of water occurred in the pit, which was excavated to 130 cm depth. The restricted size of the pit (130 by 85 cm) prevented deeper excavation; deeper excavation should be undertaken in the future to determine prehistoric depositional rates in this restricted catchment. The area around the crater is predominately hardpan, although the crater sides are thickly vegetated. Areas of very lush grass on the lower crater sides suggest the presence of seepages.

Stratigraphy

L1 c. 0–95 cm. Banded lenses of very plastic non-porous orange clay with small gravels of weathered saprolite, representing episodes of alluviation. There are some brighter orange bands with 100% clay skins on the peds representing periods of shallow standing water. Shrapnel fragments were found to 35 cm depth. At about 95 cm a goat skeleton was encountered with some bones extending into the top of Layer II. No charcoal was seen, but occasional still-green roots and vegetable debris were encountered throughout. Lower contact distinct and regular.

L2 c. 95–130 cm. Dark brown clay, very firm, very plastic, angular blocky structure, with the consistency of wet modeling clay. Similar banding and clay skins to *L1* but less distinct. Excavation ended at 130 cm. No charcoal was observed.

L1 is entirely historic in origin, attested to by the goat skeleton at the base of the layer. It represents erosion in the catchment down to the saprolitic hardpan. *L2* seems to represent settling out of alluvial sediments occurring in an environment when water remained in the crater for longer periods and there was a slower rate of deposition. It is unclear whether the excavated sediments extend back into the prehistoric period. The sequence does establish that erosion in this catchment took place at a very high rate during the historic period.

Burn Layers and Other Paleoenvironmental Sites

SITE 512 VICINITY

Site 512 Vicinity is a burn layer revealed in a hummock adjacent to Site 512 (GC-529, -781), which was investigated by the current project (see site descriptions in Rosendahl et al. 1987). The stratigraphy was as follows:

Stratigraphy

L1a c. 0–10 to 15 cm. Ahupū Formation reddish-brown silt loam, structureless. Lower contact gradual and irregular.

L1b c. 10 to 15–35 cm. Ahupū Formation, reddish-brown silt loam, subangular blocky structure. Upper contact appears to have been eroded prior to deposition of *L1a*. Lower contact very distinct and regular.

L2 35–40 cm. Burn layer of *in situ* grass rhizomes, and some shallow basins where ash has been alluvially transported and concentrated. Radiocarbon dates on charcoal (Beta-8462) 180 ± 120 B.P. calibrated to A.D. 1640–1950, highest probability 1710–1880 A.D. at .62, and (Beta-8779) 10 ± 110 B.P. calibrated to A.D. 1693–1955*, highest probability A.D. 1810–1930 at .74. Lower contact gradual and regular.

L3 c. 40–80 cm. Yellowish-red silty clay, grading to saprolitic hardpan, representing *in situ* weathering processes.

The distinction between *L1a* and *L1b* might represent *in situ* development of the Ahupū Formation into an A- and B-horizon, or alternatively, two different episodes of Ahupū deposition. The burn layer represents *in situ* burning of grassland, suggesting this was the vegetation cover present in the area during the late prehistoric or more likely the historic period. The grass is probably *pili* (*Heteropogon*) or *kalamālō* (*Eragrostis*). Large numbers of *Chenopodium oahuense* seeds were also recovered. *Chenopodium oahuense* is a shrub occurring as a weed in cleared areas associated with human activities such as agriculture (see Allen 1987 for a detailed discussion). *Chenopodium* seeds were also recovered from Site 512 hearths. Charcoal from Site 512C included *Chenopodium oahuense*, *Nototrichium* sp., and *Euphorbia* sp. (Murakami 1987), suggesting some woody vegetation was present prehistorically. *Euphorbia* (*'akoko*) trees were noted as part of the vegetation in this part of the island in 1850 (Perkins 1854). Three radiocarbon ages from Site 512 gave near-modern dates, and a fourth calibrates to A.D. 1650–1950, highest probability A.D. 1720–1820 at 0.44, indicating occupation at this site in the late prehistoric or early historic periods.[4]

The burn layer at this site seems to represent a very thin A-horizon developing on top of the *in situ* weathered B-horizon, which also underlies the cultural deposits at this site. Erosion might have occurred previous to the burning, thus leaving only a truncated, thin A-horizon, or alternatively, burning might have extensively oxidized a very organic A-horizon. The *in situ* grass roots and stems suggest that active erosion of the deposit did not occur after burning. Thus the deposition of the Ahupū Formation may have occurred considerably later than the event(s) represented by the burn layer.

Site 207 Vicinity

(GC-511, -736). This burn layer is revealed in the eastern wall of a side gulch near the headwaters of Kāneloa Gulch, occurring near the contact between the Ahupū Formation and the underlying "older alluvium" of probable Pleistocene age (Stearns 1940:126, 145, 147). At this point there is a clear A-horizon development present in the upper part of the alluvium.

Stratigraphy

L1 c. 0–30 cm. Ahupū Formation. The upper part is aeolian in deposition, the lower is alluvially transported and has some weakly developed bedding. Lower contact very distinct and regular.

L2a c. 30–45 cm. Brown loam, very ashy, granular structure. Some orange and grey flecks.

L2b c. 45–50 cm. Burn layer of carbonized grass rhizomes and stems. Adjacent to it is a natural depression (45–75 cm depth, *L2c*) where ash and charcoal appear to have washed in. Radiocarbon dates from 50-57 cm on charcoal, (Beta-8778) 100.2 ± 2.8% modern, (Beta-8777) 180 ± 60 B.P., calibrated A.D. 1654–1955*, highest probability 1725–1819 at .54. A burn layer sample from the same area (Beta-7969) produced a date of 102.4 ± 0.8% modern.

L2d c. 50–190 cm +. Brown clay loam, very firm, large blocky-platy structure, 90% clay skins, large cracks between the peds, grading into the C-horizon of the "older alluvium."

Radiocarbon sample Beta-8777 suggests that the burn layer is late prehistoric or early historic in date. *L2a* appears to represent a subsequent alluvial deposit, similar to those observed in the Ahupū Gulch alluvial sections above burn layers. Archaeobotanical analyses (Allen 1987) identified *Sida* and unidentified Leguminosae and Convolvulaceae from the burn layer, but significantly, no *Chenopodium* seeds were recovered. Allen suggests that this may be because Site 207 is away from the main inland agricultural areas and thus *Chenopodium* was not a weedy adventive in this immediate area, which would have had a grassland vegetation in the early historic period.

Site 474 Vicinity

(GC-524, -728). In the gulch adjacent to Site 474B, a burn layer up to 20 cm thick was observed at the contact point between the Ahupū Formation and the underlying "old alluvium." In this gulch, which flows to the sea just to the west of Kūaka'iwa Point, the old alluvium is about 10 m thick and sits unconformably on the saprolite basement. The Ahupū Formation is up to 1–2 m thick in the main gulch walls. The old alluvial terrace is about 75 m wide at this point. Charcoal was collected from the burn layer in a side gulch on the west side of the gulch, farther seaward where as one moves away from the main gulch the alluvial and Ahupū Formation sediments become progressively thinner. The burn layer at this point is at 25–35 cm below surface. Archaeobotanical analyses (Allen 1987) identified Leguminosae seeds in the burn layer, and the situation of the layer appears similar to that described for Site 207. No samples were submitted for radiocarbon dating, but at Site 474B (GC-523, -732) an *in situ* burn layer of grass stems and rhizomes was observed extending over the top of the cultural deposit, and a radiocarbon date was obtained (Beta-7964) of 110 ± 100 B.P., calibrated to A.D. 1660–1950, highest probability A.D. 1800–1940 at .68. This suggests a historic age for the burn layer.

DISCUSSION

Kaho'olawe and Ahupū Formations

In his 1983 report, Hommon questioned the analytical utility of the concept of an "Ahupū Formation":

> However, the occurrence of two distinct strata (1A and 1B) in a number of instances suggest that the Ahupū Formation is too broad a category to allow detailed study of the depositional history of inland Kaho'olawe (1983:148).

Hommon did not comment on the utility of the concept of a Kaho'olawe Formation, although *L3* at the inland sites examined—"a culturally sterile soil layer . . . with well-developed structure which appears to have formed *in situ*" and which pre-dates human occupation—was identified as "probably" representing the Kaho'olawe Formation (1983:148).

I do not share Hommon's doubts about the utility of the concept of an "Ahupū Formation." It can easily be recognized as an aeolian or aeolian/alluvial deposit. It is typically a red (2.5YR 4/6) to strong brown (7.5YR 4/6) loam or silt loam. In lower elevation gulch areas where the principal depositional mode is alluvial, it is often a sandy clay loam. Where A- and B-horizons have developed within this formation, the A-horizon is weak, very fine granular to very fine platy, soft, non-sticky to slightly sticky, and non-plastic to slightly plastic. The lower contact is gradual to distinct, and regular to irregular. The B-horizon is weak to strong, coarse subangular blocky, loose to slightly hard, non-sticky to slightly sticky, and non-plastic to slightly plastic. The lower contact is always distinct and usually regular. Hommon (1983) discusses these characteristics in detail.

The Kaho'olawe Formation cannot be as easily defined. As originally proposed by Morgenstein (discussed in Hommon 1980*a*:7:60), it is an alluvial or colluvial deposit but has been extended to mean any formation underlying the Ahupū Formation. What Hommon (1983:148) identifies as "probably" the Kaho'olawe Formation is an *in situ* formation derived from the weathering of the underlying basaltic bedrock, often exposed as a saprolitic hardpan. The "Kaho'olawe Formation" remains a useful concept if it is limited to such an *in situ* soil. The "older alluvium" that has been mentioned previously, although it too is pre-human in origin, represents a very different depositional history, as do the much more recent alluvial sediments and aeolian sands found in the lower sections of the gulches. These all underlie Ahupū Formation deposits.

A typical Kaho'olawe Formation sediment is silty clay, strong, coarse subangular blocky to prismatic, hard, slightly sticky and slightly plastic. Color varies considerably from yellowish-red (5YR 4/6) to strong brown (7.5YR 4/6). The profile grades to the parent weathered basaltic basement.

The Kaho'olawe Formation represents the *in situ* weathering of the original volcano and thus has formed over the last million or so years. The "older alluvium" appears to represent changed sea level and climatic conditions in the late Pleistocene. Marine dune formations relate to the period of relatively stable sea level within the last 6000 years. Alluvium in the lower reaches of the gulches represents a range of depositional conditions and ages extending back beyond human occupation and also represents some erosion within the valley catchments during the prehistoric period. The earliest dates associated with human-accelerated erosion are from Ahupū Section A (Beta-8105) calibrated to A.D. 1448–1636, and Ahupū Section C (Beta-8107) calibrated to A.D. 1645–1955*, with a highest probability of A.D. 1723–1820 at .50. These are from burn layers some depth below Ahupū Formation deposits. There are no dates from the Ahupū Formation itself, although occasional historic artifacts and faunal material (goat bone) have been recovered from it. It can be dated by comparing burn layers, the ages of the immediately underlying deposits from cultural sites, and alluvial sequences. In combination, the dates strongly suggest that the Ahupū Formation is entirely historic in origin. It now seems likely that there are no prehistoric Hawaiian sites associated with this soil formation and that the stratigraphic positions of sites previously so assigned (Hommon 1980*a*) were misidentified. The hypothesis of massive landscape degradation in the prehistoric period as outlined by Hommon (1980*a*, *b*) and Barrera (1984), and quoted extensively by Kirch (1982*a*:10; 1982*b*:4; 1983:30; 1984:108–109; 1985:153–154), appears thus to have been disproved. Although some accelerated erosion of topsoil undoubtedly did occur prehistorically, probably associated with vegetation clearance for agriculture, its effects appear to have been negligible.

Stearns' (1940) analysis of the massive erosion and landscape degradation as being caused by overgrazing by cattle, goats, and sheep from the mid-nineteenth century onward is supported by this study. Indeed, as discussed in the section on historic descriptions, the first two clear references to erosion on the island are only from 1880–1881 and the next from 1903 by which time it was evidently a serious problem.

The Burn Layers

The burn layers of grass rhizomes and stems are often found at the interface of the Ahupū Formation and underlying sediments and also within those underlying sediments. They have been variously interpreted (see earlier discussion of Hommon's hypotheses) as the result of burning for clearing agricultural plots, burning to increase growth of *pili* grass, accidental or naturally caused burning, and burning as a weapon of war. Hommon suggested that they may be the result of large-scale grassland fires intentionally started to clear land for agriculture, but which raged out of control. Erosion was then caused by heavy rain before vegetation became reestablished.

Although fire was undoubtedly used for agricultural clearance, this explanation of the burn layers would require that once burned the area was not tilled and planted. Agricultural use would have resulted in the mixing of the charcoal and ash during planting episodes. None of the distinct burn layers show evidence of such mixing. Burning to increase growth of *pili* grass seems another possibility, the grass being useful for thatching and for mulching of agricultural plots. The burning over of grassland would not normally lead to increased erosion in this environment, unless it was closely followed by an intense rainstorm. Unburned grass roots would hold the soil aggregates together until new grass sprouted. It is possible that individual burn layers might represent repeated *in situ* burning over a considerable period of time.

The earliest mention of grassland fires on Kaho'olawe is dated March 1792, and burning to encourage sprouting of grass was suggested as a cause:

> As we passed Tahoorowa, we observed large fires made on the side of the hills running in different directions that had the effect of a grand illumination, and was either intended as a compliment to us, or for the purpose of clearing away the ground for a new

crop of the grass used by the natives for covering their houses with (Chatham [Armed Tender] n.d. 123–124).

Accidental fires are another possibility. In the nineteenth century several references are made to major fires on the island. Perkins, who visited in January 1850, appears to have been a dedicated arsonist—he set fire to the grassland twice on his three-day visit. The second time it "continued to burn for nearly a week, and served as a beacon for vessels coming from Honolulu" (Perkins 1854:165).

The island was again aflame in August 1851, burning for three to four days: "The fire at night presented a grand sight—lighting up the adjacent islands and the sea for fifty miles around . . . [It] is supposed to have been accidentally set on fire by some fishermen" (*The Polynesian*, 30 August 1851, p.62, c.2). These fires do not appear to have led directly to the massive erosion of the island because plentiful pasture was observed in reports of visits to the island prior to the setting up of the sheep ranch in the late 1850s.

Burning as a weapon in war is another possible cause for the burn layers. This was suggested by the Protect Kaho'olawe 'Ohana in a 1983 exhibition at Aloha Tower; burning was specifically suggested to be linked with the raid of Kalani'ōpu'u on Kaho'olawe in 1778–1779 (recorded in Fornander 1969:II:156). If this is the case, the burn layers should in large part represent the results of a single conflagration that laid the island to waste. In March 1793, Vancouver was informed by one of the Maui chiefs of the results of this raid:

> Rannai [Lana'i] and Tohowrowa, which had formerly been considered as fruitful and populous islands, were nearly over-run with weeds, and exhausted of their inhabitants (1984:856).

A single conflagration does not, however, seem a viable explanation for the burn layers. Indeed in several cases there is evidence of multiple episodes of burning.

Whatever the cause (or causes) of the burn layers it seems that by 1792, grassland, that could be burned either deliberately or accidentally, was the dominant vegetation on the island. The main significance of the burn layers has been their presumed link to the erosion of the island. Yet need such a link exist? The general effect of burning grassland is to encourage the sprouting of useful grasses, not massive erosion. The grassland had burned extensively in 1792, 1850, and 1851 and probably at many other times previously. Yet in 1857 when the inspection was made as to the suitability of the island for grazing, large areas of suitable grassland were clearly present in the areas now eroded to hardpan. Burn layers have no necessary relation to the Ahupū Formation soils representing this erosion, except that they occur below this formation and are covered by it. The burn layers represent remnant ground surfaces that were *not* affected by this erosion, and cannot be used to signal the erosion, except to say that it occurred later.

A new factor was needed to cause the onset of massive erosion: the introduction of heavy-footed (cattle) or close-cropping (goats, sheep) animals that would destroy root systems, allowing erosion. When covered in dust storms by several inches of aeolian deposits (Ahupū Formation), the root system of the grass dies because it is "drowned" by the accretion of soil, which buries its rhizomes too deeply. Only then will it turn into easily eroded ash, which if exposed as a surface will blow away very quickly. Without the introduced animals, a grassland climax for the plateau could have been maintained indefinitely.

The earliest dated grassland burn layer is from Ahupū Gulch Section A and dates

TABLE 3. GRASSLAND BURN LAYERS: RADIOCARBON AGE DETERMINATIONS

SAMPLE PROVENIENCE	BETA LAB NO.	CALIBRATED AGE (AFTER STUIVER AND REIMER [1986])
Ahupū, Section A, Layer IIIa	8130	105.7 ± 1.1% modern. POST 1950
Ahupū, Section A, Layer IVa	8131	106.8 ± 0.8% modern. POST 1950
Ahupū, Section A, Layer VIIIa/VIIIb	8105	A.D. 1448(1486)1636. Probabilities A.D. 1459–1524 at .51, A.D. 1564–1630 at .49
Ahupū, Section B, Layer VII	8133	101.2 ± 1.2% modern
Ahupū, Section C, Layers III, IVa, IVb	8132	100.9 ± 0.8% modern
Ahupū, Section C, Layers VIa–VIc	8107	A.D. 1645 (1666, 1790, 1951, 1952) 1955*. Probabilities A.D. 1723–1820 at .50, A.D. 1641–1699 at .28
Site 512 Vicinity, Layer II	8462	A.D. 1640 (1673, 1753, 1796, 1945, 1955*) 1950. Probabilities A.D. 1710–1880 at .62, A.D. 1669–1708 at .22
Site 512 Vicinity, Layer II	8779	A.D. 1693 (1955*) 1955*. Probabilities A.D. 1810–1930 at .74, A.D. 1689–1733 at .26
Site 207 Vicinity, Layer IIc	8778	100.2 ± 2.8% modern
Site 207 Vicinity, Layer IIc	8777	A.D. 1654 (1673, 1753, 1796, 1945, 1955*) 1955*. Probabilities A.D. 1725–1819 at .54, A.D. 1663–1704 at .18
Site 207 Vicinity, Layer IIb	7969	102.4 ± 0.8% modern
Site 474B (burn layer on top of cultural deposit)	7964	A.D. 1660 (1703, 1718, 1824, 1833, 1878, 1917, 1955*) 1950. Probabilities A.D. 1800–1940 at .68, A.D. 1679–1744 at .32

to A.D. 1448–1636 (see Table 3 for age determinations from burn layers). The majority of dates, however, are clearly more recent. Two of the 12 dates show "bomb effect" (i.e., post-A.D. 1950), four more are indistinguishable from the modern standard, and the remaining five give date ranges from the mid-seventeenth century to the present. If only the highest probability ranges of these five dates are used, the following intervals result: A.D. 1723–1820, A.D. 1710–1880, A.D. 1810–1930, A.D. 1725–1819, and A.D. 1800–1940. The burn layers thus relate generally to the latest prehistoric or the historic periods. Although grassland appears to have been established quite early in part of Ahupū Gulch, in areas such as the inland plateau grassland did not occur until the eighteenth or nineteenth century.

Vegetation of Kaho'olawe

Pre-Contact vegetation patterns can be established based on general environmental factors (climate, soils, etc.), and palaeoenvironmental analyses such as charcoal identification (Murakami 1983, 1987), examination of carbonized seeds and other macrofossils (Allen 1983, 1987), and land snail analysis (Christensen 1987). None of the analyses so far undertaken relate to the vegetation prior to human occupation, but based on general environmental factors it is likely that a diverse dryland forest covered at least the windward and summit areas (cf. Forbes 1913:4; St. John 1969:533). The dry (c. 10 inches annual rainfall) western third of the island could have had a much more open vegetation where annual grassland might have been the dominant component with some shrubs present, as described by Wilkes (1844:244).

Land snail analyses (Christensen 1987 and pers. comm.) of samples from three inland locations, two clearly associated with cultural remains and the third of unknown age, support the idea that a dry savannah-forest of some kind existed on the inland plateau during the prehistoric period. None of the samples are suggestive of heavy forest cover. During the prehistoric occupation of the island various woody species must have been available, given the approximately 10,000 fireplaces found on the island (cf. Hommon 1983:151). Analyses of charcoal found in these fireplaces have identified a diverse assemblage of woody species: 18 taxa were identified, with a further 31 unidentified taxa represented (Murakami 1987). Some of these, however, represent driftwood or wood probably brought from other islands in the form of artifacts. A woody *Euphorbia ('akoko)* was the dominant component in the majority of fire pits, a woody *Chenopodium* and *Nototrichium* also occurred at several sites. *Erythrina sandwicensis (wiliwili)* was found at two sites but would tend to be underrepresented in the fireplaces because it burns quickly and leaves little or no charcoal retaining identifiable features (Murakami 1983:187). No woody *Chenopodium* or *Nototrichium* have been identified historically on Kaho'olawe, but *Euphorbia* and *Erythrina* are known. Both were first reported by the infamous Perkins in 1850. Although grassland was the dominant vegetation on the inland plateau by that time, he did note:

> At one place was passed what had once been a grove of akokoa [sic] trees, but nothing now remained save an area covered by withered trunks and branches, bleached as white as skeletons in the sun, the bark having been stripped from them by the goats. We saw akokoa and a few shrubs growing further up the mountain, and these, together with a few stunted wili wili trees were the only living representative of the vegetation kingdom worth noticing (1854:163).

Later Perkins and his companion passed through "a small clump of akokoa shrubbery which lay in our route," breaking off branches in order to force their way through (1854:163).

The French botanist Remy visited the island sometime between 1851 and 1855. Discussing the vegetation of Kaho'olawe and Ni'ihau, he wrote that there were

> quelques buissons, entre autres des euphorbiacées et violariées; mais on n'y voit ni pandanus, ni arbres à pain, ni aleurites, en un mot aucun vegetal atteignant les proportions d'un arbre [several shrubs, among them *Euphorbia* and *Violaria* [?], but one does not see pandanus, breadfruit, nor *kukui;* in a word no vegetation which reaches the size of a tree] (Remy 1862:xxiii). [Translation by Spriggs]

'Akoko and *wili wili* are again mentioned in 1857:

> There are no large trees on the mountains, there are growing akoko trees, low, not more than 4 feet high, and there are some small aalii trees, very few, and small sandalwood, and there are some other small trees, a few, and on the kula some small wili wili trees, and they are few (Nahaolelua and Richardson 1857; cf. Allen 1858).

In June 1859 it was reported that

> on the summit of the island there is about four or five thousand acres of land where I should suppose from its appearance the feed was sufficiently green throughout the year to support sheep without water. About half of this land is at present covered with a scrubby, brittle, succulent plant called 'akoko (Webster 1859).

Webster suggested that cattle be introduced to clear the *'akoko.*

What is interesting about these accounts is that by the 1850s there were few trees on the island that would have been available for firewood and of the *Euphorbia* one notes that goat damage was already substantial by 1850, the first direct reference to the presence of goats on the island. Murakami notes that the light woods of *Chenopodium, Nothocestrum, Nototrichium,* and *Erythrina* would not be highly valued as firewood as they would burn quickly (1983:187–188). The same would be true of *Euphorbia.* Their use would suggest that there were not many suitable firewood species available on the island in any quantity during late prehistory. A comparison of charcoal from early and late sites on the island would help document whether more suitable firewood species *had* existed on the island at one time and had been depleted during human occupation.

The dominant species in seed assemblages from several inland locations analyzed by Allen (1983, 1987) was *Chenopodium oahuense.* Part of this dominance might be attributed to the assumed role of *Chenopodium* as a colonizer in fallow agricultural plots in the inland plateau area.

Agricultural practices as well as firewood collection would have led to clearance of the dry forest from significant areas of the inland plateau, the area of highest rainfall. What effects would this deforestation have had? Dickinson (1981) offers some idea of the effects of tropical deforestation on climate. In relation to Kaho'olawe we have to consider microclimate and "regional" (whole island) climate. One major microclimatic effect of forest clearance is an increase in the diurnal temperature range at the ground surface by perhaps 10 °C, and immediately below the ground surface from 2 °C in forest to 5 °C in open grassland. It gets hotter. Near-surface winds within a forested area are only 20–50 percent as strong as winds at the same level in a large cleared area within the forest. Without forest, the soil dries out more quickly. Dickinson suggests that "The forest canopy is distinguished by less variable fluxes. Without it a region could proceed, after rainfall, from rapid evapotranspiration to drought-like conditions a few days later if the rainfall were not repeated" (1981:425). Deforestation also affects runoff. In forested areas, the rate of infiltration of water into the soil is increased, and horizontal surface movement of water is retarded (Dickinson 1981:423). Before secondary growth is established (or if it is not established at all), increases in erosion rates, runoff, and the possibility of flash floods are increased. Any sustained forest clearance will increase erosion rates. The valley-fill sequences observed on Kaho'olawe to be pre-Ahupū surely reflect this.

Regional climatic effects such as total rainfall on the island are more difficult to assess. The studies quoted by Dickinson (1981:427) do not agree as to whether temperature and rainfall regionally would increase or decrease because of large scale deforestation, but do agree on differences of perhaps 1 or 2 degrees celsius in mean temperature and rainfall changes of up to 10 percent. It might have become drier and hotter, thereby exacerbating the problems of agriculture in an already marginal area. Even in a good year, Kaho'olawe as a whole was near the environmental limits of Hawaiian agriculture because it lies in the rainshadow of Haleakalā, giving the island a low mean annual rainfall. Low rainfall tends to go hand in hand with low reliability of rainfall such that the lower the annual rainfall and "the more marked the seasonality of the rainfall, the less reliable the rainfall is during the rainy season" (Walsh 1981:17). Any agricultural attempts on a large scale might have killed the goose that even then would have hardly been laying golden eggs.

In the early twentieth century opinions were expressed that rainfall had decreased on Kaho'olawe as a result of overgrazing, but all opinions seem to assume that prior to ranching there was forest on the island, which as we have seen was not the case by 1850. In 1856 a similarly false argument had been advanced in respect of the Waimea-Kawaihae area on Hawai'i Island (McEldowney 1983:430–431). The main evidence was in fact an idea that rainfall had decreased at 'Ulupalakua on the Maui coast opposite Kaho'olawe. The supposed forests of Kaho'olawe in kona weather (westerly winds) attracted rain that fell on 'Ulupalakua. Destruction of the Kaho'olawe vegetation and subsequent decrease in rainfall are said to have caused the failure of the sugarcane operation at 'Ulupalakua (*Maui News*, 16 January 1904, p.3, c.3; cf. Judd 1916:123). Indeed reforestation of Kaho'olawe was proposed in 1910, specifically to test the theory of the connection between forest cover and rainfall (State Department of Forestry Files: 23 June 1910). Two interesting transformations of this myth (that Kaho'olawe was forested) are recorded in the literature. One records that it used to rain on Kaho'olawe, but, subsequent to the destruction of its forests, the kona winds now drop rain on Maui or Lāna'i instead of on the island (*Sunday Advertiser*, 14 January 1912, Feature Section, p.1, c.1–6). The other is almost the opposite of the original story, blaming forest destruction on Haleakalā, Maui, for causing the diminution of rain on Kaho'olawe (Zschokke 1932:7). The source for the original 1904 version is given as the Hon. H. P. Baldwin and for the 1932 inversion it is Mr. A. H. Baldwin. Judd's judgment on the rainfall question appears to be the most sensible:

> Kaho'olawe has been cited as an example of a place where the rainfall has been lessened on account of the destruction of the forest, but I am loath to give this much credence because so far as can be ascertained there never did occur any extensive or heavy forests on the island. It is true that if extensive forests existed there now the rain falling on the island would run off much more slowly and would be available for long periods in the form of springs and small streams which are not now found there (1916:123).

The island appeared very suitable for pastureland in the 1850s because of the grass cover on the inland plateau, a supposed "natural pasture," which in fact was created by humans. The cause of the degradation then exactly parallels that recorded by McEldowney (1983:433) for the Waimea-Kawaihae area of Hawai'i Island and by Barrau (1980:259) for the savannah of New Caledonia—that degradation was caused by overgrazing in the historic period. The Waimea-Kawaihae area has many parallels with Kaho'olawe in terms of rainfall and vegetation zones at time of contact (see McEldowney 1983 for an excellent reconstruction of pre- and post-Contact vegetation patterns). There was a coastal strip of fishing settlements and some trees such as coconut. Moving inland were the *pili*, or grasslands. *Pili* 1 lands were where the grass was an annual community in areas of 10 inches annual rainfall or less: In the Waimea-Kawaihae area this zone was used for taking wild birds and collecting grass for thatching. In basins holding some moisture, the most marginal agriculture—using diversion of ephemeral stream runoff—was practiced in the late prehistoric/early historic period. *Pili* 2 were the perennial grasslands, areas of less than 20–30 inches annual rainfall with scattered trees and shrubs. *Pili* was used as an agricultural mulch and could have been so used on Kaho'olawe. The next zone inland in the Waimea-Kawaihae area was the lower *kula*, used for agriculture. Most of Kaho'olawe (the western portion) would have been similar to *pili* 1, while the wetter parts of the inland plateau would have been *pili* 2/*kula*. The major difference is that at

Waimea-Kawaihae the *kula* zone was extensively irrigated by streams flowing from higher elevations. Of course, this could not happen on Kaho'olawe, and so marginality of agriculture was much increased. Given a dry year, and without the possibility of supplemental irrigation, crop failure would have been a possibility on Kaho'olawe.

In the Waimea area dust clouds are mentioned mostly after 1850, although according to McEldowney there are a few references to dust clouds before 1850 (in 1836, 1840, 1848). Between 1873 and 1910, the plains had become "a worthless dusty desert, perpetually encroaching on the grass" (Bird 1964:149, quoted in McEldowney 1983:433). In 1877, a Royal Commission cited cattle as being the primary cause of the diminishing quality and quantity of Waimea's water supply and even though droughts had been common during the early historic period, the severity of their effects increased after 1850 (McEldowney 1983:433). Cattle, as well as sheep and goats, might have played an important role in the sad history of Kaho'olawe, although the first clear references to erosion immediately precede their arrival on the island (Bowser 1880:576; *Hawaiian Gazette* 17 August 1881, p.3, c.2).

Mangenot's description of the effects worldwide of these introduced grazing animals might have been written for Kaho'olawe:

> The cutting hoofs of sheep and goats chop the herbs and small shrubs; the heavier cows trample them. Grazing and browsing affect each plant according to its organization: poorly rooted herbs are pulled by the roots; those having a strong root system are mutilated but remain; small trees are sheared more or less regularly according to the size and attitude of the animal (1963:119, quoted in Scudder 1972:18).

When did the deforestation of Kaho'olawe occur? Based on the results of the 1982–1983 project, the most intensive occupation of the island appears to be late in the Hawaiian sequence, in the seventeenth and eighteenth centuries. It would appear that, based on the burn layer dates, it was during the later part of this period that the dryland forest was converted to savannah in parts of the inland plateau area (see Table 3). The extent of this vegetation clearance is hard to establish but pockets of dryland forest appear to have survived into the early historic period. Whether the effects of deforestation had become acute by the time of European contact is also unclear. Factors other than deteriorating and uncertain yields might have led to a decrease in population on the island during the early historic period: warfare, disease, and a rapidly changing economic system. By 1850 goats were causing significant damage to what trees remained on the island, but for how long they had been having an impact will probably never be known with certainty.

Water Sources on Kaho'olawe

There is no indication that permanent streams have existed on the island at any time during human occupation, and water availability always appears to have been limited. Water sources mentioned historically are three traditional brackish wells (at Kanapou, Hakioawa, and Ahupū and possibly another at Waikahalulu), water remaining for six months or more in Kēalialalo and Kēalialuna craters, and the pools of water remaining after rain in the many gulches on the island. Stearns (1940:129–131) summarizes this information, and other important references are Nahaolelua and Richardson (1857), Webster (1859), *Pacific Coast Commercial Record* (1 May 1892, p.22, c.5), and Judd (1916:121). In reference to their use as a water source, it is worth noting that Keālialalo can be translated as "west salt pond" and Keālialuna as "east salt pond" (Napoka 1983). Napoka also lists Waipunape'e, "lit. hidden spring water, name for stone paved well on the eastern side of Kuheia." This information came from former pre–World War II resident Inez Ashdown, and it is not clear whether this well is prehistoric or historic. Stearns did not mention it in his listing of known wells (1940:130). Emory (1924:46–47) gives a good discussion of water sources on nearby Lāna'i, including wells caulked with "straw and mud" to keep them from becoming brackish. In historic times when a well at Kaunolū was expanded and the old seal broken, it became brackish (Emory 1924:52). Although the story of Kalaepuni being stoned to death in the Kanapou well on Kaho'olawe is interesting folklore (Fornander 1916–1919:V:198–205), the supposed depth of the well and the large numbers involved in its construction are somewhat fanciful to say the least. Emory (1924:46) discusses the practice on Lāna'i, confined to the inland plateau, of collecting dew "from the thick shrubbery by whipping the moisture into large bowls or squeezing the dripping bush tops into the vessels. Oiled tapa was also spread on the ground to collect the dew." Nahaolelua and Richardson (1857) noted "the lack of dew on the mountain" (i.e., the inland plateau) of Kaho'olawe. It is possible, however, that before the clearance of the dryland forest water might have been obtained by these methods on the island. Possible climatic effects of the forest clearance have already been discussed, and it is conceivable that water was more readily available on the island during prehistory.

Agriculture on Kaho'olawe

For agriculture, Kaho'olawe was ecologically the most marginal of the eight major Hawaiian islands. Along the coast, only in the wetter northern gulch floors would agriculture have been productive. Away from the inland plateau area, annual rainfall is only about 10 inches. Similar coastal conditions can be found south of Kīhei on Maui, on the north and northeast coasts of Lāna'i, and on the west coast of Hawai'i Island. Interestingly, the equivalent area of Lāna'i was densely populated prehistorically, with the largest *heiau* at one of the driest locations (Emory 1924:49). Kaunolū Village on the south point of Lāna'i also gets about 10 inches of rainfall per year and contains another impressive *heiau* (Emory 1924:62). Data from Land Commission Awards (LCA) on Lāna'i have been analyzed by Bacus (1984) as a parallel but better documented case to Kaho'olawe, according to rainfall, vegetation zone (based on Ripperton and Hosaka 1942), and topography (see summary in Table 4). As maximum rainfall on the summit of Kaho'olawe is about 25 inches, the crops found in the higher rainfall areas on Lāna'i—*pulu* (tree fern), *wauke* (paper mulberry), and dryland taro—were probably not present. Malo (1903:206) states specifically that taro was not cultivated on Kaho'olawe, although Forbes mentions dryland taro among crops being grown "in former times. . . according to an old native" (1913:4). Taro was also cultivated in *lo'i* on Lāna'i, but the necessary permanent streams are of course lacking on Kaho'olawe. The other crops mentioned in the Lāna'i LCAs have all been recorded historically on Kaho'olawe (Table 5). Although sweet potato is only specified as growing in the interior plateau of Kaho'olawe, the data from Lāna'i suggest that it could have been grown in the drier coastal areas as well, probably in the moisture-holding gulch bottoms. Yams and bananas were also probably grown in such situations as well as on the inland plateau. Although offer-

TABLE 4. DISTRIBUTION OF LAND COMMISSION AWARDS ON LĀNA'I ACCORDING TO LAND USE, RAINFALL, VEGETATION, AND TOPOGRAPHY*

	RAINFALL ZONE (INCHES)							VEG. ZONE**			TOPOGRAPHY***	
CROPS	10	−15	−20	−25	−30	−35	35+	A	B	C	D	E
Banana	1	—	—	1	—	—	1	1	1	1	3	—
Gourd	2	—	—	1	—	3	2	2	2	4	2	6
Pulu (tree fern)	—	—	—	—	1	—	—	—	1	—	—	1
Sugarcane	—	—	—	1	2	—	—	—	3	—	—	3
Sweet potato†	7	6	—	15	2	15	4	13	26	12	27	24
Taro (dryland)	—	—	—	1	1	—	—	—	—	2	2	—
Kī (ti)	—	—	—	1	—	—	—	—	1	—	1	—
Wauke	—	—	—	—	—	—	1	—	—	1	—	1
Other cultivated lands	9	10	1	7	6	7	7	19	17	11	25	22
TOTAL CULTIVATED LANDS	19	16	1	27	12	25	15	35	51	31	60	57
Houselots	8	4	—	7	3	4	3	12	12	5	15	14

*Data from Bacus 1984: Tables 2, 3, 4.
**Vegetation zones after Ripperton and Hosaka (1942): A = lowland shrub vegetation, ground cover sparse, conditions semidesert, with annual grasses; B = lowland shrub vegetation, plant coverage generally good, shrubs are more numerous and vigorous and the annuals are longer lived than in Zone A; C = open shrub and grasses, excellent ground cover.
***D = Coastal flat or gulch bottom. E = Plateau and high flats.
†Two parcels of sweet potato are missing from Bacus' table.

ings of *kapa* (bark cloth) (probably of *wauke*) and *'awa* (*Piper methysticum*) were recovered from the Kamōhio fishing shrine on Kaho'olawe by Stokes in 1913 (see McAllister 1933), they were almost certainly brought in from another island as both require moist growing conditions. There would thus have been probably two main agricultural zones on the island: the windward gulches from the Ahupū area to Hakioawa, and the inland plateau (cf. Bacus 1984:39). A range of crops could have been grown in each, although sweet potato appears to have been the staple (cf. Malo 1903:206). Nahaolelua and Richardson's (1857) elderly informants told them in December 1857 that "sweet potatoes will grow on the mountain if planted at the right time, they said that the potatoes were good and the tubers large." These visitors saw at Kūheia on the coast introduced tobacco and pineapple, as well as gourd and *lā'au kau* ("summer trees"). In a gulch in the inland plateau area they saw a sugarcane patch, with the plants $6\frac{1}{2}$ feet high and $5\frac{3}{4}$ inches in circumference (Nahaolelua and Richardson 1857). In May 1858 Allen saw sweet potatoes, sugarcane, and introduced melons and pumpkins growing on the inland plateau near Moa'ula (Allen 1858). Although the windward gulches probably only receive 10–15 inches of annual rainfall, the alluvial gulch floors retain moisture and create favorable niches for agriculture. The inland plateau with 20–25 inches of rainfall annually was the more suitable agricultural area. This is of course the zone of densest inland settle-

TABLE 5. Major Cultivated Plants Historically Recorded on Kaho'olawe

	Rainfall zone (inches)				Veg. zone*			Topography**		
Crop	10	–15	–20	–25	A	B	C	D	E	References
Banana	—	—	—	—	—	—	—	—	—	General refs.: Forbes 1913:4; Judd 1916:119
Gourd	—	1	—	—	1	—	—	1	—	Nahaolelua and Richardson 1857; recovered from archaeological sites (Allen 1987)
Sugarcane	—	—	—	2	—	2	—	—	—	Nahaolelua and Richardson 1857; Allen 1858; general refs.: Malo 1903:206; Judd 1916:119
Sweet potato	—	—	—	3	—	3	—	—	3	Perkins 1854; Nahaolelua and Richardson 1857; Allen 1858; general refs.: Malo 1903:206; Wilkes 1844:262; Nicholson 1889; Forbes 1913:4; Judd 1916:119
Kī (ti)	—	—	—	1	—	1	—	—	1	Keene 1983:148; general refs.: Forbes 1913:4; Stearns 1940:124
Kūpala	—	—	—	—	—	—	—	—	—	General refs.: Thrum 1902:122; Fornander 1916–1919:V:198–205; Rodman 1939:39–40
Yam	—	—	—	—	—	—	—	—	—	General refs.: Malo 1903:206; Rodman 1939:39–40
Taro	—	—	—	—	—	—	—	—	—	General ref.: Forbes 1913:4
Recorded Totals	—	1	—	6	1	6	—	1	4	

* Vegetation zones after Ripperton and Hosaka (1942). See descriptions in Table 4.
** D = Coastal flat or gulch bottom. E = Inland plateau.

ment evidence. It appears that *kī* (*Cordyline*) and sugarcane were restricted to this higher rainfall area. Some minor cultivation, particularly of gourds and sweet potato, might have taken place elsewhere on the island in sheltered spots, perhaps near coastal habitation areas.

No mention of agriculture on Kaho'olawe would be complete without mention of *kūpala*, the sweet potato–morning glory. In one Hawaiian epithet we hear "*Kaho'olawe 'ai kūpala*" (Kaho'olawe, eater of *kūpala*) (Pukui and Elbert 1971:170), and in the legend of Kalaepuni as recounted in Fornander (1916–1919:V:198–204), an old couple tell the strongman that only *kūpala* grows on the island—there is no other vegetable food (see Keene 1985:38, 78 for a discussion of this story). It should be remembered, however, that this statement was part of a ruse to make Kalaepuni thirsty so he would go down into the well where he was to be killed. Keene also notes that it might be a retrogression of the ecological situation of the 1860s–1870s when the story of Kalaepuni was put into writing rather than a reflection of the situation in about A.D. 1650, the time at which the events were said to have occurred.

Given the unreliability of rainfall on the island and the chance of general crop failure, *kūpala*, which was known as a famine food in dry areas, might have been an important resource in bad years. Whether *kūpala* was sometimes planted or was wholly wild is unclear. Isabella Abbott of the University of Hawaii (pers. comm. October 1985) has identified *kūpala* as *Ipomoea cairica* (L.) Sweet with *Ipomoea palmata* Forsk. as a synonym. It was under this latter name that Forbes recorded it on the island in 1913: "This plant which has large tuberous roots, is said to be quite conspicuous after the rains" (1913:7). Eaten in large quantities it causes diarrhea, as Kalani'ōpu'u's soldiers found out during their stay on Lāna'i in 1778 (Emory 1924:23).

CONCLUSION

The 1976–1980 archaeological survey of Kaho'olawe challenged the generally held view that the severe erosion witnessed on the island was the result of overgrazing during the historic period. It suggested instead that massive erosion was initiated during the period of prehistoric Hawaiian occupation. The subsequent 1982–1983 project (Rosendahl et al. 1987) does not support this reinterpretation and provides evidence that large-scale erosion is indeed a feature of the historic period. Erosion on a small scale in prehistory is demonstrated for the Ahupū Gulch area, and indeed accelerated erosion is an inevitable result of forest clearance and agricultural practices. The major environmental effect of prehistoric human occupation appears to have been in vegetation clearance for firewood and agriculture. It seems likely that where a diverse dry forest once existed, it had in large part been changed by the time of European contact to an open savannah of grassland and trees, probably maintained by regular burning. How much forest remained at contact is unclear; certainly none of the passing ships noticed any. The first recorded landings on the island by literate observers in the 1840s and 1850s record a savannah vegetation but also damage by goats to forest remnants. As discussed previously, the earliest clear references to erosion problems on the island are from 1880–1881, during the ranching period, and the next reference is from 1903.

A tentative revised sequence of human-induced environmental change on Kaho'olawe is offered in conclusion, starting with initial human occupation by about A.D. 900 (the earliest cultural radiocarbon date is from inland site 398A-1 and calibrates to A.D. 880–1000 [Hommon 1983:123]). The historic sequence divisions follow Hommon (1980*a*:7:9).

A.D. 900–1600. Low-intensity occupation of the island, with fishing as the primary focus. Some agricultural use of the inland plateau. Human impact on the environment was probably minor.

A.D. 1600–c. 1778. More intensive use of the inland plateau for agricultural purposes. Hommon (1986) notes, for the Hawaiian Islands in general, that after A.D. 1600 there is a significant increase in the occupation of more arid, agriculturally marginal areas. This represents attempts at increasing production to meet the demands of the domestic and public sectors of the economy. Hommon also suggests agricultural intensification as a feature of this period, for example, in the form of mulching and the reduction of fallow periods. Greater use of the inland plateau of Kaho'olawe for agriculture and reduction of fallow periods might have led to a change from a predominantly dry forest vegetation to a more open savannah, maintained by regular burning during the later prehistoric period. The burning would have encouraged growth of *pili* grass that might have been used as an agricultural mulch. Possible environmental effects of such a vegetation change have been discussed earlier but there is no clear evidence at present that vegetation clearance by European contact had rendered the island increasingly marginal for agriculture. The historic sources already quoted from the 1850s state that at that time sweet potatoes, melons, pumpkins, and sugarcane were growing well on the inland plateau (Allen 1858; Nahaolelua and Richardson 1857).

Whether this inland agricultural focus necessitated any more than temporary shelters in the inland zone seems unclear. None of the remains so far uncovered on the plateau strongly suggest permanent occupation, and the tending of sweet potatoes would not require it. Neller's paper on settlement pattern discusses this (Neller 1982). Using religious sites as an index of use intensity, he found only 13 religious sites in the inland plateau area, compared to some 70 near the coast. The more permanent-looking habitations are near the coast. However, if we allow a degree of permanent inland occupation, we would have a striking parallel with Lāna'i, the interior plateau of which has equivalent terrain and rainfall (actually in parts 5–10 inches or so higher). Here Emory found evidence of considerable occupation (Emory 1924:50), also reflected in the LCAs (Bacus 1984). He also noted eroding firepits on the Lāna'i uplands exactly similar to the present situation on Kaho'olawe: "Many oven pits containing charcoal and ashes have been exposed by wind erosion on the top lands" (Emory 1924:45).

A.D. 1778–1830. It is presumably during the period between A.D. 1778–1830 that the island's population decreased significantly for reasons that are not at present clear. Possible explanations are warfare (Kalani'ōpu'u's raid), introduced disease, and/or changing economic conditions leading to people moving to centers such as Lahaina, Maui. According to an account published in 1912 (*Sunday Advertiser*, 14 January 1912, Feature Section, p.1, c.1–6), goats were introduced to the island some time after 1793 by a Maui chief. Their effects on the vegetation during this period are unknown.

A.D. 1830–1859. For part of the time between A.D. 1830–1859, Kaho'olawe was a penal colony. In the 1830s, when the first reliable census figures are available, there were about 80 people on the island. This is the period of our first eyewitness accounts of the island, starting with the Wilkes expedition of 1841. The first mention of goats is in 1850, and they were at the time already seriously damaging trees on the inland plateau. Their numbers may have been held in check, however, by wild dogs. The earliest accounts of the vegetation by visitors to the island make it clear that savannah was the dominant vegetation type by this period.

A.D. 1859–1909. A.D. 1859–1909 was the first ranching period, during which overstocking of the island with goats, sheep, and cattle led to destruction of the vegetation and massive erosion of the topsoil.

The history of the island after 1909 is one of reclamation efforts, first by the Territorial Government (1910–1918) and then by more conservation-minded ranchers (1918–1941). Since 1941, the island has been under Navy jurisdiction, and recently reclamation efforts and programs to eradicate the wild goats have begun again.

Archaeological research has helped clarify our knowledge of past vegetation patterns on the island, human impacts on the environment, and in particular, the causes of the massive erosion of topsoil that has occurred in the last one hundred or so years. Without eradication of the goats, which in large part led to this erosion, no reclamation efforts are viable. Future revegetation efforts should concentrate on native plants known to have been growing on the island in the past, and which the 1982–1983 project has helped identify. If this were done, it would demonstrate that although man is perhaps everywhere preceded by forest, he is not inevitably followed by desert.

NOTES

1. I would like to thank Paul Rosendahl for inviting my participation in the project and other project members for material and intellectual assistance. The study was funded by the U.S. Navy, but this paper, a revised and slightly abridged version of Spriggs (1987), should in no way be considered to represent the views of Paul H. Rosendahl, Ph.D., Inc. (PHRI) or the U.S. Department of the Navy. In particular I have reworked the radiocarbon data from the 1987 report and added a general introduction to the island and the events leading up to the 1982–1983 project. I would like to thank PHRI for permission to use figures from the 1987 project, and Rob Hommon, Mikk Kaschko, and Dave Tuggle for their assistance. This paper was prepared in the Department of Prehistory, RSPacS, The Australian National University, whose institutional support is acknowledged. The paper is dedicated to the memory of George Helm and Kimo Mitchell of the PKO who died off Kaho'olawe in 1977 trying to bring the plight of the island's cultural resources into public view.
2. The main source for historical documentation of Kaho'olawe is Silva (1983), a compilation of historic references to Kaho'olawe from 1779 to the 1970s. Other references that have come to light since 1983 are included. Prominent among them is Bowser's Directory (1880) to which I was referred by Mikk Kaschko.
3. All radiocarbon ages are calibrated using Stuiver and Reimer's (1986) CALIB program (version 2.0), using the 10-year (decadal) radiocarbon age dataset and Method B, calculation of probability distribution and age ranges.
4. The relevant samples are Beta-8066 at 101.3 ± 0.8% modern, -8065 at 101.4 ± 1.2% modern, -8064 at 101.2 ± 1.1% modern, and -8438 at 160 ± 100 B.P. See Rosendahl et al. 1987: iii–46, 54, V-7.

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