Kaho'olawe Island Conveyance Commission

Consultant Report No. 2

Paleobotanical Investigations, Kaho'olawe Island, Hawai'i

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INTERNATIONAL ARCHAEOLOGICAL RESEARCH INSTITUTE, INC.

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EXECUTIVE SUMMARY

Paleobotanical investigations were undertaken on the Island of Kaho'olawe, Hawai'i to determine the original flora of the island prior to massive erosion and human impacts. This report presents findings of a literature review on previous investigations as well as the results of field and laboratory investigations. A concluding chapter integrates the new findings with earlier archaeobotanical studies. Finally, recommendations are provided for further investigations.

Field investigations described in the present report involved (1) sediment coring in Kaho'olawe's 5 volcanic craters in the interior of the island, (2) the recovery of sediment samples near Site 207, which is adjacent to the inland plateau area, and (3) the recovery of a core sample from behind the beach at Kanapou Bay on the east coast. The sedimentary units were described in detail and related to the previously identified Ahupu and Kaho'olawe Formations, the former having formed as a result of livestock overgrazing during historic times, and the latter being an ancient *in situ* soil. An Intermediate Formation, occurring between the Ahupu and Kaho'olawe Formations, was identified in the craters. A somewhat analogous sedimentary unit, designated the Moiwi Formation, was documented below the Ahupu Formation at Site 207. A burn layer occurred at its upper boundary. Both of these formations appear to represent the sedimentary record encompassing the prehistoric and pre-human contact periods.

Thirty eight samples were analyzed for palynomorphs and charcoal particles. The crater samples, unfortunately, proved disappointing in terms of pollen preservation and little paleobotanical information was forthcoming. The Site 207 samples, on the other hand, were very rich, providing an excellent time series record of vegetation for the inland plateau and adjacent areas.

The earliest vegetation, presumably pre-human, is represented by a Lowland Dry Shrubland community, probably with a few widely scattered large shrubs or small trees. This finding contrasts with the dryland forest community other investigators have inferred for

inland Kaho'olawe. Late in prehistory or perhaps early in the historic period, the Shrubland was replaced by largely a grassland community due to anthropogenic burning. This period is represented by the burn layer. Finally, the Ahupu period is represented by a much reduced grassland community, which reflects the largely barren wasteland of the inland plateau that developed soon after the introduction of grazing animals.

The Kanapou Bay sample from the coast, which produced a rich assemblage of pollen, proved to date to the historic period, possibly the early part. The pollen record was similar to that identified from the lower part of the Ahupu Formation of Site 207. The results, therefore, were of limited interest for understanding prehistoric and pre-human contact vegetation.

The charcoal particle counts proved uninformative with respect to documenting anthropogenic fire disturbance or other natural fire events on Kaho'olawe. The local charcoal particle record apparently has been overwhelmed by the influx of wind-borne particles from either Maui or Hawai'i Island.

In order to expand geographical coverage as well as to verify results of the present study, it is recommended that additional palynological sampling be undertaken in conjunction with wood species identification of charcoal in the burn layers. The present paleobotanical evidence for prehistoric and pre-human contact vegetation is derived from an extremely limited data base. Now that a better understanding has been achieved for paleobotanical research on Kaho'olawe, additional investigations can proceed in an efficient and much more focused manner.

ACKNOWLEDGEMENTS

We would like to extend a special note of thanks to Captain Milton D. Roth, Jr., USN, for his considerable effort and interest in facilitating our work on Kaho'olawe, including transportation, housing, and ground logistics. In addition, we are grateful for the quite substantial assistance proffered by Lt. Vern Young, USN, and Staff Sargent Bryan Dickinson, AF, in our field coring operation. In addition, the background research and editorial assistance of IARII archaeologist Mikk Kaschko added considerably to the quality and value of this report. We are also grateful for the support of the Kaho'olawe Island Conveyance Commission, and in particular, Mr. Hardy Spoehr for effectively and smoothly coordinating the project. Finally, we wish to acknowledge a personal and intellectual debt to Matthew Spriggs. He was instrumental in bringing us into the project, and it was his prior research that provided such a strong foundation and direction for our own investigations.

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I: INTRODUCTION

This report documents investigations conducted on behalf of the Kaho'olawe Island Conveyance Commission for the purpose of obtaining information on the past history of the island's vegetation. Such information is regarded of interest for the purpose of guiding anticipated future efforts at vegetation restoration of what is obviously a highly degraded landscape. Historic impacts related to livestock ranching, the presence of feral goats until recently, and military training activities between 1941 and 1990 have all had a tremendous impact on the native and endemic plant species of the island. For the most part, the plant communities of which they were a part have virtually vanished. Thus, paleobotanical information--data that derive from time periods prior to major impacts--would potentially be helpful in planning and carrying out future restoration efforts. In addition, of course, such information would be of considerable interest for its research value concerning any number of botanical, ecological, and archaeological questions.

Kaho'olawe Geography and Environment

The island of Kaho'olawe, located 18 km west-southwest of Maui, encompasses 117 sq. km (see Fig. 1). It has a roughly oval to triangular shape, measuring at a maximum 17 km across and 10 km in width. Maximum elevation, at Pu'u Moaulanui adjacent to Lua Makika on the eastern side of Kaho'olawe, is 450 m (1,476 ft). A relatively broad and high elevation ridge gradually descends from this point to Lua Kealialalo in the west central portion of the island, which has an elevation of 259 m (850 ft). This broad plateau-like area and the adjacent slopes are almost entirely eroded, though largely undissected, to barren saprolitic hardpan, forming what Stearns (1940:123) has called the dust bowl. The south and west sides of the ridge have a gradual slope toward the sea, while on the north side the slope tends to be much steeper and is regularly punctuated by deep gulches. The south and east coastlines tend to be marked by high cliffs (up to 800 ft). There are relatively few beaches around the island, and there are no fringing reefs offshore of Kaho'olawe.

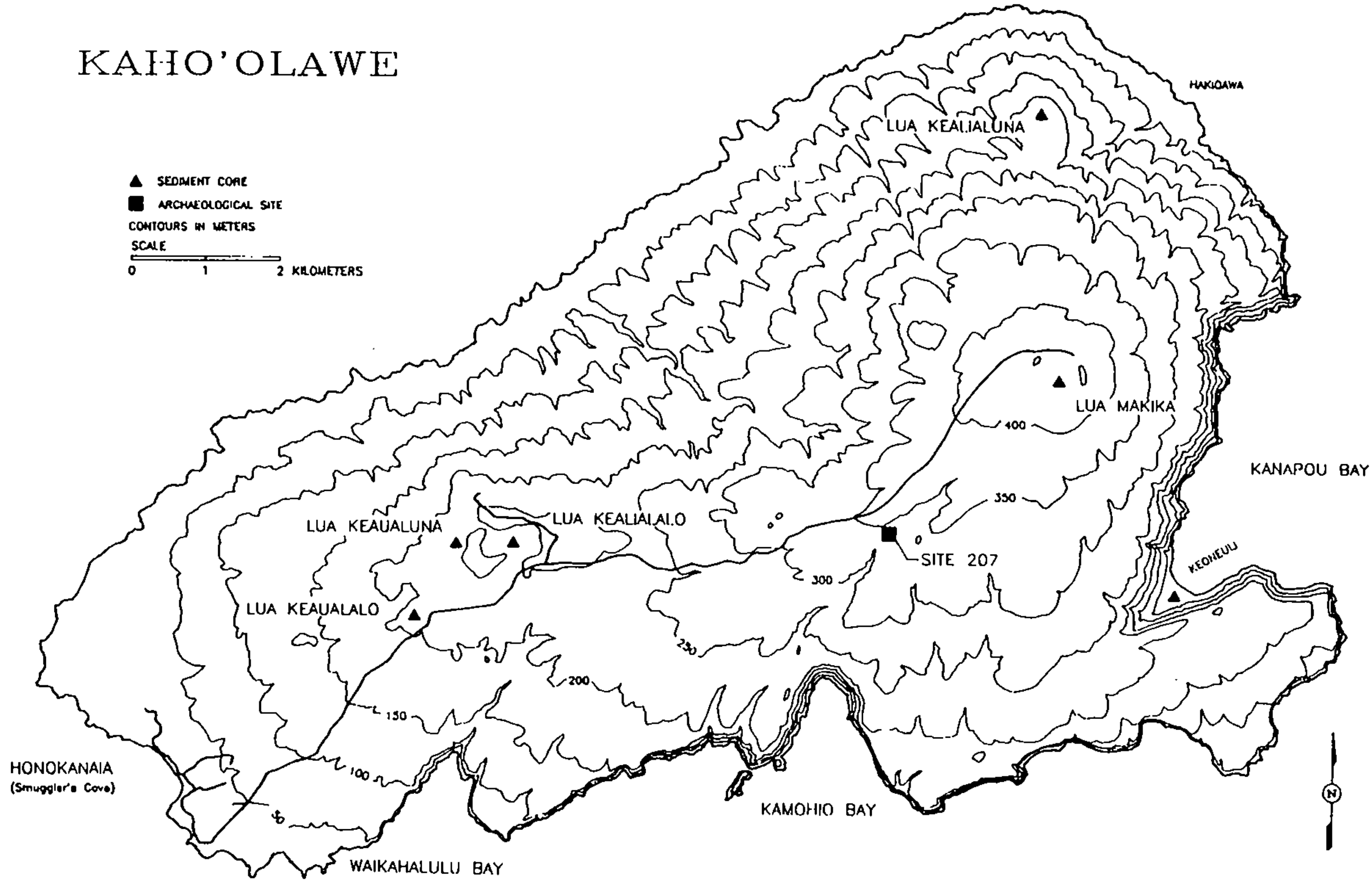

Figure 1. Map of Kaho'olawe showing sampling locations for coring tests.

Rainfall data are extremely limited, though readings from four recording stations indicate average annual rainfall to be 508 mm (20 in) per year with a low of 457 mm (18 in) and a high of 698.5 mm (27.5 in; see data in Rosendahl *et al.* 1992). Elevation does not appear to influence rainfall. Most of the island's precipitation occurs as a result of winter storms. The location of Kaho'olawe in the lee of Mt. Haleakala on Maui places it in a rain shadow, contributing to the island's aridity. Also, Kaho'olawe's low elevation virtually precludes orographic rainfall. As might be expected from the limited rainfall, there are no permanent streams on Kaho'olawe, and freshwater resources are extremely scarce (see Rosendahl *et al.* 1992:II-2 and Stearns 1940:124). Stearns (1940:131) remarks that,

> there has been apparently a progressive decrease in the quantity of ground water in the gulches, until by 1919 no water potable for stock remained.

As this decrease cannot be attributed to a general climatic dessication in Hawai'i, Stearns (1940:125) suggests it was caused by the introduction of *kiawe* (*Prosopis pallida*) trees about 1900.

Detailed temperature records are lacking from Kaho'olawe. However, the temperature values should correspond closely to those elsewhere in Hawai'i, with ranges from about 23°C in March to 27°C in September. This variation reflects seasonal variation of incident solar energy as moderated by the surrounding ocean. Daily variation in temperature exceeds that of the seasonal range. Temperatures, of course, become cooler with elevation.

Wind is a major component of the climate of Kaho'olawe. As Stearns (1940:124) observed,

> The "dust bowl" (fig. 26) and the nearly universal wind-pruned form of the trees are mute testimonials to the constant strong east winds. Kahoolawe is probably the windiest island in Hawaii.

Stearns (1940:126-127) devotes an entire subsection of his report to the effects of wind erosion on Kaho'olawe.

Regarding vegetation, Rosendahl *et al.* (1992:III-3 citing the EISC 1979 vegetation survey) refer to five major and several minor zones:

> The major zones are hardpan desert, *Prosopis* (*kiawe*) scrub forest, grasslands, coastal strand, and precipitous cliff vegetation. The components of these zones are in large part exotic, although the cliff zone harbors several native species.

Further details concerning modern vegetation are discussed in the Nature Conservancy of Hawaii biological survey report (Hawaii Heritage Program 1992), which was prepared for the Kaho'olawe Conveyance Commission. Of particular interest are the report's overlay maps of vegetation changes during the present century. In general, barren hardpan occurs over the broad central plateau of the island, while a *kiawe* scrub forest community (understory of grasses, *'ilima*, etc.) is distributed along the slopes. The other vegetation zones are quite small in comparison to these two main zones.

Project Background

Although there is some information from historical documents relating to vegetation on the island during the early and middle 19th century (see Spriggs 1991), it is especially important to consider the possible impacts by prehistoric Hawaiians living and gardening on the island. In terms of a time frame, the earliest Hawaiians to settle on Kaho'olawe had probably done so early in the second millennium A.D., perhaps by A.D. 1250 (Rosendahl *et al.* 1992:V-31). Hawaiian settlement on Kaho'olawe apparently came much later than was the case for the larger islands.

While the extent of the impact of the prehistoric Hawaiians on their Kaho'olawe environment should not be assumed *a priori*, other studies in Hawaii, in fact, have shown that Hawaiians have had a tremendous impact on native and endemic lowland plant communities. For example, it is now known that the pristine lowland plant communities existing prior to the advent of Polynesian settlers on O'ahu, which occurred about the middle of the first millennium A.D., had been completely transformed by the time of the arrival of Captain Cook in 1778 (Athens *et al.* n.d., Athens and Ward 1992).

Specifically regarding Kaho'olawe, several investigators (see especially Spriggs 1991, Murakami 1992, and Allen 1992) have indicated the role of both Hawaiians and the later historic period ranchers in large scale impacts to vegetation communities; their specific findings will be reviewed in the following section. However, it can be pointed out here that their data were generally restricted only to the Hawaiian (prehistoric until about 1850) and historic periods (after 1850). The macrobotanical and charcoal remains on which they base their interpretations, therefore, may represent a highly biased selection of what was actually present in the environment because they come only from archaeological and post-human contact sites and deposits. This makes it difficult to determine the relative importance or degree of representation of each species in the natural vegetation communities of their origin. A more significant problem, however, is that the data of Allen and Murakami are derived from time periods after potentially massive impacts had already. Because of this, their data may suffer in uncertain ways from lack of representativeness of a pristine environment.

To overcome the above-indicated problems, the basic plan of the present project was to take sediment core samples from the presumably deep and intact sediment deposits of the 5 widely distributed volcanic craters in the interior of Kaho'olawe. These craters are Lua Kealialalo, Lua Makika, Lua Kealialuna, Lua Keaualuna, and Lua Keaualalo (see Fig. 1). The craters all have basically closed basins in which sediment would tend to accumulate rather than erode away in the absence of major breaches in the crater wall. Thus, considering the highly eroded state of the plateau area, it was believed that the craters would provide an ideal opportunity for obtaining complete depositional records of Kaho'olawe that would encompass the pre-Polynesian (pre-Hawaiian) period, as well as the period of prehistoric Hawaiian occupation and the subsequent historic period. Each crater is described in detail in Section IV, which also contains oblique aerial photographs of each crater taken with a hand held 35 mm camera from a helicopter.

The sediment from the crater cores would then be described and analyzed in order to understand the depositional history of the deposit. In addition, sediment samples at selected depths would be analyzed for pollen by a palynology specialist. Regarding the latter, the pollen record, if preservation is good, is normally representative of the actual vegetation growing in the vicinity of the core locations for the time period represented by the sample. If enough organic material is present in a particular sediment sample, it is also possible to obtain radiocarbon dates to establish the age of the deposit and determine the timing of any changes in sediment type or pollen.

The coring work in the craters was accomplished as planned. However, while in the field it was decided to expand the investigations to include a location near Site 207 and also to the beach area at Keoneuli in Kanapou Bay (see Fig. 1 for locations). This was done basically in order to expand coverage around the island as well as to test different depositional contexts. Further discussion of the reasons for this expansion in the scope of work is presented in Section III.

The Field Investigations

Field investigations were conducted during two separate trips to Kaho'olawe. The first was between November 25th and 27th, 1991. Personnel for this trip included J. Stephen Athens, Ph.D., David J. Welch, Ph.D., and Michael W. Kaschko, M.A. Transportation to Kaho'olawe was provided via U.S. Marine helicopter from Ford Island, O'ahu. The crew stayed at the small military camp near Smugglers Cove (Hanakanaea). A jeep was provided for ground transportation by the military, and an Explosive Ordnance Disposal (EOD) specialist accompanied the field crew at all times. Several of the various EOD individuals contributed substantially to the often strenuous coring effort. The effective work time for the first trip amounted to 12 days. This period was regarded as a reconnaissance for the purpose of evaluating the procedures and logistical needs for completing the project. At this time partial cores were taken from only Kealialalo Crater and Kealialuna Crater.

The actual coring operation went relatively well at this time, though it became clear that the sediment deposits of the craters were deeper than originally anticipated and that heavier duty equipment would be needed to penetrate to the lower deposits. A concern also developed as to whether the sediments would contain the pollen needed for analysis, much less for radiocarbon dating. This was because the sediments appeared to be essentially entirely of mineral composition with no preserved organic or humic material. Several soil samples run by the palynologist following fieldwork seemed to confirm the general lack of pollen in the samples. The only mitigating factor, however, was that the reconnaissance cores did not penetrate below the Ahupu Formation (see discussion in Section II), and thus would not be expected to contain rich pollen assemblages. In view of this potential problem with locating appropriate sediments for vegetation reconstruction, it was decided to expand the work to two different kinds of depositional environments. These were near Site 207 and at Keoneuli of Kanapou Bay as explained above. This would hopefully maximize chances for obtaining a good pollen record, as well as provide information from different regions and depositional environments.

The second period of fieldwork took place between December 13th and 19th, 1991. The transportation and logistical arrangments were the same as for the first trip. Personnel included J. Stephen Athens, Michael W. Kaschko, Greg Burtchard, and Bruce Jones. Because of its remoteness and difficulty of access, arrangments for transportation to Keoneuli for a day of coring were made with a private helicopter company on Maui. This same helicopter was also used to secure transportation to and from Kealialuna Crater on the following day in order to maximize the time available for the coring work (otherwise ground transport time would have been nearly two hours each way with one hour on foot). Ground transportation to the sampling location near Site 207 was not a problem. All fieldwork was performed and completed as planned.

Further details on field and laboratory procedures are presented in Section III.

Organization of Report

The present report is organized into 5 sections. Section I, the present section, introduces the project and provides general background information about the project, geography, and fieldwork. Section II provides an account of the history and prehistory of Kaho'olawe, previous work on vegetation reconstruction, and a review of sediment classifications. Section III presents a review of field and laboratory procedures. Section IV provides a detailed account of all fieldwork, including a description and photographs of each coring location. Section V presents the pollen and charcoal particle analyses of the collected sediment samples. Section VI summarizes the findings and places them in the context of other investigations and various research interests. Finally, Section VII makes recommendations for further investigations. Appendix A presents findings of the textural analysis of sediment samples, and Appendix B presents findings of the geochemical analysis of selected sediment samples. The appendices are followed by a section listing references cited.

II: PREVIOUS INVESTIGATIONS

An excellent summary of previous archaeological investigations on Kaho'olawe is presented by Kirch (1985:144-154). This basically includes the investigations of Stokes in 1913, McAllister (1933) and the island-wide inventory survey of Hommon (1980a, 1980b). This latter survey identified a total of 544 sites incorporating 2,337 discrete features. Following the inventory survey, Hommon (1983) also undertook a limited amount of excavation, which provided a series of radiocarbon dates (total of 8) as well as information on floral and faunal remains. Kirch's review also includes a brief mention of historical observations concerning the island. In discussing Kaho'olawe, Kirch (1985:144) notes that the island,

> ...is unique in one respect--nowhere else [in Hawai'i] has the evidence for the settlement pattern of an entire island been preserved intact.

As a result of Hommon's survey, the entire island of Kaho'olawe was listed as a Historic District on the National Register of Historic Places.

Following Hommon's work and subsequent to Kirch's presentation on the archaeology of Kaho'olawe, Rosendahl *et al.* (1992) undertook substantial excavations at 17 archaeological sites for the purposes of data recovery and stabilization of eroding deposits. The work produced a massive amount of new data, including 98 new radiocarbon dates and a great deal of information on subsistence remains, artifacts, and several paleoenvironmental topics. The latter domain is the most relevant here and will be discussed in some detail below. For further information concerning the archaeology of Kaho'olawe, the above cited references may be consulted.

The major investigations concerning paleoenvironmental topics include those by Spriggs (1991),[1] Allen

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[1] A similar paper, a forerunner of the 1991 published article, appears in the Rosendahl *et al.* (1992) study.

(1992), Murakami (1992), and Christensen (1992). Spriggs' work, which presents an excellent compilation of historical data and sources, primarily concerns landscape and geomorphological change as a result of prehistoric and historic impacts. The report by Allen concerns the identification of macrobotanical remains from the archaeological excavations and also 4 burn layer localities (see below) in order to obtain information on the former vegetation of Kaho'olawe. The investigations of Murakami were also oriented toward vegetation reconstruction, though through the identification of wood species from charcoal. Christensen's investigations involved the study of nonmarine mollusks from selected archaeological and burn layer deposits.

The theme around which all of the paleoenvironmental studies are organized concerns landscape change--both vegetational and geomorphological--as a result of prehistoric Hawaiian impacts and later historic impacts. The earliest observers during the late 18th and early 19th centuries described Kaho'olawe with such adjectives as "a naked dreary barren waste," "rocky," "ragged," "sandy, and "altogether a poor island" (see Spriggs 1991). As Spriggs (1991:75) makes clear, however, these observations concern the island in general and not what is now the largely eroded hardpan of the inland plateau. As Spriggs (1991) demonstrates, it was not until after the beginning of sheep ranching in the 1850s that this large plateau area changed from a rich savannah grassland with shrubs and small trees, to a completely denuded and eroded landscape. Walter Murray Gibson, who assumed direction of a small Mormon colony on Lanai in 1861 and later developed a large-scale ranching operation there, provides the following graphic description with respect to the impact of sheep ranching (along with goats) on the Kaho'olawe landscape (from Bowser 1880:576 as quoted in Spriggs 1991:78):

> ...owing to being overstocked and to severe droughts the land [inland plateau area] 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 has apparently perished.

Although the above evidence suggests that a drastic alteration of the landscape had occurred as a result of ranching activities, it was a view that had been earlier challenged by Hommon (1980a). Hommon, using his island-wide archaeological site inventory along with 1,102 volcanic glass hydration rind dates,[2] implicated the prehistoric Hawaiians in the environmental degradation of Kaho'olawe. He believed, in fact, that there was a drastic decline in the Hawaiian population late in prehistory (between A.D. 1550 and 1650) due to environmental degradation and the consequent reduction in carrying capacity of the land (see summary of Hommon's views in Kirch 1985:153-154).

Soils and Landscape Change

Critical to Hommon's interpretation was his evidence for the depositional history of the "burn layers" and the Ahupu Formation that overlay them. The Ahupu Formation, typically reddish brown and easily distinguished, is an alluvial and aeolian deposited soil resulting from the massive erosion of the interior plateau. This is underlain by the Kaho'olawe Formation, a yellowish red or strong brown soil.[3] Both the Ahupu and Kaho'olawe Formations were found by Hommon to occur over virtually the entire island.

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[2] The validity of Hawaiian volcanic glass dates has since been thoroughly discounted (see especially Stevenson 1988).

[3] Hommon's (1980a) actual technical description of the Kaho'olawe Formation is a little different than that presented by Spriggs (1991) in that he does not view it as an *in situ* horizon. Hommon's (1980a:60) actual definition of the Kaho'olawe Formation, following Morgenstein, is as follows:

> The Kaho'olawe Formation is described by Dr. Maurice E. Morgenstein, who first identified it, as a "montmorillonitic, blocky B-horizon reducing, isothermic (Typic) chromustert vertisol developed from sedimentary fans ori-

Although Spriggs (1991) subsequently more precisely defined the Kaho'olawe Formation as representing the *in situ* weathering of the original volcano, Hommon and his team, as a practical matter during the course of their fieldwork essentially designated all soil layers below the Ahupu Formation as belonging to the Kaho'olawe Formation (M. Kaschko, pers. comm.). It is critical to be alert to this difference in usage to avoid confusion. Thus, Spriggs (1991:97) regarded the Kaho'olawe Formation as an ancient soil which was often exposed as a saprolitic hardpan in the upland area. However, much of the soil *directly* underlying the Ahupu Formation in the upland areas is *not* an *in situ* formation (the Site 207 locality, which is discussed in this report, is probably a fairly typical example of such a situation). Such soils, therefore, would not be regarded by Spriggs as pertaining to the Kaho'olawe Formation though Hommon would in fact consider them as such. While the definition of soil formations is not specifically within the purview of the present investigations, it is clear that Spriggs' usage of the term Kaho'olawe Formation is more precise and accords with observations presented herein. For this reason his usage will be followed in this report.

The burn layers noted above were thought by Hommon to be always found at the boundary between the Kaho'olawe and Ahupu Formations. As described by Hommon (1980a:7:61), burn layers occur in many parts of the island and "usually measure between 0.5 and 2

> ginating in the higher elevations and from alluvium and colluvium on the lower slopes." The Kaho'olawe Formation sometimes occurs as an A3 or a B3 soil horizon, but is more commonly a B2 horizon. It is usually brown to dark brown (7.5YR 4/2, Munsell notation) in color.

By way of comparison, Hommon (1980a:60) provides the following definition of the Ahupu Formation (after Morgenstein):

> "...a reddish Kaolinitic, weak granular A-horizon, oxidizing, denuded aeolian to aeolian-alluvial ferrigenous low humic latosol (Typic Torrix Oxisol) derived during hot and dry climatic conditions." This horizon commonly occurs in apedal to A3 horizon form, though B1 peds were observed in one case. It is usually reddish brown (5YR 5/4, Munsell notation) in color.

centimeters in thickness and consist of charred grass stems and small fragments of charcoal." Hommon did not directly date any of the burn layers, but observed their association with archaeological features that dated to the 15th century (see Spriggs 1991:81). Given the clearly correct identification of the Ahupu Formation with massive erosion, the conclusion was seemingly inescapable--at least to Hommon--that the prehistoric Hawaiians had been directly involved in the process of environmental degradation. This conclusion also seemed to be corroborated by the archaeological site distribution data. Thus, according to Hommon, the burning of the grasslands to facilitate agricultural planting resulted in soil instability and ultimately led to massive erosion. Historic ranching, according to Hommon (see Spriggs 1991:81) only exacerbated a process already well underway.

Spriggs' (1991) investigations, having the advantage of being focused on this single issue, arrived at a very different conclusion. For one thing, as has already been indicated, Spriggs' historical research makes it clear that there were very extensive grasslands on Kaho'olawe up until the 1850s when sheep ranching was initiated. Also, fires--the agent Hommon believes to have ultimately caused the erosion--were documented from late in the 18th century right up until the start of sheep ranching (see Spriggs 1991:98-99). These fires were of major proportions, "...lighting up the adjacent islands and the sea for fifty miles around" (*The Polynesian*, 30 August 1851 as quoted in Spriggs 1991:99). The interesting thing, however, is that there is no evidence of massive erosion resulting from these fires. Indeed, the thick grass always seemed to grow back for another round of pyrotechnics. As Spriggs (1991:99) observes,

> 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.

The radiocarbon dating results of the Rosendahl *et al.* (1992) project supports Hommon's inference of a 15th century date for the earliest burn layers. A series of 12 dates were obtained on the burn layers, which ranged in age from A.D. 1448-1636 (calibrated) to modern. Spriggs (1991:100) suggests that,

> Although grassland appears to have been established quite early in part of Ahupu Gulch [near the coast where the A.D. 1448-1636 date came from], in areas such as the inland plateau grassland did not occur until the eighteenth or nineteenth century.

A number of Spriggs' profile sections contained multiple burn layers (up to three), clearly indicating that the massive erosion of the Ahupu Formation did not begin with the onset of grassland burning, but only after the latest burn, which was presumably early historic in age. The sedimentary evidence does not suggest any serious problem with soil transport and degradation of agricultural land as a result of prehistoric Hawaiian agricultural practices.

Kaho'olawe Vegetation

There is no doubt that the burn layers represent a primarily grassland vegetation. As observed by Allen (1992:A-21), "the principal archaebotanical [sic] components of the burn layers are grass stems and rhizomes." She also notes that two shrubs were identified: *Chenopodium* and *Sida*, and there was also possibly an unidentified legume. Representatives of herbaceous taxa were also present, including *Argemone*, Convolvulaceae, and five unidentified species. Allen (1992:A-21) also states that "Tree taxa are poorly represented," which she attributes "to the small size of our samples, and the dispersed distribution of trees." Allen does not indicate what the poorly represented tree species are; perhaps her statement was intended as only a figure of speech to convey her feeling that some trees must have been present in the environment.

In contrast, Murakami's (1992) analysis of archaeological hearth samples recovered a number of woody species. Such species, of course, would be expected from hearths. Murakami's analysis, therefore, provides more of an indication of what woody plants were present in the environment and not their relative contribution to the overall vegetation cover. Though this is an unavoidable problem in the analysis of hearth remains, the data nevertheless are quite interesting in terms of complementing the findings of Allen.

Identification of the hearth charcoal from inland sites revealed that Euphorbiaceae (*'akoko*) was "a major component" in addition to *Chenopodium ('aweoweo)*, *Santalum (ili-ahi)*, *Nototrichium (kulu'i)*, *Bidens (ko'oko-'olau)*, *Canthium (alahe'e)*, and *Nothocestrum ('aiea)* (Murakami 1992:H-13). There were also a number of other species from coastal sites that were likely the result of the collection and use of driftwood for fires. In general, the woods used for fires were not of very high quality since they would burn quickly. This suggests that better alternatives were not available (Murakami 1983:187-188).

Spriggs (1991:101) also adds some interesting historical commentary concerning Kaho'olawe vegetation. His quote from Perkins (1854:163) about observations on the inland plateau where grasses were still dominant in 1850 is especially appropriate:

> 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 few shrubs growing further up the mountain, and these, together with a few stunted wili wili [*Erythrina sandwicensis*] trees were the only living representative of the vegetation kingdom worth noticing.

Perkins' reference to goats, which is the earliest known mention of this animal, is notable as it implies that they may have been a major factor in the disappearance of *'akoko*.

Another interesting aspect of Perkins' statement is that he refers to a *grove* of *'akoko* trees, implying that these trees may have had more of a clumped than dispersed distribution in the environment. It is, of course, unknown whether the clumping may have been due to differential burning as a result of the grassland fires or if it was the result of autecological factors.

An 1857 reference quoted by Spriggs (1991:101) notes that the Kaho'olawe *'akoko* are "not more than 4 feet high." This same reference also notes the presence of a few *Dodonaea* (*'a'ali'i*) trees, sandalwoods, and some *wiliwili*, all described as small and apparently relatively scarce.

In her synthesis of the prehistoric vegetation on Kaho'olawe, Allen summarizes the evidence as follows:

> Together the two sources of evidence [the fire pits and the burn layers] suggest the gradual development of a savannah-type vegetation during [the] late-prehistoric period, and eventual formation of more pure grass stands, as an outcome of tree clearance, repeated burnings, and the historic introduction of exotic herbivores. Simultaneously, colonizers like *Chenopodium* may have dominated other areas, or perhaps preceded the development of grasslands.

The grassland, of course, developed from "a diverse dryland forest," which Allen (1992:A-20) infers to have existed from a hypothetical reconstruction of vegetation by the EIS botanical survey team, evidence of woody taxa from Murakami's (1992) investigations, historical accounts, and the archaeological land snail evidence. Regarding the latter, Christensen (1992:B-5) infers "conditions somewhat less rigorous than, for example, those found...at Barbers Point, Oahu." As previously noted, the change from dryland forest to grasslands was inferred to have been a result of "human-induced fires and clearance, and later by introduced herbivores" (Allen 1992:A-20).

Spriggs (1991:82) interprets the vegetation on Kaho'olawe during the period of prehistoric Hawaiian occupation as a "...dry forest or savannah-parkland habitat," believing that "woody species were readily available." He therefore appears not to regard the change in vegetation from pre-Hawaiian occupation times to the late prehistoric period as abrupt and different as Allen seems to see it. However, Spriggs certainly acknowledges that there was substantial change.

Research Problems

Hommon's specific formulation of the question of environmental degradation on Kaho'olawe as a significant and interesting archaeological research problem has motivated a considerable amount of investigation, his own included. The more recent project of Rosendahl *et al.*, has clarified a number of aspects of this problem, including the cause behind the massive erosion on the inland plateau, which now may be clearly regarded as a product of historic ranching activities and not early Hawaiian agriculture. There remain, however, a number of related questions that should still be addressed.

The most significant of these research questions, at least from the perspective of the present project, concerns the nature of the Kaho'olawe plant communities *prior* to Hawaiian occupation of the island--that is, prior to about A.D. 1,000.[4] Allen and Spriggs, although addressing this issue, *never* obtained data from any deposits dating to this earlier pre-occupation time period. Their assessments, although valuable and meriting consideration, rest on a number of rather tenuous assumptions regarding the projection of modern, historical, and late prehistoric data back in time. As has been shown for O'ahu (Athens *et al.* n.d.), such projections may be extremely unreliable. Thus, if there is to be an understanding of pristine Hawaiian vegetation and an assessment of Hawaiian impacts to this vegetation, it will be necessary to obtain data from deposits pre-dating the Hawaiian

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[4] As noted in Section I, present evidence suggests that Hawaiians had settled on Kaho'olawe at least by A.D. 1250 (Rosendahl *et al.* 1992:V-31). The earliest radiocarbon date, obtained by Hommon (1982) has a calibrated range of A.D. 785-1035. Based on this date, Hommon believes there was some initial use of Kaho'olawe by the 10th century, but that actual settlement did not begin until between about A.D. 1,000 and 1400 (see also Kirch 1985:153).

occupation. Ideally, this should be done for a number of different environmental zones and time periods from the Holocene so that vegetational variability on the island can be identified and understood.

Other research questions that can be cited concern a host of issues related to Hawaiian settlement pattern changes through time and how these may be best interpreted (i.e., are these in response to environmental degradation, changes in agricultural practices, or some other reason?). Such questions, however, are beyond the scope of the present study and need not be discussed further here.

III: FIELD AND LABORATORY PROCEDURES

Field Procedures

The underlying assumption of the present investigations is that the volcanic craters of Kaho'olawe would be the locations most likely to contain full and uninterrupted sediment sequences as a result of their protected basins. These sediments, in turn, *potentially* (but not certainly) could provide a full pollen record that would indicate the vegetation growing in the vicinity, as well as any changes that might have occurred from the earliest times prior to Polynesian settlement on Kaho'olawe, through the period of Polynesian occupation, and continuing through the historic and ranching periods and into modern times. The fact that the craters formed enclosed basins also made it possible that ponded water would have collected in the basins at least periodically (known to occur during the historic period), forming wetland habitats conducive to the preservation of pollen.

Because it was expected that the crater sediments would be relatively hard and compacted, the use of a standard 32 inch bucket auger was planned for the major boring work. If softer sediments were encountered (as a result of moist or wet sediments), a standard piston corer would be utilized to remove intact and undisturbed soil samples (see Wright *et al.* 1965; Wright *et al.* 1984). Additional tools included a heavy chisel and hammer attachment for breaking through rocks in the bore hole, and also a screw-type auger to assist in the penetration of stiff or rocky sediments.

The auger and corer were originally attached to 3/4 inch diameter chrome-molybdenum conduit extension rods with a cross bar. As a result of experience during the first trip to Kaho'olawe, however, a change was made to 1 inch diameter conduit for increased strength and rigidity, which was clearly needed for the deeper bore holes (e.g., Core 1 reached a depth of 17.03 m).

The auger penetrated the soil in increments of 10 to 20 cm at a time. After each increment, the auger had to be raised from the hole to empty the bucket.

Sediment samples were taken at varying depths either when stratigraphic changes were observed or when the distance from the previous sample seemed to be sufficient (generally not more than one meter). The sample was retrieved from the bucket auger by first removing loose sediment around and between the auger bits, and then using a screwdriver to pry out the generally compacted sediment so that it would fall into a clean plastic bag that had been labeled with the core number and depth. No samples were taken with the corer due to the hardness of the sediments.

Field Sampling Locations

Crater Borings

In general, the field plan was to bore a single core test unit into each of the 5 craters on Kaho'olawe identified on the U.S.G.S. topographic map. These locations and their respective identifying core numbers and the maximum depth penetrated are as follows:

Lua Kealialalo	Core 1	17.03 m
Lua Kealialuna	Core 2	15.01 m
Lua Makika	Core 3	6.78 m
" "	Core 4	6.78 m
Lua Keaualalo	Core 5	2.60 m
Lua Keaualuna	Core 6	14.06 m

For ease of reference all sample bore holes are referred to as "cores," even though they are really auger bore holes.

An attempt was made to penetrate through the entire sediment sequence in each bore hole. This was possible, however, in only Cores 1, 3, 4, and 5. The depth of sediments coupled with a lack of time prevented penetration to basement rock in Cores 2 and 6. In the case of Lua Makika, a large crater, Core 3 reached rock at the unexpectedly shallow depth of 6.78 m. Although a full sediment sequence seemed to be represented in this core, it was decided to place another core in the crater to check the Core 3 results. It turned out that Core 4 reached rock at the same depth, and there is no doubt that a full sediment sequence is represented.

In all cases an attempt was made to locate the bore holes in the approximate center of the crater basin to maximize the possibility of recovering a full sediment sequence. This would also minimize the possibility of encountering rock in the bore hole that may have eroded or washed in from the crater rim and thereby prevent completion of the excavation.

Site 207

During the course of the crater coring work, it was decided that it would be useful to have a sediment sequence with the major depositional units of Kaho'olawe as discussed by Spriggs (1991) and others for comparative purposes. In particular, there was a concern whether the established two-part sequence--the early Kaho'olawe Formation and the late Ahupu Formation--with a burn layer (or series of burn layers) sandwiched in between, were relevant analytical categories for the core sequences, and how these related to Spriggs' observations. In addition, there was a simple concern to have appropriate reference material so that the various formations and soils on Kaho'olawe could be, in so far as possible, unambiguously identified in the cores. Finally, there was a concern that the crater cores might be devoid of pollen, and also that it would be of interest to sample the plateau area outside the crater basins.

Archaeological Site No. 207 was decided upon as the most accessible sampling location that had been previously described in the literature (Spriggs 1991:96). This site is in roughly the center of the island near the margin of Kanaloa Gulch at its upper end on the north side (see Fig. 1). The elevation of this location is approximately 330 m (1,082 ft). For purposes of sampling, an exposed gully bank was cleaned and faced near (but not on) the actual archaeological site. Appropriate sediment samples were then collected after recording the stratigraphy. Although the layer below the burn layer (designated L2d in Spriggs' description) does not pertain to the Kaho'olawe Formation (although Hommon designated it as such), it does provide an indication of the type of soil that may occur immediately below the burn layer of the inland plateau area. The upper layer (L1) is described as pertaining to the Ahupu Formation.

Kanapou Bay

In an effort to secure lowland sediment samples for comparative purposes for the pollen study as well as to help ensure that some pollen results would be forthcoming if the volcanic crater samples proved uninformative, an effort was made to obtain core samples from possible back-swamp deposits behind the large sand beach at Keoneuli at the southern end of Kanapou Bay. A helicopter from Maui was hired in order to reach this remote location for the one day excursion.

The Kanapou Bay coring effort did in fact yield several samples from two cores placed just behind the beach. However, these deposits were not as deep or presumably as early as had been hoped, and despite efforts to locate more substantial deposits, none could be found.

Laboratory Methods

Soils

The recovered soil samples were transported to the IARII laboratory in Honolulu where they were analyzed by D. Welch and S. Athens in accordance with the standard U.S.D.A. Soil Conservation Service format. In undertaking the analysis, a small portion of each sample, perhaps ca. 50 to 100 grams, was removed from the sample bag and placed on a small paper plate. The samples were then lined up together on a large table in proper stratigraphic order. One or more samples from each distinctive stratigraphic unit was then systematically analyzed with respect to color, texture, consistence, and structure. Having all of the samples spread out in full view made it easier to make fine distinctions between the samples and also to make certain that important general characteristics of the depositional sequences were not lost in the descriptive detail of the individual sample analysis.

In addition to the above, Welch used a chemical protocol to separate silt, clay, and sand fractions of selected soil samples from each core in order to more accurately evaluate the precise concentrations of these fundamental soil constituents.

Geochemical analysis was further undertaken on a series of samples from Core 1 in order to obtain information on the mineralogical composition of the various soils. Such information was expected to be of value for understanding the origin and formation of the various soil layers, and this proved to be the case.

Pollen and Charcoal

Pollen analysis and charcoal particle counts were undertaken by Jerome Ward. A detailed presentation of his results, along with laboratory procedures utilized, are presented in Section V of this report. Pollen analysis, of course, is a long-established paleobotanical methodology for determining ancient plant types and communities. Charcoal particle counts are useful for determining anthropogenic disturbance and also the incidence of natural fires in the environment (Tolonen 1986). For Kaho'olawe, this type of analysis was considered potentially highly useful for determining in the sediment core samples the timing of the onset of major prehistoric human impacts to the landscape, the beginning of the ranching period, and other details.

Radiocarbon Dating

A series of radiocarbon dates were to have been obtained on sediments from the cores to provide an absolute time scale for changes in sedimentary units and vegetation. Unfortunately, however, the collected soil samples were virtually devoid of organic materials, rendering the radiocarbon dating method unusable.

IV: KAHO'OLAWE FIELD INVESTIGATIONS

Kealialalo Crater -- Core 1

Kealialalo Crater (Lua Kealialalo) is located at the west end of Kaho'olawe's interior plateau (Fig. 1, Photo 1). It is quite a large crater structure. The top ridges of the crater rim, forming more or less an oval around the crater, measure roughly 1 km east-west by 0.70 km north-south. The elevation of the crater rim is approximately 250 to 259 m. The elevation of the interior basin is roughly 240 m. Evidently there is no natural drainage channel leading from the crater, though topographic map contour lines show that the crater rim has obviously been breached on the west and south sides.

Present day vegetation consists predominantely of dense *kiawe* trees and a thick undergrowth of tall grass. Much of the crater rim, especially on the north side, is bare hardpan with little or no vegetation. The central crater basin, roughly measuring 140 x 200 m) is also barren hardpan (see Photos 1, 2, and 3). However, rather than being the result of exposure to weathering processes (chiefly strong trade winds), it appears that the lack of vegetation is the result of periodic standing water. Indeed, large irregular polygonal drying cracks on the surface of this area clearly attest to the relatively recent presence of pooled water in the center of the crater (Photo 2), which must have remained for some time before it was slowly absorbed into the soil and also evaporated. Standing pools of water must occur with sufficient regularity and duration that trees are prevented from growing in this area. No water was evident in the crater basin at the time of the coring work.

Core 1

Core 1 required just under two days of field time to complete. The first period of work was undertaken on November 25 and 26, 1991 (total of about 7 hours). The bore hole was completed with a full day of work on December 14, 1991. A maximum depth of 17.03 m was reached for Core 1.

Photo 1. Low altitude aerial photo of Kealialalo Crater. View to southeast. Note area of hard pan in crater basin where Core 1 was taken. Crater rim is barely discernable to left and background.

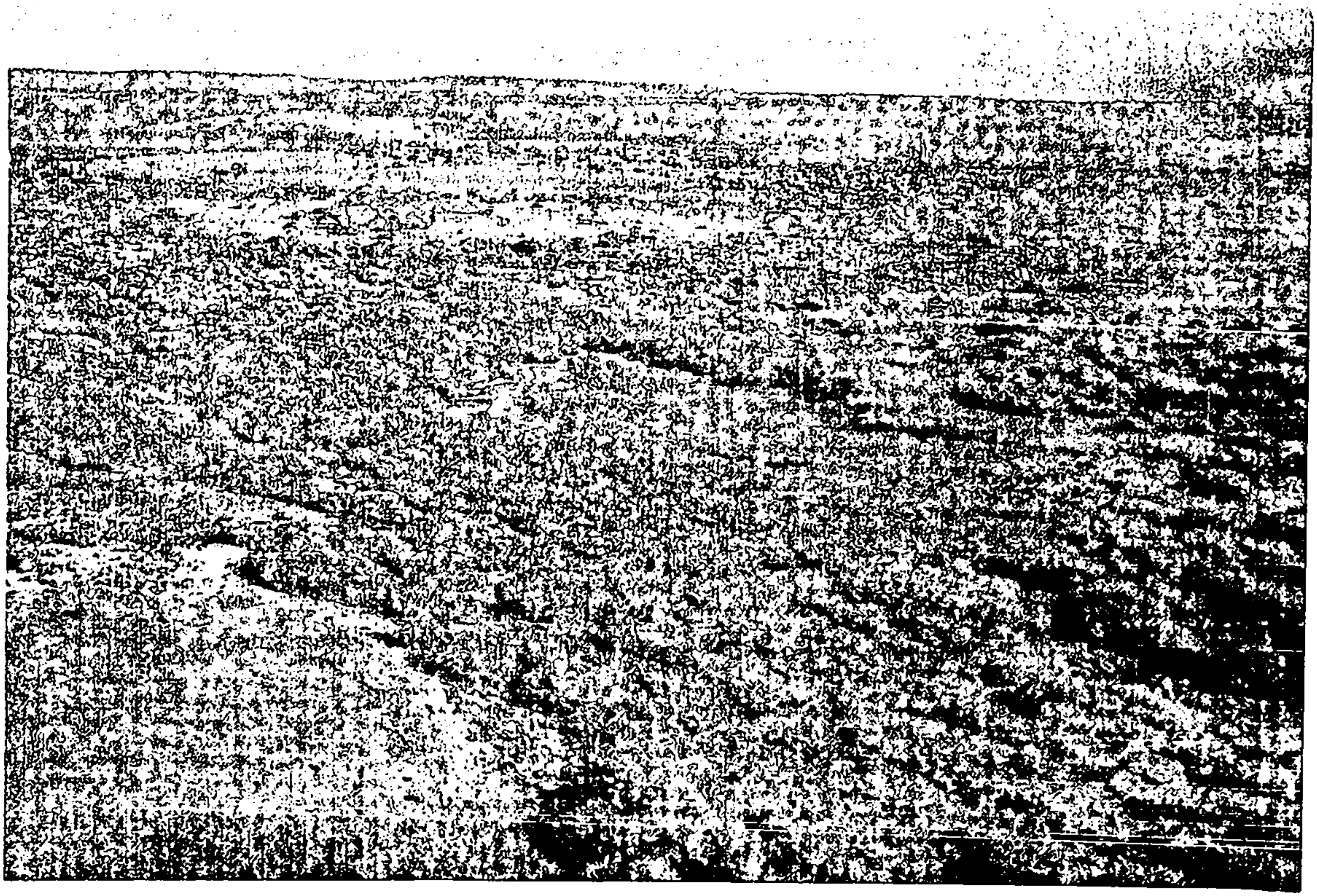

Photo 1. Low altitude aerial photo of Kealialalo Crater. View to southeast. Note area of hard pan in crater basin where Core 1 was taken. Crater rim is barely discernable to left and background.

Photo 2. Coring in basin of Kealialalo Crater. Note hardpan from previously standing water.

Photo 3. Deep augering the firm sediments inside Kealialalo Crater.

Core 1 was located approximately 30 m west of the east margin of the basin hardpan. This location appeared to be undisturbed by bombs or other explosive ordnance.

A total of 34 samples, including one from the surface, was taken from Core 1. Of these samples, 15 were analyzed for pollen and 8 were analyzed for geochemistry. Table 1 presents a listing of sediment samples with notations indicating which were analyzed for pollen and which for geochemistry.

The results of the sediment analysis are presented in Table 2. A profile showing the stratigraphic layering of Core 1 is presented in Figure 2. A full account of the textural and geochemical analyses are presented in Appendices A and B, respectively.

In general, Layers I through III form the most recent depositional sequence. These soils are reddish in color and have textures varying between silty clay and silty clay loam. They are characterized by an abundance of kaolinite/halloysite, which decreases

* * * * *

Table 1. Soil, pollen, and geochemistry samples from Core 1, Kealialalo Crater (depth in m).

surface*	3.60*	4.65
5.95*	6.58+	7.86*
8.47	9.00*	9.40+
9.75	9.92	10.36+
10.65*	10.88	11.09+
11.40*	11.64	11.83*
12.12*	12.32+	12.69
12.91*	13.10*	13.71*
14.00*+	14.24+	14.50
14.76+	15.01*	15.42
15.82	16.16	16.61
17.03*		

* pollen sample
\+ geochemistry sample

Table 2. Soil profile, Core 1, Kealialalo Crater.

Layer	Depth cm b.s.	Color,	Description Munsell*
I	surface	5YR 4/4	reddish brown; silty clay loam; consistence--dry hard, wet slightly sticky and slightly plastic; structure--moderate, medium crumb.
II	0-360	2.5YR 3/4	dark reddish brown; silty clay; consistence--dry very hard, wet sticky and plastic; structure--moderate, medium crumb.
III	360-1109	10YR 3/5	dark red; clay loam; consistence--dry hard, wet slightly sticky and slightly plastic; structure--moderate, fine to medium crumb; clay films on ped faces. There is a very slight increase in redness with depth.
IV	1109-1140	2.5YR 3/3	dark reddish brown; clay; consistence--dry hard, wet slightly sticky and plastic; structure-- moderate, fine to medium granular; clay films on ped faces.
V	1140-1212	5YR 4/5	yellowish red/reddish brown; loam; consistence --dry slightly hard, wet non-sticky and slightly plastic; structure--weak, very fine granular.

Table 2 (cont.).

Layer	Depth cm b.s.	Color, Munsell*	Description
VI	1212-1291	5YR 4/6	yellowish red; clay loam; consistence--dry slightly hard, wet non-sticky and slightly plastic; structure--weak, very fine granular. This layer has less clay and more sand than Layer V.
VII	1291-1400	2.5YR 3/4	dark reddish brown; clay loam; consistence --dry slightly hard, wet non-sticky and slightly plastic; structure--weak, very fine granular. This layer has less sand and more clay than Layer VI.
VIII	1400-1476	7.5YR 4/4	dark brown; clay loam; consistence--moist firm, wet sticky and plastic; structure--weak, fine crumb. This layer has first indication of naturally moist sediment.
IX	1476-1542	7.5YR 3/3	dark brown; clay loam; consistence--moist friable, wet non-sticky and slightly plastic; structure--weak, very fine granular. By 1501 cm the transition to Layer X is already beginning.
X	1542-1703	7.5YR 4/4	brown/dark brown; clay loam; consistence--moist friable, wet non-

Table 2 (cont.).

Layer	Depth cm b.s.	Color, Munsell*	Description
			sticky and slightly plastic; structure--weak, very fine granular. There is a little more clay in this layer than in Layer IX. Highly weathered basalt fragments (gravel size) increase with depth; sample at 15.42 m has white substance--presumably calcium carbonate--filling rock pores. Color becomes slightly lighter at the base (7.5YR 5/4).

* All Munsell colors were determined on dry sediment.

* * * * *

sharply below Layer VII. Kaolinite/halloysite are the typical products of an early stage of basalt weathering (see Appendix B). The deep red color of the sediments leave little doubt about their affiliation with the Ahupu Formation.

Layers IV through VII comprise what is here designated as the Intermediate Formation. This depositonal unit, consisting of loam and silty clay, represents a combination of *in situ* soil development and slow alluvial and/or aeolian accumulation of sediment washed or blown in from the crater rim. The top of this unit presumably dates to about A.D. 1850 when the Ahupu Formation began to form. The antiquity of the

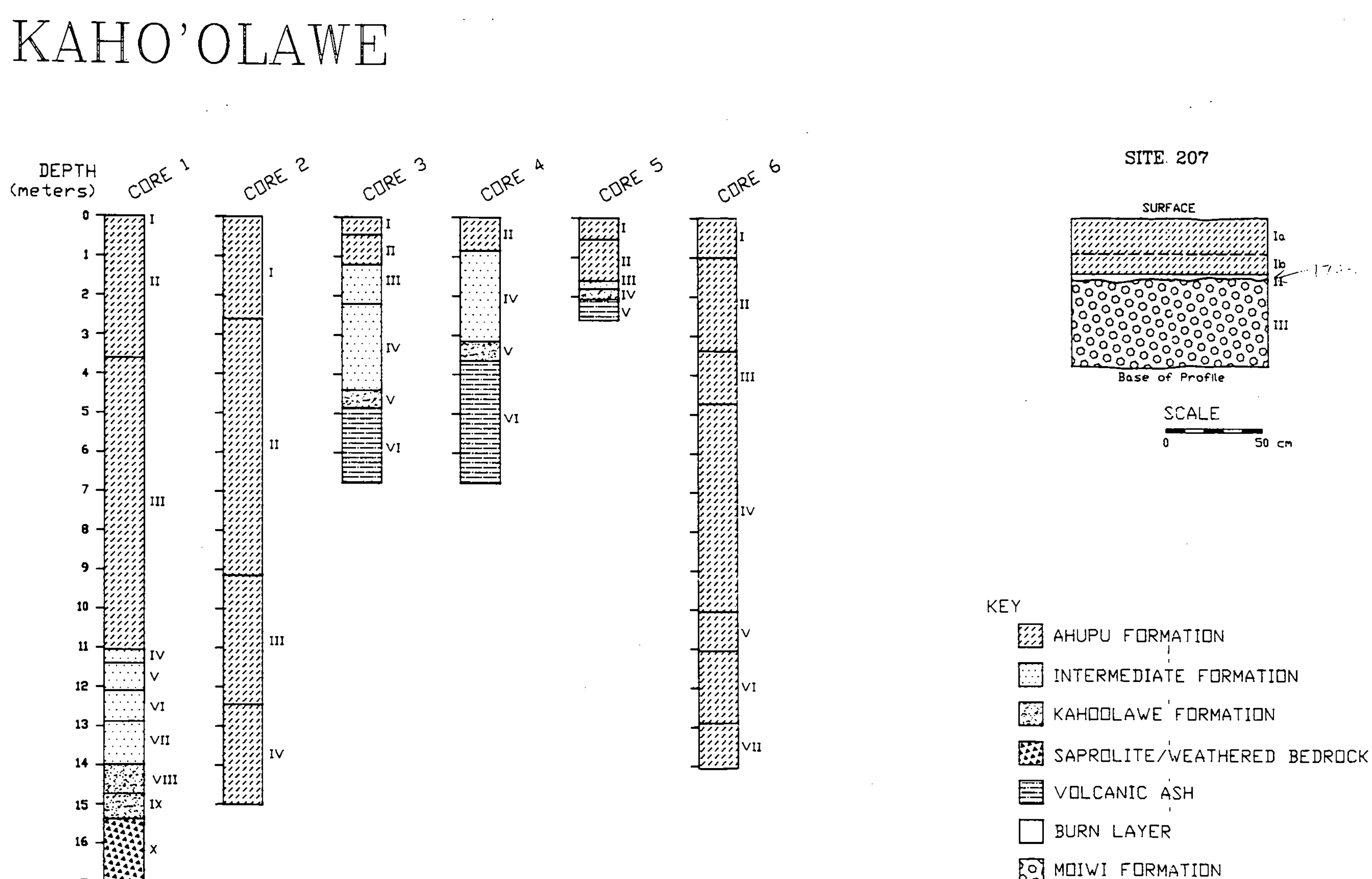

Figure 2. Profiles of Cores 1 through 6 and Site 207, Kaho'olawe Island.

base of the Intermediate Formation is unknown, though the geochemical data suggest that it is not really ancient or of geological age. It presumably would date at least to the beginning of the Holocene, and it is not unlikely that it could be much older. In terms of texture and origin, the Intermediate Formation is not very different from the Ahupu Formation. However, its accumulation was apparently not nearly as rapid and the underlying causes were quite different.

Layers VIII and IX, consisting of silty clay loam and silt loam, are believed to pertain to the Kaho'o-lawe Formation, which represents an *in situ* soil formed from the weathering of volcanic rock. Gibbsite, a product of an advanced stage of weathering of basalt, is the primary mineral component of the soil below Layer VII. The Kaho'olawe Formation is probably quite ancient.

The fourth and basal depositional unit is comprised only of Layer X. This layer consists of silt loam with highly weathered basalt fragments. Calcium carbonate has collected in the rock pores in the upper part of the unit. The rock fragments are mostly gravel-sized and smaller. Solid rock was never reached in the core.

At no place in the core was there any evidence that standing water had been present in the crater basin for protracted periods. Had this occurred, there should have been some evidence for a clay layer. A very damp horizon would also have been expected. Until Layer VIII, there was no real indication of moisture in the soil, and even for this layer it was fairly minimal. It is possible that the present occurence of standing water in the basin is only a phenomenon associated with deposition of the historic Ahupu sediments. The water that collects in the basin evidently penetrates the clayey sediments only slightly, and the rest stays on the surface where it eventually evaporates. Whether the layers below the Ahupu Formation are more permeable than the Ahupu sediments is uncertain. It is possible that the accumulation of periodic standing water only became possible with the rapid deposition of the Ahupu sediments.

Kealialuna Crater--Core 2

Kealialuna Crater (Lua Kealialuna) is located in the northeastern portion of Kaho'olawe Island. It is situated on a small bench of the steeply sloping terrain of this part of the island. At an elevation of approximately 235 m (771 ft), it is well below the inland plateau and Lua Makika (Fig. 1, Photo 4). The crater itself has a flat central basin that is at least 15 m below the rim. The rim surrounds all but a small portion of the west side where there is a small breach (Photo 4). The ground surface outside the crater slopes rather steeply to the ocean on all but the south side.

The crater is nearly circular and measures roughly 200 m in diameter from rim to rim. The basin of the crater, which is essentially flat hardpan, measures perhaps 125 m in diameter. The crater rim is heavily dissected, especially on the interior of the south side. *Kiawe* trees are abundant on the lower interior slope of the crater rim, where grass tends to be thickest. The crater basin, however, is largely devoid of vegetation except for a few scattered *kiawe* trees (Photo 5).

The hardpan of the crater basin almost certainly formed as a result of periodic standing water in the basin. At the time of the coring work, in fact, there were several small puddles of water. However, as the crater has filled with sediment to the height of the breach in the crater rim on the west side, it can no longer accumulate standing water.

Core 2

Core 2 is located in the crater basin approximately 40 m southeast of the rim breach and near a lone *kiawe* tree (Photo 5). The coring involved two full days of work on Nov. 26 and Dec. 17, 1991. During the November coring, a depth of 6.18 m was reached. The same hole was then extended to a depth of 15.01 m in December utilizing a stiffer one inch diameter drive rod.

A total of 37 sediment samples, including one from the surface, was taken from Core 2. Of these samples, 8 were analyzed for pollen. Table 3 lists

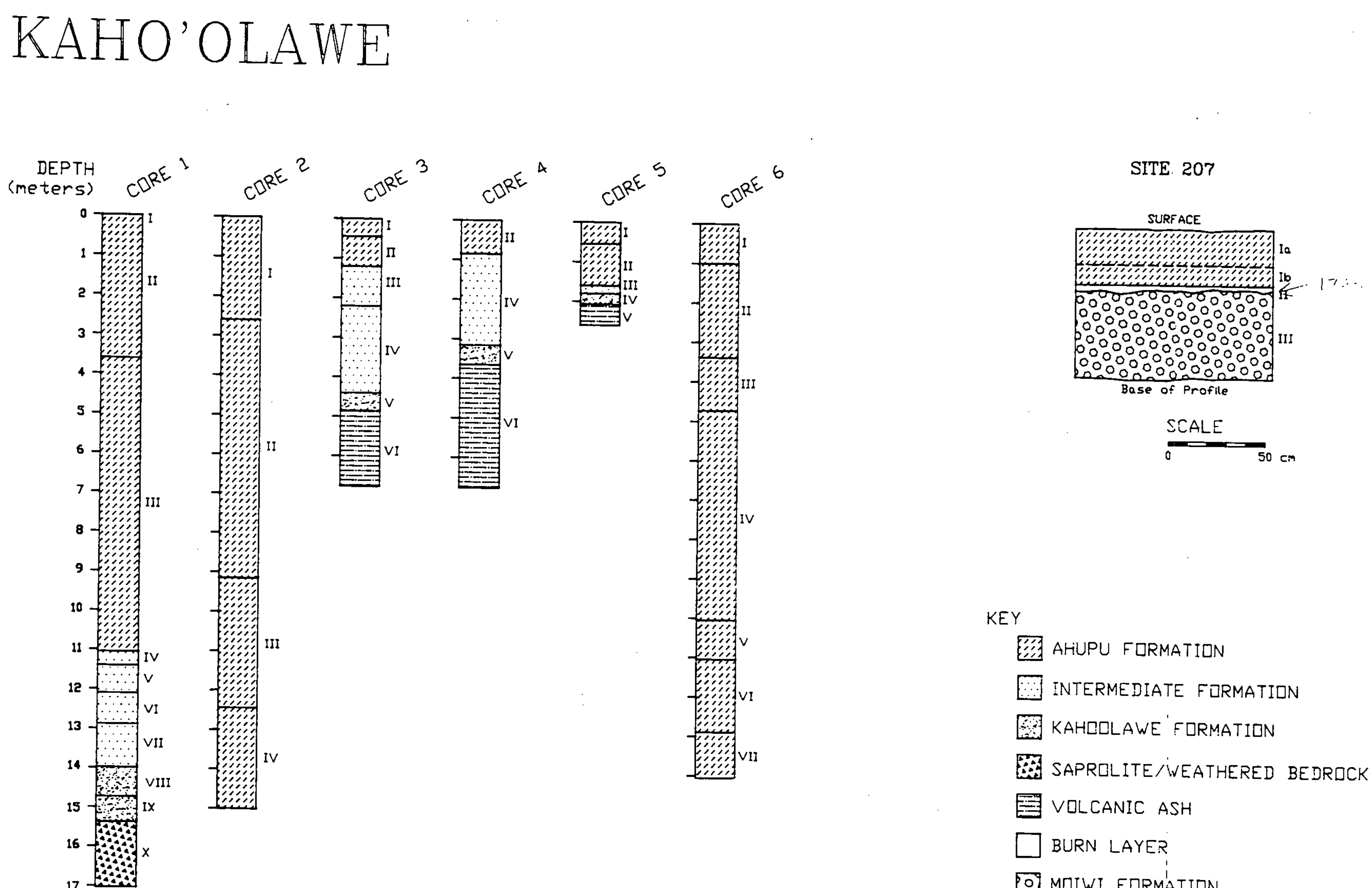

Figure 2. Profiles of Cores 1 through 6 and Site 207, Kaho'olawe Island.

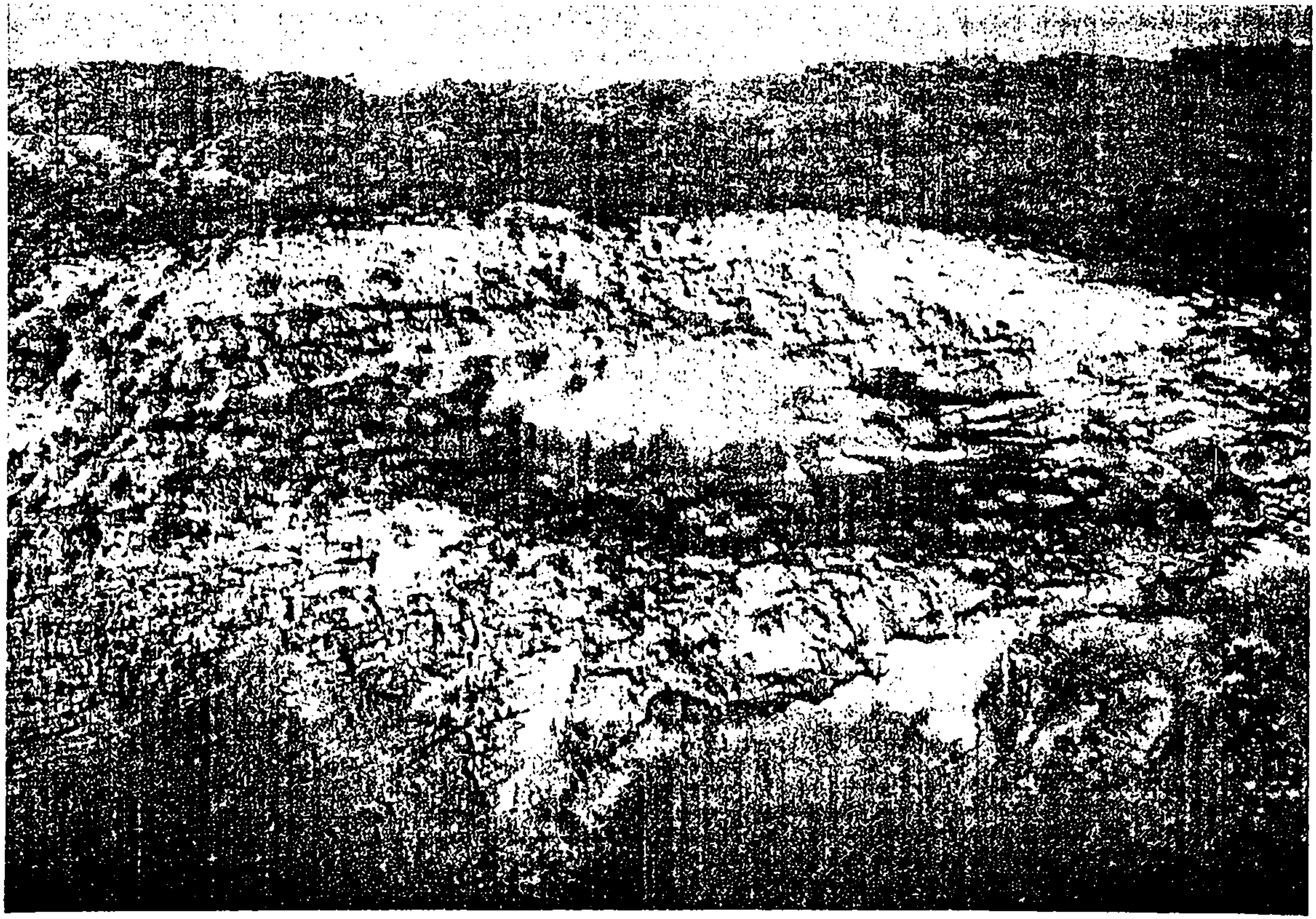

Photo 4. Low altitude aerial photo of Kealialuna Crater. View to northeast. Note area of hardpan in crater basin where Core 2 was taken. The breach in the crater rim may be seen in the left center of the photograph.

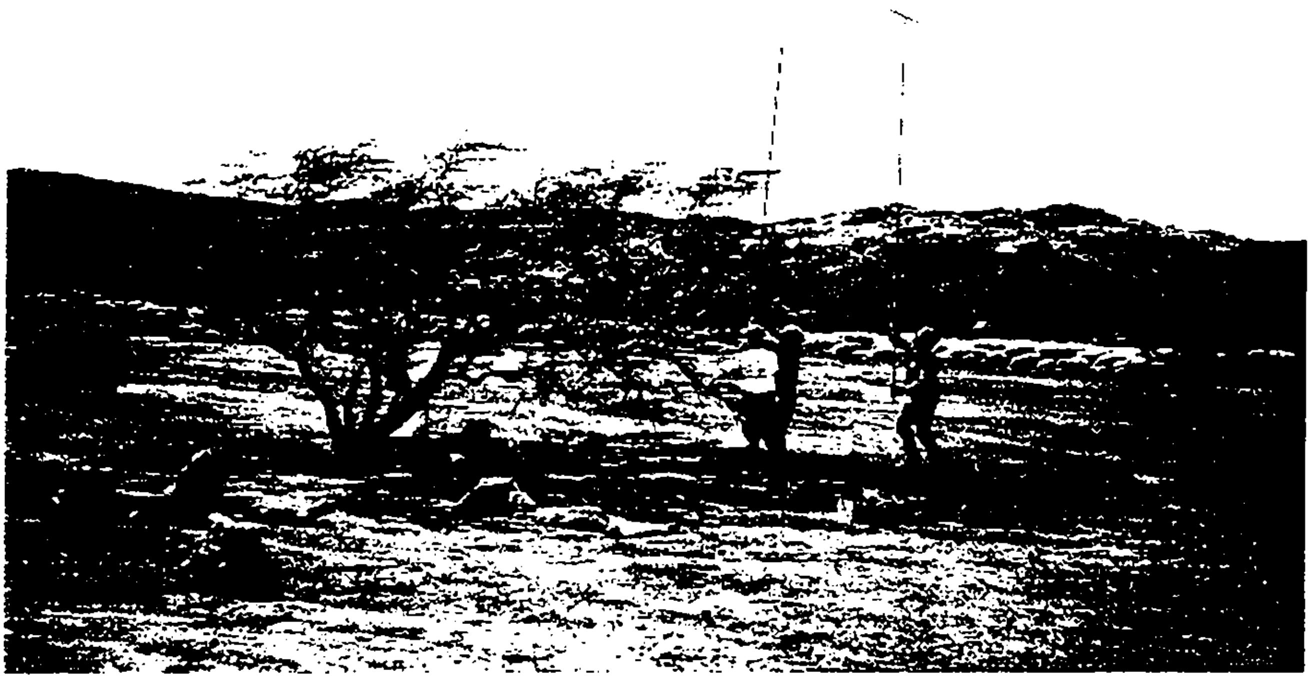

Photo 5. Coring in basin of Kealialuna Crater. Note hardpan from previously standing water. Also, note height of crater rim in background.

Table 3. Soil and pollen samples from Core 2, Kealialuna Crater (depth in m).

surface*	0.20	1.10*
2.59	3.00*	4.43
5.69*	6.18	6.48*
7.35	7.60	8.05*
8.17	8.43	9.94
9.17	9.40	9.59
9.92	10.22*	10.94
11.33	11.60	11.90
12.20*	12.30	12.40
12.50	12.64	12.84
13.01*	13.32	13.82
14.27	14.48	14.74
15.01*		

* pollen samples

* * * * *

all sediment samples. Results of the textural analysis are presented in Table 4, and a profile illustrating the stratigraphic layering of Core 2 is presented in Figure 2.

In terms of color and texture, Layers I through IV appear to pertain entirely to the Ahupu Formation. The Intermediate Formation, as identified in Core 1, could not be recognized in the Kealialuna core. Also, none of the layers were even remotely similar to the Kaho'olawe Formation. It is therefore believed that the entire sequence represents historically transported and redeposited soil (a result of alluvial and aeolian processes). Obviously a very large amount of infilling occurred within only a short span of time. The clay of Layer II probably prevented the rapid percolation of rain water, thereby facilitating the periodic accumulation and persistence of standing water in this crater.

Table 4. Soil profile, Core 2, Kealialuna Crater.

Layer	Depth cm b.s.	Color, Munsell*	Description
I	0-259	2.5YR 3/4	dark reddish brown; loam; consistence--dry slightly hard, wet slightly sticky and slightly plastic; structure--weak, fine crumb.
II	259-917	10R 3/4	dusky red; clay; consistence--dry hard, wet sticky and plastic; structure--strong, medium to coarse, subangular blocky. Clay films on ped surfaces. Small amount of decomposing gravel and pebbles in lower part of layer.
III	917-1250	10R 3/4	dusky red; silty clay; consistence--dry slightly hard, wet slightly sticky and plastic; structure--weak, medium crumb. Small amount of decomposing pebbles below 11.6 m.
IV	1250-1501	5YR 3/3	dark reddish brown; clay loam; consistence--slightly hard, wet slightly sticky and plastic; structure--weak, fine to medium crumb. Small amount of decomposing rock present in layer.

* All Munsell colors were determined on dry sediment.

Makika Crater -- Cores 3 and 4

Makika Crater (Lua Makika) is located in the east central portion of Kaho'olawe Island at its highest point (Fig. 1, Photo 6). This location is within the easternmost extension of the inland plateau area. The crater is essentially circular, having a rim to rim diameter of roughly 650 m. Its interior basin diameter is roughly 300 to 400 m. The north crater rim marks the highest point on Kaho'olawe at 452 m (1,483 ft). The elevation of the interior basin is approximately 430 m (1,410 ft). There is no clearly defined drainage channel exiting the basin.

The crater rim, exposed to strong trade winds, is generally devoid of vegetation. However, the crater basin is quite thickly vegetated on all but the eastern side, which is grass covered. The vegetation includes dense *kiawe* trees, *koa-haole* trees, *lantana*, dense California (or similar species) grass, vines, and other plants. There were no areas of barren hardpan, suggesting that standing water does not accumulate for any length of time in the basin.

With respect to archaeology, most of the rim and the entire basin has been designated as Site 150, which represents a series of 21 activity areas located mostly on the exposed rim hardpan and soil hummocks. Archaeological remains include fire-pits and hearths with charcoal, fire-cracked rock, basalt flakes and other lithic debris, and a limited amount of shell midden. No features were actually identified within the basin interior (Hommon 1980a).

Core 3

Core 3 involved a half day of work on December 15, 1991. It was located in the approximate center of the basin. This location appeared to be undisturbed by bombs or other explosive ordnance. A maximum depth of 6.78 m was reached, whereupon indurated volcanic ash was encountered. As listed in Table 5, 11 soil samples were collected. No pollen samples were processed from this core.

Because the basal depth of the core was relatively shallow considering the size of the crater and the depths reached by Cores 1 and 2, there was some con-

Photo 6. Low altitude aerial photo of Makika Crater. View to east. Rows of Tamarisk trees are in the foreground, which serve as a windbreak for a re-vegetation program.

Table 5. Soil samples from Core 3, Makika Crater (depth in m).

0.12	0.45	1.22
2.24	2.75	3.45
3.93	4.39	5.91
6.51	6.78	

* * * * *

cern that Core 3 did not reach the bottom of the soil deposit. This was partially because the indurated basal ash was initially believed to be weathered basalt. The auger, therefore could have been blocked by a rock that had tumbled into the crater from the rim. This did not seem likely considering what appeared to be a complete soil profile. However, it seemed appropriate to place another core in the crater to see if the results of Core 3 would be duplicated. This second core was designated as Core 4.

<u>Core 4</u>

Core 4 was completed in the afternoon of December 15 by the same personnel with the exception of a change in the EOD specialist. This core was placed roughly 75 m west of Core 3 in a location with dense vegetation and no evidence of recent disturbance.

Core 4 was dug in the same manner and with the same equipment as Core 3. This core penetrated to the same basal depth of 6.78 m, whereupon indurated volcanic ash was also encountered. A total of 14 sediment samples was collected from this core. These are listed in Table 6. Of these samples, 7 were analyzed for pollen.

Table 6. Soil and pollen samples from Core 4, Makika Crater (depth in m).

0.10*	0.84*	1.50*
1.96	2.46	3.15*
3.20*	3.50	4.16*
5.00	5.64	5.85
6.52*	6.78	

* pollen samples

* * * * *

From Core 3, one or more samples from each distinctive stratigraphic unit were systematically analyzed with respect to color, texture, consistence, and structure. The results are presented in Table 7. A specific analysis of the Core 4 samples was not undertaken as the stratigraphic layers present in this core were identical to those observed in Core 3.

Profiles showing the stratigraphic layering of Cores 3 and 4 are presented in Figure 2. In Core 3 the Ahupu Formation is clearly present in Layers I and II, which consist of a loam and gravelly loam that are reddish brown in color. Layers III and IV, a reddish brown clay loam and strong brown loam, respectively, appear to belong to the Intermediate Formation. The *in situ* Kaho'olawe Formation, a brown to yellowish brown soil, is present from Layer V on down to the base. The basal Layer VI consists of indurated volcanic ash.

Basically, the Core 4 sediment sequence lacks Layers I and III of Core 3. This deficiency seems odd since the cores are otherwise quite similar and were taken in relatively close proximity to one another. No explanation for this deficiency is immediately apparent.

Although having greatly foreshortened sediment sequences, Cores 3 and 4 are quite similar to that

Table 7. Soil profile, Core 3, Makika Crater.

Layer	Depth cm b.s.	Color, Munsell*	Description
I	0-45	5YR 4/4	reddish brown; clay loam; consistence--dry soft, wet slightly sticky and slightly plastic; structure--moderate, fine subangular blocky.
II	45-122	5YR 3/4	dark reddish brown; gravelly clay loam (25% gravel; gravel is highly weathered subangular basalt); consistence--dry hard, wet slightly sticky and slightly plastic; structure--single grain.
III	122-224	2.5YR 3/4	dark reddish brown; loam; consistence--dry slightly hard, wet slightly sticky and plastic; structure--moderate, fine to medium subangular blocky.
IV	224-345	7.5YR 4/6	strong brown; clay loam; consistence--dry slightly hard, wet slightly sticky and slightly plastic; structure--weak, fine subangular blocky.
V	345-393	7.5YR 4/4	brown/dark brown; loam; consistence--dry slightly hard, wet slightly sticky and slightly plastic; structure--weak, fine subangular blocky.

Table 7 (cont.).

Layer	Depth cm b.s.	Color, Munsell*	Description
VI	393-678	10YR 5/7	yellowish brown, slight variation in color with depth; clay loam with 25% to 50% indurated volcanic ash; consistence--dry soft, wet non-sticky and slightly plastic; structure--weak, fine crumb.

* All Munsell colors were determined on dry sediment.

* * * * *

recorded for Core 1 in Kealialalo Crater. The Ahupu, Intermediate, and Kaho'olawe Formation soils are present in all of these cores.

Using the layer definitions of Core 3, the sequence for Core 4 is as follows (see Fig. 2):

Layer II	0 - 84 cm
Layer IV	84 - 315 cm
Layer V	315 - 350 cm
Layer VI	350 - 678 cm

Keaualalo Crater -- Core 5

Keaualalo Crater (Lua Keaualalo) is located just off the inland plateau area and immediately southwest of Kealialalo Crater (Fig. 1). It is among the smaller crater structures on Kaho'olawe with the rim barely distinguishable from the surrounding terrain (see Photo 7). The crater measures from perhaps 150 to 200 m rim to rim with an interior basin diameter of roughly 100 m. The elevation of the crater rim is approximately 210 m (689 ft), and the interior basin is from 2 to 5 m below this. The interior of the crater has no apparent drainage channel exiting the rim.

Present day vegetation consists predominantely of dense *kiawe* trees and an undergrowth of grass along with some *'ilima*. There was no area with a hardpan surface suggestive of the presence of periodic standing water.

Core 5

Core 5, located in the approximate center of the crater, involved several hours of work the morning of December 18, 1991. A maximum depth of 2.60 m was reached. In total 8 sediment samples were retained from Core 5, none of which were utilized for pollen analysis. Table 8 presents a listing of these sediment samples.

A description and profile of the soil layers are presented in Table 9 and Figure 2, respectively. The interesting feature of Core 5 is that it is so shallow, and yet it appears to contain a full sediment sequence. Basically, Layers I and II pertain to the Ahupu Formation, Layer III pertains to the Intermediate Formation, and Layer IV belongs to the Kaho'olawe Formation. The basal Layer V consists of indurated volcanic ash.

Keaualuna Crater -- Core 6

Keaualuna Crater (Lua Keaualuna) is located on the west flank of Kealialalo Crater in the west-central portion of Kaho'olawe Island (Fig. 1, Photo 8). Like Keaualalo Crater, it is just below the inland plateau. Though smaller than Kealialalo Crater, it is nevertheless a substantial geological structure. The crater, appears to be nearly circular, though the location of the rim on the south side was not clearly defined. It measures (very roughly) 200 m in dimeter. The interior basin is generally flat, roughly measuring 75 m in diameter. A bare hardpan

Photo 7. Low altitude aerial photo of Keaualalo Crater. View to north with road to plateau at lower right. Crater rim can be barely distinguished in center of photo.

Table 8. Soil samples from Core 5, Keaualalo Crater (depth in m).

0.26	0.53	1.06
1.57	1.81	2.05
2.41	2.60	

* * * * *

clearing is present on the north side. Unlike the other crater hardpans, this is not the result of periodic standing water in the basin. Rather, it appears to be caused by localized erosion and sheet wash.

The elevation of the crater basin is somewhat less than 240 m (787 ft), which is the elevation contour on the U.S.G.S. map that appears to define the rim. The top surface of the basin is the same as the crater rim on the south side, allowing water inside the crater to be easily discharged. This prevents any periodic accumulation of standing water inside the basin, thereby allowing a dense growth of vegetation to flourish inside the crater.

Vegetation inside the crater consists predominantely of large *kiawe* trees, dense grass, and a small amount of *lantana*. The crater rim is generally similarly vegetated, though *kiawe* trees are not so numerous on the north and west sides.

Core 6

Core 6 involved one day of work on December 18, 1991. The core was located in the approximate center of the basin. A maximum depth of 14.06 m was reached. A total of 35 samples were taken from Core 6. Of these samples, 6 were analyzed for pollen. Table 10 presents a listing of sediment samples and Table 11

Table 9. Soil profile, Core 5, Keaualalo Crater.

Layer	Depth cm b.s.	Color, Munsell*	Description
I	0-53	2.5YR 3/4	dark reddish brown; very fine sandy loam; consistence--dry loose, wet non-sticky and non-plastic; structure-- single grain.
II	53-157	2.5YR 3/4	dark reddish brown (not as red as Layer I); loam; consistence--dry slightly hard, wet non-sticky and slightly plastic; structure-- weak, fine subangular blocky.
III	157-181	5YR 3/4	dark reddish brown; clay loam; consistence--dry slightly hard, wet slightly sticky and plastic; structure-- moderate, medium crumb.
IV	181-205	10YR 4/3	brown; loam; consistence--dry slightly hard, wet slightly sticky and plastic; structure--weak, medium crumb.
V	205-260+	10YR 6/2	light brownish gray, changes to 10YR 6/3 with depth (pale brown); loam with indurated volcanic ash (ash appears more weathered with depth); consistence--dry hard, wet non-sticky and slightly plastic; structure-- moderate, medium subangular blocky.

* All Munsell colors were determined on dry sediment.

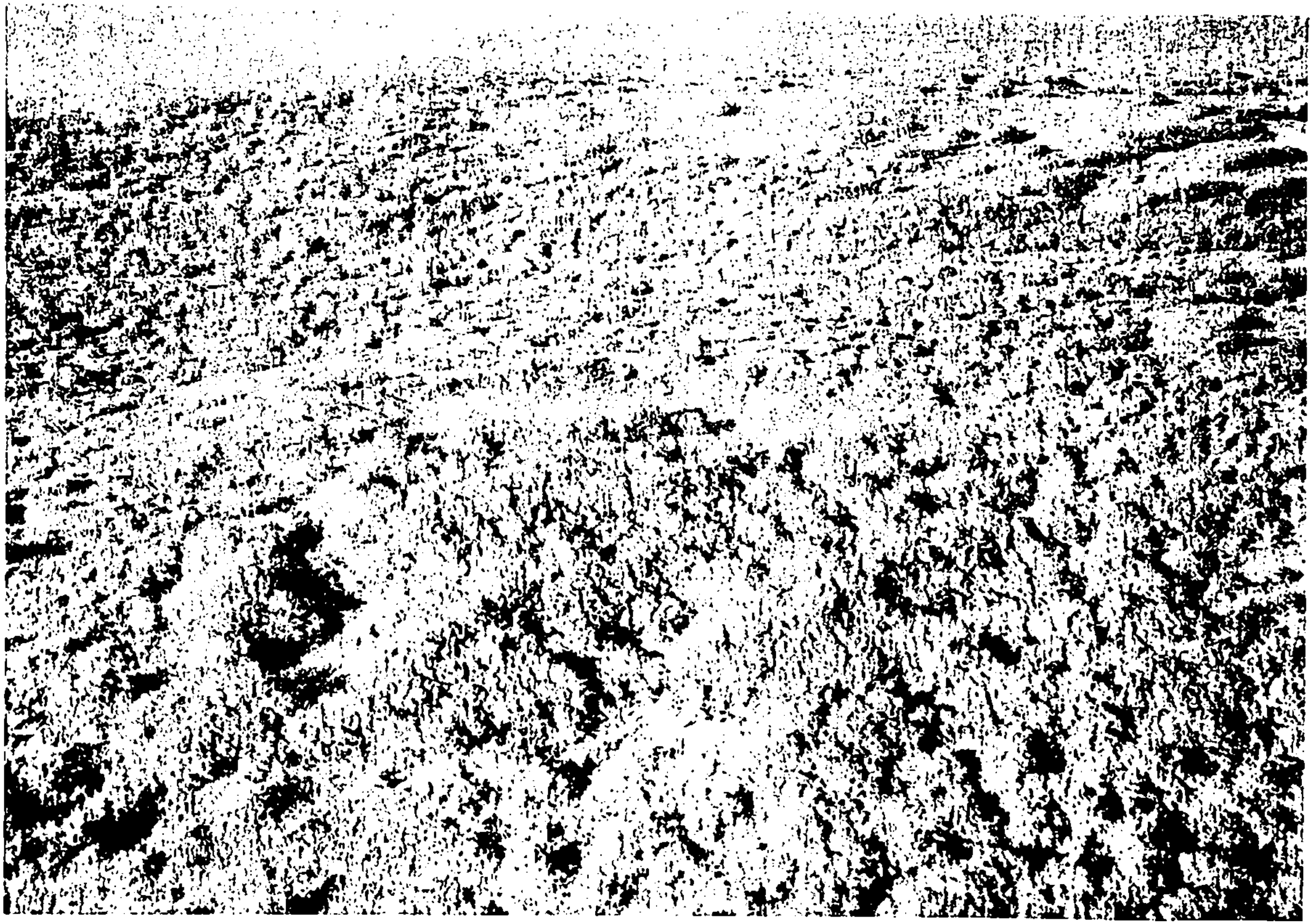

Photo 8. Low altitude aerial photo of Keaualuna Crater. View to north-northeast. Area of hardpan is in the north portion of the crater basin. The central portion of the basin is forested. The southern rim is barely discernable in the photograph.

Table 10. Soil and pollen samples from Core 6, Keaualuna Crater (depth in m).

0.20*	0.50	1.08
1.48	1.83	3.07*
3.38	3.85	4.32
4.75	5.13	5.61
6.60*	7.08	7.84
8.27	8.55	8.99
9.33	9.78	9.86
9.94	10.20	10.28*
10.43	10.60	10.75
11.08	11.24	12.19
12.93	13.00*	13.44
13.79	14.06*	

* pollen samples

* * * * *

provides the layer descriptions. Figure 2 illustrates the Core 6 profile.

The entire sediment sequence--Layers 1 through VII--appears to belong to the Ahupu Formation. Although the Ahupu and Intermediate Formations are closely related, no evidence for the latter was detected in Core 6. Also, none of the layers are even remotely similar to the Kaho'olawe Formation. Because of this, it is believed that the entire sequence belongs to the Ahupu Formation, and therefore represents recently transported and redeposited soil (a result of alluvial and aeolian processes).

Table 11. Soil profile, Core 6, Keaualuna Crater.

Layer	Depth cm b.s.	Color, Munsell*	Description
I	0-108	2.5YR 3/4	dark reddish brown; clay loam; consistence--dry slightly hard, wet slightly sticky and plastic; structure--weak, fine granular.
II	108-338	10R 3/4	dusky red; clay loam; consistence-- dry hard, wet slightly sticky and plastic; structure--medium, subangular blocky.
III	338-475	5YR 4/4	reddish brown; loam; consistence--dry slightly hard, wet slightly sticky and plastic; structure--weak, fine granular.
IV	475-1060	10R 3/5	dark red; clay loam; consistence--dry hard, wet slightly sticky and plastic; structure--moderate, fine to medium subangular blocky.
V	1060-1108	2.5YR 3/3	dark reddish brown; loam; consistence --dry slightly hard, wet sticky and plastic; structure-- moderate, fine subangular blocky.
VI	1108-1293	2.5YR 3/6	dark red; loam; consistence--dry slightly hard, wet slightly sticky and plastic; structure--moderate, fine subangular blocky.

Table 2 (cont.).

Layer	Depth cm b.s.	Color, Munsell*	Description
VII	1293-1406	10R 3/6	dark red; loam; consistence--dry slightly hard, wet slightly sticky and plastic; structure--weak, fine subangular blocky.

* All Munsell colors were determined on dry sediment.

* * * * *

Archaeological Site 207

Site 207 is located near the center of Kaho'olawe close to the margin of Kanaloa Gulch. The site is situated on the north side of the gulch near its upper reaches (see Fig. 1). The elevation of this location is approximately 330 m (1,082 ft; Rosendahl *et al.* 1992:III-10 indicate 340 m).

A comprehensive description of the site and recent investigations are presented in Rosendahl *et al.* (1992:III,10-12):

> This site was originally recorded...as a firepit exposed in the eroding face of a soil deposit....The site area has been highly dissected by erosion and has a sparse cover of *kiawe* trees and an unidentified grass. The firepit was apparently circular in original form, with a fill consisting of fire-cracked rocks resting on a charcoal lens, and about 60 cm in

diameter and 20 cm thick. The Ahupu and Kahoolawe soil formations are present in the site deposits, and the contact between them is marked by a thin layer of carbonized plant material. The firepit appeared to be associated with the Ahupu soil, but the bottom of the feature may have been intrusive into the Kahoolawe Soil....

...no distinct remains of a pit feature could be identified, and it was presumed that the previously recorded firepit remnant had already been destroyed by erosion. The exposed soil banks in an eroded area about 50 meters across were examined. The full stratigraphic sequence visible here included a base deposit of bedded alluvium with a darker charcoal-flecked layer above; this [was] covered by an intermittent but prominent grass burn layer, and at the top a red alluvial-aeolian soil overlay. The charcoal-flecked layer was identified as an A-horizon, and it was suggested that it could possibly represent an agricultural soil deposit.

Three locations were vertically faced, with soil and charcoal samples extracted from two of these.

The archaeobotanical analysis of samples from the burn layer exposed at two stratigraphic locations identified Convolvulaceae seeds, Leguminosae seeds, Graminae stems, and *Sida*. Notably absent is any evidence of *Chenopodium* sp.

The results of the radiocarbon dating analysis of three burn layer samples provided dates of less than 140 BP for Sample Location 1, and

> AD 1630-1955 (calibrated) and less than 420 BP for Sample Location 2.

Spriggs (1991:96) notes that the burn layer occurs,

> ...near the contact between the Ahupu Formation and the underlying "older alluvium" of probable Pleistocene age (Stearns 1940:126, 145, 147).

In considering the burn layer of Site 207 as well as those found at other locations, Spriggs (1991:100) states that they generally date to the latest prehistoric or early historic periods (see discussion in Section II of this report).

Investigations at Site 207

An exposed face along an erosion bank set off from the main gulch was cleaned and profiled for purposes of obtaining soil samples that could be compared with those recovered from the crater bore holes. The soils of Site 207 would provide, in a sense, a fixed point of reference both in terms of chronology and soil types. Fieldwork was conducted on the morning of December 15, 1991.

The location of the sampling area is approximately 30 m south (186° TN) of the brass site marker (Photo 9), and is not on the site proper. A measured profile is presented in Figure 2 (see also Photo 10). The layers are described in Table 12. A total of four sediment samples were collected from the cleaned face. The layers and depths to which they pertain are as follows:

Layer Ia	12-18 cm b.s.
Layer Ib	22-28 cm b.s.
Layer II	28-32 cm b.s.
Layer III	45-50 cm b.s.

Portions of each of these samples were submitted for pollen analysis.

Layer I (both "a" and "b") clearly pertains to the Ahupu Formation and seems to correspond to what Spriggs (1991:96) identified as Layer I at Site 207.

Photo 9. View of Site 207. The brass site marker is located just above and to left of individual standing on left side. View to north. Photo taken from location of sampling area.

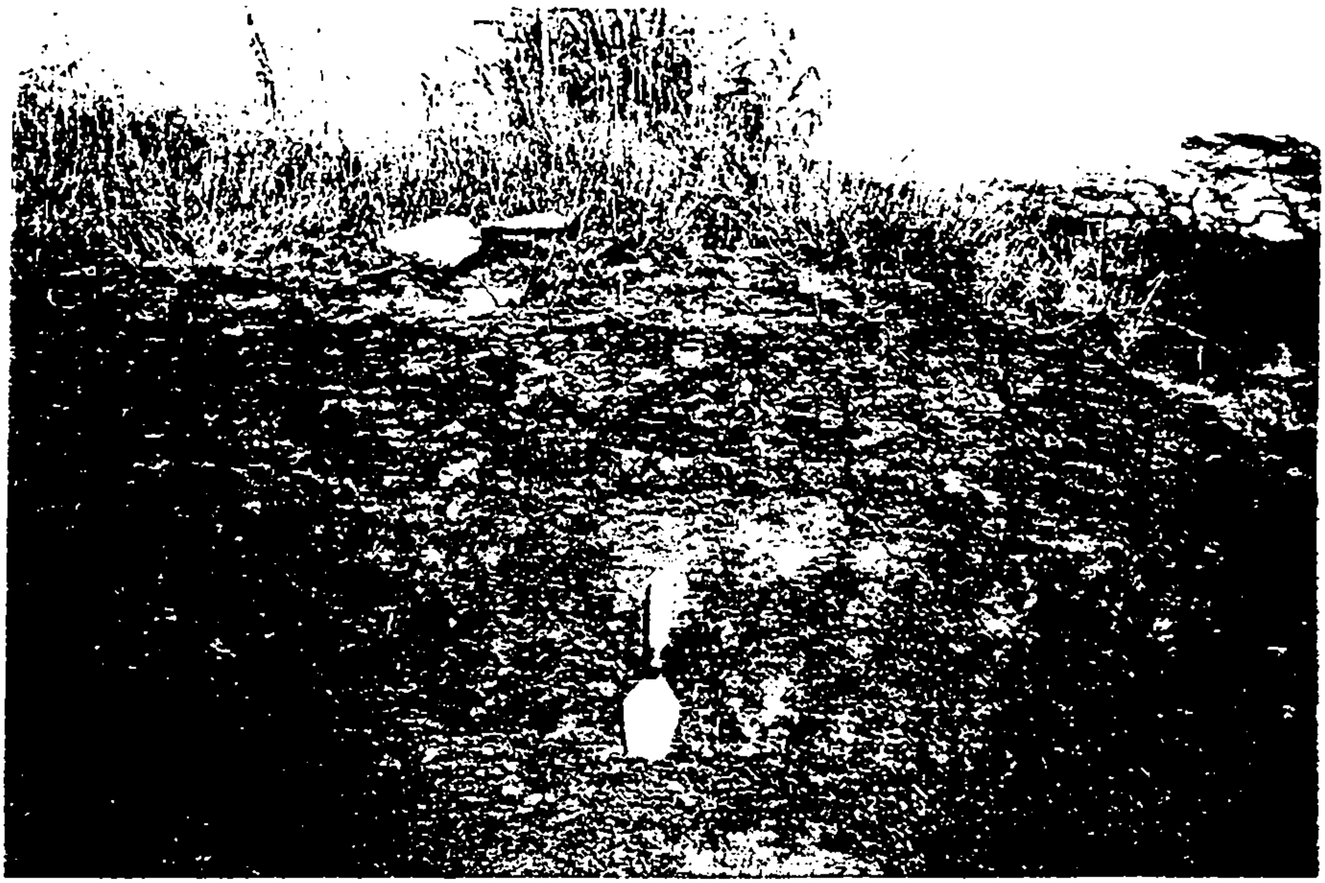

Photo 10. Close-up of cleaned face of gully exposure near Site 207. Note burn layer just above vertical trowel handle.

Table 12. Soil profile, Site 207.

Layer	Depth cm b.s.	Color, Munsell*	Description
Ia	0-18	2.5YR 3/4	dark reddish brown; loam; consistence--dry slightly hard, wet slightly sticky and slightly plastic; structure--weak, fine crumb; lower boundary diffuse.
Ib	18-28	2.5YR 3/4	dark reddish brown (slightly more reddish than Layer I); loam (very high in sand for a loam; could be a sandy loam); consistence--dry soft to slightly hard; structure--weak, fine crumb; lower boundary abrupt and smooth. An area just to the south of profile section was observed to have a band of coarse gravel just above the burn layer.
II	28-32	7.5YR 3/4	dark brown; sandy clay loam with abundant small pieces of charcoal; consistence--dry slightly hard, wet slightly sticky and slightly plastic; structure--moderate, medium crumb; lower boundary abrupt and slightly wavy. Field description noted coarse subangular sand in layer; also two discontinous charcoal bands with some charcoal below the sand.

Table 12 (cont.).

Layer	Depth cm b.s.	Color, Munsell*	Description
III	32-75+	7.5YR 3/4	same as Layer II, but peds are much harder. The profile has several vertical cracks. The soil is similar to a montmorillonite clay.

* All Munsell colors were determined on dry sediment.

* * * * *

Layer II is the burn layer. Two radiocarbon dates were obtained by Spriggs (1991:96) for this layer. Though the dates are somewhat ambiguous, it is likely that Layer II must date to either the early historic period or the late prehistoric period. Layer I, pertaining to the Ahupu Formation, must clearly date from about A.D. 1850.

What is surprising is that Layers II and III are very similar with the exception that Layer II has plentiful charcoal and coarse sand. The latter implies alluvial action at the time the soil was deposited (which evidently continued during the time represented by the early part of Layer I). The fact that both Layers II and III are so similar implies that there is probably no erosional unconformity between them.

Although Rosendahl *et al.* (1992:III,10) reported charcoal flecking in the top part of what is here referred to as Layer III, none was observed for this layer during the present project. The presence of such charcoal, however, would not be unexpected given its density in Layer II and the probability that some amount of localized bioturbation along with soil desication cracks would be expected in the upper part of Layer III.

Another interesting point concerning the similarity of the soils of Layers II and III is that it shows that the Ahupu Formation (Layer I) is clearly temporally disassociated from the burn layer. The burn layer does not simply form the lowest part of the Ahupu Formation, but instead belongs to the same formation as that of Layer III. This observation suggests that vegetation burning may not have immediately led to the onset of erosion, although it obviously occurred very soon thereafter in the case of Site 207. In this respect, the Site 207 sediment sequence appears to entirely support Spriggs' (1991:99) contention that massive erosion as evidenced by the Ahupu Formation only began with the introduction of cattle, sheep, and goats in the 1850s. The following passage from Spriggs' (1991:99) succinctly states his case:

> 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 Ahupu 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.

The question of whether Layer III might pertain to the Kaho'olawe Formation is quite interesting. The original recorders of Site 207 regarded it as such (Rosendahl *et al.* 1992:III-10). However, neither Rosendahl *et al.* (1992:III-10-12) nor Spriggs (1991) use the term for the deeper Site 207 soils (see background discussion in Section II of this report). Rather, Spriggs refers to Layer III as an "...alluvial deposit, similar to those observed in the Ahupu Gulch alluvial sections above burn layers." Rosendahl *et al.* (1992:III-10) simply refer to it as "alluvium." Their (Rosendahl *et al.* 1992:III-10) description of this layer (Layer IV in their report) states that it,

> ...grades into sterile, coarser bedded alluvial deposit below. The upper 20 cm of this layer was considered as a possible cultivation soil.

Unfortunately, neither Rosendahl *et al.* nor Spriggs present any data that clearly identify Layer III (designated Layer IV in Rosendahl *et al.* and L2d in Spriggs) as alluvial in nature. Also the present investigations do not provide any evidence that Layer III was ever used for agriculture, though this possibility cannot be discounted.

Although the present investigations were quite restricted in scope, and a clean profile was obtained from only the top 50 cm of deposit with additional informal observations on another 1.5 to 2.0 m of exposed soils beneath the profile, there was nothing about the upper deposits that would suggest stream flow or alluvial transport. Rather, it appears likely that Layer III is in a sense an *in situ* soil, though it was derived from older alluvial and aeolian sediments transported as a result of the weathering and erosion of rock and soil in the higher elevation areas of Kaho'olawe. This process of weathering, erosion, and redeposition, of upland soils, and subsequent *in situ* alteration, weathering, and soil formation occurred over a very long period, perhaps beginning "over the last million or so years," as suggested by Spriggs (1991:97).

The contribution of alluvial processes--perhaps mostly in the form of sheet wash during rains--may have been relatively limited and perhaps limited to specific storm episodes. Aeolian transport, however, would have been nearly constant and may have actually transported the bulk of the sediment now observable as Layer III.

The Moiwi Formation: A Tentative New Soil Horizon

Although further field investigations are needed, the assignment of a name for the Layer III soil horizon--certainly a presumably much more recent soil than the Kaho'olawe Formation, will facilitate comparative analysis. Here the name "Moiwi Formation" is proposed, which derives from nearby Puu Moiwi. This designation should be considered tentative until further field investigations can be conducted.

The significance of the Moiwi Formation is that its uppermost part should date to the prehistoric Hawaiian period. At lower levels it should also be the soil associated with the relatively recent geological past. Thus, in terms of understanding the island's natural vegetation, this would be the soil most likely to contain the needed pollen evidence, at least for the inland plateau area. Of course, whether or not this same soil would have formed inside the volcanic craters on Kaho'olawe is an open question. Although clearly not exactly the same kind of soil, it is quite similar to the Intermediate Formation inside the craters. It presumably formed under similar conditions and it may also date to a similar time period.

Kanapou Bay

Kanapou Bay, the remnant of a former caldera (Stearns 1940:134), is located along the east coast of Kaho'olawe (Fig. 1). At the southwestern corner of the bay, a large and steep-sided gulch descends to the sea. Sediments from the gulch have formed a small alluvial fan at its mouth. This area is known as Keoneuli. A sand beach is present at the shoreline and there are large dune formations reaching 10 m or so in height behind the beach (Photos 11 and 12). Vegetation on the sand dunes primarily consists of *kiawe* trees.

The main reason for the investigations at this location was the possibility that a backswamp (or marsh) might exist (or have existed) behind the beach berm, and that this would prove to be an ideal location for obtaining a lengthy sediment record with good pollen preservation. It was also believed that a record of the lowland vegetation would be complementary to the highland record that the crater coring would hopefully provide.

Because of the difficulty of access to Keoneuli, a helicopter was chartered from Maui to transport the investigators for the day on December 16, 1991.

Field Investigations

A dune situated roughly in the middle of the alluvial fan was first investigated by examining its exposed bank next to the dry stream channel. The base of this exposure was faced with a trowel and excavated to a depth of about 30 cm below the surface (Photo 13). Red silt bands of the Ahupu Formation extended all the way to the base of the dune (see Photo 13), and 20th century cultural debris was clearly visible at approximately 1.20 m above the base. Coarse beach sands were present below the red silt bands.

The red silt bands, which appeared to occur in all of the dunes, strongly suggest that these formations date entirely to the historic period. The deeply embedded cultural material also suggests that the dunes are relatively recent formations.

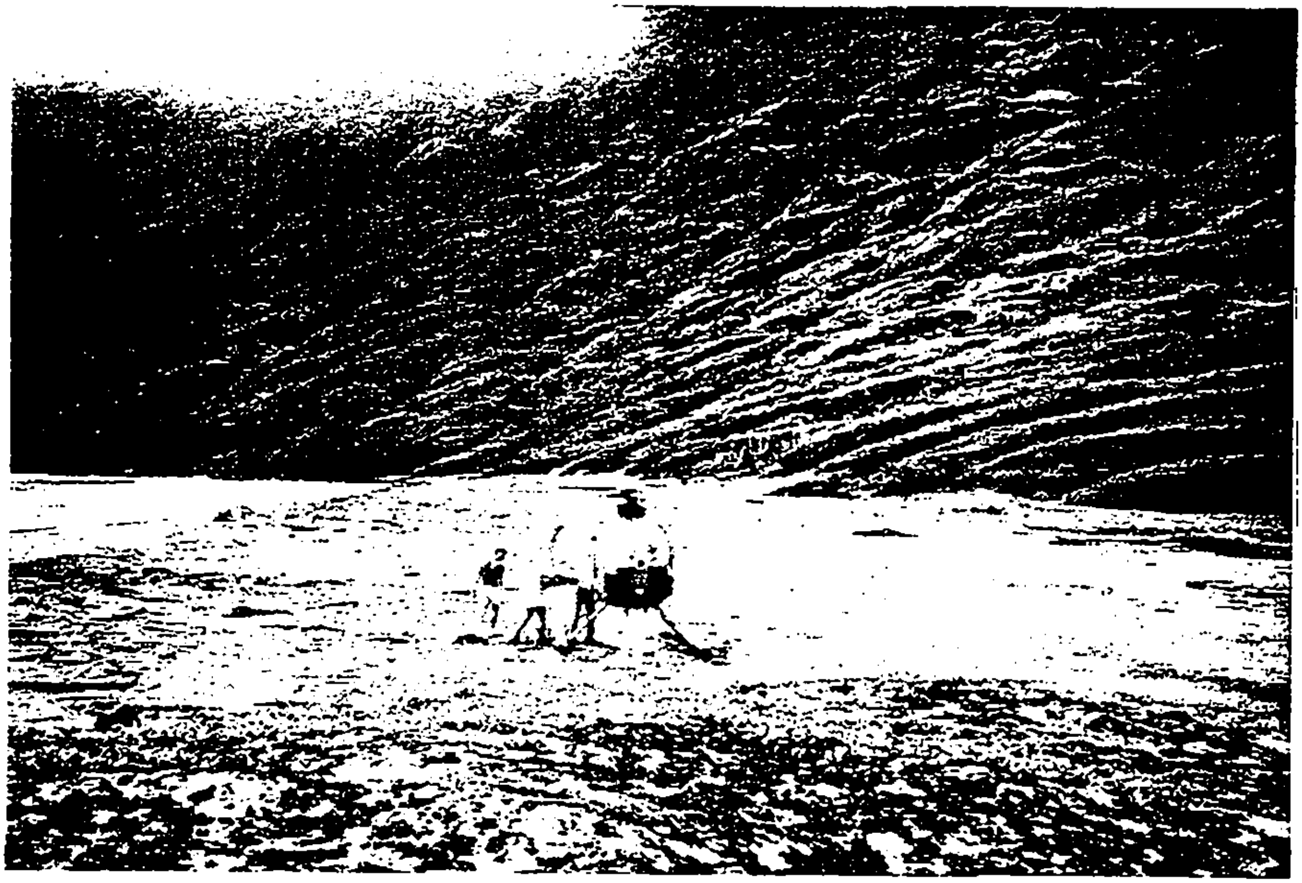

Photo 11. Keoneuli beach at Kanapou Bay. View to south.

Photo 12. Sand dunes inland of Keoneuli beach. View to back of gulch to southwest. Note dry stream channel between dunes.

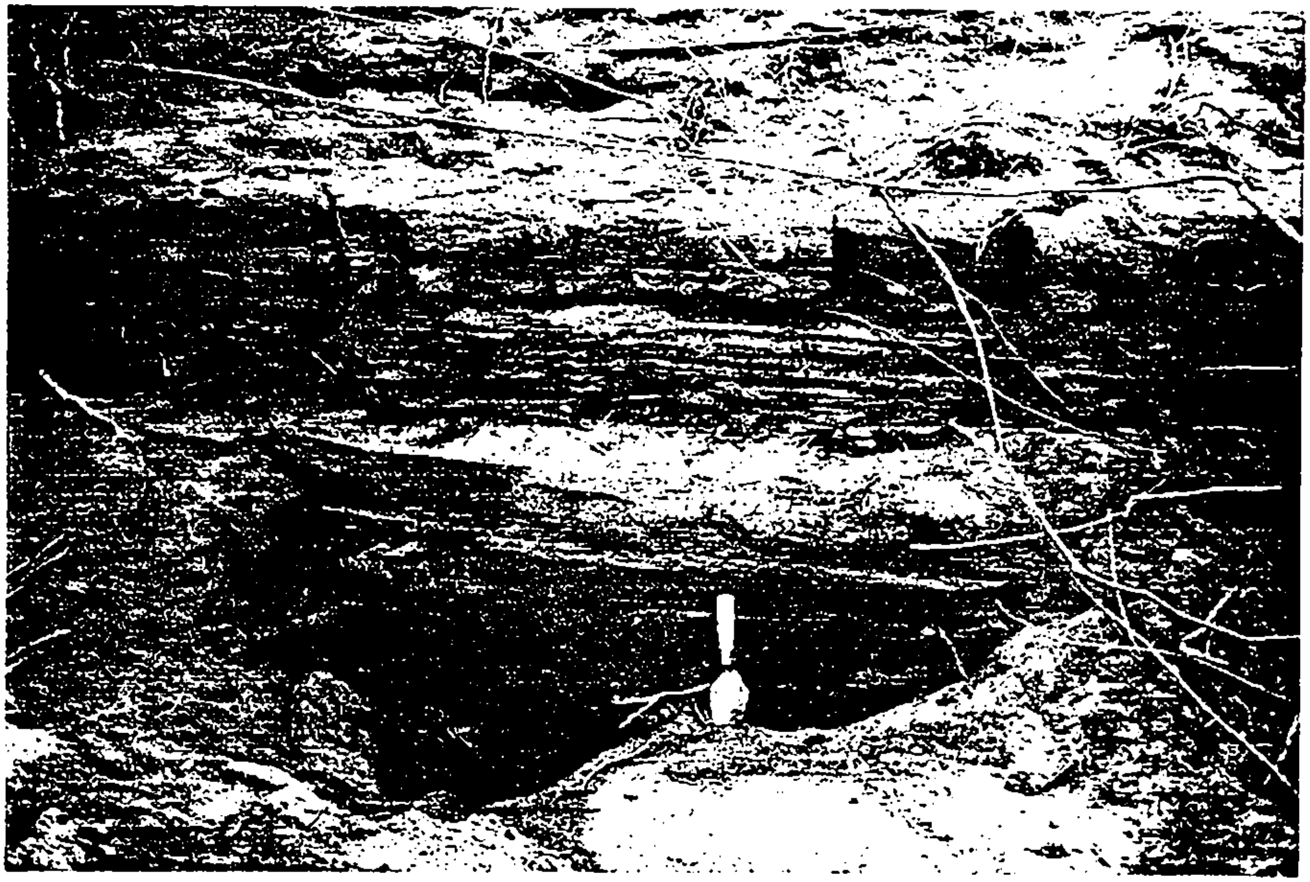

Photo 13. Close up of faced portion of dune at its base. Note the horizontal bedding in the lower Ahupu silt layer above the beach sand.

Attempts at coring (using an auger) were made in 9 locations in the flat areas between the dunes. In all cases penetration was stopped at shallow depths by rocks. In addition, an auger boring was made approximately 25 m northwest of Site 129, which is located on the slope of the south margin of the alluvial fan. The bore hole location was within a small gully area between sand dunes. The auger unit reached a maximum depth of 3.43 m, whereupon rocks prevented further penetration. Several bands of Ahupu silt were noted in the top 2 m. At this depth the sand started to become lighter in color, and by 2.5 m it was clean white sand. A small amount of marine shell was present in the sand, possibly representing archaeological midden. No sediments in the auger test were suitable for pollen analysis.

Finally, two auger units were located between the beach berm and the dune formations approximately 60 m from the shoreline and in the middle of the beach area. The first unit reached a depth of 1.5 m, while the second reached 1.88 m. A 2 m long PVC casing pipe was used to stabilize the side walls of the bore holes.

From the surface down to 1.2 m there was loamy soil, some beach sand, and a dark reddish brown band of silt loam. The reddish brown band presumably pertains to the Ahupu Formation. Below this and to 1.5 m there was a dark (7.5YR 4/4--brown, dry) layer of loamy fine sand that appeared to be very organic. By 1.88 m the sediment changed to an entirely fine carbonate marine sand that was light grayish color. The water table was approximately 50 cm below the surface. The loamy fine sand appeared ideal for pollen analysis, and a sample was collected for this purpose at 1.5 m. A report on the pollen analysis is presented in the following section. Deeper augering was not possible due to instability of the water saturated side walls of the bore holes and the lack of a longer casing pipe.

V: POLLEN AND CHARCOAL ANALYSES

Introduction

Concern over the vegetation history of Kaho'olawe has led to the recent analysis of deep cores and test trench samples for pollen, spores, and charcoal particles. These microfossils provide excellent indicators of the past composition, extent, and fire history of vegetation in an area. This is a valuable goal since relatively little is known about the plant community dynamics on Kaho'olawe in the past.

Methods

Thirty-eight samples for palynology were obtained from four cores taken in craters located on the interior of Kaho'olawe, and an additional four samples were taken from an exposed gully side wall near Site 207, also located in the interior of the island. In addition, a single sample was analyzed from a lowland beach deposit at Keoneuli of Kanapou Bay on the eastern shoreline of Kaho'olawe.

The matrix from the core samples consisted of a coarse-grained reddish-brown volcaniclastic sediment. Due to the coarse nature of the sediment and the fact that much of it appeared oxidized and of aeolian origin, a larger than normal starting volume of sediment was utilized. Ten milliliters of each sample was measured using the water displacement method in a graduated container. In order to determine the concentration of pollen and charcoal in the sediments, exotic marker grains were added to the measured quantity of sediment prior to treatment (Matthews 1969; Bonny 1972). *Lycopodium* tablets, which each contain a known number of *Lycopodium* spores, were added to the samples. By using known numbers of spores and a known sample volume to begin with, the number of fossil palynomorphs and charcoal particles can be calculated by using the formula below from Birks and Birks (1980):

$$\frac{\text{Fossil Pollen Concentration}}{\text{Exotic Pollen Concentration}} = \frac{\text{Fossil Pollen Counted}}{\text{Exotic Pollen Counted}}$$

In this case the formula was solved for the charcoal concentration, giving:

$$\text{Charcoal Concentration} = \frac{\text{Lycopodium Concentration X Charcoal Area } (mm^2)}{\text{Number of Lycopodium Spores Counted}}$$

Because of the abundant minerals present and the low quantity of organic material, the samples were unyielding to the usual suite of chemicals used to extract the organic residue. Carbonate minerals were broken down with HCl and silicates with HF, the latter requiring a second treatment to further reduce the mineral fragments. Potassium hydroxide and acetolysis solutions were then used to solubilize the organic fraction, which included humic acids, cellulose and lignin (Faegri, Kaland, and Krzywinski 1989; Moore, Webb, and Collinson 1991). Heavy liquid separation with $ZnCl_2$ was attempted on several samples in order to separate the minute amount of organic material but it was found that the large amount of mineral made this method ineffective. In most cases, the resulting residue was swirled in a watch glass (Doher 1980) to remove the larger mineral fragments, some of which were thought to be sulfates and iron-bearing types based on the color and crystal shape. As a last step, a Calgon solution was used to float off the finest clay-sized particles which often obscure viewing in concentrated samples. Finally, the pollen and charcoal residue was mounted in glycerine jelly (Erdtman 1960) which has a favorable index of refraction for viewing and photographing palynomorphs (pollen, spores, and plankton, among others). Even after all of these chemical and mechanical concentration steps, the slides contained a good deal of microscopic mineral fragments which interfered with optimal viewing of the microfossils, but not the charcoal as it was opaque and black.

Charcoal particles were measured with an eyepiece graticle (grid square size 24.4 X 24.4 μm) and their numbers recorded in each of seven grid square size classes: 0.5-1, 1, 2, 3, 4, 5, and greater than 5. The charcoal particle data was recorded as total number of particles and this was converted to total area in mm^2. The total area counted on two to four microscope slides was used to calculate the concentration (mm^2/cc) for each level. The size class data is not given here but is on file with the project records at IARII.

Palynomorphs were identified using pollen floras that include Pacific types, such as Selling (1946, 1947) and Cranwell (1953), as well as a small personal reference collection of pollen and spores. The preservation of palynomorphs was generally poor from the core sediments and good in both the Site 207 deposit and the Kanapou Bay beach deposit. Even with the low concentration of types preserved, a few unknowns were encountered. This was especially true in the 5.95 m sample of Core 1, which displayed the highest diversity of any sample. Some of the deeper samples had extremely low diversity with only a few types seen. Photo 14 illustrates a sample of the palynomorphs recovered from the Kaho'olawe samples.

Pollen and Charcoal from Cores 1, 2, 4 and 6

In general, the pollen concentration was disappointingly low, a result that was not totally unexpected considering the nature of the deposit. Loess sands in Europe have been investigated as a source of information for paleoenvironments (Fink and Kukla 1977), but the pollen concentrations are always very low (Couteaux and de Beaulieu 1976). Another factor to consider with deposits that are substantially aeolian in origin is that one is looking at an extra-local (within 300 m) and possibly a regional (beyond 300 m) pollen rain (Jacobson and Bradshaw 1981), rather than a purely local one. In the present case, Kaho'olawe is situated directly leeward of Maui and would receive silt and clay-sized particles blown from there. Based on studies of modern pollen deposition, it is safe to say that most of the pollen would be derived locally or extra-locally since it tends to fall close to the parent plant and is eventually transported by surface runoff and, in other settings, carried by streams to the catchment (Muller 1959). Therefore, most of the pollen found in the Kaho'olawe crater deposits probably came from vegetation growing in the vicinity with a minor contribution from pollen carried on air currents from a distance and deposited along with dust or rain. It is difficult to establish exactly what percentage of the pollen rain derived from Maui.

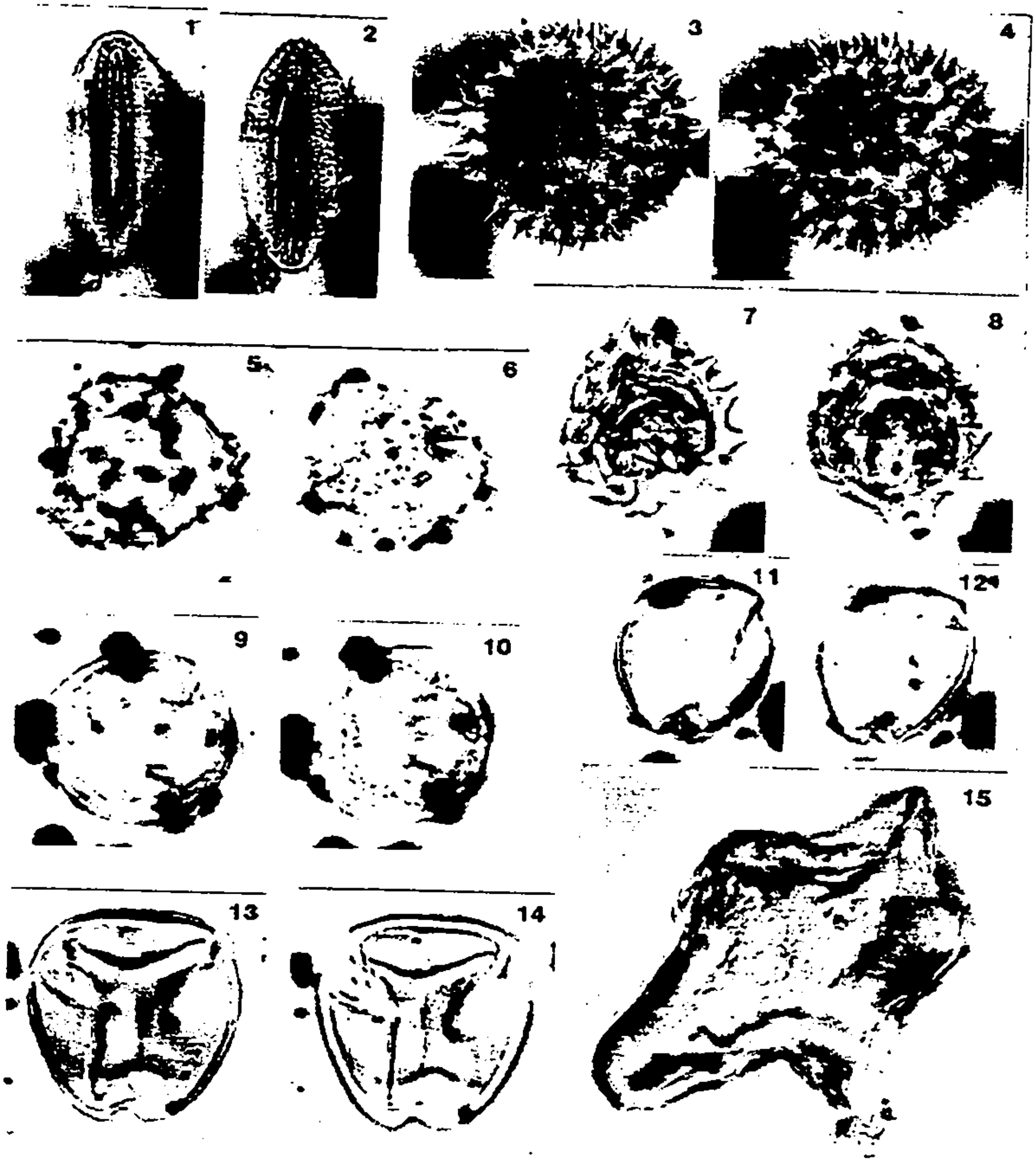

Photo 14. Photomicrographs of selected palynomorphs from the Kaho'olawe cores. All photos are x 1,000 unless otherwise indicated. (Photo 14-1,2 Euphorbiaceae type, Core 4, 6.52 m; Photo 14-3,4 *Sida* sp., Core 6, 0.2 m x 630; Photo 14-5,6 *Erythrina sandvicensis*, Core 2, 13.01 m; Photo 14-7,8 Asteraceae, high spine, Core 6, 0.2 m; Photo 14-9,10 unknown granular tricolpate type, Core 2, 10.22 m; Photo 14-11,12 *Prosopis pallida*, Core 2, 0.2 m; Photo 14-13,14 *Leucaena leucocephala*, Core 6, 0.2 m; Photo 14-15 unknown palynomorph or cuticle fragment, Core 4, 6.52 m, x 630.)

The crater deposits were all comprised of coarse-grained and oxidized sediment which is known to result in degradation of pollen and spore exine or wall layers (Havinga 1971, 1985). Since the quantity of pollen recovery was low the data were not plotted on a graph but are only given in Table 13. Core 1, the deepest of the four cores, had the poorest recovery with only four of the nine samples containing any pollen or spores. The 5.95 m sample had the highest diversity of any of the core samples. Here, grass pollen is dominant followed by that of sedges. This record, in the absence of cheno-am pollen and with low numbers of high spine Asteraceae, is suggestive of an undisturbed open wetland area receiving sedge pollen from local vegetation. The high frequency of grass pollen is probably a case of over-representation since Poaceae are wind-pollinated and tend to shed a large amount of pollen.

The 5.95 m sample also yielded several types not known from Kaho'olawe today but which could possibly have grown there in the past. These include *Pritchardia, Pandanus, Pisonia, Pleomele*, and *Colubrina*, types that would be at home in the lowland plant community as well as a number of types included in the two unknown tricolporate categories. It is difficult to rule out a source from lowland communities of Maui for these types. The single grains of *Hedyotis*, Araliaceae, and cf. *Zanthoxylum* most certainly came from the mesic-wet forests of Maui. The likely association of the 5.95 m sample with the Ahupu Formation suggests a historic age, which makes it probable that the pollen from these plants did in fact come from Maui.

Fifty spores of *Lycopodium cernuum* also were counted in the 5.95 m sample, which is consistent with a wet, open plant community. This fern ally is known from wet, open forests of the tropics.

The surface sample contained a low concentration with weedy types such as *Leucaena leucocephala* (*koa-haole*) dominant followed by cheno-am pollen. The single spore of *Cibotium* in the surface sample is out of place and must have a source from the wet forests of Maui. The other types are consistent with the pre-dominant dryland vegetation of Kaho'olawe at this time.

Table 13. Palynomorph and charcoal particle counts from Kaho'olawe Cores 1, 2, 4, and 6. Depth in meters.

Species or type	Samples from Core 1														
	Surf.	3.6	5.95	7.86	9.0	10.65	11.40	11.83	12.12	12.91	13.10	13.71	14.0	15.01	17.03
POLLEN:															
Poaceae (grass)			147												
Cyperaceae (sedge)			40												
Cheno-ams	6														
Solanaceae	3														
Asteraceae, high spine			11												
Euphorbia type			11												
Leucaena leucocephala	13														
Prosopis juliflora		1													
Dodonaea viscosa	1														
Hedyotis type			1												
Colubrina sp.			2												
Cocos nucifera			1												
Araliaceae			1												
Pritchardia sp.			1												
Pandanus tectorius			1												
Pleomele sp.			1												
Pisonia sp.			1												
Urticaceae			6												
cf. Zanthoxylum			1												
Tricolporate, small			7												
Tricolporate, undiff.			12												
Triporate, verrucate	6														
Tricolpate, granular	1	1			1										
SPORES:															
Monolete, psilate	2	1	12		1										
Monolete, granulate			4												
Cibotium	1														
Lycopodium cernuum			50												
Trilete, spiny			11												
Trilete, lg., fine spine			17												
Trilete, psilate	2	4													

Table 13 (cont.).

Species or type	Samples from Core 1														
	Surf.	3.6	5.95	7.86	9.0	10.65	11.40	11.83	12.12	12.91	13.10	13.71	14.0	15.01	17.03
FUNGI:															
Unicell, sphere, sm.			212												
Unicell, sphere, lg.			23												
Ascospores, dicellate			13												
Hyphae			16												
Cell clumps			7												
Tetraploa			5												
Others			15												
CHARCOAL:															
Marker grains	154	630	268	280	94	505	—	—	35	—	—	—	170	207	27
Total particles	503	364	758	11	167	141	—	—	90	—	—	—	75	199	98
Total area (mm^2)	.657	.372	.811	.009	.136	.224	—	—	.086	—	—	—	.048	202	.786
Concentration (mm^2/cc)	4.82	0.67	3.42	04	1.64	0.5	—	—	2.79	—	—	—	0.32	1.1	3.29

Table 13 (cont.).

	Samples from Core 2									
	Surf.	1.1	3.0	5.69	6.45	8.05	10.22	12.2	13.01	15.01
POLLEN:										
Poaceae (grass)		5	10	1			1	1		
Cheno-ams	12	35	60				7			2
Solanaceae				1			1			
Artemisia sp.							1			
Asteraceae, high spine	1	12	1					3		
Asteraceae, lophate	1	2								
Claoxylon sp.		1								
Euphorbia type		4	3							
Erythrina sandwicensis									1	
Leucaena leucocephala	99									
Prosopis pallida							13	3		
Dodonaea viscosa	1									
Sida sp.							1			
Triporate, verrucate	1									
Tricolpate, granular							4			4
SPORES:										
Monolete, psilate		4	5							
Monolete, fine verruc.		1								
Trilete, psilate			1							
Cibotium sp.		1								
Pteris sp.		1								
FUNGI:										
Unicell, sphere, sm.	1	162	1	1						
Unicell, sphere, lg.	1	43						1		
Diporate		17								
Ascospores, dicellate	2	6					1			
Basidiospores, spiny		1								
Hyphae		5								
Cell clumps		2		1						
Others	2	11	4							
CHARCOAL:										
Marker spores	75	91	45	112	127	40	317	151	0	10
Total particles	570	1607	429	72	48	42	439	463	0	0
Total area (mm^2)	499	1.4	0.37	0.06	0.044	0.036	0.76	0.76	0	0
Concentration (mm^2/cc)	7.52	17.37	9.34	0.61	0.38	1.01	2.72	3.5		

Table 13 (cont.).

Species or type	Samples from Core 4						
	0.1	0.84	1.5	3.15	3.2	4.16	6.52
POLLEN:							
Poaceae (grass)	1						5
Cheno-ams	1	1					2
Asteraceae, high spine		1					
Euphorbia type							2
Sida sp.							2
Prosopis pallida	14	3	1			3	14
Triporate, lg. psilate							2
SPORES:							
Monolete, psilate	1	1					3
Trilete, psilate		2					
Trilete, irreg.						1	
FUNGI:							
Unicell, sphere, sm.	352		36	22	516	37	1082
Unicell, sphere, lg.		2					
Ascospores, dicellate	4	4		45	68		43
Basidiospores, spiny	1						
Basidiospores, foveolate			1				1
Hyphae	40	5					90
Tetraploa	3		1		1		32
Flask shaped spore							6
Cell clumps	5						39
Others	16						17
CHARCOAL:							
Marker spores	134	178	305	505	348	430	346
Total particles	692	95	387	194	580	282	547
Total area (mm^2)	0.74	0.08	0.4	0.01	0.48	0.19	0.63
Concentration (mm^2/cc)	6.27	0.5	1.47	0.29	1.55	0.51	2.07

Table 13 (cont.).

Species or type	Samples from Core 6					
	0.2	3.07	6.6	10.28	13.0	14.06
POLLEN:						
Poaceae (grass)	102					
Cheno-ams	35					
Solanaceae	1					
Asteraceae, high spine	89					
Asteraceae, low spine	1					
Asteraceae, lophate	9					
Euphorbia type		1				
Leucaena leucocephala	305	4	1			
Prosopis pallida	1					
Sida sp.	3					
Triporate, verrucate		1				
Monosulcate, small	6					
Diporate	19					
SPORES:						
Monolete, psilate	1					
Trilete, psilate		2				1
Lycopodium cernuum	1					
FUNGI:						
Unicell, sphere, sm.	51	8	4	2		
Diporate	2					
Ascospores, dicellate	14					
Hyphae	32					
Cell clumps	8	6				
Others	3					
CHARCOAL:						
Marker spores	165	155	34	1	2	20
Total particles	680	106	103	21	23	69
Total area (mm^2)	0.53	0.08	0.08	0.15	0.01	0.05
Concentration (mm^2/cc)	3.66	0.55	2.69	17.49	6.72	3.26

The remaining Core 1 samples with pollen and spores are from the 3.6 and 9 m layers but the recovery was meager.

Core 2 had a higher frequency of palynomorphs, but with a lower overall diversity of types than in the 5.95 m sample of Core 1. *Koa-haole* is again dominant in the upper sample along with cheno-am pollen followed by a few grains of Asteraceae. At deeper levels in the core the concentration falls off as does the range of types. Of interest is the record of 18 grains of *Prosopis pallida* (*kiawe*), which was also seen sporadically in the other cores. Since *kiawe* was introduced to Kaho'olawe around the turn of the century, these deposits must be fairly youthful, which is consistent with their identification with the Ahupu Formation. At the 1.1 m level several wet forest pollen and spore types were found, including *Claoxylon*, *Cibotium*, and *Pteris*. These were likely wind-blown from the slopes of Mt. Haleakala.

Core 4 contains a low diversity assemblage with the usual low concentration values. *Prosopis pallida* (*kiawe*) is the dominant type and occurs in five of the seven samples. The basal sample at 6.52 m contains the highest diversity for the core. Because this sample is from what is thought to be an ancient soil layer, the presence of *kiawe*, introduced at the beginning of the present century, is suggestive of either a problem with bioturbation of the sediments or contamination during coring. No aquatic types were recovered which might indicate the presence of standing water but the better preservation seen here may be indicative of finer sediment or more rapid burial, which would have excluded destructive microbial activity.

Core 6 follows the same pattern as shown with the other cores, with abundant *koa-haole* pollen in the upper sample and a much lower concentration of pollen and spores at depth. A diporate pollen type of unknown affinity was seen in the upper sample. Among the spores, the single record of *Lycopodium cernuum* is again indicative of wet open conditions which may point to a period of standing water.

The record of fungi (spores and hyphae) may indicate the presence of soil horizons or at least of organic deposition occurring at the site. In Core 1 only the 5.95 m sample contained fungi in relatively high numbers along with a high diversity of pollen and spores. In Core 2, a dense concentration of fungal types occurs at the 1.1 m level with a very low density throughout the remainder of the core. Core 4 contains the most fungi consistently with peaks near the surface at 3.2 m and reaches the highest amount in the basal sample at 6.52 m. Again, bioturbation may be a problem with this core. Core 6 contains a high number of fungal spores in the near surface layer while the lower samples contain very few to none. The presence of fungal spores suggests adequate organic detritus (leaves, wood, macroinvertebrates).

The absence of fungi in many layers of these cores may have resulted from relatively aerobic conditions in the sediment, which allowed decomposition to take place.

The charcoal concentration values are shown in Table 13 and plotted in Figure 3. The data from Core 1 shows no consistent trend with several peaks alternating with lower values. Core 2 shows a similar peak to that of Core 1 around 12 m but the values gradually fall to low levels around 6 m, whereas Core 1 shows a higher concentration at this level. From 3 m to the surface, the charcoal concentration in Core 2 is relatively high and peaks in the 1.1 m sample at 17 mm^2/cc. Core 4 has very little charcoal but does show a higher concentration in the 0.1 m sample. Core 6 is most similar to Core 1 with relatively low values throughout with peaks in the basal sample at 3.26 mm^2/cc and the 0.2 m sample at 3.66 mm^2/cc. The concentration data from samples 10.28 and 13.0 m was not plotted since it was felt to be invalid due to the unusually low number of control marker spores recorded, only 1 and 2, respectively.

The question of how to interpret charcoal particle data has been discussed at length by Patterson *et al.* (1987) and Clark (1988), who have shown that sedimentary charcoal being small and light can be transported like dust particles and travel in air currents. In general it has been found that the larger charcoal particles result from nearby fires while smaller particles being lighter, may be derived from long distance transport. All of the cores had charcoal within the largest size class, which is above 5 grid squares or 3.0 mm^2 and many were around 10 grid

Kaho'olawe charcoal concentration

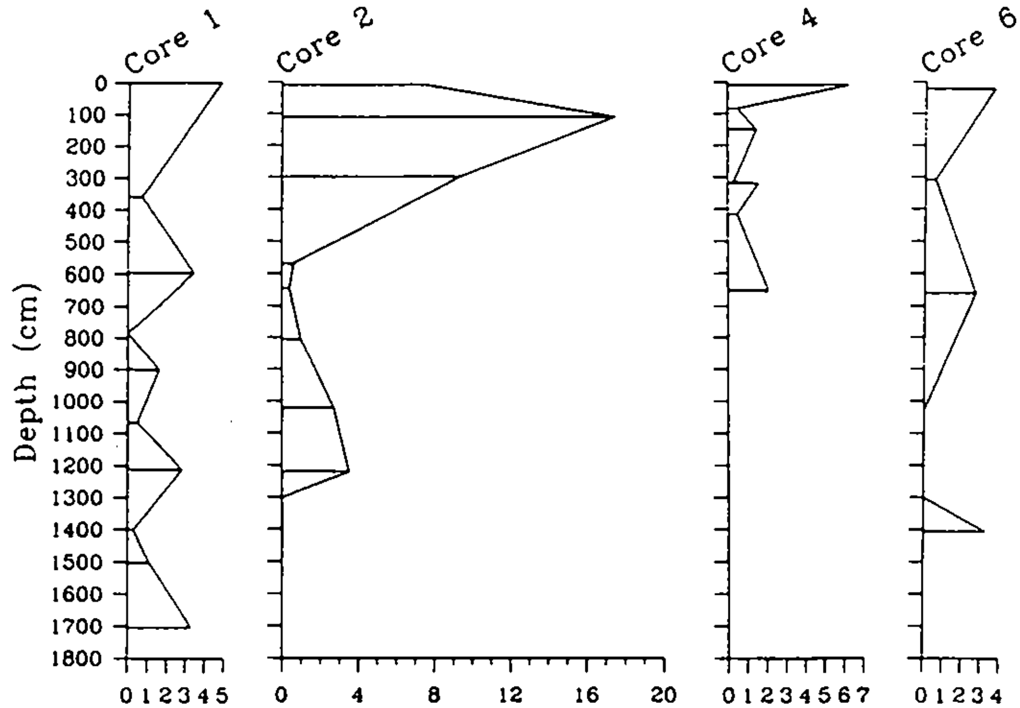

Figure 3. Graph of charcoal concentration, Cores 1, 2, 4, and 6.

squares in area or ca. 6.0 mm^2. Only Cores 2 and 4 had charcoal consistently in the higher range (data not plotted), suggesting that they were closer to the source of the fire while Cores 1 and 6 were further away or possibly were not in the direct path of wind currents.

Pollen and Charcoal from Site 207

The assemblage from Site 207 contained a total of 17 palynomorph types, a low number but not unexpected since they originated from a dryland shrub vegetation type (Table 14). The pollen assemblage is dominated mainly by three types as shown in Figure 4: Poaceae (grass), cheno-ams, and high spine Asteraceae, followed by lophate Asteraceae and Euphorbiaceae types. Cheno-ams maintain consistently high values but diminish somewhat from a high of 70 percent at the base to around 50 percent in the upper two levels. The high spine Asteraceae curve is more erratic but stays within 18-24 percent, except for the 28-32 cm level, which is associated with a fire event that probably affected plant community composition in the area. The grass curve displays a marked increase to 26 percent at this level compared to the basal sample suggestive of a colonizing effect, where grasses were invading available habitat after the burn, perhaps more successfully than the cheno-am plants which actually decline at this level compared to the basal sample.

The charcoal concentration curve shows a threefold increase from ca. 42 mm^2/cc in the basal sample to 141 mm^2/cc in the 28-32 cm sample which is suggestive of a fire in the immediate area. The upper levels record a gradual lowering of charcoal values from ca. 51 mm^2/cc in the 22-28 cm sample to ca. 19 mm^2/cc in the 12-18 cm level. Euphorbiaceae type pollen appears to recover after the fire event at level 22-28 cm, whereas Asteraceae and grass curves actually decline. While the high spine Asteraceae includes native as well as naturalized species, the Asteraceae producing lophate morphology pollen are wholly naturalized and would include *Hypochoeris* and *Sonchus* (Wagner *et al.* 1990). This suggests that levels below 28 cm may date to the pre-contact period, or at least prior to the introduction of species of the Lactuceae tribe.

Table 14. Palynomorph and charcoal particle counts from the Kaho'olawe exposed gully face near Site 207.

Species or type	Samples by depth in cm.			
	12-18	22-28	28-32	45-50
POLLEN:				
Marker grains	238	209	67	216
Poaceae (grass)	12	31	208	12
Cyperaceae (sedge)				3
Monosulcate, monocot type				2
Cheno-ams	134	212	485	496
Cheno-ams, reticulate	15			8
Solanaceae			1	1
Asteraceae, high spine	50	96	69	128
Asteraceae, lophate	10	30		
Dodonaea viscosa	4			
Euphorbia type	27	27	18	53
Sida sp.	3	1	4	2
Argemone type	1			
Gunnera sp.		1		
Hibiscus sp.			1	
Rubiaceae				1
Polyforate, large	1			1
Prosopis pallida	6	1		
Total	263	399	786	707
SPORES:				
Monolete, psilate	11	16	7	8
Monolete, granular	1		1	
Monolete, reticulate	1			
Monolete, fine verrucate	2			2
Monolete, foveolate	1			
Marattia sp.	1			
Polypodium pellucidum	2			3
Trilete, psilate				8
Trilete, spiny	6	7	7	2
Trilete, verrucate		1	1	

Table 14 (cont.).

Cibotium sp.	7	4	1	7
Gleichenia linearis		2	1	
Lycopodium cernuum		1	1	3
Azolla massulae				1
Bryophyte type				2
Pseudoschizaea sp.				1
Total:	32	31	19	37
FUNGI:				
Unicell, sphere, sm.	190	270	1020	275
Unicell, sphere, lg.	5	10	12	
Unicell, irregular	96	500	6	
Diporate	6	10	76	
Ascospores, dicellate	23	48	35	24
Basidiospores, spiny	21	11	1	3
Basidiospores, tuberculate	16	11		
Basidiospores, foveolate	5		108	1
Hyphae	53	1	17	13
Tetraploa	1			
Glomus			3	
Cell clumps	24	27	13	57
Cell chains	10	47	2	7
Box-shaped			13	
Others	13	22	10	2
Total:	463	957	1316	382
CHARCOAL:				
Marker spores	67	35	9	34
Total particles	1181	1642	1292	1636
Total area (mm^2)	1.12	1.57	1.12	1.27
Concentration (mm^2/cc)	18.8	50.78	140.9	42.14

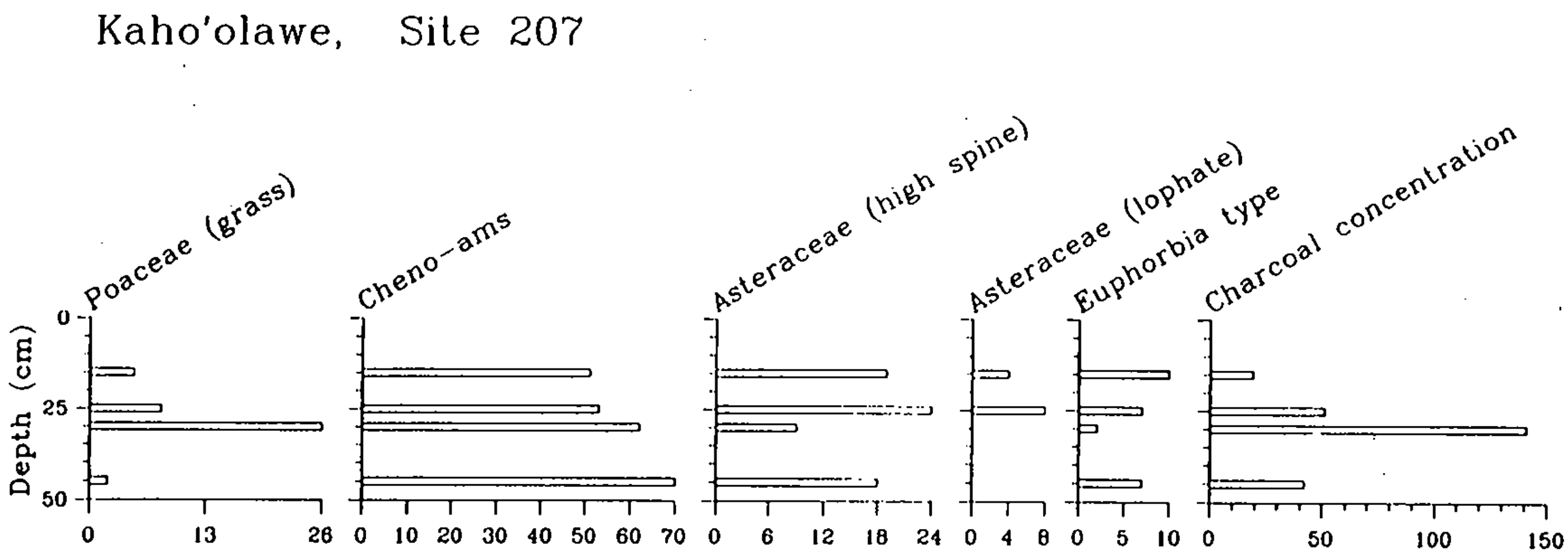

Figure 4. Pollen diagram and charcoal particle concentrations from sampling area near Site 207. The samples are plotted by depth in cm and the pollen spectra are shown by horizontal bars from four levels: 12-22, 22-28, 28-32, and 45-50 cm. Values are given as relative percent. The charcoal concentration values at the right are in mm^2/cc.

The 45-50 cm sample shows evidence of being deposited in or very near a wetland. The water fern *Azolla* prefers standing water or everwet conditions and its massulae or body fragments seen here would therefore be indicative of a marsh or pond. The bryophyte (moss or liverwort) spores seen at this level would also indicate wet conditions as they require constant moisture to complete their life cycle. *Pseudoschizaea* is a cyst of a probable green alga and has been reported from wetland localities around the world (Rossignol 1964), but its exact affinity remains unknown (Ward 1988). *Lycopodium cernuum* spores from this level are indicative of open wet habitats or marshlands. Cyperaceae (sedge) pollen was only found from the 45-50 cm level, and this family usually prefers very wet habitats. An unidentified monocot pollen type was also recorded here which may have been derived from an aquatic plant.

The pattern of fungal spore abundance appears to correlate to the period during and after the fire event. A total of 1,316 fungal spores were counted from the 28-32 cm level and 957 from the 22-28 cm level, immediately after the burn layer. Less than half of that amount were seen either in the lowest or highest sample. Additionally, a shift in fungal spore types was noted. The small unicell type appears to dominate the 28-32 cm sample while the unicell with an irregular outline is most prevalent in the 22-28 cm sample, possibly reflective of a changing vegetation composition of biomass (from woody to leafy tissue?).

It is interesting to note that the fern spores do not show a pattern of higher frequency after the fire level as expected. In many regions, ferns are the first colonizers after a fire and provide the dominant cover thereby producing a "fern spike" in the pollen record.

Most of the palynomorph types recorded in Table 2 and plotted in Figure 2 originated from plants in the watershed on Kaho'olawe and would therefore be considered a local or extra-local component. A regional or more distant pollen source would be expected for a portion of the palynoflora and was probably derived from Maui carried by wind currents and also deposited with rain. Certain types were seen that must have come from a wet forest. In this category would be pollen of the Rubiaceae type which is different from coffee, the only Rubiaceae reported from the island (Warren and Aschmann 1992). The single pollen grain of *Gunnera* seen in the 22-28 cm level must be derived from parent plants which are known to grow in wet gulches and steep slopes on Maui. The presence and amount of *Cibotium* spores is puzzling since it is a fairly large spore (50-100 µm), it occurs in every level and the nearest source today is Maui (Gagné and Cuddihy 1990). As noted above with the crater deposits, a small portion of the pollen rain of additional types are probably derived from Maui since this deposit is partly of aeolian origin.

Kanapou Bay

A single sediment sample was processed from a beach core taken at Keoneuli, Kanapou Bay, which is located on the eastern coastline of Kaho'olawe. The results are presented in Table 15.

The sample contains high levels of cheno-am pollen, which would suggest disturbance conditions. Along with the co-dominance of grass and high spine Asteraceae pollen and the overall low diversity of types, a shrubby dryland vegetation would be indicated. The pollen of Euphorbia, Sida, and Boerhavia found here would be typical of this type of vegetation, the latter being associated primarily with coastal sites. Lophate Asteraceae pollen, found only in the Cichoreae tribe, is a late arrival to the islands and would support a modern age for the deposit. At least intermitent wet conditions are indicated by the minor contribution to the assemblage of sedge pollen and a spore of Lycopodium cernuum. The high levels of fungal spores would suggest an organic-rich layer.

The charcoal concentration at 6.25 mm^2/cc is comparable to the uppermost levels in the Kaho'olawe crater cores (see Fig. 3), which presumably received charcoal from recent fires.

Table 15. Palynomorph and charcoal particle counts from beach core at Keoneuli, Kanapou Bay.

Species or Type	Layer II, 155 cm
POLLEN:	
Poaceae (grass)	44
Cyperaceae (sedge)	3
Cheno-ams	117
Asteraceae, high spine	28
Asteraceae, lophate	8
Euphorbia type	18
Sida sp.	3
Boerhavia sp.	4
Tricolporate, sm. prolate	1
Tricolporate, reticulate	3
SPORES:	
Polypodium pellucidum	1
Monolete, psilate	1
Lycopodium cernuum	1
Trilete, psilate, thick-walled	3
FUNGI:	
Unicell, sphere, sm.	211
Unicell, sphere, lg.	6
Ascospores, dicellate	7
Hyphae	10
Cells clumps	9
Glomus sp.	10
CHARCOAL:	
Marker spores	287
Total particles	817
Total area (mm^2)	.79
Concentration (mm^2/cc)	6.25

VI: PRE-HUMAN AND PREHISTORIC VEGETATION ON KAHO'OLAWE

This chapter will review and summarize the major findings concerning the pre-human contact and prehistoric vegetation on Kaho'olawe. Although most of the field and laboratory investigations concentrated on the volcanic crater cores, most of the interesting data comes from the Site 207 investigations. In addition, the data from the beach deposit at Keoneuli of Kanapou Bay will be reviewed. The botanical data obtained from these investigations--primarily pollen counts--will be compared and contrasted with interpretations offered by previous investigators.

Crater Cores

In terms of the coring effort, the volcanic craters provided a generally excellent record of sedimentation. The cores contained what appeared to be complete and uninterrupted records of the crater sediments where the lower depths could be reached. The Ahupu Formation, the reddish brown soil derived from recent massive erosion, was easily recognized. In some craters it extended to a considerable depth, suggesting the enormous magnitude of erosion and redeposition that occurred within a relatively brief time span. Immediately below the Ahupu Formation was what was here designated as the Intermediate Formation, and below this was the Kaho'olawe Formation. In several cases, indurated ashy deposits were found below the Kaho'olawe Formation, and in one case (Core 1), highly weathered basalt and saprolite were encountered.

The Intermediate Formation was the most interesting from the standpoint of paleobotanical considerations. This formation was perhaps derived from a combination of *in situ* soil development and slow alluvial and aeolian accumulation of dirt washed and blown in from the crater rim. Given its position below the Ahupu Formation, the Intermediate Formation likely dates from about A.D. 1850 at the top. At the bottom it presumably dates to some time well into the past, certainly well prior to human contact with the island.

The Kaho'olawe Formation, having a highly weathered appearance, is clearly an ancient soil horizon. Geochemical analysis (Appendix B) confirmed its considerable age and degree of weathering. There was little expectation that this layer would have any potential for paleobotanical analysis as the palynomorphs would likely have been weathered or leached away.

Regarding the palynological record from the crater cores, the results were generally disappointing. Very little useful information concerning prehistoric or pre-human contact vegetation was forthcoming. The problem was that the samples tended to be virtually devoid of pollen, or at best to have only a few scant grains. The most notable exception was a sample from Core 1 at 5.95 m, which was within the Ahupu Formation deposits. This sample was surprisingly rich with palynomorphs for reasons which are unclear. The soil was undifferentiated from that above or below it in the same layer, so the reason does not seem to be pedological.

Because the 5.95 m sample presumably post-dates ca. A.D. 1850, the results are unfortunately of limited interest. The pollen, with the high sedge counts, is suggestive of marsh or standing water conditions at the bottom of the crater. There must also have been a large amount of nearby grass, along with Asteraceae and Euphobiaceae. Because the pollen record is so distinct from the surface sample, the 5.95 m sample may represent a time period before massive erosion began. This sample is also notable for the number of lowland pollen types present, as well as a few that must have come from Maui. Wind transport of some pollen types over great distances, therefore, is apparent.

The only other core sample of some interest is the basal sample from Core 4 at 6.52 m. The significance of this sample is suspect, however, as the highest pollen count pertained to *kiawe*, which was introduced to Kaho'olawe about 1900 (Stearns 1940:125). Other identified pollen types include grass, cheno-ams, Euphorbiaceae, and *'ilima*. These plant types could be representative of an earlier plant community in the crater at Lua Makika. However, the presence of *kiawe*, more abundant than any of the other pollen types, makes the integrity of the sample suspicious.

Site 207

In contrast to the crater cores, the samples from the gully face near Site 207 proved to be quite interesting and unexpectedly rich in pollen. High pollen counts were obtained from all four samples. The top two samples were from the Ahupu Formation, the middle sample from a burn layer, and the bottom sample from a newly defined soil formation named the Moiwi Formation. This formation, approximately 2 m thick, postdates the Kaho'olawe Formation, which was not directly observed or sampled at Site 207.

Regarding the Moiwi Formation, it is believed that it is largely an *in situ* soil derived from relatively ancient alluvial, colluvial, and aeolian transported sediments. These sediments, in turn, originate from the top of Kaho'olawe Island, where they have undergone weathering and erosion. The Moiwi Formation has probably slowly accumulated and remained stable over a relatively long period of time, undergoing processes of weathering and alteration of its own.

It is believed that the Moiwi Formation is roughly analogous to the Intermediate Formation found in the crater cores, though there are some pedological differences and further study should be made before this is assumed.

Radiocarbon dates on the burn layer at Site 207 suggest that it is either late prehistoric or early historic in age (Spriggs 1991:96). The burn layer, therefore, presumably represents a period of traditional Hawaiian agriculture or land use. The top of the Moiwi Formation must date either to this period--i.e., the time of traditional Hawaiian occupation of the island--or perhaps just prior to it. Presumably the sediments of the Moiwi Formation increase in age with depth, though there is no way to verify this or calibrate age with depth at this time. The pollen record, however, suggests that already by 15 cm below the top of the Moiwi Formation, the soil may date to a pre-human contact age.

Pollen counts from Site 207 indicate a fairly restricted amount of grass during the Moiwi times with an abundance of cheno-ams, Asteraceae (high spine type), and a fair amount of Euphorbiaceae. A small amount of sedge and *'ilima* were also present along with a few other types. This assemblage changes substantially at the time represented by the burn layer, where grass becomes common, and the Asteraceae and Euphorbiaceae counts drop substantially. The cheno-am signal, an indicator of disturbance, however, remains high, with *'ilima* increasing only slightly.

In terms of vegetation cover on the high plateau region, the pollen evidence suggests that during pre-human contact times this area was probably dominated by shrub species, especially Chenopodium and Asteraceae, which were intermixed with some grasses. To characterize this area as having originally been a dryland forest, as Spriggs (1991) and Allen (1992) suggest, probably overstates the reality of the situation. To be sure, *'akoko* (Euphorbiaceae) was present in some quantity. But the historic references indicate that it may have been a variety not growing over 4 ft high. Also, Murakami (1992) has identified a number of woody taxa which, with the exception of *wiliwili*, may have been shrubs rather than trees. Even regarding *wiliwili*, the historic references suggest that it along with *'a'ali'i* were stunted besides being scarce. Also, the fact that the pollen record does not document any of Murakami's woody taxa except Euphorbiaceae and *Chenopodium* suggest they must indeed have been rare in the environment.

Given the above evidence, it is proposed that the upland plateau area of Kaho'olawe, and probably the middle and upper slopes in general, were characterized largely by a *Lowland Dry Shrubland* community. As noted by Gagné and Cuddihy (1990:71-72), this community "is usually found in association with a variety of dry or mesic forests." They describe several varieties of Lowland Dry Shrubland, of which the *Ko'oko'olau (Bidens) Shrubland* would share some of the characteristics of what might be envisioned for Kaho'olawe, including the co-dominance of *Bidens* and *Chenopodium* along with a sparse cover of grasses (Gagné and Cuddihy 1990:71). However, a shrub-like Euphorbiaceae (probably *'akoko*) would also have been relatively commonly scattered on the landscape (in contrast to its clumped distribution observed during the historic period), and several species of other large shrubs or small trees would have been much more widely scattered. However, these, for the most part, would have been too small, too widely scattered, and too limited in numbers to merit the designation of dryland forest. Finally, *Sida* (*'ilima*) bushes would have been intermixed and, less commonly, there would have been members of a few other plant families (e.g., Dodonaea, Solanaceae). The possible exception to the shrubland envisioned here would concern the vegetation found at the base of the larger gulches and similar microenvironments, where more trees, larger shrubs, and denser vegetation growth might be expected due to the greater moisture generally found in these areas.

Interestingly, Gagné and Cuddihy (1990:72) note that,

> Lowland Dry Shrublands are relatively intolerant to grazing pressure and fire, and are replaced by alien-dominated communities when subjected to these perturbations.

Given the apparent large-scale use of fire on Kaho'olawe by ancient Hawaiians as evidenced by the burn layers, and the intensive grazing of livestock during the historic period, it should be no surprise that a *Lowland Dry Shrubland* community has not been recognized for Kaho'olawe. Any relictual stands that may have existed at the time ranching began must have quickly disappeared.

Keoneuli, Kanapou Bay

Despite numerous core attempts, only the effort immediately behind the active beach penetrated deep enough to produce sediment appropriate for pollen analysis. The result produced a single sample of water-saturated loamy fine sand that appeared very humic. This was between a depth of 1.2 and 1.5 m. Because of the presence of lophate Asteraceae pollen in the sample, a type found only in the Cichoreae tribe, which is apparently an early historic introduction to Hawai'i (see Wagner *et al* 1990:266), the sample must be historic in age. The pollen results are actually very similar to those from the lower Ahupu sample (22-28 cm below surface) from near Site

207, which also suggests its relative lateness. The results, while of limited value for vegetation reconstruction, do indicate the potential other beach areas on Kaho'olawe may have for pollen study.

Charcoal Particle Analysis

In an effort to extract as much information as possible from the pollen samples, charcoal particle counts were made. Such counts have been shown to be often informative concerning both anthropogenic and natural disturbance to the environment as a result of burning (e.g., Tolonen 1986). With respect to the Kaho'olawe research, it was believed that quantification of the microscopic charcoal, which is present on the slides with the pollen, would make it possible to pinpoint where in the sediment record significant anthropogenic disturbance on Kaho'olawe began. This, of course, would make it possible to more precisely evaluate the pollen record in terms of distinguishing at what point impacts to the vegetation began.

Unfortunately, the results of the charcoal particle analysis did not yield useful results that could be interpreted as reflecting anthropogenic activity. Indeed, the results from Core 1 perhaps give the most insight as to what may be the problem. As may be seen on the graph (Fig. 3), the charcoal concentration has a rather sawtooth pattern, fluctuating back and forth between 0 or almost 0 and about 4%. This is as true for the Ahupu Formation as it is for the Intermediate and Kaho'olawe Formations. As the lower part of the curve must definitely pertain to the prehuman contact period, and may in fact be quite ancient, it is obvious that the charcoal particles are a result of a natural influx into the environment. The influx of human-produced charcoal, presumably beginning sometime during the upper part of the Intermediate Formation, apparently was so little as to be entirely masked by that produced by natural processes.

The source of the natural charcoal is unclear. It could have been produced as a result of occasional--even rare--natural fires ignited by lightning on Kaho'olawe during the dry season. More likely, however, is that it is derived from off-island sources, probably Maui, though possibly Hawai'i as well, where it was transported to Kaho'olawe by strong trade winds or occasional storm winds. The charcoal particles were probably produced by fires which started as a result of a nearly continuous record of volcanic eruptions and lava flows on these islands.

VII: RECOMMENDATIONS

The present research has been very successful in terms of defining an interesting problem that has both a practical value and a scientific value. Not only do the results increase our understanding of the pre-Western contact vegetation on Kaho'olawe, but we also have achieved a better understanding of soil formations and sediments on the island.

Despite having a better understanding of the nature of the vegetation that once covered the plateau and surrounding slopes on Kaho'olawe, there is a major problem with sample size which limits the value of the results. This is because all of the useful pollen data, in fact, derive from only a single point on the island, which is next to Site 207. There is, therefore, considerable uncertainty as to the applicability and representativeness of the data to the plateau region as a whole, much less the rest of the island and surrounding slopes. It would therefore be appropriate to test and evaluate the findings of the present project, as well as to expand the paleobotanical study to other geographical areas of the island. Building on the base that has already been established, this would not necessarily involve a major expenditure of funds or time. In fact, the work could be easily undertaken in several stages over a period of several years, concentrating on one or two geographical areas at a time, and evaluating the results of each stage in terms of future research needs and the methodology employed. At a minimum, our recommendation is to undertake the following new investigations:

1. Collect a complete column of pollen samples from the Moiwi Formation near Site 207. The formation is about 2 m thick, and at least 5 to 10 sediment samples should be collected from top to bottom. This procedure should be undertaken at several locations within the general vicinity of Site 207 and/or upper reaches of Kanaloa Gulch.

2. Select 2 to 4 additional plateau or upper-slope localities from dispersed geographical locations that have both the Moiwi Formation and the burn layer and sample these for pollen and sediment

analysis. Roughly 5 to 10 samples should be collected from each location.

3. Collect samples for sediment and pollen analysis from the Ahupu Gulch locations where Spriggs worked and also from an appropriate low elevation gulch area on the south side of Kaho'olawe. Sediments should be sampled from both the pre-human contact period and also the period of Hawaiian occupation.

4. Collection of burn layer samples for wood species identification of charcoal and radiocarbon dating. This task can be performed concurrently with points 1, 2, and 3. The burn layers, according to Spriggs, begin to appear at an earlier time in the lower elevation localities. However, sampling should emphasize recovery from diverse regions to provide information on regional variation of plant species.

   Although dating from the time of human contact, burn layer samples can provide a specific inventory of what was present in the environment in a way that analysis of hearth samples cannot due to the bias of human selection in the latter. Also, such an inventory from burn layers can greatly enhance the value of the pollen data as the preservation of wood charcoal is subject to different biases than pollen, and often the woods can be identified to genera and species unlike some of the pollen types. Thus, the integration of the pollen and wood species data will greatly increase the overall value of the study much as it has in the present study.

5. Coring behind the shoreline in beach areas. The results of Kanapou Bay core sample indicate that such locations can be highly productive in terms of pollen preservation. Perhaps with an additional effort to core several other such locations, intact prehistoric sediment layers can be located.

6. Cores 2 and 6 in Kealialuna and Keaualuna Craters were never completed due to lack of time. An effort should be made to extend the bore holes completely through the Ahupu Formation and into the lower sediments. While prospects for good pollen preservation seem rather unlikely at these

locations, information on the complete stratigraphic record would be useful for achieving a better understanding of depositional processes on Kaho'olawe, including the concept of an Intermediate Formation.

Assuming pollen preservation is as good as at the Site 207 locality, the above sampling program should provide a relatively complete body of information concerning pre-human contact vegetation on the island of Kaho'olawe, as well as its possible variation in different geographical zones. The findings of the present study, though not as complete as hoped for when the project was initially planned, have provided a good beginning effort on which to build. The hard part--setting up the research problem and establishing a baseline reference in terms of background information, field conditions, and workable methodologies, has been accomplished. In addition, the project was successful enough to be able to suggest a community type not previously considered--the Lowland Dry Shrubland--for the upland plateau, an interpretation which can and should be evaluated through further research.

APPENDIX A

Textural Analysis of Soils,

Kaho'olawe Paleobotanical Study

by

David J. Welch, Ph.D.

Textural Analysis of Soils, Kaho'olawe Paleobotanical Study

Soil samples collected during the Kaho'olawe auger coring were analyzed at the IARII laboratory. Soil from each identified layer was described on the basis of its major characteristics: color, texture, structure, and consistence. Munsell color readings were taken with the soils dry. Texture determinations were based on feel following normal field designation procedures. However particle size distribution of 21 of the soil samples were determined by liquid separation of the sand, silt, and clay fractions.

A 15 milliliter sample of soil was selected from each of the 21 samples. These samples were separated into sand, silt, and clay sizes by liquid separation based on differential settling times. LaMotte soil kit textural dispersing and soil flocculation reagents were used to promote separation of particles by size. The sand fractions were then inspected under a hand lens to determine the dominant size class or classes of the sand grains. The quantitative results of this non-rigorous type of analysis can only be considered approximate, but allow a more precise description of the texture of the sediments than could be determined by field procedures. The results of this analysis are presented in Table 16.

The textural analysis was especially valuable in demonstrating the presence of a higher percentage of sand than had originally been inferred based on the initial field analysis. Under magnification, it could be seen that the sand portion consisted of very fine sand grains which were not readily visible to the naked eye. Thus the initial analysis underestimated the amount of sand present and overestimated the amount of silt. Several soil horizons originally characterized as silty clay loams in fact are more accurately described as clay loams. The textural descriptions used in the main body of this report reflect the results of this liquid separation textural analysis.

The five crater samples from what appeared to be Ahupu Formation layers (Core 1 Layer III, Core 2 Layers II, III, and IV, and Core 3 Layer II) were generally higher in clay content than typical Ahupu Formation soils, which Spriggs (1991: 97) describes as mostly loam or silt loam in texture. In Cores 1 and 3 and Core 2 Layer IV these were clay loams, with fairly equal percentages of sand, silt, and clay, while the Core 2 Layer II and III soils were a clay and silty clay, respectively. The high percentage of clay is probably a result of erosion of ancient *in situ* B-horizon Kaho'olawe Formation deposits and alluvial deposits high in clay. The great depth these historic deposits attain reflects the ability of the Kaho'olawe craters to trap such eroding materials. In more exposed areas where the Ahupu Formation is generally more medium textured, the finer clay particles have probably largely blown away in the strong winds that blow across the island.

The great depth and high clay content of Ahupu deposits, even in Kealialuna on the windward side of the island, would suggest that the sediments being deposited are derived not only from erosion of older soils on Kaho'olawe, but possibly also from soil erosion on Maui. Thus the Ahupu Formation deposits may reflect not only de-vegetation of Kaho'olawe following the introduction of cattle, sheep, and goats, but also destruction of vegetation on the leeward slopes of Haleakala on Maui and resultant erosion there. This suggestion is supported by the pollen evidence from the cores, which include several types that were undoubtedly of non-local origin, and most likely were blown in from Maui.

Soils from the intermediate layers were quite variable in texture which probably reflects both variation in parent materials for their origin and differing environments of deposition and soil formation. The intermediate layers from Core 1 were all quite high in clay: Layers IV and V are clays; Layer VI is a clay loam. Layer V has a high percentage of silt, while Layer VI is more sandy. Generally, these soils are probably derived from long term alluvial and colluvial infilling of the crater basins, though aeolian transport was probably also a factor.

The samples from the Kaho'olawe Formation are loams or clay loams. Layers VII and IX from Core 1 are clay loams and have fairly equal percentages of sand, silt, and clay. Core 3 Layer VI and Core 5 Layer V are both loams, considerably more sandy than the Core 1 samples. Color more than texture seems to be the most obvious characteristic distinguishing the Kaho'olawe Formation deposits from the Intermediate layers and Ahupu Formation.

Three basal samples, from Core 1 Layer X, Core 3 Layer VI, and Core 5 Layer V, were analyzed. The Core 1 sample appears to be partially weathered basalt bedrock, the parent material of the overlying Kaho'o-lawe Formation. The soil is a clay loam with clay the most common constituent. Pieces of saprolitic basalt were first screened from the sample before the particle size separation was conducted, a step that was not necessary for the other samples tested. The Core 3 and Core 5 basal layers appear more likely to be weathered volcanic ash horizons. These loams are high in both very fine sand and silt, have an "ashy" feel, and contain pieces of weathered ash. The ash may very likely be wind-blown ash from volcanic eruptions of Haleakala on Maui.

The Site 207 samples, the only analyzed samples collected from outside a crater, contain relatively high percentages of sand. The percentage of sand is just high enough that Layer I could be described as either a loam or a sandy loam and Layers II and III as sandy clay loams. Both layers were described as sandy clay loams in the initial site descriptions by Rosendahl et al. (1992: III-11). The texture as well as the color of the burn layer (Layer II) and the Layer III deposit are nearly identical and the burn layer clearly seems associated with the earlier Moiwi Formation rather than the Ahupu Formation.

Table 16. Results of Soil Particle Size Analysis.

Sample	Layer	Sand %	Silt %	Clay %	Texture
CORE 1					
850	III	22	42	36	clay loam
1109	IV	22	31	47	clay
1183	V	9	41	50	clay
1232	VI	38	28	34	clay loam
1428	VIII	39	32	29	clay loam
1500	IX	37	30	33	clay loam
1661	X	30	33	37	clay loam
CORE 2					
735	II	12	18	70	clay
992	III	18	40	42	silty clay
1474	IV	30	42	38	clay loam
CORE 3					
45	II	34	32	34	clay loam
122	III	37	43	20	loam
275	IV	41	30	29	clay loam
345	V	44	28	28	loam
591	VI	24	40	36	clay loam
CORE 5					
157	III	44	18	38	clay loam
181	IV	47	33	19	loam
241	V	44	38	18	loam
SITE 207					
18	I	51	34	14	sandy loam
28	II	52	26	22	sandy clay loam
45	III	49	27	24	sandy clay loam

APPENDIX B

Mineralogy of Soil Samples from

Kaho'olawe, Hawai'i

by

Jane S. Tribble, Ph.D.

Mineralogy of Soil Samples from Kaho'olawe, Hawai'i

Eight soil samples from Kaho'olawe were analyzed for mineralogy by X-ray diffraction on a Scintag PAD V Powder Diffraction System. The samples, all from Core 1 at Kealialalo Crater, were as follows: 6.58 m, 9.40 m, 10.36 m, 11.09 m, 12.32 m, 14.00 m, 14.24 m, and 14.76 m.

Random mounts of powdered samples were scanned from 2-32°2θ at 2°2θ/min using CuKα radiation. Minerals identified in the soils include kaolinite (± halloysite), gibbsite, goethite, and possibly maghemite. The clay minerals kaolinite and halloysite are hydrous aluminosilicates of similar composition but different structure. They are both common weathering products in Hawai'i and differentiation between them requires work beyond the scope of this project. Gibbsite is an aluminum hydroxide, and is a weathering product formed in areas of high rainfall and good drainage. Goethite is an iron oxyhydroxide, and maghemite an iron oxide, both typical weathering products in Hawai'i. Weathering of basalt in subtropical climates generally proceeds in stages. Initially, primary basalt minerals are altered or dissolved, and clay minerals (typically kaolinite, halloysite, and montmorillonite) are formed. In areas of high rainfall, and short residence time of water in the soil (good drainage), the clay minerals are subsequently leached, leaving a residual soil of aluminum and iron oxides, hydroxides and oxyhydroxides.

Kaolinite/halloysite is most abundant in the shallowly buried samples (see Fig. 5 for a representative pattern). There is a sharp decrease in kaolinite/halloysite abundance at a depth of 1400 cm and the two deepest samples are free of these clay minerals. The abundance of gibbsite mirrors that of kaolinite/halloysite. It is absent in the shallowest sample (658 m), and then increases in abundance with depth. Gibbsite is the primary component of the samples from depths of 1400 m and greater (see Fig. 6 for a representative pattern). Goethite (and possibly maghemite) is present as a minor component in all samples analyzed.

The mineral abundances indicate that samples from depths of 1400 cm and greater have undergone a greater degree of weathering than the shallower samples. This contrast in severity of weathering could reflect a longer period of exposure at the ground surface, or a change in weathering conditions such as amount of rainfall.

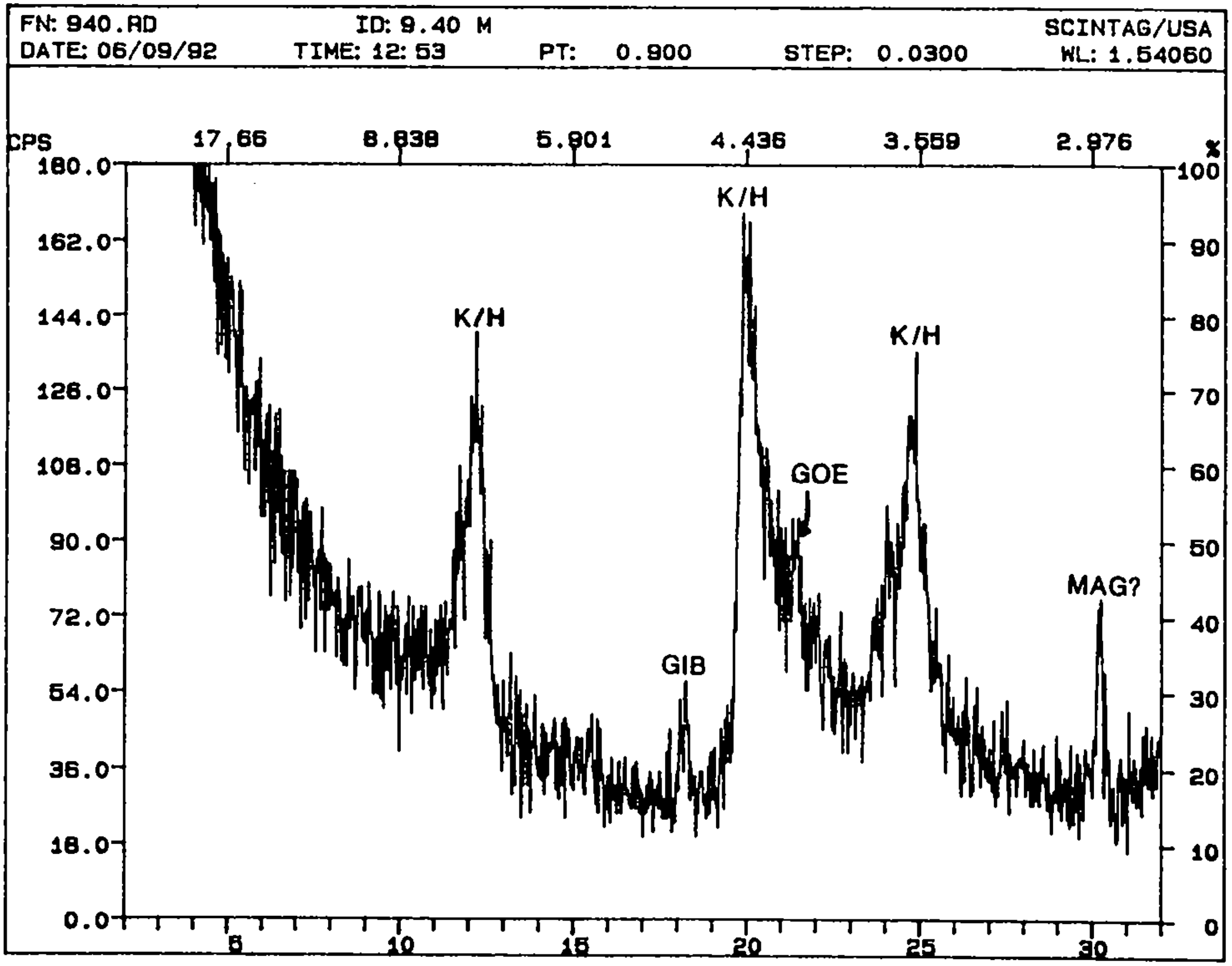

Figure 5. Representative X-ray diffraction pattern for kaolinite/halloysite in the Kaho'olawe Core 1 samples (above 14 m).

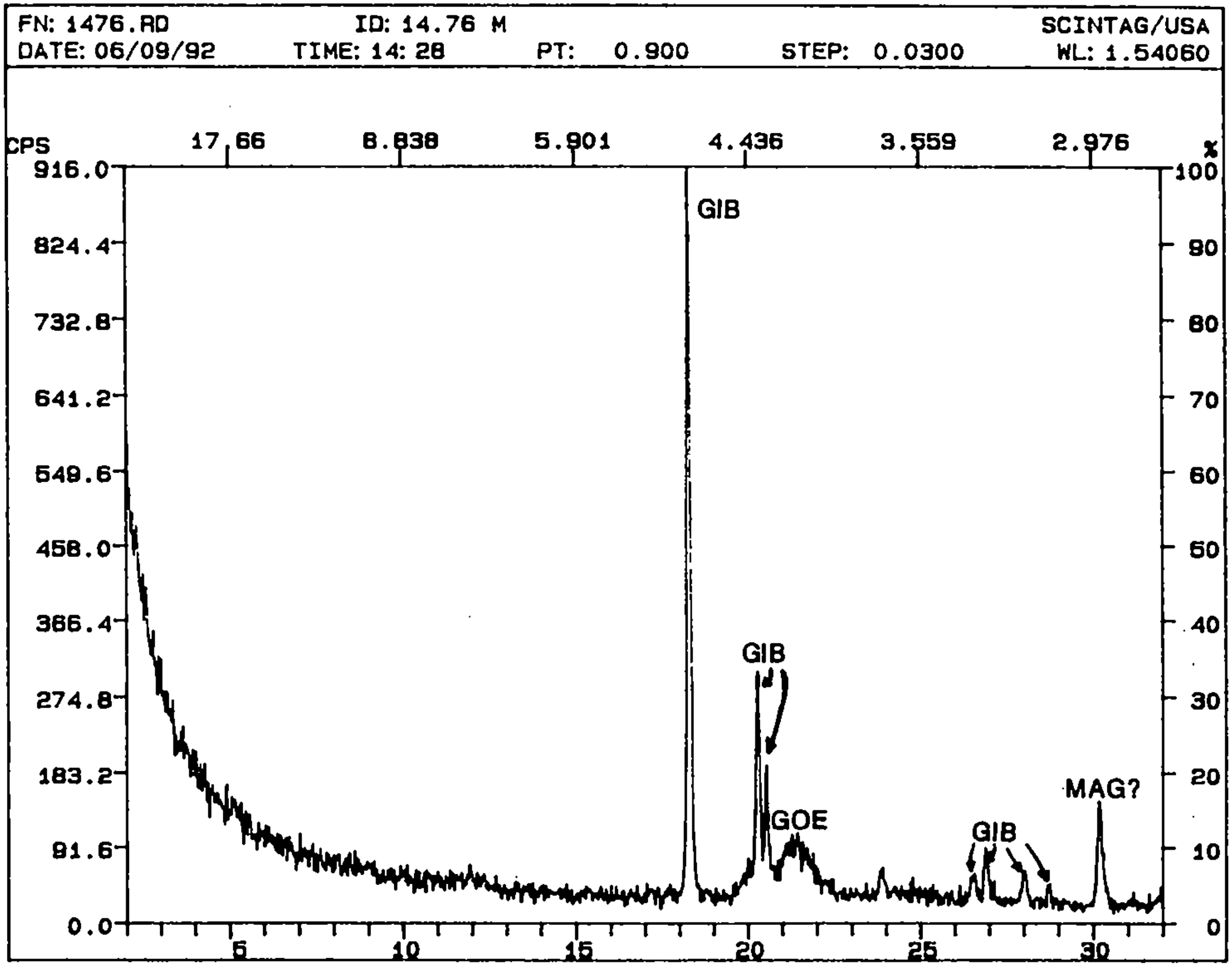

Figure 6. Representative X-ray diffraction pattern showing Gibbsite in the Kaho'olawe Core 1 samples (below 14 m).

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