WĒKIU BUG HABITAT
QUANTITATIVE CINDER EVALUATION

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Prepared for

The Outrigger Telescopes Project

June 2005

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Cover: View of Mauna Kea from the Junction of the Saddle Road and Access Road.

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MAY 2005

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II. EXECUTIVE SUMMARY

The Mauna Kea Science Reserve (MKSR) is located on the summit of Mauna Kea, the tallest mountain in Hawai'i. Within the reserve are the world's two largest optical telescopes, constituting the W.M. Keck Observatory (WMKO). The slopes of Pu'u Hau'oki directly adjacent to and below the WMKO are part of a unique natural environment that supports the Wēkiu bug, a rare insect. Wēkiu bug habitat generally occurs on the upper elevations of Mauna Kea. Populations of Wēkiu bugs also occur on other cinder cones above about 11,700′ (3,570 m) elevation.

The National Aeronautics and Space Administration (NASA), together with the California Institute of Technology (CalTech)/Jet Propulsion Laboratory (JPL), the California Association for Research in Astronomy (CARA) and the University of Hawai'i (UH), have proposed to protect and enhance Wēkiu bug habitat on Pu'u Hau'oki to mitigate potential disturbance by on-site construction and installation of the Outrigger Telescopes Project. To that end these participants have prepared the Wēkiu Bug Mitigation Plan and Wēkiu Bug Monitoring Plan. A key element of the Wēkiu Bug Mitigation Plan is restoration of Wēkiu bug habitat.

A protocol for Wēkiu bug habitat restoration was developed by Pacific Analytics, LLC in conjunction with the U.S. Fish and Wildlife Service and other scientists familiar with Wēkiu bug ecology. Plans call for restoration of habitat adjacent to the WMKO site and at the bottom of the Pu'u Hau'oki crater. The intent is to make it possible for Wēkiu bugs to establish resident populations within the restored areas.

During a review of the Wēkiu Bug Experimental Habitat Restoration Protocol, a committee of scientists advising the Office of Mauna Kea Management recommended increasing the size of cinder for the restoration medium from 1-cm (1/2-inch) or larger to 2.5-cm (1-inch) or larger. In order to evaluate this recommendation, the U.S. Fish and Wildlife Service asked NASA to conduct a quantitative evaluation of the size and depth distribution of cinders in Wēkiu bug habitat in a locality near where the proposed Outrigger Telescopes Project would be restoring Wēkiu bug habitat.

Sampling of Wēkiu bug habitat is being conducted to answer one main Question of Interest.

What is the size and depth distribution of cinder in Wēkiu bug habitat?

On May 13, 2005, cinder was sampled at ten sites, five on Pu'u Hau'oki and five on Pu'u Wēkiu. At each site, the surface cinder was noted before sampling began. Cinder was sorted into five size-classes and weighed, and the depth from the cinder surface to the ash layer was measured. The size-classes sampled were:

Class 1 – greater than 5-cm (~2-inches),
Class 2 – greater than 2.3-cm (~1-inch) to 5-cm,
Class 3 – greater than 1-cm (~½-inch) to 2.3-cm
Class 4 – greater than 0.6-cm (~¼-inch) to 1-cm
Class 5 – less than 0.6-cm (~¼-inch)

Observations about the vertical distribution of the cinders were also recorded. Cinder depth ranged between 8-cm (3-inch) and 11-cm (4.5-inch).

The size of cinder and proportion of cinder in the five size-classes is highly variable in Wēkiu bug habitat. The proportion of cinder in size-class 1 varied from 0 to 46%, in size-class 2 from 6 to 44%, in size-class 3 from 6 to 42%, in size-class 4 from 1 to 26%, and in size-class 5 from 2 to 51%.

On average, about fifty percent of the cinder in Wēkiu bug habitat fell into two cinder size-classes, Class 2 (5.0 to 2.3-cm) and Class 3 (2.3 to 1.0-cm). Total number of Wēkiu bugs captured in adjacent monitoring stations was positively correlated with the proportion of these two cinder size-classes.

Observations of the vertical distribution of cinder at each site indicated that the cinder is size-sorted (graded), with larger cinder near the surface and smaller cinder below (normally graded).

The pattern of cinder size-class distribution was about the same on Pu'u Hau'oki and Pu'u Wēkiu, although geological analysis suggested the percentage of the middle size-classes (Classes 2 and 3) was slightly higher on Pu'u Hau'oki.

III. INTRODUCTION

The Mauna Kea Science Reserve is located on the summit of Mauna Kea, the tallest mountain in Hawaiʻi. Within the reserve are the world's two largest optical telescopes, constituting the W.M. Keck Observatory (WMKO). The slopes of Puʻu Hauʻoki directly adjacent to and below the WMKO are part of a unique natural environment that supports the Wēkiu bug, a rare insect. Wēkiu bug habitat generally occurs on the upper elevations of Mauna Kea. Populations of Wēkiu bugs also occur on other cinder cones above 11,700′ (3,570 m) elevation.

Mauna Kea volcano first grew above sea level about 400,000 years ago, and after a period of rapid growth lasting another 300,000 years, late-stage volcanism produced the coalescing cinder cones that make up Mauna Kea's summit today (Moore and Clague, 1992). The exact ages of these cones are not known, although radiometric dating of an associated lava flow suggests that they formed around 40,000 years ago during a period of extensive glacial cover on Mauna Kea (Porter, 1987). The presence of ice and snow on the summit caused each of the summit eruptions to involve spectacular interactions between "fire and ice", and the nature of the materials resulting from these eruptive vents reflects these water-magma interactions. Early stages of all these eruptions occurred beneath ice and the early eruptive products consist of finely fragmented, glassy material (hyaloclastites), such as those exposed on the lower flanks of Puʻu Poliahu and Puʻu Waiau. These hydrothermally-altered hyaloclastites also likely underlie the surface deposits of Puʻu Hauʻoki and Puʻu Wēkiu, as was shown by the seismic studies of Furomoto and Adams (1968). As these eruptions continued and overlying ice and snow was melted and boiled away, these cones then projected through the ice, and the eruptive activity became more magmatic in nature, with less interaction with water.

The present day cinder cones are mantled by a variety of different types of "tephra" (any material ejected from the source vents by erupting gas) formed during the later stages of eruption. Most tephra clasts consist of "scoria" – light-weight, glassy lava clasts filled with abundant small gas bubbles. These scoria fragments are mostly red and red-orange in color, indicating extensive oxidation during eruptive activity or by subsequent weathering. Dense, angular, fine-grained grey or tan rock fragments are also common in the tephra, and were formed either as discrete fluid volcanic bombs, or by breakup of these bombs during impact. Hydrothermally altered rock fragments and aggregates of altered hyaloclastites are also found amongst the tephra, and may account for much of the fine interstitial material, as these materials are soft and friable, and readily disaggregate.

Current plans call for adding four to six Outrigger Telescopes on the WMKO site. The Outrigger Telescopes would be placed strategically around the existing Keck Telescopes.

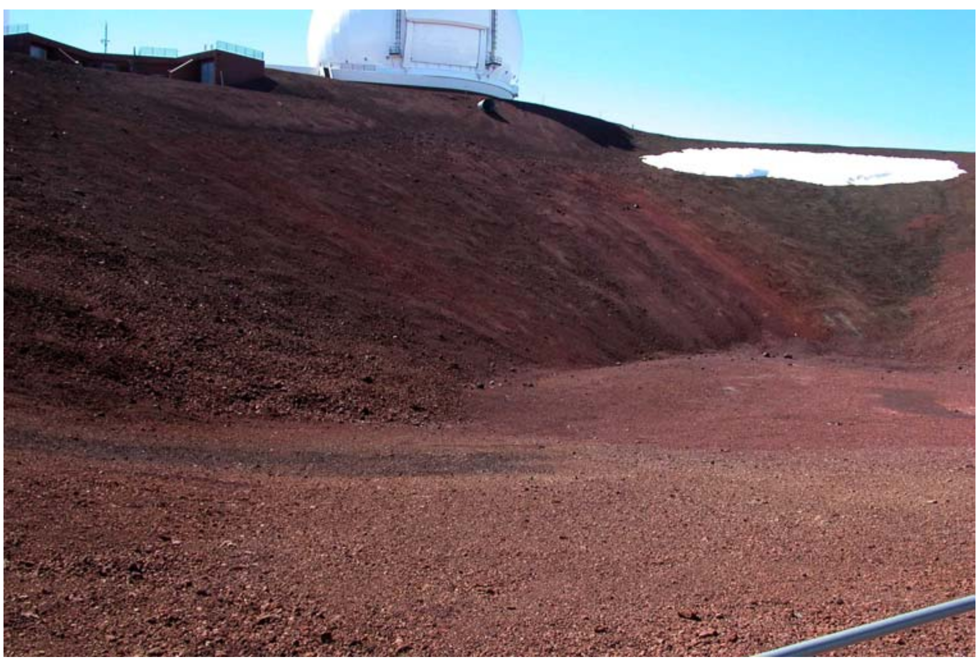
The National Aeronautics and Space Administration (NASA), together with the California Institute of Technology (CalTech)/Jet Propulsion Laboratory (JPL), the California Association for Research in Astronomy (CARA) and the University of Hawaiʻi (UH), have proposed to protect and enhance Wēkiu bug habitat on Puʻu Hauʻoki to mitigate potential disturbance resulting from on-site construction and installation of the Outrigger Telescopes Project. To that end these participants have prepared the Wēkiu Bug Mitigation Plan and Wēkiu Bug Monitoring Plan. A key element of the Wēkiu Bug Mitigation Plan is restoration of Wēkiu bug habitat.

A protocol for Wēkiu bug habitat restoration was developed by Pacific Analytics, LLC in conjunction with the U.S. Fish and Wildlife Service and other scientists familiar with Wēkiu bug ecology. Plans call for restoration of habitat adjacent to the WMKO site and at the bottom of the Puʻu Hauʻoki crater. The intent is to make it possible for Wēkiu bugs to establish resident populations within the restored areas.

The proposed restoration activity would use cinder excavated for the Outrigger Telescopes as the habitat restoration medium. All cinder not used for backfill or site grading would be screened to obtain suitably sized cinder and washed to remove excess dust. The screened and washed cinder would be spread at proposed restoration areas in a layer about 30-cm to 46-cm (12- in to 18-in) deep. After time, this would result in suitable habitat believed to be within the desired depth range for Wēkiu bug habitation (Pacific Analytics, LLC 2000). Cinder on the margins of the restored areas would be placed to ensure that contact with the existing habitat would be established.

During a review of the Wēkiu Bug Experimental Habitat Restoration Protocol, a committee of scientists advising the Office of Mauna Kea Management recommended an increase in the size of cinder for the restoration medium from 1-cm (1/2-inch) or larger to 2.5-cm (1-inch) or larger. In order to evaluate this recommendation, the U.S. Fish and Wildlife Service asked NASA to conduct a quantitative evaluation of the size and depth distribution of cinders in Wēkiu habitat in a locality near where the proposed Outrigger Telescopes Project would be restoring Wēkiu bug habitat.

Sampling of Wēkiu bug habitat was approved by the Office of Mauna Kea Management on May 2, 2005. The purpose of the sampling was to gather quantitative information about the structure of the cinder habitat used by Wēkiu bugs. The information will be used to evaluate, modify, and improve the proposed Wēkiu Bug Experimental Habitat Restoration Protocol to make successful restoration more likely.



The inner slopes of Pu‘u Hau‘oki crater where cinder sampling took place.

IV. QUESTION OF INTEREST

Question

What is the size and depth distribution of cinder in Wēkiu bug habitat?

Justification:

The proposed Wēkiu bug habitat restoration activity would use cinder excavated for the Outrigger Telescopes as the habitat restoration medium. While the size and depth of cinders where traps have been placed during the several Wēkiu bug assessments were reported, quantitative information about the size and depth distribution of the cinder has never been gathered. This information is necessary for the U. S. Fish and Wildlife Service to evaluate restoration protocol options.

Sampling goals:

1) To describe the size and depth distribution of the cinder in Wēkiu bug habitat,

2) To investigate correlations of cinder size with trap capture rates, and

3) To compare the size distribution of the cinder where Wēkiu bugs have been captured on Puʻu Hauʻoki and Puʻu Wēkiu.

V. METHODS

Sieve Construction

Four sieves for sampling cinder were constructed using materials available from local sources. Sieve frames were constructed of 2x4 studs, and measured XX-cm by xx-cm (approximately 0.1-m^2). The sieves were made of galvanized steel hardware cloth. The sizes of available hardware cloth determined the sieve opening sizes. Sieves were constructed that would sort cinder into five size-classes.

Class 1 – greater than 5-cm (~2-inches),
Class 2 – greater than 2.3-cm (~1-inch) to 5-cm,
Class 3 – greater than 1-cm (~½-inch) to 2.3-cm
Class 4 – greater than 0.6-cm (~¼-inch) to 1-cm
Class 5 – less than 0.6-cm (~¼-inch)

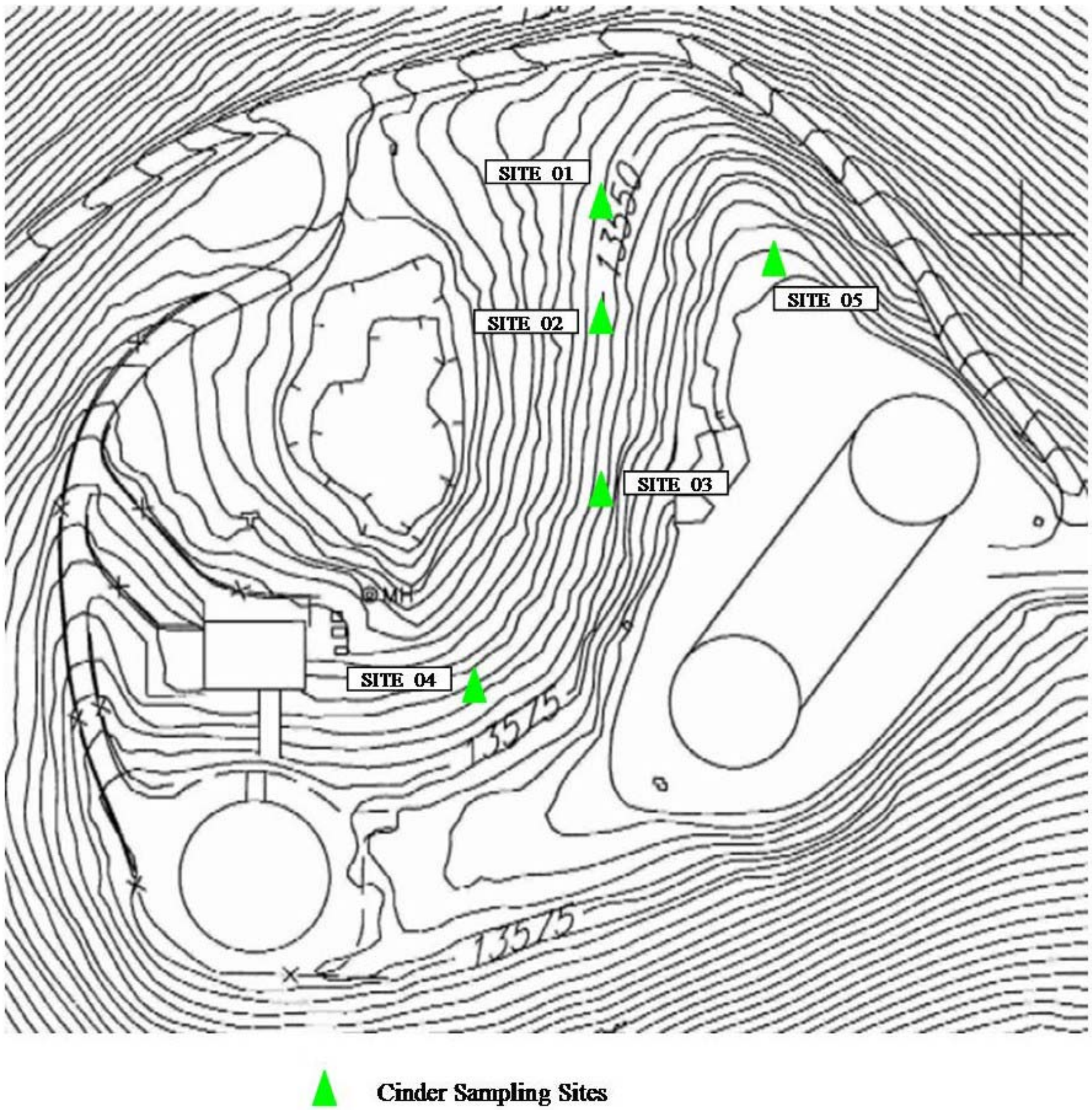
Sieve used to sample the Cinder.

Cinder sampling on the inner slopes of Puʻu Hauʻoki.

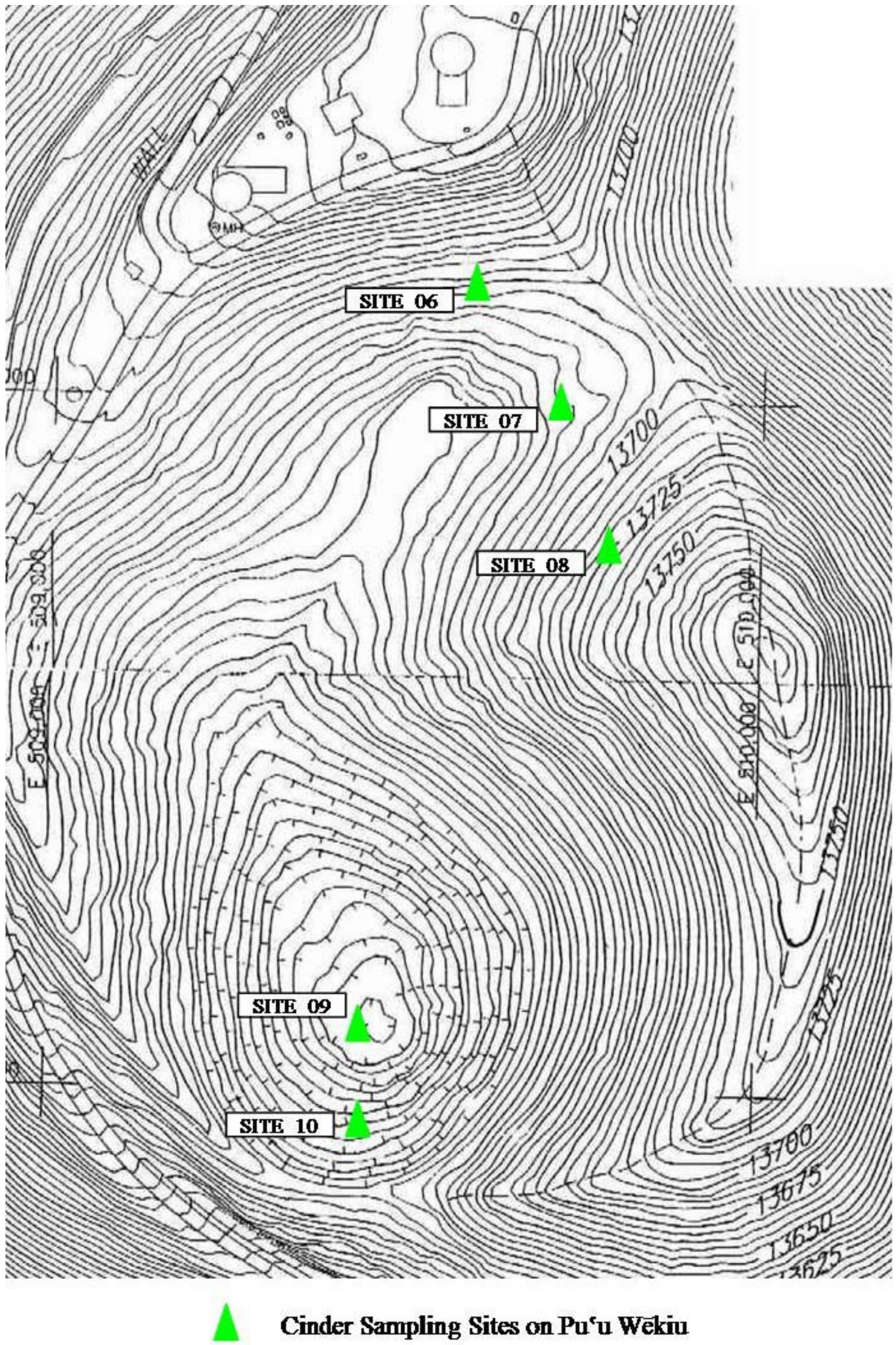
Locations

Cinder was sampled at ten sites, five on Puʻu Hauʻoki and five on Puʻu Wēkiu near Wēkiu Bug Baseline Monitoring stations (Map 1 and Map 2).

The locations of the cinder sampling sites ten Baseline Monitoring stations were selected at random, five on Puʻu Hauʻoki and five on Puʻu Wēkiu. Cinder sampling sites were established within about 5-m of the selected monitoring stations.



MAP 1. Cinder Sampling Sites on Pu'u Hau'oki.



MAP 2. Cinder Sampling Sites on Puʻu Wēkiu.

Protocol for Sampling

The sampled habitat was accessed with a minimum of disturbance to the habitat and cinder slopes. Care was taken to avoid creation of new trails or evidence of foot traffic. After sampling, rakes were used to remove obvious footfalls, trails, and other sampling-caused disturbance.

Step 1. Locate known Wēkiu bug habitat near Wēkiu Bug Baseline Monitoring sampling stations and delineate a 0.1-m^2 cinder sampling site using wood stakes. Note: The first sampling site (Site 1 Puʻu Hauʻoki) was 0.5-m^2. After sampling this site it was decided to reduce the sampling sites to 0.1-m^2 in order to reduce habitat disturbance.

Step 2. Evaluate and describe the surface cinders.

Step 3. Remove the cinder within the sampling area down to the ash layer and place the cinder in the sieve stack.

Step 4. Measure the depth of loose cinder from the surface to the ash layer.

Step 5. Size-sort the loose cinders using four sieves. Sieves sorted cinder into the five size-classes.

Step 6. One at a time, empty each size-class sieve into a bucket and weigh the cinders.

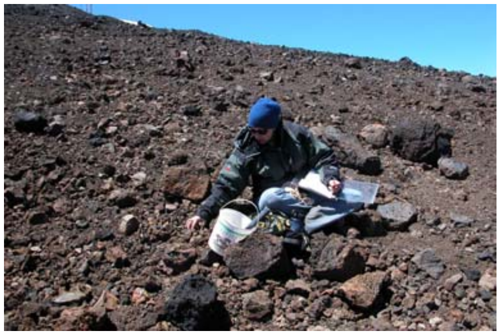
Step 7. Record the weight for each size-class.

Step 8. Return the cinder to the sampling site and rake to repair obvious disturbance.

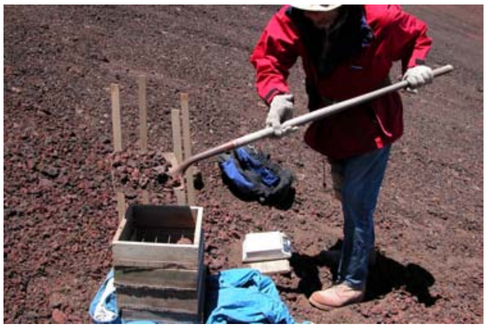
Several days after sampling was completed, project personnel returned to the sampling sites and made further efforts to remove trails and other obvious signs of disturbance.

Steps for quantifying cinder

Step 1
Establish sampling site

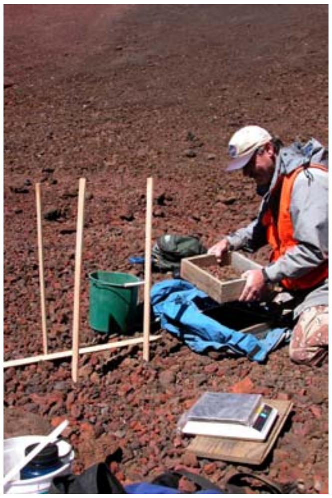


Step 2
Evaluate surface cinders



Step 3
Remove cinder to ash layer

Step 4
Measure depth to ash layer



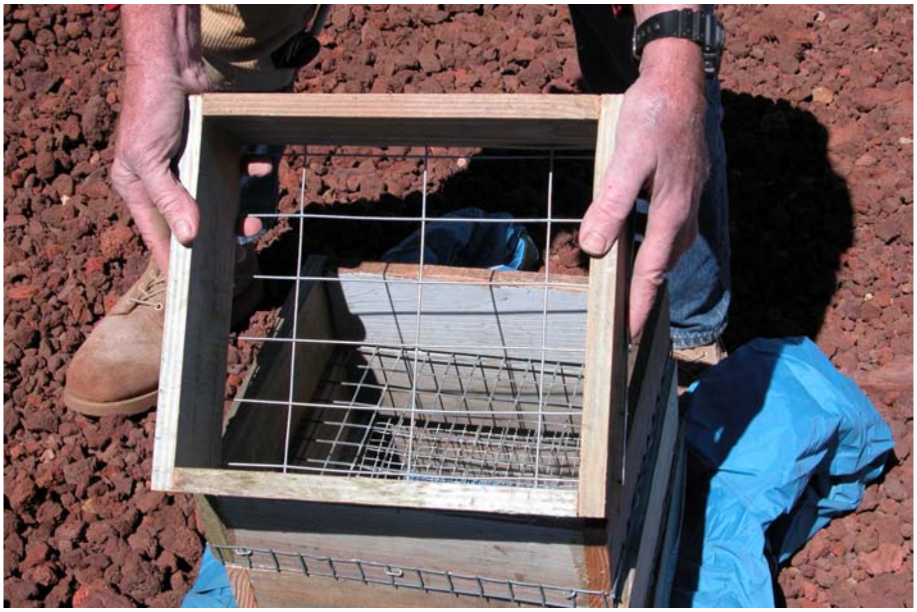
Step 5
Size-sort cinder with sieves

Step 6
Weight each size class

Step 7
Record weight of each size class

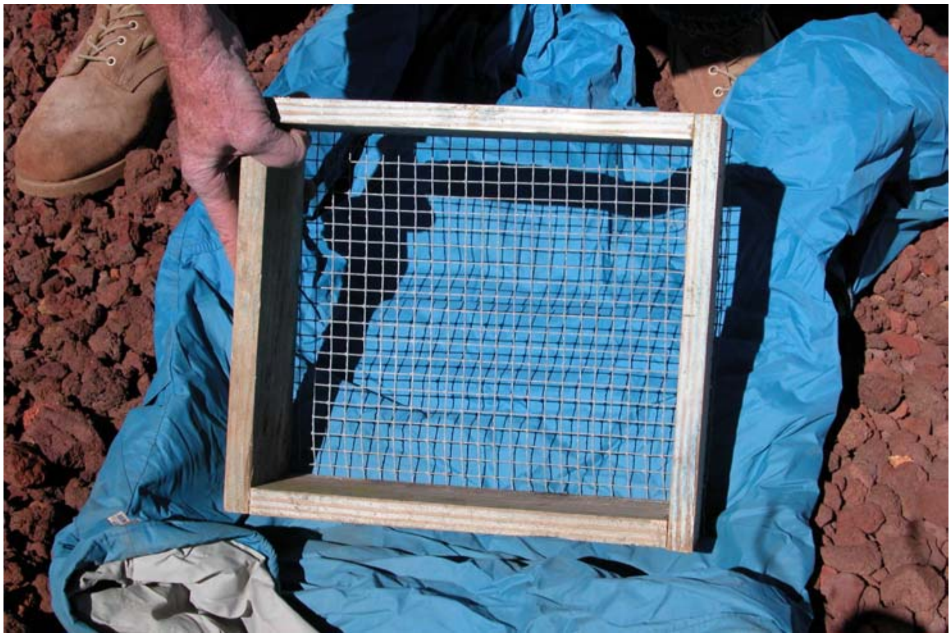
Step 8
Restore sampling site

Sieves used for quantifying cinder

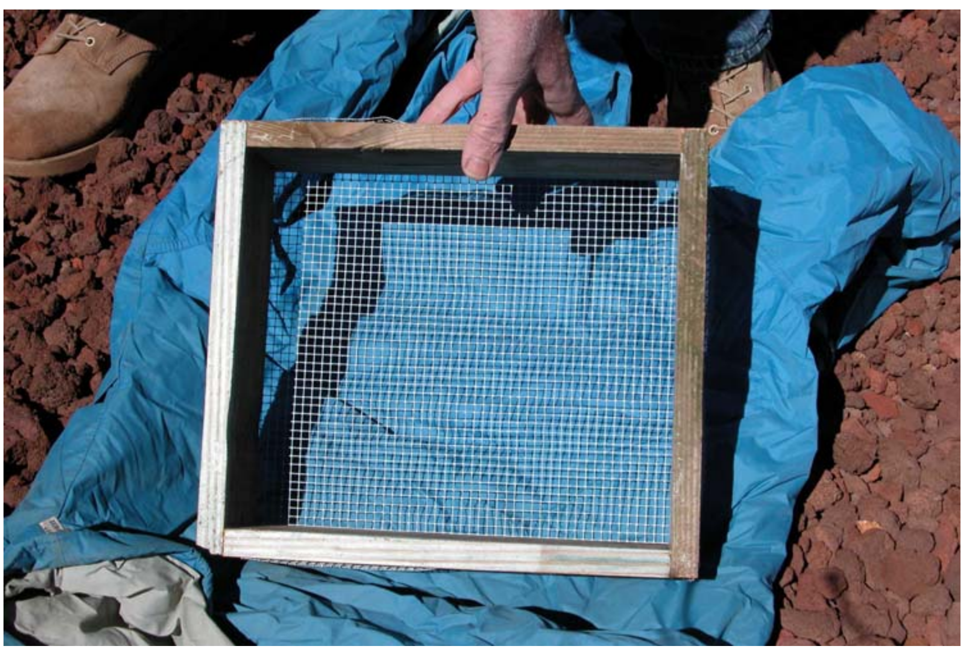


Sieve for Cinder Size-Class 1
Openings are 5.0-cm by 10.0-cm

Sieve for Cinder Size-Class 2
Openings are 2.3-cm by 2.3-cm



Sieve for Cinder Size-Class 3
Openings are 1.0-cm by 1.0-cm



Sieve for Cinder Size-Class 4
Openings are 0.6-cm by 0.6-cm

Sampling Sites

Site 1 on Pu'u Hau'oki
Most surface cinder 1-cm or larger

Site 2 on Pu'u Hau'oki
Most surface cinder 2.3-cm or larger

Site 3 on Pu'u Hau'oki
Most surface cinder 1-cm or larger

Site 4 on Pu'u Hau'oki
Most surface cinder 2.3-cm or larger

Site 5 on Pu'u Hau'oki
Most surface cinder 2.3-cm or larger

Site 6 on Pu'u Wēkiu
Most surface cinder 2.3-cm or larger

Site 7 on Pu'u Wēkiu
Most surface cinder 3-cm or larger

Site 8 on Pu'u Wēkiu
Most surface cinder 1-cm or larger

Site 9 on Pu'u Wēkiu
Most surface cinder 1-cm or larger

Site 10 on Pu'u Wēkiu
Most surface cinder 3-cm or larger

Statistical Analysis

MANOVA and ANOVA

The size-class proportion data for each Site was transformed using an ARCSINE-SQUARE-ROOT transformation (Sokal and Rohlf 1981). The transformed data were then analyzed using Multivariate Analysis of Variance (MANOVA) to test for differences between the two cinder cones, Pu'u Hau'oki and Pu'u Wēkiu. Analysis of Variance (ANOVA) was used to test the transformed data for each cinder size-class for differences between the two cinder cones. Statistical tests were conducted using S-Plus 2000 (MathSoft 1999). Two combinations of size-classes were also tested with ANOVA. The first combination was of three size-classes (Class 1, Class 2, and Class 3). The second combination was of two size-classes (Class 2 and Class 3).

For an alternative perspective, the MANOVA and ANOVA analyses were repeated using ratios instead of proportions. The ratio of the weight of each of the four largest size-classes relative to the weight of the smallest size-class (e.g. Weight of Class 1/Weight of Class 5) was calculated and the MANOVA and ANOVA analyses repeated. The total number of Wēkiu bugs captured during the 2nd Quarter 2005 Baseline Monitoring Session at the monitoring station nearest the cinder sampling site was used as a covariate in the MANOVA and ANOVA analyses. These were the trap capture rates were concurrent with the cinder sampling. Results of the tests are presented in Appendix A. Statistical tests were conducted using S-Plus 2000 (Mathsoft 1999).

SPEARMAN'S RANK CORRELATION

The cinder size-class proportion data were compared to the number of Wēkiu bugs captured in the nearest traps used for the 2nd Quarter 2005 Wēkiu Bug Baseline Monitoring. Spearman's Rank correlation coefficient was calculated and the alternative hypothesis that the correlation coefficient was greater than zero was tested (Mathsoft 1999). The test was conducted for each cinder size-class and for three size-class combinations. The first combination was of three size-classes (Class 1, Class 2, and Class 3). The second combination was of two size-classes (Class 1 and Class 2). The third combination was two other size-classes (Class 2 and Class 3). The 2nd Quarter Baseline Monitoring data for Wēkiu bug captures were used because they were collected concurrently with the cinder sampling and because they were the only complete available data of Wēkiu bug capture counts collected adjacent to the cinder sampling sites. Results of the tests are presented in Appendix B.

GEOLOGICAL STATISTICS GRAIN SIZE COMPARISON AND CHARACTERIZATION OF TEPHRA

To simplify and extract meaningful information concerning grain size characteristics from multiple samples, geologists employ various data reduction methods. These include the graphical representation of the grain size class proportions (e.g. as histograms or frequency curves) as well as summary statistics that describe the grain size distribution. These statistics include the mean grain size, standard deviation (a measure of sorting), skewness and kurtosis values.

Because cinder was sieved and the size of every grain was not measured and because the shape of the frequency curve is affected by the sieve interval used, special statistical methods are required to analyze grain-size distribution (Folk and Ward 1957, Boggs, 1987).

Grain size parameters were calculated by graphical linear interpolation using GRADISTAT version 4.0 (Blott and Pye, 2001). Grain size distribution statistics were interpreted using standardized measures (Folk and Ward 1957).

Sorting (σ_G)		Skewness (Sk_G)		Kurtosis (K_G)	
Very well sorted	< 1.27	Very fine skewed	$^-0.3$ to $^-1.0$	Very platykurtic	< 0.67
Well sorted	1.27 – 1.41	Fine skewed	$^-0.1$ to $^-0.3$	Platykurtic	0.67 – 0.90
Moderately well sorted	1.41 – 1.62	Symmetrical	$^-0.1$ to $^+0.1$	Mesokurtic	0.90 – 1.11
Moderately sorted	1.62 – 2.00	Coarse skewed	$^+0.1$ to $^+0.3$	Leptokurtic	1.11 – 1.50
Poorly sorted	2.00 – 4.00	Very coarse skewed	$^+0.3$ to $^+1.0$	Very leptokurtic	1.50 – 3.00
Very poorly sorted	4.00 – 16.00			Extremely leptokurtic	> 3.00
Extremely poorly sorted	> 16.00				

Geometric Folk and Ward (1957) measures for interpretation of Graphical results.

VI. RESULTS

SAMPLING

On May 13, 2005, cinder was sampled at ten sites, five on Pu'u Hau'oki crater and five on Pu'u Wēkiu. At each site, the surface cinder was described before sampling began. The weight of the cinder in five size-classes and the depth to the ash layer were measured and recorded (Table 1). Observations about the vertical distribution of the cinders were also recorded.

The mean percentage size-class contributions to the total weight and standard errors were calculated for each cinder cone (Table 2) and plotted (Figure 1). The overall mean percentage size-class contribution to total weight was calculated (Table 3) and plotted (Figure 2).

The mean percentage size-class contribution and their standard errors were calculated for cinder larger than 1-cm for each cinder cone (Table 4) and plotted (Figure 3).

The overall mean percentage size-class contribution and their standard errors were calculated for three combination size-classes (Table 5) and plotted (Figure 4).

There was no evidence of a difference in the size-class distribution of cinder between Pu'u Hau'oki and Pu'u Wēkiu (F-stat = 0.3555, df = 5, 4, p-value = 0.8566, see Appendix A). There was no evidence of a difference in any of the five cinder size-classes between Pu'u Hau'oki and Pu'u Wēkiu (see Appendix A for details).

There was evidence of a correlation between the number of Wēkiu bugs captured at adjacent monitoring stations during the 2nd Quarter 2005 Wēkiu Bug Baseline Monitoring and the proportion of cinder less than 5-cm and greater than 1-cm (sum of proportions of size-classes 2 and 3). See Appendix B for details.

TABLE 1.
CINDER SIZE-CLASS DATA
The weights (kilograms) and percentages of total weight of five cinder size-classes sampled in Wēkiu bug habitat on Pu'u Hau'oki and Pu'u Wēkiu in May 2005. Also included is the Total Weight (Kilograms) and Depth to Ash Layer for each Sampling Site.

	Size-Class						
Location	Class 1 > 5.0-cm	Class 2 > 2.3-cm	Class 3 > 1.0-cm	Class 4 > 0.6-cm	Class 5 < 0.6-cm	Total Weight	Depth to Ash Layer
SITE 1 Pu'u Hau'oki	1.48 6%	6.82 26%	5.66 22%	5.31 20%	6.76 26%	26.03	11.0-cm
SITE 2 Pu'u Hau'oki	2.37 46%	2.30 44%	0.32 6%	0.07 1%	0.11 2%	5.17	9.0-cm
SITE 3 Pu'u Hau'oki	0.14 2%	0.75 13%	2.48 42%	1.18 20%	1.32 22%	5.87	9.0-cm
SITE 4 Pu'u Hau'oki	0.31 5%	1.32 21%	1.51 24%	0.77 12%	2.41 38%	6.32	9.0-cm
SITE 5 Pu'u Hau'oki	0.27 5%	1.95 37%	1.99 37%	0.70 13%	0.42 8%	5.33	8.0-cm
SITE 6 Pu'u Wēkiu	4.53 40%	4.52 40%	0.94 8%	0.36 3%	0.84 8%	11.19	11.0-cm
SITE 7 Pu'u Wēkiu	2.42 24%	0.72 7%	2.66 26%	1.68 17%	2.60 26%	10.08	9.0-cm
SITE 8 Pu'u Wēkiu	0.00 0%	0.36 6%	1.17 18%	1.67 26%	3.31 51%	6.51	9.0-cm
SITE 9 Pu'u Wēkiu	0.15 2%	2.70 34%	3.25 40%	1.30 16%	0.65 8%	8.05	9.0-cm
SITE 10 Pu'u Wēkiu	3.35 30%	2.48 22%	2.08 19%	1.60 14%	1.57 14%	11.08	8.0-cm

TABLE 2.
CINDER SIZE-CLASSES

The mean percentages (standard errors) of total weight of five cinder size-classes in Wēkiu bug habitat on Pu‘u Hau‘oki and Pu‘u Wēkiu sampled in May 2005.

	Size-Class				
Location	Class 1 > 5.0-cm	Class 2 > 2.3-cm	Class 3 > 1.0-cm	Class 4 > 0.6-cm	Class 5 < 0.6-cm
Pu‘u Hau‘oki	13% (8%)	28% (6%)	26% (6%)	13% (3%)	19% (6%)
Pu‘u Wēkiu	19% (8%)	22% (7%)	22% (5%)	15% (4%)	21% (8%)
Overall Average	16% (6%)	25% (4%)	24% (4%)	14% (2%)	20% (5%)

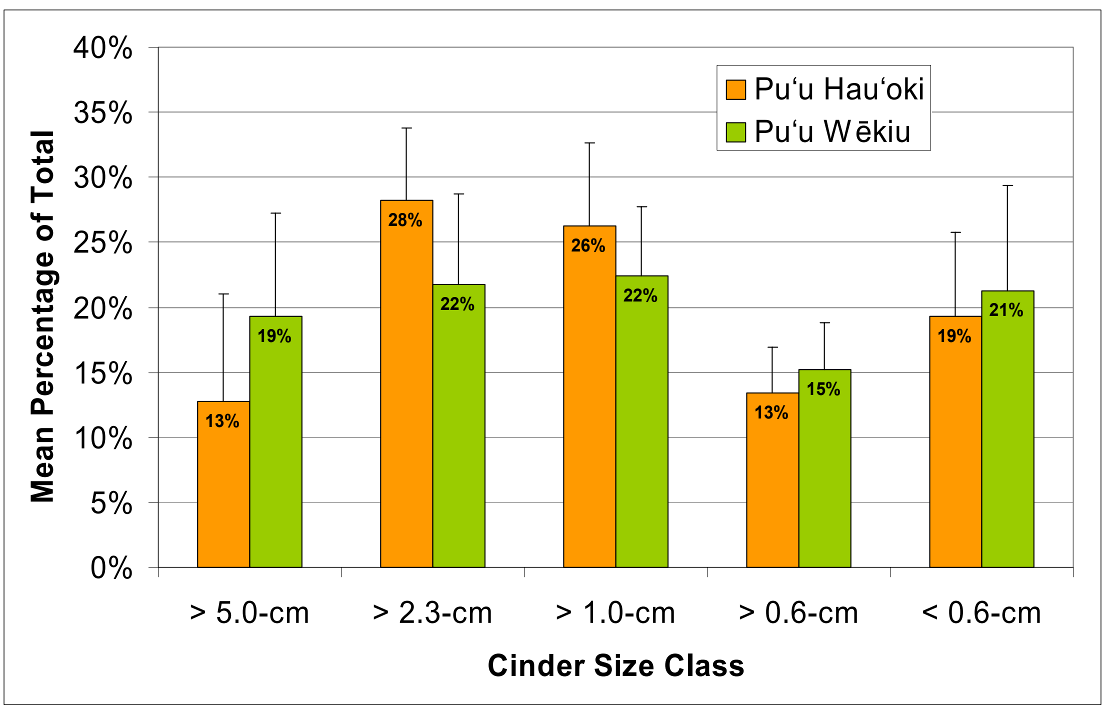


FIGURE 1. Distribution of Cinder Size-Classes. A plot of the mean percentages (with standard error bars) of total weight of five cinder size-classes in Wēkiu bug habitat on Pu‘u Hau‘oki and Pu‘u Wēkiu sampled in May 2005.

TABLE 3.
CINDER SIZE-CLASSES

The overall mean percentages and standard errors of total weight of five cinder size-classes in Wēkiu bug habitat sampled on Pu'u Hau'oki and Pu'u Wēkiu in May 2005.

Size-Class	Class 1 > 5.0-cm	Class 2 > 2.3-cm	Class 3 > 1.0-cm	Class 4 > 0.6-cm	Class 5 < 0.6-cm
Average	16%	25%	24%	14%	20%
Standard Error	6%	4%	4%	2%	5%

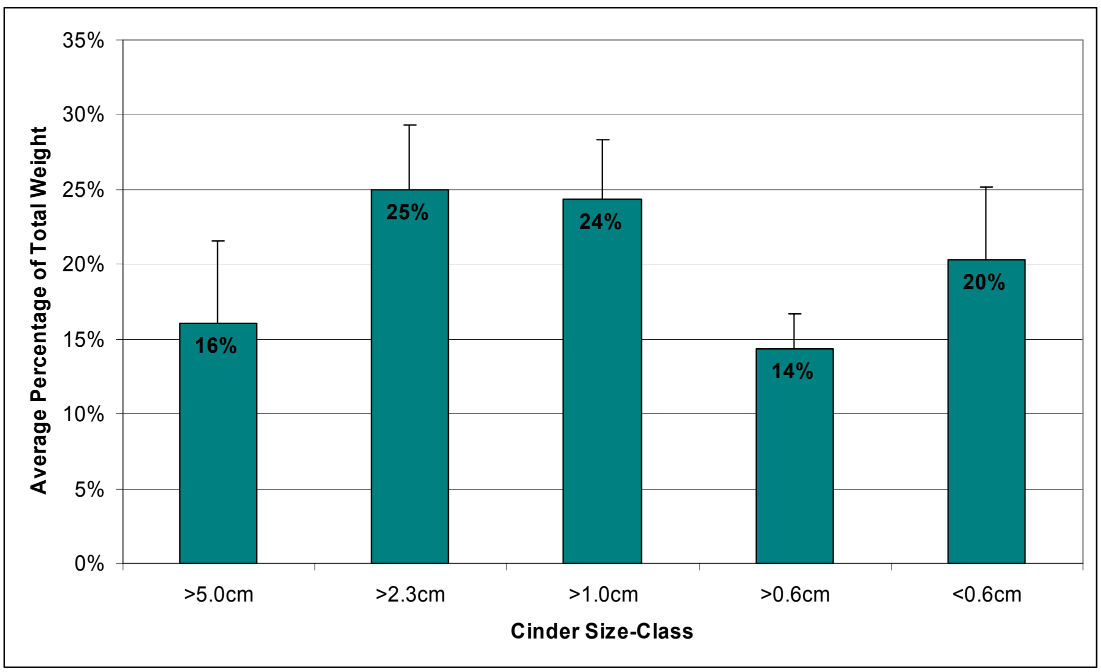


FIGURE 2. Distribution of Cinder Size-Classes. A plot of the overall mean percentages (with standard error bars) of total weight of five cinder size-classes sampled in Wēkiu bug habitat on Pu'u Hau'oki and Pu'u Wēkiu in May 2005.

TABLE 4.
CINDER SIZE-CLASSES GREATER THAN 1-CM

The overall mean percentages and standard errors of total weight of three cinder size-classes sampled in Wēkiu bug habitat on Pu‘u Hau‘oki and Pu‘u Wēkiu in May 2005.

Size-Class	Class 1 > 5.0-cm	Class 2 > 2.3-cm	Class 3 > 1.0-cm
Average	21%	36%	43%
Standard Error	6%	4%	7%

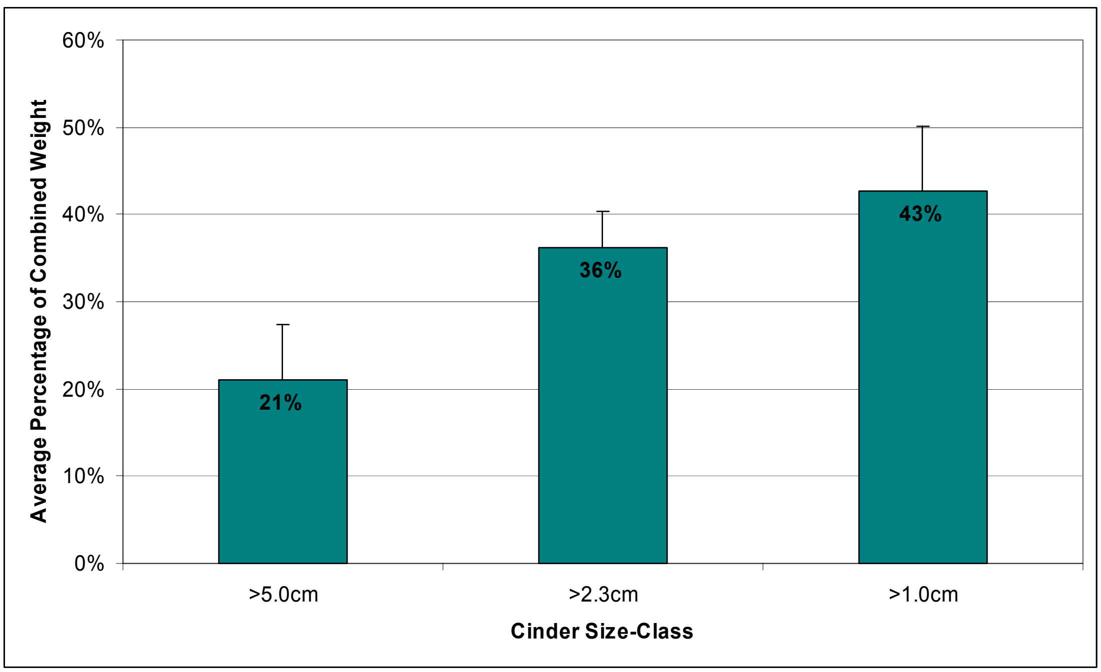


FIGURE 3. Distribution of Cinder Size-Classes Greater Than 1-cm. A plot of the overall mean percentages (with standard error bars) of total combined weight of three cinder size-classes in Wēkiu bug habitat on Pu‘u Hau‘oki and Pu‘u Wēkiu sampled in May 2005.

GEOLOGICAL STATISTICS

TABLE 5.
COMBINATION CINDER SIZE-CLASSES

The mean percentages (standard errors) of total weight of three combined cinder size-classes sampled in Wēkiu bug habitat on Pu'u Hau'oki and Pu'u Wēkiu in May 2005.

CINDER CONE	Large (> 5.0-cm)	Medium (1.0 to 5.0-cm)	Small (< 1.0-cm)
Pu'u Hau'oki	13% (8%)	54% (5%)	33% (9%)
Pu'u Wēkiu	19% (8%)	44% (9%)	37% (11%)

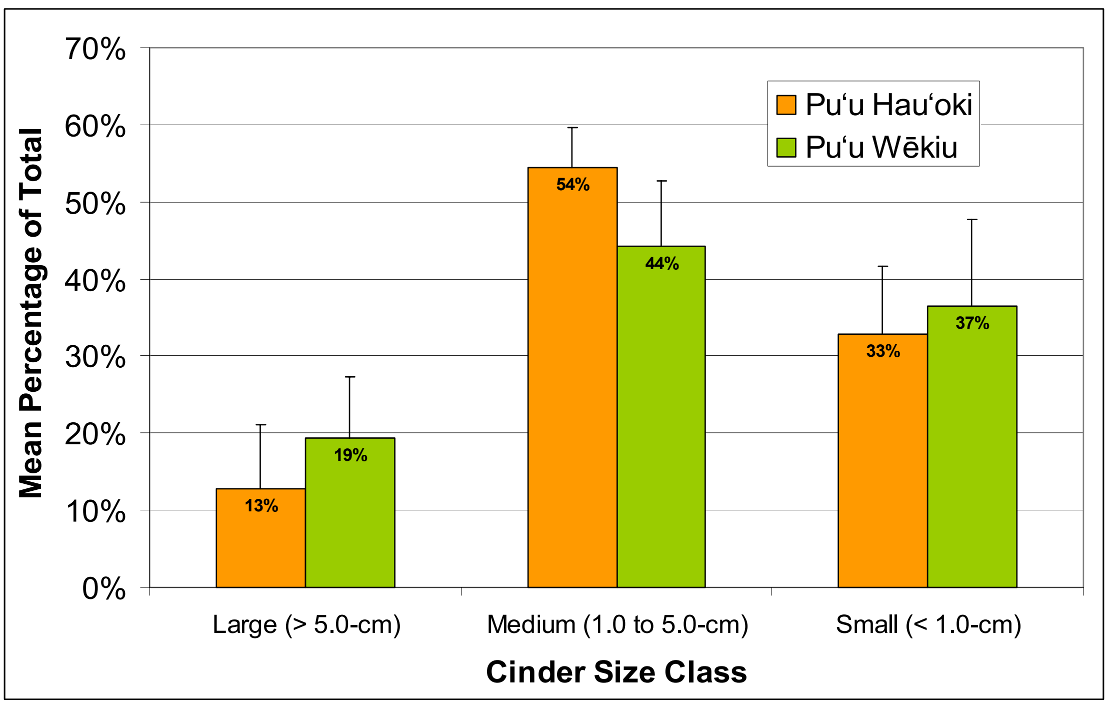


FIGURE 4. Distribution of Cinder Size-Class Combinations. A plot of the mean percentages (with standard error bars) of total weight of three cinder size-classes sampled in Wēkiu bug habitat on Pu'u Hau'oki and Pu'u Wēkiu in May 2005.

GRAIN SIZE COMPARISON AND CHARACTERIZATION OF TEPHRA DISTRIBUTION

Geological statistics calculated from graphic interpolation of cinder size-class proportion data.

TABLE 6.
GEOLOGICAL GRAPHIC MEASURES
The Graphical Measures of Grain-Size Distribution calculated from Cinder Size-Class proportion data collected on Puʻu Hauʻoki and Puʻu Wēkiu in May 2005.

MEASURES	Puʻu Hauʻoki	Puʻu Wēkiu
MEAN (mm)	9.845	9.590
SORTING (Standard Error)	7.435	5.132
SKEWNESS	-0.049	-2.308
KURTOSIS	1.587	0.879

Geological Interpretation

The mean grain sizes at both sites are very similar, differing by only about one-quarter of a millimeter. According to the Folk and Ward (1957) method of interpreting physical descriptions from specific values for sorting, the grain size distributions on both cinder cones are rated as *very poorly sorted*. The average skewness value for the Puʻu Hauʻoki sample indicates a *symmetrical* distribution (i.e., there are about an even number coarse grains as fine ones). Puʻu Wēkiu exhibits a *very fine skew*, although an extreme value in one of the samples (Site 10) greatly influenced this measure. Puʻu Hauʻoki shows a *very leptokurtic (sharp-peaked)* frequency curve, suggesting that the grain size distribution at this site is dominated by the size classes in the mid-range (1- to 5-cm). Puʻu Wēkiu shows a *platykurtic (flat-peaked)* frequency curve, indicating a more even distribution of grain sizes across all size classes.

VII. DISCUSSION

Cinder Size Distribution

Sampling of habitat was conducted in habitat adjacent to Wēkiu Bug Baseline Monitoring stations where trap capture rates have been highest for each cinder cone. Adults and juvenile stages of Wēkiu bugs have been captured in cinder habitat similar to that described in this study.

Adult Wēkiu bug captured in a live-trap during 1st Quarter 2005.

On average, about fifty percent of the cinder in Wēkiu bug habitat fell into two size-classes, Class 2 (5.0 to 2.3-cm) and Class 3 (2.3 to 1.0-cm) size-classes (Table 2). The number of Wēkiu bugs captured in nearby traps in May 2005 was positively correlated with the combined proportion of these two size classes, but was not significantly correlated with the proportion of cinder in any individual size-class alone or in any other combination (Appendix B).

The next most abundant size-classes were the largest (Class 1 - > 5.0-cm) and the smallest (Class 5 - < 0.6-cm) which accounted for about 16% and 20% respectively, of the total sample weight.

On average, cinder 1-cm or larger made up about 65% of the sampled Wēkiu bug habitat (Table 2). If restoration cinder is limited to 2.5-cm or larger, the resulting restoration medium would be composed of cinder that makes up only 41% of Wēkiu bug habitat.

While the mean proportions of the size-classes on Puʻu Hauʻoki and Puʻu Wēkiu varied, there was no evidence of a significant difference. The pattern of cinder size-class distribution was about the same on Puʻu Hauʻoki and Puʻu Wēkiu (Figure 1, Appendix A MANOVA).

Our observations of the vertical distribution of cinder at each site indicated that the cinder is size-sorted (graded), with larger cinder near the surface and smaller cinder below, a condition known as normally graded.

This is consistent with habitat descriptions from the six Wēkiu bug studies that have been conducted (Howarth and Stone 1982, Howarth et al. 1999, Polhemus 2001, Brenner 2002-2004, Englund et al. 2002, 2005).

Wēkiu bugs may prefer habitat sorted in this manner because large interstitial spaces near the surface which allow the bugs to easily move about while they forage for aeolian insects, while smaller interstitial spaces lower in the habitat medium provide a refuge to escape predators and adverse weather conditions.

As in previous studies, the depth of loose cinder was found to vary between 8-cm (3-inch) and 11-cm (4.5-inch) (Table 1). Spaces between islands of habitat were composed mostly of fine-grain particles with scattered cinder 1 to 5-cm in size or larger.

The abundance and persistence of snow may also influence the distribution of Wēkiu bugs. Photo taken March 2005.

By placing restoration cinder 30-cm to 46-cm (12-inches to 18-inches) deep and allowing it to size-sort over time, we feel that the resulting restoration will be similar to existing Wēkiu bug habitat where high numbers of these bugs have been found.

Geological Discussion

The results of graphical linear interpolation of the grain size distribution generally show small differences between Pu'u Hau'oki and Pu'u Wēkiu, although the greater abundance of mid-size grains in Pu'u Hau'oki is suggested (Figure 4). Because the sample size was very small, and only four sieving intervals were used, the measures of distribution were affected by extreme outlier values. For example, a single cobble-size lava bomb found in any of the samples would have a large effect on the resultant statistics. Therefore comparisons between Pu'u Hau'oki and Pu'u Wēkiu using these data must be viewed with caution. The suggestive differences can only be tested by more extensive sampling.

Sources of Error

Estimating the relative proportion of the total volume for each cinder size-class would have required extremely destructive sampling of the habitat. We therefore used the each size-class percentage of total sample weight to estimate the relative volumes of the size-classes. This procedure may have led to inadvertent overestimates of the relative proportion of some size classes. For example, the largest size-class comprises from 0% to 46% of the total sample weight, and averaged 16% overall. However, the relative volume of this size-class was likely smaller. The weight of this size-class was largely dependent on individual, dense rocks that may have caused our estimates of the volume to be higher than would have been observed from actual volume measurements.

The smaller size-class proportions may also have been overestimated. While removing loose cinder from the sampling site it was difficult not to inadvertently pick up a small amount ash and sand below the loose cinder. This could have caused overestimates of relative volume of the smallest cinder size-classes.

Conclusions

1) On average, Wēkiu bug habitat is composed largely of cinder that varies in size from 1-cm to 5-cm (Figure 1 and Figure 2).

2) The sizes of the cinders in Wēkiu bug habitat are highly variable (Table 1).

3) The size distribution and depth of cinder on Puʻu Hauʻoki is similar to that found on Puʻu Wēkiu, although our limited sampling suggests Puʻu Hauʻoki may have a slightly higher proportion of medium-size (1- to 5-cm) cinders.

4) Loose cinders are between 8-cm (3-inch) and 11-cm (4.5-inch) deep in Wēkiu bug habitat.

Acknowledgements

We thank Amanda Leonard for her help sampling the cinder. We thank Timothy Scheffler for his contribution towards analysis and interpretation of the geological statistics. We thank Pam Scheffler for her review and suggestions for improving the manuscript. We thank the Office of Mauna Kea Management for allowing this study to be conducted and the Mauna Kea Rangers for their assistance and support during our field work. Special thanks to Sidina Dedah for reviewing the statistical analyses presented in this report. This study was funded by the National Aeronautics and Space Administration through a contract with Science Applications International Corporation.

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APPENDICES

APPENDIX A

MANOVA

AND

ANOVA

Proportion Data Analysis

MANOVA

There was no evidence of a difference in the median proportions of the five cinder size-classes between the two cinder cones, Pu'u Hau'oki and Pu'u Wēkiu (F-stat = 0.3555, df = 5, 4, p-value = 0.8566).

MANOVA Table

	df	Pillai Trace	approx F-stat	num df	den df	P-value
PU'U	1	0.3077	0.3555	5	4	0.8566
Residuals	8					

ANOVA

There was no evidence of a difference in the median proportions of any of the five cinder size-classes or two combinations of size-classes between the two cinder cones, Pu'u Hau'oki and Pu'u Wēkiu.

ANOVA Tables

Response: Class 1 = > 5.0-cm

	Df	Sum of Sq	Mean Sq	F Value	P-value
PU'U	1	0.010950	0.010950	0.14882	0.7097
Residuals	8	0.588629	0.073579		

Response: Class 2 = > 2.3-cm

	Df	Sum of Sq	Mean Sq	F Value	P-value
PU'U	1	0.020261	0.020261	0.65909	0.4404
Residuals	8	0.245928	0.030741		

Response: Class 3 = > 1.0-cm

	Df	Sum of Sq	Mean Sq	F Value	P-value
PU'U	1	0.004170	0.004170	0.15748	0.7019
Residuals	8	0.211837	0.026480		

Response: Class 4 = > 0.6-cm

	Df	Sum of Sq	Mean Sq	F Value	P-value
PU'U	1	0.002489	0.002489	0.13510	0.7227
Residuals	8	0.147380	0.018423		

Response: Class 5 = < 0.6-cm

	Df	Sum of Sq	Mean Sq	F Value	P-value
PU'U	1	0.002337	0.002337	0.05236	0.8248
Residuals	8	0.357012	0.044627		

Response: Class Combination 1 (> 5-cm, > 2.3-cm, > 1-cm)

	Df	Sum of Sq	Mean Sq	F Value	P-value
PU'U	1	0.0075317	0.00753170	0.1086864	0.7501
Residuals	8	0.5543803	0.06929754		

Response: Class Combination 2 (> 2.3-cm and > 1-cm)

	Df	Sum of Sq	Mean Sq	F Value	P-value
PU'U	1	0.0283454	0.02834536	1.051964	0.3351
Residuals	8	0.2155614	0.02694517		

Ratio Transformation Analysis with Wēkiu Bug Captures as a Covariate

MANOVA

There was no evidence of a difference between the two cinder cones, Pu'u Hau'oki and Pu'u Wēkiu, in the mean ratios of the weight four largest cinder size-classes relative to the weight of the smallest cinder size-class (F-stat = 0.3555, df = 5, 4, p-value = 0.8566).

MANOVA Table

	df	Pillai Trace	approx F-stat	num df	den df	P-value
bugs	1	0.580031	1.381127	4	4	0.3810
PUU	1	0.489061	0.957179	4	4	0.5164
Residuals	7					

ANOVA

There was no evidence of a difference between the two cinder cones, Pu'u Hau'oki and Pu'u Wēkiu, in any of the mean ratios of the weight four largest cinder size-classes relative to the weight of the smallest cinder size-class.

ANOVA Tables

Response: Class 1/Class 5 = (> 5.0-cm)/(< 0.6-cm)

	Df	Sum of Sq	Mean Sq	F Value	P-value
bugs	1	9.8946	9.89459	0.217987	0.6548
PUU	1	73.4645	73.46445	1.618493	0.2439
Residuals	7	317.7345	45.39064		

Response: Class 2/Class 5 = (> 2.3-cm)/(< 0.6-cm)

	Df	Sum of Sq	Mean Sq	F Value	P-value
bugs	1	0.0226	0.02256	0.0005068	0.9827
PUU	1	44.1195	44.11949	0.9912733	0.3526
Residuals	7	311.5553	44.50789		

Response: Class 3/Class 5 = (> 1.0-cm)/(< 0.6-cm)

	Df	Sum of Sq	Mean Sq	F Value	P-value
bugs	1	7.60806	7.608064	3.401400	0.1077
PUU	1	2.20504	2.205038	0.985825	0.3538
Residuals	7	15.65721	2.236745		

Response: Class 4/Class 5 = (> 0.6-cm)/(< 0.6-cm)

	Df	Sum of Sq	Mean Sq	F Value	P-value
bugs	1	0.562641	0.5626414	2.607282	0.1504
PUU	1	0.600463	0.6004632	2.782548	0.1392
Residuals	7	1.510573	0.2157961		

APPENDIX B

SPEARMAN'S RANK CORRELATION ANALYSIS

SPEARMAN'S RANK CORRELATION

The results of Spearman's Rank Correlation tests between cinder size-class proportions and the total number of Wēkiu bugs captured in the nearest traps used for 2nd Quarter 2005 Wēkiu Bug Baseline Monitoring. The data used for the analyses are given in Table B-1.

Sampling Site	Cinder Cone	Class 1	Class 2	Class 3	Class 4	Class 5	Combined Classes 1, 2, and 3	Combined Classes 1 and 2	Combined Classes 2 and 3	Wēkiu bug Counts
1	Pu'u Hau'oki	0.06	0.26	0.22	0.20	0.26	0.54	0.32	0.48	25
2	Pu'u Hau'oki	0.46	0.44	0.06	0.01	0.02	0.97	0.90	0.51	19
3	Pu'u Hau'oki	0.02	0.13	0.42	0.20	0.22	0.57	0.15	0.55	54
4	Pu'u Hau'oki	0.05	0.21	0.24	0.12	0.38	0.50	0.26	0.45	34
5	Pu'u Hau'oki	0.05	0.37	0.37	0.13	0.08	0.79	0.42	0.74	117
6	Pu'u Wēkiu	0.40	0.40	0.08	0.03	0.08	0.89	0.81	0.49	2
7	Pu'u Wēkiu	0.24	0.07	0.26	0.17	0.26	0.58	0.31	0.34	1
8	Pu'u Wēkiu	0.00	0.06	0.18	0.26	0.51	0.24	0.06	0.24	2
9	Pu'u Wēkiu	0.02	0.34	0.40	0.16	0.08	0.76	0.35	0.74	15
10	Pu'u Wēkiu	0.30	0.22	0.19	0.14	0.14	0.71	0.53	0.41	8

Table B-1. Correlation Data. The data that were used for correlation analyses. The table includes the proportion of total weight for each of the five cinder size-classes, and the proportion of three combinations of size-classes, and the total number of Wēkiu bugs that were captured at adjacent Baseline Monitoring stations during the 2nd Quarter 2005 monitoring session.

RESULTS

Class 1 = > 5.0-cm vs. 2nd Quarter 2005 Total Number of Wēkiu bugs
rho = -0.21
Z-stat = -0.6565, p-value = 0.7442

There is no evidence that the Spearman's Rank Correlation Coefficient between the proportion of the > 5-cm cinder size-class and the number of Wēkiu bugs captured in the nearest traps used for 2nd Quarter 2005 Wēkiu Bug Baseline Monitoring is greater than 0 (p-value = 0.7442).

Class 2 = > 2.3-cm vs. 2nd Quarter 2005 Total Number of Wēkiu bugs
rho = 0.25
Z-stat = 0.7295, p-value = 0.2328

There is no evidence that the Spearman's Rank Correlation Coefficient between the proportion of the > 2.3-cm cinder size-class and the number of Wēkiu bugs captured in the nearest traps used for 2nd Quarter 2005 Wēkiu Bug Baseline Monitoring is greater than 0 (p-value = 0.2328).

Class 3 = > 1.0-cm vs. 2nd Quarter 2005 Total Number of Wēkiu bugs
rho = 0.45
Z-stat = 1.3314, p-value = 0.0915

There is suggestive evidence that the Spearman's Rank Correlation Coefficient between the proportion of the > 1.0-cm cinder size-class and the number of Wēkiu bugs captured in the nearest traps used for 2nd Quarter 2005 Wēkiu Bug Baseline Monitoring is greater than 0 (p-value = 0.0915).

Class 4 = > 0.6-cm vs. 2nd Quarter 2005 Total Number of Wēkiu bugs
rho = -0.13
Z-stat = -0.4012, p-value = 0.6558

There is no evidence that the Spearman's Rank Correlation Coefficient between the proportion of the > 0.6-cm cinder size-class and the number of Wēkiu bugs captured in the nearest traps used for 2nd Quarter 2005 Wēkiu Bug Baseline Monitoring is different than 0 (p-value = 0.6558).

Class 5 = < 0.6-cm vs. 2nd Quarter 2005 Total Number of Wēkiu bugs
rho = -0.09
Z-stat = -0.2917, p-value = 0.6148

There is no evidence that the Spearman's Rank Correlation Coefficient between the proportion of the < 0.6-cm cinder size-class and the number of Wēkiu bugs captured in the nearest traps used for 2nd Quarter 2005 Wēkiu Bug Baseline Monitoring is greater than 0 (p-value = 0.6148).

Class Combination 1 (> 5.0-cm, > 2.3-cm, and > 1-cm) vs. 2nd Quarter 2005 Total Number of Wēkiu bugs
rho = -0.01
Z-stat = -0.0364, p-value = 0.5145

There is no evidence that the Spearman's Rank Correlation Coefficient between the combined proportions of the > 5.0-cm, > 2.3-cm, and > 1-cm cinder size-classes and the number of Wēkiu bugs captured in the nearest traps used for 2nd Quarter 2005 Wēkiu Bug Baseline Monitoring is greater than 0 (p-value = 0.5145).

Class Combination 2 (> 5.0-cm and > 2.3-cm) vs. 2nd Quarter 2005 Total Number of Wēkiu bugs
rho = -0.05
Z-stat = -0.1823, p-value = 0.5723

There is no evidence that the Spearman's Rank Correlation Coefficient between the combined proportions of the > 5.0-cm and > 2.3-cm cinder size-classes and the number of Wēkiu bugs captured in the nearest traps used for 2nd Quarter 2005 Wēkiu Bug Baseline Monitoring is greater than 0 (p-value = 0.2559).

Class Combination 3 (> 2.3-cm and > 1-cm) vs. 2nd Quarter 2005 Total Number of Wēkiu bugs
rho = 0.67
Z-stat = 1.9879, p-value = 0.0234

There is strong evidence that the Spearman's Rank Correlation Coefficient between the combined proportions of the > 2.3-cm and > 1.0-cm cinder size-classes and the number of Wēkiu bugs captured in the nearest traps used for 2nd Quarter 2005 Wēkiu Bug Baseline Monitoring is greater than 0(p-value = 0.2559).