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Electron Microprobe Analyses of Glasses from Kīlauea Tephra Units, Kīlauea Volcano, Hawaii

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Cover: The Pāhala Ash in outcrop. (USGS photograph by D.A. Clague)

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[Appendix tables are available in separate files. Tables A1a–A3d are in an Excel workbook. Table B1 is a PDF]

Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)

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By Rosalind T. Helz,[1] David A. Clague,[2] Larry G. Mastin,[1] and Timothy R. Rose[3]

Introduction

This report presents approximately 2,100 glass analyses from three tephra units of Kīlauea Volcano: the Keanakāko‘i Tephra, the Kulanaokuaiki Tephra, and the Pāhala Ash. It also includes some new analyses obtained as part of a re-evaluation of the MgO contents of glasses in two of the three original datasets; this re-evaluation was conducted to improve the consistency of glass MgO contents among the three datasets. The glass data are a principal focus of Helz and others (in press), which will appear in the AGU Monograph Hawaiian Volcanoes—From Source to Surface. The report is intended to support this publication, in addition to making the data available to the scientific community.

Description of Tephra Units and Glass Samples

Keanakāko‘i Tephra

The youngest of the three tephra units is the Keanakāko‘i Tephra, recently described by Swanson and others (2012). This unit, which forms much of the upper surface around Kīlauea’s caldera, was produced by a series of magmatic, phreatomagmatic, and phreatic explosions that erupted over three centuries’ time. The lower part of the Keanakāko‘i Tephra is predominantly vitric and the upper part is predominantly lithic. The Keanakāko‘i glass samples included in this report were described by Mastin and others (2004) and cover most of the interval during which vitric tephra predominated (ca. A.D. 1500–1700; Swanson and others, 2012). The samples were collected at the Sand Wash and Southwest fissure sections, both of which are about 4 meters (m) thick, although a few additional samples from nearby also were collected (see fig. 1 in Mastin and others, 2004). The approximately 300 glass analyses presented in table A1a are from 28 samples. These are listed in the same sequence as those given in table 1 of Mastin and others (2004), which gives the stratigraphic location using nomenclature of Decker and Christiansen (1984) and McPhie and others (1990). A different, thicker section of the Keanakāko‘i has been investigated by Garcia and others (2011); the range of glass compositions found was similar to the results presented in this report.

The thin sections analyzed contain a representative pinch of ash mounted in epoxy on a glass slide and polished for microprobe analysis. Most samples are very fine grained, and many contain hydrated (palagonitized) glass fragments. However, fresh glass is widespread and the analyses presented here were taken on fresh, juvenile material. Crystal fragments are also

[1]U.S. Geological Survey.
[2]Currently at the Monterey Bay Aquarium Research Institute, Moss Landing, Calif.
[3]Smithsonian Institution, Washington, D.C.

present, and include olivine ± chromite, augite, plagioclase, and (rarely) orthopyroxene (opx). In all cases, 4 to 21 glass shards were analyzed within each sample.

Kulanaokuaiki Tephra

The most extensive set of glass analyses included in this report is from the Kulanaokuaiki Tephra of Fiske and others (2009), which is the upper subunit of the previously undivided Uwēkahuna Ash of Dzurisin and others (1995). This unit was erupted between A.D. 400 and 1000, and is made up of thin deposits from a series of explosive eruptions, with considerable time gaps between events. Unlike the Keanakāko‘i Tephra, surface exposures of this unit are rare — the work of Fiske and others (2009) depends on correlations between widely separated sections, based on the position of a unique glass layer with unusually high TiO_2 and K_2O contents, which they designated Kulanaokuaiki 2.

Glass analyses presented in tables A3a–d come from three different sections of the Kulanaokuaiki Tephra plus the Jack’s Pit section, which includes some of the older Uwēkahuna Tephra. Detailed stratigraphic field descriptions of each section are shown in table B1. The sections consist of multiple layers — the Tree Molds section (65 centimeters (cm) thick) has 16 analyzed layers, the composite Uwēkahuna section (2 m thick from the base of Kulanaokuaiki 2 to the top of the unit) has 17 analyzed layers, and the South Flank section (56 cm thick) has 9 analyzed layers. The fourth section (Jack’s Pit) lies mostly beneath the Kulanaokuaiki 2 marker bed, and consists almost entirely of the lowermost Kulanaokuaiki plus older Uwēkahuna material. As can be seen in comparing the MgO data in tables A3a–d, the compositional frequency distribution in the older Uwēkahuna Tephra is similar to that in the Kulanaokuaiki unit proper.

Microprobe mounts for the Kulanaokuaiki contain selected tephra shards in epoxy, polished on only one side, which are therefore viewable in reflected light only. Individual glassy shards were handpicked using a binocular microscope. Some were bubble walls, but most were intact Pele’s tears or Pele’s hair. Phases present include olivine ± chromite (sometimes as inclusions in olivine), plus augite and plagioclase in the more differentiated samples. As for the Keanakāko‘i Tephra, multiple glass shards (typically 5–31) were analyzed within each layer sampled.

Pāhala Ash

The Pāhala Ash is the oldest of the three units included in this report. The data presented here are from a single section of Pāhala Ash found at the top of Hilina Pali, where it is overlain by a Kīlauea flow dated at approximately 23 ka (Easton, 1987). This section and a series of older ashes, all intercalated with Kīlauea flows (Easton, 1987), were collected and reported on briefly by Clague and others (1995). The relationship of this tephra section to the many other ash localities, which have been called Pāhala (as shown in Easton, 1987), is unknown. According to Clague and others (1995), the section includes no obvious breaks in stratigraphy. The stratigraphic continuity of the lower 16 m of the sampled section of the Pahala Ash is shown in the cover photograph of this open-file report. The 61 (of 66) samples included herein were collected at arbitrary heights ranging from 0.09 to 25.84 m throughout the 26-m-thick section, measured as height above the underlying flow.

The sample mounts consist of small clusters of shards and lapilli, mostly in the 0.5- to 1.0-millimeter-size range. These are mounted in epoxy on glass slides, and can be examined in transmitted as well as in reflected light. Because of the absence of finer material, and the fact that these relatively large shards are mostly unaltered, the Pāhala mounts allow a relatively clear look

at the petrology of the unit (see photomicrographs in Helz and others, in press). Partly in consequence of the relatively larger shards, the 707 analyses reported here include data for 11 glass inclusions in olivine crystals. As for the other datasets, 6 to 20 glass shards have been analyzed from each sample.

Re-Evaluation of MgO Contents of Tephra Glasses

As part of presenting the glass data for the three tephras described above, this report includes the results of a re-evaluation of the MgO contents of the Keanakāko‘i and Pāhala analytical suites. MgO content is an important parameter of glass chemistry because it is the most variable oxide in Kīlauea glasses (as it is in most suites of basaltic glasses). Also, for glasses in equilibrium with olivine (as all of these glasses are), glass MgO is a proxy for quenching temperature, as documented in Helz and Thornber (1987). For these reasons, MgO contents of the various tephra glasses were the primary focus of the discussion in Helz and others (in press). Accordingly, it is important to maximize the intercomparability of MgO values among the three datasets and with other data on Kīlauea glasses.

The tephra glass data presented in this report were originally collected as follows:

1. Most of the Keanakāko‘i data, provided here by L.G. Mastin, were obtained by Mel Beeson in 1994 using the electron microprobe at the U.S. Geological Survey (USGS) in Menlo Park. The remaining data were collected by Mastin between 1999 and 2001 in the same USGS laboratory.
2. The Kulanaokuaiki data, provided here by T.R. Rose, were obtained by Rose using the electron microprobe at the National Museum of Natural History (Smithsonian Institution) in Washington, D.C., between 1995 and 2010.
3. The Pāhala data, provided here by D.A. Clague, were obtained by Alice Davis, using the electron microprobe at the USGS in Menlo Park in early 1997.

It is common practice in analyzing unknown basalt glasses to collect data on basalt standard glasses of known composition for comparison. If the compositions of the known glasses are offset from the official analyzed values in a particular microprobe session, it is possible to correct the unknown glasses for the offset, as described by Byerly and others (1977) and Helz and Hearn (1998). This does not affect the absolute accuracy of the data, but can improve the internal precision of a data suite, especially when the data have been collected over many years, as was the case for the Kīlauea East Rift eruption glasses, where the samples were from eruptions that occurred over 12 years’ time (Helz and Hearn, 1998).

For the Keanakāko‘i and Pāhala datasets, the internal reference glass used was a submarine basalt glass (VG-2) analyzed by E. Jarosewich and widely distributed as a microprobe standard (Jarosewich and others, 1979). The nominal MgO content of VG-2 is 6.71 weight percent; however, many workers have reported persistently higher values. D.A. Clague repeatedly obtained MgO=6.95 percent on VG-2 in the USGS microprobe laboratory in Menlo Park, and other workers have reported MgO as high as 7.07 percent (for example, Niu and others, 1999). The original values for MgO in the Keanakāko‘i and Pāhala glasses were not adjusted for these higher values obtained on VG-2. The Keanakāko‘i data were also not corrected for a -1 percent offset in observed MgO relative to the 6.71 percent value. Whether the original Menlo Park Pāhala glass analyses were adjusted to be consistent with MgO=6.71 percent is not known.

The Kulanaokuaiki glass data of T.R. Rose were obtained using a different standardization/internal checking procedure, so there is an issue of intercomparability among the

three suites of analyses. In order to evaluate this problem, R.T. Helz and T.R. Rose rechecked subsets of the Keanakāko‘i and Pāhala glasses using our customary glass analytical routines. For R.T. Helz, this involved using a different reference glass (the 1965 Makaopuhi lava lake glass, designated A99 by Jarosewich and others, 1979) with the preferred glass standard values and correction procedure as described in Helz and Hearn (1998). For the Keanakāko‘i, Helz rechecked glasses from 6 of 28 samples; for the Pāhala, Helz rechecked 8 of 66 samples. A few of the Pāhala glasses, including the extreme compositions, were also rechecked by T.R. Rose, using his customary glass analytical procedure; this also uses A99 as a standard, but without making any secondary adjustments. The results are shown in table 1, and the complete analyses are included in the Keanakāko‘i and Pāhala spreadsheets in tables A1b and A2b, respectively. As anticipated, the MgO contents of glasses in most reanalyzed chips run 4 to 5 percent higher than in the original analyses. This is consistent with (1) the original data either having been corrected for MgO in VG-2 at 6.71 percent or for no correction and (2) the observations of many workers that the MgO content of VG-2 is at least as high as 6.95 weight percent.

Comparisons of the old but corrected MgO glass analyses with the new (rechecked) MgO analyses, together with comparisons for original CaO analyses and new (rechecked) CaO values, are shown in figures 1 (Keanakāko‘i glasses) and 2 (Pāhala glasses). CaO was selected for further comparison between the old and new analyses because (1) its range is relatively large in these glasses and (2) it enables one to see instances in which the original shard was not successfully identified and reoccupied.

Most reanalyzed Keanakāko‘i glasses lie close to the 1:1 line in both graphs. In the case of MgO, this means that it is necessary to correct the original MgO content (with VG-2 at 6.66 percent MgO according to the old session results) to at least MgO=6.95 weight percent. The CaO graph confirms that there generally is not a problem with the original CaO values. The other major oxides also reproduced well, as can be seen from comparison of the analytical results in tables A1a and A1b. However, for shards 413-11 and 423-3, the old and new values for MgO and CaO are inconsistent, falling well off the 1:1 line. These are suspected mismatches (see table 1).

Table 1. Summary of MgO results obtained by reanalysis of selected glasses, Kīlauea tephra units, Kīlauea Volcano, Hawaii.

[Rechecks on shards, as anticipated: New MgO results 4 to 5 percent higher than in original datasets. Numbers shown in column 3 indicate shard samples from the tephra samples shown in column 2. For example, shard sample 66-2 is shown in column 3 as "2" without the prefix. Complete analyses with the full sample numbers are shown in tables A1b and A2b]

Date of reanalysis	Tephra sample	Rechecks on shards, as anticipated	Other results	New shards analyzed
10/23/2012 7/11/2013 7/13/2013	Pāhala #66	2,3,4,5,6,8,9	1,7–MgO much higher 10–MgO not uniform	
10/23/2012	Pāhala #65	1–14		
7/11/2013 7/13/2013	Pāhala #59	1,2,3, 5,6,7		
12/3/2012	Pāhala #35	1,3,4,6,7,8,9		2
12/3/2012	Pāhala #37	2,3	1,6–MgO no change 7–mismatch	4–rim on olivine
12/4/2012	Pāhala #33	2,3,5,6	1–MgO no change	+ one unlabeled chip
12/4/2012	Pāhala #32	1–9		
2/25/2013 7/13/2013	Pāhala #14	1–6, 9,10–12	7–mismatch	
12/5/2012	Keanakāko‘i #432	averaged all		
12/5/2012	Keanakāko‘i #419	1,2,4,8,12,14,15,17	9?, 10–mismatch	
12/5/2012	Keanakāko‘i #413	1–6, 8–10, 12	11–mismatch	
1/8/2013	Keanakāko‘i #416	1,2,6,7		
1/8/2013	Keanakāko‘i #423	4,5,6,8,10	3–mismatch	1,2
2/25/2013 7/11/2013	Keanakāko‘i #514	3,4,7,8,9,10	1–heterogeneous, altered	

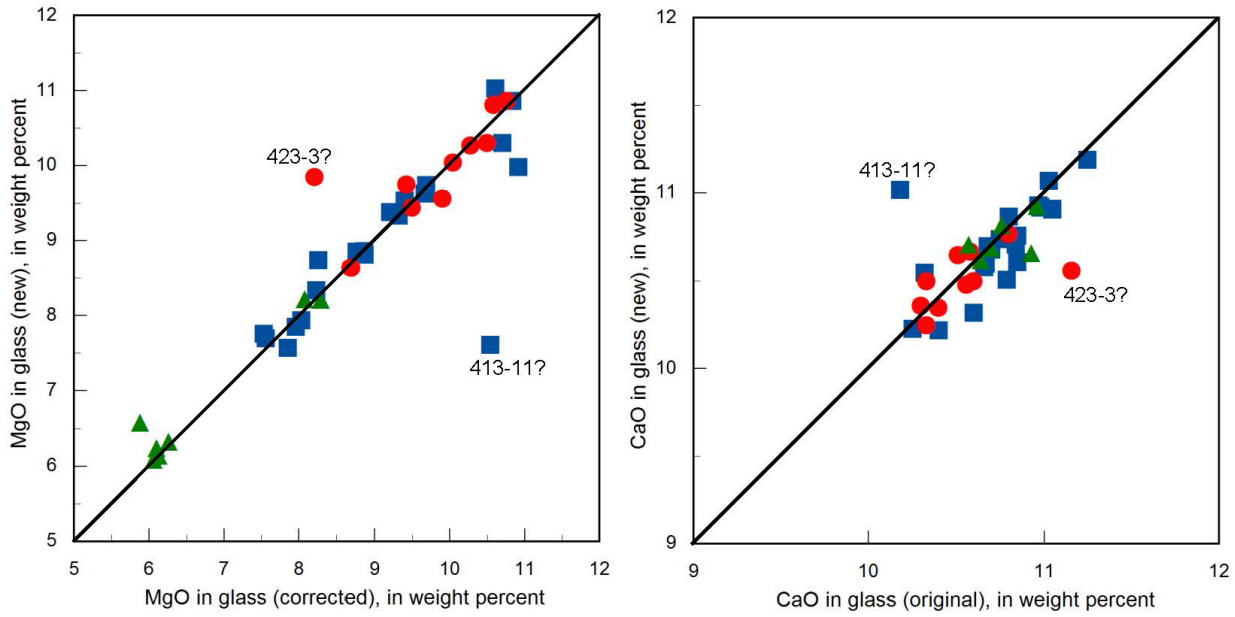

Figure 1. Graphs showing comparison of new (rechecked) values of MgO (left) and CaO (right) in glasses from the Keanakāko‘i Tephra with previous results on the same glass shards. The old MgO values have been adjusted upward, assuming that MgO in the VG-2 standards glass is 6.95 percent. The old CaO values are the original, uncorrected values. Blue squares = 12/5/2012 data; red circles = 1/8/2013 data; green triangles = 2/25/2013 data. Labeled analyses discussed in text.

Reanalyzed glasses from the Pāhala suite, again using CaO as well as MgO for comparison, are shown in figure 2. As is the case for the Keanakāko‘i glasses, most rechecked MgO values fall near the 1:1 line, consistent with an upward correction that assumes VG-2 has an MgO content of at least 6.95 weight percent. However, some shards from the uppermost sample in the Pāhala section (shards 66-1, 66-7, perhaps highly heterogeneous shard 66-10), with MgO contents greater than approximately 12 weight percent, analyze higher still for reasons that are not clear. These unexpectedly higher MgO contents were observed in both sets of recheck analyses, so are considered to be real. As in the Keanakāko‘i data, there appears to be no problem with the original CaO contents. Two shards (37-7 and 14-7) that did not reproduce in either MgO or CaO are presumed to represent cases of mismatch, as in the Keanakāko‘i.

An additional oddity in some of the rechecked Pāhala data is that the new MgO value obtained for a few Pāhala shards (37-1, 37-6, and 33-1, see table 1) were the same as the old data (see tables A2a and A2b). In each case, these shards contain fine-grained quench olivine. We suggest that the “fit” between old and new data can be explained by the original analysis (a single point) having been slightly contaminated by quench olivine. The rechecked analyses are the average of four points, carefully placed to avoid quench olivine.

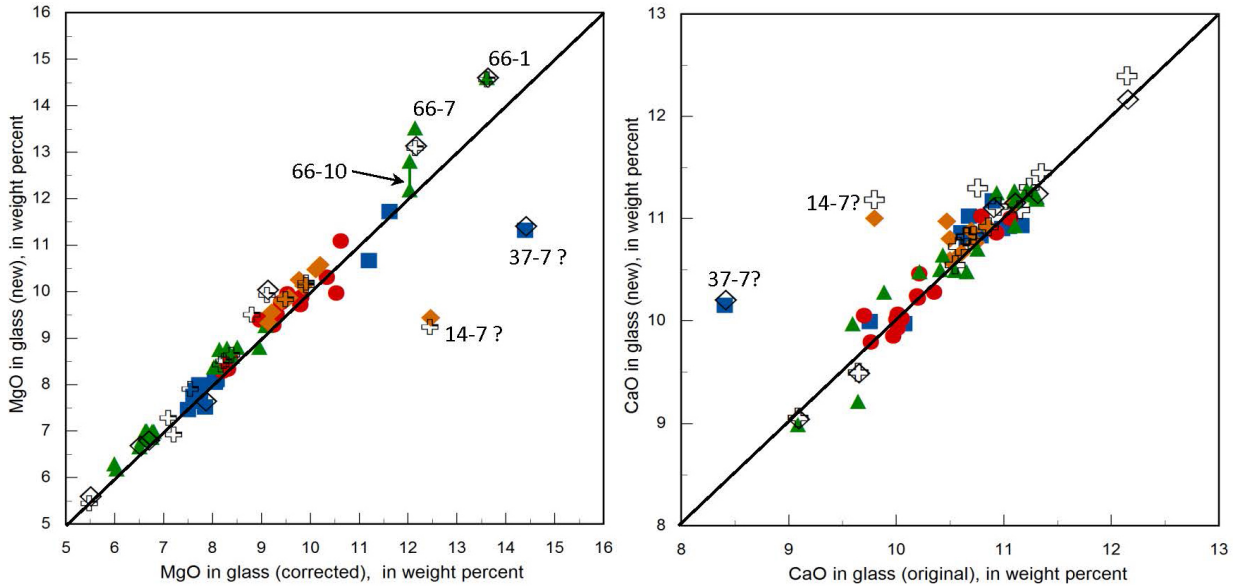

Figure 2. Graphs showing comparison of new (rechecked) values for MgO (left) and CaO (right) in glasses from the Pāhala Ash, with previous results on the same glass shards. The old MgO values have been adjusted upward, assuming that MgO in the VG-2 standards glass is 6.95 percent. The old CaO values are the original, uncorrected values. Green triangles = 10/23/2012 data; blue squares = 12/3/2012 data; red circles = 12/4/2012 data; orange diamonds = 2/25/2013 data; open black crosses = 7/11–13/2013 data; open black diamonds = T.R. Rose data. Labeled shards discussed in text.

Description of Analytical Tables

The glass data are in the workbook attached as an appendix to this report. Overall, the spreadsheets contain the following information: sample ID, date of analysis (when known), number of points in the average for each glass analysis, and stratigraphic position (height in section in meters or position in sequence). The data are listed from the top down within each section. These columns are followed by the analytical data, which include all major elements plus sulfur in most datasets, plus the analytical summation. A final column includes further information on the material analyzed. Details on the individual tables include the following:

1. Table A1a includes 298 analyses of basaltic glasses from the Keanakāko‘i Tephra plus a few differentiated/interstitial glasses (455-10, 419-1, 420-3, and 405-3) and one fragment of opx (419-11), as noted in the “Comments” column of the table. The rechecked glasses are in table A1b, where successful rechecks have “R” following the sample ID. Mismatches from table 1 are designated “X” in the sample ID column. There are 35 successful rechecks (including the dacitic glass fragment 419-1) and 4 mismatches, including another fragment of opx (419-10X). The two sets of analyses differ slightly in that the original Keanakāko‘i analyses include Cl, while the new analyses include Cr_2O_3.
2. Table A2a contains 707 analyses of basaltic glass from the Pāhala Ash, including 11 glass inclusions in olivine. Most of these are single points, with occasional 2- and 3-point averages as indicated in table A2a. The original Pāhala analyses include Cl (as do the Keanakāko‘i data), but do not include Cr_2O_3. The new analyses, presented in table A2b, include Cr_2O_3, but do not include Cl. Table A2b contains approximately 70 Helz replicates plus a range of compositions for the strongly zoned glass in sample 66-10, a

few analyses of new shards (as indicated in table 1), and the additional 9 replicate analyses made by Rose. Table A3c contains analyses of standard glass A99 obtained during the reanalysis process, plus analyses of VG-2, which was analyzed as an unknown in the same sessions.

3. Tables A3a-d contain glass analyses from four sections of the Kulanaokuaiki Tephra, totaling 1,095 analyses. These are the Tree Molds section (254 analyses in table A3a), the Uwēkahuna section (326 analyses in table A3b), the South Flank section (149 analyses in table A3c), and the Jack's Pit section (366 analyses in table A3d). These files are followed by the section descriptions in table B1.

Discussion

This report presents approximately 2,100 analyses of basaltic glasses, adjusted after reanalysis to be internally consistent with each other, assuming that standard glass VG-2 contains 6.95 percent MgO. The concentrations of other major elements in the original analyses are not significantly different from those obtained in the replicate analyses, as was illustrated for CaO in figures 1 and 2. Remaining issues arising from the re-evaluation process include (1) determining possible reasons for the few major-element mismatches found and (2) some comments on the comparability of sulfur contents of the glasses in the old and new analyses. In addition, we review the presence and nature of some relatively differentiated material (MgO<7.5 weight percent) that occurs in these otherwise primitive basaltic glass tephra.

Mismatches in the Population of Rechecked Shards

In the Keanakāko'i samples, the occasional mismatches in the rechecked dataset (4 out of 39 rechecked shards, counting grain "419-10X" that analyzed as opx rather than glass) most likely result from difficulty in identifying and reoccupying each original shard, given the very fine grain size of the Keanakāko'i material, and the large number of grains in each thin section.

In the case of the Pāhala samples, the mounts contain sparser and larger shards, so the mismatches are less easily explained. However, one of the mismatched shards (14-7) contains abundant quench olivine. It is possible that the original single-point analysis was contaminated by this olivine, to a greater extent than appears to have been the case for shards 37-1, 37-6, and 33-1, discussed previously. The other mismatched shard (37-7) is immediately adjacent to new shard 37-unk. The latter is devitrified, with individual points containing 11.71 to 17.42 percent MgO (table A2b). By contrast, the shard labeled 37-7 is a clear, uniform brown glass, and two replicate analyses obtained similar MgO contents (11.30 and 11.38 weight percent). It seems likely that the single point in the original data (reported as containing 14.31 percent MgO) was in fact from the devitrified shard, not from 37-7.

Sulfur Contents of the Glasses—Original Versus Replicate Analyses

The datasets for the Keanakāko'i and Pāhala Tephras report sulfur contents for all glasses, both as SO_3 (weight percent) and as sulfur (S) in parts per million (ppm). The Keanakāko'i glasses contain an average of 330 ppm sulfur (Mastin and others, 2004). The replicate analyses mostly overlap the range of sulfur contents in individual samples, as can be seen in figure 3a below. These sulfur contents are higher than most subaerially erupted lavas, and are presumably a consequence of rapid ejection and quenching of these eruptive products.

Figure 3b shows the original Pāhala glasses, plus all replicate glasses, with the 11 analyses of glass inclusions in olivine shown separately. The average sulfur content of these

glasses appears to be higher than in the Keanakāko‘i, lying between 400 and 600 ppm sulfur. The replicate analyses have values broadly similar to the original analyses, with the exception of those from samples 65 and 66, which tend to run even higher than the originals (compare tables A2a and A2b). The sulfur levels in these upper two samples reach levels approaching sulfide saturation, although immiscible sulfide liquid has not been observed. This is an unexpected result, and is quite unusual in subaerially erupted basalts.

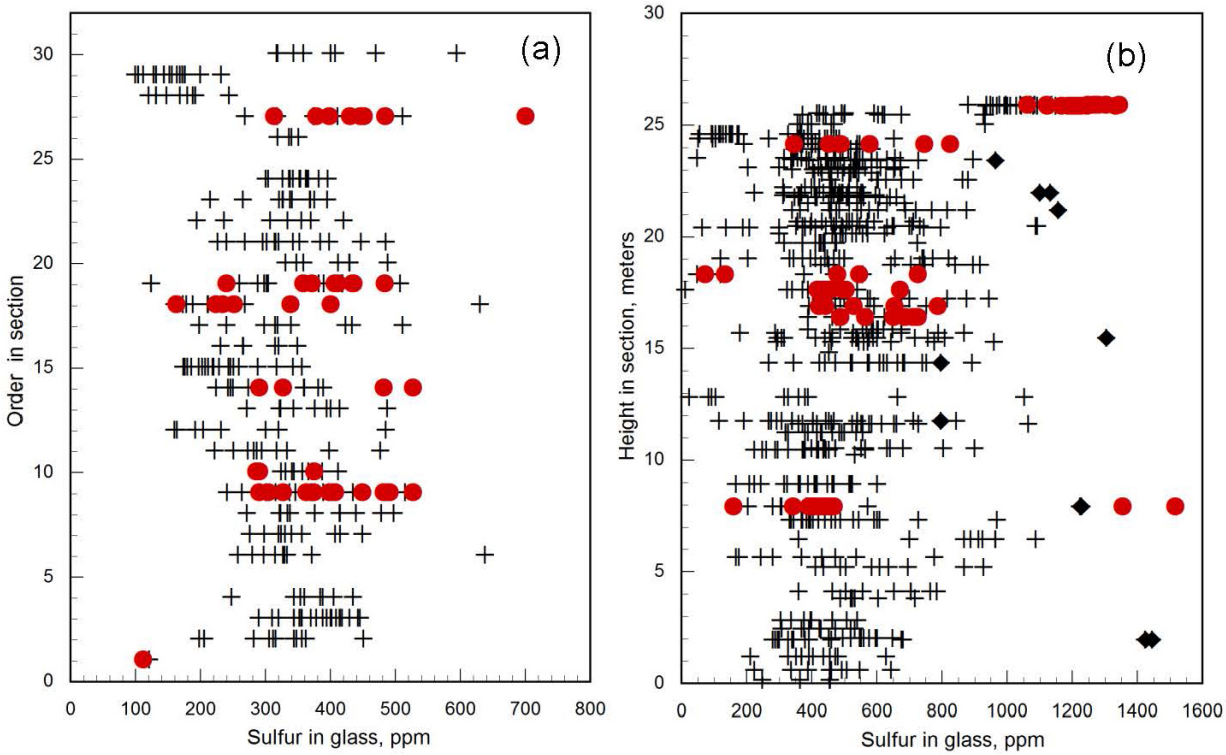

Figure 3. Graphs showing stratigraphic distribution of sulfur in parts per million (ppm) in glasses from the (a) Keanakāko‘i and (b) Pāhala Tephras. Original analyses = black crosses; replicate analyses = red circles; glass inclusions in olivine = black diamonds.

Differentiated Components in the Tephras

Most fresh glasses in these three tephra deposits have primitive basaltic compositions, with MgO greater than 7.5 percent; the discussion in Helz and others (in press) reviews the possible significance of MgO variation in these primitive glasses. All units contain lithic fragments, however, and some of these are partially molten. Crystal fragments also reveal the presence of relatively differentiated and (or) near-solidus components of the tephras. There is relatively little differentiated material in the Pāhala; however, the somewhat more abundant differentiated material in the Keanakāko‘i and the Kulanaokuaiki datasets will be reviewed here.

Highly differentiated glasses (MgO<6.0 percent) in the Keanakāko‘i suite include shards from unit IIB2 (405-3O-3), unit IIC1 (420-3, 419-1), and unit IIIA (455-10) (see table A1a, this report; table 1 of Mastin and others, 2004). Two are interstitial glasses in lithic fragments, but the other two are independent shards. Their stratigraphic distribution suggests that minor, differentiated material (probably of shallow origin) may be present in many of the vitric-ash layers in this unit.

Two grains of opx have been found in sample 419 of the Keanakāko‘i suite. Opx is uncommon in Kīlauea lavas. It was reported by Anderson and Wright (1972) in the early 1955 lavas, who gave its composition as $En_{62.8–72.3}$, Al_2O_3=0.61–1.70 weight percent. Opx found in the late 1960 lavas is similar in composition ($En_{69.7–70.5}$, Al_2O_3=0.61–0.67 weight percent) as reported in Wright and Helz (1996). The grains found in sample 419 are $En_{65.1–66.0}$, with Al_2O_3=0.62–0.65 weight percent. The relatively low En content and low Al_2O_3 content of the opx is consistent with a shallow origin in differentiating, stored magma for all three occurrences.

In addition to these dispersed, differentiated components, both the Keanakāko‘i and the Kulanaokuaiki include occasional layers that are dominated by differentiated glasses. The survey of Mastin and others (2004) includes sample 514, a mix of differentiated, degassed glass scoria (MgO=5.84–6.22 weight percent) and highly vesicular, more-magnesian (MgO=8.04–8.24 weight percent) scoria (Helz and others, in press). In the Kulanaokuaiki, both unit 2 and unit 3 contain relatively differentiated glasses (Rose and others, 2000; Fiske and others, 2009).

Figure 4 shows the TiO_2 contents of some of these differentiated glasses plotted against their MgO contents, to allow a discussion of the various processes involved in the development of the layers that contain them. Glasses from Keanakāko‘i sample 514 are clearly bimodal, are consistently low in TiO_2, and appear to lie along a single line of liquid descent. The other glasses illustrated in figure 4 are from the two lowest analyzed layers in the Uwēkahuna section of the Kulanaokuaiki Tephra. Both layers include low-TiO_2 and high-TiO_2 glasses, which cannot lie on a common line of liquid descent. Note that the low-TiO_2 glasses fall in the gap in the Keanakāko‘i data; such relatively low TiO_2 levels are the rule in prehistoric Kīlauea compositions (Wright, 1971). The high-TiO_2 glasses are from the high-Ti,K marker horizon of Fiske and others (2009); their TiO_2 contents are as high as those seen in the 1959 summit lavas, which are the most Ti-rich lavas known from Kīlauea (Wright, 1971).

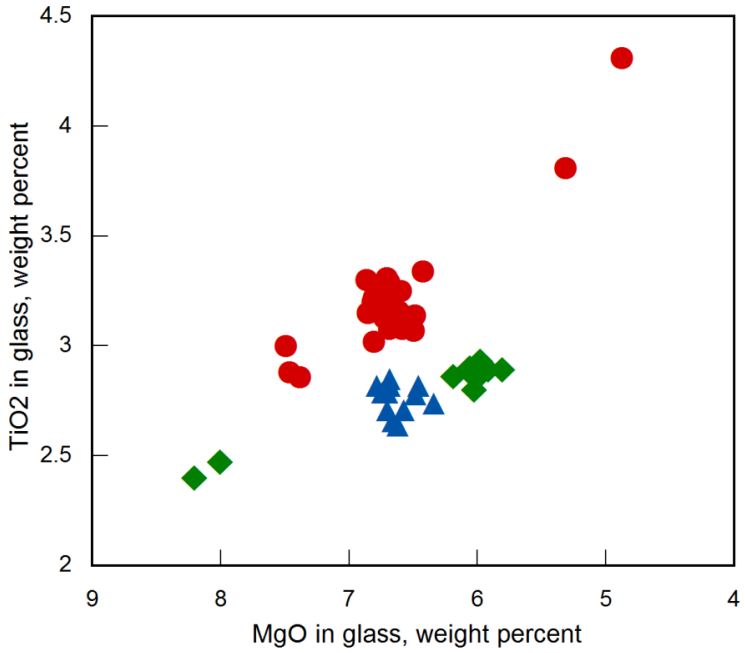

Figure 4. TiO_2 versus MgO (weight percent) for selected differentiated glasses from the Kulanaokuaiki and Keanakāko‘i Tephras. Red circles = high-TiO_2 glasses from layers 1–3 in the Uwēkahuna section of the Kulanaokuaiki; blue triangles= low-TiO_2 glasses from layers 1–2 in the same section. Green diamonds = glasses from a bimodal scoria layer (sample 514) in the Keanakāko‘i, in which some glasses have differentiated compositions.

The data on these few layers are of interest because they show that, in each case, the layers with differentiated glasses contain material from two distinct magma bodies. The Kulanaokuaiki layers have tapped two differentiated (but otherwise unrelated) magmas with different TiO_2 contents. By contrast, sample 514 from the Keanakāko‘i contains two groups of scoria that may lie on the same liquid line of descent, but are separated by a gap of approximately 30 degrees in temperature (Helz and Thornber, 1987) and with conspicuously different volatile contents immediately prior to eruption, as shown by gross differences in vesicularity (see photomicrographs in figs. 6a and 6b of Helz and others, in press) and slightly higher sulfur contents in the more magnesian glasses.

This is important because the basic field unit of the tephra deposits at Kīlauea is the “layer.” These layers are discernible in the field on the basis of color, texture, and weathering characteristics, but are otherwise somewhat ill-defined. Mastin and others (2004) showed color photographs of the sections they sampled, as did Fiske and others (2009). Also, rough layering in the Pāhala is visible in the photograph on the title page of this report. These images give some idea of what the layers look like. However, there is no ready way of knowing how much time is represented by an individual layer. Nevertheless, for the few examples cited above, the glass data show clearly that some individual layers have sampled at least two distinct magma bodies. It is possible that the dominant layers containing more primitive basalt glasses (reviewed in Helz and others, in press) are also derived from two or more discrete magma bodies, but it will be more difficult to discern such heterogeneity in the more magnesian glasses.

Summary

This report contains previously unpublished analyses of approximately 2,100 glasses from three tephra units of Kīlauea Volcano—the Keanakāko‘i Tephra, the Kulanaokuaiki Tephra, and the Pāhala Ash. For the first and third of these units, we have rechecked about 10 percent of the analyses to see whether the originally reported MgO contents were consistent with other data on Kīlauea samples. MgO in the original analyses for the Keanakāko‘i and Pāhala Tephras was found to be low by 4 to 5 percent of the amount present, reflecting a problem with the reported MgO content in standard glass VG-2. The glass analyses presented here have been corrected assuming that the MgO content of VG-2 is 6.95 percent by weight. The corrected analyses should be consistent with other Kīlauea glass data in the literature. It is hoped that making these data available will advance the study of explosive activity at Kīlauea Volcano.

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Appendixes A and B

Appendix tables are available in separate files. Tables A1a–A3d are in an Excel workbook. Table B1 is a PDF. Clicking on an appendix title below will link to the file.

Appendix A. Analyses of glasses from the Kīlauea tephra units, Kīlauea Volcano, Hawaii.

Table A1a. Glass analyses from Keanakāko‘i samples, with MgO corrected.

Table A1b. Replicate glass analyses of selected Keanakāko‘i samples.

Table A2a. Glass analyses from Pāhala samples, with MgO corrected.

Table A2b. Replicate glass analyses of selected Pāhala samples.

Table A2c. Glass standard analyses obtained during replicate analysis sessions.

Table A3a. Glass analyses from the Tree Molds section of the Kulanaokuaiki Tephra.

Table A3b. Glass analyses from the composite Uwēkahuna section of the Kulanaokuaiki Tephra.

Table A3c. Glass analyses from the South Flank section of the Kulanaokuaiki Tephra.

Table A3d. Glass analyses from the Jack's Pit section of the Kulanaokuaiki Tephra.

Appendix B. Detailed descriptions of the four sections of Kulanaokuaiki and Uwēkahuna tephra, Kīlauea Volcano, Hawaii.

Table B1. Detailed descriptions of the four sections of Kulanaokuaiki and Uwēkahuna tephra

This table contains detailed descriptions of the four sections of Kulanaokuaiki and Uwēkahuna tephra for which glass analyses are presented in tables A3a–d. Further information on the location of these sections and their field relations can be found in Fiske and others (2009).

The sections are presented in the same order as the analytical data:

1. Tree Molds section notes
2. Uwēkahuna composite section notes
3. South Flank section notes
4. Jack's Pit section notes

The notes were written by R.S. Fiske and edited for inclusion here by T.R. Rose. Note: Observations made using a binocular microscope on dried samples of tephra are inserted into descriptions in FULL CAPS. Carbon-14 dates are in boldface.

Section I. Locality name: S9-17, also informally as "Tree Molds."

This locality is located in the pali (cliff) face just south of the Tree Molds area of the park.

Interval (cm)	Sample	Field/BINOCULAR description
0-2	S9-17-1	Organic-rich layer with some frothy pumice lapilli, high-fountain type, up to 2 cm diameter. Check for charcoal; this is probably the layer dated by Lockwood. VITRIC ASH, ABUNDANT MED-COARSE NEAR-RETICULITE PUMICE.
2-8	S9-17-2	Dark gray fine ash with Pele's Tears. FINE-MEDIUM GLASSY PUMICE LAPILLI PLUS PELE'S TEARS; PUMICE YELLOW-GREEN ON FRESH BREAK; SCATTERED BITS OF CHARCOAL ROOTLETS COLLECTED. SAMPLED AS S9-17-2C. **690 B.P. (A.D. 1252-1332)**
8-12	S9-17-3	Brown, fine to coarse ash with up to 2-cm pieces of reticulite. Tan in upper 5 mm. HIGHLY VITRIC; TAN COLOR CAUSED BY VERY FINE CLAY COATING; ASH CONTAINS ABUNDANT, VERY FINE PELE'S TEARS; POORLY CONSOLIDATED.
12-15	S9-17-4	Fine to coarse glassy pumice, crystalline pumice, and common lithics up to 2 cm. Pumice is up to 1.5 cm diameter, but sample is dominated by lithics. HALF LITHIC, HALF PUMICE PLUS PELE'S TEARS PLUS PELE'S HAIR PLUS RETICULITE; NON-LITHIC FRACTION DOMINANT IN FINER MATERIAL.
15-17	S9-17-5	Red-brown, fine-medium ash. A few black Pele's Tears. Might be vesicular. VESC. VITRIC TUFF, BIMODAL, COARSE GLASSY SAND IN VERY FINE VITRIC ASH.

This locality is located in the pali (cliff) face just south of the Tree Molds area of the park.—Continued

Interval (cm)	Sample	Field/BINOCULAR description
17-19	S9-17-6	Fine to coarse lapilli. Pumice up to 2.5 cm. Many centimeter-size lithics, but the real giants are pumice. One lithic to 2 cm. PUMICE IS CRYSTALLINE TYPE; FINE FRACTION DOMINATED BY LITHICS, BUT ABUNDANT BLACK VITRIC PIECES. Note: Lithics in this layer collected more thoroughly in August 2001, but the bag is labeled S9-17-6.
19-21	S9-17-7	Fine to coarse ash. DOMINANTLY COARSE LITHIC ASH WITH SOME COARSE VITRIC ASH; PIECES OF VESC. VITRIC TUFF.
21-24	S9-17-8	Dominantly fine to coarse crystalline pumice. Some centimeter-size lithics too. ABUNDANT GLASSY PUMICE, DESCRIPTION OTHERWISE CONFIRMED.
24-28	S9-17-9	Moderately well-sorted, pinkish-tan, medium ash. MEDIUM ASH CONSISTS OF ABOUT HALF IS LOOSE CRYSTALS--OLIVINE, WATER-CLEAR PLAGIOCLASE--AND HALF MOSTLY LITHIC AND FINE ASH, GIVING IT PINK COLOR.
28-34	S9-17-10	Dominantly fine to medium ash, with, at top, 1-cm layer of Pele's Tears and hair. Reddened at top. VESICULAR, POORLY SORTED VERY FINE TO MEDIUM ASH WITH COARSE PELE'S TEARS AND TEAR FRAGMENTS AND COMMON WHITE LITHIC FRAGMENTS, WHITE INSIDE WITH LITTLE BLACK FLECKS (HYDROTHERMALLY ALTERED?)
34-43	S9-17-11	Orange reticulite and black Pele's Tears. Reticulite to 2 cm and larger. FIELD DESCRIPTION CONFIRMED.
		---------HIGH Ti-K GLASS LAYER= K-2 ---------
43-48	S9-17-12	Tan, fine-medium ash. VESICULAR TUFF, POORLY SORTED FINE-MEDIUM LITHIC AND CRYSTAL ASH.
48-52	S9-17-13	Fine to very coarse lapilli, dominantly lithic. Lithics up to 6 cm. Nothing like anything in Kulana. ADD: COMMON CRYSTALLINE PUMICE (4 CM PIECE INCLUDED).
52-62	S9-17-14	Vesicular tuff with large lithics in it. Two such lithics are 6 cm. Red, medium ash makes up most of bed. Definitely vesicular. Bottom is very hard. COARSER LAYERS IN VESICULAR TUFF ARE FINE PUMICE AND VITRIC LAPILLI WITH VERY LITTLE FINE MATERIAL.
62-64	S9-17-15	Dark gray to green, vitric vesicular tuff. Different color from that of overlying unit and not nearly as hard. COARSER GRAINS IN VESICULAR TUFF ARE BLACK GLASS IN A MATRIX OF YELLOW-TAN, MUCH FINER, GLASS; OCCASIONAL LOOSE OLIVINE CRYSTALS. SORTING BIMODAL.
64-65	S9-17-16	Pink, very fine ash with abundant coarse sand to fine lapilli grains. Filters down into rubbly top of underlying a`a flow at 65 cm. COARSE ASH WITH ABUNDANT VITRIC COMPONENT COATED WITH YELLOW WAXY ALTERATION; POSSIBLE ACCRETIONARY LAPILLI (ONLY ONE CONFIRMED).
65	S9-17-17	Orange reticulite in pockets in a`a flow. DOMINANTLY HIGH-FOUNTAIN PUMICE WITH BLACK PELE'S TEARS.

Section II. Locality names: F9-6, F9-7, F02-26, informally known as "Uwēkahuna Bluff."

This is a composite of several sections at the base of and part way up the Uwēkahuna Bluff.

F9-7. Upper part of Uwēkahuna ash just south of northern end of Uwēkahuna laccolith. Continue a kind of composite section, because of better developed upper beds here. Started section at top of bed with gigantic lithics, at 119-139 in F9-6. Sample interval was measured from the base of the section.

Interval (cm)	Sample	Description
20-36	F9-7-5	Compacted pumice and fine ash and Pele's tears. Resembles golden pumice. F02-26-26 is this same deposit.
18-20	F9-7-4	Poorly sorted coarse sand to medium lithic lapilli. F02-26-25 is an approximate equivalent.
14-18	F9-7-3	Very dark green to black Pele's tears, hair, and vitric ash. Upper surface has reddened color.
10-14	F9-7-2	Reddish brown, fine-coarse sand, irregularly bedded. Upper portion has red speckled appearance with free olivine. Lower part is better-sorted fine ash with scattered vesicles.
0-10	F9-7-1	Thickness variable because of irregular underlying surface. Glassy, medium greenish-gray pumice, high fountaining type. A few clasts to 4 cm of frothy pumice. Scattered lithics to several centimeters across.

F9-6. Below southern hump on Uwēkahuna laccolith; same site as UWEB-1
Section log; logged from bottom up, but notes in top-down stratigraphic order

Interval (cm)	Sample	Description
149-176		Compacted vitric golden pumice and ash. Probably crushed as F9-6-5. Also Pele's tears.
139-149		Medium-coarse, red-speckled, dark-brown ash with abundant free olivine crystals, well sorted.
119-139		Very poorly sorted ash to gigantic lithics. Lenses of vitric ash.
104-119		Tan to pink very fine ash, vesicular in places. One prominent layer of fine-coarse lithic lapilli that is very poorly sorted and is about 2/3 to top. Lower third has abundant fine lithic lapilli in fine ash matrix.
102-104		Well-sorted fine lithic lapilli.
		Section F9-7 (above) is a more complete section from here up.
67-102		Coarse lithics of variable thickness.
61-67	F9-6-5	Compact, somewhat hardened layer of highly vesicular, beautifully glassy pumice, and tears. No void fraction between grains. Could have had reticulite, which is now mashed to make bed somewhat hard. Glass is amber colored.
60-61	F9-6-4	Relatively well sorted, fine-medium lithic lapilli.

This is a composite of several sections at the base of and part way up the Uwēkahuna Bluff.—Continued

F9-6. Below southern hump on Uwēkahuna laccolith; same site as UWEB-1—Continued Section log; logged from bottom up, but notes in top-down stratigraphic order—Continued

Interval (cm)	Sample	Description
54-60	F9-6-3	Green-gray, sand to medium pumice lapilli and scattered lithics. Lithics to 2.5 cm.
10-54		Interbedded very fine to medium ash, dark green beds interlayered with olive glass. Vitric. Many lenticular layers of fine to medium lithic lapilli and glassy ash. Lapilli up to 2 cm. Sample comes from lower third of deposit.
0-10	F9-6-1	Equal mix of crystalline pumice and lithics.

F02-26 (Top down)

Cumul. thickness	Unit thickness (cm)	Sample	Field/BINOCULAR description
0-9	9	F02-26-26	Vitric pumice and coarse ash, dark gray-green. VITRIC PUMICE, MEDIUM ASH TO MEDIUM LAPILLI; GOOD GLASSY SKINS; VESICLES UNUSUALLY SMALL AND OF UNIFORM SIZE.
9-10	<1	F02-26-25	Thin layer of very fine pink ash at the top of unit #24. LITHIC, VITRIC, CRYSTALLINE ASH, POORLY SORTED; ABUNDANT PIECES OF FRESH VITRIC TEARS AND HAIRS; MOST GRAINS COATED WITH VERY, VERY FINE PINK ASH.
10-19	9	F02-26-24	Coarse ash to lapilli, very poorly sorted. Mostly lithic, but see some vitric pumice. FINE ASH TO FINE LAPILLI, LITHIC. BUT SEE SOME VITRIC PUMICE AND DENSE, GLASSY CLASTS. AGAIN, MANY CLASTS COATED WITH FINE RED-BROWN ASH.
19-22	3	F02-26-23	High-fountain pumice, lens with maximum thickness of 3 cm. Probably the unit with high MgO glass. VITRIC PUMICE; BIMODAL VESICLE SIZES; SOME GLASSY SKINS; NOT VERY FRESH LOOKING.
22-37	15	F02-26-22	Very fine tan vitric? ash, vesicular. An 18-cm rock forms a prominent sag in this unit. LEDGE-FORMING VERY FINE ASH TO FINE LAPILLI, VERY POORLY SORTED. MOST CLASTS APPEAR TO BE LITHIC, BUT ALL ARE COATED BY VERY, VERY FINE ASH. THE THIN SECTION WE HAVE OF THIS UNIT SHOWS IT TO CONTAIN LOTS OF VITRIC DEBRIS.
37-58	21	F02-26-21	Fine-coarse lithic ash and fine-coarse lithic lapilli (to 4 cm). FINE ASH TO MEDIUM LAPILLI, MOSTLY LITHIC, BUT COMMON VITRIC PUMICE.

This is a composite of several sections at the base of and part way up the Uwēkahuna Bluff.—Continued

F02-26 (Top down)

Cumul. thickness	Unit thickness (cm)	Sample	Field/BINOCULAR description
58-61	3	F02-26-20	Green vitric ash, Pele's tears, pumice lapilli. Many lapilli are iridescent. Lithics from the above unit penetrate through this unit. VITRIC PUMICE (WITH SKINS) AND COMMON LITHICS. ASH MATRIX LOOKS LIKE CRUSHED PUMICE.
61-64	3	F02-26-19	Very poorly sorted, coarse lithic ash to coarse lapilli; lithics and scoria-spatter? Clasts have red-orange surfaces. ASH TO LAPILLI, MOSTLY VITRIC PUMICE (COATED WITH VERY FINE RED ASH). MINOR LITHICS; MATRIX IS VITRIC.
64-71	7	F02-26-18	Fine to medium lapilli; scoria and vitric pumice. Some fine ash matrix. MEDIUM ASH TO MEDIUM LAPILLI; 98 PERCENT IS VITRIC PUMICE WITH SKINS. A FEW LITHICS.
71-82	11	F02-26-17	Coarse ash to medium lapilli, lithic. Poorly sorted. At the base of the bluff, we found cored bombs and pieces of gabbro, but we don't see these here. MEDIUM ASH TO MEDIUM LAPILLI, VITRIC PUMICE, 60 PERCENT; LITHICS, 40 PERCENT. PUMICE SKINS.

This marks the top of the conspicuous dark vitric ash interval. This interval is 41 cm thick.

Cumul. thickness	Unit thickness (cm)	Sample	Field/BINOCULAR description
82-92	10	F02-26-16	Laminated fine greenish-gray vitric ash; also see a lithic component. VERY FINE TO MEDIUM ASH, VITRIC. SCATTERED SMALL PUMICE FRAGMENTS.
92-100	8	F02-26-15	Medium to coarse vitric-lithic ash. Basal 2 cm is coarser. Top 2 cm has abundant lithics to 3 cm. MEDIUM TO COARSE VITRIC ASH; A FEW PUMICE CHUNKS; SCATTERED LITHIC ASH. THE FINER GRAINED VITRIC CLASTS ARE ONLY MODERATELY VESICULAR.
100-109	9	F02-26-14	More poorly sorted, fine, green-gray vitric ash with abundant coarse lithic ash and lithic lapilli. Many lithics are reddened. The top 2 cm in rich in vitric pumice (some in bag). SAME AS F02-26-15 ABOVE.
109-123	14	F02-26-13	Very fine, green-gray vitric ash; contains a <1 cm layer of medium ash. Thin bedded and laminated. VERY FINE TO MEDIUM VITRIC ASH; SCATTERED PUMICE LAPILLI; SEE NO LITHICS.

This marks the base of the conspicuous well-bedded dark vitric ash.

Cumul. thickness	Unit thickness (cm)	Sample	Field/BINOCULAR description
123-125	2	F02-26-12	Pumice lapilli, fresh, vitric. Stringers of pink ash run through the unit (probably lithic-crystalline ash). In places, this unit thickens to 5 cm and contains large lithics. Large cored bombs locally disrupt the unit. One softball-size cored bomb completely penetrated the unit and rests at the top of the underlying unit. We sampled this softball as a non-numbered sample. It is loose in the packing box. MEDIUM ASH TO SMALL PUMICE LAPILLI; VITRIC (SKINS); SCATTERED LITHIC LAPILLI.
		02-26-12A	Cored bomb fragments plus some pink ash.
125-129	4	F02-26-11	Black-skinned pumice lapilli in fine vitric ash. Probably a continuation of the unit below. FINE ASH TO MEDIUM PUMICE LAPILLI, VITRIC; LOTS OF SKIN, TEARS. SEE NO LITHICS.
129-133	4	F02-26-10	Black-skinned ash, tears, and pumice lapilli; fresh. COARSE ASH TO MEDIUM LAPILLI, VITRIC PUMICE. LOTS OF SKIN; SEE NO LITHICS.
133-146	5-13	F02-26-9	Fine ash to medium lapilli (lithic), poorly sorted, orange. Its' top surface has lithic lapilli that stick up into the overlying unit. Note: any black vitric material in this sample filtered down from above. FINE ASH TO MEDIUM LAPILLI, LITHIC. VERY FINE ASH COATS CLASTS.
146-166	20	F02-26-8	Fine ash to gravel, extremely poorly sorted. Lithics (to 5-6 cm) are distributed throughout the unit. The ashy matrix is lithic, with crystals and vitric ash(??) --High Ti-K glass = K-2 – MEDIUM ASH TO MEDIUM LAPILLI, LITHIC. RARE VITRIC PUMICE.

Here we first note that steeply dipping normal faults cut the section. One fault appears to cut all units in the hole and has a displacement of 12 cm, caldera side up! The other fault abruptly dies at the top of unit F02-26-12 , the base of the 41-cm dark vitric interval described above. This could be evidence that there is a hiatus in the section and that this fault formed before the overlying vitric interval was deposited.

Cumul. thickness	Unit thickness (cm)	Sample	Field/BINOCULAR description
166-167	1	F02-26-7	Black-skinned Pele's hair, tears, and pumice; fresh glass. This thin unit is pockety on the top of unit #6 below. -- High Ti-K glass = K-2 -- COARSE ASH TO MEDIUM LAPILLI; VITRIC PUMICE, FRESH SKINS, A FEW LARGE TEAR FRAGMENTS.
167-176	9	F02-26-6	Orange-brown, very poorly sorted vitric ash to coarse lapilli; altered. Note pieces of scoria and lithics in the sample—also one small cored bomb. The bottom and top of this unit are irregular ("unconformity bounded"). Note a near vertical fracture filling that might suggest this is an old deposit. -- High Ti-K glass= K-2 -- MEDIUM ASH TO MEDIUM LAPILLI; LITHIC/VITRIC RATIO = 70/30. FINE VITRIC ASH COATS PUMICES.
		F02-26-6A	Fairly dense pumice lapilli from upper part of unit.

SECTION III. Locality name: S0-7, informally known as "South Flank."

Location: Pit dug just north of fire road on Ainahou Ranch. Depth in centimeters below ground surface.

Interval (cm)	Unit	Sample	Field/BINOCULAR description
0-20	?		Very poorly sorted, fine ash to medium pumice lapilli. Contains roots at top. Beautiful glassy pumice. Common medium lithic lapilli. No bedding; looks reworked.
20-23	Keanakāko'i?	S0-7-1	Contains abundant charcoal. Dominantly coarse ash to medium glassy-type pumice lapilli with some lithic lapilli of medium size. CHARCOAL PICKED**.** Could be layer 6. MIX OF GLASSY AND CRYSTALLINE PUMICE (DOMINANT) WITH SOME RETICULITE; COMMON LITHICS IN FINE LAPILLI RANGE. STILL LOTS OF CHARCOAL AFTER PICKING. **630 B.P. (A.D. 1292-1401)**
23-26	Keanakāko'i?	S0-7-2	Dark gray, poorly sorted, fine ash to medium lapilli. Organic rich. Charcoal present. CHARCOAL PICKED**.** Might be reworked Kulanaokuaiki but just above unreworked Kulanaokuaiki. CONFIRMED; ABUNDANT CHARCOAL REMAINS AFTER PICKING. **510 B.P. (A.D. 1319-1352)**
26-28	Kulanaokuaiki	S0-7-3	Brown, dominantly coarse ash and fine lapilli. This layer demarks a color change in the pit, with brown below. CHARCOAL PICKED. COMMON PELE'S HAIR AND BLACK GLASS FRAGMENTS.
28-32	Kulanaokuaiki	S0-7-4	Dark gray, very poorly sorted, organic-rich, fine ash to large pumice lapilli. On eastern side of pit, the layer thins and may actually pinch out. CHARCOAL PICKED, BUT NOT SUBMITTED. ABUNDANT PELE'S TEARS/HAIR AND RETICULITE FRAGMENTS.
32-34	Kulanaokuaiki	S0-7-5	Brown, fine-medium, crystalline-type pumice and lithics. Looks very much like Kulanaokuaiki 3. Has big chunks of reticulite too. Not much matrix. CONFIRMED. CHARCOAL PICKED BUT NOT SUBMITTED.
34-36	Kulanaokuaiki	S0-7-6	Very poorly sorted, fine ash to medium glassy pumice lapilli. Organic rich and charcoal bearing. Possibly the High Ti-K layer. CHARCOAL PICKED. NO OBVIOUS VITRIC MATERIAL OTHER THAN PUMICE **1290 b.p. (A.D. 656-783)** ----------High Ti-K glass = K-2 ----------
36-39	Kulanaokuaiki	S0-7-7 S0-7-7C	Poorly sorted, fine ash to medium, commonly glassy, lapilli. Really gradational upward to the next layer. Gray to gray-brown color. Kulanaokuaiki 1? CHARCOAL PICKED. COMMON LITHICS. A FEW BLACK GLASS FRAGMENTS. **1310 B.P. (A.D. 642-782)** ----------High Ti-K glass = K-2 ----------
39-54	?	S0-7-8	Pretty well sorted, very fine ash, with occasional lapilli scattered throughout. Brown at top and bottom and red in middle. No bedding seen. A few glassy pumice lapilli to 1.5 cm diameter. CONFIRMED.
54-56		S0-7-9	Fine ash with abundant lithic lapilli, commonly to 2 cm. Rests directly on flow surface, which dips southeast. CONFIRMED.

Section IV. Locality name: F0-1 and F01-2, also informally as "Jack's pit."

This pit is in the southwest corner of the Ola`a tract and was originally opened by Jack Lockwood and others. It is 2 meters inside the fence along Wright Road. It has also been studied by soil scientists.

Interval (cm)	Unit	Sample	Field/BINOCULAR description
0-10	Ku	F0-1-0.5	Fine brown ash with abundant rootlets; high Ti, K glass = K-2.
10-12	Ku	F0-1-1	Pumice with glassy skin in muddy matrix. BLACK SKIN PUMICE AND TEARS.
12-30	Ku	F0-1-1.5	Green-brown, moderately well sorted fine ash, vesicular. In places see coarse lithic ash grains.
30-32	Ku	F0-1-2	Dark gray, moderately sorted, medium-grained vitric ash. Gradational to unit above. Base of unit highly undulatory. DARK GRAY VITRIC ASH, MEDIUM GRAINED.
32-45	Ku	F0-1-3	Thickness variable. Gray, poorly sorted fine ash to medium pumice lapilli. Coarsely vesicular and hardened. Some pumice approaches reticulite. All pumice seems to be glassy, highly vesicular, high-fountain type. PUMICE IS HIGHLY VESICULAR, GLASSY. APPROACHES RETICULITE. MATRIX CONTAINS ABUNDANT GLASSY FRAGMENTS.
45-48	Ku	F0-1-3.5	Buff-tan ash, reddened at top. Extremely fine—almost like modeling clay. LOTS OF BLACK GLASS AND RETICULITE.
At 48	Ku	F0-1-4	Isolated clasts of reticulite along this level. Note that there is an obvious color change here; tephra is brownish above and reddened below. This may be the vestiges of the basal Keanakakoi reticulite. Also noteworthy is that bedding below this level is very uniform. GOOD RETICULITE.
48-53	Ku	F0-1-4.5	Very fine, brown ash. The upper part locally appears dark (near black) and might be organic-rich. LOTS OF BLACK GLASS AND RETICULITE.
53-56	Ku	F0-1-5	Poorly sorted, very fine to coarse ash. Probably altered glass with free olivine crystals. Contains conspicuous cream-white clasts, which might be altered pumices. LOTS OF FREE OLIVINE CRYSTALS; FEW PELE'S HAIRS AND TEARS. THE LIGHT-COLORED CLASTS ARE PROBABLY ALTERED PUMICES.
56-64	Ku	F0-1-6	Brown, poorly sorted, very fine ash to medium lapilli. Pumice is mix of crystalline and glassy types. A few lapilli are lithics. LOTS OF PELE'S HAIR AND BLACK GLASSY FRAGMENTS; PUMICE RANGES TO >2 CM AND IS CRYSTALLINE; SEE FEW >1 CM LITHICS.
64-67	Ku	F0-1-7 F0-1-7c	Dark gray-black, possibly organic rich, very fine ash. VITRIC/CRYSTAL ASH BOUND TOGETHER WITH BROWN ORGANIC MATERIAL. LOTS OF PELE'S TEARS. THIS MAY BE THE HIGH Ti-K UNIT?? WILL TRY TO PICK OUT ORGANIC MATERIAL LATER (F0-1-7c). **1470 B.P. (A.D. ~ 530)**

This pit is in the southwest corner of the Ola`a tract and was originally opened by Jack Lockwood and others. It is 2 meters inside the fence along Wright Road. It has also been studied by soil scientists. ─Continued

Interval (cm)	Unit	Sample	Field/BINOCULAR description
67-87	Ku	F0-1-8C	Very poorly sorted fine ash with occasional pumice lapilli; stringers of dark carbon-bearing material, look like plant fragments and leaves. Sample F0-1-8C taken from lens in middle of unit. One of these dark stringers extends laterally to limb cast "hole." This hole is about 10 cm in diameter, and we easily stick the measuring tape 70 cm horizontally into it! VERY FINE, DARK-BROWN ORGANIC SOIL WITH COARSE LITHIC ASH.
87-94	Ku	F0-1-9	Greenish-gray, medium-coarse pumice lapilli. Lapilli surfaces are reddened. Occasional lithic lapilli to 3 cm. Probably a mix of crystalline and glassy pumice. SEE RARE GLASSY PUMICE AND RARE LITHIC LAPILLI. THE CRYSTALLINE PUMICE, WHICH IS BY FAR DOMINANT, DOES NOT APPEAR TO CONTAIN OLIVINE PHENOCRYSTS.
94-96	Ku/Uwe?	F01-2-1	Fine ash, red. HIGHLY ALTERED VITRIC ASH WITH ABUNDANT FRESH BLACK GLASS SHARDS.
96-102	Ku/Uwe?	F01-2-2	Fine ash, brown, with some coarse ash. THE COARSE ASH IS MOSTLY LITHIC; FEW LITHIC LAPILLI TO 1.5 CM. RARE BLACK GLASS FRAGMENTS.
102-104	Ku/Uwe?	F01-2-3	Vitric, orange. HIGHLY ALTERED VITRIC ASH; RARE BLACK GLASS FRAGMENTS AND A FEW ALTERED MEDIUM PUMICE LAPILLI.
104-105	Ku/Uwe?	F01-2-4	Ash, fine, dark brown. Rests directly on lava toe, possibly organic-rich. Not recognized last year, hence the added 1-cm thickness. GRAY, FINE ASH WITH ABUNDANT BLACK GLASS SHARDS. FEW ORANGE PUMICE LAPILLI; SOME CHARCOAL. (Note: We collected additional material from this site and will combine the charcoal recovered with that already separated from this unit.)
At 105			Top of lava flow toe. C-14 by J. P. McGeehin yielded **2770 +/- B.P.** (W5345).
>105		F1-1-10C	Just below toe: dig out pocket of dark ash rich in plant fragments(?). There is more tephra below the lava which was considered to be "Pāhala Ash" (age 23 ka b.p) by previous workers. GOOD CHARCOAL. **2090 B.P. (202-16 B.C.)**

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