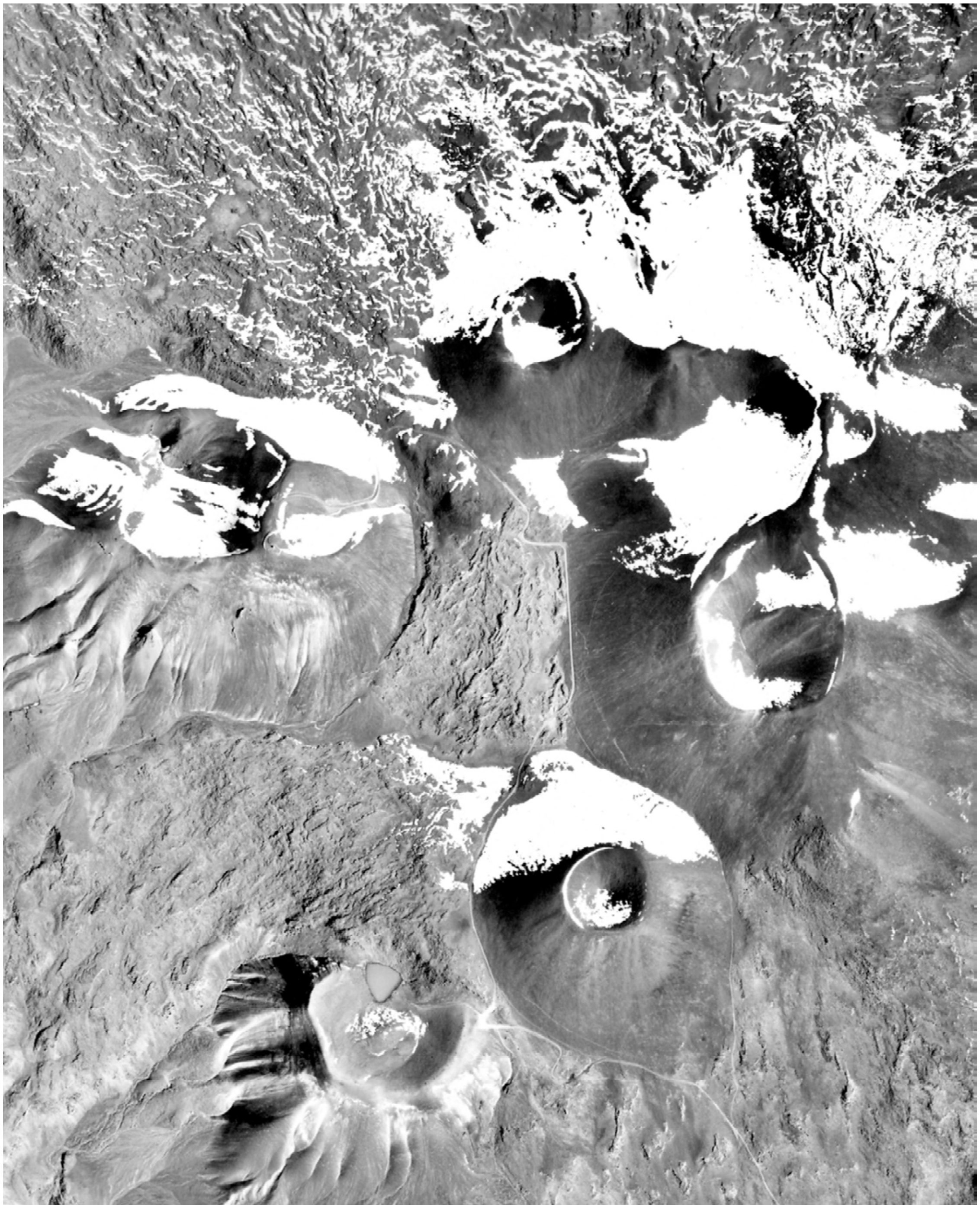

Possible Geologic Factors Influencing Wēkiu Bug (*Nysius wekiuicola*) Distribution on Mauna Kea, Hawai‘i Island

Hawaii Biological Survey

Final Report **June 2006**

POSSIBLE GEOLOGIC FACTORS INFLUENCING THE DISTRIBUTION OF THE WĒKIU BUG ON MAUNA KEA, HAWAII

FINAL REPORT

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EXECUTIVE SUMMARY

The wēkiu bug is a rare species occurring only at the summit of Mauna Kea, Hawaii with only 128 individuals collected in wide-ranging studies by the Hawaii Biological Survey since 2002. Although considerable efforts have been undertaken to learn more about the distribution and ecology of this insect, until now the habitat preferences have not been examined in a geological context. Involving a collaboration between entomologists and geologists, this report marks the first geological assessment of wēkiu bug habitat use, with the seemingly consistent pattern of finding these bugs in the uppermost areas of cinder cones throughout the Mauna Kea summit region. Of particular interest is the finding that wēkiu bugs are currently only inhabiting areas of the summit that lie within the limit of the glacial ice cap that reached its maximum size about 20,000 years ago, and disappeared by about 16,500 years ago. At the glacial maximum, the ice cap was a broad carapace of ice, about 10 km (6.2 mi) in diameter, averaged about 75 m (245 ft) thick, and covered an area of about 70 km^2 (27 mi^2). The highest cinder cones inside the ice limit rose above the glacier, forming nunataks (ice-free areas rising above a surrounding glacier) in the summit region.

The distribution of wēkiu bugs is related to topography: wēkiu bugs have been found predominantly on or near the crater rims of cinder cones that formed nunataks during the last glaciation or that lay at the glacier limit. The increasing altitude of such sites parallels the rise of the glacial-age snowline across the upper slopes of the mountain. The preferred habitat of the bugs is on cinders and spatter near the unmodified crests of cinder cones; the crests of glacially overridden cones apparently lack suitable habitation sites. More significantly, bug habitats are concentrated on these cones in areas where seasonal snow remains longest, i.e., on north- and east-facing slopes and on slopes shaded by local topography. Such snow patches increase in number and area with increasing altitude above the limit of glaciation. Below the glacial limit, seasonal snow quickly disappears and wēkiu bugs have not been found. The moist margins of snow patches are places where eolian detritus is concentrated during ablation, thereby providing rich source of food for wēkiu bugs.

INTRODUCTION

Isolated atop Hawaii's highest volcano, the occurrence of the rare and small wēkiu bug raises questions regarding the possible role of geologic factors in its distribution. Mauna Kea is a dormant volcano, and the only peak in the islands with unequivocal evidence of recent glaciation. Could the geology and glacial history of the summit region, where the bug survives, provide clues regarding its habitat preferences and possible persistence in a few biologically limited enclaves? Based on geologic evidence, several hypotheses can be assessed.

GEOLOGY OF MAUNA KEA

Mauna Kea at 13,796 ft (4206 m) is the highest of the five emergent volcanoes that comprise the island of Hawaii (Figure 1). Its exposed lavas record the final phases of shield construction, as well as post-shield eruptions (Wolfe *et al.* 1997). The former are predominantly basalt, whereas the latter consist mainly of hawaiite and mugearite. Associated within both volcanic assemblages are pyroclastic deposits in the form of cinder cones (puʻu in Hawaiian) and related volcanic cinder and ash layers spread downwind from each pyroclastic vent. Cinder cones on the upper slopes of the mountain are all associated with hawaiite eruptions and include those produced by the youngest eruptions of the volcano about 5000 years ago. More than 50 prominent cinder cones are present above the 10,000-ft level on the mountain, all but several having been built during the last ca. 50,000 years.

Glaciation of Mauna Kea

The summit of Mauna Kea does not reach the modern snowline (the lowest limit of perennial snow) and therefore does not support a glacier. However, during the Pleistocene glacial ages, the snowline descended below 12,500 ft (3800 m) altitude, giving rise to a succession of ice caps that covered the upper slopes of the mountain (Porter 1979, 2005). The last ice cap apparently reached its maximum size about 20,000 years ago and disappeared by about 16,500 years ago. At the glacial maximum, the ice cap was a broad carapace of ice, about 10 km (6.2 mi) in diameter and averaging about 75 m (245 ft) thick, that covered an area of about 70 km^2 (27 mi^2) (Figure 2). The highest cinder cones inside the ice limit rose above the glacier, forming nunataks (ice-free areas rising above a surrounding glacier) in the summit region. These were clustered in several groups that trend west, northeast, and southeast from the volcano's crest. The ice cap had a digitate margin along some sectors, the result of ice flowing around and between these cinder cones. In other sectors the ice limit had a more-linear trend and lay at a more uniform altitude.

The oldest cinder cones on the upper slopes of Mauna Kea belong to the Laupahoehoe volcanics and are estimated to be about 60,000 years old. Wekiu bug habitats somewhat similar to present ones may therefore have existed on the mountain since at least 60,000 year ago and may have increased in number as successive cones were constructed between 60,000 and 20,000 years ago. None of the cones have been dated independently by the K/Ar method; their ages are inferred from dates of related lava flows or from their relative position in the overall volcanic stratigraphy. The crests of cones may not have been favorable habitat sites during glacial times, because they lay above the snowline. Cinder-cone nunataks therefore may have been covered by perennial snow, leading favorable wēkiu habitats to shift downslope to cones that lay near or below the snowline. As the snowline rose and the cones near the summit were deglaciated at the end of the last glaciation, bugs may have migrated upslope to cones that were now ice-free. In this event, bug occupancy of the summit cones may have occurred primarily during interglaciations (e.g., like the present). The use of molecular clocks, or fossil remains in the sediment of Lake Waiau, may permit an estimate of the time span since wēkiu bugs colonized these habitats. Thus, it may be possible to gain information about the chronology of eruptions on Mauna Kea by examining wēkiu bug colonization history.

<u>Glacial Modification Of Cinder Cones</u>

Cinder cones lying beyond the effects of glacial erosion and deposition have average slope angles of 22-24° (the natural angle of repose of cinders) (n=16) and their summit craters generally are distinct, with their walls also at the angle of repose. By contrast, the slopes of cinder cones that have been modified by encroaching glacier ice have average slope angles of 26-28°, but reach angles of 30-32° (n = 13); the crater rims of overridden cones are smoothed and the craters are shallow, having been partly or largely filled by glacial deposits.

<u>Glacial Limit</u>

The limit of the ice cap in the terminal zone is marked by one of several end moraines and by the upper limit of erratic stones on cinder cones (Figure 3). Whereas the cones are composed of reddish to black cinders and bombs, glacial erratic boulders are composed mainly of light-gray hawaiite. The approximate upper limit of the last ice cap in the zone below the glacial-age snowline is therefore marked by a relatively abrupt downslope transition from cinders to scattered erratic boulders. Former ice limits and glacier thickness can thus be inferred using moraines, erratic limits, and glacially modified overridden cinder cones (Porter 2005).

GLACIALLY MODIFIED CINDER CONES NEAR THE SUMMIT (Figure 4)

<u>Puʻu Wēkiu, Puʻu Hau Oki, and Puʻu Kea</u> (13,796 ft, ca. 13,650 ft, and ca. 13600 ft; 4208 m, ca. 4163 m, and ca. 4148 m) form a cluster of overlapping cinder cones at the summit of the mountain. The road to the telescopes

atop Pu‘u Wēkiu exposes varicolored cinders suggestive of alteration by hydrothermal waters; possibly the cone was erupted subglacially. The steep slope on this side of the pu‘u further suggests glacial erosion. The summit rises some 200 ft (61 m) above the floor of the crater, at the bottom of which permafrost was encountered in an excavation dug in the early 1970s. North of the crater, the original topography has been extensively modified and lowered during construction of the telescopes, which is also the case on Pu‘u Hau Oki and Pu‘u Kea. At least 30 ft (10 m) of the summit of Pu‘u Hau Oki was shaved off during construction of the Keck and Subaru facilities, and the crater bottom received approximately 40 ft (12 m) of fill. Few if any original surfaces remain at the crests of these cones. It seems likely that the tops of all three of these cones formed a major nunatak at the very crest of the former ice cap. The highest part of the ice cap probably lay in the closed depression between Pu‘u Hau Oki and Pu‘u Kea. Perennial ice likely filled the crater of Pu‘u Wēkiu.

Wēkiu bugs have been found throughout Pu‘u Wēkiu/Hau Oki/Kea cinder cone complex at 13,722–13,765 ft (4185–4198 m) and Pu‘u Hau Oki at 13,570–13,594 ft (4157–4179 m) (Englund *et al.* 2005, 2006) at sites that would have been near or above the inferred upper limit of the ice cap and in places where residual snow cover lingers longest during the year. Prior to the development of the Keck and Subaru facilities, this cinder cone complex had the highest wēkiu bug densities ever recorded, with nearly 12,000 captured in 1982 (Howarth and Stone 1982). Core areas with highest populations in 1982 were the upper portion of the steeply sloping cinder cone areas of Pu‘u’s Wēkiu, Hau Oki and Kea (Howarth and Stone 1982). At certain times of year such as in the spring time, relatively large numbers of wēkiu bugs can still be found around the Pu‘u Hau Oki crater area, with much smaller numbers found in Pu‘u Wēkiu (Pacific Analytics 2005).

<u>Pu‘u Hau Kea</u> (13,441 ft; 4097 m) is a symmetrical cinder cone at the crest of the volcano. No evidence was found indicating that the glacier overtopped the cone. Erratics were not seen on its slopes and its crater lacks a fill of glacially derived debris. The crest was probably a nunatak during the last glaciation, although the crater likely was filled with immobile snow and ice at that time. The western and southwestern slopes of the cone reach angles of 30°, implying glacial erosion along the outside flanks below the crest. Ice may nearly have reached the rim on the N and E sides, but was several tens of meters lower on the SW and W sides. Gelifluction lobes are found on the lower slopes above the base of the cone and stand at or below the angle of repose (ca. 24°).

This cinder cone has an important and relatively large wēkiu bug population. For example, 473 individuals were collected at the summit area in only 4 days of trapping in June 2001 (Englund *et al.* 2002) at sites on and near the crater rim, as well as in the crater, between altitudes of 13,370 and 13,540 ft (4075–4127 m). In contrast to Puʻu Poliahu or the Wēkiu/Hau Oki/Kea complex, Hau Kea is one of the few large high-elevation nunataks to have never had a road or telescope development at its summit.

Puʻu Poliahu (13631 ft.; 4157 m) lies directly west of Puʻu Wēkiu, and like Puʻu Waiau, it contains bedded hyaloclastite deposits with large bombs. Its W, S, and E slopes reach angles of 30-32°, indicating glacial erosion. Its crater is open to the NW and a large alluvial fan spreads N and W from it on the lower slopes. Being close to the summit of the mountain, it lay in the accumulation zone of the glacier and flowed NW and SW around it. The crest of the cone was well above the snowline, so although the cone was surrounded by ice, the summit and adjacent NW and W slopes probably formed a nunatak. The crater likely had ice in it, which may have flowed out to the NW.

Whereas eight wēkiu bugs were collected from the NE slope of Puʻu Poliahu in 1982, they were not found here again until 2005, once more on the same NE slope of the cone at altitudes of 13,538–13,613 ft (4129–4152 m). In 2005, wēkiu bugs were much more common and were abundant along the edge of melting snowbank (Englund *et al.* 2006).

Puʻu Waiau (ca. 13,190 ft; 4020 m) lies immediately southwest of Puʻu Hau Kea and is unique in having a small lake, Lake Waiau (13,020 ft; 3969 m), in its shallow crater. The cone is eroded on its downslope flanks (south and southwest), and is partly overlain on its north by a subglacially erupted hawaiite flow. Its construction may date to the penultimate (Waiau) glaciation. On the western and southwestern slopes gully and slope erosion have exposed a bomb–bearing deposit of light-brownish hyaloclastite, a mineral that implies subaqueous eruption. Hawaiite boulders, possibly derived from a flow within the shallow crater, are clustered ca. 5-10 m below the highest sector of the rim. This small sector may have stood above the glacier; however, the crest of the cone lies ca. 250 ft (76 m) below the crest of Puʻu Hau Kea, and therefore is not likely to have been a large nunatak at the glacial maximum. The upper limit of ice was about 13,150 ft (4010 m).

Wēkiu bugs have not yet been collected around Puʻu Waiau, either at sites on the cone rim or the top of the adjacent ice-contact lava flow (altitudes of 13,181–13,248 ft; 4020–4040 m), or in the vicinity of Lake Waiau.

Pu'u Ko'oko'olau (ca. 12,500 ft; 3810 m) lies just upslope from several prehistoric adz quarries and directly above a large pit crater at ca. 12,200 ft (3720 m) on the south side of the mountain. The crater rim rises only about 50-60 feet above the lavas that underlie it. There appears to be glacial sediment on the northern side of the crater, on the crater floor, and possibly in the pit crater. At this location, the ice cap likely was at least 40-50 m (110-140 ft) thick, so the cone probably was entirely overridden by the glacier. Nevertheless, the NW and E sectors of the crater rim are relatively sharp-crested, so possibly these formed small nunataks (at least during deglaciation). The pu'u has not yet been visited for sampling.

Pu'u Pohaku (13,186 ft; 4019 m) lies 1.5 mi (2.5 km) NWW of the cluster of cones at the summit, is ca. 0.3 mi (500 m) in basal diameter, and rises about 200 ft (60 m) above its base. The crater is very shallow and filled by cone-derived rubble consisting of cinders and bombs. No erratics are present, probably because the cone lies upslope from the glacial-age snowline. The crater is seasonally occupied by a shallow (2 m)-deep lake that forms either above shallow permafrost or relatively impermeable sediment at shallow depth. Powdery dark-yellowish-brown silt that may either be eolian or the weathered matrix of sediment comprising the cone may reduce permeability in the shallow crater. Slopes on the west, south, and east sides reach angles of 30-32°, pointing to glacial erosion. The cone likely was overridden by ice on its north and east sides where the crater rim is lowest. A small sector of the highest part of the crest of Pu'u Pohaku may have stood above the ice surface.

A relatively small population of wēkiu bugs has been found here, and were collected at an altitude of 12,883 ft (3911 m) near the cinder cone base on the northeastern slope. Two individuals (one in 2004 and one in 2005) were collected in the identical trap, which is in the lower cone flank, but away from light-gray hawaiite substrate (Englund *et al.* 2006).

CINDER CONES OF THE NE RIFT ZONE (Figure 5)

Pu'u Māhoe (13,154 ft; 4012 m) is a pair of adjacent cones, the highest point of which lies 1.2 mi (1.9 km) NNE of the summit Pu'u Wēkiu. It is one of a series of cones that collectively define the northeast rift zone of Mauna Kea. The northeastward-sloping surface of the ice cap suggests that the summits of both cones likely stood above the glacier and comprised a single elongate nunatak or two smaller ones aligned in a NE direction. In 2002, one wēkiu bug was collected at 13,154 ft (4012 m) at the west base of the southwestward-most cone (Englund *et al.* 2002).

Pu‘u Poepoe (12,679 ft; 3867 m) lies about a mile (1600 m) east of Pu‘u Māhoe. The cone is rather symmetrical, with a relatively shallow crater. The glacier, flowing from the west, diverged around the cone to form a nunatak. Despite the long distance between Pu‘u Poepoe and the summit cone complex, this cinder cone has the distinction of having the largest wēkiu bug population of the outer cones. In 2002, 33 wēkiu bugs were recovered at 12,500 to 12,580 ft (3812–3837 m) on the upper, nonglaciated flank of the cone. All wēkiu bug captures on this cone were in a narrow zone around the uppermost crater rim area, with as many as 9 collected in a single trap (Englund *et al.* 2002)

Pu‘u Ala (12,610 ft; 3846 m), a large cone north of Pu‘u Poepoe, has a well-defined crater that shows no evidence of glacier overriding. In fact, a clear erratic limit along the southern side of the cone defines a NE-sloping ice limit some 200 ft (60 m) below the summit crater. The cone probably was close to the glacier margin; it may have been a nunatak, bordered on its NE side by thin ice that separated it from Pu‘u Hoaka. More likely, it merely produced a deep embayment in the glacier margin, with tongues of ice on either side. The crest and upper slopes of the cone clearly rose above the glacier surface. On Pu‘u Ala wēkiu bugs have been collected at three sites at or near the summit, two near the crest (between 12,350–12,390 ft; 3765–3779 m), and the other directly south of it on the southern middle slope of the cone (12,270 ft; 3742 m).

Pu‘u Makanaka (12,414; 3786 m), one of Mauna Kea’s largest cinder cones, lies at the glacial limit on the southern side of the NE rift zone. The ice cap flowed along the western base of the cone, leaving a distinctive grayish hawaiite-rich deposit. The crater is ca. 300 ft deep and unmodified, except by mass wasting. The one wēkiu bug capture at Pu‘u Makanaka was at 11,920 ft (3636 m), above the base of the cinder cone on the western flanks and close to the glacial limit. The finding of this individual bug in 2002 on the lower flank of the large cinder cone is most unusual but may be related to its being in the vicinity of the glacial limit.

Red Hill (11,863 ft; 3618 m) lies downslope (NE) from Pu‘u Makanaka, well beyond the limit of the former ice cap. This large cone was intensively sampled in both 2004 and 2005, and even though wēkiu bugs were common in other areas at the same time trapping was being conducted here, no bugs were found in a transect of up the northern slope and into crater rim, between 11,220 and 11,954 ft (3420 and 3645 m).

Pu‘u Hoaka (12,076; 3683 m), which lies a mile (1.6 km) NW of Pu‘u Makanaka, also lay at the margin of the ice cap. Ice encroached on the lower western and southern slopes of the cone, which produced an embayment in the glacier margin. Wēkiu bugs have not yet been captured at Pu‘u Hoaka: The eastern slope and summit area was sampled for the first time in 2005. Sites between 11,502–12,127 ft (3508–3699 m) produced no bug captures, although the area around the glacier margin on the western edge of the cone has not been examined for wēkiu bugs.

Pu‘u 11,989 (3657 m), a mile WNW of Pu‘u Hoaka, also lay at the glacial limit, with ice flowing around the lower southwestern and southern slopes. This cone has not been sampled by entomologists.

CINDER CONES SOUTH OF THE SUMMIT CLUSTER (Figure 6)

Pu‘u Lilinoe (12,987 ft; 3961 m) is the highest of a series of cones that trend southward from the summit cluster toward the Mauna Loa-Mauna Kea saddle. This cone formed a small nunatak during the glacial maximum. Its glacially eroded flanks reach angles of 28-32° and erratic boulders are concentrated along its lower slopes. The summit crater appears unmodified, so the glacier apparently surrounded but did not overtop it. Sampled for the first time in 2005, Pu‘u Lilinoe was found to support a robust wēkiu bug population. A total of 6 wēkiu bugs were collected between 12,498 and 12,798 ft (3012 and 3903 m) during a brief three-day sample period.

Pu‘u S of Lilinoe (12,600 ft). This small cone has an apparent upper limit of erratics along its eastern flank suggesting its top likely formed a small nunatak. Although the flanks and the summit of this pu‘u were sampled in May 2005, the area of the small nunatak at the summit was not extensively sampled. No wēkiu bugs were collected on its summit.

Pu‘u 12,411 (3785 m) lies at the glacial limit. Its top and SE side near the crest likely were ice-free. If true, the cone produced a major reentrant in the margin of the ice cap, due in large part to the funneling of ice along its western and eastern flanks by ice flowing along lower ground on either side of the cones upslope. This cinder cone lies on the south side of the road at the VLBA radio telescope facility. In May 2005 traps on the northern slopes of this cone produced no wēkiu bugs.

Pu'u 12,090 is immediately west of the summit road at the ca. 11,900 ft level. This cinder cone is easily visible from the road and adjacent to a large John Burns Highway road marker, on the western side of the summit road. Its slopes have been smoothed by glacier ice, and its crater is filled with glacial deposits. Light-colored erratic boulders are scattered across its eastern and northern slopes. The southernmost part of its crater rim and the adjacent southern slope may have remained ice free, forming an embayment in the ice-cap margin. This area was sampled in 2002 (called Pu'u 1W in Englund *et al.* 2002), though efforts were not made to sample inferred ice-free areas on the southernmost part of its crater rim at that time. In 2002, no wēkiu bugs were found on the northwestern rim of the crater or at several sites NW and S of the main cone.

CINDER CONES EAST OF PU'U 12,411 (Figure 6)

Pu'u 11, 910 has erratics on its N and W slopes, on the crater rim, and in the crater, which is largely filled with glacial sediments. However, no erratics were seen on the eastern sector of the rim and adjacent eastern slope, which may have been a small nunatak downglacier from the crest of the cone. A site visit here in 2005 estimated the amount of ice-free portion of the cinder cone to be less than 1 ac (0.4 ha). The ice cap was thin in this area, likely only several meters thick as it was at the margin of the ice cap. This cinder cone is particularly significant because the lowest wēkiu bug capture on record came from here in 2002 (Englund *et al.* 2002), with a single wēkiu bug obtained from a trap on the lower NE side of this cone at 11,715 ft (3573 m). The population here is likely small due to marginal habitat, and no wēkiu bugs were collected here during extensive trapping in 2005, despite their being common in other areas of the summit (Englund *et al.* 2006).

Pu'u 11,625 (3546 m) has a crater that opens to the southeast, and is close by Pu'u 11,910 (see above). The ice cap, flowing from upslope (NE), surrounded the cone on the northern and western slides, and it flowed over the crater rim onto its floor. In 2005 no wēkiu bugs were found at sites ranging between 11,640 and 11,710 ft (3550 and 3572 m) in a transect from the northern rim of the crater to the base of the western slope, respectively.

CINDER CONES SOUTH OF THE GLACIAL LIMIT (Figure 7)

Pu'u Keonehehe'e, a small cone immediately to its northwest, and Pu'u 11,606 ft (3540 m) to its east all lay beyond the ice-cap limit. The former has been mapped as a Holocene cone and therefore would not have been present when the last ice cap existed. This area was extensively trapped in 2002 and no wēkiu bugs were found at any of these cones, though an undescribed endemic Lycosid spider was abundant throughout the cinder cones in this region.

CINDER CONES OF THE NW RIFT ZONE (Figure 8)

"Horseshoe Crater" (ca. 12,800 ft; 3904 m) is a large cinder cone at the western glacial limit. The highest (upslope) part of its crest was overridden by the glacier and is mantled with glacial deposits. Its southern and northeastern crests are sharp and apparently unmodified. Ice flowed into the crater, which is open to the northwest, and left glacial deposits on the crater floor and the crater's breached NW margin. In 2005, no wēkiu bugs were obtained at sample sites between 12,710 and 12,848 ft (3877 and 3919 m) on the glacially overridden crest, though nonglaciated areas on the southern and northeastern crests have not yet been sampled. A large snowpack laden with dead insects was sampled for over a month in the spring of 2005 but this seemingly ideal habitat produced no wēkiu bugs.

Lower Cones W and SW of Horseshoe Crater are clustered along the upper Northwest Rift Zone. A small cone at ca. 12,260 (3739 m), immediately southwest of "Horseshoe Crater," was overridden by ice, which terminated at or somewhat beyond its western crest. Puʻu 11,672 (3560 m) lies immediately west of it, and its southwestern base is less than 300 ft beyond the glacial limit. This area was sampled in 2005, and no wēkiu bugs were obtained at two sites (11,355 and 11,753 ft.; 3463 and 3585 m) on its southeastern slope and crest.

RELATIONSHIP OF GEOLOGIC AND CLIMATIC FACTORS TO DISTRIBUTION OF WĒKIU BUGS

Relation to bedrock geology and topography

Wēkiu bugs have been found almost entirely on the upper slopes and crater rims of cinder cones at or above the limit of glaciation. They have not been found on inter-cone expanses of ice-scoured bedrock or on glacial deposits. Their preferred substrate therefore appears to be nonglaciated cinders and lava spatter. Only a few have been found on glacial deposits on lower slopes of cones, but areas lacking glacial erratics.

Relationship to glacial geology

Wēkiu bugs have been found almost exclusively on cinder cones that formed nunataks during the last glaciation or on cones that lay at the glacial limit and either were surrounded by ice on several sides or were partly overridden by ice. In only two cases were they encountered on cones thought to have been completely overridden by the glacier, on Puʻu Pohaku and Puʻu 11,910 (beyond the VLBA), although a small nunatak may have occurred at the latter cone (see Cinder Cones East of Puʻu 12,411 section).

Relationship to altitude

Sites where bugs have been found range in altitude from 11,715 to 13,765 ft (3573–4198 m). The occurrences lie at progressively higher altitudes upslope from the glacial limit (i.e., the trend surface of occurrences rises toward the summit, at least on the NE and S sectors of the mountain where collection sites and cinder cones are concentrated). Therefore, the altitudinal distribution of the bugs appears to be a function of the summit altitude of cones that were nunataks during glaciation. Altitude alone is likely not a primary factor in bug distribution.

Relationship to late-lying snow

Except for sites at or close to crater rims, wēkiu bugs have been found mainly on north- and east-facing slopes of the highest cones (75%). These are sites where seasonal snow persists longest on the upper slopes of the mountain, consistent with the low angle of incident solar radiation during the late winter and early spring and with topographic shading. A snapshot of the recent distribution of late-lying snow fields was obtained from vertical aerial photographs taken on March 7, 1965 (Figures 9 and 10). The residual snow on that date was restricted to cones reaching altitudes of 12,500 ft (3812 m) or higher. The largest snowfields lie on the summit cluster of cones, which are also the highest cones on the mountain (exceeding 13,000 ft; 3965 m).

SUMMARY AND CONCLUSIONS

In summary, the altitudinal distribution of wēkiu bugs is related to glacial geology: the bugs have been found predominantly on or near the crater rims of cinder cones that formed nunataks during the last glaciation, or which lay at the glacial limit. The rise in altitude of such sites toward the top of the volcano parallels the rise of the glacial-age snowline across the upper slopes of the mountain. The preferred habitat of the bugs is on cinders and spatter near the unmodified crests of cinder cones; the crests of glacially overridden cones apparently lack such habitat. More significantly, bug habitats are concentrated on these cones in areas where seasonal snow remains longest, i.e., on north- and east-facing slopes, and on slopes shaded by local topography. Such snow patches increase in number and area with increasing altitude above the limit of glaciation. Below the glacial limit, seasonal snow quickly disappears and wēkiu bugs have not been found. The moist margins of snow patches are places where eolian detritus is concentrated during ablation, thereby providing a rich source of food for the bugs

Impact of Telescopes on Wēkiu Bug Habitats

Construction of large telescopes near the summit of Mauna Kea has modified or also eliminated some of the preferred substrate habitats of the wēkiu bugs. In most cases, site preparation has led to bulldozing of cone summits to create a level surface; thus the rims have been removed or flattened and some craters have been filled. An example is the summit of Pu‘u Hau Oki, where during the construction of the Keck Observatory the top 10 meters of the cinder cone summit was removed and the crater floor was filled with approximately 12 meters of pyroclastic debris. If late-lying snow patches are a primary factor in bug distribution, then one would anticipate finding bugs near, if not on, the unmodified snowy slopes of cinder cones where telescopes have been sited. Indeed, wēkiu bugs are still common not far from the Keck Observatory (Englund *et al.* 2005, Pacific Analytics 2005), possibly due to the late snowpack that can persist in and around the Hau Oki crater. Because the bugs apparently do not like bedrock substrates, telescopes sited on the glacially modified lava flows in the summit region may have little or no local impact on the bugs; such sites may also provide more stable telescope foundations.

Potential Wēkiu Bug Habitat to Sample

Since 2002 (as of March 2006), a total of only 128 wēkiu bugs have been collected during Bishop Museum surveys, indicating that although locally common in a few areas, this species is now rare throughout its overall range at the Mauna Kea summit. The main objective of current and previous wēkiu bug surveys has been to determine overall distribution and abundance of the bugs throughout their range; these data will ultimately aid in conservation planning. Because we have found convincing relationships between the glacial geology of the Mauna Kea summit region and wēkiu bug habitat use we should closely examine areas with promising geology where the wēkiu bugs have not previously been found or sampled. As the Mauna Kea summit is a large area and difficult to access, much of it still remains either lightly sampled or unsampled. By examining the geology of unsampled cinder cones and also unsampled areas of previously sampled cones, a predictive list of environmentally promising habitats to sample has been compiled (Table 1). Specific areas proposed for future sampling are shown in Figure 11. This list emphasizes nunataks and cinder cone areas close to nunataks, and areas near or within the glacial limit, as well as known areas of late-lying snow. These areas will be sampled for wēkiu bugs during the upcoming 2006 and 2007 field seasons.

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Tables

Table 1. Potential habitat sites to examine in areas where wēkiu bugs have not been previously found, based on geologic considerations such as snowpack and glacial history.

Cinder Cone Area	Area/Aspect	Elevation to survey
Pu‘u Makanaka	Summit and north facing slopes	3,785 m
Pu‘u Waiau	Summit and adjacent north facing slopes	4,077 m
Pu‘u Pohaku	Crest and north facing side of cone	4,020 m
Pu‘u Poliahu	Summit and north face of western ridge	4,085 m
Pu‘u Hoaka	Crest and north slope below crest	3,681 m
Pu‘u 11,989 nr. Hoaka	Southwestern and southern slopes	3,655 m
Horseshoe Crater	North Facing Crests of Crater Rim (N and S segments)	3,844 m
Pu‘u Ala	Top of north facing rim of crater	3,844 m
Pu‘u Ko‘oko‘olau	Northwest and Eastern sectors of crater rim	3,796 m
Pu‘u 12,090 (by John Burns sign)	Southern crater rim and south slope of crater	3,685 m

Figures

Figure 1. Satellite image of the upper glaciated region of Mauna Kea (source: GOOGLE Earth). Light-purplish area coincides closely with the distribution of glacial deposits of the last (Makanaka) glaciation.

Figure 2. Topographic map of upper slopes of Mauna Kea showing limit of the last ice cap and location of nunataks within this limit. Dashed lines are approximate positions of ice limits.

Right-lateral moraine of Makanaka ice cap in upper Waikahalulu Gulch. Aa lava in foreground is a postglacial flow that was erupted about 5000 years ago. The moraine is ca. 20,000 years old based on cosmogenic-isotope surface-exposure dating.

Upper limit of erratic hawaiite boulders on Puu Poepoe mark a minimum upper limit of the glacier

Puu 12,090, a glacially overridden cinder cone near the glacial limit. Glacial drift fills the crater and erratic stones are dispersed across the flank.

Figure 3. End moraine and erratics of Makanaka glaciation on upper slopes of Mauna Kea

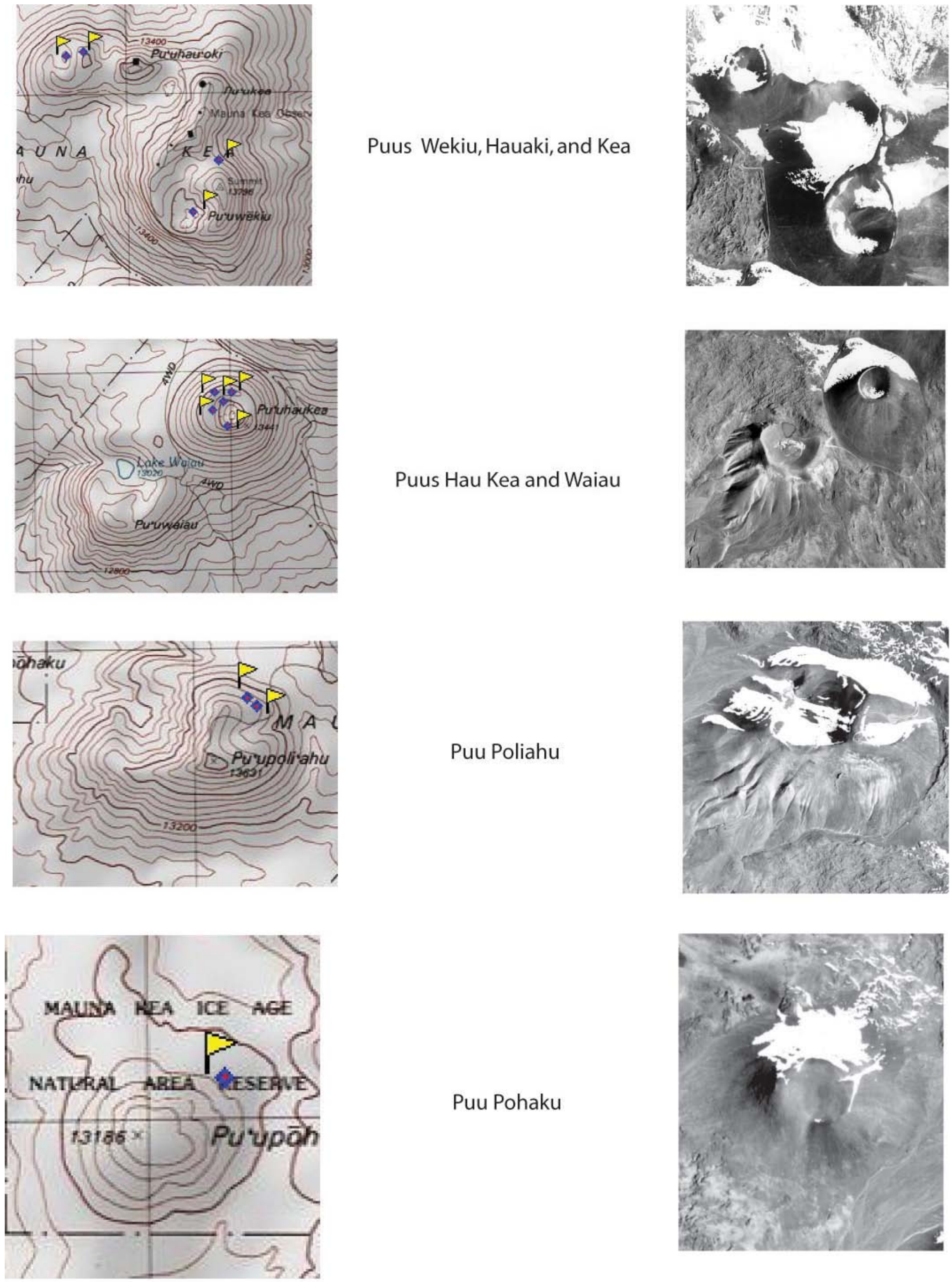


Figure 4. Glacially modified cinder cones near the summit of Mauna Kea. Flags mark sites where Wekiu bugs were collected

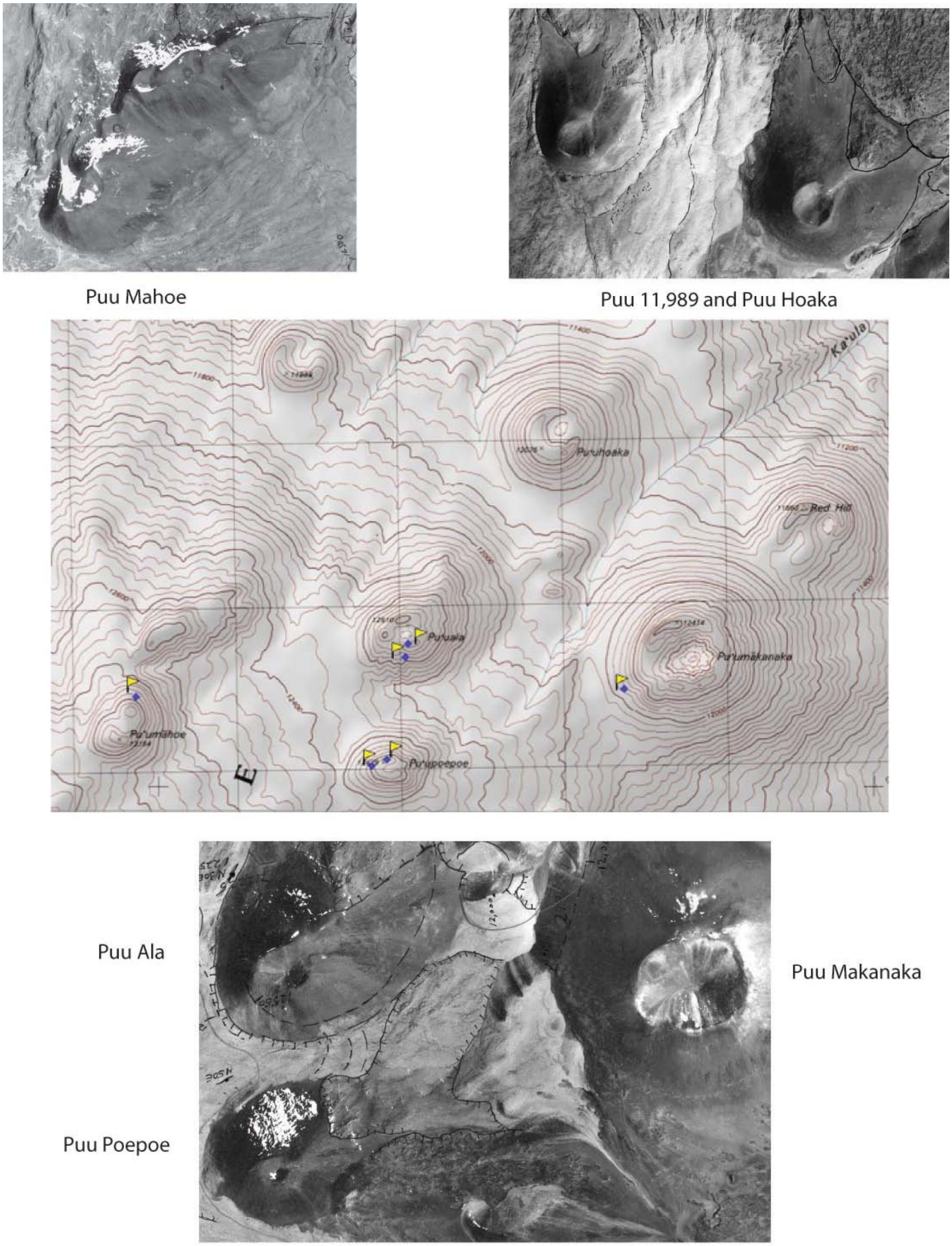


Figure 5. Cinder cones of the NE rift zone. Flags show location of sites where Wekiu bugs were collected.

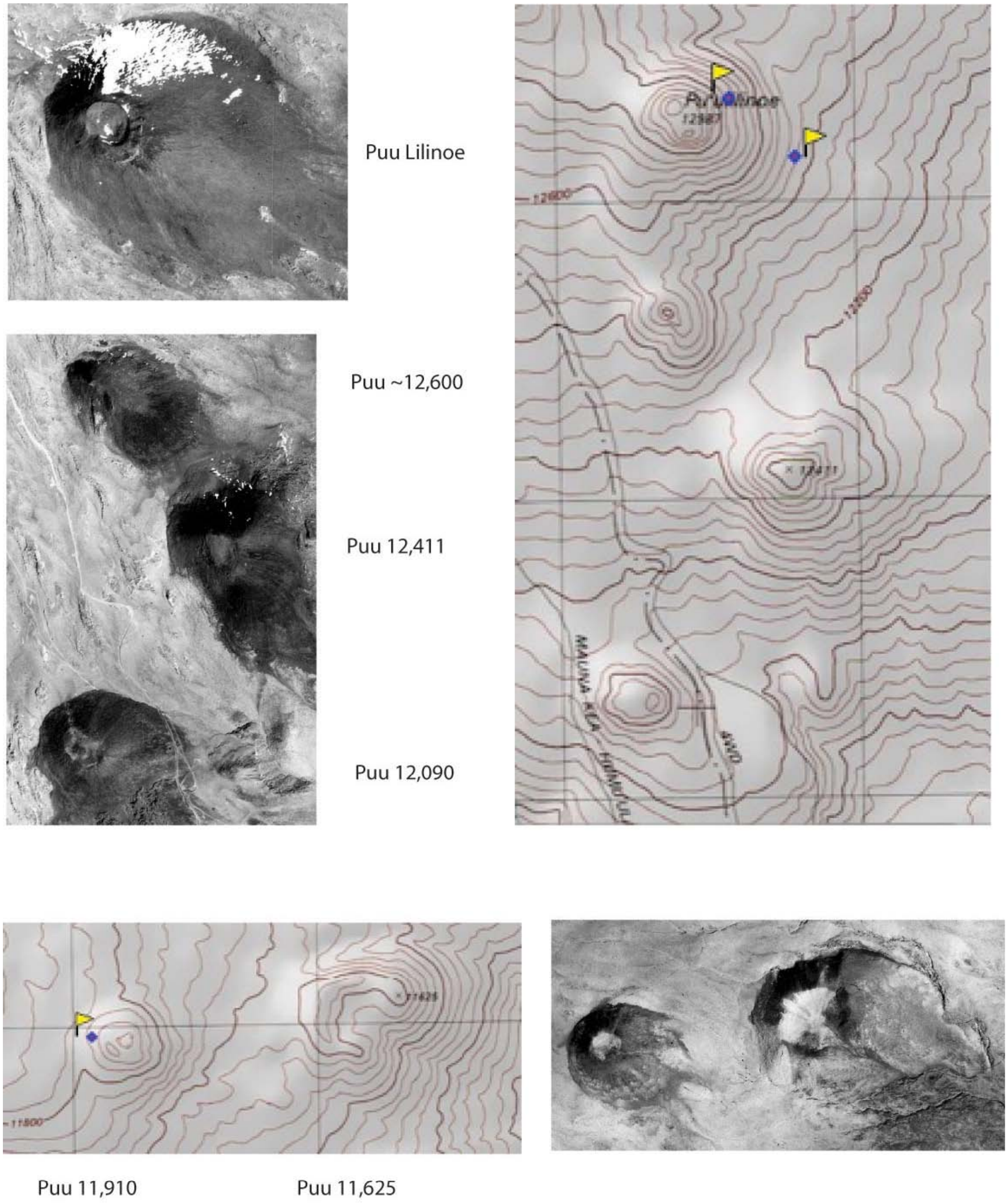
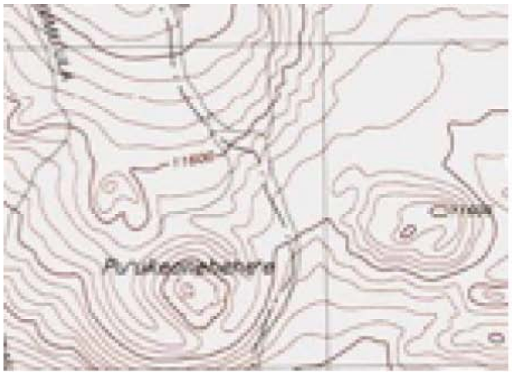
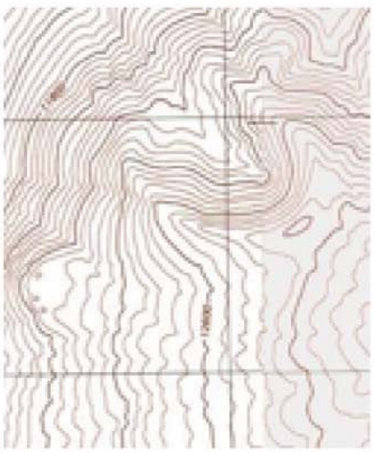


Figure 6. Cinder cones south and east of the summit cluster. Flags denote sites where Wekiu bugs were collected.



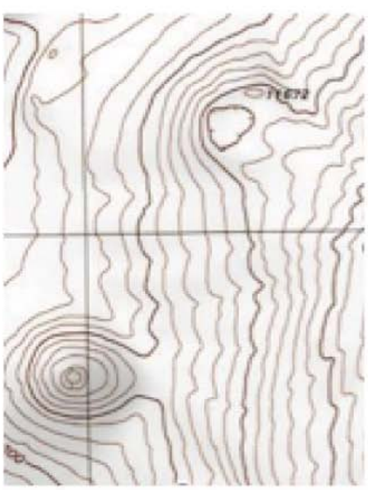
Puu Keonehehee

Figure 7. Cinder cones south of the glacial limit



"Horseshoe crater"

Puu 12,260



Puu 11,672

Puu ~11,590

Figure 8. Cinder cones of the NW Rift Zone.

9. Vertical aerial photograph of the summit region of Mauna Kea taken March 7, 1965, showing the distribution of late-lying snow patches (U. S. Geological Survey photo EKL-14CC-88).

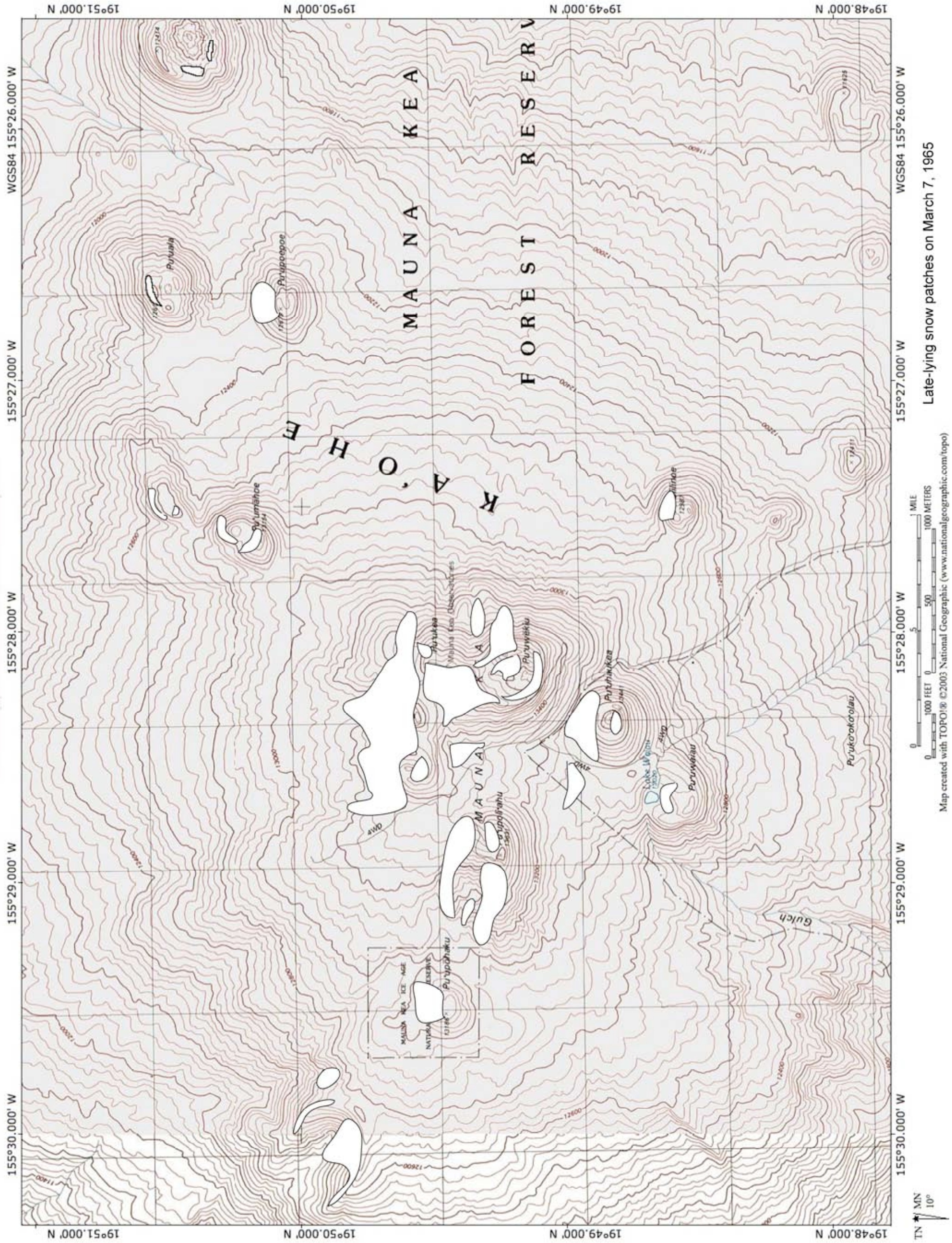


Figure 10. Location of late-lying snow patches on the upper slopes of Mauna Kea on March 7, 1965, based on US Geological Survey vertical aerial photograph EKL-14CC-88. The patches lie mainly on north-facing slopes of cinder cones and on shaded slopes of craters.

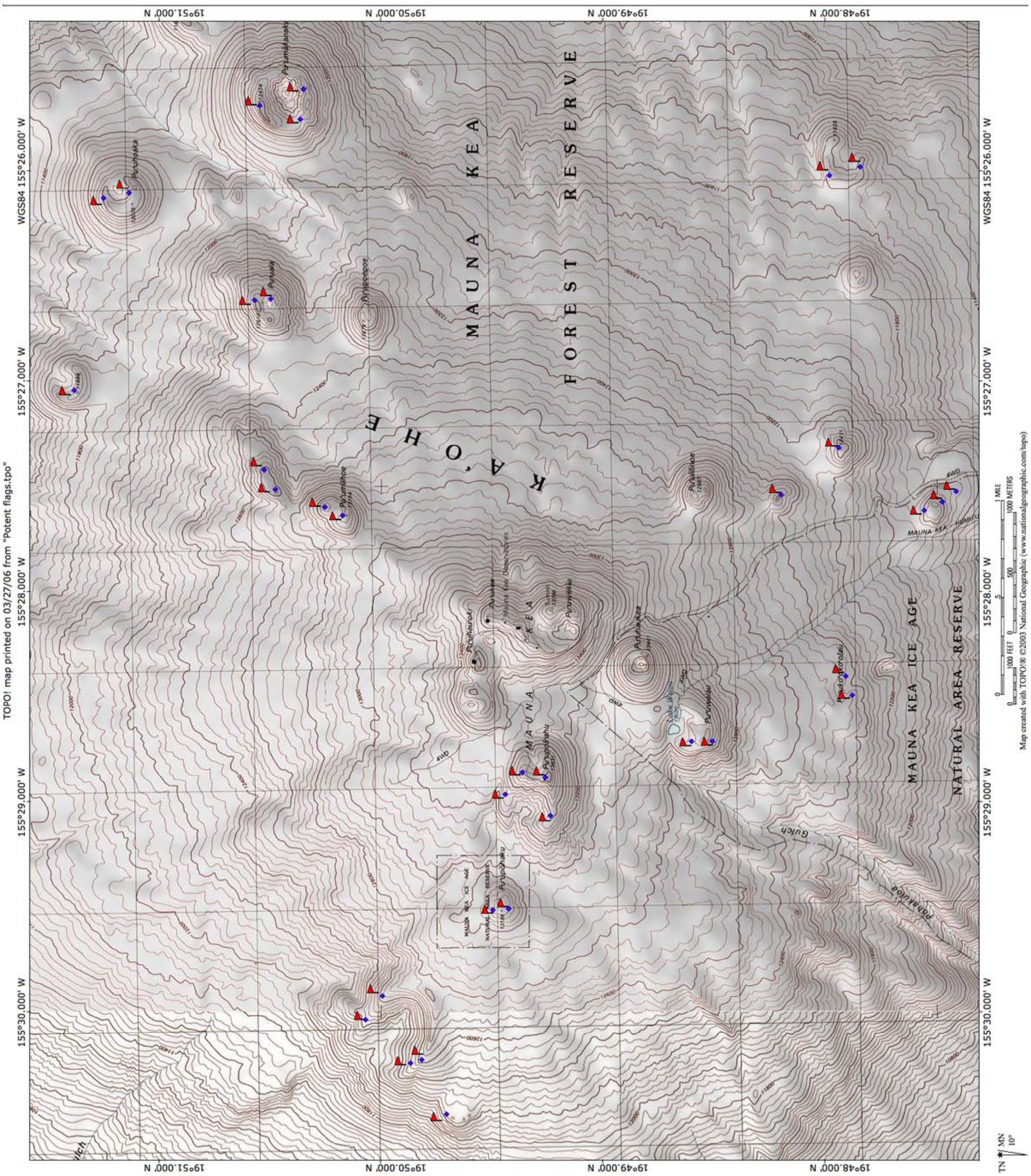


Figure 11. Potential wēkiu bug habitats and areas to sample based on snowpack and geological considerations.