Holocene Eruptions of Mauna Kea Volcano, Hawaii

Abstract. *Postglacial lava flows, interstratified with thick locally derived sheets of tephra, cover some 27.5 square kilometers on the south slope of Mauna Kea. Most of the volcanics were erupted about 4500 years ago and overlie a regionally extensive paleosol which developed largely during the last glaciation.*

Reconnaissance geologic studies on the glaciated upper slopes of Mauna Kea volcano during the first half of the present century demonstrated that eruptive activity had largely ceased by the close of the last glaciation (*1*). Several fresh lava flows in the summit area that rest on glacial drift were cited as evidence that intermittent volcanism continued into the Holocene, but neither the relative nor absolute ages of the flows were determined. Studies currently in progress on Mauna Kea have disclosed that the products of Holocene volcanism on the southern slope of the mountain are more extensive than was formerly thought, and several absolute dates have been obtained for a complex stratigraphic succession of lava flows and intercalated tephra (*2*) layers.

Stearns and Macdonald (*3*) assigned postglacial volcanics on Mauna Kea to the Upper Member of the Laupahoehoe Series, the lower boundary of which was placed at the top of the Makanaka drift sheet on the upper slopes of the mountain. Below an altitude of about 3300 m, Makanaka sediments are discontinuous and consist mainly of gravelly outwash confined to narrow gulches and to fans deposited along the northern margin of the Mauna Kea–Mauna Loa saddle. Between altitudes of 2000 and 3350 m on the south slope of the mountain, the stratigraphic interval that corresponds approximately to that of the Makanaka drift is marked by a widespread paleosol, which is well developed and exposed near the Humuula Sheep Station in the saddle (Fig. 1). This ubiquitous soil constitutes an ideal stratigraphic marker horizon throughout at least 90 km^2 and separates Pleistocene tephra and lavas from overlying volcanics of Holocene age. Although commonly buried by younger lava flows and tephra sheets, the Humuula paleosol is seen in relict occurrences in several kipukas (*4*) near timberline (at about 2900 m).

Mauna Kea lava flows and tephra sheets that postdate the Humuula paleosol are listed in Fig. 2. The absence of well-developed weathering profiles within this succession suggests that the eruptions were probably rather closely spaced in time. However, colluvium containing organic matter was found between two cinder layers at one locality, which may indicate a quiet period of sufficient length to permit mass-wasting and the development of a partial vegetation cover.

With the exception of the Hale Pohaku lava flow, which lacks an associated cinder cone (puu), each eruptive event involved construction of such a cone and deposition of a blanket of coarse tephra, followed by eruption of one or more lava flows. Cinder cones were built during the initial pyroclastic phase and were subsequently modified by lava issuing from their flanks or bases. Two tephra layers, originating from Puu Kole and Puu Loaloa, are exposed in many natural and artificial cuts, and isopachs drawn on each unit indicate a general exponential decrease in thickness away from their respective sources (Fig. 1). The Puu Loaloa tephra is more than 10 m thick near the source vent and completely blankets the lower portions of the Puu Kole and Hale Pohaku flows, producing a relatively featureless constructional surface broken

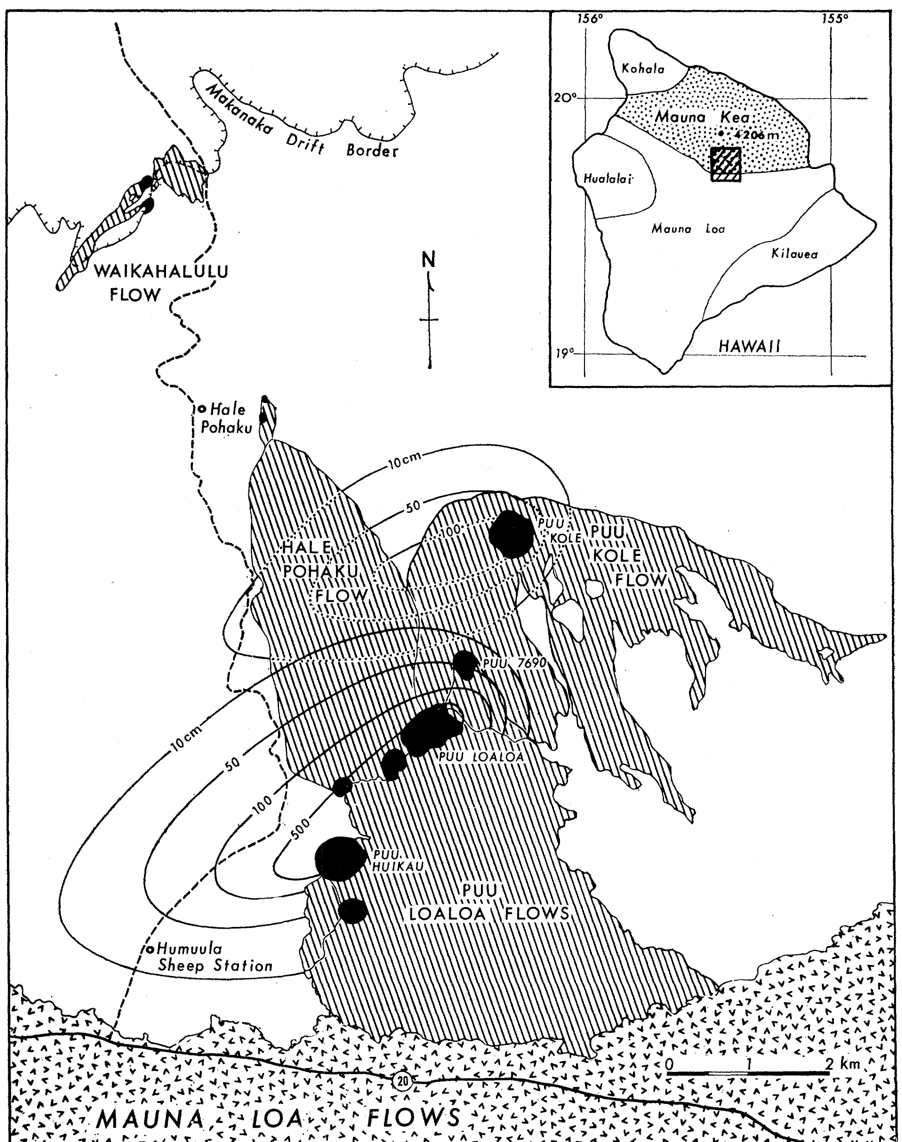

Fig. 1. Distribution of Holocene cinder cones (black) and lava flows (shaded) on the south slope of Mauna Kea. Isopachs drawn on Puu Kole and Puu Loaloa tephra layers are given in centimeters. The location of State Highway 20 is indicated in the area of the Mauna Loa flows.

Table 1. Radiocarbon dates related to Humuula paleosol and Holocene volcanic units.

Laboratory No.	Stratigraphic position and location of sample	^{14}C age (years ago)
I-5291	Top of Puu Loaloa tephra at base of modern solum; 2265 m on Hale Pohaku Road 0.5 km southeast of Puu Hookomo	845 ± 95
UW-165	Top of Humuula paleosol beneath Puu Loaloa tephra; 2024 m in gully 0.8 km east of Humuula Sheep Station	4470 ± 70
I-5295	Colluvium between Puu Kole and Puu Loaloa tephra; 2396 m in gully 1 km south-southeast of Puu Kole	4560 ± 110
I-5292	Top of Humuula paleosol beneath Puu Kole flow, 2195 m in gully 1.8 km northeast of Puu Loaloa on north side of Keanakolu Road	4400 ± 110
I-5293	Top of Humuula paleosol beneath Puu Kole tephra; 2231 m in gully 1.8 km northeast of Puu Loaloa on north side of Keanakolu Road	4460 ± 110
I-5294	Top of Humuula paleosol beneath Puu Kole tephra; 2390 m in gully 1 km south-southeast of Puu Kole	4420 ± 110
UW-166	Top of Humuula paleosol beneath Puu Kole tephra; 2158 m in gully on west side of Keanakolu Road 0.8 km north of Puu Huikau	4790 ± 70

only by postdepositional gullies. A thinner and less extensive layer of tephra originated from Puu 7690, but, because it is exposed infrequently, the thickness data are insufficient for the construction of isopachs. However, lateral variations in maximum particle size indicate that the plume of tephra traveled in a southwesterly direction, consistent with the orientation of the other two principal Holocene tephra plumes and with prevailing tradewinds of today.

Each of the three principal Holocene tephra layers consists of highly vesicular black cinders, which grade laterally into ash with increasing distance from the source vent. Unlike some older pre-Humuula tephra layers, none contains phenocrysts of olivine.

A thin layer of powdery, very pale brown ash, which is exposed discontinuously at the surface on the lower slopes of Mauna Kea, was also found on a late prehistoric Mauna Loa lava flow in the saddle; apparently it is not present on historic flows. Although data are scanty, no lateral variations in thickness or grain size are obvious across that part of the saddle and adjacent slopes shown in Fig. 1. Unlike older Holocene tephra layers encountered on Mauna Kea, the ash is extremely fine-grained and the shards are transparent. Possibly it originated during a late prehistoric eruption of Kilauea volcano, like the violent steam explosions of 1924 or like those that are regarded as having produced the older, regionally extensive blanket of Pahala ash on the southeast side of the island (*5*).

Makanaka outwash gravel west of Hale Pohaku lies on a distinctive coarse black tephra containing olivine phenocrysts, without intervening soil, which in turn overlies lava flows erupted toward the end of the last interglaciation. If soil developed on the tephra prior to deposition of Makanaka outwash, it must have been largely eroded away by meltwater during the ensuing glaciation. The Humuula paleosol found on this ash in nearby relict occurrences is deeper and has stronger profile characteristics than does the postglacial soil developed on the outwash. Consequently, the Humuula soil-forming interval is inferred to include most or all of the last glaciation and possibly part of the preceding interglaciation.

From several small vents at altitudes of 3500 to 3600 m, postglacial lavas flowed 2 km down Waikahalulu Gulch and now overlie terminal Makanaka drift, but the flows cannot be related directly to the Holocene tephra and lava succession on the lower slopes of the mountain.

Lavas younger than the Humuula paleosol on the lower slopes of the volcano include two small flows that issued from vents 0.5 km east of Hale Pohaku and four larger flows and flow complexes. The Hale Pohaku flow and the Puu Kole flow are the oldest of these, and their exposed surfaces cover an area of 6.7 and 9.5 km^2, respectively. The two flows may have erupted almost simultaneously, for no definitive overlap relationships could be found along their contact and they both lie in the same stratigraphic position with respect to the Puu Kole tephra and the Puu 7690 tephra.

Only 0.5 km^2 of a lava flow from Puu 7690 is exposed, the remainder being buried beneath a complex of flows that issued from Puu Loaloa and related cinder cones. The Loaloa flows cover 10 km^2 upslope from the margin of overlapping Mauna Loa flows, but numerous small kipukas of the flow complex, not shown in Fig. 1, are scattered within the boundaries of a pre-1843 Mauna Loa flow north of State Highway 20.

The total area covered by exposed portions of Holocene flows on the south slope of Mauna Kea amounts to some

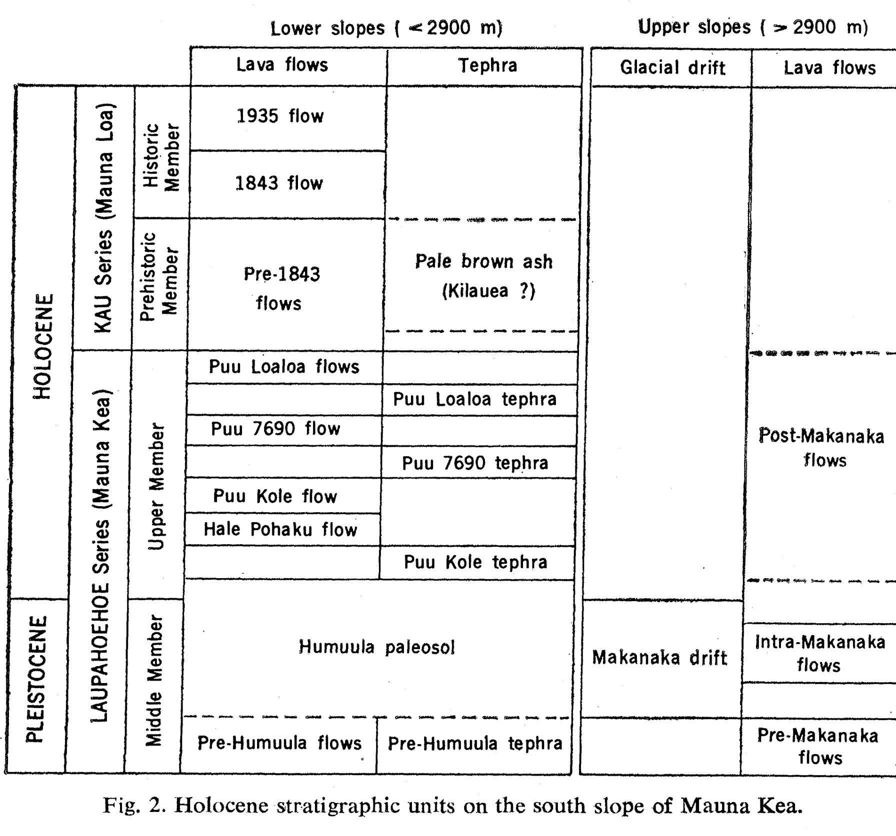

Fig. 2. Holocene stratigraphic units on the south slope of Mauna Kea.

27.5 km^2. The thickness of the flows is quite variable but is generally not closely determinable except near their margins. Near their sources, the flows reach thicknesses of about 30 m; surface relief on the larger flows locally approaches 10 m. If one assumes an average flow thickness of 10 m, probably a reasonable approximation, the minimum volume of the postglacial lavas is 0.25 km^3. However, the total areal extent of the larger flows is not known with certainty, and, because estimates of mean thickness are based on few exposed sections, the actual volume may be somewhat greater.

Radiocarbon determinations of six charcoal samples collected near the top of the Humuula paleosol at widely separated localities provide limiting ages for the Holocene eruptions on the south slope of the mountain and record the end of the Humuula soil-forming interval (Table 1). Within the statistical limits of error, the small difference in age between samples that lay directly beneath Puu Kole tephra, Puu Kole lava, and Puu Loaloa tephra suggests that the entire volcanic succession resting on the paleosol was erupted within a brief interval of probably no more than several hundred years. This conclusion is supported by the absence of weathering horizons between the top of the Humuula paleosol and the modern surface soil. If the entire succession represents a single eruptive episode, the outcrop pattern and stratigraphic relationships indicate that the vents must have opened progressively downslope, a phenomenon common to historic eruptions on the island (*6*). An upper limiting date of 845±95 years for Puu Loaloa tephra, obtained from charcoal at the base of the modern solum, may postdate the eruption of the underlying tephra by a considerable span of time.

Radiocarbon dates were obtained for algal sediments from the bottom of Lake Waiau, a shallow body of water at 3970-m altitude which lies within the glaciated area (*7*). These dates indicate that the summit ice cap must have largely disappeared by about 10,000 years ago. The Humuula soil-forming interval terminated some 5500 years later in those areas mantled by postglacial volcanics. Therefore, the top of the buried Humuula paleosol lies temporally above the boundary between the Middle and Upper Members of the Laupahoehoe Series. In areas unaffected by Holocene volcanism, soil formation presumably has continued uninterrupted to the present. In comparison with the Humuula paleosol, soil developed on the postglacial lavas and tephra sheets during the past 4500 years is thinner and has weaker profile characteristics.

A layer of dark ash approximately 4500 years old was noted in a sediment core taken from Lake Waiau (*8*). The layer, formed by several separate ash falls, lies 1.5 m below the top of the core and consists of particles as large as 1 mm in diameter. The ash was attributed to an eruption of a nearby cone (*8*), but all cinder cones lying inside the 3700-m contour (within 3 km of Lake Waiau) are Pleistocene in age; therefore, the ash may have originated in one or more of the major pyroclastic eruptions on the south slope of the mountain (Puu Kole or Puu Loaloa), which also occurred about 4500 years ago. The grain size and thickness of the ash in the lake sediments apparently are consistent with such a distant source. A layer of similar dark-gray ash, 15 cm thick, was found overlying Makanaka drift in shallow soil pits excavated 1.5 km northwest of Summit Cone at an altitude of 4040 m. Dark-gray ash also was encountered in the vicinity of Pohakuloa State Park in the Mauna Kea–Mauna Loa saddle, where it blankets the surface of a Makanaka outwash fan. A layer of finer dark ash, as much as 4 cm thick and underlying 50 cm of alluvium, occurs near the surface of a fan at the west end of the U.S. Army Pohakuloa Training Area, some 3 km farther west. If these separate ash occurrences all represent the same eruptive event (or events), the mid-Holocene tephra blanket must originally have covered an area of at least 250 km^2, which would make it a widespread and useful stratigraphic marker horizon across the upper slopes of the volcano.

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References and Notes

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2. Tephra is a collective term for all air-deposited pyroclastic sediments ejected from a volcanic vent during an eruption. It includes volcanic dust, ash, cinders, lapilli, scoria, pumice, bombs, and blocks.
3. H. T. Stearns and G. A. Macdonald, *Hawaii Div. Hydrogr. Bull.* **9** (1946).
4. Kipukas are island-like areas of older land surrounded by later lava flows.
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20 January 1971

Theoretical and Experimental Basis for a Specific Countertransport System in Membranes

Abstract. *A sodium ion carrier transport system contains the antibiotic monensin in the membrane and uses a* pH *gradient as an energy source. The experimental results are in accord with theoretical predictions based on a mechanism which is understood on a molecular level.*

Our experiments demonstrate the selective transport of sodium ions across a membrane. The membrane contains a carrier that reacts selectively with a sodium ion and transports the ion across the membrane against its own concentration gradient. The energy source for this transport comes from the simultaneous diffusion of a second solute. The results represent an example of coupled facilitated diffusion similar to the oxygen–carbon monoxide system reported earlier (*1*). In these systems, solute fluxes can be coupled hundreds of times more strongly than in conventional multicomponent diffusion. Such membranes should find major industrial applications in specific chemical separations and in pollution control, and they should provide convenient biological analogs for the membranes found in living systems.

The main feature of the mechanism is that the carrier reacts competitively with both the solute being transported against its own gradient and with a second solute supplying the necessary energy. The mechanism by which this membrane functions is understood explicitly on a molecular level and includes consideration of reaction and diffusion of all species within the membrane. Whereas our discussion is primarily concerned with a specific mem-