AN EARLY 19TH CENTURY RETICULITE PUMICE FROM KILAUEA VOLCANO

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ABSTRACT

Remnants of a fragmented reticulite pumice deposit, referred to as the golden pumice, along the southwest rim of Kilauea caldera are the product of episodes of lava fountaining of undocumented date within the caldera. At its best locality, the 2.8-m deposit consists of a basal fine-grained, well-bedded unit, 20 cm thick; an intermediate massive homogeneous unit, 1 m thick, consisting of coarse, jagged, firmly packed fragments; and an upper fine-grained unit, 1.6 m thick, of well-sorted and well-bedded pumice. The intermediate unit may be a product of massive direct fallout from lava fountains, and the finer grained upper and lower units may be pumice wind-drifted from a plume plus pumiceous debris reworked by wind. The pumice locally rests with angular unconformity on beds of 1790 pyroclastic debris and is overlain by a thin layer of 1924 lithic tephra. Layers of reworked pumiceous debris and 1790 lithic debris within the golden pumice suggest that its emplacement was episodic and may have occurred over a year or two. The stratigraphic succession and recorded observations of volcanic activity since 1823 indicate that the pumice formed between 1790 and 1823. The amount of erosion and deposition occurring between emplacement of the 1790 deposits and the pumice favors a date in the later part of this interval, possibly around 1820. We speculate that the golden pumice represents early phases in development of the lava conduit for the current fire-pit crater, Halemaumau, the most active center within Kilauea caldera during the 19th and 20th centuries.

INTRODUCTION

Surficial deposits of fragmented reticulite pumice at the southwest edge of Kilauea Crater were thought by Jaggar (1925, p. 3, 8) to be part of an underlying deposit of pyroclastic debris erupted in 1790, and they were included, by inference at least, within the Keanakakoi Formation by Wentworth (1938, p. 93). Christiansen interprets this pumice as a product of high lava fountains following an earlier episode of phreatomagmatic activity about 1790 (Christiansen, 1979; Decker and Christiansen, 1984, p. 125); Macdonald and Abbott (1970, p. 315) seemingly agree. The deposit is clearly not related to pumice at the base of the Keanakakoi Formation of Wentworth (1938, p. 95–96, 101) or to pumiceous products of post-1924 events (Wentworth, 1938, p. 149; Macdonald, 1955, p. 57; Macdonald and Abbott, 1970, p. 92–93; Richter and others, 1970, p. E5–E36). In order to distinguish this particular reticulite pumice from such older and younger deposits of similar nature, it is here informally called the golden pumice. Its stratigraphic position, between materials erupted in 1790 and 1924, was recognized by Macdonald (1949, p. 70, 72) and Macdonald and Abbott (1970, p. 315), who did not, however, discuss its origin or precise age. In this paper we present evidence that it represents a distinct event, separate from 1790 activity but early within the 1790–1924 interval, an interpretation seemingly favored, but without supporting arguments, by Finch (1947), Powers (1948, plate 3D), and Stearns (1966b, p. 40).

ACKNOWLEDGMENTS

Kilauea lies within Hawaii Volcanoes National Park, and we are indebted to park authorities for the privilege of access. The study was warmly and cooperatively supported by the U.S. Geological Survey's Hawaiian Volcano Observatory and financially aided by Grant W–13, 709 from the National Aeronautics and Space Administration. R.L. Christiansen has generously made available unpublished information from his extensive studies of the 1790 Keanakakoi Formation. Appreciation is expressed for constructive critical reviews and suggestions by Christiansen, D.A. Swanson, T.L. Wright, and R.T. Holcomb. W.G. Melson of the Smithsonian Institution kindly supplied records of a chemical analysis of 1820(?) Kilauea glass.

LOCATION AND DISTRIBUTION

Accumulations of the golden pumice are best preserved along the southwest margin of Kilauea caldera (fig. 15.1). The nearly circular, 1-km-wide pit crater of Halemaumau, last active in 1982, indents the caldera floor within 1 km of the best pumice exposures. The thickest accumulations of the golden pumice are trapped within open cracks and stream-cut gullies dissecting the southwest caldera wall and the immediately adjacent outer slope of the volcano, northwest and southeast of Crater Rim Road where it descends to the caldera floor (fig. 15.1). For convenience, the channels are termed caldera-wall gullies, although the larger ones extend headward tens of meters outside the caldera rim. The first 13 larger gullies south-southeast (fig. 15.2) of the descending reach of Crater

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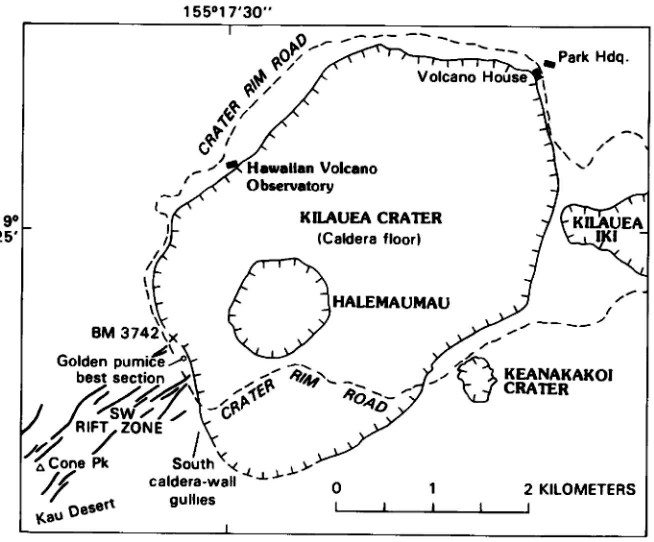

FIGURE 15.1.—Major features of Kilauea Crater and location of best section of the golden pumice.

Rim Road expose particularly informative sections. For identification, these gullies are sequentially numbered south from Crater Rim Road as 1–S, 2–S, and so on.

Remnants of the golden pumice also lie in protected places within the Kau Desert from the caldera rim southwestward more than 3 km, to and beyond Cone Peak (fig. 15.1). Their greater abundance in the northwestern part of the Kau Desert presumably reflects the direction of the dominant trade-wind flow (S. 60°–70° W.) somewhat oblique to the S. 45° W. axial trend of the desert tract.

MICROSTRATIGRAPHIC UNITS AND RELATIONS (SEE FIG. 15.3)

THE 1790 PART OF THE KEANAKAKOI FORMATION OF WENTWORTH (1938)

Stratigraphy of the Keanakakoi Formation of Wentworth (1938, p. 92–104; see also, Powers, 1948) has been most thoroughly and recently investigated by Christiansen (1979; Decker and Christiansen, 1984, p. 124–127) in a study not yet fully published. During investigation of stripping of Keanakakoi debris in Kau Desert, Malin and others (1983, p. 1149–1150) divided the 1790 part of the formation into three units: upper lithic, intermediate predominantly vitric, and lower mixed lithic and vitric; this subdivision is employed here.

Sherzer (1923, p. 460–461), Finch (1947, p. 2), and Powers (1948, p. 288) felt that only the upper lithic unit, or part of it, was emplaced by the 1790 phreatomagmatic eruptions of Kilauea, but Christiansen (1979) attributes the bulk of the Keanakakoi Formation of Wentworth (1938) to an evolutionary cycle of such activity that began around 1790. Malin and others (1983, p. 1151, 1155) favor Christiansen's interpretation, but they suggest, largely because of evidence of penecontemporaneous redistribution of tephra, that the successive eruptions occurred over a period of several years, including 1790. Easton (chapter 11) has reduced the rank of the Keanakakoi and included it in his Puna Basalt. Easton's Keanakakoi Ash Member consists mostly of deposits of the 1790 eruption, but slightly older reticulite pumice occurs at the base and the golden pumice at the top. In this paper we will use the modifier 1790 to designate that part of the Keanakakoi thought to have been formed by these explosive eruptions, without meaning to imply that all the material was necessarily emplaced within the single year 1790.

THE RETICULITE (GOLDEN) PUMICE

The thickest, most complete section of golden pumice observed (fig. 15.4) lies within the head of a gully extending outward from the caldera rim along a crack bearing S. 55° W. in the southwest rift zone (fig. 15.1). This exposure is about 30 m from the caldera brink, roughly 50 m northeast of Crater Rim Road, 78 m N. 15° E. from the SW Rift sign at the parking turnout, and 205 m S. 37° E. of BM 3742 (Kilauea Crater quadrangle). Within the 2.8-m section exposed here, upper, intermediate, and basal units are distinguished (fig. 15.3).

The basal 20 cm are well layered and consist of abraded-looking pumice fragments, mostly about 1 cm in size, in a sparse sand-size matrix of angular vitric fragments. This basal unit includes much Pele's hair and a few scattered lithic clasts as large as 6 mm, and near the top it contains a coarse sandy layer rich in lithic grains.

The massive, homogeneous intermediate unit, 1 m thick, consists of closely packed jagged pumice fragments, mostly 2–5 cm in diameter but ranging from 1 cm to 10 cm. It is nearly devoid of matrix, except for irregular vitric fragments broken from compacted pumice clasts. Tight packing has made the jagged pumice fragments interlock, giving the unit a cohesion that is expressed in a near-vertical outcrop face and in the toughness of detached pieces. No lithic fragments have been found within primary deposits of this coarse pumice, either here or in many other exposures.

The upper unit consists of 1.6 m of thinly and evenly bedded pumice, the fragments being mostly of 1-cm size. These clasts, although still angular, are consistently smaller, more regularly shaped, less jagged, and far more uniform in size than clasts of the intermediate unit. However, 53 cm above the base of the upper unit is a 5-cm layer of coarser fragments with intermediate-unit characteristics. Beds in the upper unit are mostly 3–4 cm thick, though ranging from 1 cm to 7 cm, and generally have a sparse matrix of sand-size vitric fragments. They do not display the inverse grading that typically results from flow emplacement (Sparks, 1976). Distributed throughout the upper unit are 1-cm-thick continuous beds principally composed of dense glass fragments; these layers emphasize the well-bedded aspect of this unit. Much Pele's hair is also present, especially in the lower part of the unit, and a few sparsely scattered lithic fragments, several millimeters in diameter, have been found. In the best section, a 4-cm sandy layer 10 cm from the top contains numerous lithic and crystal grains, some well worn. More

FIGURE 15.2.—View south-southeast from Crater Rim Road showing 20-m-high tephra-mantled southwest wall of Kilauea Crater, caldera-wall gullies, and 1974 lava flow along left margin. Light reflects from patches of crusted veneer on the detrital apron. U.S. Geological Survey photograph by J.D. Griggs.

and larger lithic fragments are seen within the upper unit at some other localities, where secondary reworking has clearly occurred (figs. 15.5*A*, 15.6).

In the best section, contacts between these units are sharp but conformable. Elsewhere, the contact between upper and intermediate units is unconformable (fig. 15.7) or marked by layers containing reworked lithic materials (fig. 15.5*A*). Disconformities and layers of reworked pumiceous and lithic debris also are found within the upper unit.

At the best section, the golden pumice rests with sharp contact upon coarse lithic-vitric sand, possibly dating from 1790; elsewhere it rests upon fluvial gravels, 1790 pyroclastic beds, or lava bedrock. Not all exposures of pumice display all units, the basal and intermediate units being more nearly ubiquitous and of less varying thickness than the upper unit. Remnant patches of pumice in the Kau Desert immediately southwest of the caldera rim are slablike and probably primary, but within a few hundred meters farther southwest the stratigraphy of the best section disappears and the packing and shape of pumice fragments change; preservation of these accumulations in settings protected from the northeast trade winds suggests secondary eolian reworking and redistribution. A secondary surficial crust of grayish chocolate-brown hue and irregular lumpy texture has formed on most such deposits, masking the nature of the underlying material. This crust, 2–4 mm thick, fractures easily owing to fragility of the understratum, but the crust itself is firm. Even though surficial crusts are known to form rapidly on surfaces in the Kau Desert (Malin and others, 1983, p. 1150). the thickness and firmness of this crust indicate at least slight antiquity for the deposits.

The golden pumice is primarily a reticulite (Wentworth and Williams, 1932, p. 41, 47–50) consisting of delicate, interconnected filaments of sideromelane glass (Heiken, 1974, p. 5) outlining oval and crudely polygonal patterns 0.5–2 mm in diameter. It is not as close to a perfect reticulite (Stone, 1926, p. 29; Macdonald, 1972, p. 127) as the basal Keanakakoi pumice (Wentworth, 1938, p. 95–96; Heiken, 1974, p. 5; Christiansen, 1979) or as that produced by the 1969–1974 Mauna Ulu fountains, because it has a wider range in the size and shape of openings and a more copious coating of dense black, gray, or brown glass on fragments. The golden pumice is light, having a specific gravity near 0.06 and a

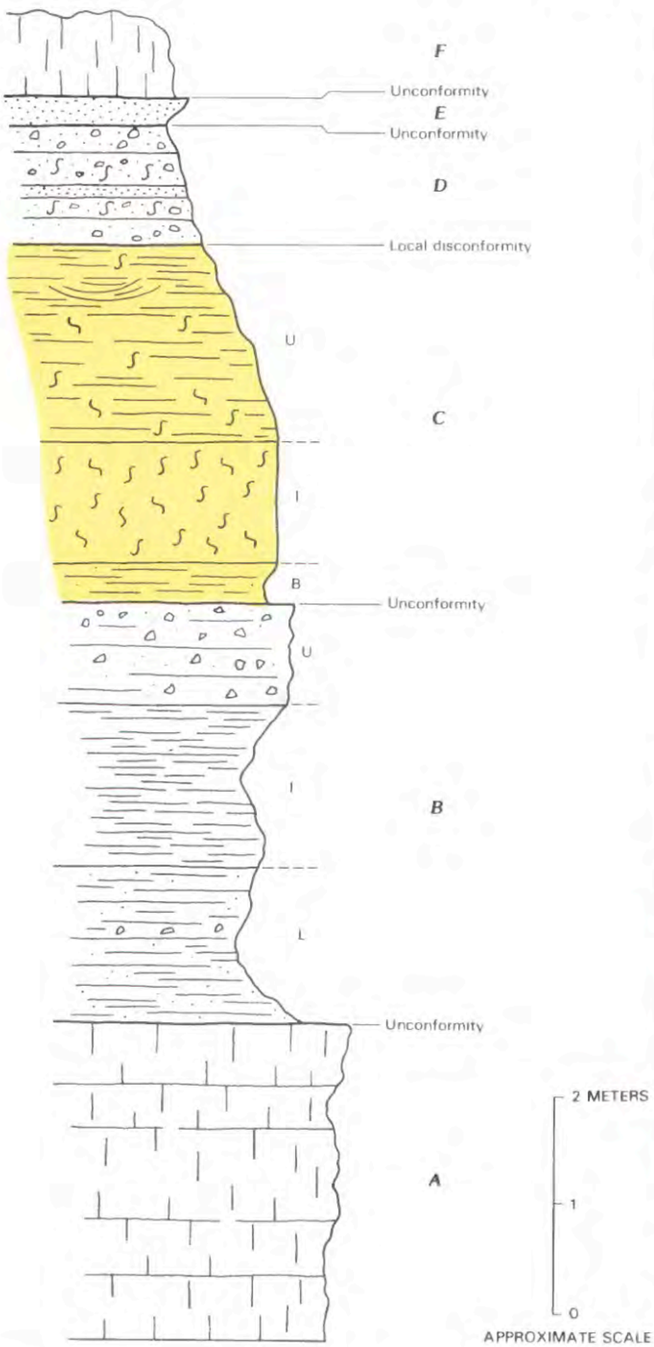

FIGURE 15.3.—Schematic columnar section, within area of southwest caldera rim. Units shown: ***A***, Crater-wall lava flows, >100 m thick, age at top 0.2–0.35 ka (Holcomb, 1980, p. 253). ***B***, ***C***, Keanakakoi Ash Member. ***B***, 1790 deposits; lower (L), intermediate (I), and upper (U) units (Malin and others, 1983), 4 m thick. ***C***, Golden pumice; basal (B), intermediate (I), and upper (U) units, 2.8 m thick, date about 1820. ***D***, Reworked mixed pumiceous and 1790 lithic debris, 1 m thick, date about 1820. ***E***, Lithic tephra, 1–7 cm thick, date 1924. ***F***, Pahoehoe lava flows, 2–3 m thick, dates 1971 and 1974.

porosity probably approaching 97 percent, and is so fragile that it crushes easily in the hand. In more perfect Hawaiian reticulite, Wentworth (1938, p. 149) measured a specific gravity of 0.043 and estimated a porosity of about 98 percent, consistent with Dana's (1891, p. 163) earlier figures. Although reticulite can form as a froth on the surface of some ponded gas-rich lava flows near vents, most Hawaiian reticulite is regarded as the product of vigorous lava fountaining.

REWORKED 1790 LITHIC DEBRIS AND PUMICE

Within the deposits constituting the detrital apron (fig. 15.8) dissected by the caldera-wall gullies are layers of reworked material derived from the adjacent tephra-mantled caldera wall. These layers, mostly 10–40 cm thick, may consist solely of 1790 lithic fragments, solely of pumice, or of mixtures of lithic and pumiceous fragments. Such layers lying below, between, and above beds composed solely of primary pumice (figs. 15.5–15.7) indicate that reworked debris was being intermittently delivered to the detrital apron before, during, and after emplacement of the golden pumice.

1924 LITHIC TEPHRA

The historically observed (Jaggar and Finch, 1924; Stearns, 1925; Jaggar, 1947, p. 205–259) explosive phreatic eruption of

FIGURE 15.4.— Best section of golden pumice exposed in gully near southwest rim of Kilauea caldera. B, bedded basal unit; I, massive intermediate unit; U, upper well-layered unit. The golden pumice is here overlain by 1924 crusted lithic tephra. U.S. Geological Survey photograph by J.D. Griggs.

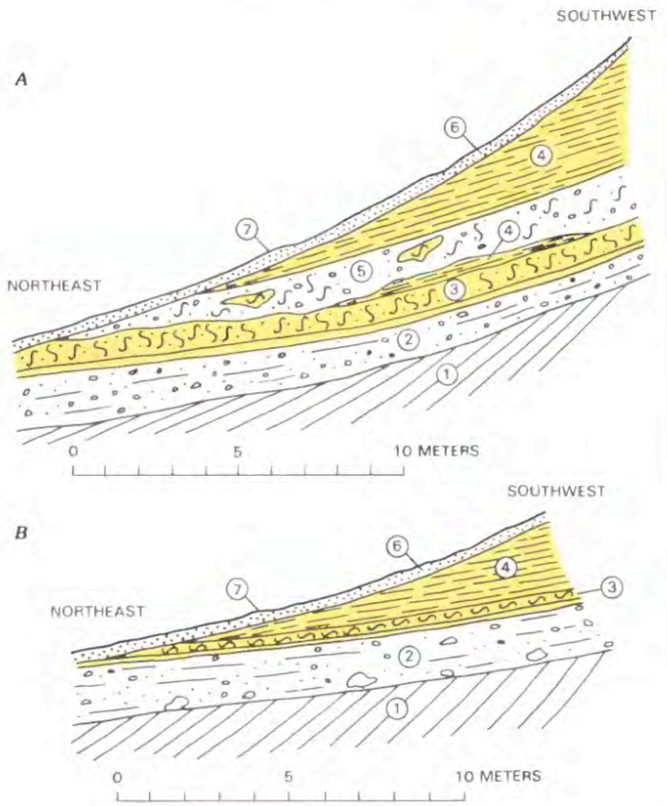

FIGURE 15.5.—Examples of angular unconformities of golden pumice and associated beds with 1790 deposits below and crusted apron veneer above. 1, 1790 beds; 2, reworked 1790 lithic debris, 20–40 cm thick; 3, basal and intermediate units of golden pumice, 45 cm; 4, upper unit of pumice, >1 m; 5, reworked mixed pumiceous and lithic debris, 60 cm; 6, apron veneer of reworked loose lithic-vitric sand, 20 cm; 7, crust on apron veneer. Angular unconformities below 2 and 6, and disconformity below 5. ***A***, South wall of caldera-wall gully 6–S. ***B***, South wall of caldera-wall gully 9–S.

Kilauea in 1924 produced a thin mantle, now crusted, of fine ash and sand- to granule-size fragments, mostly of dense lava, which covered much of the study area (Finch, 1925; Powers, 1948, plate 3D; Macdonald, 1949, p. 72; Macdonald and Abbott, 1970, p. 315). Scattered remnants of this mantle remain, filling shallow swales or forming residual scabs rising a few centimeters in relief on the present surface near and for a few hundred meters southwest of the southwest caldera rim.

Most such patches cover areas of only a few square meters or less. They are as much as 7 cm thick, but more commonly 2–4 cm. Although variable, the deposits display a reasonably consistent microstratigraphy: a basal 1–4 cm of distinctive pink, irregularly laminated fine ash, in many places containing accretionary lapilli, is succeeded by 0.3–0.5 cm of loose, matrix-free angular lithic granules, overlain by 1–2 cm of gray ash containing coarse sand and angular lithic granules, topped by a firm 1–3 mm crust in which abundant angular lithic granules are embedded. The crust has a distinctive rough texture, imparted by the projecting granules, and a medium brown color. Occasional larger lithic fragments (2–4 cm) in this crust may have been secondarily introduced from nearby exposures of 1790 lithic debris, because fragments that large do not here characterize the 1924 material beneath the crust. Lithologies of the lithic clasts in this deposit appear to duplicate those in the block field created around Halemaumau by the 1924 explosions. In the study area, the 1924 tephra rests upon golden pumice (Stone, 1926, p. 29) or, where that is lacking, directly upon the 1790 upper lithic unit.

APRON VENEER AND CRUST

A layer of loose sand and granule particles, 5–20 cm thick, capped by a firm crust, 1–3 cm thick, veneers large parts of the interfluve surface of the detrital apron in the area of caldera-wall gullies, south-southeast of Crater Rim Road (fig. 15.2). In its texture, firmness, setting, and general appearance, this crust so closely resembles the 1924 crust that it was initially and mistakenly so identified. However, it is pinkish rather than brown and lacks the characteristic underlying microstratigraphy, especially the fine ash. Furthermore, the sand and granule grains of this crust and the underlying conformable layers are a mixture of vitric and lithic particles, not solely lithic as in the 1924 deposit.

The apron veneer is a reworked deposit, which may contain 1924 debris but also includes older material, much of it vitric and probably derived from the golden pumice. It presumably dates from later than 1924, but because of its thickness and coherence perhaps only one or two decades later. It has been undermined by lateral recession of the walls of arroyo-like gullies, 1–2 m deep, cut into the alluvial apron, and so the crust may antedate that episode of dissection. In many exposures, the apron crust makes a spectacular

FIGURE 15.6.—North wall, lower reach of gully 5–S. A, reworked lithic debris. B, basal and intermediate (coarse) pumice units. C, primarily reworked lithic debris. D, reworked mixed pumiceous and lithic material. E, detrital apron crust. U.S. Geological Survey photograph by J.D. Griggs.

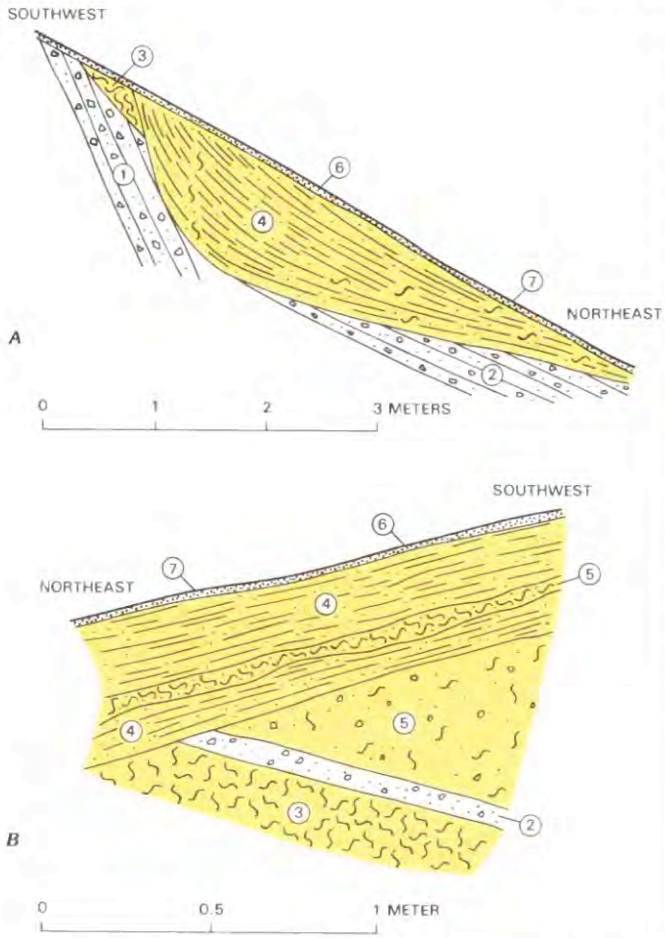

FIGURE 15.7.—Examples of unconformity between upper and intermediate units of golden pumice. 1, 1790 beds; 2, reworked 1790 lithic debris; 3, basal and intermediate units of pumice; 4, upper unit of pumice; 5, reworked coarse pumice; 6, reworked mixed pumiceous and lithic debris; 7, crusted apron veneer. ***A***, North wall of gully 8–S; ***B***, South wall of gully 1–S.

angular unconformity with the golden pumice and associated deposits (figs. 15.5, 15.7*A*).

SETTING AND RELATIONS

Microstratigraphic relations are best exposed in the first 13 major caldera-wall gullies south of Crater Rim Road. Each gully consists of a steep V-shaped upper reach indenting the caldera wall and a gentler, flat-floored arroyo-like reach cut into the detrital apron below (fig. 15.8), and each gully has experienced at least three episodes of dissection. Initially, narrow steep-walled slots, 2–3 m deep, were formed in the nearly horizontal lava flows composing the steep caldera walls, presumably by rock falls, avalanching, and fluvial erosion. These bedrock slots were subsequently partly or wholly filled by 1790 debris, forming some spectacular examples of tephra-bed draping or base-surge plastering on steep bedrock faces (fig. 15.9). Much of the 1790 debris was subsequently removed by further erosion, which locally cut through to bedrock. Deposits of pumice then partly refilled the gullies, mantled the upper gully walls, and added to the detrital apron. Such gully-wall pumice mantles form a striking large-angle unconformity with the more steeply inclined 1790 beds (fig. 15.9). Continued erosion has subsequently removed much of this caldera-wall pumice, but remnants are still seen on walls in the upper reaches of many gullies, particularly 8–S (fig. 15.10). A smaller angle unconformity between 1790 beds and the golden pumice, or associated conformable layers of reworked materials, is displayed in the walls of the lower reaches of many gullies (figs. 15.5, 15.11). A sharp angular unconformity also separates 1790 ash beds from reworked deposits of golden pumice in the Kau Desert (fig. 15.12).

Storm-water erosion within the gullies and colluvial reworking of debris mantling the caldera wall, both of which occurred contemporaneously with deposition of the upper golden pumice unit, added material to the detrital apron. Eventually most of the easily transportable debris was removed from the caldera wall, and regrading and dissection of the depositional apron occurred as the detrital load decreased. Lavas emplaced in 1971 and 1974 now bury the outer margin of the detrital apron (fig. 15.8).

ORIGIN AND EMPLACEMENT OF THE GOLDEN PUMICE

Historically, deposits of fragmented reticulite in Hawaii have been formed by high lava fountains associated with fissure eruptions on the flanks (Swanson and others, 1971) and in the summit calderas of Kilauea (Macdonald and Abbott, 1970, p. 82, 93; Richter and others, 1970) and Mauna Loa (Macdonald and Abbott, 1970, p. 62). The golden pumice has generally been regarded as the product of lava fountaining at an unidentified site or sites within Kilauea caldera. One can speculate concerning the changes that occurred at that source to produce the differences between the coarse, homoge-

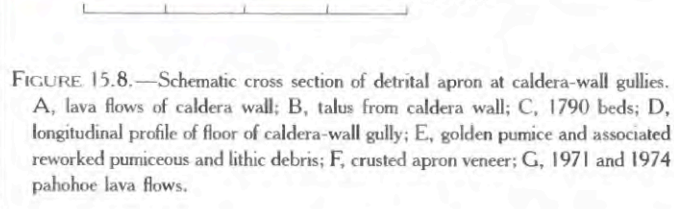

FIGURE 15.8.—Schematic cross section of detrital apron at caldera-wall gullies. A, lava flows of caldera wall; B, talus from caldera wall; C, 1790 beds; D, longitudinal profile of floor of caldera-wall gully; E, golden pumice and associated reworked pumiceous and lithic debris; F, crusted apron veneer; G, 1971 and 1974 pahohoe lava flows.

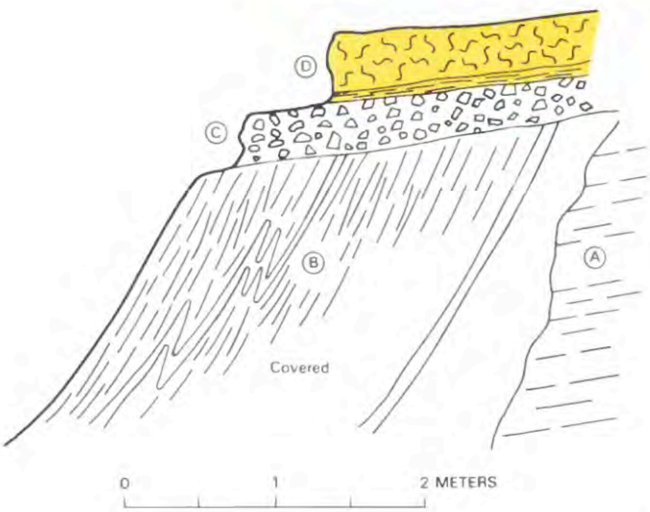

FIGURE 15.9.—Slump-deformed 1790 ash layers plastered on caldera wall and unconformably overlain by reworked lithic rubble and golden pumice, south side of caldera-wall gully 3–S. A, inferred caldera wall; B, 1790 ash beds; C, lithic-cobble rubble; D, lower and intermediate units of golden pumice.

neous, massive, tightly packed intermediate unit and the finer, well-layered, better sorted, more loosely packed basal and upper units.

Reticulite is so light that the behavior of individual fragments is strongly influenced by air currents; smaller particles, those with minimal glass coating, and those thrown highest are presumably the most strongly affected. Motion pictures of lava fountains show a central cone of debris falling back to the ground close to the fountain. This we shall term direct fallout to distinguish it from the more diaphanous plumes of material that drift for greater distances downwind (fig. 15.13). Most direct fallout follows a reasonably normal trajectory and consists largely of dense lapilli, glass, spatter and other forms of consolidated lava. A transition presumably exists between such direct fallout and drifted plume material. The coarse, closely packed pumice fragments of the intermediate unit appear to have come down directly out of the air, without significant secondary tumbling, wear or reworking. We speculate that it accumulated in the outermost part of the fallout zone and that large pumice fragments were so abundant they formed a clotted mass. We therefore refer to it as direct-fallout pumice, even though it probably drifted to some degree with the wind before coming to the ground.

Deposits of plume pumice should consist of smaller and better sorted fragments, possibly showing some evidence of attrition owing to buffeting contacts within the plume. If strong winds accompany the eruption, as commonly happens in Hawaii, such fragments may experience some eolian transport over the ground surface before coming to rest. Despite this complexity in their history, accumulations of both fallout and plume pumice are herein treated as primary. Both are highly susceptible to reworking by wind or water subsequent to their initial deposition, and such reworking imposes differences in texture, packing, coherence, fragment shape, contamination, and degree of layering that identify the resulting accumulations as of secondary origin.

Indications that much of the material composing the upper and basal units of the golden pumice has been secondarily transported by wind include the following: Good sorting; thin, even, regular layering; local cross-lamination; wear on pumice particles that has made them less jagged and removed some of the surficial glass coating; open packing; thin discrete layers of fine glass fragments; and inclusion of scattered lithic fragments, 2–3 mm in size, and thin layers rich in lithic sand. The well-bedded appearance of the upper and basal units results largely from the presence of numerous thin, continuous, even layers of fine vitric fragments that have specific gravities at least 25 times that of reticulite. These layers most likely formed as lag concentrates at times when strong trade winds removed accumulated pumice particles from the study area, leaving the smaller, denser glass fragments. Less probably, they may represent either changes in material being ejected or in the sorting of materials within plumes. Although the upper and lower units of the golden pumice contain a number of thin layers that may be primary plume pumice, and the upper unit clearly contains one 5-cm layer of primary fallout pumice, both units are inferred to be largely secondary in origin, on the basis especially of their excellent thin, regular bedding.

Deposition of fallout pumice and of plume or secondary pumice at the same site at different times could be caused by changes in the magnitude of fountaining at a fixed source or by migration of fountaining along a rift. Both are known to occur in Hawaii. Whatever the change was during the formation of the golden pumice, it was abrupt, not transitional, because the contacts between units

FIGURE 15.10.—Remnants of draped basal and intermediate units of golden pumice resting with angular unconformity on 1790 beds on northwest wall of gully 8–S. A, caldera-wall lavas; B, 1790 beds; C, golden pumice. U.S. Geological Survey photograph by J.D. Griggs.

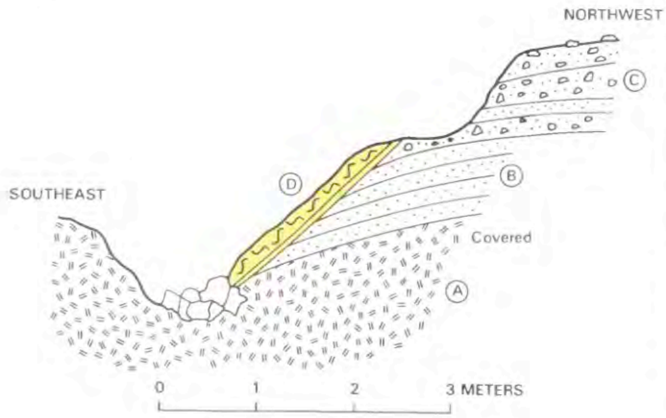

FIGURE 15.11.—Angular unconformity of draped basal and intermediate units of golden pumice on 1790 beds, north wall of gully 7–S. A, lavas; B, lower and intermediate units of 1790 deposits; C, upper lithic unit of 1790 deposits; D, basal and intermediate units of golden pumice.

are sharp. We find no compelling evidence to choose between these two alternatives, but it is perhaps simpler to imagine variations in fountaining at a fixed site, especially in accounting for the isolated 5-cm coarse fallout layer in the upper unit. The microstratigraphy of the golden pumice and associated deposits in the caldera-wall gullies (figs. 15.5–15.7) suggests that fountaining ceased completely on occasion, allowing both deposition by other processes and erosion to occur.

TEMPORAL CONSIDERATIONS

When, within the 1790–1924 period, was the golden pumice emplaced, and how much time was involved? Dana (1891, p. 43) visited Kilauea in 1877 and described deposits of reticulite along the caldera rim resting on coarse lithic conglomerate. This was almost certainly the golden pumice on the 1790 upper lithic unit. Wilkes's 1841 description (1845, p. 169–170) of coarse pumice filling open cracks of the southwest rift is almost identical to our description of the golden pumice intermediate unit. Observations of spumose lava, light as a sponge, wind-drifted, and visible all around on the surface of the Kau Desert a short walk southwest of Kilauea on August 1, 1823 (Goodrich, 1826, p. 22; Ellis, 1827, p. 162), strongly suggest that the golden pumice had been formed by that time. Probably it had formed not long before, because the pumice fragments were abundant and widely scattered and the deposits apparently not crusted, as they are now. These observations, and the improbability that lava fountaining adequate to create the golden pumice would go unrecorded after 1823 (Dana, 1891), point to the 1790–1823 interval as the likely time for the unit's origin.

A time late in that period would be particularly favored if the considerable erosion and reworking of 1790 lithic debris that occurred before pumice emplacement had been accomplished by normal fluvial and colluvial processes. However, the possibility that a more powerful process, such as base surge, might have produced the effects rather quickly deserves consideration in view of the fact that base surges are thought to have played a major role in emplacement of the 1790 deposits (Swanson and Christiansen, 1973, p. 85; Christiansen, 1979; Decker and Christiansen, 1984, p. 125). Spectacular U-shaped scour channels, local unconformities, and large bedforms within 1790 deposits for at least 0.5 km outward from the caldera rim are strong evidence for the action of base surges.

Kilauea caldera is large enough to have contained an intracaldera base surge that could have traversed the caldera floor and ascended the caldera wall. Accumulations of 1790 ash, showing base-surge characteristics, on large slump blocks on the caldera wall below Volcano House indicate to R.L. Christiansen (written commun., 1984) that this indeed happened. Likewise, the steep (60°–80°) inclination of fine 1790 ash beds (fig. 15.9) on the low southwest caldera wall is more likely to be the product of plastering of fine moist debris against the steep bedrock face by a steaming base surge than of draping by airfall deposition. These steep beds have been sharply truncated by erosion at the heads of nearly all the major caldera-wall gullies studied south of Crater Rim Road. A base surge acting in an erosive mode could have affected nearly universal truncation almost instantly. Such a surge would have had to occur late in the 1790 activity because at least part of the upper lithic unit is truncated (fig. 15.7*A*). The erosion required to form the uncomformity between golden pumice and 1790 beds might have been caused either by a base surge or by other more common surface processes.

It seems unlikely that the sandy gravel layers (figs. 15.5, 15.6) and the cobbly rubble (fig. 15.9) lying between golden pumice and the truncated 1790 beds in both the upper and lower reaches of the caldera-wall gullies are the result of base surges, because this reworked debris has been transported back toward the caldera floor rather than outward. Such debris layers were probably deposited by

FIGURE 15.12.—Angular unconformity of coarse pumice on fine-grained, well-layered 1790 ash on southwest flank of Cone Peak, about 80 m N. 16° E. from benchmark. U.S. Geological Survey photograph by J.D. Griggs.

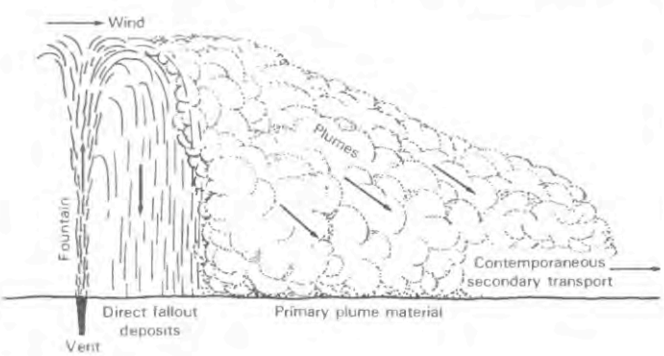

FIGURE 15.13.—Diagrammatic sketch of lava fountain, wind-drifted plumes, and related deposits. Variations in fountain height and character can produce superimposition or interlayering of different types of primary pumice deposits.

more slowly acting colluvial and fluvial processes. Relations in the caldera-wall gullies thus suggest that erosional truncation of 1790 beds could have occurred as a final gasp of the 1790 activity, but the deposition of reworked lithic layers may have occurred later and more slowly.

Pumice accumulations in the Kau Desert provide some insight on these relations. Along the western edge of the desert, a little northwest of the Kau Desert trail and about 1 km outward from the caldera rim (Kilauea Crater quadrangle), a wide fluvial arroyo 1 m deep has been eroded in 1790 deposits and older lava. Within this channel is a dissected alluvial fill of gravel, sand, and silt composed largely of reworked 1790 lithic material, capped by the golden pumice (fig. 15.14). The amount of fluvial work accomplished here before pumice deposition must have required a significant part of the 1790–1823 interval. In this same area, the golden pumice in many places rests directly upon lava bedrock from which the 1790 deposits must have been stripped before the pumice was laid down.

A favored setting for remnants of golden pumice in the Kau Desert is small niches on the flanks of little residual scabs, 30–50 cm high, on the eroded crusted surface of the 1790 upper lithic unit. Resistant overhanging ledges on such scabs make the pumice superficially appear to be interbedded with the lithic layers, and excavation is required to reveal that it is only inset (fig. 15.15). A secondary crust on the pumice, incorporating lithic fragments shed from the overhanging ledge, further obscures relations. Considerable modification of the surface of the crusted and irregularly cemented 1790 lithic layer by differential weathering, rainbeat, aqueous sapping, and probably eolian erosion had occurred to produce the scabs and their niches before the pumice was emplaced. Such modification could easily have required two or three decades. The overhanging ledges strongly suggest that erosion occurred after rather than before cementation. Even though most accumulations of golden pumice in the Kau Desert more than a few hundred meters from the caldera have probably formed by eolian reworking, such reworking likely occurred soon after pumice eruption, because newly formed pumice is very susceptible to eolian transport by the strong and prevailing northeast trade winds. Relations in the Kau Desert thus suggest pumice emplacement late in the 1790–1823 interval.

Another temporal question is the time involved in depositing the golden pumice and associated materials. The microstratigraphy of these units, as exposed in the walls of the caldera-wall gullies, strongly suggests that this was not a single brief episode. Successive eruptions of pumice were separated by intervals during which erosion created disconformities within the deposits, and stripping of detritus from the adjacent caldera wall introduced layers of pumiceous, lithic, or mixed pumiceous-lithic debris. During the period of golden pumice eruption, construction of the detrital apron at the base of that wall by colluvial, fluvial, eolian, and airfall processes was continuing.

Under current climatic conditions, the Kilauea summit is occasionally subjected to downpours of rain that create freshets and sheet floods across the surface of the detrital apron. In some years, several such events occur, in others none. Similar events probably occurred within the 1790–1823 interval and would have been capable of creating the erosional disconformities within the pumice sequence and introducing the interlayers of reworked debris. The time required to produce the golden pumice sequence may therefore have been anywhere from part of a year to several years.

Eruptive activity within Kilauea was greater than normal from about 1820 to 1832 (Hitchcock, 1911, p. 160–182; Macdonald and Abbott, 1970, p. 69–72), and it involved refilling of eruptive centers and associated lava fountaining. Native reports (Dana, 1891, p. 45) suggest that eruptive activity in Kilauea between March and June of 1823, before Ellis' visit of August 1 that year, was greater than anything occurring between 1790 and 1820

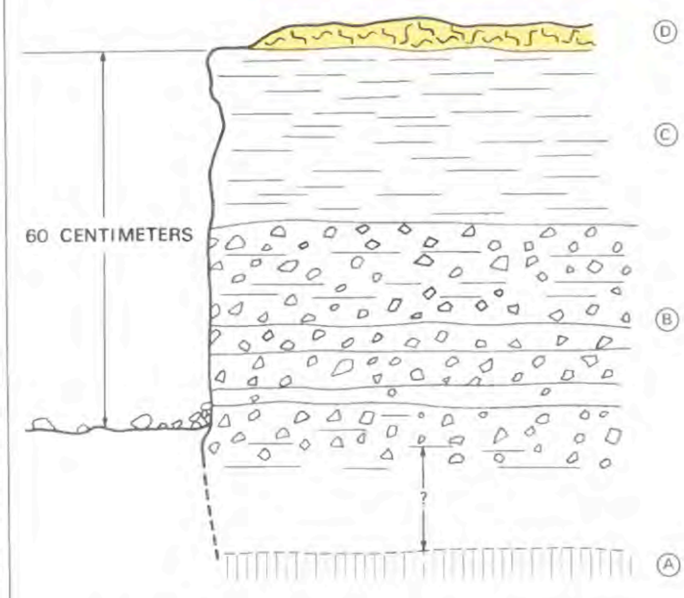

FIGURE 15.14.—Streambank exposure showing floodplain sand and silt (C) and fluvially reworked 1790 gravelly lithic debris (B) lying between coarse golden pumice (D) and the 1790 upper lithic unit or lava bedrock (A), northwest margin Kau Desert, 1 km southwest of Kilauea caldera.

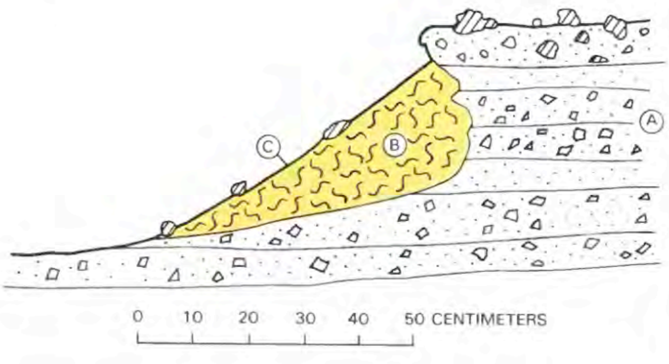

FIGURE 15.15.—Inset of crusted golden pumice within niche on flank of erosional scab on surface of upper lithic unit of 1790 deposits, Kau Desert. A, crusted upper lithic layer (1790); B, golden pumice; C, surface crust incorporating secondary lithic fragments.

(Goodrich, 1826, p. 27). The interval 1820–1823 appears adequate to accommodate the golden pumice, and the reported high degree of activity in Kilauea starting about 1820 favors that period.

Exactly when Halemaumau came into existence is not known. The crater probably did not exist as a specific topographic feature until some time after the 1790 outburst, for whose deposits it apparently was not the source (Stearns, 1966a, p. 134). A map drawn by Byron's lieutenant, Malden, in 1825 (Brigham, 1909, p. 45) shows a fairly large pit at the Halemaumau site, and various other early observers (Goodrich, 1826, p. 24; Ellis, 1827, p. 164, 170; Dana, 1891, p. 46–54; Brigham, 1909, p. 43–44) identified the southwestern part of Kilauea caldera, near the present Halemaumau, as the site of most intense activity. Although Halemaumau did not become a single crater until about 1905 (Richter and others, 1962, p. B53), we are intrigued with the speculative thought that the golden pumice may be a product of early activity of the volcanic conduit destined to determine the location of this present-day fire pit of Kilauea.

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