NOTES ON THE 1916 ERUPTION OF MAUNA LOA

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The writer's observations and comments on this eruption divide naturally into four parts:

I. Distant observation and photographic record of the outbursts of fumes on May 19, and of the beginning of flow on May 21–22, 1916.

II. Observation at the front of the Honomalino branch of flow on May 23.

III. A hurried reconnaissance of the Kahuku branch of flow, and of the flow-source region, on May 30–31.

IV. A thorough examination and photographic record of conditions throughout the region of the source of flow, made in the company of Dr. A. L. Day, in the six days, June 28—July 3, 1916.

Treatment under these headings makes for a somewhat extended and rambling account; but it has been found very difficult to present the complicated sequence of observations, which in some respects are unrelated, in any more succinct way.

I[1]

The beginnings of this eruption were noticed first in the early morning hours of May 19, 1916. No immediate premonitory symptoms were recognized previously. The earliest observations which have come to notice were made by Captain D. F. Nicholson, of the steamship "Hamakua," and by Mrs. R. A. McWayne, of Papa.

At about 3:45 in the morning, while sitting on the bridge as the "Hamakua" was steaming around South Point, Captain Nicholson experienced an earthquake. The sea was smooth and

[1] Much of the matter in Part I was published at once in the *Weekly Bulletin* of the Hawaiian Volcano Observatory, IV, No. 5, pp. 34–37; but this report was necessarily fragmentary, and partly erroneous, so it is restated here.

the weather calm and cloudless. Suddenly the ship trembled from stem to stern, as though it had grounded on a beach, and loose things in the ship's galley were disturbed; also the smooth sea surface suddenly became agitated violently by the commingling of several different systems of waves, an action which kept it in a state of turmoil for about a minute. (No shock so strong as this one was recognizably registered in the Whitney Laboratory of Seismology at Kilauea.)

A little later, at about 4:15 A.M., Captain Nicholson heard a sound lasting for about three seconds, which he likened to a volley of musketry, and he then saw what he described as a spiral column of fumes rising from a point high up on the south flank of the mountain. From her residence above the road near Papa, Mrs. McWayne in the early morning hours saw a bright glow high up the mountain.

During the morning and forenoon hours of May 19 a swarm of local earthquakes was registered at the Whitney Laboratory. All these were extremely feeble shocks, even when considered from the seismographic point of view. The earliest of them was recorded a little before three in the morning. Beginning in the late forenoon a lull followed, less than twenty-four hours in duration.

Throughout the evening and night of May 18, and the morning and forenoon of May 19, the weather was brilliantly clear. Looking westward from the Hawaiian Volcano Observatory, situated on the northeast margin of the crater of Kilauea, one could see nearly the whole profile of Mauna Loa outlined sharply against the sky. From late evening until dawn there was brilliant moonlight. Until midnight, and at 6:15 A.M., no signs of eruption were seen from the vicinity of the observatory. However, at about 6:15 A.M. the beginning of a fresh outburst of fumes, high on the mountain slope, was seen by Captain Nicholson, whose ship had then come to anchor at Honuapo.

At about 7 A.M., perhaps a little before, a definite outbreak and uprush of fumes became visible at Kilauea. At first a group of cloud-forms appeared high up on the south flank of Loa, rising from behind the mountain profile at a distance of at least twenty-five miles, as viewed from near the observatory. Here these were

first seen by Joseph Moniz. Though their appearance and development exhibited peculiarities, Moniz at first thought them to be ordinary cumulus clouds, such as frequently rise from behind the mountain. Yet they held his attention. After about ten minutes, since they continued to rise straight upward at the same place, he pointed them out to others; but still there was doubt as to their character, and he allowed more than a half-hour to pass by before he called the attention of the writer to them, at about 7:35 A.M., having grown surer that they were columns of fumes.

When first seen by the writer there were two chief standing columns in which fumes were swirling rapidly straight upward and merging in a double cumulus crown. The column higher up the slope was somewhat larger and taller than that lower down; and these were then separated by a clear interval whose width was about the same as the diameter of the larger column—about 1,000 feet. As soon as possible the writer began making a series of photographic records of this action, illustrating its development throughout the rest of its duration.[1] Five of these are shown here, Plate II, *a*, *b*, *c*, *d*; Plate III, *a*. The life of this outbreak was short.

The higher fume column then rose above the mountain profile probably from 11,000 to 12,000 feet, and the lower from 8,000 to 10,000 feet. Very quickly other subordinate columns appeared, first at both sides and then in between the chief ones, and soon all had merged into a single pillar of uprushing fumes, issuing more and more copiously and rising to higher and higher altitudes. By 7:45 (Plate II, *a*) the diameter of this column had thus increased to more than a mile, where a little earlier the total width including the clear space did not exceed 3,000 feet. The column had now reached a height of 15,000–18,000 feet above the mountain profile. Its stem resembled a huge column fluted with drapery hung in simple vertical folds. The cumulus crown still showed a double head, and thus continued to indicate the positions of the two dominant fume columns which, in reality, persisted throughout

[1] These views—12 (14) in all—were made on Wratten Panchromatic M plates, quarter-plate size, through a K_3 filter and a Zeiss Double Protar lens, F = 13 cm., with a stop of *f*45. Time exposures of about five seconds were made with the earlier views; but, with increasing actinicity, the later exposures were clipped a little short.

the outbreak. Also a smoke ring is shown encircling the upper part of the column below the crown. By eye observation the writer did not notice this ring until about 7:50 A.M. Despite this he feels confident that it had not begun to form when he first saw the eruption cloud.

After 7:50 A.M. the form of the eruption cloud underwent rapid changes as the continued emanation of fumes added to its bulk, and convection currents and varying winds at different altitudes continually reshaped it. At 8:00 A.M. the diameter of the stem had increased to from $1\frac{1}{2}$ to $1\frac{3}{4}$ miles and the smoke ring, which had rapidly enlarged, had begun to fray and spread horizontally about equally in all directions, except for a slight elongation toward the northwest, forming the striking mushroom shown in Plate II, *b*. By this time the crown had reached a height of 20,000 feet, or more, above the mountain profile, and its tip was just beginning to fray in the upper wind.

At a little after 8:00 A.M. the uprush of fumes began to dimish, and by 8:30 the two dominant columns were again separated, and the subordinate columns had ceased to rise continuously. The fume cloud had spread rapidly at the level of the smoke ring, forming a cloud blanket, and this, with the fraying and drift to eastward from the summit of the crown, gave rise to the beautiful cloud-form shown in Plate II, *c*. This has been likened aptly to a ballet dancer. The emanation of fumes continued to diminish rapidly, as is emphasized in the view (Plate II, *d*) taken at 9:05 A.M. Only a graceful cloud-form then remained, with thin columns of rising fumes.

By 10 A.M. (Plate III, *a*) it required keen observation to detect any further output of fumes; and by 10:30 this could be made out only by experienced eyes. By 11:00 A.M. the action was doubtful, and it grew more and more doubtful afterward—though cloud-forms occasionally appeared where undoubted fume columns had been rising. By noon nothing could be seen but a frayed stratum of high cloud overspreading the sky above the mountain. This exhibited ripple-marking, like cross-waved cirrus. It persisted until after sunset.

From about 8:30 A.M. on, short-lived, subordinate columns, wisplike in appearance, were noted at points a little higher up the slope than previously and at points much farther down the slope also, over a span from five to seven times as great as the width of the fume column at its greatest. These lateral columns did not persist individually, and gradually they ceased to appear.

Until the smoke began to fray and spread out like a blanket, the columns of upcurling fumes were fleecy white in appearance in the bright morning sun, with cream tints also, like cumulus cloud; and so too was the cumulus crown. As the blanket spread, however, it shadowed first the column and then its own lower surface, so that these shaded portions took on a faint, graduated coloring in which brownish and purplish tones of a faded-out quality were commingled with various shades of gray. This coloration developed quickly with the horizontal outspread of the fumes. No truly dark-colored fumes were seen.

After the cumulus crown had risen into the upper air and had begun to fray and drift eastward, such action continued until the lessened emanation of the fumes brought it to an end, late in the forenoon. Altogether, however, only a small percentage of the fumes reached the uppermost levels. Most of the drift was to the northwestward. By 8:00 A.M. this tendency for the horizontal fume-cloud blanket to draw out in the northwest direction was noted. By 9:30 the drift in this direction of the blanket as a whole had become noticeable, and by 10:30 such shifting was marked. This spreading and drift of the cloud blanket to the west and northwest until it stretched out back of the mountain profile, so as to extend below the skyline, made a cloud-colored background against which were rising the cloud-colored fumes, slightly tinted with brown. This made the fuming very hard to see, but there is no doubt of its rapid and progressive diminution after 8:00 A.M. During the afternoon no rising fumes were seen definitely. But for a very short time, just at sunset and after, very thin, translucent fumes were seen, brown in the transmitted light of the western sky.

In the early evening there was cloud and mist intermittent with brief, clear glimpses. From the observatory no definite glow could be seen, but there appeared to be a very faint radiation of

light over the dark sky from a point on the slope near the place of outbreak, though apparently a little lower down. That this emanated from the eruption was, and is, doubtful. It was too faint to be a positive illumination. However, it is the understanding of the writer that a faint glow was seen that night by Captain Nicholson when off Fisherman Point. This and subsequent events strengthen the probability that the faint light seen from the observatory was, in reality, from the eruption.

From the observatory no fumes were seen on the 20th, nor early on the 21st. From Kealakeakua, however, a "pillar of smoke" was seen early in the morning of the 20th by Miss Paris, a lifelong resident of Hawaii, familiar with the appearance of the mountain profile and with the characteristics of eruption here. This appeared high up on the south slope as seen from Kona. From the observatory, just at sunset in the evening of the 21st, thin brown-toned fumes were seen by transmitted light rising from near the place of outbreak. They appeared somewhat more pronounced, even, than on the evening of the 19th.

A small amount of lava probably was ejected at the time of this outbreak. This was reported as seen by men high on the slopes back of Naalehu and Kahuku, and in Kona, but the action was quickly over.

As mentioned earlier, the swarm of earthquakes which preceded and accompanied the first uprush of fumes was followed by a lull in the registration of shocks, of less than twenty-four hours' duration. After this they began to register in greater number than before, and in most instances with greater amplitude also. Intervals of quiet were short. The resumption and continuation of this seismic activity led to expectation of the outbreak of flow. Flow broke out, considerably lower down the slope than the place of first outbreak, in the late evening of May 21. With little doubt it was first seen by the writer, at about 11:15 P.M. It was at once brought to the attention of others at the Volcano House near by, and from here the news was spread by telephone on the eastern side of the island. On the western side of the island the outbreak was first noticed a little before midnight by Mrs. McWayne, and there the news was similarly spread.

Probably the outbreak was noticed by the writer almost as soon as it occurred. The night was clear, except for a low bank of clouds at the northeast. At 10:00 P.M. and earlier there was no suggestion of illumination anywhere along the southern segment of the mountain profile. At about 11:15 P.M. the writer went from the Volcano House to the observatory to see that the seismographs were in good working order before retiring (for, owing to the frequency and energy of the shocks, there was likelihood of the disarrangement of the struts and levers). The moon had just risen, but it was still hidden behind the bank of clouds at the northeast. However, a faint, diffuse moonlight spread over the sky. Upon mounting the observatory porch a very faint light was seen radiating from a point behind the mountain profile much lower down the southern slope than the place of first outbreak. The effect was similar to that sometimes produced here just as a planet or a bright star drops below the mountain profile. After inspection of the seismographs, however—perhaps three minutes later—this radiating light had become more definite, although the illumination of the sky by the moon had grown brighter. Almost at once it took on a pinkish hue. Then the word was spread instantly. Judging by the rapidity of its development in the first ten minutes after it was discovered, the outbreak did not take place (or more strictly, become visible from the observatory) earlier than 11:00 P.M., and probably not earlier than 11:10 P.M. Its discovery was little later than its occurrence.

During the ten or fifteen minutes after it was first seen the light at the fountainhead grew rapidly, and a small diffuse cloud of fumes appeared. This increased quickly also, and the glow steadily grew brighter and more ruddy. Soon the fumes at the top began to drift to the northwest up the mountain slope behind the profile. At the same time the progressive extension of a faint ruddy illumination down the slope behind the profile was detected. Flow had begun. As soon as possible, at about 11:45 P.M., the director of the observatory, Professor T. A. Jaggar, Jr., and the writer set out by motor and proceeded southwestward and westward to a point near the boundary of the Kona district of Hawaii beyond the western branch of the flow of 1907—a distance of about

sixty miles—and back again, arriving at the observatory at about 6:45 A.M., May 22. West of the village of Waiohinu several stops were made, both going and returning, to observe and photograph. All along the way from the observatory to the turning-point, and back again, a gradual and steady increase was noted in the height, amount, and spread of the fumes; and, until dawn, in the brilliancy of the illumination at the fountainhead. A well-defined northwest drift of the fumes in the upper strata of the air gradually developed.

From the upland flats along the road near Kahuku, and points to the westward, a long line of faint reddish illumination was seen extending to the right from the fountainhead. The course of this was judged to be about south-southeast from the source. At first it was considered to be light from the surface of a pool, but as it elongated rapidly it was soon thought to be a line of illumination above a flowing stream. This opinion was confirmed by a visit to this flow made later in the day by Messrs. J. W. Waldron and T. Hardy.

At about 4:00 A.M., May 22, we met Mr. Samuel Kauhane at the roadside gate of the ranch house at Kahuku—a man to whom the south slope of Loa was well known—and he expressed the opinion that the outbreak was higher up the mountain than the group of old cones at Puu o Keokeo. This proved to be the case.

Upon our return to the observatory a photograph (Plate III, *b*) was made at 8:30 A.M. (as early as weather conditions would permit), to show the position and development of the fume column and crown rising above the fountainhead. This view should be compared with Plate II, *a* to gain an understanding of how much lower down the mountain than the place of earlier outbreak the place of later outbreak is situated. The true azimuth from the observatory of the apparent center of this fume column at the source was found to be about S. 66° W. (the azimuths of the upper and lower limits of the greater column of the earlier outbursts were approximately S. 82° 30′ W. and S. 85° 30′ W.). This azimuth, projected upon the government map, indicated a source low on the southwest flank of the mountain, and, assuming this source to lie in the line of the south-southwest rifting from summit to sea, it was near the line of the upper branch of the flow of 1907 at an

altitude of 6,500 feet—as shown approximately on the government map—a little above Puu o Keokeo. This location was confirmed by field survey, though multiple mouths were found along a linear rift at the source, and the altitude was found to be a little higher than 6,500 feet at the lowest point of the actual source. The region of the fountainhead thus is between 30 and 35 miles west-southwest from the observatory.

In contrast to this, the region of the earlier outburst, determined by projecting the azimuths given above, is intercepted along the course of the great rift-line between approximate contour lines drawn on the government map, as follows: the upper and lower limits of the great trunk column of uprushing fumes are thus indicated at about 11,600 and 11,000 feet above sea, and the diameter of the column is thus indicated at considerably over a mile; similarly, the *approximate* upper and lower limits of the span marked by subordinate sporadic columns of rising fumes may be taken as 12,000+ and 10,000− feet, determining the width of this at five miles, or more. All these are approximate values. Nevertheless, this source is thus found to stand higher up the mountain than the early estimates placed it.

In the late afternoon of the first day of eruption, May 22, the writer returned to the southern part of the island, and spent the evening and night in observing the changes in the magnificent illumination from places along the road over the upland flats west of Kahuku. This locality was reached just at nightfall; it was then cloudy, with brief showers; however, before long the clouds lifted, though they continued to cover the sky. Little by little the character and extent of the illumination became visible.

Since the dark hours of the morning a great change had taken place. At the fountainhead both the action and the illumination were somewhat greater than when last seen in the early morning, but here the change was least. The faint red illumination extending toward the right (toward Waiohinu over upland Kahuku) had died out. But toward the left, toward Kona, a long line of brilliantly illuminated fume and cloud demarked the course of a flow which had rushed down the mountain toward Honomalino. In early evening this was still advancing at a considerable rate. The

marked illumination, which we may designate as the primary glow, was most brilliant at the fountainhead, and above the front of this flow (where its outflashing was augmented by the light from the burning forest); but also above the course of the flow between its front and source the glow was much brighter than the general sky glare. This formed a band of primary illumination whose length, as seen from the gate about a mile west of the ranch house at Kahuku, was very close to seven miles; and its brilliantly lighted arch rose about three-quarters of a mile above the mountain profile (Plate III, *c*).

A diffuse red glow covered the sky everywhere and, in early evening, low-lying cloud and fog banks clinging to the mountain slopes below the road, and illumined dimly by reflections from the cloud layer above, led to a current erroneous opinion that the flow already had advanced down the slope beyond the road in Kona.

Owing to the wretched state of the road surface, a serious congestion of motor traffic (some 250 motors headed westward and about 80 headed southward, toward a meeting-point near Honomalino, on a road too narrow for passing or turning except at widely separated places), and much uncertainty as to the exact course, rate, and behavior of the flow, the writer spent most of the night at a gate on the road about a mile west of Kahuku, where he returned after going to within three to four miles of a group of houses at Honomalino which stood in the apparent path of the flow.

The photograph (Plate III, c^1) shows the scene from this station as it appeared just before midnight, May 22. In this view, of course, the bright reddish glow which covered all the sky does not appear, but simply the brilliant arch of the primary illumination, as designated above. During the night the following changes were observed:

A little after midnight there was noticed a rapid spread of very brilliant glow to the right of the fume column rising at the fountainhead. This was a conspicuous feature of the action until after 1:00 A.M. It was thought to indicate a flow toward Kahuku. This

[1] Made on a Wratten Panchromatic M plate exposed 30 minutes at *f*/6.3.

judgment was confirmed by Messrs. Waldron and Hardy, who witnessed its outrush from the high camp they occupied that night.

Beginning gradually, probably before midnight, certainly as early as 1:00 A.M., there was noted a rapid decrease[1] in the brillancy of illumination above the line of flow extending toward Honomalino. By 3:00 A.M. this, as seen from our station, was quenched completely; there remained only the diffuse glow of the clouded sky and the brilliantly lighted column of fumes rising at the fountainhead, and a much subdued glow above the front of the flow. And this last was decreasing rapidly. By 4:00 A.M. the earliest light of dawn found the illumination at the fountainhead much like that of the previous morning, with the lines of illumination above the courses of flow almost wholly quenched.

Shocks of earthquake continued to occur. Some were strong enough to disarrange the struts and levers of the seismographs. This made it inadvisable for the writer to be absent from the observatory except at times when the director could be present; so, after a brief visit to the front of the Honomalino branch, the writer returned to Kilauea.

During the evening and night of May 23–24 it was seen from the observatory that the glow had extended far to the left of the fountainhead in a direction estimated at south-southeast. No such extension of the band of illumination had been seen in the evening or night of May 22–23. This was due to the renewal of flow toward Kahuku on a much larger scale than in the beginning. Ultimately the Kahuku branches developed much greater magnitude than those in Kona. During this evening and night, May 23–24, this glow was seen through shifting clouds, so that no good opportunity for making a photographic record presented itself in the earlier hours. And, owing to his complete loss of sleep on the two previous nights, the writer undertook no prolonged watch. During the evening and night of May 24–25 this illumination appeared elongated farther to the south, and perhaps slightly abated in intensity. A photographic record of this (Plate III, *d*)

[1] It should be noted that moonrise occurred between midnight and one o'clock, but that this decrease in illumination was positive, nevertheless, as evidenced by the glow above the Kahuku tongue.

was obtained in the early morning hours of May 25, from 1:15 to 1:45 A.M. In a lessening degree this glow was seen in the evenings of May 25 and 26, and very faintly on the evenings of May 27 and 28. On the latter date it was near to the vanishing point.

II

The writer reached the front of the Honomalino branch of this flow at about 11:00 A.M., May 23, at a point about three miles, by trail, above the road. Here the flow was of *a–a*, still advancing at a slow rate of speed. This was difficult to estimate on account of the irregular character of the ground and the brief time available for watching. Though moving much more slowly than earlier, the advance was still steady. Possibly the maximum forward movement of any considerable section of the front was ten feet in an hour. The average over the whole front was less, perhaps four to five feet in an hour. At this front the flow was narrow, not more than a quarter of a mile in width. The depth at the front was variable, from six to ten or fifteen feet. Its surface, both on the top and at the front and sides, was bristling with ragged points and edges of brownish-black *a–a*. In this surface were innumerable cracks, mouths, and ovens through which the red-hot matter shone out. From many of these blue flames were flaring fitfully.

According to the writer's observation, carefully concentrated on this point, its mode of flow at this stage was as follows:

At the front, between the top and bottom, there was a slow, forward, bulging motion of the intermediate layer, from four to ten feet thick. As this progressed it produced fragmentation of the thick, stiffened surface over it, pulling and breaking this away from its contiguous parts at the more slowly moving top and bottom, and also breaking it up into an irregular mosaic with the changing curvature of the surface of the front. At short intervals blocks of the fragmented surface would be rotated into unbalanced positions, when they would spall off from their own weight and drop to the foot of the front, leaving for a moment bright, red-hot scars where they had scaled away from the matrix within. Repeated examination of these scars showed continuous red-hot matter of very viscous consistency, which cooled very quickly, tending only to

bulge out a little without spurting or jetting. No cracks could be made out on these freshly bared, red-hot surfaces. They exhibited every appearance of a viscous continuum. Once they had crusted over, however, the tendency to crack and bristle again became noticeable. At this place the fragmentation and texture-forming of these rough-surfaced blocks suggested very strongly the breaking and cracking of candy pulled too long. There was no observable gas action.

The whole effect here was one of creep, or overrunning, with the plane of maximum rate of flow intermediate between the top and the bottom. The action was that of a very viscous, fluid or plastic, substance, flowing very slowly and exerting subsurface traction upon a surface crust too stiff to *draw* or *pull* much.

It is thought that the matter was here cooled to a point where it could still flow, or creep along, under blanketing, but once in touch with the air it set so stiffly that any further strain fragmented it. Pieces artificially broken away from the bulging surfaces cooled without further fragmentation, and without the development of *a–a-texture*[1] on those surfaces of the fragments which were glowing when broken away. These exhibited the rough fracture of cold basalt. The rough, pointed, and edged texture of the natural *a–a* surface was *seen* in some cases to be due to the drawing out of points and the shaping of rough edges as the blocks were tilted and rotated away from each other, and from the plastic matrix within, while the forward bulging movement was taking place.

The mechanism of the formation of *a–a* has been considered a very involved and complicated process, and the problems suggested by it difficult of solution. The writer does not consider that the observed action described above will serve to explain all cases and details. But it does, he considers, indicate strongly that *a–a*

[1] A word concerning *a–a-texture* may not be out of place. As seen in Hawaii *a–a* is not only block-lava, heaped flows of piled blocks and fragments of various shapes and sizes, but each of these fragments is a separate unit, and its whole exterior surface, in most instances, is characterized by an exceedingly rough aggregation of points, edges, blades, spikes, knobs, etc., produced there in the process of the spalling and transport of the blocks by the *drawing*, and possibly sometimes by spurting, of the red-hot viscous basalt.

generally results from fragmentation or granulation in the course of flows of lava grown too stiff for further plastic flow under the prevailing conditions—whether this results from rapid cooling due to rapid escape of gas, to slow cooling, or to stiffening due to the development of crystalline phases, throughout the mass, or in lumps so as to form a sludge. The time is not ripe for discussion and comparison of all these factors and their interrelationships.

But the action described above, with suitably conceived modifications applicable in the region of more rapid streaming, and where greater masses and higher temperatures are involved, appears to the writer to be capable of explaining *most* of the vagaries of surface texture and miniature surface forms exhibited by *a–a* in Hawaii. Everything that the writer has seen in connection with this outbreak, and all the reports that have come to his attention, indicate that there was no *excessive* evolution of volcanic gases from the molten lava on this occasion; and all indications are that the temperature of the melt has not been excessively high. This points to a *relatively* cool and viscous fluid. And so far this supports the view of its action sketched here. It is, of course, not unlikely that still other mechanisms are involved in the forming of *a–a*, and emphatically there is no disposition to question any which rest upon observation or sound rationale. However, to the writer it seems unnecessary to appeal to unobserved, recondite, special mechanisms to explain the fragmentation and textural qualities of *a–a*. This view is in accord with the tenor of a view expressed to the writer by Dr. William T. Brigham, of the Bishop Museum in Honolulu, that *a–a* is the slush ice, or floe ice, in a cooled and freezing stream (the granulation by motion of a stiff, overcooled fluid on the point of solidifying). This seems the best short expression of the idea..

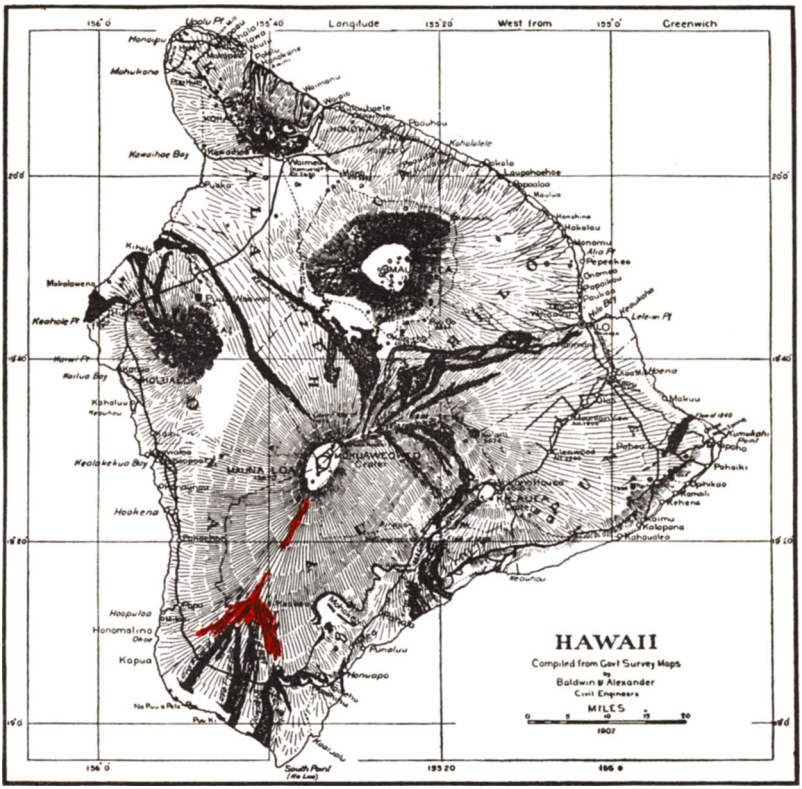
The writer saw the action just as the stream had slowed up, almost undoubtedly on account of failing supply at the source of this branch. Thus the failure of pressure from above and the radiation of heat all along the course led to rapid increase of sluggishness. At this stage of the flowing there was practically no gas action at the front. Blue fumes were rising from the surface, along with heat-disturbed air, but these were so thin that from a

tree near the front the writer was able to look a long way up the flow. The only hindrance to good seeing was the shimmer of the air produced by the heat radiation. The surface showed many oven-like openings, and a few small conelike forms were seen, but these were of temporary nature, and not true cones. No explanation of their formation occurred to the writer. One that was watched was slowly destroyed as the forward motion progressed.

The falling blocks made a tinkling sound, and the forward motion of the upper surface was accompanied by a low grinding sound, but these noises were low and inaudible at a short distance. The quiet character of the advance at this stage was very striking. At intervals loud detonations were heard. These were ascribed to the action of the hot lava on buried vegetation. The sounds made by the crackling of the falling trees and bushes were the loudest of the frequent noises, and the crackling produced by the burning of green vegetation was the most continuous and conspicuous. At this stage of the flow its approach was so quiet that it gave practically no warning at a distance of fifty yards. Trees were being felled by the flow, partly by burning through at the stump, but in some instances by overturning as a result of the forward motion of the flow.

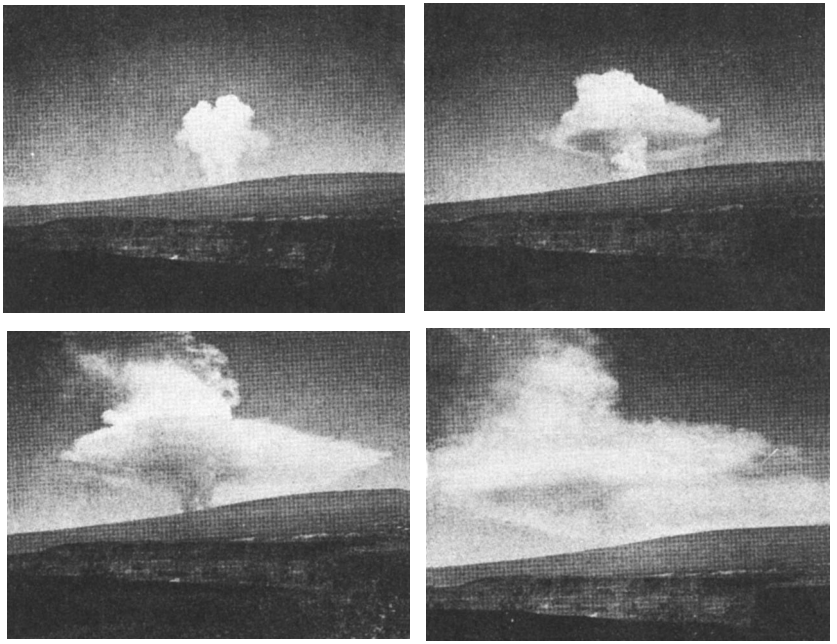
There were smells of subliming sulphur, sulphur acids, and of cinders and charcoal. None of these was strong enough to be very annoying. Others reported the smell of coal gas. This was not noted by the writer, but was noticed by a large number of people, and the fact must therefore be accepted. This was in the wooded region, and here these carbon-gas odors could be ascribed to the action of the lava on vegetation. However, along the Kahuku branch of the flow such carbon-gas odors were plainly noticed by many at points well above the wooded region, where vegetation was so scanty as to be negligible. And some have reported noticing these odors near the lower end of the source in a barren region where there is strictly no vegetation. It seems, therefore, that carbon gases almost unquestionably were emitted from the lava of this eruption.

[*To be continued*]



Map of Hawaii, showing *diagrammatically* in red the flow of 1916, and the upper outbreak source, with older flows in black. On this map the upper portion of the flow of 1907 is not indicated *precisely*. This passed down the mountain on the west side of Puu o Keokeo.

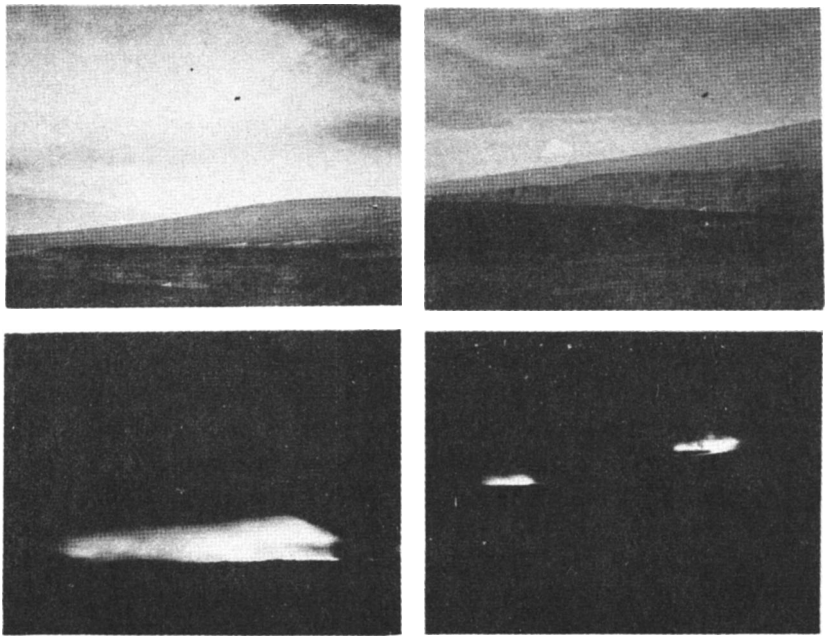
a *b*



c *d*

Views *a*, *b*, *c*, and *d* show successive stages in the development of the fume cloud [*a* at 7:45, *b* at 8:00, *c* at 8:30, and *d* at 9:05 A.M.] of the earlier outbreak on May 19, 1916, as seen at a distance of about 25 miles, in a direction a little south of west, from the Hawaiian Volcano Observatory.

a *b*



c *d*

a, showing a later stage, at 10:00 A.M., in the spread of the fume cloud of May 19, 1916.

b, showing the fume cloud above the head of flow at 8:30 A.M., May 22, 1916, as seen at a distance of 30–35 miles, in a direction S. 66° W. from the Hawaiian Volcano Observatory.

c, showing the brightly illuminated arch, or "primary glow," above the source, and the course of the Honomalino stream, as seen just before midnight, May 22, 1916, at a distance of about 10 miles in a direction about N.N.W. from near Kahuku. This illuminated band or arch was about 7 miles in length and about ¾ mile in height. Besides it, a bright, diffused red glow covered the entire clouded sky—an effect not shown by the view.

d, a view from the Hawaiian Volcano Observatory exposed from 1:15 to 1:45 A.M., May 25, showing the illuminated fume cloud above Kilauea (lower left) at a distance of 2½ miles from the camera, of about 1,500 feet spread, and the illumination above the Kahuku stream (upper right), partly hidden by clouds at the south, distant 30–35 miles, with a spread of about 5 miles and a height of a little less than 1½ miles at maximum.