OCCASIONAL PAPERS

No. 29

Geomorphic Divisions of The Island of Hawaii

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UNIVERSITY OF HAWAII BULLETIN
VOLUME XV JUNE, 1936. NUMBER 8

The University of Hawaii Bulletin is issued once in each of the following months: November, December, January, February, March, April, May, June, July and October. Entered as second class matter at Honolulu, T. H., under act of Congress of August 24, 1912.

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INTRODUCTION

The Island of Hawaii exemplifies in striking fashion the wide applicability of the Structure-Process-Stage formula of Davis in the description and interpretation of land forms. The structure in this case is volcanic, and it includes a great variety of both positive and negative forms. Processes include weathering and stream erosion under rainfall ranging from 70 to 200 inches annually, the action of the wind in drier districts, marine erosion, and a variety of other erosional and depositional coastal phenomena, Pleistocene glaciation and the work of ice and snow at high altitudes. The great contrasts in rainfall, with a wide range in age of the volcanic structures gives the island a far greater variety of stages reached and hence variety of geomorphic aspect than is found in any other island of the group and probably than in any other truly oceanic island in the Pacific area.

Over most of Hawaii, the original volcanic structures are strikingly apparent and but little modified. Thus the study of these forms, merely located in this outline, should attract the physiographer who wishes to see in their initial form the volcanic features which are often so greatly modified in other islands and other regions.

The following geomorphic subdivisions of Hawaii are described in brief synoptic form, the descriptions being based on a 4-month reconnaissance of the island in 1929 under the auspices of the Hawaiian Volcano Research Association and supplemented by briefer visits in 1924 and 1935. The very fine topographic maps by the U. S. Geological Survey were studied critically before, during and after the field work.[1] The writer has discussed the names and

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[1] Wentworth, C. K., *Pyroclastic Formations of the Island of Hawaii*, (In Manuscript). Wentworth, C. K., "Mauna Kea, The White Mountain of Hawaii," *Mid-Pacific Magazine*, 48: 290-296, 1935.

and boundaries of the divisions with several of his colleagues, and is especially indebted to H. S. Palmer and J. W. Coulter of the University of Hawaii and A. E. Jones of the Board of Water Supply for constructive criticism.

GEOGRAPHIC RELATIONS AND GENERAL CONFIGURATION

Hawaii stands at the southeast end of a chain of volcanic mountains nearly 2,000 miles long, which rise to heights of 20,000 to 31,000 feet above the surrounding floor of the ocean. Of the height of the island, measured from the ocean bottom on the east, almost six-tenths is below sea level; of its volume possibly not over a thirtieth rises above the sea. This great bulk, submarine as well as subaerial, is the product of an enormous number of volcanic eruptions. Most of them have been effusions of lava, but associated with these have been a few explosive eruptions.

Hawaii is composed of five principal volcanic domes, located over crustal rifts or intersections of rifts. The larger two of the domes, Mauna Kea and Mauna Loa, form the chief mass of the island, extending from the southern point to the curving northeast coast. Kilauea is an independent dome forming a spur extending out from the east flank of Mauna Loa. Hualalai lies nearly due west of the saddle between Mauna Loa and Mauna Kea. The Kohala dome forms the northern lobe of the island.

Though the Kohala mass at the north end of the island has generally been regarded as oldest of the volcanic mountains, there has been much speculation concerning the order of formation of the domes and their relations to buried land masses. Present state of knowledge has been summarized by Stearns.[1] A similar outline of events is contained in an earlier statement by Jaggar.[2] The oldest land mass of the island is thought to be the buried dome of Ninole basalt probably poured from a vent about eight miles southwest of the summit of Mauna Loa. Next the Kohala dome was formed on the line of weakness known as the Kea rift. Stearns believes that the erosion and great amount of subsequent filling of the valleys of the Ninole dome by lava flows indicates that this dome was formed and dissected at

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[1] Stearns, H. T. and Clark, W. O., "Geology and Water Resources of the Kau District, Hawaii," *U. S. Geol. Survey, Water Supply Paper 816*, 102-104, 1930.

[2] Jaggar, T. A., Jr., "Seismometric Investigation of Hawaiian Lava Column," *Seis. Soc. Amer. Bull.*, 10: 190-195, 1920.

an earlier date than the Kohala dome, though no direct and immediately conclusive evidence is known.

Following the formation of these two domes, volcanic activity apparently shifted to the point of intersection of the Loa and Kea rifts and much of the present dome of Mauna Kea was formed. Following a period of faulting which involved parts of the Ninole and Kohala domes, it appears likely that the Kilauea vent was opened at the point of intersection of faults of the Mauna Kea rift system with faults which had been developed on the east side of the Ninole dome. At about the same time and in a similar manner it is thought that the growth of Hualalai commenced. Still later, a new vent on the northeast slope of the old Loa Ridge became active and the present summit dome of Mauna Loa and the caldera of Mokuaweoweo were formed. This, in brief, is thought to have been the sequence of dome formation by which the subaerial portion of the present island of Hawaii was built up.

COMPONENT VOLCANIC DOMES

General dimensions of the five domes are given in the following table:

TABLE I

Dimensions and Form of the Domes of Hawaii

Name	General Outline	Length-Width (Miles)	Area Square Miles	Area Per Cent	Summit Elevation
Kohala	Elliptical	22 - 15	234	5.8	5505
Mauna Kea	Elongate	51 - 25	919	22.8	13784
Mauna Loa	Three-pointed star	75, 73, 64	2035	50.5	13680
Hualalai	Paraboloid	24 - 20	290	7.2	8251
Kilauea	Sigmoid Belt	51 - 14	552	13.7	4090

THE KOHALA DOME

The southwestern side and northwestern end of the Kohala dome are only slightly eroded and the surface retains the almost unbroken symmetry of the original domed surface. Following the slopes around the north end of the island, the dissection becomes more and more pronounced as a result of the heavier rainfall of windward exposure and at the southeastern end of the Kohala dome is the profoundly dissected area extending from Pololu Gulch to Waipio Gulch. This contrast in degree of dissection and some

probable differences in history, together with the concentration of cinder cones in the summit area of the Kohala dome, constitutes the basis for recognizing three geomorphic areas listed below.

The Mauna Kea Dome

The northern part of the Mauna Kea dome overlaps the Kohala dome. In turn, along its southern and southwestern sides, the Mauna Kea dome is overlapped by Mauna Loa lava flows along lines extending east and northwest from the saddle at Humuula. Between the Mauna Loa flows and the Kohala dome the western shoreline of the Mauna Kea dome is only 4 miles long. Between Hilo and Waipio the northeastern slope of the dome passes under sea level along a coastline approximately 45 miles in length, interrupted by wavecut cliffs ranging from fifty to several hundred feet in height and probably by corresponding submarine benches.

The lower slopes of the Mauna Kea dome have an average gradient of 500 feet to the mile. The upper portion of Mauna Kea is sub-circular with long and short diameters of 16 and 13 miles at the 7,000 foot level. It is more cone-shaped than the dome of the lower part of the mountain. On all sides there is a pronounced steepening of slope above elevations of six to seven thousand feet, and continuing to the level of the great summit plateau. On the southern part of the east slope this steeper slope extends from 6,500 to 11,500 feet. On the north side, above Makahalau, the limits are 6,300 and 11,750 feet. On the west there is a gradual increase between 6,000 and 8,000 feet and the summit plateau is reached at 12,500 feet. Pronounced steepening on the south side is found at 7,200 feet.

Disregarding the cinder cones, the summit area of Mauna Kea is a nearly flat, only slightly domed surface about 5 miles in diameter, and has elevations of 12,500 and 11,500 feet on its west and east margins, respectively. The lateral slopes of this summit area fall not over 500 or 600 feet to the mile in contrast to the border slopes of the summit mass, which generally slope 1,500 to 2,000 feet to the mile. The center of the upper dome reaches about 13,000 feet and is surmounted by a group of summit cones which rise nearly a thousand feet higher.

The Mauna Loa Dome

The three-pointed ground plan of the Mauna Loa dome is due to the indentation of its lower parts by the Mauna

Kea, Hualalai and Kilauea domes. Between these bounding domes two narrow Mauna Loa fingers reach the coast, one south of Hilo and the other at the northwest shore south of Puako. The third arm of the Mauna Loa dome includes the entire southwestern part of the island, extending from Punaluu nearly to Kailua, with a coast seventy-five miles long.

The eastern finger has an average slope of about 250 feet to the mile down to the elevation of about 200 feet. Seaward, the slope is about 40 feet to the mile and the topographic details of certain parts of this surface suggest that they may be remnants of an older surface, only parts of which have been veneered by later Mauna Loa flows. The eastern slope of the south arm averages 1,000 feet to the mile. The southwestern and western slopes adjacent to the great southwest ridge, do not exceed 400 feet per mile, but increase to 750 feet and continue at this gradient down to the smoothly curving shoreline of the Kona district. The profile of the southwest ridge has a slope scarcely exceeding 250 feet to the mile. The average slope of the northwestern finger from Humuula to Puako is less than 250 feet to the mile. At the summit of Mauna Loa is the great caldera of Mokuaweoweo.

The Hualalai Dome

The summit of the Hualalai dome lies about 3,100 feet above and seven and one-half miles northwest of the saddle between it and Mauna Loa. The upper portion of the dome, down to 5,000 feet on the southeast and 3,000 feet on the north and west sides, has steep slopes which in places reach 1,400 feet to the mile. Below these elevations the slopes decrease and do not exceed 500 feet near the west coast and 300 feet along the northwest shoreline.

The Kilauea Dome

The exposed part of the Kilauea dome has the form of a long, slightly sigmoid belt which parallels the southeast coast of Hawaii. The summit of the dome is almost buried by Mauna Loa flows and only about 4 square miles of its surface slopes toward Mauna Loa. The eastern slope, extending 25 miles to the east cape of the island, averages only about 150 feet to the mile. South of the eastern rift zone, all the slopes face the southeastern coast and have gradients of 250 to 400 feet per mile in the eastern part. South and southwest of the summit caldera the Kilauea slopes down to 2,500 feet range from 100 to 200 feet per

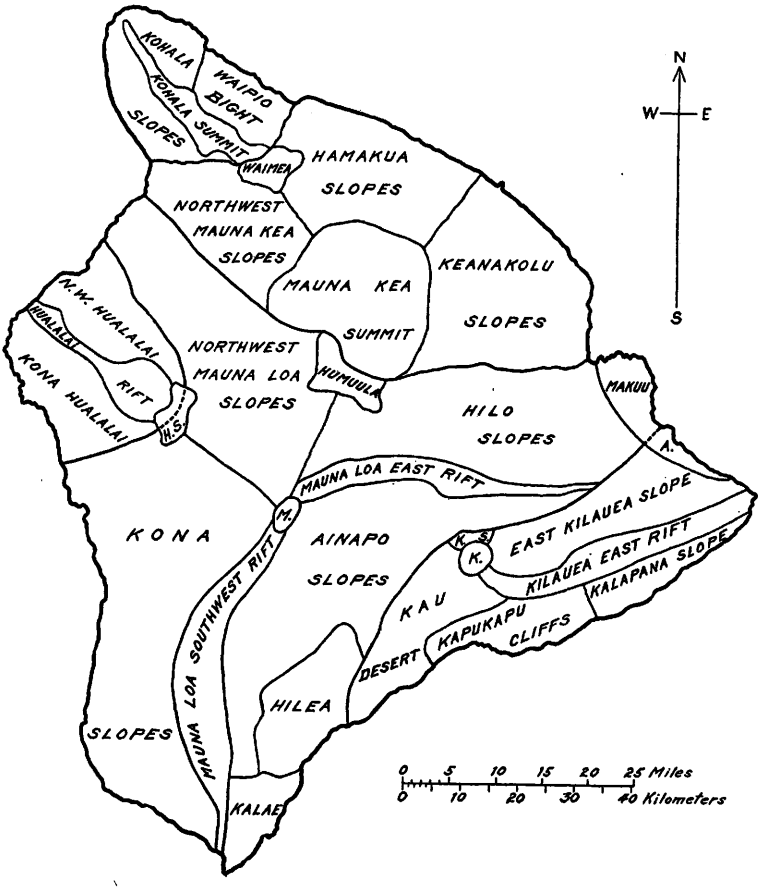

FIGURE 1—Map of Island of Hawaii, showing boundaries of geomorphic divisions. Dotted lines show margins of domes where these do not correspond with boundaries of geomorphic divisions.

mile. Seaward from this contour is a system of fault scarps which account for a marked steepening of the slope. Westward is a belt of Kilauea slope which falls toward the southwest and parallel to the Mauna Loa margin at the rate of about 165 feet to the mile.

GEOMORPHIC DIVISIONS

On the basis of original volcanic forms and subsequent modification by erosion, the island has been divided into the thirty geomorphic areas described below and listed in the following table:

TABLE II

Names and Areas of Geomorphic Divisions (1)

Name	Area (Sq. Mi.)
KOHALA	
Kohala Summit	50
Kohala Slopes	116
Waipio Bight	68
MAUNA KEA	
Mauna Kea Summit	209
Hamakua Slopes	218
Keanakolu Slopes	307
Northwest Mauna Kea Slopes	163
Waimea Plain	22
MAUNA LOA	
Mokuaweoweo Caldera	7.9
Mauna Loa East Rift Zone	74
Humuula Saddle	33
Hualalai Saddle	15
Mauna Loa Southwest Rift Zone	128
Ainapo Slopes	381
MAUNA LOA, Cont.	
Hilo Slopes	328
Northwest Mauna Loa Slopes	355
Kona Slopes	514
Kalae Slopes	53
Hilea Blocks	112
HUALALAI	
Hualalai Summit and Rift Zone	56
Northwest Hualalai Slopes	105
Kona Hualalai Slopes	122
KILAUEA	
Kilauea Caldera	9.6
Kilauea Saddle	6.5
Kilauea East Rift Zone	92
Kilauea East Slopes	160
Makuu Apron	59
Kalapana Slopes	57
Kapukapu Cliffs	81
Kau Desert	128
TOTAL	4030

(1) Totals for the Mauna Loa, Hualalai and Kilauea domes, will not quite check those shown in Table I because of the two divisions, Hualalai Saddle and Makuu Apron, which consist of parts of two domes.

KOHALA SUMMIT

Axial and summit portion of Kohala dome, marked by upward of fifty pyroclastic cones at elevations from 500 feet at north end to 5,000 feet in summit portion. Merges with Kohala Slopes on northeast, west and southwest; cut by Waipio Bight on east and by Waimea Plain at south. Long weathered surface only slightly dissected by streams of fairly well-established drainage net.

Kohala Slopes

Northeast, west and southwest slopes of Kohala dome. Well-developed drainage system on east side, with fairly complex branching, gradually gives way around north end to rudimentary pattern on west. Increase in drainage lines on southwest. Valleys on east are cut 150 feet deep and are complexly branched. Original dome slopes vary from 500 to 700 feet per mile. On east side are 75 per cent intact, on west are 99 per cent intact. West and north sea cliff under 50 feet, east cliff ranges to 100 feet high.

Waipio Bight

Deeply dissected segment of east slope, Kohala dome. Coast marked by cliff 500 to 1,000 feet high, embayed one to two miles inland from adjacent coastline. Original upper surface accordant with Kohala slopes to north. Several large, flat-bottomed, apparently drowned and aggraded, valleys run far inland with blunt, steep-walled heads and side cliffs, 1,000 to 3,000 feet high. Other valleys widened at mouth are partially hanging at the sea cliff. Not over 50 per cent of original surface intact. Unusual degree of valley and cliff cutting possibly induced by faulting or possibly due to much greater age than adjacent sectors, but adequate data not available.

Mauna Kea Summit

The part of the Mauna Kea dome marked by numerous cinder cones lying above the contour of 6,000 feet. Its lower slopes, up to 11,000, or 12,000 feet, on different sides, rise 1,000 feet or more to the mile and are markedly steeper than slopes below about 6,000 feet. A few drainage lines reach 12,000 feet; Lake Waiau perennial at 13,007 feet. Clear marks of Pleistocene glaciation above 11,000 feet generally and of modern wedgework of ice and snowbank creep.

Hamakua Slopes

Northern lower slope Mauna Kea dome, Kemole to Ookala. Slopes of about 500 feet per mile with numerous consequent drainage courses in shallow trenches cut in ash mantle. Near coast and to southeast valleys are deeper and cut in rock. Coastal cliff mainly 50 to 250 feet high; 350 feet at southeast.

Keanakolu Slopes

Eastern, lower slopes Mauna Kea dome, southeast of Ookala. Slopes averaging 400 feet per mile, generally ash-mantled and with close-spaced consequent drainage pattern,

especially between elevations of 4,000 and 1,000 feet. In this zone valleys are 15- to 25-foot trenches, as many as 5 to 15 to the mile along the contours. Sharply overlapped by Mauna Loa flows at south along Wailuku River.

NORTHWEST MAUNA KEA SLOPES

Entire exposed lower slopes facing west coast. Grade 300 feet per mile. Rudimentary drainage pattern, 3 or 4 channels continuous from summit area. Terrane is old pahoehoe with large mounds in places.

WAIMEA PLAIN

Gently sloping surface of saddle where growing Mauna Kea dome overlapped Kohala dome. Through axis of saddle for 10 miles relief is only 350 feet. Kohala summit rises sharply on the north. Waimea Plain merges with Hamakua Slopes on east and with Northwest Mauna Kea Slopes on southwest. Terrane marked by a few small pyroclastic cones and by extremely irregular contours typical of volcanic saddle areas.

MOKUAWEOWEO CALDERA

Summit area of active volcano, Mauna Loa, marked by elongate line of calderas dominated by Mokuaweoweo, 2.8 by 1.7 miles, with domed floor and surrounded by tangential fault scarp walls 50 to 650 feet high. Other smaller pit calderas, axial rift cracks and tangential faults with downthrow toward center.

MAUNA LOA EAST RIFT ZONE

Zone 2 to 3 miles wide, down axis of ridge-like projection of eastern Mauna Loa dome, marked by small vent cones, vent ramparts, cracks and the like, over a deep-seated rift along which eruptions have long taken place. Topographic divide between Hilo Slopes and Ainapo Slopes. Cut off eastward at about 3,000 feet by overlap of Kilauea flows.[1]

HUMUULA SADDLE

Gently sloping saddle at lava-parting where Mauna Loa dome encroaches on Mauna Kea dome. A central, nearly level area is bounded on the south by an area of reduced north-facing Mauna Loa flow slopes and on the west and east by reduced slopes of Mauna Loa lava flows, all in-

[1] According to A. E. Jones, the existence of earthquake foci along a line trending northeastward toward the Makuu coast suggests that the Mauna Loa East Rift may trend somewhat northward of the course shown in Figure 1. The latter is based on mapped topographic features.

cluded in the Saddle division. Slopes are reduced as a result of the turning of Mauna Loa flows to west or east because of obstruction by the Mauna Kea dome. Area marked by a few Mauna Kea cinder cones now surrounded as inliers by Mauna Loa lava flows, including both aa and pahoehoe.

Hualalai Saddle

Gently sloping saddle area where Mauna Loa overlaps Hualalai dome. Reduced slopes characteristic of saddle areas. Marked by one undrained depression and several small pyroclastic cones, related probably to adjacent Hualalai summit and rift division.

Mauna Loa Southwest Rift Zone

Zone 2 to 5 miles wide extending from Mokuaweoweo caldera area to Kalae, the south tip of the island. Is the axis of the southwest ridge of the dome, built over the deep-seated, southwest rift, is marked by numerous vent cones, cracks and pits, and terminates in the fault scarp of Pali Mamalu or Pali o Kulani which forms the west boundary of the Kalae Slope.

Ainapo Slopes

Regular, lava-flow slopes south and east of Mauna Loa summit between northeast and southwest rift areas. Gradients range from 400 to 1,000 feet per mile. Flows chiefly pahoehoe at east, mainly aa at south. Area overlaps the Kilauea dome from Glenwood to Wood Valley; lower edge west of Volcano House marked by fault scarps parallel to Kilauea boundary. At south, Ainapo Slopes overlap but have not buried the Hilea Blocks division. West of Halfway House and up to 7,000 feet is area marked by moderately complete drainage pattern, remainder devoid of marked drainage lines.

Hilo Slopes

Mauna Loa lava-flow slopes extending eastward from the lava parting south of Humuula and lying between the Mauna Loa east rift area and the Keanakolu slopes of the Mauna Kea dome. Above 6,000 feet are mostly aa flows sloping 500 feet per mile, below this level are fewer aa flows and slopes range from 200 to 300 feet per mile. Wailuku River flows along the north margin of this area, receiving all its branches from the older and ash-covered Mauna Kea surface. Below 2,000 feet there are small inliers of well-developed drainage at Kamana and Waiakea Plantation which appear to be much older surfaces surrounded by more re-

cent Mauna Loa lava flows but the detailed history is not known. The remainder of the area is devoid of any drainage pattern.

Northwest Mauna Loa Slopes

Lava-flow slopes of Mauna Loa extending from Mokuaweoweo, between the Mauna Kea and Hualalai domes to the coast for five miles southwest of Puako. Slopes 250-300 feet per mile seaward from Humuula saddle, increasing gradually above 6,000 feet to 900 feet above the 10,000 foot level. Uneroded and devoid of drainage pattern except single channel passing through Keamuku and possibly related to Mauna Kea terrane. A large proportion of aa flows. Coast fringed by low alluvial flats.

Kona Slopes

Mauna Loa lava flow slopes facing west coast from Hualalai to Kalae. This is the largest single geomorphic area, containing 514 square miles. In northern portion, above 7,000 feet, grade is 800 to 900 feet, at south where contours approach southwest rift area grade is reduced. Lower 3,000 to 5,000 feet altitude is steep, with grades of 600 to 1,200 feet; above this altitude grades are 350 to 600 feet. At extreme south grades are reduced to 300 feet at coast and 500 feet above 3,000 foot level. Area devoid of drainage pattern. From Kealakekua southward are scattered fault scarps and apparent buried scarps suggesting that large segment of island has slipped away by normal faulting and caused the steepening of lava slopes along the lower portion of this area. Aa flows predominant.

Kalae Slopes

Mauna Loa slopes in part overrun by post-Pahala lavas but also in part bearing Pahala ash at surface. A block separated by faulting from downthrown slopes west of Pali o Kulani and distinguished from Hilea Blocks division by non-exposure of pre-Mauna Loa topography. Well-marked, initial consequent drainage on Pahala ash areas on southeast slope. Scarps related to block faulting in northeast part.

Hilea Blocks

Area partly over-run by Mauna Loa flows of the Kamehame formation, but showing partially buried block-faulted remnants of an older dome with Pahala ash on top surface and Ninole ash outcropping in edges. Some fault scarps buried but reflected in steeper Mauna Loa flow surfaces.

Considerable irregular drainage, consequent to irregular, compound, existing topography and due largely to water-holding properties of Pahala ash.

Hualalai Summit and Rift Zone

Elongate area including Hualalai summit and extending northwest to coast. Marked by upward of 100 cones and pit craters developed over a deep-seated crustal rift and on the axis of a pronounced ridge in the Hualalai dome.

Northwest Hualalai Slopes

Slopes of Hualalai flows, aa and pahoehoe, grade 700 feet in upper part, 250 feet near coast. Near east margin is rift zone marked by Anahulu cliffs and great cone of Puu Waawaa. No drainage lines or significant erosion. Coast low.

Kona Hualalai Slopes

Lava flow slopes, mostly pahoehoe, grade 1,000 feet in upper portion near rift area, reduced to 700 feet lower down at south and to as low as 100 feet in the Keahole lava fan which forms the west point of the island. No drainage except single stream inland from Kailua.

Kilauea Caldera

Small oval district comprising the domed floor and fault-scarp walls of Kilauea crater with adjacent cracks and the central, active pit of Halemaumau. Forms of volcanic origin and with slight modification by gravity collapse, building of talus cones, and the like.

Kilauea Saddle

A small, saddle-shaped area lying between the rim of Kilauea crater and the Mauna Loa slope; a portion of the Kilauea dome marked by ash-mantled kipukas,[1] gentle slopes, undrained pits, all typical of saddle areas. General elevation about 100 feet lower than Kilauea rim and relief of main portion about 100 feet.

Kilauea East Rift Zone

Elongate rift zone, 2 to 5 miles wide, extending from Kilauea crater to the east point of Hawaii, Cape Kumukahi. Marked by vent cones, large and small pit craters and cracks along line of crustal rift. No surface drainage. Erosion essentially limited to gravity work on walls of pits and edges of crack grabens.

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[1] Kipuka is an Hawaiian word applied to an area not covered by a surrounding lava flow or series, analogous to a "driftless area" in glacial parlance.

Kilauea East Slopes

Kilauea lava flows extending eastward from Kilauea crater north of Kilauea east rift area and overlapping Mauna Loa northeast rift area. Below 2,000 feet merges with Mauna Loa flows along boundary. Grades 150 to 200 feet. Gives way to Makuu Apron at 150 feet. Moderate development of drainage in certain older, partly ash-covered areas near Glenwood and along Volcano Road to Olaa. Remainder uneroded.

Makuu Apron

Low shore fan of lava flows, fronting both Mauna Loa and Kilauea lava slopes. Grade under 50 feet per mile. Coastal cliffs 10 to 30 feet. No drainage or significant fluvial erosion.

Kalapana Slopes

Lava flow slopes south of Kilauea east rift area and east of Kamoamoa. Grades range from 200 to 500 feet, strongly steepened locally over probable buried fault scarps related in genesis to those still exposed in the Kapukapu area to the west. No drainage. Coastal cliffs variable, 10 to 40 feet.

Kapukapu Cliff

Southern Kilauea slope marked by successive fault scarps, *not buried by later lavas,* parallel to coast and fault-steepened submarine slope. Scarps show slopes of 40 to 70 degrees, heights up to 1,500 feet and lengths of 5 to 10 miles. No drainage lines at east but fairly well marked channels on western half. Stream erosion very slight.

Kau Desert

Kilauea southwest rift and flow slope area long known as Kau Desert. Bounded on northwest by overlapped, fault-steepened Mauna Loa flank, on southeast by Kapukapu Cliffs. Marked on northern part by vent cones, pits, craters and numerous cracks, parallel both to Mauna Loa faults and to faults of the Kapukapu division. In southern part Kilauea flow slopes swing from southwest slopes to south-facing slopes and in places over-run and have buried scarps of the Kapukapu faults. Some drainage in central southern portion. Coastal cliffs 25 to 100 feet.