Chapter 4

GEOLOGY AND PETROGRAPHY OF VOLCANIC ROCKS OF LUALUALEI VALLEY, WAIANAE RANGE, OAHU, HAWAII

John M. Sinton
Hawaii Institute of Geophysics
University of Hawaii
Honolulu, Hawaii 96822

INTRODUCTION AND OBJECTIVES

Background

Previous geologic mapping in and around Lualualei Valley, Oahu was undertaken by Stearns as part of a survey of the geology and groundwater of the island of Oahu (Stearns, 1939; Stearns and Vaksvik, 1935). Except for minor field checking by Macdonald (1940), Stearns' mapping has stood as the definitive field-based work in this region to the present. This earlier work defined three members in the Waianae Volcanic Series; the distinctions between individual members were largely based on field orientation. These members were defined as follows (Stearns and Vaksvik, 1935):

> A lower member is comprised of mainly olivine-rich basalts; these lava flows generally dip away from Puu Kailio (Fig. 1) at angles of 10-20°.
>
> The middle member consists of olivine and plagioclase-rich flows, generally with sub-horizontal dips. The middle member overlies the lower member with angular unconformity.
>
> An upper member unconformably overlies the middle member; the contact is commonly marked by a reddened soil horizon. Upper member flows consist mainly of feldspar-rich alkalic differentiates.

This kind of work, along with subsequent studies by Stearns and Macdonald (*e.g.* 1942) allowed those authors to formulate a four-stage generalized model for Hawaiian volcanism as follows (see Macdonald and Abbott, 1970):

1. A shield-building stage is dominated by tholeiitic basaltic volcanism. This stage probably constitutes 95% of the volume of most Hawaiian volcanoes.

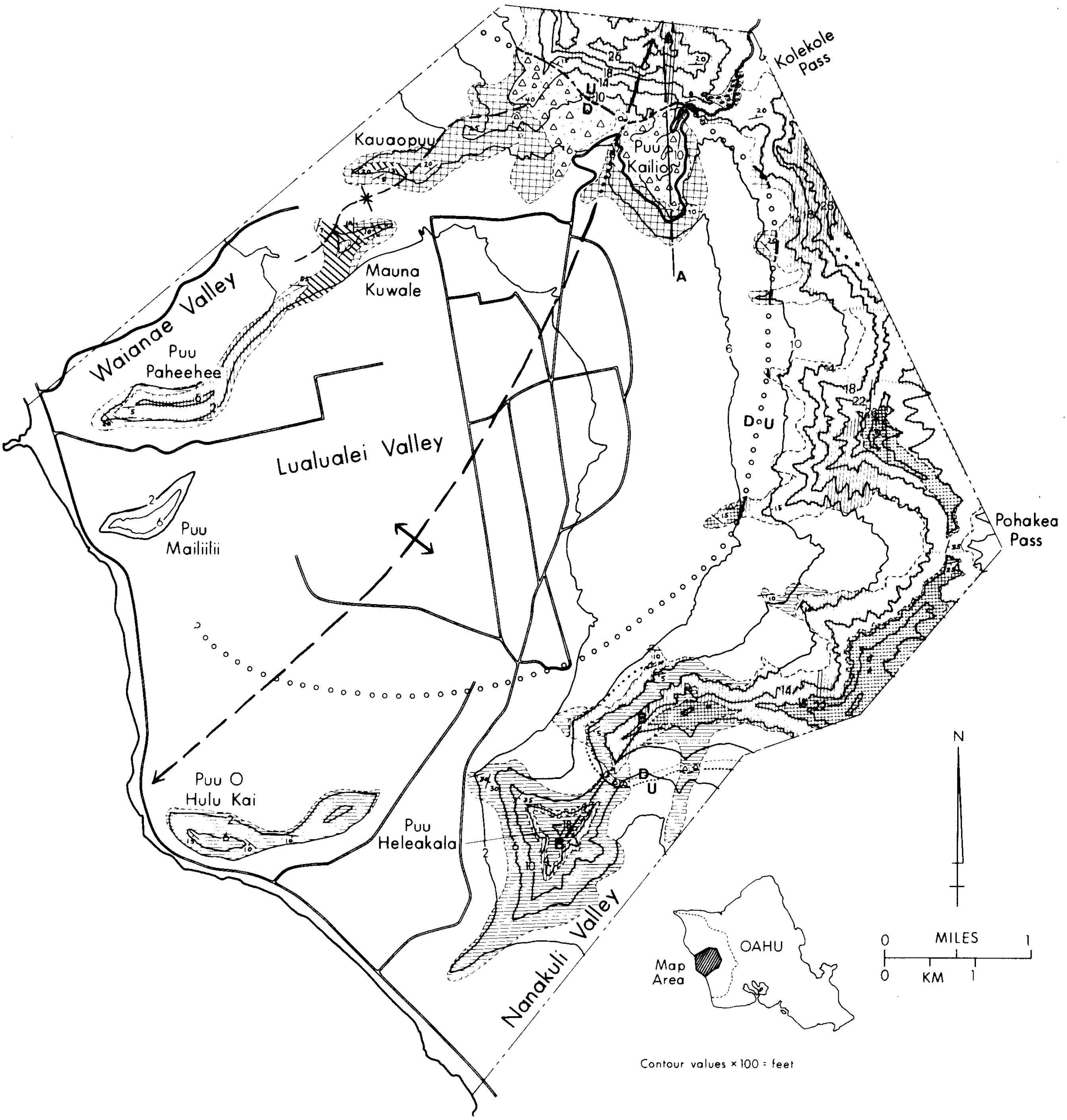


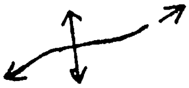
Figure 1. Geology of Lualualei area, Oahu.

LEGEND

Lithologies

□	unpatterned areas include alluvial and colluvial sediments, marine sediments and unmapped basalts (Puu Mailiilii)
∴	Kolekole Pass Conglomerate - deeply weathered, poorly-bedded volcanigenic conglomerate/breccia, devoid of dikes and probably post-volcanic in origin
▦	hawaiite - massive thick-bedded flows of hawaiite, locally with olivine microphenocrysts
△	polymict vent and talus breccias, cut by dikes at Puu Kailio
▥	plagioclase-phyric basalt, locally with olivine, hypersthene and/or augite phenocrysts; pahoehoe and aa lava flows
▧	hornblende ± biotite ± hypersthene - phyric glassy rhyodacite; contains gabbroic and peridotitic xenoliths at Mauna Kuwale
⊞	pyroxene basalts, mainly sparsely phyric augite - hypersthene ± olivine ± plagioclase pahoehoe and aa basaltic lava flows
▤	olivine - phyric basalts ± hypersthene ± plagioclase; mainly pahoehoe with minor aa lava flows

Symbols

	strike and dip of flow planes in lava flows, bedding in breccias
	syncline
	anticline showing direction(s) of plunge
	faults, dotted where covered
	lines of cross-sections (see text)

Geology by John M. Sinton, 1978

2. Most Hawaiian volcanoes apparently undergo partial collapse near the summit regions late in the shield-building stage. This collapse gives rise to caldera structures. Locally it is possible to distinguish precaldera or extra-caldera flows from post- or intra-caldera flows. Such flows were respectively considered by Stearns to be represented by the lower and middle members of the Waianae Volcanic Series.

3. Alkalic volcanism produces a thin cap on more advanced Hawaiian volcanoes. The alkalic flows may show a wide range of lithologies, but generally overlie the tholeiitic shield-building and caldera-fill lavas with a marked discontinuity. Locally, (e.g. East Maui--Stearns and Macdonald, 1942) tholeiitic and alkalic flows may be interbedded. The upper member of the Waianae Volcanic Series represents stage 3 alkalic volcanism.

4. Following a profound period of erosion on several islands, volcanism briefly resumes with the eruption of highly silica undersaturated basanites and/or nephelinites. Such post-erosional volcanism is represented on Oahu by the Honolulu Volcanic Series (Stearns and Vaksvik, 1935) but is apparently restricted to areas outside of the limits of the Waianae Volcano.

This generalized model of Hawaiian volcanism has gained wide acceptance by many workers and has come to be regarded as a model for oceanic island formation and evolution.

Geochronologic studies of Waianae volcanic rocks (McDougall, 1964; Funkhouser et al., 1968; Doell and Dalrymple, 1973) indicate that the subaerial eruptions took place from about 2.4 to 3.6 million years ago. However, these authors also found that there is no systematic age variation between the lower and middle members; both members accumulated about 3.0 to 3.6 m.y. before present (B.P.) The upper member formed 3.0 to 2.4 m.y.B.P. Any unconformity between the upper member and the lower or middle member is not discernible by this method. It therefore appears that the lower and middle members of the Waianae Volcanic Series, as defined by Stearns and Vaksvik (1935) and utilized by Macdonald (e.g. 1940, 1968; Macdonald and Katsura, 1964; Macdonald and Abbott, 1970), do not have time-stratigraphic significance. It was therefore necessary to re-map this area in order to better define age relationships, as well as structural effects, that might be important in the present study.

In contrast to the member mapping of Stearns, I have attempted to map individual lithologies in order to define the stratigraphical relationships within the volcano. The results of this mapping are presented in Figure 1. It is clear that individual lithologies also do not have regional time-stratigraphic significance. However, individual lithologic sections, along with structural criteria, help define the evolution of the volcano in terms of the rock-types produced. Since individual lava flows have restricted areal extent, lithologic sections are not expected to be similar in different areas, even over the same time interval.

However, the present mapping (see discussion below) shows that certain characteristics can be ascribed to certain evolutionary stages of the volcano.

Lithologic Units

Olivine-Phyric Basalts

The oldest units mapped in the area consist mainly of tholeiitic basalts with olivine phenocrysts. Such olivine-phyric basalts occur at Puu O Hulu Kai, Puu Heleakala, Puu Paheehee and interbedded with other lithologies between Puu Heleakala and Pohakea Pass (Fig. 1). This lithology is defined as rocks where olivine is the dominant phenocryst phase; plagioclase, augite and/or hypersthene may locally form less abundant phenocrysts. Interbedded with the olivine-phyric basalts are thin flows of other lithologies, too thin to show on Figure 1.

At Puu O Hulu Kai, olivine-phyric basalts dominate the 200-meter-thick section. In most of this section, olivine is the only phenocryst phase and locally constitutes 30% of the rock. Some rocks contain subsidiary plagioclase, augite and/or hypersthene phenocrysts. Thin interbeds of plagioclase-rich basalts locally occur. One flow contains phenocrysts of olivine, plagioclase and augite in sub-equal proportions with lesser hypersthene. Plagioclase-free olivine basalts at Puu Paheehee contain minor augite and hypersthene phenocrysts.

The section at Puu Heleakala is more diverse. Again, olivine-phyric lavas dominate the section and most of these are plagioclase-free rocks. Hypersthene is an abundant phenocryst phase in some samples. One interbed of olivine-free plagioclase-augite-phyric lava occurs in the lower part of the section; this unit is too thin to be shown on Figure 1.

Pyroxene Basalts

Pyroxene-rich basalts are exposed below rhyodacite at Mauna Kuwale and at Kauaopuu, below breccia at Puu Kailio, and west of the fault line south of Kolekole Pass (Figure 1). These rocks tend to be sparsely phyric, but porphyritic rocks of this unit all contain significant amounts of the pyroxene minerals augite and/or hypersthene. Aphyric lavas are locally abundant, particularly along the Kolekole Pass road.

Pyroxene basalts, exposed below the rhyodacite at Mauna Kuwale and at Kauaopuu, range from aphyric to hypersthene-augite-olivine-phyric to olivine-free, hypersthene-augite-plagioclase-phyric variants. Lavas exposed below breccia at Puu Kailio are sparsely phyric augite-plagioclase ± olivine basalts. They are notably fine grained and most samples contain interstitial glass. A sample from 1.5 km southeast of Puu Kailio contains small augite and hypersthene grains as the only phenocrysts.

Plagioclase-Phyric Basalts

Plagioclase-phyric basalt is the most abundant rock-type encountered in this study. It is also petrographically quite diverse. The distribution of plagioclase-phyric basalts is shown on Figure 1. In this lithology, the phenocryst assemblage is dominated by plagioclase feldspar, generally of composition An 55-65. However, accessory phases are quite variable. The second most abundant phenocryst is generally olivine with lesser augite, hypersthene and/or pigeonite. Locally rocks mapped as plagioclase-phyric basalt contain plagioclase, olivine and pyroxene in sub-equal proportions. Such three-phenocryst basalts are common at Puu Paheehee, both sides of Kolekole Pass and interbedded with olivine basalts between Puu Heleakala and Pohakea Pass.

Plagioclase locally attains phenocryst size up to 4 cm in length and accounts for 40-50% of some rocks. Especially plagioclase-phyric lavas are exposed above rhyodacite at Mauna Kuwale, at Puu Paheehee, southeast of Kolekole Pass and at Pohakea Pass. At Pohakea Pass, plagioclase-phyric lavas may be mildly alkalic. At this locality, hawaiite overlies weathered plagioclase-phyric lava, separated by several cm of red ashy soil. The lower plagioclase-phyric lava contains microphenocrysts of olivine and has groundmass andesine and alkali feldspar. This may indicate that the upper plagioclase-phyric lavas of the Waianae Volcano are transitional to alkalic hawaiites. Where mapped, the hawaiites exclusively overlie plagioclase-phyric lavas.

Rhyodacite

A hornblende ± biotite ± hypersthene, glassy rhyodacite occurs at Mauna Kuwale and at Kauaopuu. This lithology is about 100 meters thick at Mauna Kuwale where it apparently consists of a single flow. It locally contains small inclusions of dunite, wehrlite and gabbro, and discrete rounded crystals of augite. Near the top of the unit, tuffaceous inclusions are also abundant, and this flow may have been associated with a somewhat explosive eruption.

Hawaiites

Alkalic cap lavas occur as hawaiites, mainly along the ridge running from Kolekole Pass, south to Pohakea Pass and then southwest toward Puu Heleakala (Fig. 1). In addition, hawaiites occur 2.5 km west of Pohakea Pass. Hawaiites in this area are not strongly porphyritic; plagioclase, olivine and rare augite locally form microphenocrysts. Na-plagioclase, augite, oxides and alkali feldspar comprise the groundmass.

Breccias

A variety of breccias are present in the area. These include monolithic aa flow breccias that have not been distinguished from the other lithologic units that characterize the flows. However, polymict breccias occur at several localities in the area and are important stratigraphic horizons. Well-bedded polymict breccias are exposed at Puu Kailio and on the next ridge to the west (Fig. 1). These breccia beds have dips up to 40° and are mainly composed of poorly sorted talus debris, including clasts of several flow and dike lithologies. Breccias at Puu Kailio also include some ash and may be partly vent breccias. The Puu Kailio breccia beds are cut by abundant dikes of several lithologic types. Polymict breccias also occur in small outcrops west and southwest of Pohakea Pass, in the saddle north of Puu Heleakala and cutting the ridge that projects south into Nanakuli Valley (Fig. 1). These breccias appear to have accumulated along scarps and therefore are important structural markers (see structure).

Kolekole Pass Conglomerate

A deeply weathered volcanigenic conglomerate fills the saddle at Kolekole Pass. The fine silt matrix includes sub-angular to sub-rounded clasts from about 10 cm up to several meters of volcanic fragments. These fragments show marked spheroidal weathering. Compared to the Puu Kailio breccia, this unit is poorly bedded, probably quite thin and is not cut by dikes. It also has generally more rounded clasts and is more deeply weathered.

Structure

Unconformities

Several important unconformities provide evidence relating the eruptive history of the volcano. Evidence for breaks in the eruptive activity are rare in the older olivine basalts of Puu O Hulu Kai and of Puu Heleakala. These flows probably accumulated fairly rapidly. Thin, reddened soil horizons are locally present at Puu Paheehee and north of the saddle north of Puu Heleakala. Apparently, middle stage post-caldera eruptions were somewhat less continuous.

The tops of the pryoxene basalt flows that underlie breccia at Puu Kailio are notably weathered. This weathering probably indicates an important period of quiescence in this region during accumulation of the lower beds of breccia.

A red soil horizon up to 1 meter thick underlies hawaiites at Pohakea Pass and also on the ridge, 2 km northeast of Puu Heleakala. This horizon indicates a significant period of relative inactivity before the onset of alkalic volcanism in the Waianae volcano.

Folds

Hawaiian volcanoes are not folded in the sense of having undergone major deformational folding. However, shield volcanoes have the form of constructional anticlines. In addition, small synforms and/or antiforms can commonly be found in Hawaiian volcanoes. These are mainly constructional features where lava has flowed over uneven topography. Some may form from slight post-depositional warping as the volcanic edifice grows and deforms.

The orientation of lava beds in and around Lualualei Valley defines a large dome or doubly plunging anticline (Fig. 1). This dome reflects the original shield volcano structure, with lava flows dipping (flowing) away from the central axis. The orientation of lava flows on the ridges indicates that the dome axis runs approximately through Puu Kailio (Fig. 1). More important than the orientation of this feature is its age. Lava flows underlying breccia at Puu Kailio and the breccias themselves do not show attitudes reflecting this structure. Indeed their orientations were gained despite the development of the domal structure of the volcano, and probably formed in a caldera.

A small syncline is present along Mauna Kuwale and Kauaopuu ridges (Fig. 1). Its origin is not well known but it probably is constructional in origin, and reflects flows of lavas over a topographic trough.

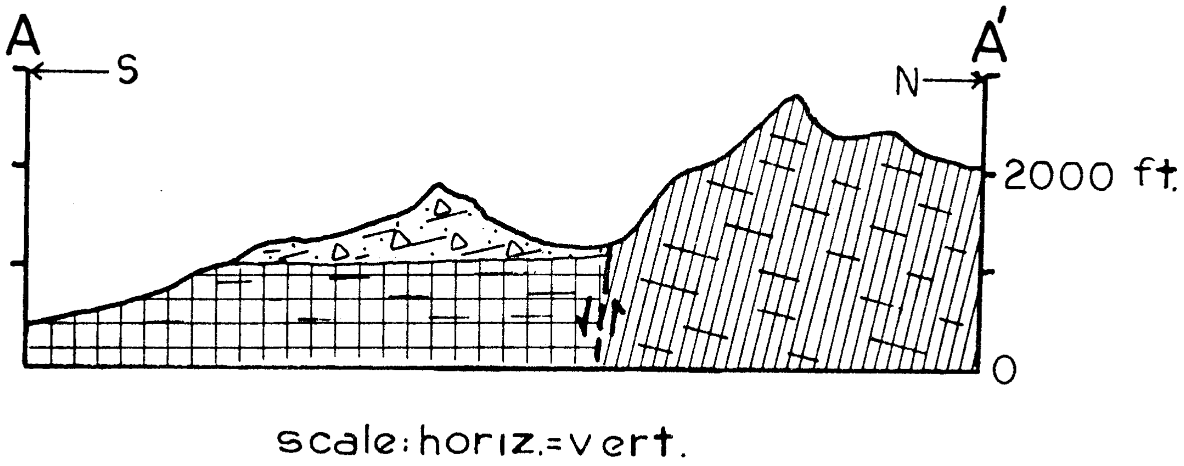
Faults

Two important faults are designated on Figure 1. Both are probably normal faults, produced during the collapse or caldera stage of the volcano. A large fault is partly buried by breccia between Puu Kailio and Kolekole Pass. It marks the boundary between plagioclase-phyric basalts and breccia or pyroxene basalts. Breccias in the vicinity of Puu Kailio apparently accumulated at the base of the south-facing scarp of this fault (Fig. 2).

Another fault cuts the saddle north of Puu Heleakala. Here breccias accumulated at the base of a northeast-facing scarp; subsequent flows from the north ponded against these breccias (Fig. 2).

These faults and talus breccias provide important evidence for the morphology and structural control of the evolving Waianae Volcano. Lava flows on the down-thrown side of the Kailio fault have gentle dips and generally do not show the domal structure of the beds outside of this fault. In addition, the fault strike largely parallels the strikes of flows on the ridges around Lualualei Valley. Such data provide strong evidence that this major fault marks the boundary of a large depression centered along the domal axis of the volcano; hence it is interpreted as a caldera boundary. Structural relations as outlined above, near to and around this structure are analogous to those of the active calderas of Mokuaweoweo (Mauna Loa) and Kilauea. The maximum dimension of the Waianae Caldera, as presently mapped, is about 7 km, or just slightly larger than Kilauea and/or Mokuaweoweo calderas. The Waianae Caldera walls appear to be eroded away, or buried by younger flows to the southwest and west. The western boundary apparently lies outside of the map area. Flows of Puu Paheehee are caldera-fill lavas.

The small depression boundary indicated by the saddle fault north of Puu Heleakala may be continuous with breccia 2 km northeast of Puu Heleakala (Fig. 1). These data are consistent with a small pit crater 1 1/2 - 2 km in dimension. This crater was filled by lavas flowing from the northeast and north. The northern walls are buried and thus are not exposed. This depression apparently continues to the east, outside of the present map area.



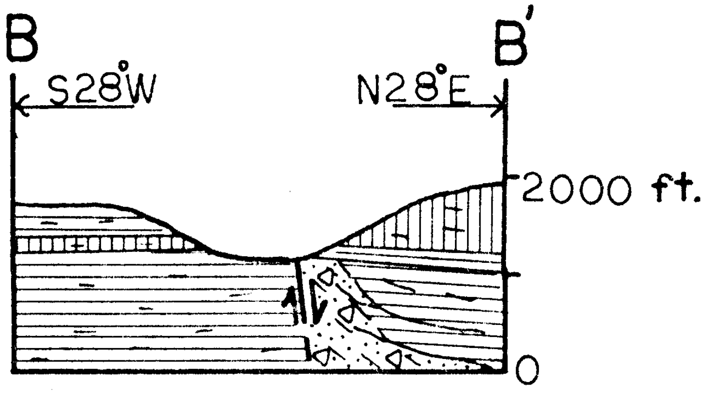


Figure 2. Cross sections along A-A' and B-B' section lines as shown on Fig. 1. Lithologic patterns as in Fig. 1. Dashed lines indicate dips of beds. Arrows along faults indicate relative movements. Subsurface geology on section B-B' after Stearns and Vaksvik (1935).

Vents and Rifts

The breccia at Puu Kailio contains significant amounts of ash and is cut by a complex of dikes ranging in lithology from tholeiitic picrite to hawaiite. This region probably marks the site of pronounced post-caldera activity and is interpreted as a vent. Flows that must have once covered breccia in this region have been removed by erosion. This interpretation is consistent with that of Stearns and Vaksvik (1935) who suggested that Puu Kailio represents the center of Waianae volcanic activity.

By analogy with the active rift systems of Mauna Loa and Kilauea, rift zones should show an anticlinal structure cut by abundant dikes. Dikes cut much of the section of Figure 1 but are especially abundant at Kolekole Pass, Puu Kailio, Mauna Kuwale and Puu O Hulu Kai. Dikes are significantly rarer along the Puu Heleakala - Pohakea Pass ridge. As such, the present mapping has not documented well-defined rift zones in this area. The abundant dikes at Puu Kailio and Puu O Hulu Kai are consistent with a zone roughly aligned along the dome axis (Fig. 1), possibly with a second zone running approximately northwest through Mauna Kuwale.

DISCUSSION

The oldest rock units exposed in the area are olivine basalts of Puu O Hulu Kai and Puu Heleakala. These units correlate with the "lower member" of Stearns and Vaksvik (1935). The intra-caldera pyroxene-basalt, olivine basalt, rhyodacite and plagioclase phyric basalt flows are intermediate age and may approximately correlate in time with crater fill flows north of the Heleakala saddle. These in turn unconformably underlie summit and flank eruptive flows of hawaiite. One intra-caldera hawaiite flow occurs *ca.* 2 km west of Pohakea Pass. Its source probably lay to the southwest, within the caldera. Plagioclase-phyric basaltic flows in the vicinity of Kolekole Pass are of unknown age. They are extra-caldera flows but are probably continuous with hawaiite north of Pohakea Pass, and therefore are likely to be mainly fairly late-stage tholeiitic flank eruptions.

The above inferred relations provide evidence for interpreting the generalized petrological evolution of the Waianae Volcano. The oldest flows are dominated by olivine basalts. Younger tholeiitic eruptions were increasingly fractionated with plagioclase and pyroxene becoming more abundant. Olivine basalts are a rare or minor constituent of caldera-fill or late-stage flank eruptive sequences. The Mauna Kuwale rhyodacite is the most differentiated tholeiitic rock known from the Hawaiian Islands. It is interbedded with fairly highly differentiated caldera-fill lavas and therefore comprises part of a relatively late stage of tholeiitic volcanic activity. The youngest tholeiitic flows in this region are plagioclase-phyric basalts. Such flows may be mildly alkalic below the unconformity separating the shield-building and alkalic cap lavas. This may indicate that the Waianae Volcano had evolved to transitional tholeiitic-alkalic volcanism prior to the period of quiescence represented by the unconformity that marks the base of hawaiite volcanism. Alkalic volcanics above this unconformity are all hawaiites in this area. Alkalic olivine basalts, mugearites and trachytes are not exposed in and around Lualualei Valley, nor are representatives or equivalents of the basanite-nephelinite Honolulu Volcanic Series.

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