Chapter 1

INTRODUCTION TO THE GEOLOGY OF OAHU

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INTRODUCTION

Oahu was the "gathering place" for Hawaiian Island kings and chiefs. The word Oahu is of Polynesian origin, but its original meaning has been lost. Oahu was the first of the Hawaiian Islands sighted by Capt. James Cook in 1778. It is located in the northern portion of the Hawaiian Island chain, the fifth island northwest of the island of Hawaii. Oahu is the third largest island in the chain, containing 1555 km^2, and is 64 km long and up to 38 km wide. There are 80 km of sandy shoreline on Oahu, which is more beach than on any other Hawaiian island. Today, Oahu is the site of the state capital, Honolulu, and contains 80% of the state population.

The island of Oahu consists of two main shield volcanoes, each with numerous parasitic vents. Erosion has deeply dissected these great shield volcanoes, leaving long narrow ridges. Waianae Range, on the west, is 1,280 m high and 35 km long; the Koolau Range on the east is 992 m high and 59 km long (Fig. 1). An erosional unconformity between the lavas of the two volcanoes is exposed along Kaukonahua Gulch at the eastern base of the Waianae Range, where lavas from Waianae Volcano dip 10° to 15° northeastward and are overlain by lavas from the Koolau Volcano dipping 5° northwestward (Macdonald and Abbott, 1970).

Canyons hundreds of meters deep were cut into the shield volcanoes during a hiatus in volcanic activity. Renewed volcanism occurred in the southern portion of the Koolau Range, forming tuff cones, cinder cones, small shield volcanoes and isolated lava flows. This post-erosional volcanic activity is known as the Honolulu Volcanic Series (Stearns and Vaksvik, 1935).

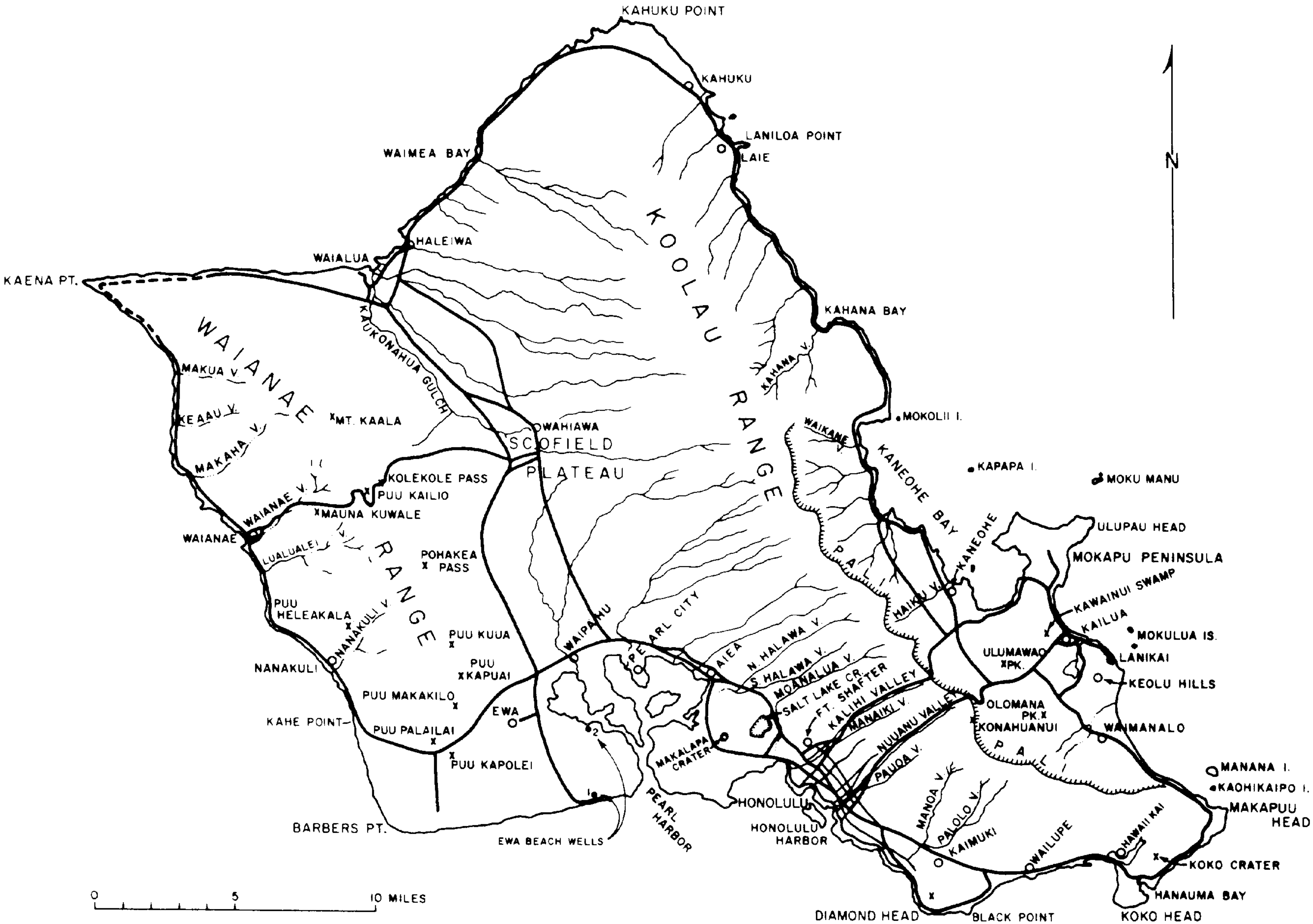

Figure 1. Map of Oahu showing names of places mentioned in text (after Macdonald and Abbott, 1970).

Waianae Volcano

Macdonald (1940) subdivided the Waianae Range into three members on the basis of structural criteria (Fig. 2). The lower member includes the thin lava flows and associated pyroclastic rocks that comprise the main mass of the Waianae shield volcano dipping 4^{o} to 14^{o}. The middle member consists of nearly flat-lying lavas which accumulated in the caldera. The upper member forms a thin cap mantling the entire top of the volcano. The lower and middle member are composed of tholeiitic composition lavas, although near the upper contact of the middle member, alkalic basalts occur. The upper member consists principally of hawaiite with minor alkali olivine basalts. Macdonald and Katsura (1964) and Macdonald (1968) present over sixty chemical analyses from two traverses on a ridge projecting WNW into Nanakuli Valley which includes lavas from all three members. Only one post-erosional eruption has been documented in the Waianae Range. In Kolekole Pass, a small alkali olivine basalt flow rests on alluvium which accumulated in a deep stream-cut valley.

Most of the western portion of Waianae Volcano has been removed, exposing the shallow interior of the volcano. Three rift zones are marked by regions of innumerable dikes. The two principal rift zones trend NW and SSE from the summit. A less prominent rift trends NE (Stearns and Vaksik, 1935).

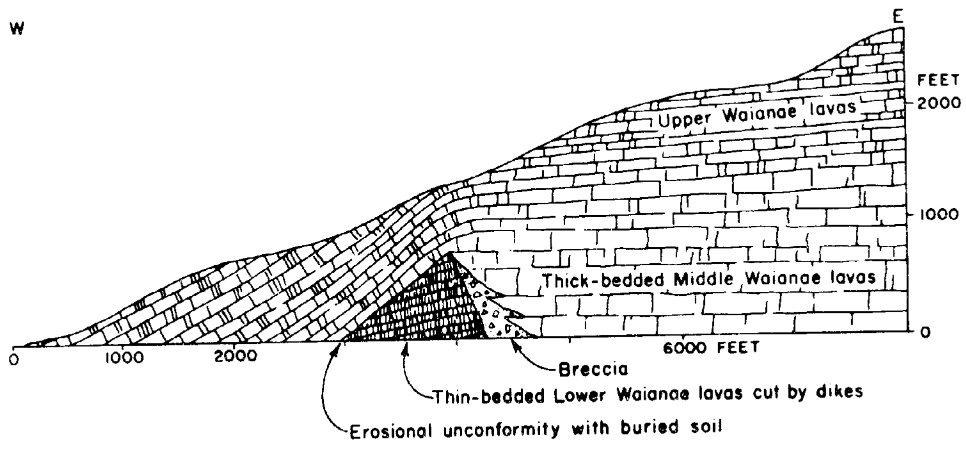

Figure 2. Geologic cross section of the ridge separating Keaau and Makaha Valleys, Waianae Range illustrating the three members of the Waianae Volcanic Series (from Macdonald and Abbott, 1970).

The caldera of Waianae Volcano extends from Kokokole Pass on the west, to the northern side of Makaha Valley on the north and the head of Nanakuli Valley on the south (see Fig. 1; also Sinton, this volume). The lavas that accumulated in the caldera are massive, thick and nearly horizontal (Macdonald, 1940). Lavas eventually spilled over the western rim of the caldera. This is well recorded in the ridge northwest of Makaha Valley (Macdonald and Abbott, 1970). A rhyodacite lava is interbedded with the caldera-filling basaltic lavas. It is the most differentiated tholeiitic lava known from the Hawaiian Islands (see Bauer, this volume, for details).

There are no sharp breaks between middle and upper member lavas in the caldera; beds are conformable and the change in composition from tholeiitic to alkalic is transitional (Macdonald and Katsura, 1964; Macdonald, 1968). Outside the caldera, the change from lower member to upper member is abrupt, both chemically and mineralogically, and is marked by an erosional surface and locally, a reddish brown, ashy soil 15 to 95 cm thick. Five cinder cones on the southeast portion of Waianae volcano are the most recent units of the upper member.

Koolau Volcano

Koolau Volcano, unlike other Hawaiian volcanoes, has virtually no alkalic lavas. A plagioclase-phyric basalt with plagioclase phenocrysts up to 2.5 cm long from Moanalua Valley is slightly alkalic (Macdonald and Abbott, 1970). A flow in Kaukonahua Gulch near the western margin of the Schofield Plateau may be an alkalic basalt, but it is too altered to determine its parentage using a chemical analysis (Macdonald and Abbott, 1970). Therefore, Koolau Volcano just reached the stage of transition from tholeiitic to alkalic composition lavas when volcanic activity stopped.

The Koolau Formation consists almost totally of tholeiitic basalt lavas erupted from vents along a fissure zone which extends over 48 km in length. The average flow is 3 m or less thick. Tuff beds represent no more than 0.1 percent of the whole mass of the volcano. The sequence of lavas is exceptionally uniform, with no apparent break in deposition (Wentworth, 1951). Wentworth and Winchell (1947) examined hundreds of thin sections of Koolau Formation lavas. They found as much petrographic variation for rocks separated by a few meters as samples widely separated horizontally and vertically. No systematic variation was recognized. Random variations are in plagioclase and olivine content of the lavas which locally may constitute 30% of the rock (Wentworth, 1951). In general, the Koolau Formation lavas are identical to tholeiitic lavas from other Hawaiian volcanoes (Wentworth and Winchell, 1947). Representative analyses are given in Table 1.

Erosion has deeply encised the Koolau Volcano, exposing rift zones that are delineated by the presence of dike complexes. Locally, up to 360 dikes outcrop per kilometer, ranging in width from 10 cm to 3 m (Macdonald and Abbott, 1970). Excellent exposures of dikes may be seen on the Pali Highway near Castle Junction and on the section of H-3 Interstate Highway near the

Table 1. Representative Chemical Analyses of Volcanic Rocks from Oahu*

	Waianae Volcanic Series			Koolau Volcanic Series		Honolulu Volcanic Series	
	Lower C-15	Middle C-49	Upper C-42	Makapuu Pt. 10403	9948	Moiliili Quarry	Kapuo Flow C-164
SiO_2	50.80	46.56	45.88	51.94	49.62	36.34	44.85
SiO_2	1.93	2.57	3.83	2.58	1.52	2.87	2.13
Al_2O_3	15.25	14.15	16.39	14.18	12.68	10.14	13.26
Fe_2O_3	2.91	3.26	3.39	2.81	3.21	6.53	2.36
FeO	7.23	8.98	10.00	8.14	7.60	10.66	10.60
MnO	0.16	0.17	0.18	0.08	0.09	0.20	0.18
MgO	8.27	9.54	5.92	7.21	13.86	10.68	10.82
CaO	9.83	10.41	8.90	9.24	7.48	13.10	10.91
Na_2O	2.15	2.21	3.30	2.52	2.36	4.54	3.00
K_2O	0.28	0.57	1.02	0.35	0.15	1.78	0.80
H_2O^-	0.32	0.53	0.24	0.12	0.34	1.00	0.75
H_2O^+	0.75	0.93	0.29	0.59	0.67	1.00	0.25
P_2O	0.25	0.34	0.59	0.35	0.04	1.02	0.53
Total	100.13	100.24	99.93	100.15	99.61	99.90	

CIPW Norms

	Lower C-15	Middle C-49	Upper C-42	Makapuu Pt. 10403	9948	Moiliili Quarry	Kapuo Flow C-164
Q	4.56			6.24		LC 8.28	
Or	1.67	3.34	6.12	2.22	1.11	AK 11.95	Or 5.00
Ab	17.83	18.34	27.77	20.96	19.91		13.10
An	31.41	26.97	26.97	26.41	23.62	1.67	20.29
Ne						21.02	6.53
Di	12.48	18.35	11.09	14.15	10.84	17.39	25.56
Hy	22.64	12.26	0.76	19.74	28.84		
Ol		8.98	12.34		6.75	29.23	21.26
Mt	4.18	4.87	4.87	4.18	4.64	9.51	3.48
Il	3.65	4.86	1.30	4.86	2.89	5.47	4.10
Ap	0.67	0.67	1.34	0.67		2.35	1.34

*From Macdonald and Katsura (1964) for Waianae Series; Wentworth and Winchell (1947) for Koolau Series; Dunham (1933) for Moiliili Quarry; Macdonald (1968) for Kaupo flow.

Kaneohe Marine Corps Air Station, although both of these areas lie within the caldera. The main rift zones extend toward the NW and SE. A minor rift zone also characterized by numerous dikes extends toward the SW.

The caldera of the Koolau Volcano was about 13 km long and 6.5 km wide, extending from near Waimanalo on the southeast, beyond Kaneohe on the northwest and to the base of the Pali on the southwest. Adams and Furumoto (1965) determined seismic velocities up to 7.0 km/s for rocks at depths of 3 km, which they interpret as a plutonic body about 6 km across.

Within the caldera, the rocks have been extensively hydrothermally altered. Secondary minerals include chlorite, clay, opal, chalcedony, quartz epidote and zeolites. Excellent small crystals of quartz and zeolites have been found in the Keolu Hills area and around Olomana Peak.

A period of erosion followed the end of volcanic activity. The eastern flank of the volcano was removed and valleys over 600 m were cut. The island slowly sank during this period, perhaps 350 m (Macdonald and Abbott, 1970).

Honolulu Volcanic Series

This period of erosion was interrupted by at least forty separate volcanic eruptions (Table 2; Clague, this volume). Many of these eruptions were extremely violent, forming tuff cones and base surge deposits (Fisher, 1977). The composition of the lavas range from alkalic olivine basalt to melilite nephelinites (Winchell, 1947). Many of these lavas contain mafic and ultramafic xenoliths which may represent fragments of the underlying crust and upper mantle (Jackson and Wright, 1970; Leeman, this volume). K/Ar dating of Honolulu Series basalts commonly yields inconsistent or unreasonably old ages. This may be the result of partial or complete assimilation of ultramafic and mafic xenoliths (Lanphere and Dalrymple, in press).

Jackson and Wright (1970) noted that xenoliths and host basalts are compositionally zoned around the Koolau Volcano caldera. Xenoliths near the caldera are mostly dunite with minor lherzolite in melilite-nepheline basalts. Lherzolite xenoliths become more abundant on the flanks of the volcano in nepheline basalts. Along Koko Rift on the SE edge of the volcano, alkalic olivine basalts contain no xenoliths. Garnet-bearing samples only have been recovered from Salt Lake Crater, Aliamanu Crater and Kaau Crater. Garnet has not been reported from any other Hawaiian island.

Radiometric Ages

Samples from Oahu have been age dated with use of K-Ar techniques by McDougall (1964), Funkhouser and others (1966, 1968), Gramlich and others (1971), Doell and Dalrymple (1973) and Lanphere and Dalrymple (in press). For Waianae Volcano and Koolau Volcano, Doell and Dalrymple (1973) provide the most comprehensive study (see Fig. 3). The ages reported here are considered best ages based on reproducibility, stratigraphic consistency and the amount of atmospheric Ar^{40} present in the sample (Doell and Dalrymple, 1973).

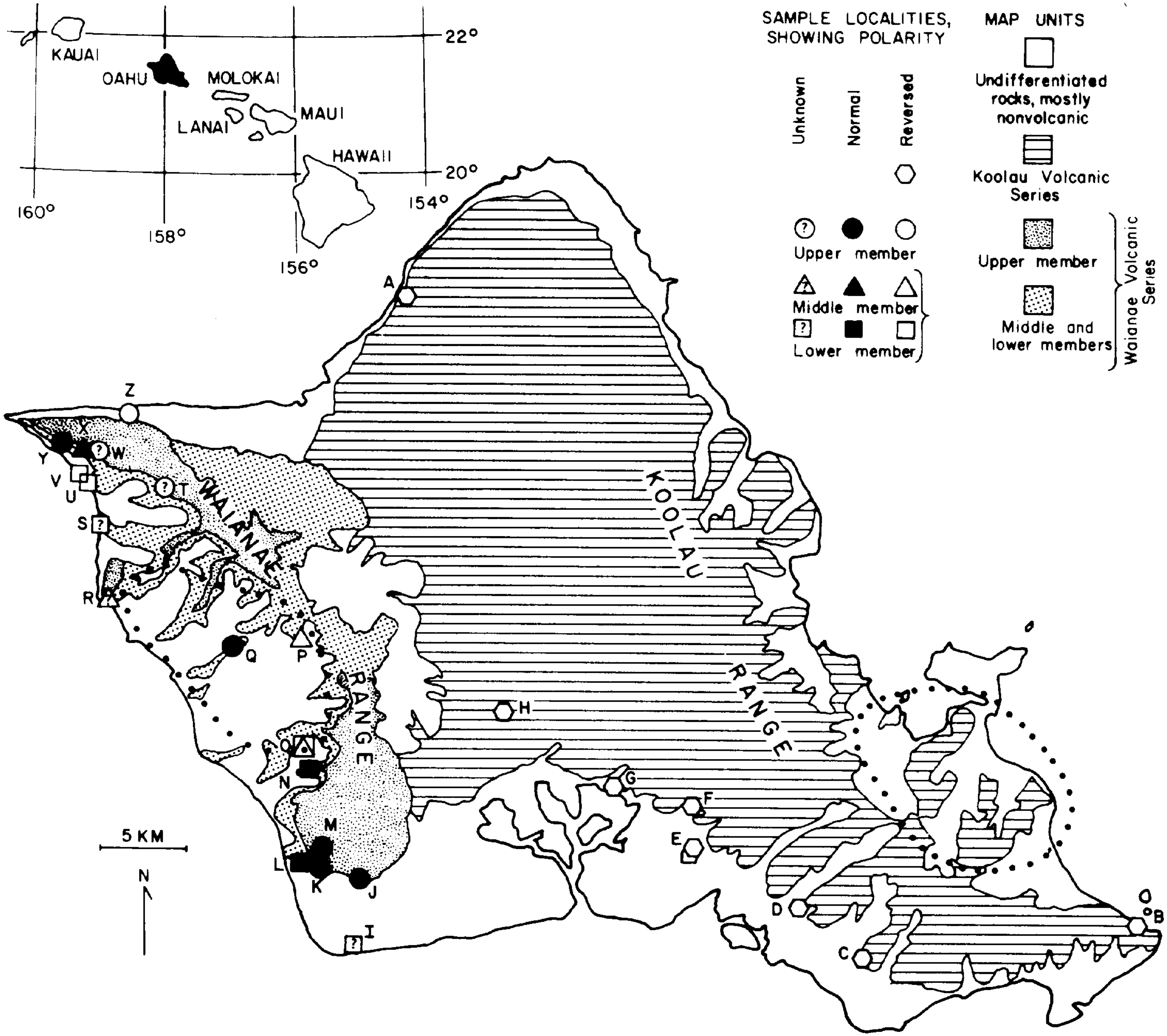

Figure 3. Generalized geologic map of Oahu with K-Ar ages and paleomagnetic data (after Doell and Dalrymple, 1973).

The lower and middle members of the Waianae Volcanic Series are approximately contemporaneous, 3.0 to 3.8 m.y. old, within the precision of the ages at the 90% and 95% confidence levels (McDougall, 1964; Doell and Dalrymple, 1973). The upper member lavas are younger (2.4 to 3.1 m.y. old) than middle and upper member lavas at the 90% level of confidence, but not at the 95% confidence level (see Fig. 4).

K-Ar ages for Koolau Volcano range from 1.8 to 2.6 m.y., overlapping slightly with ages for the upper member of the Waianae Series. An interval of approximately 0.8 m.y. was required for the construction of the main mass of both volcanoes, which is consistent with other age estimates for the formation of Hawaiian volcanoes (see Macdonald and Abbott, 1970; Swanson, 1972).

K-Ar dates for Honolulu Volcanic Series lavas are difficult to obtain because ultramafic xenoliths, which are common in these lavas, contribute excess radiogenic ^{40}Ar (Lanphere and Dalrymple, in press). Some of the calculated ages for Honolulu Series lavas are older than the underlying Koolau Volcano lavas (e.g. Puu Hawaiiloa--6.05 and 14.3 m.y.); others are highly variable from the same unit (e.g. Pyramid Rock--0.56-3.62 m.y.) (Lanphere and Dalrymple, in press). Of the 12 samples analyzed by Lanphere and Dalrymple (in press), only six yielded internally consistent and reproducible ages. There ages range from 0.32 to 0.58 and are listed in Table 2. Because of the problems of excess radiogenic ^{40}Ar, Lanphere and Dalrymple are reluctant to accept an age for a single vent. Rather, they conclude that the Honolulu Volcanic Series is probably less than 0.6 m.y. old.

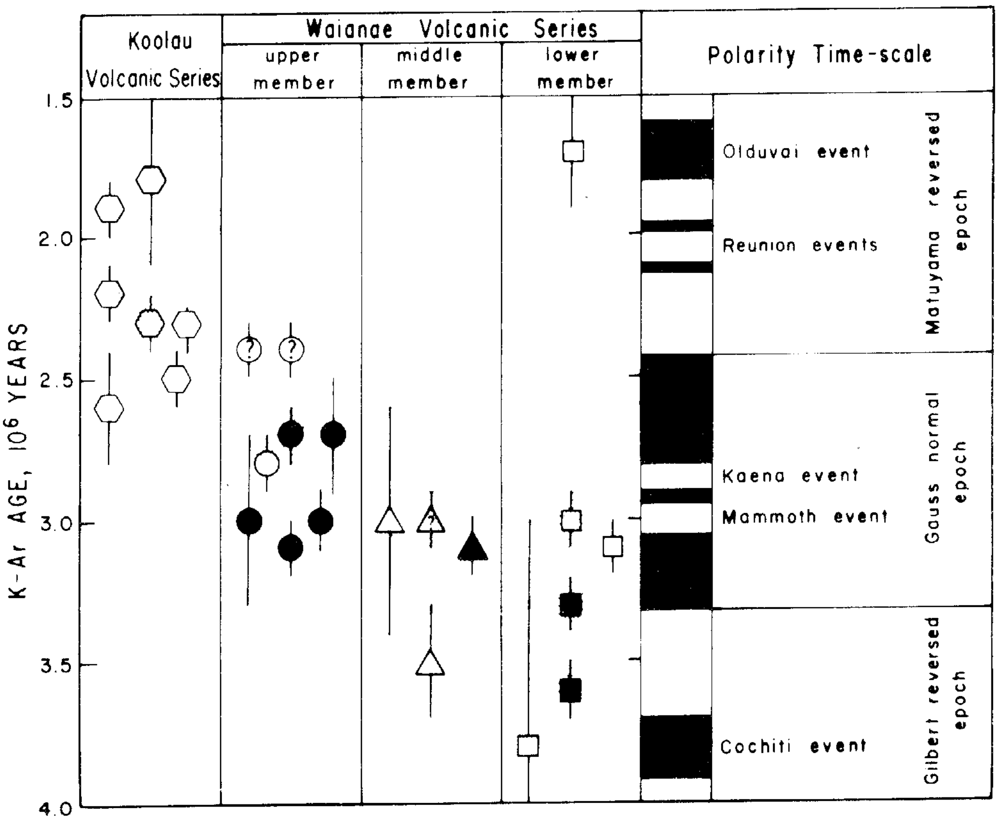

Figure 4. Best K-Ar ages and magnetic polarities for Koolau and Waianae volcanic rocks, Oahu. Vertical bars are estimated standard deviations of analytical precision. Other symbols are in Figure 3 (after Doell and Dalrymple, 1973).

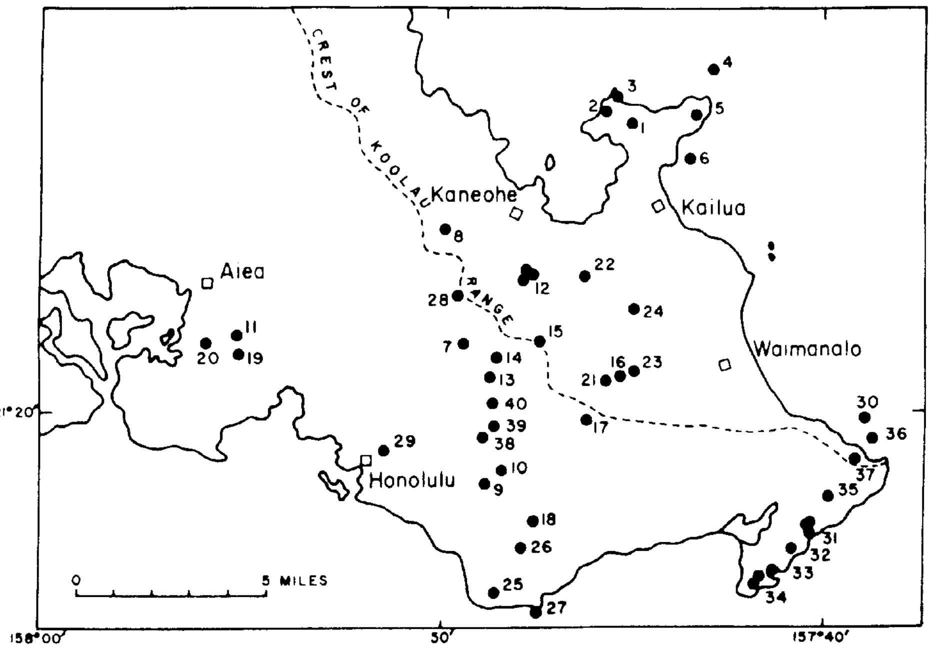

Figure 5. Map showing location of Honolulu Volcanic Series vents. Numbers of vents correspond to numbers on Table 2. (From Macdonald and Abbott, 1970).

Table 2. Eruptions of the Honolulu Volcanic Series (see Figure 5)

Eruption (vents)	K-Ar Age (m.y.)	Resulting Structures	Composition of Magma
1. Hawaiiloa		Cinder cone and lava flow	Melilite nephelinite
2. Pali Kilo		Cinder cone (?) and lava flow	Nephelinite
3. Pyramid Rock	0.56 - 0.83 ?	Lava flow	Nephelinite
4. Moku Manu		Tuff cone	Nephelinite
5. Ulupau		Tuff cone (and lava flow?)	Nephelinite
6. Mokolea		Lava flow	Melilite nephelinite
7. Kalihi	0.58 ± 0.02	Cinder cone and lava flow	Melilite nephelinite
8. Haiku		Cinder cone and lava flow	Melilite nephelinite
9. Rocky Hill		Spatter cones and lava flow	Nephelinite and melilite nephelinite
10. Manoa		Cinder cone and lava flow (?)	Nephelinite
11. Aliamanu		Tuff cone with lava flow in crater	Melilite nephelinite
12. Kaneohe	0.70 ± 0.06 ?	Cinder cones and lava flow	Nephelinite and melilite nephelinite
13. Luakaha	0.36 ± 0.06	Cinder cone and lava flow	Nephelinite and melilite nephelinite
14. Makuku		Cinder cone and lava flow	Melilite nephelinite
15. Pali		Cinder cone and lava flow	Nephelinite
16. Makawao (may be a Koolau vent)		Tuff-breccia in vent	Basaltic glass and accidental (Koolau) fragments
17. Kaau		Pit crater, lava flows tuff deposits and mudflows	Melilite nephelinite
18. Mauumae	0.43 ± 0.04	Spatter cone and lava flow	Nephelinite
19. Salt Lake and		Tuff cones	Melilite nephelinite (?)
20. Makalapa		Tuff cones	Melilite nephelinite (?)
21. Ainoni	2.01 ± 0.05 ?	Cinder cone and lava flow	Nephelinite
22. Castle	0.47 - 1.04 ?	Cinder cone and lava flow	Nephelinite with a little melilite

Table 2. Eruptions of the Honolulu Volcanic Series (Continued)

Eruption (vents)	K-Ar Age (m.y.)	Resulting Structures	Composition of Magma
23. Maunawili		Cinder cone and lava flow	Nephelinite
24. Training School	1.13 ± 0.09 ?	Cinder cone and lava flow	Nephelinite with a little melilite
25. Diamond Head (Leahi)		Tuff cone	Nepheline basanite (?)
26. Kaimuki		Shielf volcano	Basanitoid
27. Black Point	0.48 ± 0.08	Lava flow	Nepheline basinite
28. Kamanaiki		Lava flows	Melilite nephelinite
29. Punchbowl	0.53 ± 0.04	Tuff cone and lava flows	Nephelinite
Koko fissure			
30. Manana		Tuff cone	Basanitoid
31. Koko Crater		Tuff cone	Basanitoid
32. Kahauloa		Tuff cone with lava flows	Basanitoid
33. Hanauma		Tuff cone	Basanitoid
34. Koko Head		Tuff cone with lava flow	Basanitoid
35. Kalama		Cinder cone and lava flow	Nepheline basanite
36. Kaohikaipu		Cinder cone and lava flow	Nepheline basanite
37. Kaupo	0.32 ± 0.04	Spatter conelet and lava flow	Basanitoid
Tantalus group			
38. Round Top		Cinder and ash	Melilite nephelinite (?)
39. Sugar Loaf		Cinder cone, ash, and lava flow	Melilite nephelinite
40. Tantalus		Cinder cone, ash, and lava flow	Melilite nephelinite

K-Ar ages - Lanphere and Dalrymple (in press). Other data - Macdonald and Abbott (1970).

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