

## THE HAWAIIAN-EMPEROR VOLCANIC CHAIN

### Part II

### Stratigraphic Framework of Volcanic Rocks of the Hawaiian Islands

By Virginia A.M. Langenheim and David A. Clague

#### ABSTRACT

Stratigraphy is an important tool for understanding the geologic history of the volcanoes of the Hawaiian Islands, providing a framework for much information from other geologic and related fields. Three major eruptive stages in a Hawaiian volcano's life—shield stage (tholeiitic), postshield stage (alkalic), and rejuvenated stage (alkalic)—have generally provided a basis for dividing the volcanic rocks into stratigraphic units. Such units are basic to stratigraphy, and suitable nomenclature for them helps promote unambiguous scientific communication regarding the spatial and temporal relations of rocks. The stratigraphic nomenclature of the Hawaiian Islands is herein reviewed and updated to reflect current scientific needs and to be consistent with the most recent (1983) North American Stratigraphic Code.

The major divisions of volcanic rocks on each island formerly called "Volcanic Series" are all considered to be of formational rank and renamed accordingly. Their names reflect either a predominant commonly accepted lithologic type (such as "Basalt") or the variety of volcanic lithologies in the unit (those units are called "Volcanics"). Only those subdivisions of the major units that are currently considered to be useful as formally named units of member or lesser rank are retained; others are considered to be informal. Principal and other reference localities are designated for those well-established units for which a type locality was not previously specified.

We give in tabular form a brief summary of each stratigraphic unit, including its lithology, occurrence, thickness, type and reference localities, stratigraphic relations, age, and any stratigraphic changes made herein.

#### INTRODUCTION

Stratigraphy is an important tool for understanding the geologic history of the Hawaiian Islands, providing a framework into which much of the scientific information contributed by other geologic and related fields can be fit in an organized manner.

The purpose of this paper is to present a brief summary of the volcanic stratigraphy of the islands, and, because the discrimination of stratigraphic units is basic to stratigraphy, to review the stratigraphic nomenclature for these rocks and update it as far as possible to reflect current scientific needs and to conform to the most recent North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983). In order to present a better view of the stratigraphy of the volcanic rocks of the islands, we begin with a short discussion of the geologic setting.

#### ACKNOWLEDGMENTS

We thank R.L. Christiansen and R.W. Decker for their constructive critical reviews. We also gratefully acknowledge the following persons for their helpful comments and suggestions: D.A. Brew, E.E. Brabb, T.J. Casadevall, G.B. Dalrymple, R.M. Easton, M.O. Garcia, R.T. Holcomb, P.W. Lipman, J.P. Lockwood, J.G. Moore, R.B. Moore, D.W. Peterson, S.C. Porter, J.M. Sinton, D.A. Swanson, G.P.L. Walker, and E.W. Wolfe.

We are deeply grateful to Cynthia Barclay and William Fedasko for their assistance in searching the literature and with the preparation of the typescript.

#### GEOLOGIC SETTING

The Hawaiian Islands consist of a chain of volcanoes that stretches about 2,700 km (1,700 mi) across the northern Pacific Ocean in a northwesterly direction from the Island of Hawaii to Kure Island (fig. 1.20). The principal (so-called Windward) Hawaiian Islands of Hawaii, Maui, Kahoolawe, Lanai, Molokai, Oahu, Kauai, Niihau, and Kaula lie at the southeastern end of the chain. All of these islands are formed by large volcanoes, though Kaula is only a small crescent-shaped erosional remnant of a tuff cone, presumably resting on a large submerged volcano. Some of the islands are formed by a single volcano, others by two or more coalesced volcanoes. The subaerial part of these volcanoes, which constitutes only a small fraction of the total mass of each volcano, is typically shield shaped. In older volcanoes, this shield shape is largely modified by erosion. The rocks of the southeastern islands are almost entirely of volcanic origin; only minor amounts of sedimentary rocks occur. Northwest of the Windward Islands lie the so-called Leeward Hawaiian Islands (fig. 1.20), which consist of small volcanic islets and atolls; only few of the volcanoes there rise above the sea.

The age of the volcanoes increases progressively from the southeast end, where the volcanoes are still active, to the northwest end, where the volcanoes are about 30 Ma. Most of the volcanoes have been extinct for millions of years. The only historical eruptions have been at East Maui (Haleakala) Volcano on the Island of Maui, and Hualalai, Mauna Loa, and Kilauea Volcanoes on the Island of Hawaii; Mauna Loa and Kilauea are frequently active.

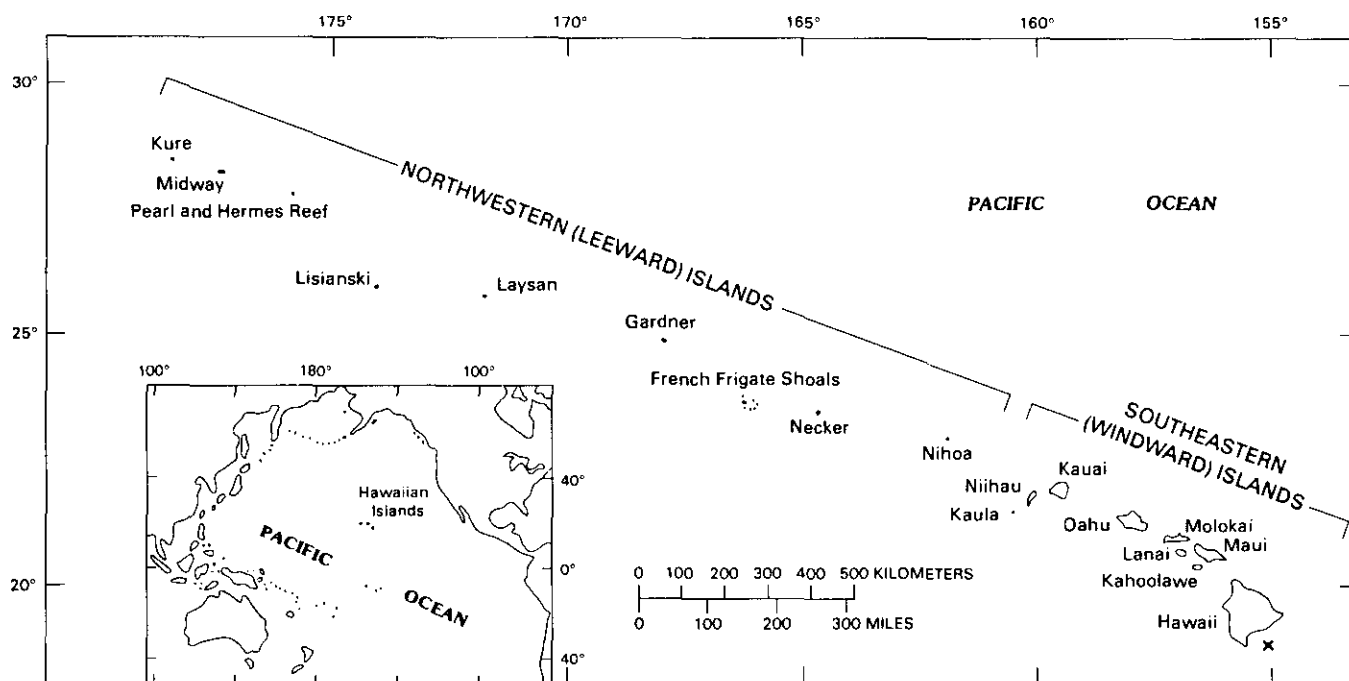


FIGURE 1.20.—Index map of Hawaiian Islands. x, Loihi Seamount.

Hawaiian volcanoes go through four major eruptive stages—presshield, shield, postshield, and rejuvenated stages—in their evolution and growth, and each stage is represented by rocks of distinct chemical and mineralogical composition. The stages used in this report are from Clague and Dalrymple (chapter 1, part I); see also Peterson and Moore (chapter 7) for discussion of alternative nomenclature. All but the preshield stage are well studied and documented (Stearns, 1940b; Macdonald and Katsura, 1964; Macdonald, 1968). Although an individual volcano may become extinct before all the stages are complete, the general sequence of stages is typical of well studied Hawaiian volcanoes.

Very little is known about the preshield stage, which includes the earliest phase of submarine activity and, in the one known example (Loihi Seamount, fig. 1.20), apparently consists of alkalic basalt and basanite (Moore and others, 1982). The main volcanic edifice (more than 95 percent of the total volume of the volcano) is constructed, in perhaps a million years or less, by voluminous eruptions of silica-rich tholeiitic basalt (and rare rhyodacite and icelandite) during the shield stage. The shield stage, as used here, includes the submarine eruption of tholeiitic basalt, which precedes the subaerial shield-forming eruptions. During the shield stage or at the beginning of the next stage, the postshield stage, a caldera may form and be filled with tholeiitic and (or) alkalic basalt. This process of caldera formation and filling was previously referred to as the caldera-filling or caldera-collapse stage, but is here considered to be a phase of the shield stage or postshield stage. During the postshield stage, a relatively thin cap of alkalic basalt and associated differentiated lava (ankaramite, hawaiiite, mugearite, benmoreite, and trachyte) covers the main shield. This alkalic lava makes up less than 1 percent of the total volume of the volcano. Later, after a relatively

long period of volcanic quiescence and erosion, a very small amount of silica-poor lava (alkalic basalt, basanite, nephelinite, and nepheline melilitite; rare ankaramite and hawaiiite known on East Maui Volcano only) erupts from isolated vents; this stage is referred to here as the rejuvenated stage.

During the shield and postshield stages, eruptions are not confined to the summit area of a volcano, but also occur along extensive zones of fissures, called rift zones, that extend down the flanks of the volcano. These zones are usually marked at the surface by collapse craters, cinder and spatter cones, and grabens, and below the surface by large numbers of dikes. During the rejuvenated stage, however, eruptions occur at vents unassociated with the preexisting rift zones, with the exception of rejuvenated-stage lava on East Maui Volcano.

The shield stage is represented by lava that is dark colored and forms relatively long and thin flows. Most of these flows have sparse to abundant olivine phenocrysts, and some have abundant large phenocrysts of plagioclase. Pyroclastic deposits are minor components during the shield stage.

The postshield stage is represented by lava that is commonly lighter colored than shield-stage lava and contains pyroxene, olivine, and plagioclase phenocrysts. This lava forms shorter and thicker flows. Pyroclastic deposits are more abundant during the postshield stage. There is little evidence of erosion between the eruption of shield-stage lava and postshield-stage lava.

The lava that ponds in a caldera during the shield stage or at the beginning of the postshield stage is usually massive and may show columnar structure.

Rejuvenated-stage lava is also dark colored, but usually forms thick flows with few or no phenocrysts; pyroclastic deposits are

common during this stage.

The shield, postshield, and rejuvenated stages have generally formed the basis for the major stratigraphic divisions or subdivisions of the rocks of the Hawaiian volcanoes (fig. 1.21).

## PREVIOUS STUDIES

The geology of the Hawaiian Islands has been studied for more than a hundred years (see Clague and Dalrymple, chapter 1, part I, and Peterson and Moore, chapter 7, for summaries of geologic investigations). Early geologic investigations concentrated on the main southeastern islands and were mainly reconnaissance and general descriptive studies. These early studies were superseded by detailed mapping of the eight major southeastern islands beginning in the 1930's and continuing for nearly 30 years. H.T. Stearns and his coworkers, in a series of bulletins published by the Hawaii Division of Hydrography, produced detailed geologic maps (at scale of 1:62,500, except Hawaii at 1:125,000) and descriptions of the Islands of Oahu (Stearns and Vaksvik, 1935; Stearns, 1939, 1940a), Lanai and Kahoolawe (Stearns, 1940b), Maui (Stearns and Macdonald, 1942), Hawaii (Stearns and Macdonald, 1946), Niihau (Stearns, 1947b), Molokai (Stearns and Macdonald, 1947), and Kauai (Macdonald and others, 1960; Stearns was not a coauthor of this report, but did much of the geologic mapping).

These bulletins have provided the basic stratigraphic framework for subsequent petrologic, mineralogic, geochemical, and geophysical investigations of the islands. Only a few stratigraphic studies have been done since publication of the bulletins, and those studies and detailed geologic mapping have been mainly on the Island of Hawaii.

## STRATIGRAPHIC NOMENCLATURE

The classification and naming of stratigraphic units (used here as synonymous with lithostratigraphic units), although to some extent arbitrary and artificial, helps promote concise and unambiguous scientific communication as to the spatial and temporal relations of rocks. Stratigraphic units can be formally or informally named; both are useful in stratigraphic work. Formally named units, however, are named and defined in accordance with procedures outlined in the Code, and any major changes made to them, such as boundary or rank changes, need to be justified.

In the Hawaiian Islands, formal stratigraphic names have been applied only to rock units on the eight main southeastern Hawaiian Islands (Hawaii, Maui, Kahoolawe, Lanai, Molokai, Oahu, Kauai, and Niihau), and these names are almost entirely restricted to volcanic rocks and the sedimentary rocks closely associated with them. Other sedimentary units, such as beach and reef deposits, have been formally named, but they are not discussed here.

Stearns and his coworkers divided the rocks of each volcano into one or more major units that they formally named as "Volcanic Series" (see remarks column in table 1.12). These "Series" consisted of rocks resulting from a succession of extensive eruptions. Some of the "Series" consisted entirely of volcanic rocks, whereas others consisted of volcanic rocks, related intrusions, and their weathering

products. Some of the "Series" were not subdivided, whereas others were subdivided either into formations or into members. Although the use of "Volcanic Series" as part of a formal name conformed to the "stratigraphic code" in use at the time the unit was named (Ashley and others, 1933), it does not conform to later codes, including the present (1983) code (American Commission on Stratigraphic Nomenclature, 1961, 1970; North American Commission on Stratigraphic Nomenclature, 1983), which restricts the use of the term "Series" to chronostratigraphic units.

The above inconsistencies, plus recent petrologic, mineralogical, and geochemical studies, have necessitated changes in the stratigraphic nomenclature for the volcanic rocks of the Hawaiian Islands<sup>1</sup> because (1) the lithic or descriptive terms of the names do not conform to the current stratigraphic code or do not reflect modern petrologic classification; (2) the ranks of the units are unclear or inappropriate; and (3) formalization of some names is not now considered to be necessary or useful.

The basic guidelines used in this report for updating the stratigraphic usage in the Hawaiian Islands are those recommended by the 1983 North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983). Any changes to the stratigraphic nomenclature made in this report, such as revision (change of rank or lower or upper boundary), redefinition (change of name), and abandonment of formally named stratigraphic units, have been approached as follows:

(1) Formal names are retained only for units that serve a useful purpose and require the stability of nomenclature that formalization affords. As stratigraphic units of any rank become established by repeated demonstration of their usefulness, those formal names that have not been used for a few decades or are currently not thought to serve a useful purpose are abandoned as formal names, but the geographic term of their name may be used informally to identify particular flows (and their associated cones) or beds.

(2) Major stratigraphic units on each volcano are all considered to be of formational rank, and are all formally named units. The ranks of stratigraphic units are important in that they give some concept of the scale of the units in relation to other units. Some of these units could have been considered to be units of group rank, but this does not seem necessary. The volcanic products of one volcano (except for some ash deposits) do not occur on other volcanoes, although they may overlap or interfinger at their boundaries where two or more volcanoes coalesce. Therefore, the units of a volcano can be considered to be essentially confined to one large "mountain," and group rank does not seem appropriate. This approach would also give some consistency to the stratigraphic nomenclature of all the islands.

(3) Formally named subdivisions of the major stratigraphic units are those units of member or lesser rank that are distinctive and (or) extensive. Many of the major units of the Hawaiian volcanoes are very often difficult to subdivide because of rapid lateral changes and lack of key beds.

<sup>1</sup>G.A. Macdonald had planned to revise the stratigraphic nomenclature of the Hawaiian Islands (written commun. to R.W. Kopf, 1976, 1977) before his untimely death in 1978.

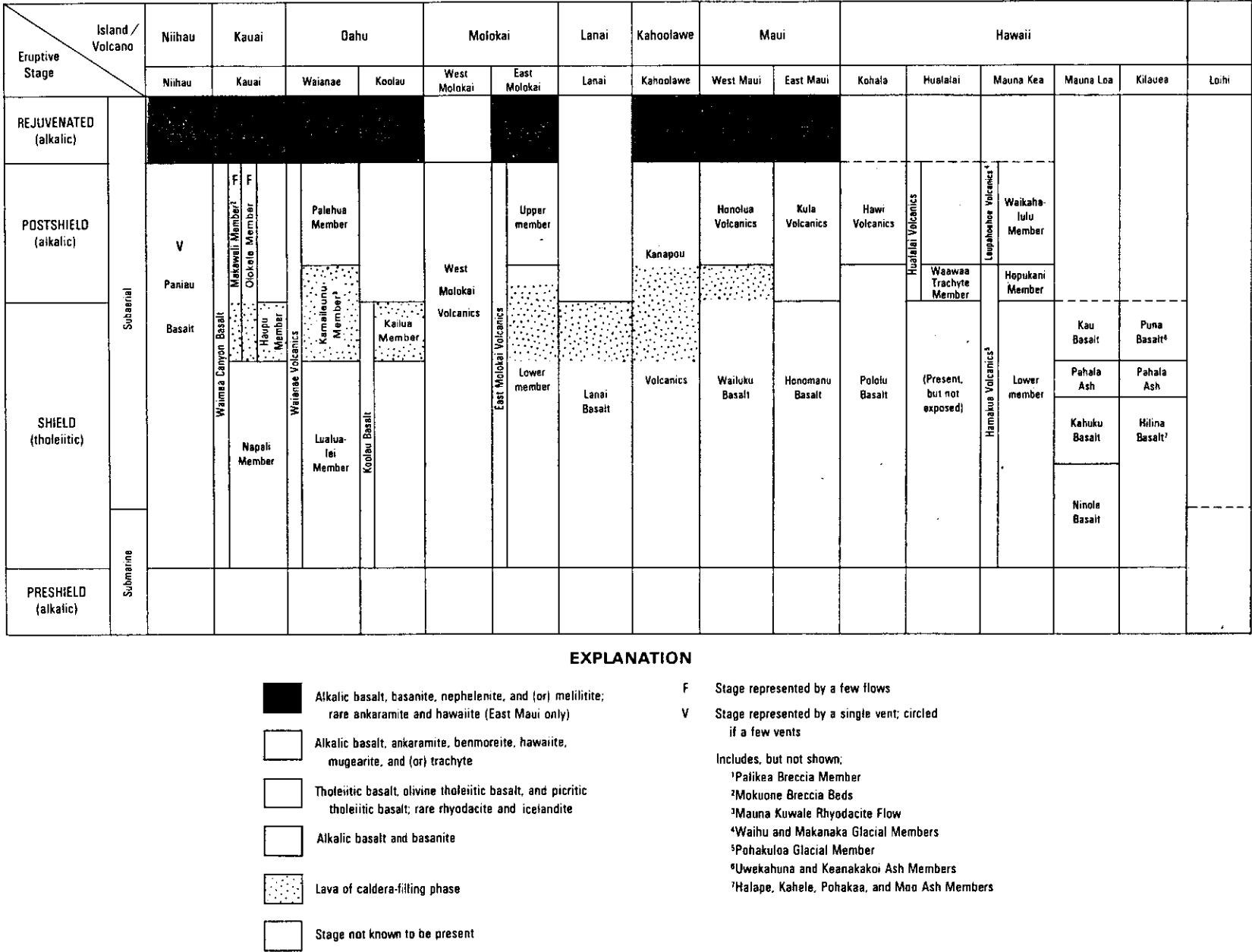


FIGURE 1.21. —Chart showing relations of eruptive stages to volcanoes and stratigraphic units, southeastern Hawaiian Islands, arranged approximately from northwest (left) to southeast (right) (see fig. 1.20 for location). No age correlation between units on different volcanoes implied. Dashed lines indicate end of stage not implied. Base of oldest unit on each volcano (except Loihi) assumed to be at the base of the shield stage.

(4) Formal names of the major stratigraphic units consist of a unique geographic term followed by a simple and generally accepted lithic term, such as "Basalt," or by the term "Volcanics." The initial letter of each term is capitalized. "Basalt" is used for units that consist entirely or almost entirely of basalt, whether tholeiitic or alkalic. An example is the Puna Basalt. The general term "Volcanics" (equivalent to the term "Formation") is used for units that do not have a predominant rock type or are composed of rock types such as hawaiite, mugearite, trachyte and basanite. Examples are the Lahaina Volcanics, Hamakua Volcanics, and Honolulu Volcanics (table 1.12).

The term "Formation" was not used because it does not convey that the unit is composed of volcanic rocks. The term "Volcanic Complex," which indicates a diverse assemblage of extrusive volcanic rocks, related intrusions, and their weathering products, could have been used for some units. However, we tentatively have opted for the term "Volcanics," because it is a shorter term, has precedence of use in the Hawaiian Islands, and does not introduce a new term until the need is confirmed by future investigations.

In general, the term "Basalt" is used for units that represent all or part of the shield stage, although a minor part of the postshield stage may also be represented. The term "Volcanics" is used for units that represent all or part of the postshield stage and for units that represent both shield stage and postshield stage. All units that represent the rejuvenated stage, with the exception of the Kiekie Basalt of Niihau Volcano, are termed "Volcanics."

(5) Formal names of subdivisions of the major units consist of a unique geographic term followed by the appropriate rank term—"Member," "Flow(s)," or "Bed(s)." An intervening lithic or descriptive term may be used in member names and is used in bed and flow names. The initial letter of each term is capitalized. Examples include the Napali Member, Kahele Ash Member, Makanaka Glacial Member, Mokuone Breccia Beds, and Mauna Kuwale Rhyodacite Flow.

Members, flows, and beds can also be informally named. Informal members are designated solely by their lithology or by their stratigraphic position, and none of the initial letters of their names is capitalized. Examples are ash member and lower member. The terms "historic member" and "prehistoric member" are not used in this report because age should play no part in differentiating lithostratigraphic units. Informal flows and beds are similarly designated, such as lower flow, upper flows, ash bed, and breccia beds, but may also combine a geographic term with the unit term or terms; only the initial letter of the geographic term is capitalized. Examples are the Kona ash beds, Kilea flow, and Makapipi flows. With one exception (see Waianae Volcano), all named flows in the Hawaiian Islands are considered to be informal in this report.

(6) A principal reference locality is herein designated for some well established units for which a type locality was never specified. For units that previously had more than one type locality specified, the one here considered to be the more accessible is retained as the type, and the other localities are redesignated as reference localities.

A designated stratotype (type section or type locality) is essential in the definition of a formal stratigraphic unit because it

serves as the standard for the unit and constitutes the basis for its recognition. It should therefore be representative of the concept of the unit. Because of the nature of Hawaiian volcanic activity, the stratotype for many of the Hawaiian volcanic units is not truly representative of those units, and reference sections or localities become invaluable in illustrating the lithologic diversity within a unit or the stratigraphic relations with other units. We have not attempted to specify additional reference sections or localities in this report, but we hope this will be done in future stratigraphic studies.

## STRATIGRAPHIC SUMMARY

The stratigraphy of the eight main Hawaiian Islands is briefly discussed below by island and volcano from southeast to northwest.

A summary of the formally named stratigraphic units used in this report is given in table 1.12, including a brief description of the lithology, occurrence, thickness, type and reference localities, stratigraphic relations, and age of each. The descriptions of the units were largely taken from the sources cited in the remarks column. Informal units are listed if they were previously formally named. Type localities are used throughout the table, even though some of the units have specified type sections.

Almost all of the isotopic ages shown in the table are K-Ar ages. Numerous radiocarbon ages have been determined for the youngest volcanoes but, with a few exceptions, are not shown. For a summary of radiocarbon ages for the Island of Hawaii, see Rubin and others (chapter 10). The relative ages assigned to the stratigraphic units are based on the Decade of North American Geology time scale (Palmer, 1983), which has the following epoch boundaries: Miocene-Pliocene, 5.3 Ma; Pliocene-Pleistocene, 1.6 Ma; and Pleistocene-Holocene, 10 ka. A correlation diagram of the major stratigraphic units is presented as figure 1.22.

Stratigraphic changes that are made in this report, using the guidelines of the Code and the approach discussed previously, are indicated in the remarks column and discussed below. Former names that have been applied to the units are also indicated in the remarks column. We have not used glottal stops in the geographic part of lithostratigraphic-unit names, although some authors have used them in other publications.

## HAWAII

The Island of Hawaii, the largest of the Hawaiian Islands, consists of five coalesced volcanoes: Kilauea, Mauna Loa, Mauna Kea, Hualalai, and Kohala (fig. 1.23). Mauna Kea is the highest of these volcanoes; Mauna Loa is the largest by volume. Little erosion has occurred on these volcanoes except on the northeastern sides of Kohala and Mauna Kea.

## KILAUEA VOLCANO

Kilauea, the youngest volcano of the island and still very active, consists entirely of shield-stage tholeiitic lava that issued from the summit caldera and the east and southwest rift zones. The rocks of the volcano are divided into the Hilina Basalt (older) and the

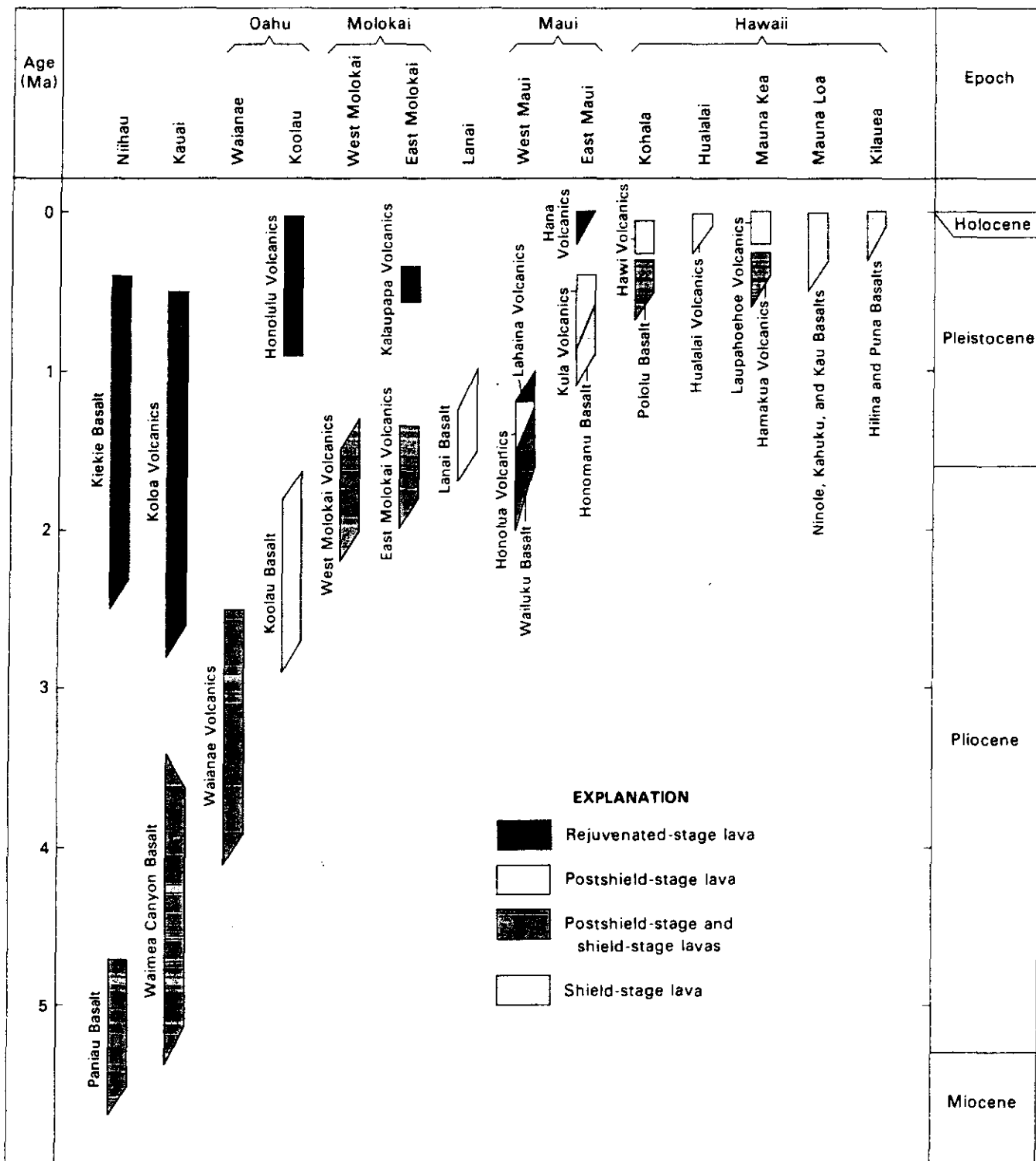


FIGURE 1.22.—Correlation diagram of isotopically dated major volcanic stratigraphic units of southeastern Hawaiian volcanoes. Modified from Clague and Dalrymple (chapter 1, part I, fig. 1.6). Diagonal lines indicate overlapping or uncertain ages. Epoch boundaries from Palmer (1983).

Puna Basalt (younger), generally separated from one another by the Pahala Ash (see subsection "Mauna Loa Volcano"; see also Easton, chapter 11). The Hilina Basalt is exposed only in fault scarps located along the south flank of the volcano. The Hilina Basalt includes the Halape (oldest), Kahele, Pohakaa, and Moo (youngest) Ash Members (Easton, chapter 11). The Puna Basalt

covers almost the entire surface of Kilauea and essentially consists of all post-Pahala lava (see discussion below). The Puna includes the prehistoric Uwekahuna (older) and historical Keanakakoi (younger) Ash Members.

The ages of the Hilina and Puna Basalts are not well known. The Hilina Basalt is probably older than the approximately 31-ka

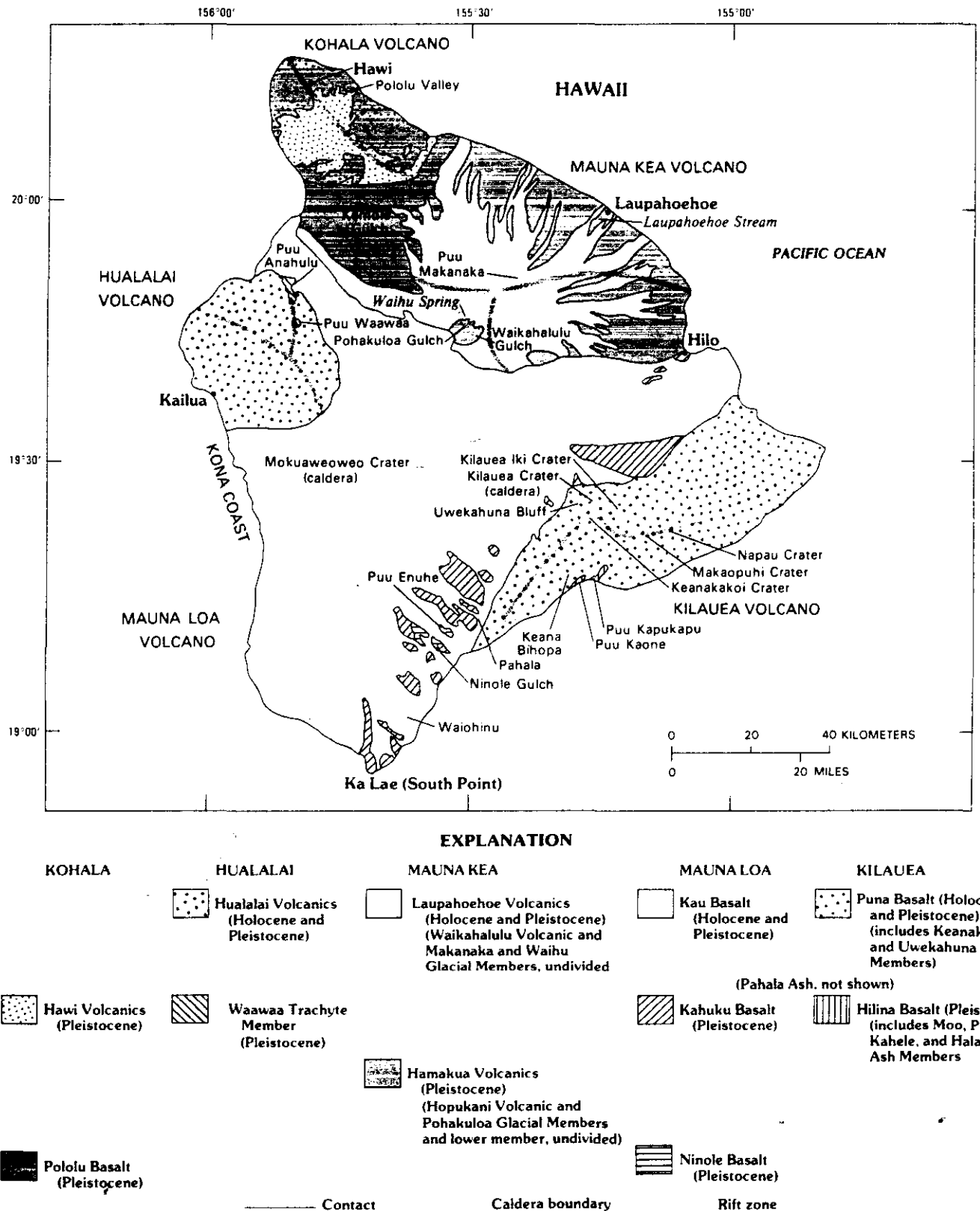


FIGURE 1.23.—Generalized geologic map of the Island of Hawaii, showing localities mentioned in text. Modified from Macdonald and others (1983), Easton (chapter 11), and Porter (1979a, 1979b). Rift zones from Fiske and Jackson (1972). Caldera boundary of Mauna Kea Volcano is inferred to be buried beneath younger lava (see Porter, 1972).

radiocarbon age obtained from the base of the Pahala Ash on Mauna Loa, and the oldest exposed Hilina flows are estimated to be about 100 ka (Easton, chapter 11). Most of the Puna Basalt was erupted during the last 10,000 years, but a Puna flow intercalated with the Pahala Ash at Puu Kaone was radiocarbon dated at about 22 ka (see Easton, chapter 11). The Uwekahuna Ash Member of the Puna Basalt has radiocarbon ages ranging from 2.17 ka to 1.04 ka; however, the age of the eruption or eruptions is uncertain. The ash could have been deposited about 2.1 ka (Casadevall and Dzurisin, chapter 13; Lockwood and Rubin, 1986) or about 1.5 ka (Holcomb, chapter 12).

#### MAUNA LOA VOLCANO

The lava of Mauna Loa, like that of Kilauea, is all shield-stage tholeiitic lava that has mostly issued from the summit caldera and southwest and northeast rift zones.

The oldest exposed rocks belong to the Ninole Basalt, which forms a series of steep-sided hills on the southeast flank of the volcano. The Ninole, which was originally named the Ninole Basalt by Stearns (1926), was later called the Ninole Volcanic Series by Stearns and Macdonald (1946). Recently, Lipman (1980) used the name Ninole Volcanics. As the Ninole is all tholeiitic basalt, the term used by Stearns (1926) is more informative and is used here. The Ninole was thought to represent remnants of an earlier shield volcano mostly buried by lavas from Mauna Loa (Stearns and Macdonald, 1946), but recent studies indicate that it may merely be deeper parts of the Mauna Loa shield, no more than a few hundred thousand years old, that have been uplifted along normal faults (Lipman, 1980).

Unconformably overlying the Ninole are the Kahuku Basalt (older) and Kau Basalt (younger) (table 1.12), which are separated by the Pahala Ash. Lipman (1980) recently used the terms Kahuku Volcanics and Kau Volcanics, but as these units are composed entirely of basalt, they are here renamed the Kahuku Basalt and Kau Basalt, respectively. The Kahuku Basalt crops out on the east and south sides of the volcano. The Kau Basalt covers most of the surface of Mauna Loa and consists of all post-Pahala lava.

The Pahala Ash is a distinctive yellowish vitric ash that has been largely altered by weathering to a reddish brown mixture of clay minerals and hydrated oxides. The thickness of the unit varies considerably, but it is locally more than 15 m thick (Easton, chapter 11).

These ash deposits were originally the uppermost part of what Noble and Clark (in Washington, 1923) called the Pahala Series, which also included the underlying flows. Stone (1926) used the term Pre-Kilauea Series for the uppermost ash and underlying flows, and restricted the name Pahala to the uppermost ash deposits, calling them the Pahala Ash. He applied the name Pahala Ash to ash deposits of Mauna Loa and Kilauea, but not to those of Mauna Kea. Stearns and Clark (1930) used the name Pahala Basalt for both the uppermost ash deposits and the underlying flows. The flows of their Pahala Basalt are herein called the Kahuku Basalt on Mauna Loa and the Hilina Basalt on Kilauea. Wentworth (1938) used the term Pahala Tuff in the same general sense as the Pahala

Ash of Stone (1926), but also used the term Waiau Formation (recently abandoned by Porter, 1973) for equivalent ash on Mauna Kea and the term Glenwood Tuff for equivalent ash on parts of the east slope of Mauna Loa. Stearns and Macdonald (1946) and Davis and Macdonald (in Avias and others, 1956), however, considered the Pahala Ash to be a persistent ash formation that was derived from several sources. They believed the Pahala occurred on all the volcanoes, separating their major units on Kilauea (Hilina and Puna Volcanic Series), Mauna Loa (Kahuku and Kau Volcanic Series), and Mauna Kea (Hamakua and Laupahoehoe Volcanic Series) and capping the older unit (Pololu Volcanic Series) of Kohala and a member (Waawaa Volcanics) of the Hualalai Volcanic Series of Hualalai.

Current mapping on Mauna Kea, Hualalai, and Kohala indicates that the extensive surficial ash deposits on these volcanoes were locally derived and are genetically distinct from the Pahala Ash on Kilauea and Mauna Loa (E.W. Wolfe, oral commun., 1986). Therefore, we are geographically limiting the Pahala to the occurrences on Kilauea and Mauna Loa.

The age of the Ninole Basalt is considered to be no more than a few hundred thousand years. The single published K-Ar age of 0.54 Ma has an estimated uncertainty of 0.4 m.y. (see Clague and Dalrymple, chapter 1, part I). The Kahuku Basalt and the Kau Basalt are approximately coeval with the Hilina Basalt and Puna Basalt, respectively, of Kilauea. The Pahala Ash on Mauna Loa and Kilauea is considered by Easton (chapter 11) to be entirely of Pleistocene age (between about 30 ka and 10 ka).

#### MAUNA KEA VOLCANO

Mauna Kea last erupted about 3.6 ka (Porter, 1979a). The volcano passed through the shield stage into the postshield stage and produced a cap of differentiated lava that almost completely buried the original subaerial shield. It is uncertain if a summit caldera existed; however, a small caldera has been inferred to lie buried beneath the younger lava (Porter, 1972). Rift zones are less pronounced than on Kilauea and Mauna Loa, but westerly, southerly, and easterly rifts are suggested by alignments of cinder cones. The lower northeastern slope of the volcano has gulches cut into it, whereas the other slopes are generally little affected by erosion. The upper slopes of the volcano were glaciated during the Pleistocene.

The rocks of the volcano were divided into the Hamakua Volcanic Series and the overlying Laupahoehoe Volcanic Series by Stearns and Macdonald (1946). The Hamakua represents the shield stage and part of the postshield stage; the Laupahoehoe represents the rest of the postshield stage. These units, considered to be of formational rank by Stearns and Macdonald (1946), were subdivided by them into informal members.

Recently, Porter (1979a, 1979b; see also Porter, 1973, 1974; Porter and others, 1977) formally redefined the Hamakua and Laupahoehoe to include glacial deposits, raised them to group rank, and subdivided both units into formally named volcanic and glacial formations. They subdivided the upper part of the Hamakua Group into the Hopukani Formation (volcanic) and the Pohakuloa Formation (glacial), but Porter (1979a, 1979b) called the lower part of



the group the "lower member of Stearns and Macdonald (1946)." Porter and others (1977; see also Porter, 1973, 1974) originally subdivided their Laupahoehoe Group into three volcanic formations—Liloe (oldest), Hanaipoe, and Waikahalulu (youngest) Formations—and two interstratified glacial formations—Waihu and Makanaka Formations. The Makanaka included the Kemole Member, a volcanic unit. This usage was superseded by a threefold subdivision of the Laupahoehoe Group (Porter, 1979a, b), in which all of the volcanic rocks were assigned to the Waikahalulu Formation; the names Liloe, Hanaipoe, and Kemole were abandoned as formal names of lithostratigraphic units and were formally applied to chronostratigraphic units—the Liloean, Hanaipoean, and Kemolean Stages.

Because the use of the Hamakua and Laupahoehoe as units of group rank is not consistent with the approach used here for the rest of the volcanoes of the Hawaiian Islands, these units are here reduced to formation rank and renamed the Hamakua Volcanics and Laupahoehoe Volcanics. Their subdivisions are reduced to member rank and renamed to reflect the overall nature of their lithologies (see table 1.12).

The Hamakua is considered to be of Pleistocene age and the Laupahoehoe of Pleistocene and Holocene age on the basis of K-Ar and radiocarbon dating (Porter, 1979a) (table 1.12).

#### HUALALAI VOLCANO

Hualalai Volcano last erupted in 1800–1801, when several flows issued from the well-defined northwest rift zone. Less well defined rift zones trending north and southeast are marked by numerous cinder and spatter cones. It is not known whether the volcano had a summit caldera. Shield-stage tholeiitic lava is not exposed on Hualalai Volcano, but tholeiitic rocks are known to occur in the subsurface and in the submarine part of the volcano (Moore and others, chapter 20; Clague, 1982).

The entire subaerial surface of the volcano consists of post-shield-stage alkalic basalt, with minor hawaiite and trachyte, named the Hualalai Volcanic Series by Stearns and Macdonald (1946). They included within the Hualalai a trachyte cone and flow, which they called the Waawaa Volcanics. Though they gave the Waawaa what is now considered to be a formational rank name, they clearly considered it to be a member of the Hualalai (Stearns and Macdonald, 1946, p. 143), and it is so considered here (table 1.12).

Stearns and Macdonald (1946) did not apply a name to the ash deposits that mantle the slopes of the volcano, although Wentworth (1938) had earlier called these deposits the Kona Tuff Formation. Later, Davis and Macdonald (in Avias and others, 1956) presumably included the Kona Tuff Formation within the Hualalai, effectively giving the Hualalai group status. R.B. Moore (oral commun., 1986) suggests that this unit should never have been formally named; it is here abandoned as a formal name and the unit is informally called the Kona ash beds. Thus, the Hualalai is here reduced to formational rank and renamed the Hualalai Volcanics.

The Hualalai Volcanics is largely of Holocene age, but the oldest flows are of Pleistocene age (Moore and others, chapter 20).

The Waawaa Trachyte Member has a published K-Ar age of  $0.4 \pm 0.3$  Ma (Funkhouser and others, 1968), but recent unpublished K-Ar determinations by G.B. Dalrymple (oral commun., 1986) indicate the trachyte is about 0.105 Ma.

#### KOHALA VOLCANO

Kohala Volcano is an oval volcano built up around northwest and southeast rift zones. It is deeply dissected on its northeast side. Arcuate faults near the summit of the volcano suggest that a caldera formed during the shield stage but was later buried by the younger lava in the postshield stage.

The volcanic rocks of Kohala Volcano were originally divided by Stearns and Macdonald (1946) into the Pololu Volcanic Series (older), composed of shield-stage tholeiitic basalt with caldera-filling postshield-stage alkalic basalt near the top, and the Hawi Volcanic Series (younger), consisting of differentiated alkalic lava of the postshield stage (table 1.12). Neither of these units has been subdivided, and they are here renamed the Pololu Basalt and Hawi Volcanics, respectively, to reflect their lithologies. The Pololu Basalt and Hawi Volcanics are of Pleistocene age on the basis of K-Ar determinations (McDougall, 1969; McDougall and Swanson, 1972) (table 1.12).

#### MAUI

The Island of Maui (fig. 1.24), the second largest of the Hawaiian Islands, consists of two large coalesced volcanoes, East Maui (or Haleakala) Volcano and West Maui Volcano, connected to one another by an isthmus formed when lava of East Maui banked against the already existing West Maui Volcano. The Maui volcanoes are more dissected than the volcanoes of the Island of Hawaii.

#### EAST MAUI (OR HALEAKALA) VOLCANO

East Maui Volcano last erupted about 200 years ago and has a large summit crater called Haleakala Crater, which is primarily of erosional origin (Macdonald and others, 1983). East Maui is the youngest Hawaiian volcano to have rejuvenated-stage lava.

The rocks of the volcano were originally divided by Stearns and Macdonald (1942) into the Honomanu Volcanic Series (oldest), Kula Volcanic Series, and Hana Volcanic Series (youngest), representing the shield, postshield, and rejuvenated stages, respectively (table 1.12). The Kula eruptions took place along southwest, east, and northwest rift zones. The Hana eruptions are unique among Hawaiian rejuvenated-stage eruptions because their vents are aligned along preexisting rift zones (southwest and northwest rift zones), the erosional period preceding these eruptions was rather short ( $<0.4$  m.y.), and ankaramite and hawaiite are present.

The Honomanu Volcanic Series is almost completely buried by later lava and is only exposed in the seacliffs along part of the north coast. The Honomanu Volcanic Series was not subdivided by Stearns and Macdonald (1942), and it was more recently called the Honomanu Formation in the Haleakala Crater area by Macdonald

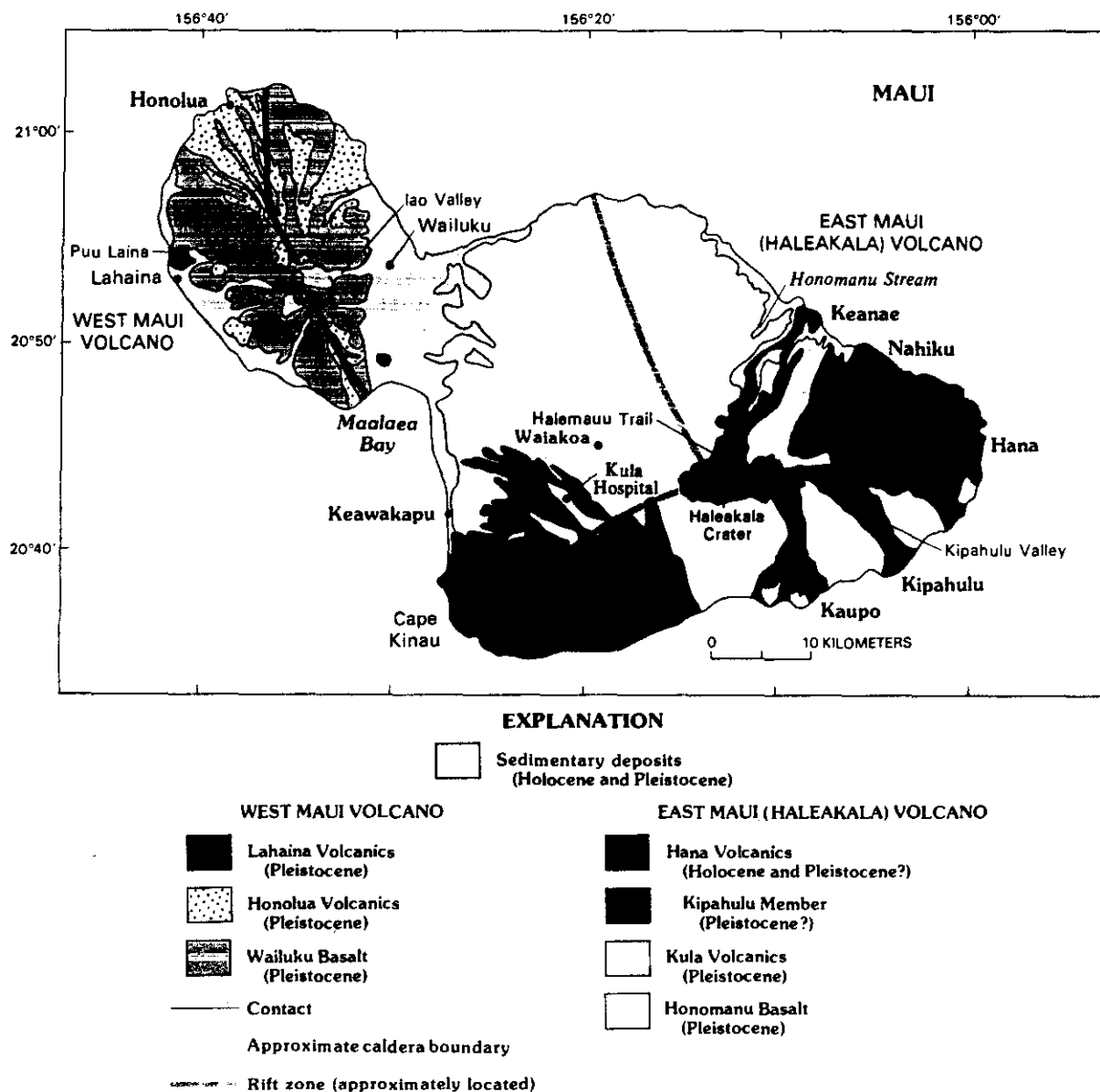


FIGURE 1.24. — Generalized geologic map of Maui, showing localities mentioned in text. Modified from Macdonald and others (1983). Rift zones from Fiske and Jackson (1972). West Maui Volcano caldera boundary from Macdonald and others (1983, fig. 20.4).

(1978). As it consists entirely of tholeiitic basalt, it is here renamed everywhere the Honomanu Basalt.

The Kula Volcanic Series of Stearns and Macdonald (1942), which was later called the Kula Formation by Macdonald (1978), is here renamed the Kula Volcanics to reflect its varied lithology. Rocks in the lower part of the south wall of Haleakala Crater that Stearns and Macdonald (1942) had originally assigned to the Honomanu were excluded from the Honomanu and named the Kumulihi Formation by Macdonald (1978). As these rocks appear more properly to belong to the Kula (Macdonald and

others, 1983, p. 391), they are here tentatively included in the Kula, and the name Kumulihi Formation is not used.

The Kula was named by Stearns (1942) for the settlement of Kula (now called Waiakoa) along the roads leading to the Kula Sanatorium or Hospital on the west slope of the volcano, but he did not designate a type locality. Macdonald and Davis (in Avias and others, 1956), however, did specify the type locality as "Kula, a district on the west slope of East Maui Mountain." This "locality" is here considered to be along Highway 37 near Waiakoa (Kula Post Office), about 7 km northeast of Kula Hospital. Other accessible

sections of the Kula, according to Stearns, are along the Kaupo-Kipahulu road near Kipahulu and along Halemau Trail in the Haleakala Crater area; these are here considered to be reference localities.

Stearns and Macdonald (1942) subdivided the Hana Volcanic Series into many local formally named units in the Keanae and Nahiku areas along the northeast coast. It was not clear whether they intended these units to be of member or formation rank (see Stearns and Macdonald, 1942, p. 94, 95), but they applied formational-rank names to these units. Macdonald and Davis (in Avias and others, 1956) considered them to be formations. In Kipahulu Valley in the southeastern part of the island, however, Stearns and Macdonald (1942) included only the Kipahulu Member within the Hana. The Kipahulu was later raised in rank by Macdonald and Davis (in Avias and others, 1956) to Kipahulu Formation, though in later publications by Macdonald and Abbott (1970), Macdonald and others (1983), and Stearns (1985) the term Kipahulu Member is used. Thus the Hana had previously been considered to be of group rank. Macdonald (1978) did reduce the rank of the Hana in the Haleakala Crater area, using the name Hana Formation, but he did not address the status of the formational rank units in the Keanae and Nahiku areas.

Therefore, the following changes are here made to the Hana: The Hana is reduced to formational rank everywhere and renamed the Hana Volcanics. Its subdivisions in the Keanae and Nahiku areas, being mainly single flows of very limited extent, are abandoned as formally named units and are used informally (table 1.12). The Kipahulu is retained as a member of the Hana because it is a fairly extensive unit and is separated from earlier Hana flows by an erosional unconformity. The historical lava flow of about 1790 in the Cape Kinau area (Oostdam, 1965) is considered to be part of the Hana, although it was not included in the Hana by Stearns and Macdonald (1942), and they gave "1750?" as the date of the flow. Finally, to correct an error in Keroher and others (1966, p. 1976), the Hana does not include the Kaupo Mudflow.

The Pleistocene age of the Honomanu Basalt and Kula Volcanics is well documented by K-Ar determinations (Naughton and others, 1980) (table 1.12). No isotopic ages have been determined for the Hana Volcanics, but it is here considered to be Pleistocene(?) and Holocene. The Kipahulu Member is probably Pleistocene, judging by its relations to older units.

#### WEST MAUI VOLCANO

West Maui Volcano is incised by deep valleys and is considered to be extinct. Lava was erupted from a small central caldera and from the north and southeast rift zones.

The rocks of West Maui Volcano were divided by Stearns and Macdonald (1942) into three major units—Wailuku Volcanic Series (oldest), Honolua Volcanic Series, and Lahaina Volcanic Series (youngest). These units represent the shield stage and postshield caldera-filling phase, the postshield stage, and the rejuvenated stage, respectively.

Stearns and Macdonald did not subdivide the Wailuku and Honolua, which are here renamed the Wailuku Basalt and Honolua

Volcanics, respectively. They did, however, include two formational-rank units, the Kilea Volcanics and the Laina Volcanics, within their Lahaina Volcanic Series. The Lahaina was recently reduced to formational rank and renamed the Lahaina Volcanics by Clague and others (1982), but they did not address the status of the Kilea and Laina. The Kilea Volcanics and Laina Volcanics are two small flow units with associated cinder cones; because they are of such limited extent, they are here abandoned as formally named units and their names used informally (table 1.12). The name Lahaina Volcanics of Clague and others (1982) is retained here.

Isotopic age determinations of the Wailuku Basalt and Honolua Volcanics (McDougall, 1964; Naughton and others, 1980) (table 1.12) indicate a Pleistocene age for both units. The Lahaina Volcanics is less well dated, but it is also considered to be Pleistocene. The single K-Ar age of  $1.30 \pm 0.10$  Ma (Naughton and others, 1980) is considered to be too old on stratigraphic grounds.

#### KAHOOLAWE AND LANAI

Each of these islands consists of a single shield volcano with a summit caldera, and each has been little dissected.

##### KAHOOLAWE VOLCANO

The lava of Kahoolawe Volcano was erupted along a prominent southwest rift zone (fig. 1.25). The caldera was almost completely buried beneath a cap of later lava.

The rocks that form essentially all of the Island of Kahoolawe, the smallest of the major islands, were called the Kanapou Volcanic Series by Stearns (1946). The Kanapou, which is not subdivided and is here renamed the Kanapou Volcanics, represents the shield stage, a caldera-filling phase of both the shield and postshield stages, and the postshield stage. The small rejuvenated-stage vents that occur in the sea cliffs on the west side of Kanapou Bay were not considered by Stearns (1946) to be part of the Kanapou, and they are not so considered here.

The alkalic part of the Kanapou Volcanics has been dated at about 1 Ma (Naughton and others, 1980); the tholeiitic part is undated, but is presumed here to be Pleistocene also. The rejuvenated-stage vents are not isotopically dated. They were considered to be of Holocene age by Macdonald and others (1983), but this age is probably too young.

##### LANAI VOLCANO

The Island of Lanai was built by eruptions from the summit and along northwest, southwest, and southeast rift zones (fig. 1.26). The caldera was mostly filled by lava flows, but its remnant is now covered by alluvium.

The volcanic rocks of Lanai represent the shield stage, including the caldera-filling phase, and they were called the Lanai Volcanic Series by Stearns (1946). Wentworth (1925) had originally applied the name Lanai Basalt to the lava flows of Lanai Volcano and the name Manele Basalt to the small crater remnant

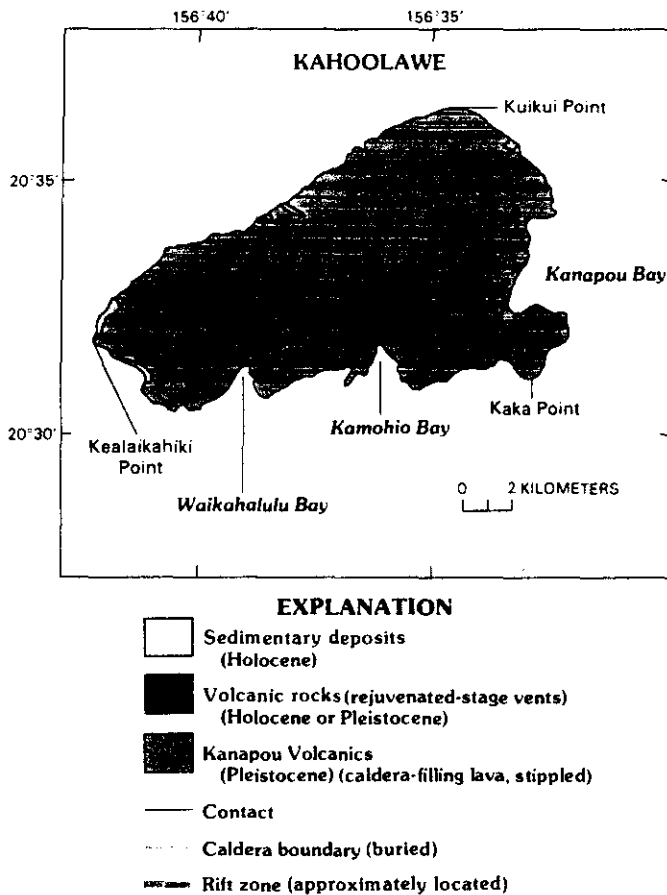


FIGURE 1.25.—Generalized geologic map of Kahoolawe, showing localities mentioned in text. Modified from Macdonald and others (1983). Rift zone from Fiske and Jackson (1972).

that forms the headland southwest of Manele Bay. Stearns (1946) redefined the Lanai to include not only the lava flows but also other associated rocks (pyroclastic and intrusive rocks) in a unit he called the Lanai Volcanic Series; he did not include Wentworth's terms Lanai and Manele Basalts as part of the Lanai Volcanic Series. However, Macdonald and Davis (in Avias and others, 1956) included (improperly) the Lanai Basalt, which included Manele Basalt, in the Lanai Volcanic Series, seemingly giving group status to the later unit.

The Lanai Volcanic Series of Stearns (1946) is here reduced to formational rank and renamed the Lanai Basalt. Though there is a chance of confusion with the Lanai Basalt of Wentworth, which consisted only of the lava flows, it would be more misleading to call the unit "Lanai Volcanics" because it consists totally of shield-stage tholeiitic basalt.

The term Manele Basalt is here abandoned as a formal name because it has essentially the same lithology and same age as the Lanai Basalt, as used here, and is of extremely limited extent and the term has been applied to a former high stand of the sea.

The Lanai Basalt is of Pleistocene age based on a K-Ar isochron age of  $1.28 \pm 0.4$  Ma (Bonhommet and others, 1977) (table 1.12).

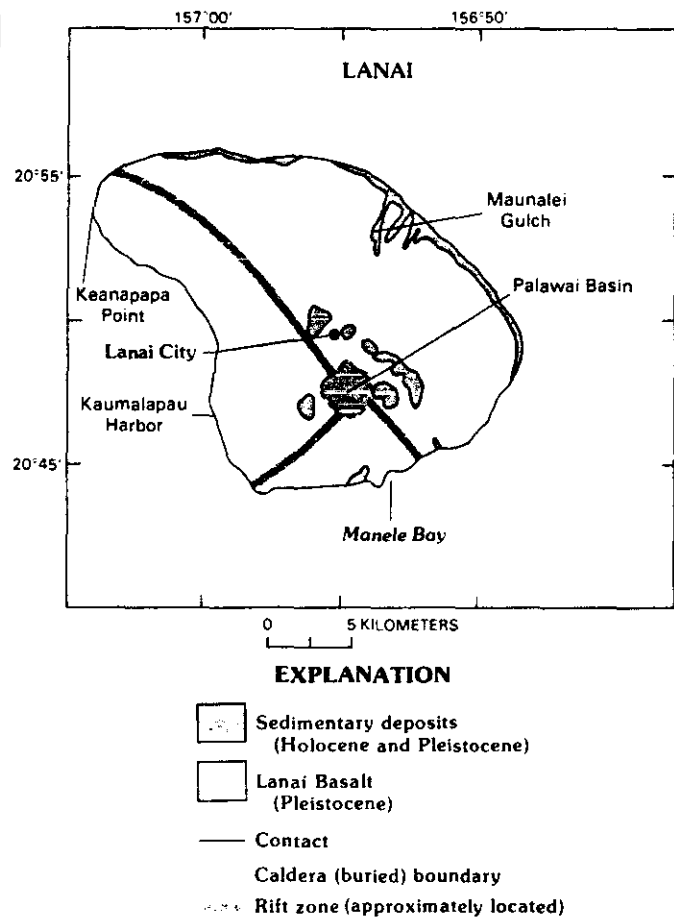


FIGURE 1.26.—Generalized geologic map of Lanai, showing localities mentioned in text. Modified from Macdonald and others (1983). Rift zones from Fiske and Jackson (1972). Caldera boundary inferred to be largely coincident with Palawai Basin.

## MOLOKAI

The Island of Molokai is another volcanic doublet, made up of two coalesced volcanoes—East Molokai and West Molokai Volcanoes (fig. 1.27). East Molokai Volcano had a summit caldera; there is no evidence that West Molokai Volcano had one. Both volcanoes are deeply dissected along their northern coasts.

### EAST MOLOKAI VOLCANO

East Molokai Volcano was built principally by eruptions from the summit caldera and along east and northwest rift zones.

The volcanic rocks of East Molokai Volcano were divided by Stearns (1946, 1947a) into the East Molokai Volcanic Series (older) and the Kalaupapa Basalt (younger).

The East Molokai Volcanic Series, here renamed the East Molokai Volcanics, was subdivided by Stearns into two informal members—lower and upper members. The lower member represents the shield stage and part of the postshield stage; both stages include a caldera-filling phase. The upper member represents the rest of the postshield stage.

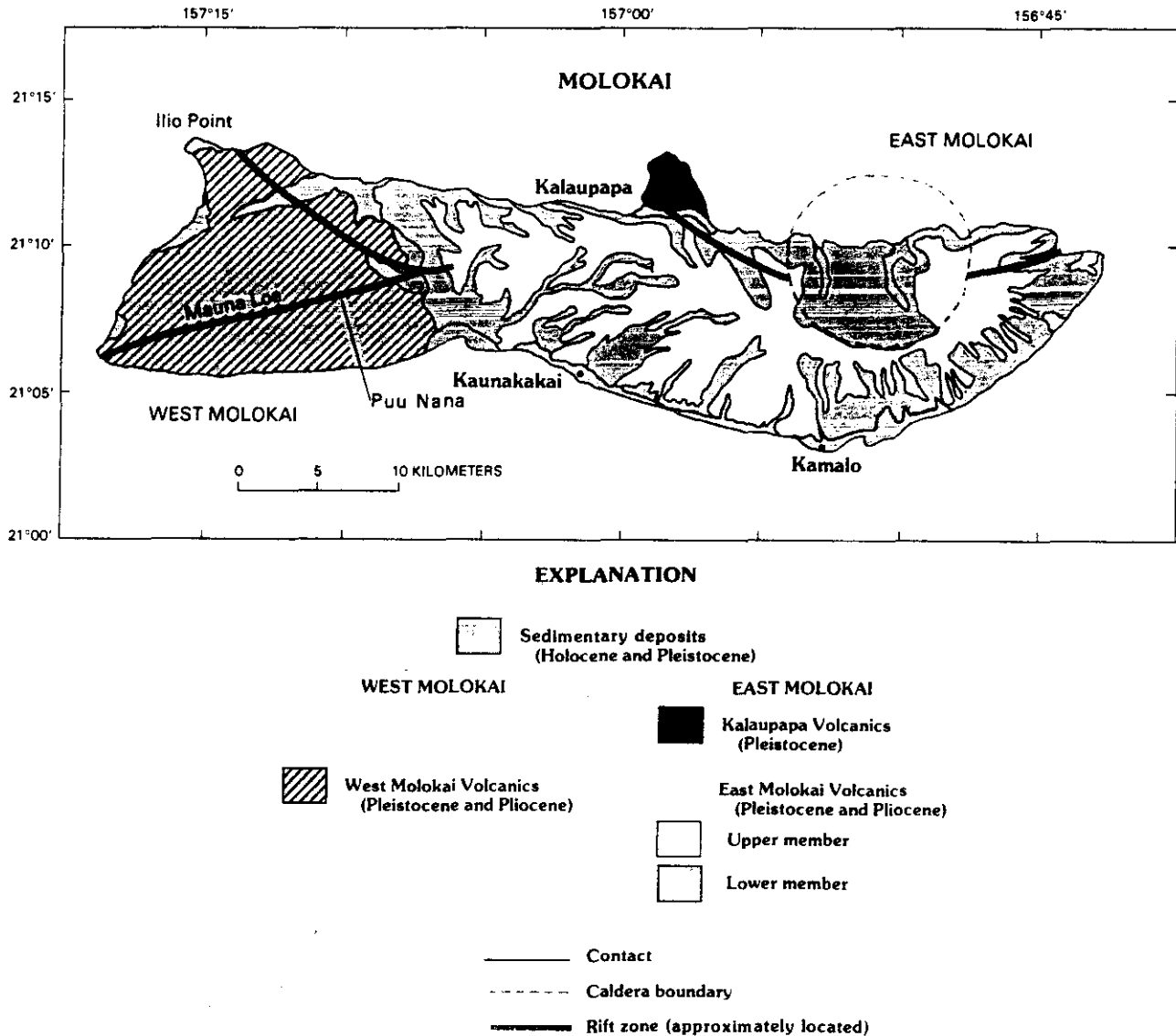


FIGURE 1.27.—Generalized geologic map of Molokai, showing localities mentioned in text. Modified from Macdonald and others (1983). Rift zones from Fiske and Jackson (1972). East Molokai Volcano caldera boundary from Holcomb (1985).

The Kalaupapa Basalt, which consists of alkalic basalt and basanite, is here renamed the Kalaupapa Volcanics to reflect the range of compositions present. The Kalaupapa has been proposed as a separate shield (see Macdonald and others, 1983; Holcomb, 1985), but it is here considered to represent a rejuvenated-stage vent associated with East Molokai Volcano on the basis of its age and chemistry (see Clague and others, 1982).

The East Molokai Volcanics is largely Pleistocene, but its lowermost flows are Pliocene on the basis of K-Ar age determinations on its lower and upper members (McDougall, 1964; Naughton and others, 1980) (table 1.12). The Kalaupapa Volcanics has a Pleistocene age based on K-Ar determinations of  $0.57 \pm 0.02$  and  $0.35 \pm 0.03$  Ma (Clague and others, 1982).

#### WEST MOLOKAI VOLCANO

West Molokai Volcano was built by eruptions principally along a northeast rift zone that crosses the summit area (Puu Nana) and along a northwest rift zone. There is no evidence of a summit caldera.

All of the volcanic rocks of West Molokai Volcano were called the West Molokai Volcanic Series by Stearns (1946, 1947a). The West Molokai Volcanic Series, which was not subdivided by Stearns, is here renamed the West Molokai Volcanics to reflect its varied rock types. The West Molokai Volcanics represents the shield and postshield eruptive stages.

The age of the West Molokai Volcanics is considered to be

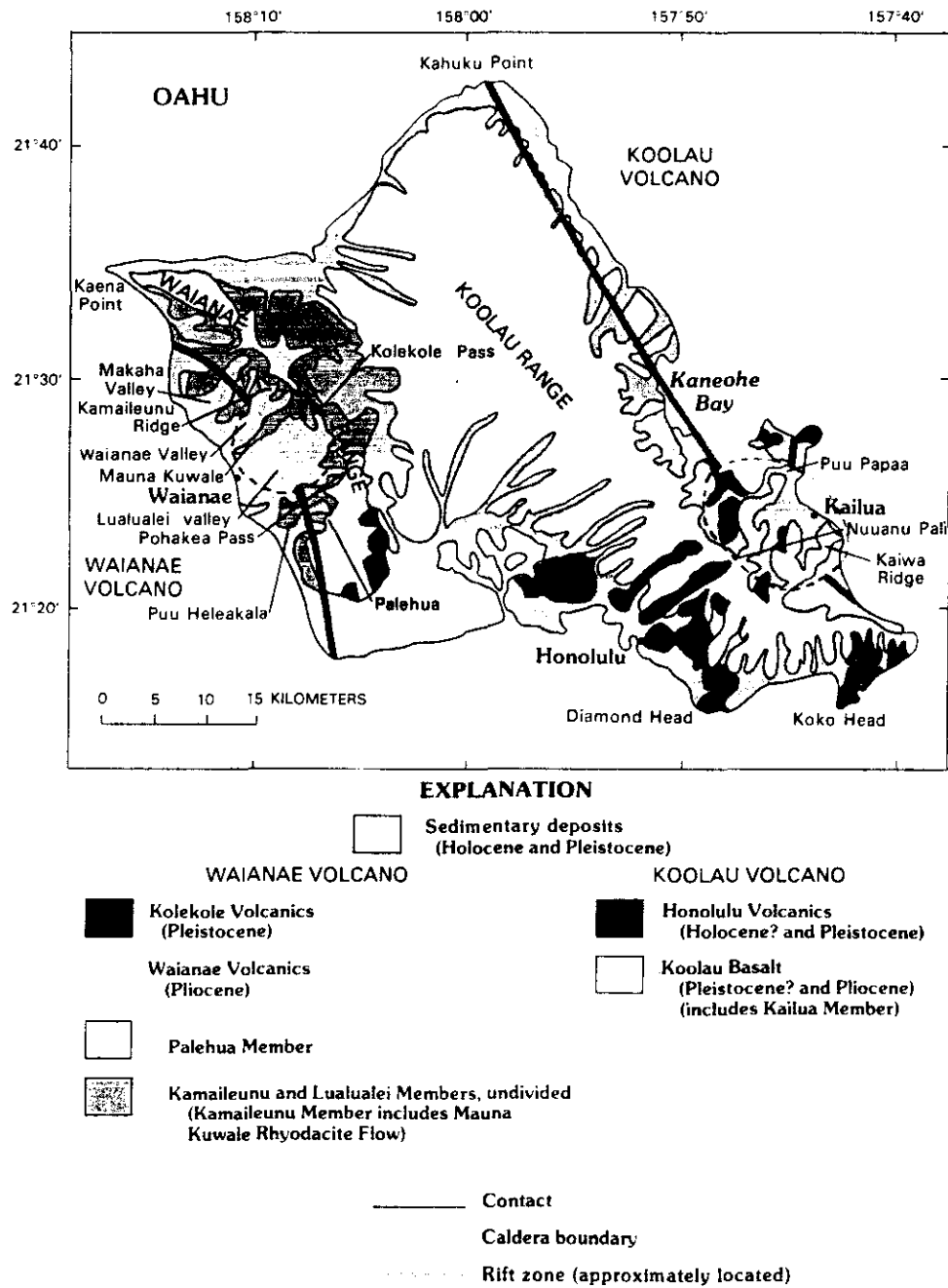


FIGURE 1.28.—Generalized geologic map of Oahu, showing localities mentioned in text. Modified from Macdonald and others (1983) and Sinton (in press). Rift zones from Fiske and Jackson (1972). Koolau Volcano caldera boundary from Clague and Frey (1982); Waianae Volcano caldera boundary from Sinton (in press).

Pliocene and Pleistocene on the basis of K-Ar determinations by Naughton and others (1980) (table 1.12).

**OAHU**

This island is made up of the highly dissected remnants of two shield volcanoes—Koolau Volcano (east) and Waianae Volcano (west) (fig. 1.28)—that have lost their original shield outline and

are now two northwest-trending ridges shaped mainly by erosion. Both volcanoes had summit calderas.

**KOOLAU VOLCANO**

The lava of Koolau Volcano was principally erupted from the caldera and along the northwest and southeast rift zones. A major dike complex occurs in the rift zones (Walker, chapter 41). The vents

for the youngest lava (rejuvenated stage) show no relationship to the preexisting rift zones.

The rocks of this volcano were originally divided by Stearns (1935, 1939) into three major volcanic units—the Kailua Volcanic Series (oldest), the Koolau Volcanic Series, and the Honolulu Volcanic Series (youngest). The Koolau and the Honolulu represent the shield stage and rejuvenated stage, respectively. Stearns originally believed the Kailua Volcanic Series represented an older lava series that was under or close by the summit caldera of Koolau Volcano, but that it was not part of Koolau Volcano. He later (Stearns, 1940a) recognized that the Kailua was part of the Koolau Volcano, representing the caldera complex. Macdonald and Davis (in Avias and others, 1956) included (improperly) the Kailua Volcanic Series in the Koolau Volcanic Series. Although the ranks they intended for these units are not clear, it is here presumed that the Kailua Volcanic Series was of formational rank.

More recently the Koolau has been considered to be of formational rank. It was called the Koolau Formation by Wentworth (1951) and the Koolau Volcanics by Lanphere and Dalrymple (1979) (table 1.12). It is here renamed the Koolau Basalt because it consists entirely of shield-stage tholeiitic basalt. Although Wentworth (1926, fig. 15) also used the term "Koolau basalt" in the explanation of a page-size geologic map of a small area of Oahu, he did not describe the unit and there does not seem much chance of confusion with the Koolau Basalt as used here. The Kailua Volcanic Series is here reduced in rank and renamed the Kailua Member of the Koolau Basalt.

The Honolulu Volcanic Series was defined by Stearns (1935) to consist of rejuvenated-stage lava that erupted from more than 35 vents on the southern slopes of the volcano. These lavas are strongly alkalic and form a variety of cones (tuff, cinder, spatter), many with associated lava flows. The eruptions presumably did not come in rapid succession, but occurred over a long period of time. Their general sequence (Macdonald and others, 1983) (table 1.12) has been based largely on the relative degree of weathering and erosion and on relations to stands of the sea because few superpositional relations are known and isotopic ages are considered unreliable.

The Honolulu Volcanic Series was of group rank as defined by Stearns (1935, 1939) because it was made up of numerous formally named units of formational rank (table 1.12). Hay and Iijima (1968) and Clague and others (1982) also considered the Honolulu to be of group rank. Lanphere and Dalrymple (1979) and Clague and Frey (1982) used the formational-rank term Honolulu Volcanics, but did not address the status of its formally named subdivisions. The Honolulu is here considered to be of formational rank, and the term Honolulu Volcanics is retained to reflect its range of lithologic compositions.

The formally named eruptive units that make up the Honolulu could have been reduced in rank and retained as formally named members, but, because most are single flows of very limited extent, this seems unnecessary; they are here all considered to be informal units (table 1.12).

The age of the Koolau Basalt is Pliocene based on K-Ar ages ranging from 2.7 to 1.8 Ma (Doell and Dalrymple, 1973);

however, a Pleistocene age cannot be ruled out for the youngest flows (table 1.12). The Kailua Member has not been isotopically dated, but is probably Pleistocene.

The K-Ar ages reported for the Honolulu Volcanics range from about 0.9 to about 0.03 Ma, but there are large differences (sometimes a factor of ten) in the ages reported by different investigators for the same eruptive units (see Clague and Dalrymple, chapter 1, part I; Macdonald and others, 1983). The Honolulu is certainly in part Pleistocene on the basis of published K-Ar ages, but because of the unreliability of some of the ages, a Holocene age cannot be ruled out for the youngest flows.

#### WAIANAE VOLCANO

Waianae Volcano was built by eruptions from the summit caldera and along the principal northwest and southeast rift zones.

The rocks of the volcano are divided into the Waianae Volcanics, representing the shield and postshield stages (both including a caldera-filling phase), and the Kolekole Volcanics, representing the rejuvenated stage (Sinton, in press). The Waianae was originally named the Waianae Volcanic Series and subdivided into three informal members (lower, middle, and upper) by Stearns (1935). He described these members but did not map them separately (Stearns, 1939). The Waianae has recently been subdivided by Sinton (in press) into three formally named members—the Lualualei (oldest), Kamaileunu, and Palehua (youngest) Members. These members are, for the most part, equivalent to Stearns' lower, middle, and upper members, respectively (table 1.12; see Sinton, in press). The Kamaileunu Member includes the Mauna Kuwale Rhyodacite Flow and several icelandite flows. These are the only known occurrences of rhyodacite and icelandite in the Hawaiian Islands. The rhyodacite flow was given formal status by Sinton (in press), and because it is of such distinctive lithology it is also considered to be formal here.

A Pliocene age for the Waianae Volcanics is inferred from K-Ar determinations ranging from 3.9 to 2.5 Ma (Doell and Dalrymple, 1973) (table 1.12). Funkhouser and others (1968) reported an average K-Ar age of about 2.4 Ma for the Mauna Kuwale Rhyodacite Flow, but this age is inconsistent with their reported ages for the overlying lava flow (4.3 Ma) and dikes (about 3 Ma) cutting the rhyodacite. According to Sinton (in press), the Mauna Kuwale probably has a minimum age of 3.2 Ma. The Kolekole Volcanics has not been isotopically dated but is tentatively considered by Sinton (in press) to be Pleistocene.

#### KAUAI

##### KAUAI VOLCANO

The Island of Kauai (fig. 1.29) consists of a single deeply eroded shield volcano with a summit caldera 15-20 km across, the largest in the Hawaiian Islands, and at least two flank calderas, the only ones known in the islands. Lava erupted not only in the calderas, but also from northwest and southeast rift zones. After a period of erosion, rejuvenated-stage lava erupted from about 40

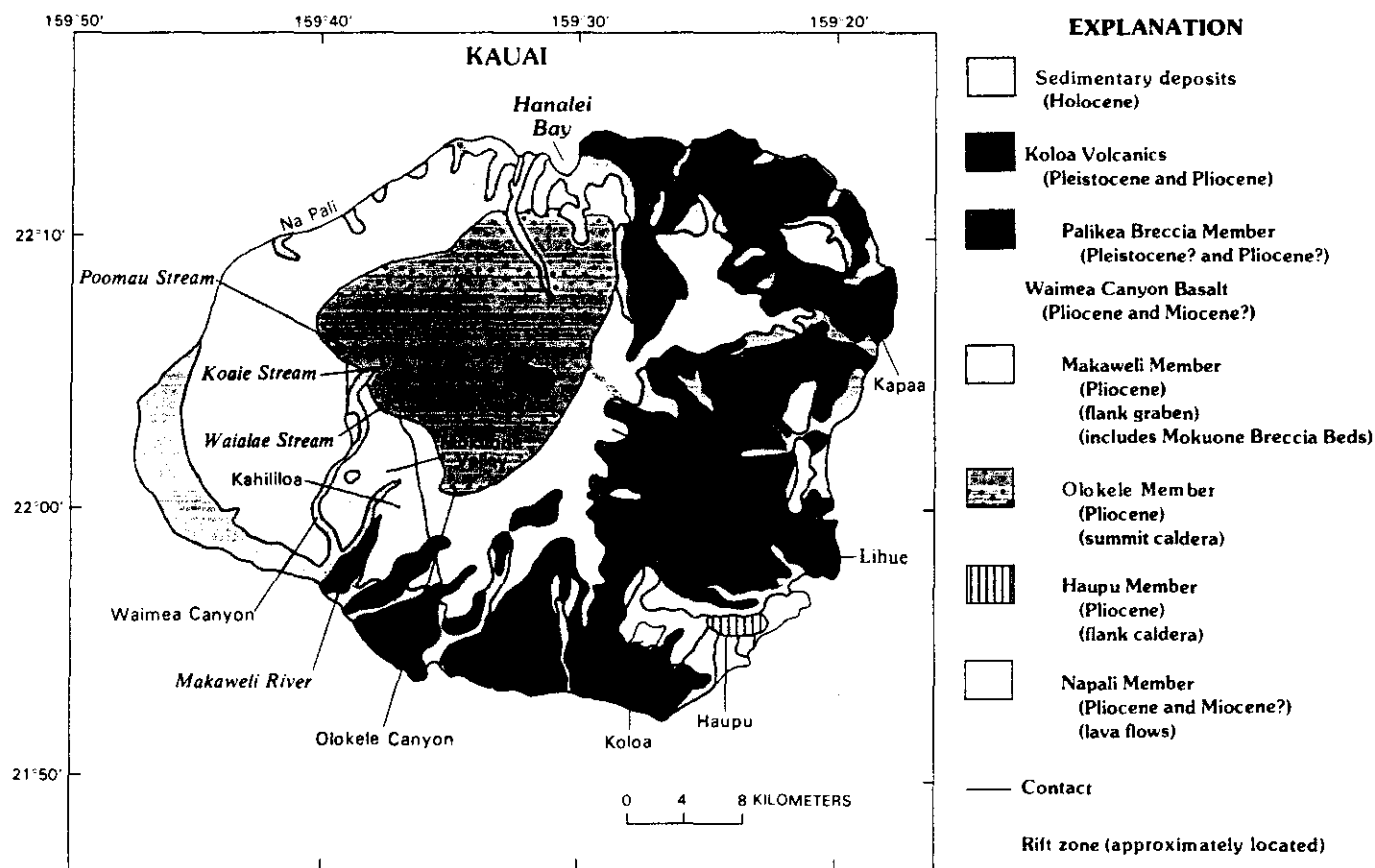


FIGURE 1.29.—Generalized geologic map of Kauai, showing localities mentioned in text. Modified from Macdonald and others (1983). Rift zones from Fiske and Jackson (1972). Summit caldera and southeast flank caldera are represented by Olokele Member and Haupū Member, respectively. Another flank caldera is represented by Lihue basin, a subcircular basin 10-15 km wide, which is almost bisected by southeast rift zone. There is no evidence that shield-stage or postshield-stage lava poured into this caldera, but it was later filled with rejuvenated-stage lava (Koloa Volcanics).

vents scattered over the eastern two-thirds of the island; these vents show no relation to the older rift zones.

The rocks of Kauai Volcano were originally divided by Stearns (1946) into the Waimea Volcanic Series (older), later renamed the Waimea Canyon Volcanic Series (Macdonald, 1949), and the Koloa Volcanic Series (younger). The Waimea Canyon represents the shield stage including the caldera-filling phase. Postshield-stage hawaiite is rare and occurs only at the top of the Waimea Canyon (fig. 1.21, table 1.12). The Koloa represents the rejuvenated stage.

The Waimea Canyon Volcanic Series was subdivided by Macdonald and others (1954, 1960) into four formally named formations—the Napali, Haupū, Olokele, and Makaweli Formations. The Makaweli Formation as defined by Macdonald and others (1960) included associated sedimentary deposits, which were called the Mokuone Member.

In order to have a nomenclature consistent with the other volcanoes of the Hawaiian Islands, the following changes are here made to the Waimea Canyon Volcanic Series: The Waimea Canyon is reduced to formational rank and renamed the Waimea Canyon

Basalt to reflect its predominant lithology. Its subdivisions are reduced to member rank and called the Napali, Haupū, Olokele, and Makaweli Members. The sedimentary unit included within the Makaweli is reduced in rank and renamed the Mokuone Breccia Beds (table 1.12).

Although the Napali, Haupū, Olokele, and Makaweli Members consist of essentially the same rock types, they are distinguishable and extensive units. The Napali Member consists of thin-bedded flank flows, whereas the Olokele and Makaweli Members consist of massive or thick-bedded flows. The Olokele is separated from the Makaweli and from the Napali by faults. The Haupū, which presumably represents a small caldera on the southeast flank of the volcano, also consists of thick-bedded flows, but it is isolated from the Olokele and Makaweli Members and is surrounded by older thin-bedded flows of the Napali Member.

The Napali, Olokele, and Makaweli Members had more than one type locality specified by Davis and Macdonald (in Avias and others, 1956) and Macdonald and others (1960). One of the localities is here retained as the type locality for each unit, and the other localities are redesignated as reference localities (table 1.12.).



The Koloa Volcanic Series, as defined by Stearns (1946) and Macdonald and others (1960), included within it a sedimentary unit that they named the Palikea Formation. The Palikea Formation consists largely of breccia underlying and interbedded with Koloa lava flows. The breccia, which grades laterally in some places into stream-laid conglomerate, is primarily made up of fragments of the Waimea Canyon Basalt and represents the rapid shedding of debris from the steep slopes of the volcano before and during Koloa time. Clague and others (1982) reduced the Koloa Volcanic Series to formational rank and renamed it the Koloa Volcanics, but they did not discuss the status of the Palikea Formation. The Palikea is here reduced in rank and renamed the Palikea Breccia Member of the Koloa Volcanics.

The Waimea Canyon Basalt is largely of Pliocene age, but the oldest flows may be Miocene, as indicated by K-Ar ages ranging from about 5.1 to 3.6 Ma (McDougall, 1964; 1979). The age relations between the caldera-filling-phase members are not known, but the Olokele Member is considered to be older than the Makaweli Member, and the Haupu Member is thought to be coeval with the Olokele.

The Koloa Volcanics is largely Pleistocene, an age indicated by all the published K-Ar ages, but unpublished K-Ar ages of 2.59 and 2.01 Ma (G.B. Dalrymple, oral commun., 1986) suggest that the oldest flows are Pliocene. The age of the Palikea Breccia Member is not known, but it is probably Pliocene and Pleistocene on the basis of its stratigraphic relations to Koloa lava flows.

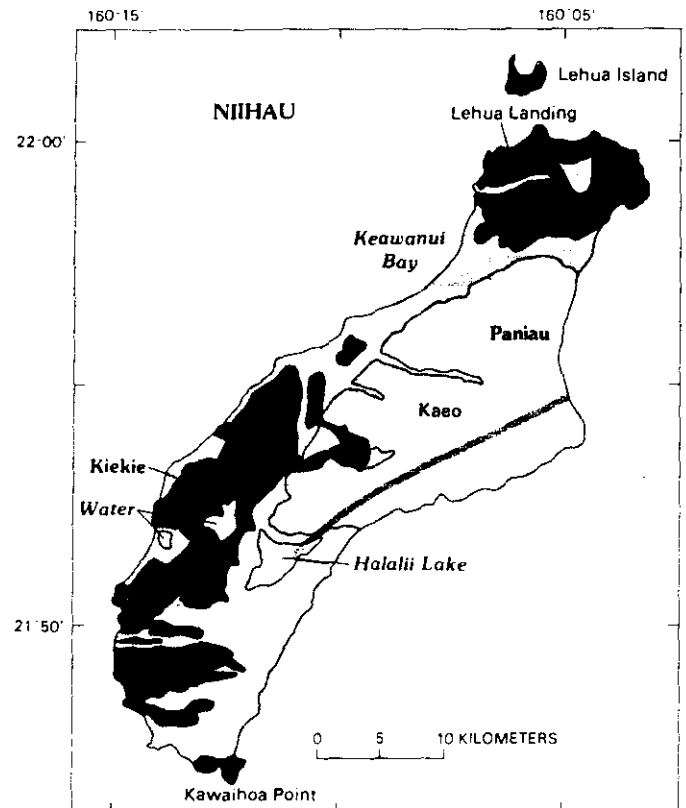
#### NIIHAU

#### NIIHAU VOLCANO

The Island of Niihau (fig. 1.30) is the deeply eroded remnant of a shield volcano. The central highland area, which consists of shield-stage tholeiitic lava, is fringed by a low coastal platform, which consists of rejuvenated-stage lava. The shield-stage lava was erupted from a southwest rift zone; the summit of the shield (and former caldera?) was presumably northeast of the present island.

The rocks of the volcano were divided by Stearns (1946, 1947b) into two major units—the Paniau Volcanic Series (older) and the Kiekie Volcanic Series (younger). The Paniau almost entirely represents the shield stage; a single postshield-stage vent that occurs at Kaeo and a couple postshield alkalic basalt dikes along the east coast of the island are also considered in this report to be part of the Paniau Basalt. These units are here renamed the Paniau Basalt and Kiekie Basalt, respectively. Although all of the rejuvenated-stage units on the other islands are called "Volcanics," the name Kiekie Volcanics is not used here because the Kiekie consists entirely of alkalic basalt.

No isotopic ages for the Island of Niihau have been published. However, unpublished K-Ar data for 11 flows of the Paniau indicate a Miocene and Pliocene age (G.B. Dalrymple, oral commun., 1986). The Kiekie Basalt was considered to be of Pleistocene age by Stearns (1947b) on the basis of its relations to Pleistocene



#### EXPLANATION

- Sedimentary deposits (Holocene and Pleistocene)
- Kiekie Basalt (Pleistocene and Pliocene)
- Paniau Basalt (Pliocene and Miocene)
- Contact
- Rift zone (approximately located)

FIGURE 1.30. — Generalized geologic map of Niihau, showing localities mentioned in text. Modified from Macdonald and others (1983). Rift zone approximately follows dike swarm mapped by Stearns (1947b).

shorelines, but unpublished K-Ar ages (G.B. Dalrymple, oral commun., 1986) indicate a Pliocene and Pleistocene age.

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TABLE 1.12. — *Summary of stratigraphic units for main southeastern Hawaiian Islands*

[Volcanic rocks and closely associated intrusive rocks and sedimentary deposits only. Units on each volcano are listed from youngest to oldest; see text for further explanation. All isotopic ages (in parentheses) and K-Ar ages (in millions of years), recalculated from new decay constants, unless otherwise noted; see summary by Clague and Dalrymple (chapter 1, part I). The term "partly" (in parentheses) preceding a former name indicates that the unit as then defined is equivalent to only part of the unit as used here; the term "part" (in parentheses) following a former name indicates that the unit as used here is equivalent to only part of the unit as then defined]

Unit (this report)	Description	Age	Remarks
<b>HAWAII</b>			
<b>Kilauea Volcano</b>			
<b>Puna Basalt</b>	Shield-stage lava of tholeiitic basalt and picritic tholeiitic basalt. Historic and pre-historic lava flows and minor intercalated pyroclastic deposits. Exposed over most of surface of Kilauea. Maximum exposed thickness: > 100 m. Type locality: Uwekahuna Bluff at Kilauea Crater (caldera). Reference localities: at Napau, Makaopuhi, and Kilauea Iki Craters, and near Keana Bihopa (see Easton, chapter 11). Overlies and is locally intercalated with Pahala Ash; interfingers with Kau Basalt of Mauna Loa Volcano. Includes Keanakakoi Ash Member and Uwekahuna Ash Member:	Holocene and Pleistocene ( $^{14}\text{C}$ , 1.13–22.6 ka) (see text)	Puna Basalt (Easton, chapter 11). Formerly: Kamehame Basalt (part) (Stearns, 1926, 1930); Puna Volcanic Series (Stearns and Macdonald, 1946); Puna Formation (Easton and Garcia, 1980).
<b>Keanakakoi Ash Member</b>	Lithic and vitric ash. Pyroclastic surge and minor airfall deposits. Mainly represents explosive eruption of A.D. 1790, but has slightly older reticulite pumice at base and post-1790 but pre-1823 reticulite pumice at top. Occurs around Kilauea Crater (caldera). Maximum exposed thickness: ~11 m. Type locality: just southwest of Keanakakoi Crater. Is interbedded with historic Puna lava flows.	Holocene	Keanakakoi Ash Member (Easton, chapter 11). Formerly: Keanakakoi Formation (part) (Wentworth, 1938; Powers, 1948); "aa" [erroneously for ash?] member (part) of Puna Volcanic Series (Stearns and Macdonald 1946, p. 108); Keanakakoi Formation (part) of Puna Volcanic Series (Davis and Macdonald in Avias and others, 1956); Keanakakoi Member (part) of Puna Formation (Easton and Garcia, 1980); (partly) Keanakakoi Formation (Malin and others, 1983).
<b>Uwekahuna Ash Member</b>	Mostly ash. Mainly pyroclastic surge deposits. Exposed near base of Kilauea Crater (caldera) and on southeast flank of Mauna Loa. Maximum exposed thickness: ~5 m. Type locality: Uwekahuna Bluff. Interbedded with prehistoric Puna lava flows.	Holocene ( $^{14}\text{C}$ , see text)	Uwekahuna Ash Member (Easton, chapter 11). Formerly: Uwekahuna Ash of Kilauea Series (Stone, 1926); Uwekahuna Formation (Wentworth, 1938; Powers, 1948); Uwekahuna Tuff of Puna Volcanic Series (Stearns and Macdonald, 1946, p. 194); Uwekahuna Ash of Puna Volcanic Series (Macdonald, 1949, p. 65, 67; Davis and Macdonald in Avias and others, 1956); Uwekahuna Member of Puna Formation (Easton and Garcia, 1980).
<b>Pahala Ash</b>	Vitric ash, largely palagonitized. Occurs on Mauna Loa and Kilauea Volcanoes (see text). Maximum exposed thickness: ~15 m. No type locality designated; named for exposures near town of Pahala on south slope of Mauna Loa. Principal reference locality: Moololo, just southwest of Keana Bihopa; reference localities: Puu Kapukapu and Puu Kaone, all on Kilauea Volcano (see Easton, chapter 11). Overlies Hilina Basalt on Kilauea and Kahuku Basalt on Mauna Loa.	Pleistocene	Geographically restricted (see text). Pahala Ash (Easton, chapter 11). Formerly: Pahala Series (part) (Noble and Clark in Washington, 1923); Pahala Ash of Pre-Kilauea Series (Stone, 1926); Pahala Basalt or Formation (part) (Stearns, 1930); Pahala Tuff (Wentworth, 1938); Pahala Ash (part) (Stearns and Macdonald, 1946; Davis and Macdonald in Avias and others, 1956); Pahala Formation (Easton and Garcia, 1980).

TABLE 1.12.—Summary of stratigraphic units for main southeastern Hawaiian Islands—Continued

Unit (this report)	Description	Age	Remarks
HAWAII--Continued			
Kilauea Volcano--Continued			
Hilina Basalt	Shield-stage lava of tholeiitic basalt, olivine tholeiitic basalt, and picritic tholeiitic basalt. Predominantly flows with associated pyroclastic deposits. Exposed in Hilina fault system escarpments along south flank of volcano. Maximum exposed thickness: ~300 m. Type locality: just south of Keana Bihopa. Reference localities: Keana Bihopa and Puu Kapukapu. Base not exposed. Includes Moo, Pohakaa, Kahele, and Halepe Ash Members, all intercalated with Hilina lava flows.	Pleistocene (see text)	Hilina Basalt (Easton, chapter 11). Formerly: Pahala Basalt (part) (Stearns and Clark, 1930); Hilina Volcanic Series (Stearns and Macdonald, 1946); Hilina Formation (Easton and Garcia, 1980; Decker and Christiansen, 1984).
Moo Ash Member	Mostly yellow-brown ash and palagonite. Maximum exposed thickness: ~3 m. Type locality: Keana Bihopa. Reference locality: Puu Kapukapu.	Pleistocene	Moo Ash Member of Hilina Basalt (Easton, chapter 11). Formerly: Moo Member of Hilina Formation (Easton and Garcia, 1980).
Pohakaa Ash Member	Thickest of ash members. Yellow- to reddish-brown-weathering palagonite, vitric ash, and soil. Exposed thickness: 1-4 m. Type locality: Pohakaa Arroyo, about 3 km southwest of Keana Bihopa. Reference locality: Puu Kapukapu.	Pleistocene	Pohakaa Ash Member of Hilina Basalt (Easton, chapter 11). Formerly: Pohakaa Member of Hilina Formation (Easton and Garcia, 1980).
Kahele Ash Member	Crudely bedded red clay with palagonite. Exposed thickness: 10-125 cm. Type locality: Pohakaa Arroyo, about 3 km southwest of Keana Bihopa. Reference locality: Puu Kapukapu.	Pleistocene	Kahele Ash Member of Hilina Basalt (Easton, chapter 11). Formerly: Kahele Member of Hilina Formation (Easton and Garcia, 1980).
Halepe Ash Member	Palagonite and poorly bedded clay. Exposed thickness: 10-50 cm. Type locality: Keana Bihopa. Reference locality: Puu Kapukapu.	Pleistocene	Halepe Ash Member of Hilina Basalt (Easton, chapter 11). Formerly: Halepe Member of Hilina Formation (Easton and Garcia, 1980).
Mauna Loa Volcano			
Kau Basalt	Shield-stage lava of tholeiitic basalt, olivine tholeiitic basalt, and picritic tholeiitic basalt. Historic and prehistoric lava flows and minor intercalated pyroclastic deposits. Exposed over most of surface of Mauna Loa. Maximum exposed thickness: > 185 m. Type locality: west wall of Mokuaweoweo Crater (caldera). Overlies Pahala Ash and Kahuku Basalt; interfingers with Puna Basalt of Kilauea Volcano.	Holocene and Pleistocene	Renamed. Formerly: Kamehame Basalt (part) (Stearns, 1926, 1930); Kau Volcanic Series (Stearns and Macdonald, 1946); Kau Formation (Porter, 1971, 1974); Kau Volcanics (Lipman, 1980).
Pahala Ash	See description under Kilauea.	Pleistocene	See "Remarks" under Kilauea; see also text under Mauna Loa.
Kahuku Basalt	Shield-stage lava of tholeiitic basalt, olivine tholeiitic basalt, and picritic tholeiitic basalt. Lava flows and minor intercalated pyroclastic deposits. Exposed on east and south sides of Mauna Loa. Maximum exposed thickness: 180 m. Type locality: Kahuku Pali, a fault escarpment running north of Ka Lae. Overlies (fault or unconformity) Ninole Basalt.	Pleistocene	Renamed. Formerly: lower member of Pahala Basalt (part) (Stearns, 1930); Kahuku Volcanic Series (Stearns and Macdonald, 1946); Kahuku Volcanics (Lipman, 1980).
Ninole Basalt	Shield-stage lava of tholeiitic basalt, olivine tholeiitic basalt, and picritic tholeiitic basalt. Lava flows with pyroclastic deposit near top. Exposed north of Waiohinu on southeast slope of Mauna Loa. Maximum exposed thickness: ~600 m. Type locality: walls of valley at Puu Enuhe, near Ninole Gulch. Base not exposed.	Pleistocene (0.54±0.4) (see text)	Ninole Basalt (Stearns, 1926, 1930) (see text). Formerly: (partly) Ninole Tuff (Wentworth, 1938); Ninole Volcanic Series (Stearns and Macdonald, 1946); Ninole Volcanics (Lipman, 1980).

TABLE 1.12.—Summary of stratigraphic units for main southeastern Hawaiian Islands—Continued

Unit (this report)	Description	Age	Remarks
HAWAII--Continued			
Mauna Kea Volcano			
<b>Laupahoehoe Volcanics</b>	Postshield-stage alkalic lava flows and associated volcanic and sedimentary deposits. Occurs on most of surface of Mauna Kea. Typical exposed thickness: 50-100 m. Type locality: near town of Laupahoehoe. Reference localities: in Waikahalulu and Pohakuloa Gulches. Conformably overlies Hamakua Volcanics. Divided into Waikahalulu Volcanic Member, and Makanaka and Waihu Glacial Members:	Holocene and Pleistocene	Reduced in rank and renamed (see text). Formerly: (partly) Laupahoehoe Volcanic Series (Macdonald, 1945; Stearns and Macdonald, 1946); Laupahoehoe Series (Porter, 1971); Laupahoehoe Group (Porter, 1973, 1974, 1979a, 1979b; Porter and others, 1977).
Waikahalulu Volcanic Member	Postshield-stage lava predominantly of hawaiite, but some alkalic basalt and ankaramite. Flows and associated pyroclastic deposits. Occurs on upper and lower slopes of volcano. Typical exposed thickness: 50-100 m. Type locality: in Waikahalulu Gulch. Reference locality: in Pohakuloa Gulch. Conformably, and locally unconformably, overlies Hamakua Volcanics. Interstratified with Makanaka and Waihu Glacial Members.	Holocene and Pleistocene ( $^{14}\text{C}$ and K-Ar, 0.0045-0.19)	Reduced in rank and renamed (see text). Formerly: (partly) Laupahoehoe Volcanic Series (Stearns and Macdonald, 1946); (partly) Waikahalulu Formation of Laupahoehoe Group (Porter, 1974, Porter and others, 1977); Waikahalulu Formation of Laupahoehoe Group (Porter, 1979a, 1979b).
Makanaka Glacial Member	Gravel and diamicton. Exposed on upper slopes of volcano. Exposed thickness: > 10 m. Type locality: Puu Makanaka. Reference localities: in Waikahalulu and Kemole Gulches. Interrelated with Waikahalulu lavas. Younger than Waihu Glacial Member.	Pleistocene	Reduced in rank and renamed (see text). Formerly: Makanaka Drift (Wentworth and Powers, 1941; see also Stearns, 1945); Makanaka Formation (part) of Laupahoehoe Group (Porter, 1974; Porter and others, 1977); Makanaka Formation of Laupahoehoe Group (Porter, 1979a, 1979b).
Waihu Glacial Member	Mainly conglomerate and diamictite. Exposed mainly on upper slopes below summit of Mauna Kea. Exposed thickness: generally < 30 m. Type locality: near Waihu Spring. Reference localities: in Pohakuloa Gulch and near Waihu Spring.	Pleistocene	Reduced in rank and renamed (see text). Formerly: Waihu Drift (Wentworth and Powers, 1941); Waihu Conglomerate (Stearns, 1945); Waihu Formation of Laupahoehoe Group (Porter and others, 1977; Porter, 1974, 1979a, 1979b).
<b>Hamakua Volcanics</b>	Divided into three members: upper two formally-named members represent postshield-stage lava flows and pyroclastic cones and associated sedimentary (glacial) deposits; informal lower member represents shield-stage lava flows. Type locality: in south wall of Laupahoehoe Stream gulch. Reference locality: Pohakuloa Gulch.	Pleistocene	Reduced in rank and renamed (see text). Formerly: (partly) Hamakua Volcanic Series (Stearns and Macdonald, 1946); Hamakua Group (Porter, 1973, 1974, 1979a, 1979b; Porter and others, 1977) (see text).
Pohakuloa Glacial Member	Gravel and diamicton. Exposed mainly in Pohakuloa and Waikahalulu Gulches. Maximum exposed thickness: ~40 m. Type locality: west wall of upper Pohakuloa Gulch. Reference locality: in Waikahalulu Gulch. Locally overlies upper flows of Hopukani Volcanic Member.	Pleistocene	Reduced in rank and renamed (see text). Formerly: Pohakuloa Drift (Wentworth and Powers, 1941); Pohakuloa Formation of Hamakua Group (Porter, 1974, 1979a, 1979b; Porter and others, 1977)
Hopukani Volcanic Member	Postshield-stage lava of alkalic basalt, ankaramite, and hawaiite. Flows and cinder cones. Exposed mainly in gulches on lower windward slopes of Mauna Kea and in saddle between Mauna Kea and Kohala Volcanoes. Exposed thickness: ~25 m. Type locality: in south wall of Laupahoehoe Stream gulch. Reference localities: in Pohakuloa and Waikahalulu Gulches. Overlies lower member.	Pleistocene (0.27±0.04, 0.375±0.050)	Reduced in rank and renamed (see text). Formerly: upper member of Hamakua Volcanic Series (Stearns and Macdonald, 1946); Hopukani Formation of Hamakua Group (Porter, 1974, 1979a, 1979b; Porter and others, 1977).

TABLE 1.12.—Summary of stratigraphic units for main southeastern Hawaiian Islands—Continued

Unit (this report)	Description	Age	Remarks
HAWAII--Continued			
Mauna Kea Volcano--Continued			
Lower member	Shield-stage lava of tholeiitic basalt, olivine tholeiitic basalt, and picritic tholeiitic basalt. Exposed in sea cliffs and gulches along northeast coast of Mauna Kea (so-called Hamakua coast) and near mouths of valleys between Hilo and Laupahoehoe. Exposed thickness: probably ~150 m. Base not exposed.	Pleistocene	Formerly: lower member of Hamakua Volcanic Series (Stearns and Macdonald, 1946, p. 154, fig. 31) (see text).
Hualalai Volcano			
Hualalai Volcanics	Postshield-stage lava of alkalic basalt and rare hawaiiite. Historic and prehistoric lava flows and associated pyroclastic deposits. Covers entire surface of Hualalai Volcano. Maximum exposed thickness: ~150 m. Type locality: around town of Kailua. Interfingers with Kau Basalt of Mauna Loa Volcano. Base not exposed. Includes Kona ash beds (informal) and Waawaa Trachyte Member (formal) (see text).	Holocene and Pleistocene	Reduced in rank and renamed (see text). Formerly: Hualalai Volcanic Series (Stearns and Macdonald, 1946).
	Kona ash beds		Abandoned as formally named unit (see text). Formerly: Kona Tuff Formation (Wentworth, 1938); unnamed unit of Hualalai Volcanic Series (Stearns and Macdonald, 1946); Kona Tuff Formation of Hualalai Volcanic Series (Davis and Macdonald in Avias and others, 1956).
Waawaa Trachyte Member	Trachyte cone and flow. Occurs in Puu Waawaa-Puu Anahulu area. Exposed thickness: ~275 m. Type locality: Puu Waawaa. Base not exposed.	Pleistocene (0.105, see text)	Renamed. Formerly Waawaa Volcanics [Member] of Hualalai Volcanic Series (Stearns and Macdonald, 1946, p. 143) (see text).
Kohala Volcano			
Hawi Volcanics	Postshield-stage lava of mostly mugearite and hawaiiite with some trachyte and benmoreite. Lava flows and associated pyroclastic deposits. Occurs in summit area and parts of slopes of Kohala Volcano. Exposed thickness of flows: ~30 m. Type locality: in Kumakua Gulch, about 1 km east of Hawi. Underlies Quaternary surficial deposits. Conformably, locally unconformably, overlies Pololu Basalt.	Pleistocene (0.061±0.001, 0.261±0.005)	Renamed. Formerly: Hawi Volcanic Series (Stearns and Macdonald, 1946).
Pololu Basalt	Shield-stage lava of tholeiitic basalt, olivine tholeiitic basalt, and picritic tholeiitic basalt; postshield-stage caldera-filling alkalic basalt near top. Thin lava flows and associated pyroclastic deposits. Occurs on upper and lower slopes of Kohala. Maximum exposed thickness: ~900 m. Type locality: on northwest side of Pololu Valley. Base not exposed.	Pleistocene (0.304±0.091-0.459±0.028)	Renamed. Formerly: Pololu Volcanic Series (Stearns and Macdonald, 1946).

## VOLCANISM IN HAWAII

TABLE 1.12.—*Summary of stratigraphic units for main southeastern Hawaiian Islands—Continued*

Unit (this report)	Description	Age	Remarks
<b>MAUI</b>			
<b>East Maui (Haleakala) Volcano</b>			
<b>Hana Volcanics</b>	<p>Rejuvenated-stage lava of alkalic basalt and basanite; rare ankaramite and hawaiite. Lava flows and associated intrusive rocks and pyroclastic and sedimentary deposits. Exposed in summit region and on eastern and south-western slopes. Exposed thickness: &gt; 300 m. Type locality: village of Hana. Unconformably overlies Kula Volcanics. Includes Kipahulu Member in Kipahulu Valley. Also includes historic flow of A.D. 1790 in Cape Kinau area and numerous informal flows in Nahiku and Keanae areas (see text) that are listed below in sequence (youngest to oldest) from Stearns and Macdonald (1942):</p> <p>Nahiku area:</p> <p>Hanawi flow Paakea flow Kuhiwa flow Mossman flow Kapaula flow Makaino flow Waiaka flow Makapipi flows Big Falls flows</p> <p>Keanae area:</p> <p>Keanae flow Waiokamilo flow Piinaau flow Ohia flow Wailuanui flow Pauwulu flow</p>	Holocene and Pleistocene(?)	<p>Reduced in rank, revised to include historic (A.D. 1790) flow, and renamed (see text). Formerly: Hana Volcanic Series (Stearns, 1942); Hana Formation (Macdonald, 1978); Hana Group (Clague and others, 1982).</p> <p>Abandoned as formally named units (see text). Formerly all in Hana Volcanic Series (see Macdonald, 1942; Macdonald and Davis in Avias and others, 1956):</p> <p>Hanawi Basaltic Andesite Paakea Basalt Kuhiwa Basaltic Andesite Mossman Picritic Basalt Kapaula Basaltic Andesite Makaino Basaltic Andesite Waiaka Basaltic Andesite Makapipi Basalt(s) Big Falls Picritic Basalt(s)</p> <p>Formerly all in Hana Volcanic Series (see Stearns, 1942):</p> <p>Keanae Basalt Waiokamilo Basalt Piinaau Basalt Ohia Basalt Wailuanui Basalt Pauwulu Basalt</p>
<b>Kipahulu Member</b>	<p>Late alkalic rejuvenated-stage lava of alkalic basalt and basanite; rare ankaramite and hawaiite. Lava flows. Exposed thickness: &gt; 400 m. Type locality: Kipahulu Valley. Unconformably overlies Hana Volcanics (older flows), Kula Volcanics, and Honomanu Basalt.</p>	Pleistocene(?)	<p>See text. Formerly: Kipahulu Member of Hana Volcanic Series (Stearns, 1942); Kipahulu Formation of Hana Volcanic Series (Macdonald and Davis in Avias and others, 1956); Kipahulu Member of Hana Volcanic Series (Macdonald and Abbott, 1970; Macdonald and others, 1983; Stearns, 1985).</p>
<b>Kula Volcanics</b>	<p>Postshield-stage lava of hawaiite with some ankaramite and alkalic basalt. Lava flows with associated intrusive rocks and pyroclastic and sedimentary deposits. Exposed in summit region and on all slopes. Maximum exposed thickness: ~600 m. Type locality: near Waiakoa, on west slope of volcano; reference localities: near Kipahulu and along Halemau Trail (see text). Overlies Honomanu Basalt.</p>	Pleistocene (0.46-0.86, 0.41±0.09)	<p>Renamed. Formerly: Kula Volcanic Series (Stearns, 1942); (partly) Kula Formation (Macdonald, 1978). Includes rocks formerly called Kumulihi Formation by Macdonald (1978) (see text).</p>
<b>Honomanu Basalt</b>	<p>Shield-stage lava of tholeiitic basalt, olivine tholeiitic basalt, and picritic tholeiitic basalt. Lava flows and associated intrusive rocks and rare pyroclastic deposits. Exposed in summit region and on north, northeast, and southwest slopes. Maximum exposed thickness: ~250 m. Type locality: in Honomanu Stream valley. Base not exposed.</p>	Pleistocene (0.75±0.04)	<p>Renamed. Formerly: Honomanu Volcanic Series (Stearns, 1942); (partly) Honomanu Formation (Macdonald, 1978).</p>



TABLE I.12.—Summary of stratigraphic units for main southeastern Hawaiian Islands—Continued

Unit (this report)	Description	Age	Remarks
MAUI--Continued			
West Maui Volcano			
Lahaina Volcanics	Rejuvenated-stage lava of basanite and picritic basanite. Lava flows and associated pyroclastic deposits. Exposed in small areas on west and southeast sides of West Maui. Exposed thickness of flows: 3-20 m; cones, ~45 m. No type locality designated. Principal reference locality <sup>1</sup> : Puu Laina. Unconformably overlies Honolua Volcanics. Locally includes two informal flows:  Laina flows and cinder cone Kilea flow and cinder cone	Pleistocene (1.30±0.10, see text)	Lahaina Volcanics (Clague and others, 1982) (see text). Formerly: Lahaina Volcanic Series of Stearns (1942); Lahaina Group (Naughton and others, 1980).  Abandoned as formally named units. Formerly of Lahaina Volcanic Series (Stearns, 1942): Laina Volcanics Kilea Volcanics
Honolua Volcanics	Postshield-stage lava of mugearite, trachyte, and hawaiite. Lava flows and associated domes dikes, and pyroclastic deposits. Caps ridges on all flanks of volcano. Maximum exposed thickness: ~300 m. Type locality: village of Honolua. Overlies Wailuku Volcanics.	Pleistocene (1.18-1.20, 1.50±0.13)	Renamed. Formerly: Honolua Volcanic Series (Stearns, 1942).
Wailuku Basalt	Shield-stage lava of tholeiitic basalt, olivine tholeiitic basalt, and picritic tholeiitic basalt, and postshield-stage caldera-filling lava of alkalic basalt. Lava flows with associated intrusive rocks and pyroclastic and sedimentary deposits. Widely exposed on West Maui Volcano. Maximum exposed thickness: > 1,500 m. Type locality: south wall of Iao Valley. Base not exposed.	Pleistocene (1.32±0.04, 1.58-1.97)	Renamed. Formerly: Waikulu Volcanic Series (Stearns, 1942).
KAHOOLAWE			
Kahoolawe Volcano			
Kanapou Volcanics	Postshield-stage lava of alkalic basalt and hawaiite; postshield-stage caldera-filling lava of alkalic basalt; shield-stage caldera-filling lava of tholeiitic basalt; shield-stage lava of tholeiitic basalt and olivine tholeiitic basalt. Lava flows and associated pyroclastic deposits and intrusive rocks. Forms essentially all of island. Maximum exposed thickness: ~450 m. Type locality: cliffs of Kanapou Bay. Base not exposed.	Pleistocene (upper alkalic part, 1.03±0.18)	Renamed. Formerly: Kanapou Volcanic Series (Stearns, 1946; Macdonald and Davis in Avias and others, 1956).
LANAI			
Lanai Volcano			
Lanai Basalt	<sup>1</sup> Shield-stage (including caldera-filling phase) lava of tholeiitic basalt, olivine tholeiitic basalt, and picritic tholeiitic basalt. Lava flows and associated pyroclastic deposits and intrusive rocks. Forms almost all of island. Maximum exposed thickness: > 1,000 m. No type locality designated. Principal reference locality <sup>1</sup> : Maunalei Gulch on northeast side of island (J.G. Moore, oral commun., 1986). Base not exposed.	Pleistocene (1.28±0.4)	Reduced in rank and renamed (see text). Formerly: (partly) Lanai Basalt and Manele Basalt (Wentworth, 1925); Lanai Volcanic Series (Stearns, 1946); Lanai Volcanic Series (which [improperly] included Lanai Basalt, and Lanai Basalt [improperly] included Manele Basalt) Macdonald and Davis in Avias and others, 1956).

TABLE 1.12.—*Summary of stratigraphic units for main southeastern Hawaiian Islands—Continued*

Unit (this report)	Description	Age	Remarks
LANAI--Continued			
Lanai Volcano--Continued			
	(Manele crater remnant)		Abandoned as formally named unit (see text). Formerly: Manele Basalt (Wentworth, 1925); Manele Basalt of Lanai Basalt of Lanai Volcanic Series (Macdonald and Davis in Avias and others, 1956).
MOLOKAI			
East Molokai Volcano			
Kalaupapa Volcanics	Rejuvenated-stage lava of alkalic basalt and basanite. Lava flows and associated cone. Makes up Kalaupapa peninsula. Maximum exposed thickness: ~125 m. Type locality: Kalaupapa peninsula. Unconformably overlies East Molokai Volcanics.	Pleistocene ( $0.35 \pm 0.03$ , $0.57 \pm 0.02$ )	Renamed. Formerly: Kalaupapa Basalt (Stearns, 1946, 1947a; Clague and Frey, 1982).
East Molokai Volcanics	Divided into two informal members. Upper member: postshield-stage lava of mugearite, with lesser amounts of hawaiite and trachyte. Lava flows and associated pyroclastic deposits and intrusive rocks. Lower member: shield-stage (including caldera-filling phase) lava of tholeiitic basalt, olivine tholeiitic basalt, and picritic tholeiitic basalt, and postshield-stage (including caldera-filling phase) alkalic basalt. Lava flows and associated intrusive rocks and pyroclastic and sedimentary deposits. Makes up almost all of East Molokai. Maximum exposed thickness: > 1,500 m. Type locality: cliff south of Kalaupapa peninsula. Locally overlies West Molokai Volcanics of West Molokai Volcano. Base not exposed.	Pleistocene and Pliocene (1.35–1.49, upper member; 1.52 and $1.76 \pm 0.07$ , lower member)	Renamed. Formerly: East Molokai Volcanic Series (Stearns, 1946, 1947a).
West Molokai Volcano			
West Molokai Volcanics	Postshield-stage lava of hawaiite and alkalic basalt; shield-stage lava of tholeiitic basalt. Lava flows and associated intrusive rocks and pyroclastic deposits. Forms most of West Molokai. Maximum exposed thickness: > 400 m. Type locality: West Molokai mountain (Mauna Loa). Locally overlapped by East Molokai Volcanics. Base not exposed.	Pleistocene and Pliocene $1.52 \pm 0.6$ , 1.89, $1.84 \pm 0.7$ , $1.90 \pm 0.06$ )	Renamed. Formerly: West Molokai Volcanic Series (Stearns, 1946; 1947a)
OAHU			
Koolau Volcano			
Honolulu Volcanics	Rejuvenated-stage lava, ranging from alkalic basalt, basanite, and nephelinite to melilitite. Exposed on southwest and northeast flanks of Koolau Range. No type locality designated; named for exposures in city and county of Honolulu. Honolulu Volcanics consists of an assemblage of local informally named lava flows, cinder, spatter, and tuff cones, and ash deposits (see text and below; sequence listed below from Macdonald and others, 1983). Unconformably overlies Koolau Basalt.	Holocene(?) and Pleistocene ( $0.03$ – $0.9$ ) (see text)	Honolulu Volcanics (Clague and Frey, 1982) [also Lanphere and Dalrymple, 1979]. Formerly: Honolulu Volcanic Series (Stearns, 1935, 1939); Honolulu Series (Winchell, 1947); Honolulu Group (Hay and Iijima, 1968; Clague and others, 1982).

TABLE 1.12.—*Summary of stratigraphic units for main southeastern Hawaiian Islands—Continued*

Unit (this report)	Description	Age	Remarks
OAHU--Continued			
Koolau Volcano--Continued			
			Abandoned as formally named units see text). Formerly all in Honolulu Volcanic Series (Stearns, 1935, 1939, 1940a; see also Avias and others, 1956, for other former names):
	Hawaiiiloa flow (and associated cone)		Hawaiiiloa Volcanics
	Pali Kilo flow (and associated cone?)		
	Pyramid Rock flow		Pyramid Rock Basalt
	Moku Manu tuff cone		Moku Manu Volcanics
	Ulupau tuff cone (and flow?)		Ulupau Tuff (also Ulupau Head Tuff); Mokapu Basalt (part)
	Mokolea flow		Mokolea [misspelled Mokulea by Stearns (1935)] Basalt; Mokapu Basalt (part)
	Kalihi flow (and associated cone)		Kalihi Volcanics
	Haiku flow (and associated cone)		Haiku Volcanics
	Rocky Hill flow (and associated cones)		Rocky Hill Volcanics (Basalt)
	Manoa cinder cone (and lava flow?)		
	Aliamanu flow (and associated cone)		Aliamanu Tuff (Basalt)
	Kaneohe flow (and associated cones)		Kaneohe Volcanics
	Luakaha flow (and associated cone)		Nuuanu Volcanics (Basalt) (part)
	Makuku flow (and associated cone)		Nuuanu Volcanics (Basalt) (part)
	Pali flow (and associated cone)		Pali Volcanics
	Makawao tuff and breccia deposits		Makawao Breccia
	Kaau flows (and associated tuff and mudflow deposits)		Kaau Volcanics (Basalt, Tuff)
	Mauumae flow (and associated cone)		Mauumae Volcanics
	Salt Lake tuff cone		Salt Lake Tuff
	Makalapa tuff cone		Makalapa Tuff
	Ainoni flow (and associated cone)		Ainoni Volcanics
	Castle flow (and associated cone)		Castle Volcanics
	Maunawili flow (and associated cone)		Maunawili Volcanics
	Training School flow (and associated cone)		Training School Volcanics
	Diamond Head tuff cone		Diamond Head Tuff [also Diamond Head Black Ash; Black Point Ash]
	Kaimuki flows		Kaimuki Volcanics (Basalt)
	Black Point flow		Black Point Basalt
	Kamanaiki flows		Kamanaiki Basalt
	Punchbowl flows (and associated cone)		Punchbowl Volcanics
	Manana tuff cone		Manana Tuff
	Koko Crater tuff cone		Koko Volcanics (part)
	Kahauloa flows (and associated cone)		
	Hanauma tuff cone		Koko Volcanics (part)
	Koko Head flow (and associated cone)		Koko Volcanics (part)
	Kalama flow (and associated cone)		Kalama Volcanics
	Kaohikaipu flow (and associated cone)		Kaohikaipu Volcanics
	Kaupo flow (and associated conelet)		Kaupo Basalt
	Round Top cinder and ash deposits		
	Sugarloaf flow (and associated cinder cone and ash deposits)		Sugar Loaf Basalt
	Tantalus flow (and associated cinder cone and ash deposits)		Tantalus Basalt
Koolau Basalt	Shield-stage lava of tholeiitic basalt, olivine tholeiitic basalt, and rare picritic tholeiitic basalt; near top, rocks transitional between tholeiitic and alkalic basalt. Lava flows (typically thin-bedded) with associated intrusive rocks (dikes) and minor pyroclastic and sedimentary deposits. Widely exposed in Koolau Range. Maximum exposed thickness of flows: probably > 1,000 m. No type locality designated. Principal reference locality: Nuuanu Pali. Locally unconformably overlies Waianae Volcanics of Waianae Volcano. Base not exposed. Includes Kailua Member:	Pleistocene(?) and Pliocene (1.8-2.7)	Renamed (see text). Formerly: Koolau Basalt (Wentworth, 1926); Koolau Volcanic Series (Stearns, 1935); Koolau Series (Wentworth and Jones, 1940; Winchell, 1947); Koolau Basalt Series (Wentworth and Winchell, 1947); Koolau Formation (Wentworth, 1951); Koolau Volcanics (Lanphere and Dalrymple, 1979).

TABLE 1.12.—Summary of stratigraphic units for main southeastern Hawaiian Islands—Continued

Unit (this report)	Description	Age	Remarks
OAHU--Continued			
Koolau Volcano--Continued			
Kailua Member	Shield-stage caldera-filling tholeiitic basalt and olivine tholeiitic basalt. Thick-bedded lava flows and dikes cutting them. Exposed near town of Kailua. Exposed thickness: ~500 m. No type locality specified. Principal reference locality <sup>1</sup> : Kaiwa Ridge. Reference locality <sup>1</sup> : east side of Puu Papaa. In fault(?) contact with Koolau extracaldera flows. Base not exposed.	Pleistocene(?)	Reduced in rank (see text). Formerly: Kailua Volcanic Series (Stearns, 1935); Kailua Volcanic Series of Koolau Volcanic Series [improperly] (Macdonald and Davis in Avias and others, 1956).
Waianae Volcano			
Kolekole Volcanics	Rejuvenated-stage alkalic lava. Flows and cones. Occurs near Kolekole Pass and at south end of Waianae Range. Thickness at type locality: ~2 m. Type locality: Kolekole Pass. Unconformably overlies flows of Waianae Volcanics and alluvium.	Pleistocene	Kolekole Volcanics (Sinton, in press). Formerly: (partly) Kolekole Volcanics (Stearns, 1946; Macdonald and Davis in Avias and others, 1956).
Waianae Volcanics	Postshield-stage lava of hawaiite with rare alkalic basalt and mugearite; postshield-stage caldera-filling lava of alkalic basalt; shield-stage caldera-filling lava of tholeiitic basalt; shield-stage lava of tholeiitic basalt, olivine tholeiitic basalt, and picritic tholeiitic basalt. Flows and associated intrusive, pyroclastic, and sedimentary rocks. Exposed over most of Waianae Range. Base not exposed. Divided into Palehua (youngest), Kamaileunu, and Lualualei (oldest) Members.	Pliocene	Waianae Volcanics (Sinton, in press) (see text). Formerly: Waianae Volcanic Series (part) (Stearns, 1935); Waianae Volcanic Series (Stearns, 1946).
Palehua Member	Postshield-stage lava of hawaiite with minor alkalic basalt and mugearite. Flows and associated pyroclastic deposits. Occurs at higher elevations throughout Waianae Range. Maximum exposed thickness: > 300 m. Type locality: near Palehua. Conformably, locally unconformably, overlies Kamaileunu Member.	Pliocene (2.5-3.2)	Palehua Member of Waianae Volcanics (Sinton, in press). Formerly: upper member (part) of Waianae Volcanic Series (Stearns, 1935); upper member of Waianae Volcanic Series (Stearns, 1946).
Kamaileunu Member	Postshield-stage caldera-filling lava of alkalic basalt, hawaiite, and rare ankaramite, grading down into shield-stage caldera-filling lava of tholeiitic basalt and rare icelandite. Thick flows and associated rocks. Well exposed in ridges bounding Waianae, Lualualei, and Makaha Valleys. Maximum exposed thickness: > 600 m. Type locality: Kamaileunu Ridge. Reference localities: near Puu Heleakala and Pohakea Pass. Conformably, locally unconformably, overlies Lualualei Member. Includes formally named Mauna Kuwale Rhyodacite Flow:	Pliocene (3.0-3.5)	Kamaileunu Member of Waianae Volcanics (Sinton, in press). Formerly: lower member (part) and middle member (part) of Waianae Volcanic Series (Stearns, 1935).
Mauna Kuwale Rhyodacite Flow	Rhyodacite. Exposed on Mauna Kuwale and Kauaopuu ridges. Exposed thickness: ~135 m. Type locality: Mauna Kuwale. Underlies hawaiite and overlies icelandite of Kamaileunu Member.	Pliocene (see text)	Mauna Kuwale Rhyodacite Flow of Kamaileunu Member (Sinton, in press). Formerly: part of lower member of Waianae Volcanic Series (Stearns, 1935); part of upper member of Waianae Volcanic Series (Stearns, 1940a); Mauna Kuwale Trachyte (McDougall, 1963, 1964); Mauna Kuwale Rhyodacite of upper Waianae Volcanic Series (Funkhouser and others, 1968).
Lualualei Member	Shield-stage lava of tholeiitic basalt, olivine tholeiitic basalt, and picritic tholeiitic basalt. Thin-bedded flows and associated rocks. Occurs mainly in Lualualei Valley. Exposed thickness: > 450 m. Type locality: Puu Heleakala. Base not exposed.	Pliocene (3.0-3.9)	Lualualei Member of Waianae Volcanics (Sinton, in press). Formerly: lower member (part) and middle member (part) of Waianae Volcanic Series (Stearns, 1935).

TABLE 1.12.—Summary of stratigraphic units for main southeastern Hawaiian Islands—Continued

Unit (this report)	Description	Age	Remarks
<b>KAUAI</b>			
<b>Kauai Volcano</b>			
<b>Koloa Volcanics</b>	Rejuvenated-stage lava of alkalic basalt, basanite, nephelinite, and melilitite. Lava flows and associated pyroclastic deposits. Widely exposed over eastern two-thirds of island. Maximum exposed thickness: ~650 m. Type locality: vicinity of town of Koloa. Unconformably overlies Waimea Canyon Basalt. Locally includes Palikea Breccia Member, which underlies and is intercalated with Koloa lava flows.	Pleistocene and Pliocene (0.62, 1.21, 1.46, 2.01, 2.59) (see text)	Koloa Volcanics (Clague and others, 1982) (see text). Formerly: Koloa Series (Hinds, 1930); Koloa Volcanic Series (Stearns, 1946; Macdonald, 1949; Macdonald and others, 1954, 1960; Macdonald and Davis in Avias and others, 1956).
Palikea Breccia Member	Breccia and lesser conglomerate. Exposed in narrow bands over eastern two-thirds of island. Maximum exposed thickness: ~215 m. Type locality: Palikea ridge, about 5 km southeast of Kawaikini peak.	Pleistocene(?) and Pliocene(?)	Reduced in rank and renamed (see text). Formerly: Palikea Formation of Koloa Volcanic Series (Macdonald and others, 1954, 1960; Davis and Macdonald in Avias and others, 1956).
<b>Waimea Canyon Basalt</b>	Shield-stage lava of tholeiitic basalt, olivine tholeiitic basalt, and picritic tholeiitic basalt; rare postshield-stage hawaiite near top. Lava flows and minor pyroclastic deposits. Widely exposed. Total exposed thickness: ~800 m. Type locality: walls of Waimea Canyon. Divided into Makaweli, Olokele, Haupu, and Napali Members.	Pliocene and Miocene(?) (3.6-5.1)	Reduced in rank and renamed (see text). Formerly: Kauai Lavas (Hinds, 1930); Waimea Volcanic Series (Stearns, 1946); Waimea Canyon Volcanic Series (Macdonald, 1949; Macdonald and others, 1954, 1960; Davis and Macdonald in Avias and others, 1956; Stearns, 1967).
Makaweli Member	Shield-stage caldera-filling lava of tholeiitic basalt, olivine tholeiitic basalt, and picritic tholeiitic basalt; postshield-stage hawaiite flow near top of unit. Represents south flank graben. Predominantly thick-bedded flows. Exposed in southwestern part of island. Maximum exposed thickness: ~450 m. Type locality <sup>1</sup> : West wall of Makaweli River canyon. Reference locality <sup>1</sup> : east wall of lower Waimea Canyon. Includes Mokuone Breccia Beds at base of and intercalated with flows. In fault contact with Olokele and Napali Members.	Pliocene (3.60-4.15)	Reduced in rank (see text). Formerly: Makaweli Formation of Waimea Canyon Volcanic Series (Macdonald and others, 1954, 1960; Davis and Macdonald in Avias and others, 1956).
Mokuone Breccia Beds	Breccia with lesser conglomerate. Exposed in narrow bands in southwestern part of island. Maximum exposed thickness: ~300 m. Type locality: walls of Mokuone Valley, west of Kahililoa.	Pliocene	Reduced in rank and renamed (see text). Formerly: Mokuone Formation (Macdonald and others, 1954); Mokuone Member of Makaweli Formation (Davis and Macdonald in Avias and others, 1956; Macdonald and others, 1960).
Olokele Member	Shield-stage caldera-filling lava of tholeiitic basalt, olivine tholeiitic basalt, and picritic tholeiitic basalt; postshield-stage hawaiite flow near top. Represents large summit caldera. Thick-bedded flows and associated pyroclastic deposits. Exposed in central part of island. Maximum exposed thickness: ~800 m. Type locality <sup>1</sup> : walls of upper Olokele Canyon. Reference localities <sup>1</sup> : walls of Poomaa, Koaie, and Waialae Streams. In fault contact with Makaweli and Napali Members.	Pliocene	Reduced in rank (see text). Formerly: Olokele Formation of Waimea Canyon Volcanic Series (Macdonald and others, 1954, 1960; Davis and Macdonald in Avias and others, 1956).
Haupu Member	Shield-stage caldera-filling lava of tholeiitic basalt, olivine tholeiitic basalt, and picritic tholeiitic basalt. Represents southeast flank caldera. Thick-bedded flows exposed on Haupu ridge. Maximum exposed thickness: ~500 m. Type locality: south side of Haupu ridge. Separated from Napali Member by buried caldera faults(?).	Pliocene	Reduced in rank (see text). Formerly: Haupu Volcanic Series (part) (Stearns, 1946); Haupu Formation of Waimea Canyon Volcanic Series (Macdonald and others, 1954, 1960).

TABLE 1.12.—Summary of stratigraphic units for main southeastern Hawaiian Islands—Continued

Unit (this report)	Description	Age	Remarks
KAUAI--Continued			
Kauai Volcano--Continued			
Napali Member	Shield-stage lava of tholeiitic basalt, olivine tholeiitic basalt, and picritic tholeiitic basalt. Mostly thin-bedded flows and associated pyroclastic deposits. Widely exposed. Maximum exposed thickness: ~800 m. Type locality: west wall of Waimea Canyon. Reference locality: northwest coast of island (Napali coast). Base not exposed.	Pliocene and Miocene(?) (4.3-5.1)	Reduced in rank (see text). Formerly: Napali Formation of Waimea Canyon Volcanic Series (Macdonald and others, 1954, 1960).
NIIHAU			
Niihau Volcano			
Kiekie Basalt	Rejuvenated-stage lava of alkalic basalt. Lava flows and pyroclastic deposits. Forms low coastal plain. Maximum exposed thickness: ~90 m. Type locality: town of Kiekie. Unconformably overlies Paniau Basalt.	Pleistocene and Pliocene (see text)	Renamed. Formerly: Kiekie Volcanic Series (Stearns, 1946, 1947b); Kiekie Volcanics (Clague and others, 1982).
Paniau Basalt	Shield-stage lava of tholeiitic basalt, olivine tholeiitic basalt, and rare postshield-stage alkalic basalt. Lava flows and associated intrusive rocks, minor ash. Single post-caldera stage alkalic vent at Kaeo. Comprises central highlands of island. Maximum exposed thickness: ~350 m. Type locality: east side of Paniau hill. Base not exposed.	Pliocene and Miocene (see text)	Renamed. Formerly: Paniau Volcanic Series (Stearns, 1946, 1947b).

<sup>1</sup>Here designated.

#### Addendum

Some units on the Islands of Hawaii, Maui, and Oahu listed in table 1.12 and discussed in the text were also formerly called "Formations" as follows (listed in alphabetical order): Hana Formation (East Maui Volcano, Maui); Hawi Formation (Kohala Volcano, Hawaii); Honolulu Formation (West Maui Volcano, Maui); Honolulu Formation (Koolau Volcano, Oahu); Honomanu Formation (East Maui Volcano, Maui); Hualalai Formation (Hualalai Volcano, Hawaii); Kahuku Formation (Mauna Loa Volcano, Hawaii); Kau Formation (Mauna Loa Volcano, Hawaii); Kolekole Formation (Waianae Volcano, Oahu); Koolau Formation (Koolau Volcano, Oahu); Kula Formation (East Maui Volcano, Maui); Lahaina Formation (West Maui Volcano, Maui); Ninole Formation (Mauna Loa Volcano, Hawaii); Pololu Formation (Kohala Volcano, Hawaii); Waawaa Formation (Hualalai Volcano, Hawaii); Waianae Formation (Waianae Volcano, Oahu); and Wailuku Formation (West Maui Volcano, Maui). See Easton, R.M., and Gaiswinkler-Easton, M., 1983; A guide to the geology of the Hawaiian Islands--Hawaii, Maui, and Oahu: Joint Annual Meeting of the Geological Association of Canada, Mineralogical Association of Canada, and Canadian Geophysical Union, Field Guidebook, v. 2, p. 1-91.