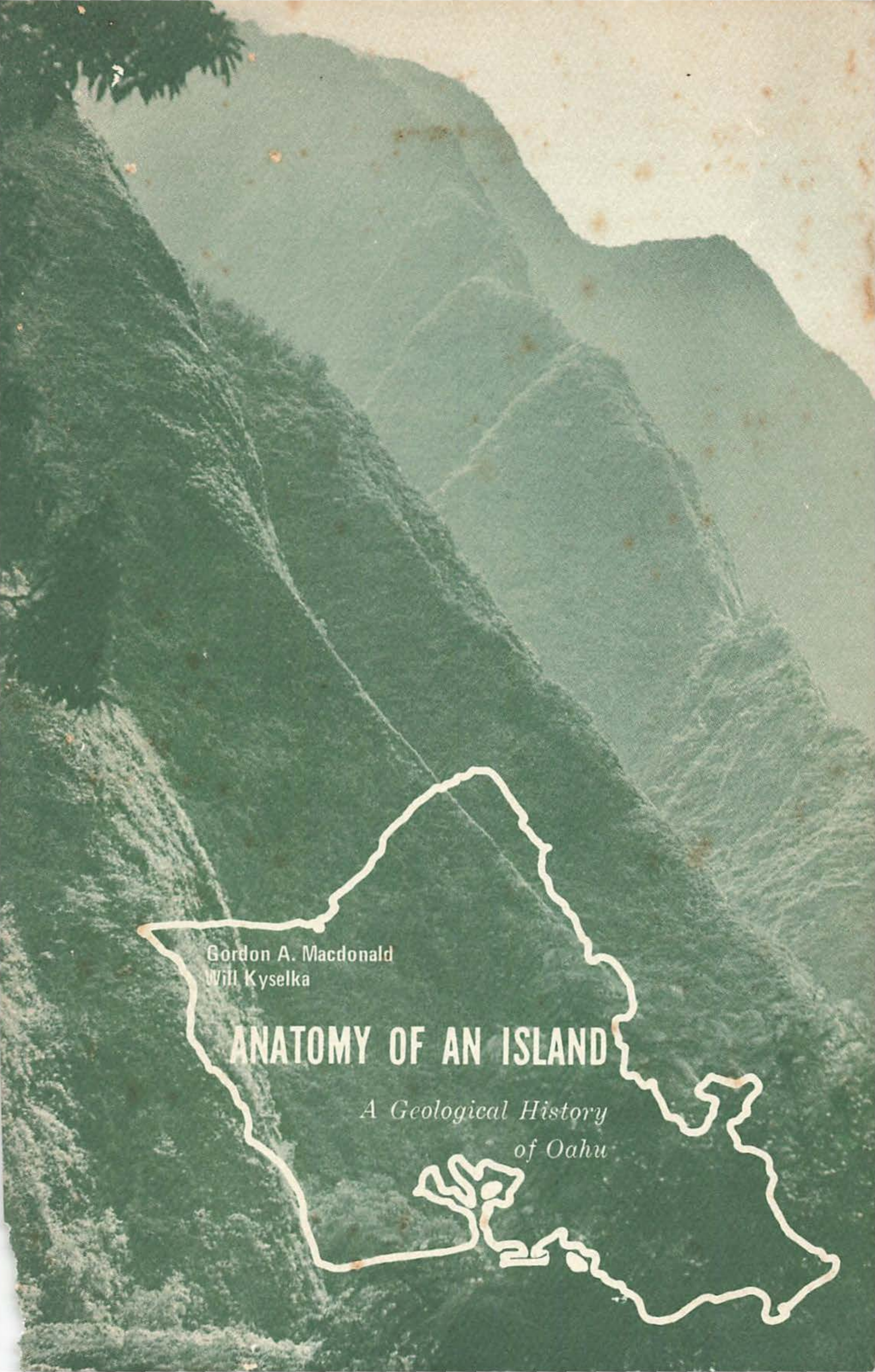

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A Geological History of Oahu

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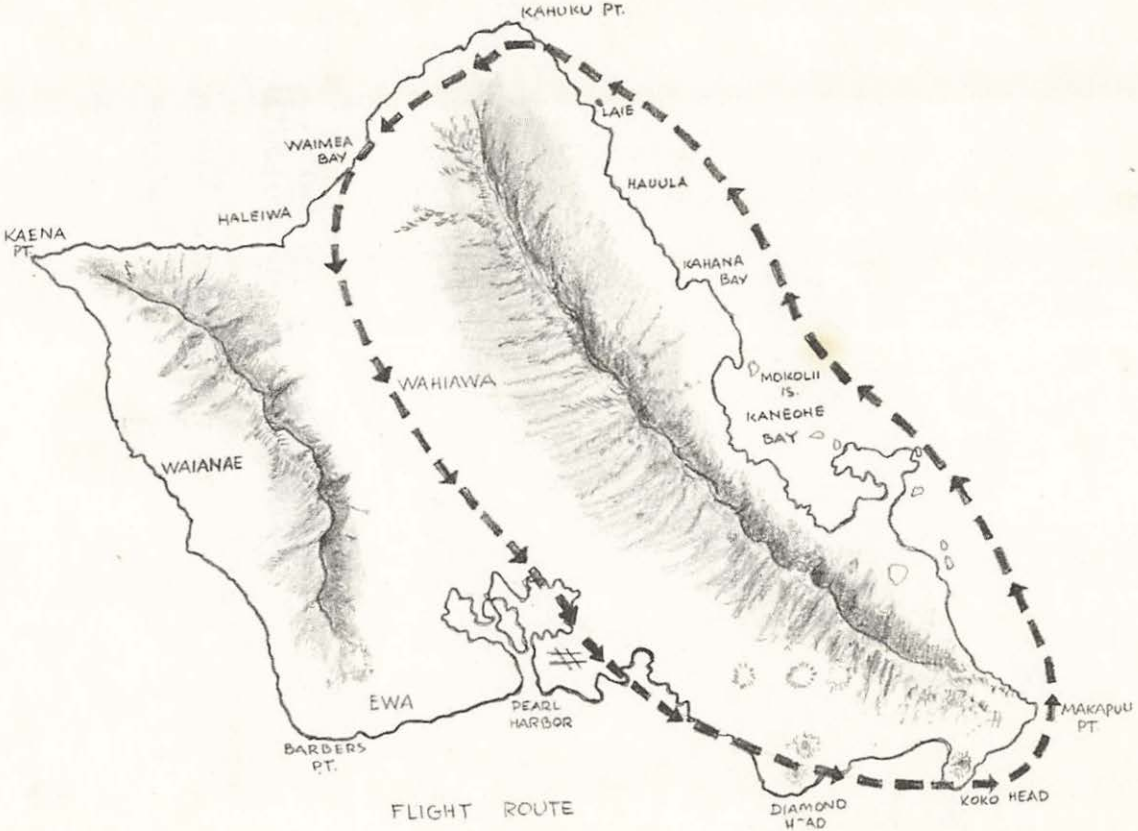

FLIGHT ROUTE

ANATOMY OF AN ISLAND

A Geological History
of Oahu

GORDON A. MACDONALD
and
WILL KYSELKA

Illustrated by
James Komuro

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PREFACE

VULCAN WAS THE Roman god of fire, and from his name the term volcano was derived to refer to a vent in the crust of the earth from which fire, steam, and molten rock erupt or pour. The violence and explosive fury of a fiery, fuming, detonating convulsion of the earth is a never-to-be-forgotten experience. Active volcanoes may be identified with ease. Yet we may (and many people do) live on or in dormant or extinct volcanoes without being aware of it. It is often difficult to recognize the true nature of the familiar surroundings which we take for granted and do not question. To see them for what they really are, we often need a different view or perspective.

The purpose of this book is to provide the reader with new and different perspectives of the Island of Oahu—a new spatial perspective achieved by viewing the island as if from a great altitude, and a new time perspective gained by emphasizing the process of formation and development. The drawings in this booklet and views of the island from high in the air show the physical features—mountains, cones, plains, craters—as they appear at present. Viewed in this fashion, we may see relationships with a new clarity. We may really understand what we see. Time perspective permits us to look at the process of growth, the achievement of maturity, and the eventual death of a volcanic island in the Pacific. We may see the forces that build contending with the forces that destroy.

This guide to the geology of Oahu was prepared for students who, as a part of their course work, take a flying trip around the island. However, it is also useful to those who come as visitors to this island and to those who live among the volcanic features and who may have little understanding of their form or meaning. Readers will find encouragement in the text to hike the trails of Oahu and to experience a new meaning when looking down from the height of Tantalus, Diamond Head, or Puu Konahuanui—a new meaning born of understanding through experience.

There is an increasing interest today in the earth sciences. It is in response to this interest that this book has been prepared as a further contribution of Bishop Museum to the knowledge of the Pacific world.

ROLAND W. FORCE

Bernice Pauahi Bishop Museum
Honolulu, Hawaii
August, 1966

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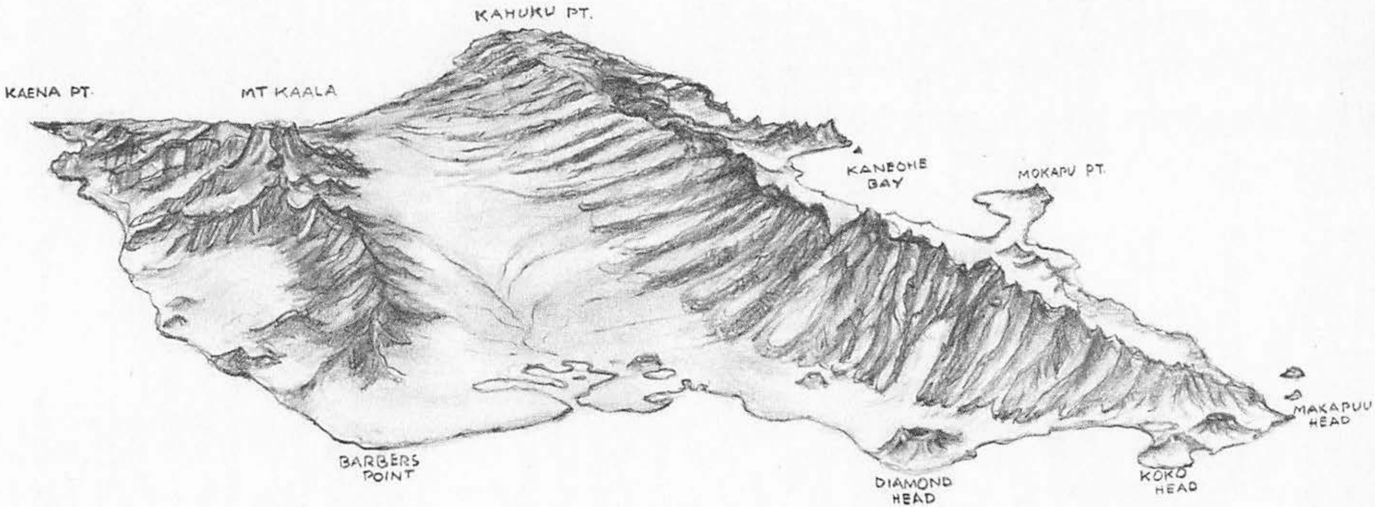
THE ISLAND OF OAHU is made up of the tops of two old volcanoes. However, when we look at it, we do not seem to see volcanoes. Instead, we see two jagged mountain ranges—the Waianae and the Koolau—joined together in a plateau that slopes gently toward the sea. We see a cliff, or **pali**, running along the seaward side of each mountain range, and a flat coral plain bordering the island in most places.

We see nothing of the form popularly associated with volcanoes—graceful, upswept slopes of solitary cones rising to snow-covered, pointed peaks, such as the majestic Mt. Fuji in Japan, Mt. Mayon in the Philippines, or Mt. Hood in Oregon. Nor do we see at first glance much that resembles the dome-shaped Mauna Loa on the Island of Hawaii, to which Oahu's volcanoes are related in structure, if not in present form.

And for good reason: the Waianae and Koolau are no longer "living" volcanoes. They have shown no life for perhaps the last three million years, except for a brief flurry of activity that ended a few thousand years ago. In their youth, both volcanoes sent fountains of liquid lava high into the air and huge flows of molten rock rushing down their flanks and into the sea many thousands of times to build the biggest volcanoes on earth. The history of volcanic activity is literally written in the rocks that you can see exposed in valley walls and in the beautiful cones that dot the southeastern end of the island.

Because the Waianae and Koolau are no longer active, they no longer look like volcanoes. Their once-rounded tops have been deeply cut by streams and the material carried away. What was once high is now low; what was once smooth is now rough and rugged. The wearing-away of the peaks has been going on for several million years. Little wonder, then, that the present appearance is so unlike the past form.

If we think of volcanic islands as going through a kind of life cycle, then we would have to say that Oahu is an island in middle



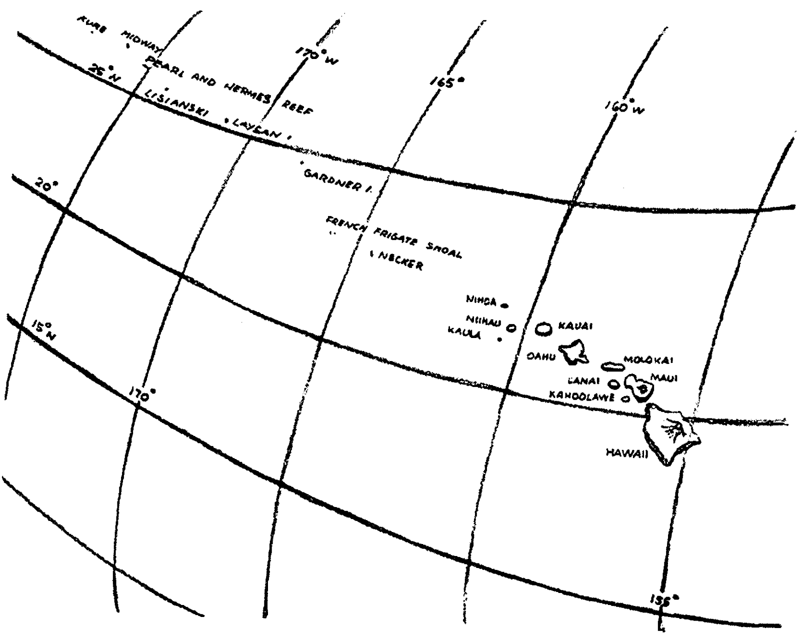
The Island of Oahu, looking north. It is made up of two highly dissected volcanoes that are joined together in a high plateau and bounded by a coastal plain.

age. Along the chain to the southeast are younger islands that show us what Oahu looked like in its youth. The islands to the northwest show what Oahu will look like in its old age.

THE HAWAIIAN CHAIN

A chain of volcanic islands, known as the Hawaiian Chain, stretches 1,600 miles across the middle of the North Pacific Ocean. The only active volcanoes are at the extreme southeastern end.

The Island of Hawaii looks young. Its volcanoes are still active,

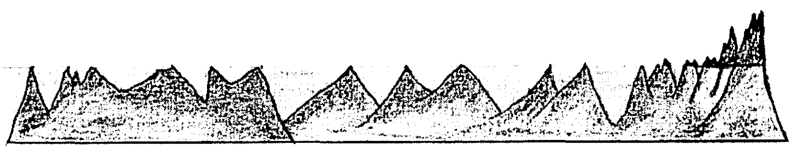


The islands in the Hawaiian Chain are the tops of old volcanoes. This island chain stretches about 2,000 miles across the middle of the Pacific Ocean.

still modifying and enlarging the island. The slopes of the volcanoes are smooth and scarcely cut by streams. Very little dissection of the volcanoes has taken place so that the island's generally rounded appearance indicates its youth.

The islands to the northwest appear to be older. They show the characteristic wrinkles of age—deep valleys, broad canyons, subdued hills, deep soils. Not only do they look older, they are older as shown by recent elaborate means of dating rocks.

Beyond Kauai and Niihau, the islands are so old that some of them no longer exist as islands; they have been worn down to sea level and are now known only as shallow places in the ocean, or **shoals**. French Frigate Shoal is one of these planed-off volcanoes. Even farther northwestward along the chain are the oldest of all the volcanic islands—islands so very old that they have actually sunk part-way back into the earth, leaving their flattened tops as much as 3,000 feet below the surface of the Pacific.



The view of the Hawaiian Chain in cross section shows that only the volcanoes at the southeastern end rise very high above sea level. The vertical scale is greatly exaggerated.

THE HAWAIIAN RIDGE

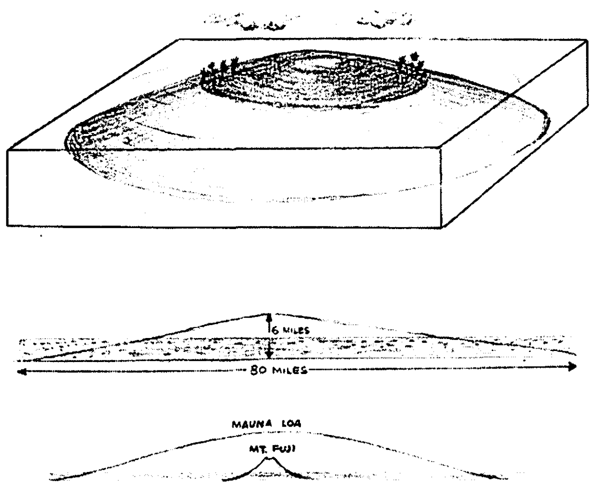
The islands of the Hawaiian Chain are the tall peaks of volcanoes along the Hawaiian Ridge. The ridge strikes in a northwest-southeast direction across the middle of the Pacific. It is made up of the biggest volcanoes on earth and contains the tallest peak on the planet. The tops of some of the volcanoes along the ridge appear above the sea as islands in the Hawaiian Chain, with Midway at one end and Hawaii at the other, some 1,600 miles away. Beyond Midway to the northwest, the ridge continues in a line of **sea mounts**, or submerged volcanoes, only one of which (Kure Island) reaches the surface.

The base of the Hawaiian Ridge is a broad, low swell 500 miles wide and a half-mile high. From this huge platform the islands rise abruptly. This sudden, sharp rise is best known by the Island of Hawaii, where Mauna Kea rises 13,794 feet above sea level only 45 miles from a point where the ocean is more than three miles deep. The total rise of nearly six miles is the greatest change in elevation in so short a distance that is known anywhere on earth.

A mountain six miles high is a tremendous weight on the crust of the earth. The crust bends as the rock beneath it flows to adjust to the great pressure. The volcano settles. A trench around the Hawaiian Ridge is evidence of the slow sinking of the islands—a gradual submergence back into the earth from which they sprang.

VOLCANOES OF THE HAWAIIAN RIDGE

The world's largest volcanoes lie along the Hawaiian Ridge. Mauna Kea is the highest; Mauna Loa is the largest and most massive. The gently rounded, dome-shaped profiles of the Hawaiian volcanoes resemble the curved shields of ancient Germanic warriors, and are called **shield volcanoes.**



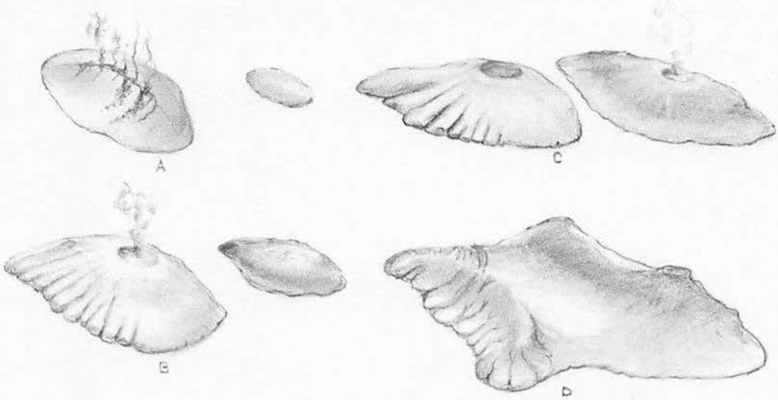
The volcanoes that form the islands in the Hawaiian Chain are dome-shaped (top). The world's biggest volcanoes lie along the Hawaiian Ridge. Mauna Loa on the Island of Hawaii is about 80 miles across at its base and 6 miles high (center). Shield volcanoes are the most massive on earth. Mauna Loa has about a hundred times as much material in it as does Mount Fuji in Japan (bottom).

The great shield volcanoes of Hawaii are built of lavas that erupt quietly, with little explosion, and spread rapidly from the vent, sometimes flowing as much as 30 miles before cooling. Such highly mobile lavas, rich in iron and magnesium, but poor in silicon, are called **basalts.**

A less-mobile type of lava is called **andesite.** It is rich in silicon and erupts at low temperatures. Slow-moving and sluggish, this sticky lava tends to pile up around the vent, and explosions throw large amounts of broken rock into the air. Continued activity builds the pile of material around the vent higher and higher into pointed peaks. Volcanoes around the rim of the Pacific are generally andesitic in composition and have pointed cones. Within the Pacific Basin, however, we find the shield-shaped basaltic cones.

GEOLOGIC HISTORY OF OAHU

Volcanic activity broke out along a swelling on the floor of the Pacific about 25 million years ago, in a period known to geologists as mid-Tertiary. Basaltic lavas poured from the cracks, spread rapidly, and slowly built gigantic shield volcanoes.



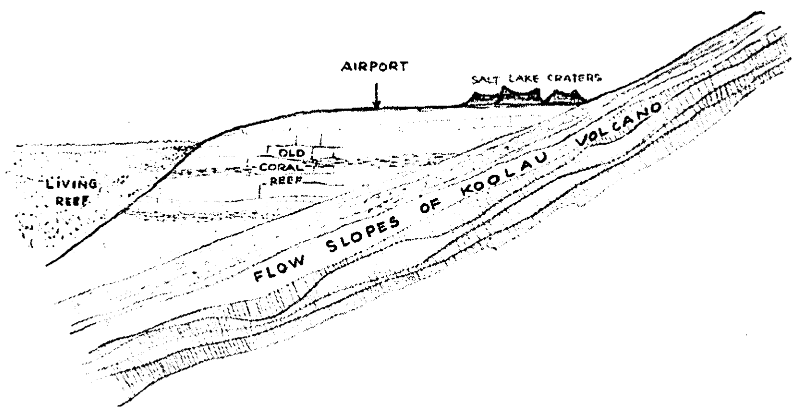
Stages in the growth of Oahu. *A*—The Waianae volcano (left) is already well developed by the time the Koolau (right) begins to appear. *B*—A caldera forms at the summit of the Waianae. Lava pours into Schofield but not into the big leeward valleys. *C*—The Waianae volcano ceases activity while the Koolau continues to build and fill in the region between the two volcanoes. *D*—The two volcanoes join to form one island. Erosion carves the completed island that we know today.

The Waianae Volcano

The present island of Oahu came into being about ten million years ago when the top of the Waianae volcano broke the surface of the Pacific. Lava flowed from three sets of cracks that eventually intersected to form a central vent near the present Kolekole Pass.

Rainfall on the youthful Waianae was heavy. The Koolau did not exist at that time to take the moisture from the trade-wind clouds, but for a long time lava flows were so frequent that erosion could make little headway. The rain sank into the porous lavas instead of running off as streams.

Then the volcano began to crack; its summit region sank in to form a broad crater, called a **caldera.** The crater was low on the eastern side and lava continued to escape and pour down that side of the cone, but on the west the high crater wall prevented lava from flowing down the western slope. Streams carrying run-off water down the western slope carved the deep amphitheater-headed valleys of Lualualei, Makaha, and Makua.



The Honolulu International Airport is built on an old coral reef. Volcanic eruptions broke through the reef to build the Salt Lake Craters.

While these big valleys were being cut, the eastern side remained in a young condition, without valleys. Thus, erosion on the older western side gained a great head start, and that is why the valleys we see today on the Waianae side are so much bigger than those on the Schofield side of the volcano.

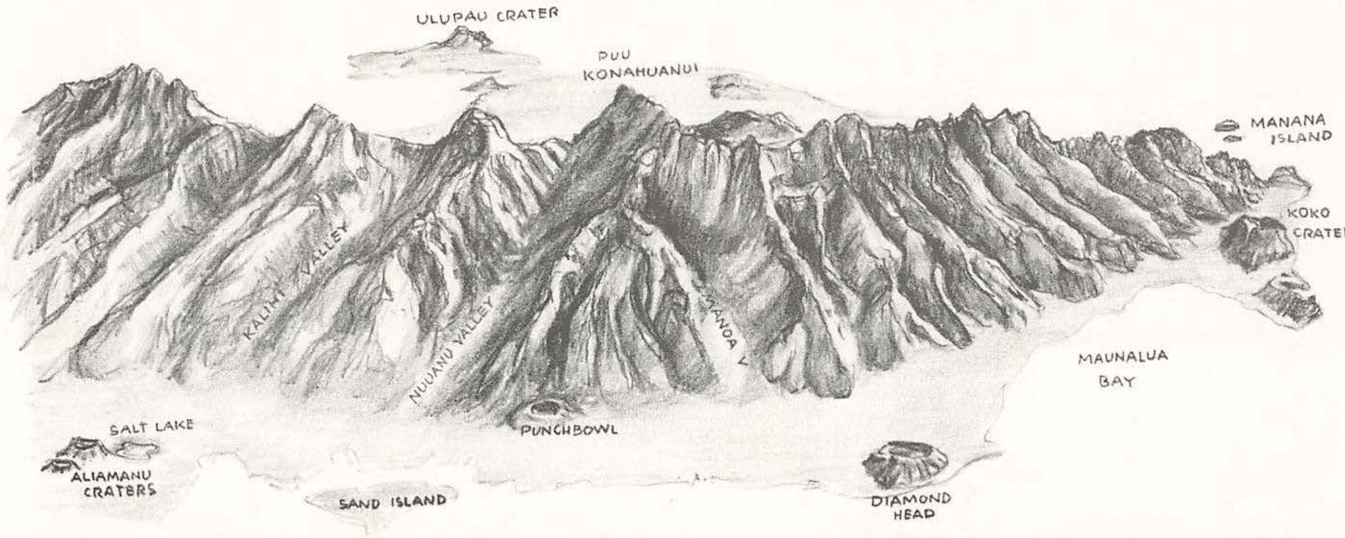
The Koolau Volcano

The Koolau volcano appeared a few million years later as a separate island a few miles to the east of the Waianae. The two volcanoes continued building, gradually filling in the ocean between them to form a single island. Finally, the Waianae volcano became extinct, and lava flows from the Koolau volcano banked against its side to form the present Schofield Plateau.

The Koolau erupted along cracks that extended from beyond Kahuku on the north past Makapuu on the south. A central vent and summit depression, or caldera, formed near the present region of Kaneohe and Kailua. The major activity stopped about 3 million years ago. A long period of valley-carving, known as the Great Erosional Period, followed, during which the great amphitheater-headed valleys on the windward side joined together to form the scalloped Pali.

Much later, perhaps a quarter of a million years ago, a new set of cracks opened in a roughly north-south direction across the deeply eroded Koolau, and again molten rock, called **magma,** rose to the surface in another burst of volcanic activity. During this period, known as a **secondary activity,** eruptions flattened some of the valley floors and built a series of cones around the south-eastern end of the Koolau.

Late volcanic activity in the Salt Lake region forced Halawa and Moanalua Streams to find new channels to the sea.



The southeastern end of the Koolau Range is highly dissected. Late eruptions near the sea built the prominent tuff cones of Salt Lake, Punchbowl, Diamond Head, Koko Head, Koko Crater, and Ulupau Head.

Changing Sea Levels

During the last million years the level of the sea around Oahu repeatedly rose and fell as great glaciers formed and melted away on the continents. At the same time, a little glacier covered the top of Mauna Kea. The changing sea at its extremes stood as much as 250 feet higher and 300 feet lower than its present level.

As the sea level rose, the shore line crept inland. The rising sea swept away old beaches, submerged tidal pools, drowned river valleys. It built new beaches, enlarged bays, deposited coral, and cliffed the ends of the long slopes that ran from the tops of the mountains down to the edges of the sea.

During one of the last of its rises, probably 80,000 years ago, the sea stood at a level about 25 feet higher than it is now, and remained there for some centuries. This ancient sea was warm. Coral flourished in it and built reefs around the island. This old coral reef forms a platform around the edge of the island varying in width from a few feet in some places to as much as five miles at Ewa.

GEOLOGIC FIELD TRIP

Let us now take a flying trip around the island. Generally, going "around the island" means going around the Koolau Range, which is what we plan to do here. We start at Honolulu International Airport, pass Diamond Head, and round Koko Head and Makapuu, then travel along the windward side to Kahuku for a view of the north end of the island. Turning southward we fly over the Schofield Plateau, have a distant look at the Waianae, and return to Honolulu.

Salt Lake Region

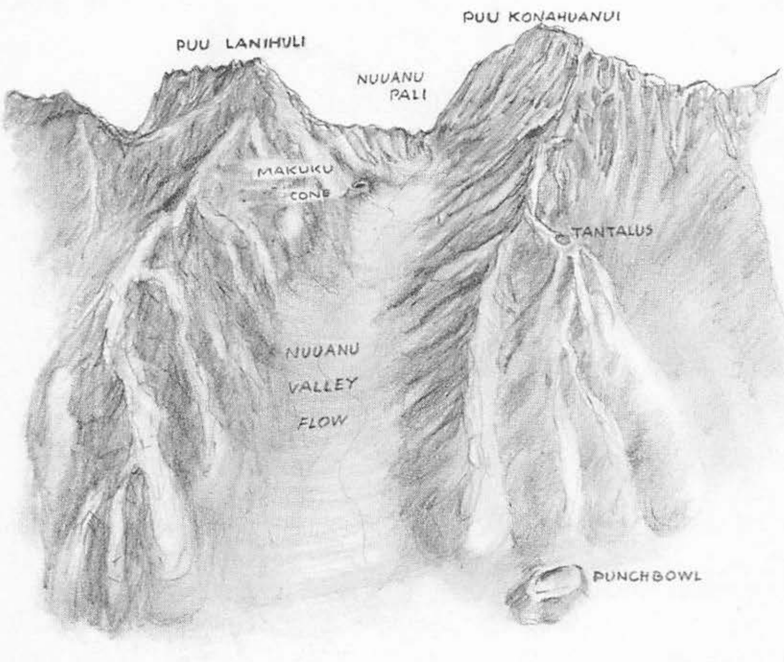
The Honolulu International Airport, along with much of the city of Honolulu, is built on the old coral bench left by the recent 25-foot-high stand of the sea.

Directly inland from the airport is Salt Lake Crater. It erupted through the old coral plain. Broken-up rock material thrown into the air by explosions fell back around the vent, burying a forest of loulu palms, koa, and ohia trees, and building a broad, flat cone with a crater at its top.

As the airplane in which you are riding gains altitude, you will begin to see the lake that now fills the crater depression. Once the lake was salty and the name "Salt Lake" was then appropriate. During dry periods, water around the margins of the lake evaporated, leaving a thick deposit of salt crystals. Old historical accounts tell of early Hawaiians gathering the salt for their own use as well as for sale. Undoubtedly, this "Hawaiian salt" added flavor to many an ancient luau.

How deep the lake was and how it was fed were mysteries that excited the imaginations of the early residents. Some thought that it was "bottomless." In 1840 the geologist James D. Dana decided to investigate the mystery. He carried a canoe into the lake. His soundings showed the deepest part of the so-called bottomless lake to be only 16 inches!

Today the lake is no longer salty. An artesian well, drilled into the crater early in this century, changed it into a brackish-

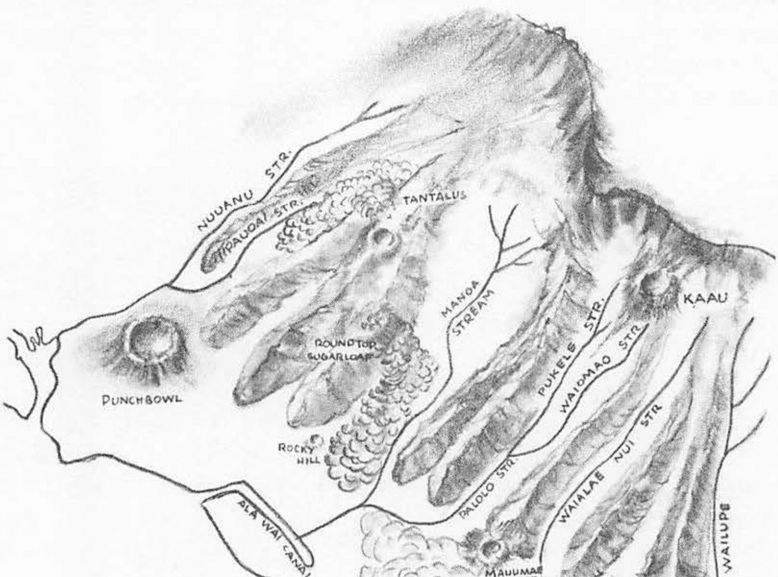


Nuuanu Valley was once a deep V-shaped valley. Eruptions from Makuku and another, older cone on the opposite side flooded the valley and made the present flat floor.

water mullet pond. The lake now forms the center of a modern housing development. The name, Salt Lake, persists even though the conditions change.

Aliamanu and Makalapa Craters are near by. We often call them "craters" even though we generally see them as "cones," rising more than 400 feet above the surrounding coral plain. The words "crater" and "cone" are often misused. A **crater** is a depression or pit often found at the top of a cone; a **cone** is the hill built by the accumulation of volcanic material around a vent. When we are on the ground, it is the cone we see, but from the air we can look into the crater—and on Oahu we find that some are filled with vegetation, some with water, and some with houses.

The three cones—Salt Lake, Aliamanu, and Makalapa—were formed very late in the geologic history of Oahu during the period



Late eruptions in the Honolulu region built prominent cones and diverted well-established streams.

of renewed volcanic activity. Eruptions of this period that broke out near the sea built Oahu's famous landmarks—Diamond Head, Punchbowl, Koko Crater, Ulupau Head, and Salt Lake.

Late eruptions often blocked well-established streams and forced them to find new channels to the sea. Halawa and Moanalua Streams once flowed in parallel valleys directly to the sea. Now, as you see on the map on page 8, they swing sharply away from each other as they leave their valleys to enter the sea in opposite directions. The reason for the sudden change is, of course, the recent volcanic activity in the region that built the Salt Lake cones.

Salt Lake volcanoes are **tuff cones**—one of three types of cones you will see on this air trip. Tuff cones are made of fine brown ash blown up in steam explosions which took place when molten rock, working its way toward the surface from deep in the earth, came in contact with water-saturated rocks. Pressure built up in super-heated water just as it does in an ordinary pressure cooker and was released suddenly and catastrophically in steam explosions. Tuff cones are found near the sea where water is abundant, and their explosive craters are wide, shallow, and saucer-shaped.

Southeastern Oahu

The mountain that you see on your left as you fly toward Koko Head is the southeastern end of the Koolau Range. It is part of the volcano that erupted several million years ago along a rift from Makapuu to Kahuku. The eruptions built a broad, rounded volcano that must have looked much like the present Mauna Loa.

Streams have cut deeply into the sides of the old Koolau volcano—more deeply on the windward than on the leeward, or Honolulu, side. The contrast is striking. The Honolulu side has long, deep valleys that are separated by high, knife-edged ridges. The windward side has fewer but wider valleys. Greater erosion here has cut away the divides between the valleys and united the valley heads in the 2,500-foot Pali.

Kalihi and Nuuanu Valleys

Two of the greatest gashes on the Honolulu side of the Koolau volcano are Kalihi and Nuuanu Valleys. Both were carved during the Great Erosional Period that followed the building of the volcano. You can get an idea of how long the erosional period was when you consider the tremendous amount of rock that was removed and how slowly it is done—so slowly, in fact, that you will see little if any natural change in the valleys during your lifetime. Yet, how far from being a gently rounded volcano is the Koolau Range today!

The Great Erosional Period was a time of quiet, a time of little, if any, volcanic activity. The quiet time ended, though, as new eruptions—**secondary** eruptions—broke out on the slopes of the range and at the heads of the deeply eroded valleys. Lava ran down the valleys, spread out, and flattened the floors of Kalihi and Nuuanu, as well as Pauoa, Manoa, and Palolo Valleys.

The vents of the secondary eruptions in the mountains are hard to find. They are in regions of high rainfall, heavy erosion, and thick vegetation. You can see the old Makuku cone in Nuuanu Valley, however, just west of the upper reservoir about a mile from the Pali gap. The Pali Highway cuts through the eastern edge of the cone. Flows from Makuku and another older cone on the opposite side of the valley gave Nuuanu its flat floor.

Manoa Valley is a deep, amphitheater-headed valley. Lava poured into it from Puu Kakea, diverting Manoa Stream to the east. Tantalus lies on a sharp valley divide between Manoa and Nuuanu Valleys. Kaau Crater is at the head of Palolo Valley.

Pauoa Valley

The valley to the east of Nuuanu is Pauoa. The upper end is filled with a thick lava flow from Tantalus. Pauoa Stream cascades over the steep face of this old flow on its way toward the sea. It does not flow directly into the sea, but into Nuuanu Stream. Like Halawa and Moanalua Streams, Pauoa was blocked and diverted by late volcanic activity—in this case, Punchbowl.

Punchbowl, or Puowaina, is a tuff cone similar in origin to the Salt Lake cone. It, too, erupted on a coral reef at the edge of the Koolau slopes in a series of gigantic steam explosions.

Tantalus

High up in the mountains behind Punchbowl is Tantalus, an ordinary cinder cone built on the side of the Koolau volcano. It is also the source of the lava flow that partly filled Pauoa Valley. A **cinder cone** is an accumulation of volcanic material thrown out of a vent by fountains of liquid lava. Cinder cones have bowl-shaped craters in contrast to the broader, saucer-shaped craters of tuff cones.

Tantalus broke out on a sharp ridge that separates Nuuanu and Manoa Valleys. The top of Tantalus is over 2,000 feet above sea level, but only the upper 200 feet is the cinder cone itself. The volcanic material in the cone is loose and the particles are only slightly cemented together, so that you can easily break it apart in your hand.

For a closer look at Tantalus, try hiking the excellent trails that have been built in the region. They afford the hiker many happy hours of exploration and discovery—including guavas, thimbleberries, mountain apples, orchids, ginger—and a close look into the crater of Tantalus itself.

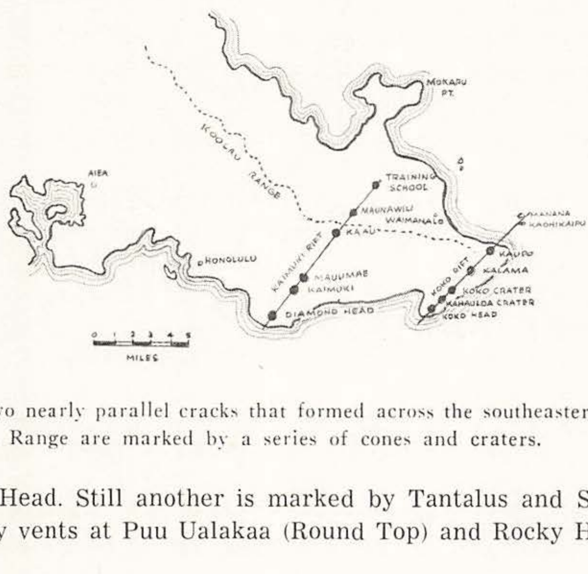
Puu Kakea (Sugar Loaf)

Farther along the ridge but at a somewhat lower level lies Puu Kakea, more commonly called Sugar Loaf. Like Tantalus, it is both a cinder cone and the source of a valley-filling lava flow.

Lava poured out of a vent just seaward of the Sugar Loaf cone, cascaded down the wall of Manoa Valley, and spread over the valley floor. The new lava flow blocked Manoa Stream and forced it over against the far side of the valley between the present site of the East-West Center and Waahila Rise. The University of Hawaii campus is built on the slightly sloping Sugar Loaf flow. The lower edge of the flow was quarried for many years by the Moiliili Quarry Company. You can see the 50-foot man-made "pali" left by the quarrying operation when it was abandoned during the middle of this century.

Rift Zone Activity

In the period of secondary eruptions, several cracks appeared across the Koolau Range, now marked by a series of craters, cones, and flows. One of the cracks, or **rifts**, is at Kaimuki, another is at



Two nearly parallel cracks that formed across the southeastern end of the Koolau Range are marked by a series of cones and craters.

Koko Head. Still another is marked by Tantalus and Sugar Loaf, and by vents at Puu Ualakaa (Round Top) and Rocky Hill.

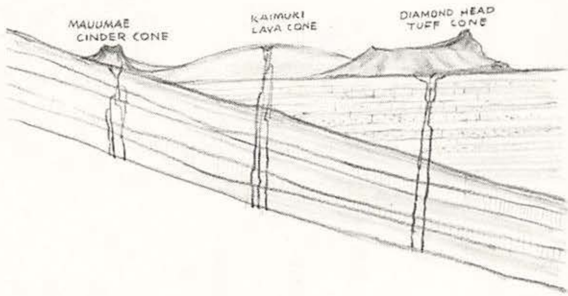
Kaimuki Rift

Eruptions along the rift that runs through the community of Kaimuki built four prominent cones on the Honolulu side of the Koolau Range. Diamond Head is the most famous of these; the others are Kaimuki, Mauumae, and Kaau. Maunawili, on the windward side, and possibly the vents near the present Training School also lie along the rift.

The Kaimuki rift is interesting because three different types of cones—cinder, tuff, and lava—are all present and within a mile of Kaimuki. We will first have a look at Kaau Crater, then the three types of cones at Kaimuki.

Kaau Crater. Kaau Crater lies at the head of Palolo Valley at a height of 1,600 feet. It is covered with vegetation that blends into that of the mountain behind it, so that it is hard to see. The crater itself is about a quarter of a mile in diameter and once contained a lava lake. A swamp now covers the crater floor, some 1,600 feet in diameter. The swampy floor, glinting in the afternoon sun, looked to one hiker "as if a giant hand had pressed a huge new dime into the green Koolau ridges."

Mauumae Cinder Cone. A small cone of cinder and spatter, Mauumae, is located on the Kaimuki rift at the foot of Wilhelmina



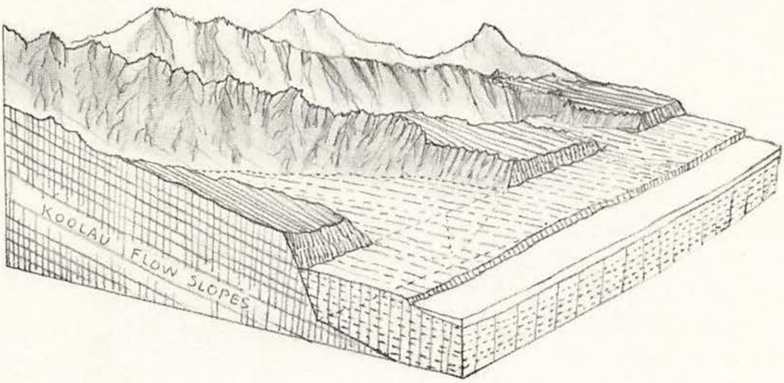
Three types of cones—cinder, lava, and tuff—are all found on the same rift within a mile of Kaimuki.

Rise. Now a house-covered hill, it rises about 50 feet above its surroundings, a quarter of a mile north of Waialae Avenue. During the eruption of Mauumae, fountains of liquid lava produced cinder, spatter, and ash. The ash was carried by the wind and scattered. The blobs of lava that were hurled into the air partially solidified in flight, fell back near the vent, and built a spatter cone. Quantities of this spatter rolled down into Palolo Valley.

Kaimuki Lava Cone. Kaimuki is a low, dome-shaped hill lying between Mauumae and Diamond Head. It is the only secondary lava cone on Oahu and is built of many flows of highly fluid lava that erupted quietly and spread rapidly from a vent that can be located today just behind the Kaimuki Fire Station. The eruptions at Kaimuki repeated on a small scale the history of the activity of the Koolau volcano itself by piling up flows into a broad shieldlike dome.

Palolo Stream was diverted by the building of the Kaimuki lava cone. The stream now swings westward as it emerges from its valley to follow the edge of the Kaimuki cone past St. Louis Heights. Here it joins Manoa Stream, and together they flow into the ocean by way of the Ala Wai Canal.

Diamond Head. The world's most famous tuff cone is at the seaward end of the Kaimuki rift. It blasted its way into existence through the coral reef in a series of catastrophic steam explosions. Now brooding quietly over the city of Honolulu, Diamond Head's



The broad, flat slopes of Wilhelmina Rise and St. Louis Heights narrow to knife-edged ridges at higher elevations where rainfall is more abundant.

present serenity suggests little of the violence and turmoil that attended its birth some 100,000 years ago.

The crater is nearly circular and shallow, typical of the saucer-shaped craters formed by steam explosions. A small lake once existed on the floor of the crater and was described a hundred years ago as varying greatly in size according to the amount of rainfall. The water was a source of **Euglena**, a microscopic plant-animal creature. The toad, **Bufo marinis**, once thrived abundantly around the margins of the lake. It is now being filled in and bulldozed out of existence.

The uneven rim of Diamond Head is generally about 400 feet above the sea. The highest point is 763-foot Leạhi Peak on the southwestern side. Because ash that is blown into the air during eruptions is carried by winds and deposited on the leeward side, this high peak indicates that the northeast trade winds were blowing at the time of eruption.

The cone of Diamond Head has been deeply gullied, and rain furrows appear as great scratches on its sides. Relentless pounding by the sea has worn Diamond Head back far enough to expose some of its internal structure. Eventually a coral reef built up which now protects its seaward side and takes the brunt of the force of the crashing waves.

The Munro Botanical Trail circles the base of Diamond Head on the Waikiki side just above Kapiolani Park. A hike along this trail will give you a chance to examine the big tuff cone closely and affords a good view of the wide, tabular slopes of St. Louis Heights and Wilhelmina Rise, the Kaimuki and Mauumae cones, the rounded top of Mt. Olympus at the head of Palolo Valley, and the 3,105-foot Puu Konahuanui, the highest peak of the Koolau Range.

Black Point. An eruption from a vent southeast of Diamond Head poured dense lava into the sea to build the headland we know as Black Point. The Hawaiians called it Kupikipikio, because of its turbulent waters. From the air you can see that the waves attack the headland directly, but that the shore on either side of it is protected by a reef.

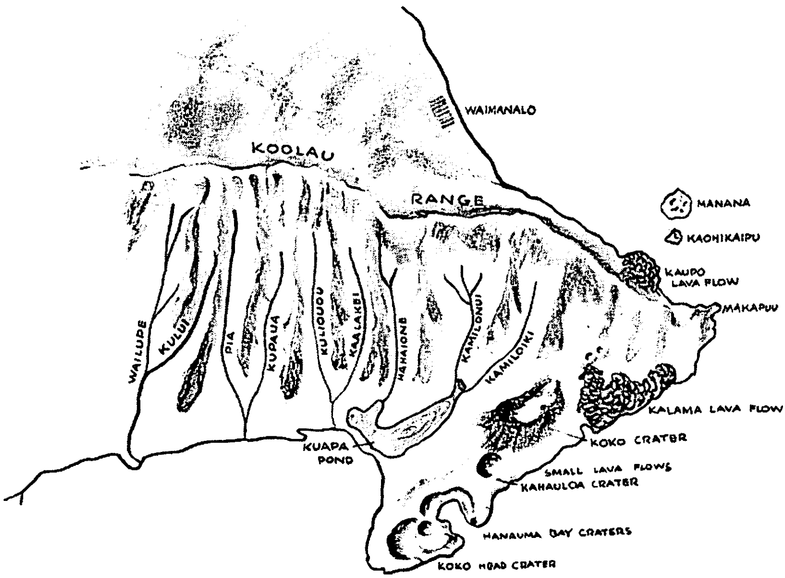
Maunalua Bay. The late eruptions along the Kaimuki and Koko rifts extended the island southward and brought Maunalua Bay into existence. It is about five miles long and shallow. A white line of breakers far from shore marks the reef.

Behind Maunalua Bay, long spurs of the Koolau Range slope gently from the mountain crest down to the sea but break suddenly and sharply just above sea level. This sudden break is due to cliffing by the sea when it stood about 25 feet higher than it does today. The communities of Waialae-Kahala, Aina Haina, and Kuliouou are built on the reef laid down by that high stand of the sea.

Kuapa Pond was once a bay, but the sea built a sandy beach—called a **bay-mouth bar**—across its mouth and turned it into the present pond. The highway runs the full length of it. You will see another well-developed bay-mouth bar at Waimea, on the northern end of the island.

Koko Rift

We now come to the second of the two main rifts across the southeastern end of the Koolau Range. A line of tuff cones marks the Koko rift.



The Koko ridge, a recent addition to the island, is made up of tuff cones interspersed with a few lava flows.

Koko Head. The sides of Koko Head, or Kuamookane, show clearly the effects of weathering. One side of it is being worn back by waves while the other is being carved by rain water.

The shallow waters of Maunalua Bay protect the western side of Koko Head from pounding by heavy seas. The chief agent of erosion here is rain that runs off the slopes, gullying the sides of the cone. Since this part of the island receives little rain, erosion is slight. However, huge rain furrows, as much as 100 feet across and 40 feet deep, show that slow processes carried on over a long period of time can achieve remarkable results.

The other side of Koko Head is quite different in appearance, for this is the side that is attacked directly by the sea. There is no reef here to protect the cone—nothing to break the force of the waves.

A hike around the end of Koko Head is difficult, but it will impress you with the relentless power of erosion. Here you can see spectacular cliffs 300 feet high carved in layered tuff, the deep notches cut by run-off water, and sea caves of unknown extent continually being enlarged by the sea which swirls in and out about four times a minute.

Hanauma Bay. The sea broke into one of the craters along the Koko rift and created Hanauma Bay. Around the edge of the bay is a bench, five to ten feet above the present sea level. This bench marks a pause in the gradual retreat of the sea from 25 feet above to the present level. A hike along the platform will take you through a natural arch made by a lava flow that poured into Hanauma crater from a vent just to the northwest.

Several other small pits and craters are found in the Hanauma Bay region. Kahauloa Crater, now the site of a rifle range, is one. A bed of tuff laid down during the Kahauloa eruption is exposed in cuts along the highway; it contains thousands of white fragments of coral, torn from the reef below by the explosions.

The deep blue color of the water off Koko ridge is an indication of its great depth. Volcanic activity along the ridge was so recent that conditions are not yet right for the growth of a protective reef. Waves traveling for thousands of miles across the ocean burst into whiteness on the unprotected tuff ridge, so the ridge is heavily eroded. Layers of tuff, cut by the sea and sculptured by the wind, stand in fantastic forms along the ridge. The remorseless power of the sea, wind, and rain to eventually destroy an island is shown at its best along the Koko ridge.

Koko Crater. The highest tuff cone on the island is the 1,208-foot Koko Crater. It is a horseshoe-shaped cone, open to the northeast where there is no wall. A trail enters the crater through the breached wall. You can enjoy a hike beneath kiawe and wiliwili trees and see many different varieties of cactus in the botanical garden being built by the State Park system to preserve and enhance the beauty of the crater.

The highest point of Koko Crater is opposite its lowest side. Here, just as at Diamond Head, the ash thrown upward into the air during the eruption was carried by trade winds to the southwest to build up the leeward side of the cone.

A natural arch is found high up on the outer slopes of Koko Crater in the dry valley across from the Blow Hole.

Kalama Flow. Just beyond Koko Crater, in Kalama Valley, there was once a small cone, the source of the Kalama lava flow. Now the cone has been almost completely dug away for construction material. However, you can see the extent of the flow spreading

The Koko Peninsula marks a rift along which much volcanic activity took place. The sea is wearing back the peninsula at a rapid rate.

out over the flat land toward the sea coast. Its black rock forms the coast for about a mile beyond Sandy Beach.

Makapuu. Makapuu Head is a 647-foot peak that seems to stand by itself. At first glance you might think it an eruption separate from that of the Koolau. It is, however, simply an erosional remnant of the old Koolau volcano, isolated in part by the cutting of a wide valley that the road now ascends. The head of the valley has been cut off by the sea cliff carved by the waves on the north shore.

Kaohikaipu and Manana Islands. Two islands north of Makapuu Point mark the limit of activity along the Koko rift. The larger of the two is Manana Island, 361 feet high. It is a tuff cone that erupted a mile off shore, and is more commonly known as Rabbit Island.

The smaller of the two islands, Kaohikaipu, is a dark, flat cinder cone that formed on dry land when the sea was lower than it is now. The two islands illustrate the contrasting types of cones that are formed when conditions of eruption differ—a tuff cone in the presence of water, a cinder cone in its absence.

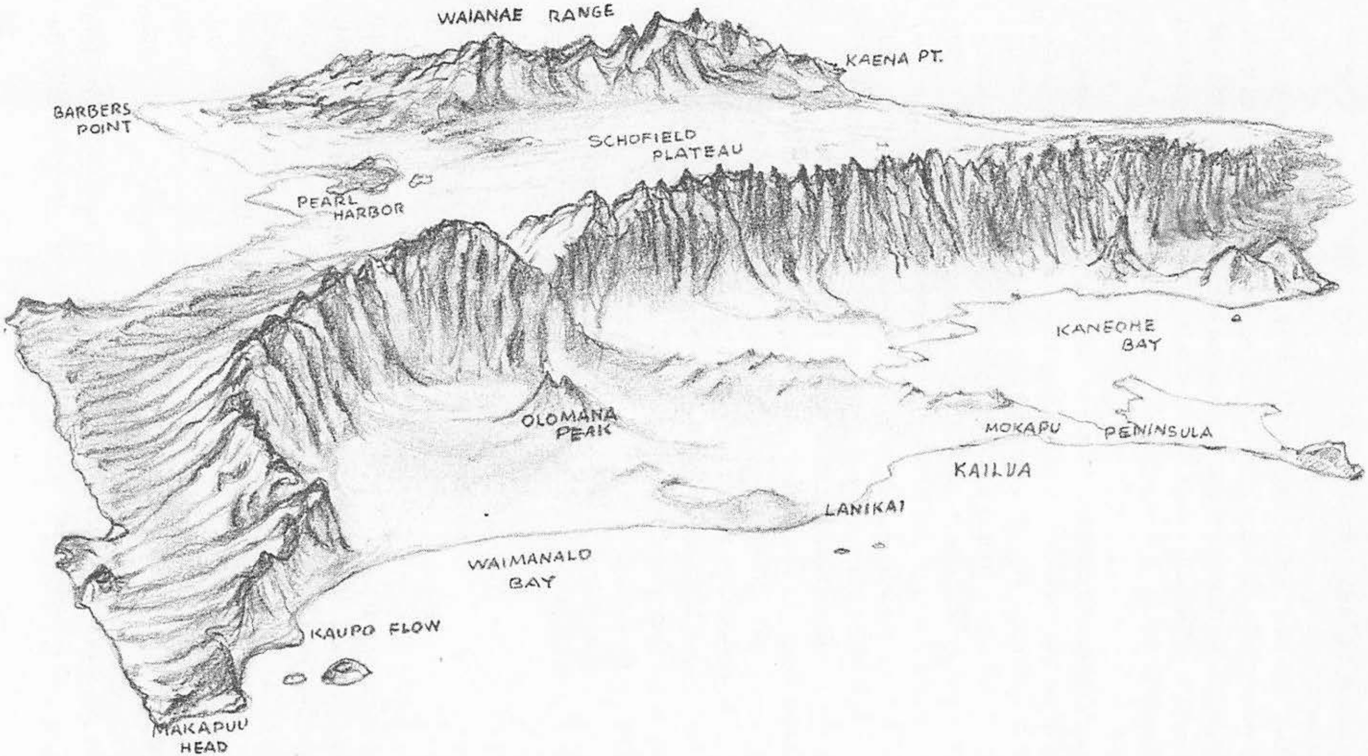
Kaupo Flow. Lava poured out of the side of the cliff behind what is now Sea Life Park and ran down into the ocean to build a small headland. The old Hawaiian village of Kaupo once occupied this site. The Kaupo flow was a late eruption, perhaps the most recent of all the secondary eruptions on Oahu. The vent is about 250 feet up on the face of the cliff, but it is hard to see—particularly so when there are whales and porpoises to be seen cavorting in the Sea Life Park tanks below.

Windward Oahu

Rounding Makapuu Head, we now fly a course to the northwest along the windward side of the Koolau Range. The most prominent feature on this side of the island is, of course, the famous Pali. We travel along its face and over the old eruptive center of the Koolau volcano. We pass a number of islands, fly over a fringing reef and along the eastward sloping flanks of the old Koolau cone.

The Pali

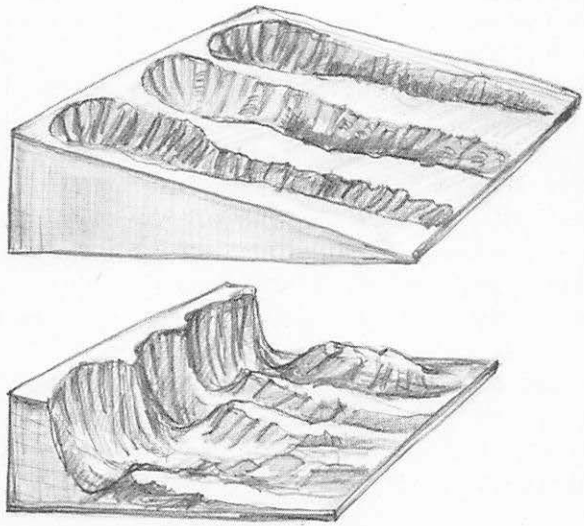
As we leave Makapuu Head, you can see that the difference between the leeward and windward sides of the Koolau Range is



The long, gentle slopes on the leeward side of the Koolau Range give way to abrupt cliffs on the windward side. The former eruptive center of the Koolau volcano is in the region near Kailua.

striking. The long, gentle slopes of the Honolulu side are abruptly terminated at the crest by vertical cliffs a half-mile high on the windward side.

You will see that the character of the cliff changes as you fly northward along the Pali. There is good reason for this. The Pali was carved by falling rain and pounding sea. These are two different agents of erosion that leave distinguishing marks—massive sea cliffs in some places and corrugated walls in others.



The Pali is formed by the wearing away of divides between streams. As the divides are worn away (above), the valley heads unite to form the scalloped cliffs of windward Oahu (below).

Behind Kaupo we find a region of well-developed sea cliffs 1,000 feet high. The sea carves such cliffs by knocking rock fragments loose and sending sand and pebbles that grind away at the base of the cliff in regular surges of water every few seconds for hundreds of thousands of years. Heavy seas occasionally hurl great blocks of rock and boulders against the cliff, chipping it away with even greater force. Such pounding and pulverizing may eventually undercut the face of the cliff; the unsupported rocks then topple and the cliff retreats farther.

The massive sea cliffs of Kaupo grade into the fine 3,000-foot columns of the Pali. The most spectacular part of the Pali is the region of stream-cut fluted columns that begins behind the town of Waimanalo.

Early geologists wondered how the Pali was formed. Some thought it was carved by the sea when it stood at a higher level; others thought that the Koolau volcano cracked and the eastern portion slipped into the sea, leaving a fault scarp, or cliff. We now know that neither sea-cliffing nor faulting produced the Pali, but streams. Stream action alone is enough to explain the columnar structure.

The fluted columns of the Pali began with streams that developed on the smooth slopes of the Koolau volcano soon after it stopped building. Fed by moisture from trade-wind clouds, the streams enlarged and deepened their valleys, leaving high, sharp ridges between. We saw much the same kind of thing on the Honolulu side at the beginning of our flight—knife-edged ridges separating deep, amphitheater-headed valleys. Because of greater rainfall at higher altitudes, the windward divides wore down faster at their heads than at their seaward ends. The ridges were eventually worn away almost completely and the valley heads united to form the Pali. Hills were left at distances from the Pali where rainfall is less.

The Pali, then, is a series of overlapping valleys—big valleys like Manoa—that have united at their heads to form an impressive cliff. We can consider it as a stage in the erosional dissection of a basaltic shield volcano.

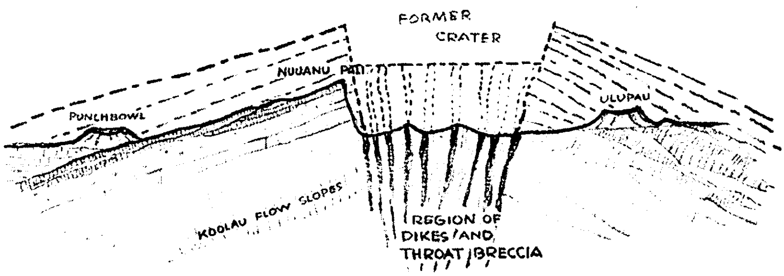
Eruptive Center

Beyond Waimanalo, in a region of small hills, is an isolated mountain that sweeps up into a sharp 1,643-foot peak. It is Olomana Peak, and it is in the old crater region of the Koolau volcano.

The volcano was built by lava rising to the surface through thousands of cracks. At the end of each eruption, lava froze in the cracks to make a **dike**. You can see many of these dikes, each about two feet in width, in the high cuts made for the Pali Highway near Castle Junction. Dikes are thickest in the region of the eruptive center.

The top of the Koolau volcano was about a mile above sea level when it stopped building. It had a crater, or caldera, at its top, similar to the calderas now at the top of Kilauea and Mauna Loa on the Island of Hawaii. A caldera is formed by the collapse of the top of a volcano as molten rock beneath it is withdrawn, removing support. The Koolau crater covered the region from Waimanalo to Kailua, Kaneohe, and perhaps a little beyond.

For a long time hot gases rose through the rocks inside the crater. The gases, rising from great depth, altered the rock through



A cross-sectional view of the Koolau volcano between Punchbowl and Ulupau Head showing the old eruptive center.

which they passed and made it softer. The soft rock was easily eroded, and what was once the highest part of the Koolau volcano has now been reduced almost to sea level.

The Mokulua Islands that lie a mile off shore are part of the old volcano outside of the crater region, so that the crater boundary must have been between these islands and the community of Lanikai. All the rest—nearly one-half—of the volcano that formerly lay off shore has been eroded away. The ocean waves sweep around the Mokulua Islands to converge on the shoreward side. If conditions are right, you may see some beautiful wave diffraction patterns.

Mokapu Region

The Mokapu Peninsula lies between Kailua and Kaneohe. It is a flat bit of land extending about three miles out into the ocean, forming the southern boundary of Kaneohe Bay. The flatness of the coral peninsula is broken by Pyramid Rock, the Puu Hawaiiloa cinder cone, and the 683-foot tuff cone Ulupau Head.

Ulupau Head erupted off shore in a series of steam explosions. As an off-shore tuff cone, it may have once looked much like Manana Island does today. The water between the mainland of

Oahu and Ulupau Head was shallow at the time of eruption, so when the sea level dropped, the coral reef that makes up most of Mokapu was exposed, tying the island to the mainland as a peninsula.

A mile out in the ocean beyond Ulupau Head are two tiny remnants of an eroded tuff cone—Moku Manu.

Kaneohe Bay Region

The appearance of Kaneohe Bay from the air may surprise you. Ordinarily you see it from the ground as a large bay of blue-green water with a few scattered islands and a white line of breakers marking the reef far off shore.

But from the air, how shallow it looks, how filled with islands, how crowded it appears! Most of the "islands" you see from the air are not islands at all. They are isolated coral colonies that have built up close to the surface and appear light in color, but they do not actually rise above the surface of the bay. The reef that separates Kaneohe Bay from the ocean is the nearest approach to a so-called **barrier reef** that we find anywhere in the Hawaiian Islands. Most of the Hawaiian reefs are **fringing reefs**—that is, reefs without any extensive lagoon between them and the shore line.

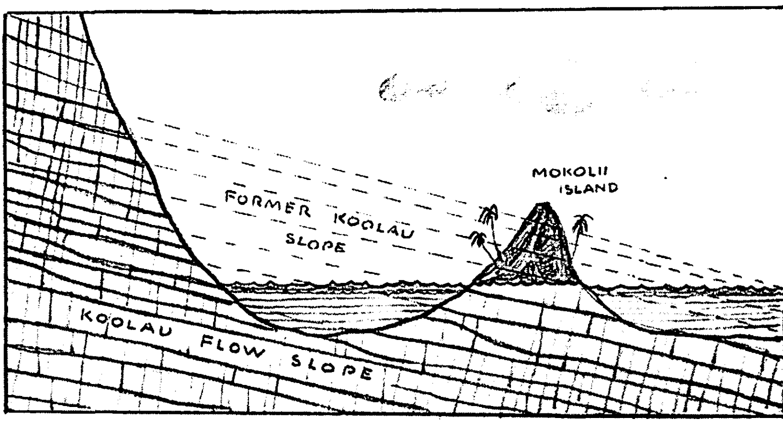
Looking toward the mountains, you can see the rounded head of Haiku Valley. It is a deep, amphitheater-headed valley, the kind that forms the scallops along the Pali when the interstream divides wear away. Two others, Waihee and Waiahole, are broader amphitheater-headed valleys that are more open than Haiku and nearer to forming the long walls of the Pali.

Here, above Kaneohe Bay, you are about in the mid-point of the Pali, and one of Nature's grandest views is before you.

Mokolii Island, the most picturesque of all the islands in eight-mile Kaneohe Bay, lies a half-mile off the northern shore. It is cone-shaped, and at first glance you might take it for some kind of secondary eruption. It is not a separate volcanic cone, however, but part of the old Koolau volcano that was cut away from the main mass by the sea and left standing as a little island, or **sea stack.**

Kaaawa-Kahana Region

Kaneohe Bay ends in an abrupt wall 1,900 feet high. Here we find something that has been missing on our trip so far along the windward side—the northeast-sloping lava beds of the old Koolau volcano. Looking back, we can see the huge crescent-shaped caldera region that is bounded on one side by the Pali. The sea that en-



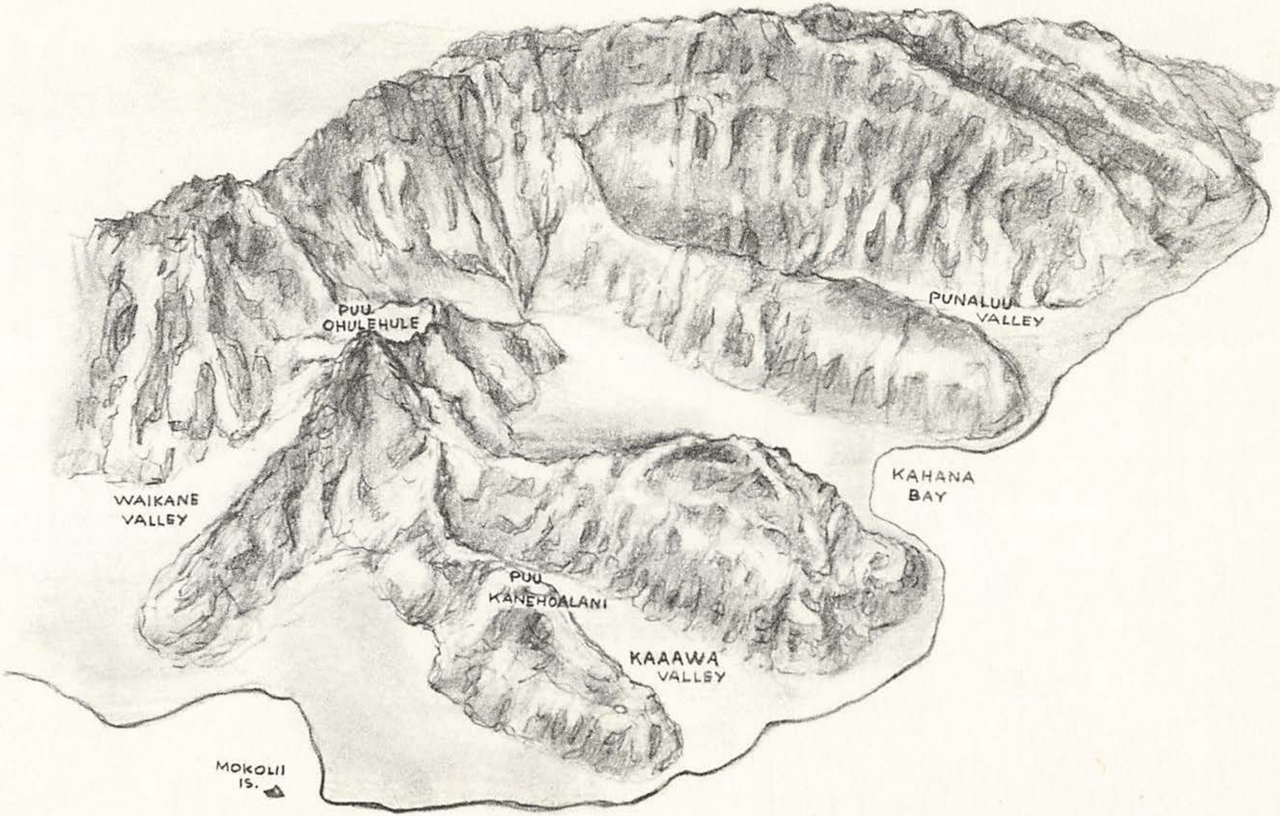
Mokolii Island, commonly called "Chinaman's Hat," has the appearance of a small cone, but it is a sea stack, a former part of the Koolau volcano that now has been isolated by the action of the sea.

larged the caldera carried away much of the eastern flank of the Koolau. The eastern-sloping beds of the volcano are prominent structures in the sides of the deep valleys in the stubby four-mile peninsula between Mokolii Island, commonly called "Chinaman's Hat," and Kahana Bay.

Kaaawa Valley has steep walls and a flat floor, caused by the gradual submergence of the island and the deposition of sediment by the stream where it entered the bay. The sharp peak at the end of Kaaawa Valley is Puu Ohulehule, 2,265 feet high. It is a prominent landmark and can be seen at the head of several different valleys.

Laie

Just before reaching Hauula, you may catch a glimpse of Sacred Falls. Kaluanui Stream plunges down the Pali in a series of three falls. You can see all three from the air. If you hike to the falls, you find yourself in a region of dikes, old feeders for the Koolau



The northeast slopes of the Koolau volcano begin at the far end of Kaneohe Bay. The flat-floored valleys in this region indicate a gradual submergence of the island.

volcano. The stream valley is so narrow and the walls so precipitous that you can see only the lower of the three falls, 65 feet high.

The small islands at Laie are old sand dunes that have turned to stone. During a time when the sea was lower, winds blew beach sand up into sand dunes. Vegetation anchored the dunes, and rain water and salt spray carrying dissolved chemicals percolated through them and cemented them into hard rock. The sea returned, worked around the dunes, and separated them from the mainland into little islands.

Northeastern Oahu

As the plane swings around the northern end of the Koolau Range and inland of Kahuku Point, you will see a great difference in the surface of the land. Streams here have not cut so deeply into the flanks of the volcano. The slopes have been very little modified, very little dissected by erosion, and are the nearest to the original slopes of the volcano that you find in the entire range. The Pali in this region has given way to a mere 500-foot sea cliff that runs for miles along the northern shore, then gradually dies out.

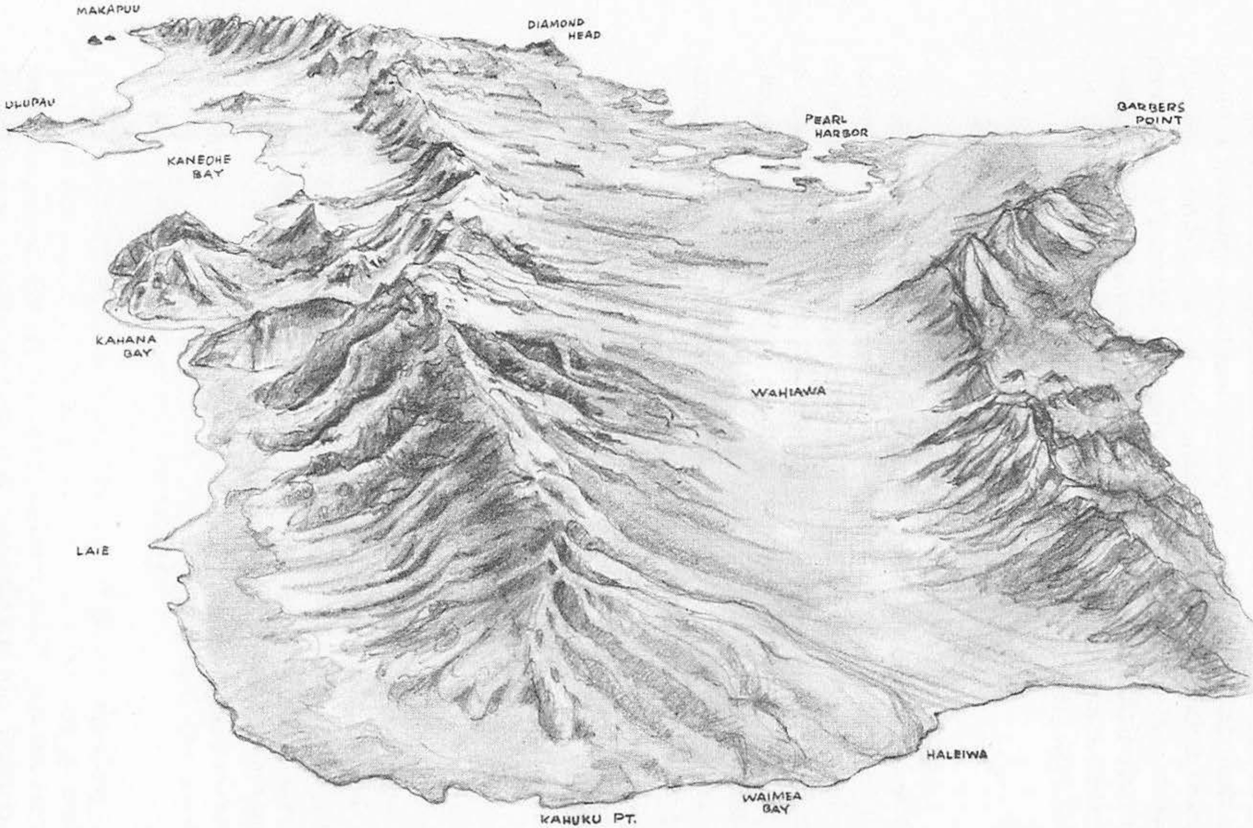
Waimea

At Waimea we see a bay-mouth bar that is much smaller than the one at Kuapa Pond. Waves and currents pile up sand at the mouth of the Waimea River. Only during times of heavy rainfall does the river have enough power to keep its channel to the sea clear. It generally enters the ocean by seeping through the bar.

Two large rectangular arrangements of stone on the top of the cliff to the east of Waimea River are the remains of an old Hawaiian heiau, Puu o Mahuka, the largest heiau on the island. Trails lead to this ancient sacred place and also to Waimea Falls.

Schofield Plateau

The flight southward between the Koolau and Waianae Ranges takes us over deep gulches cut by Anahulu, Helemano, and Puamoho Streams. These streams drain the plateau to the northwest and empty into Waialua Bay. The green pineapple and sugar-cane



A view of the island from the extreme north point. The Koolau volcano (left) erupted along rifts extending from Kahuku to Makapuu. The eruptive center is near Kaneohe where the greatest amount of erosion has occurred.

fields lie on flats between the gulches that are cut into rock reddened by weathering. Stream meanders are well developed in this region and show brilliantly in the reflecting sunlight.

The land between the two volcanoes is saddle-shaped. It rises to 900 feet between Waialua Bay and Wahiawa, then gradually descends toward Pearl Harbor. The sloping Schofield Plateau was formed by lava flows from the Koolau volcano lapping up against the edge of the older Waianae volcano.

Waianae Range

Looking toward the west, you can see the entire eastern slope of the Waianae Range. The crest of the range is jagged and irregular because of heavy dissection by erosion. The conspicuous flat-topped peak at the northern end of the range, often shrouded in clouds, is the 4,025-foot Mt. Kaala, the highest point on Oahu. It is a very-little-eroded remnant of the original surface of the volcano.

The deep gap in the Waianae Range behind Schofield Barracks is Kolekole Pass, 1,725 feet above sea level. The old crater region of the Waianae volcano is just on the other side of the pass. The Waianae eruptive center, like the Koolau, has been eroded away and nothing is left but its roots.

Coastal Plain

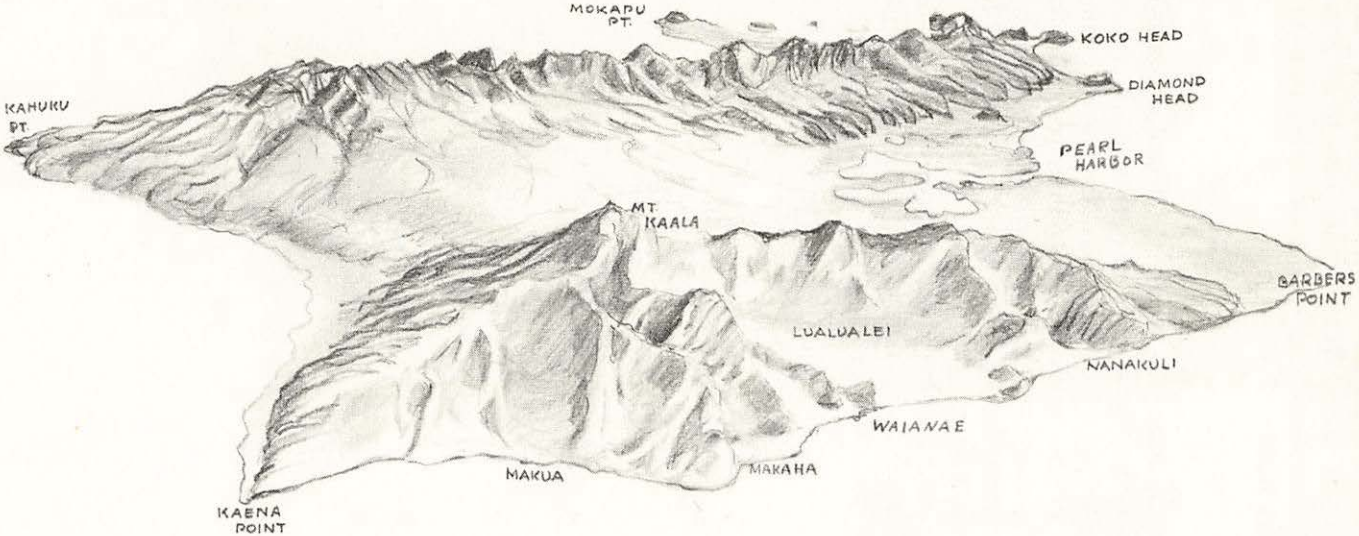
Continuing southward, we fly over deep gulches cut into the southerly slopes of the Schofield Plateau. The two most prominent are those cut by Kipapa and Waikele Streams, which flow into the Pearl Harbor lochs.

The sloping plateau gives way to the large, flat Ewa coastal plain that stretches out to Barbers Point at the extreme southwestern corner of Oahu. It was built during the 25-foot stand of the sea and is about five miles wide at Ewa.

Pearl Harbor

On the glide path into the airport, you will pass over Pearl Harbor with its several arms, or **lochs.** Pearl Harbor is a drowned

The Waimea River is often blocked by a bay-mouth bar. A prominent sea-cliff runs along this northern shore of Oahu. Cultivation of the land has accentuated the flatness between the deep valleys in this region. The rectangle above the river to the left is the Puu o Mahuka Heiau.



A view of the island looking east. The crescent-shaped Waianae Range is smaller but higher and older than the Koolau. The former crater of the Waianae volcano lay in the region of Lualualei and Waianae Valleys.

valley system. The lochs are former stream valleys that were cut when the sea was lower. When the sea rose to its present level, water invaded the deeply cut valleys, drowning them to form the lochs of Pearl Harbor.

* * * * * *

The quick airplane trip around the Island of Oahu may help you understand the changes that have taken place in two volcanic cones in a matter of a few million years. You also may gain a greater appreciation of the continual struggle between the forces that build volcanic islands and those that destroy them, and see more clearly than before that an island is really a temporary feature on the face of the Pacific.

As surely as Oahu came out of the sea, one day it will return to the sea. The present physical features of Oahu are but a stage in the life of the island—a stage that is ours to enjoy.

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ANATOMY OF AN ISLAND provides new perspectives of the Island of Oahu—a new spatial perspective by viewing the island as if from a great altitude, and a new time perspective gained by emphasizing the process of formation and development. The drawings in this book and views of the island from high in the air show the physical features—mountains, cones, plains, craters —as they appear at present. Viewed in this fashion, we may see relationships with a new clarity. We may really understand what we see.

ANATOMY OF AN ISLAND was prepared for students who, as part of their course work, take a flying trip around the island. However, it is also useful to those who come as visitors to this island and to those who live among the volcanic features and who may have little understanding of their form or meaning. Readers will find encouragement in the text to hike the trails of Oahu and to experience a new meaning when looking down from Tantalus, Diamond Head, or Puu Konahuanui—a new meaning born of understanding through experience.

Bishop Museum Press