GEOLOGY AND GROUND-WATER RESOURCES OF THE ISLAND OF KAUAI, HAWAII

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HAWAII DIVISION OF HYDROGRAPHY

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By Gordon A. Macdonald, Dan A. Davis, and Doak C. Cox

ABSTRACT

Kauai is one of the oldest, and is structurally the most complicated, of the Hawaiian Islands. Like the others, it consists principally of a huge shield volcano, built up from the sea floor by many thousands of thin flows of basaltic lava. The volume of the Kauai shield was on the order of 1,000 cubic miles. Through much of its growth it must have resembled rather closely the presently active shield volcano Mauna Loa, on the island of Hawaii. When the Kauai volcano started its growth is not known with certainty, but it is believed that activity started late in the Tertiary period, possibly in the early or middle part of the Pliocene epoch. Growth of the shield was rapid and probably was completed before the end of the Pliocene.

Toward the end of the growth of the shield, its summit collapsed to form a broad caldera, the largest that has been found in the Hawaiian Islands. Like the calderas of Kilauea and Mauna Loa, that of Kauai volcano had boundaries that were, in part, rather indefinite. The principal depression was bordered by less depressed fault blocks, some of which merged imperceptibly with the outer slopes of the volcano. Elsewhere the caldera rim was low, and flows spilled over it onto the outer slopes. The well-defined central depression of the Kauai caldera was approximately 10 to 12 miles across.

At about the same time as the formation of the major caldera, another, smaller caldera was formed by collapse around a minor eruptive center on the southeastern side of the Kauai shield. Lavas accumulated in the calderas, gradually filling them and burying banks of talus that formed along the foot of the boundary cliffs. The caldera-filling lavas differed from those that built the major portion of the shield in being much thicker and more massive as a result of ponding in the depressions. The petrographic types for the most part are the same throughout. Both the flank flows that built most of the shield and the flows that filled the calderas are predominantly olivine basalt. Picrite-basalt (oceanite), containing very abundant large phenocrysts of olivine, and basalt containing little or no olivine are present but together comprise less than 10 percent of the whole. Late in the period of filling of the major caldera a small amount of basaltic andesine andesite was extruded.

Near the end of the period of filling of the major caldera further collapse occurred, forming a large graben on the southwestern side of the shield. Lava flows erupting within the caldera poured southwestward over the cliff bounding the graben and spread over the gently sloping graben floor. Near the present Waimea Canyon their advance was obstructed by the fault scarp at the west edge of the graben. The cliff along the northeast edge of the graben eventually was buried by lava flows from within the caldera, but that along the west edge continued to stand above the level of the flows in the graben. The flows that accumulated in the graben are of the same types as those that filled the caldera, and like them are mostly thick and massive because of ponding by the graben walls and of the gentle slopes of the graben floor over which they spread.

The rocks of the major Kauai shield volcano are known as the Waimea Canyon volcanic series. The thin flows that accumulated on the flanks of the shield, which compose the major portion of the volcanic edifice, are named the Napali formation of the Waimea Canyon volcanic series. The rocks that accumulated in the big summit caldera are named the Olokele formation, and those that filled the small caldera on the southeast flank of the shield are named the Haupu formation. The volcanic rocks accumulated in the graben on the southwestern side of the shield are named the Makaweli formation of the Waimea Canyon volcanic series, and sedimentary

rocks interbedded with them are known as the Mokuone member of the Makaweli formation.

Few vents of the Waimea Canyon volcanic series have been recognized, probably because most of them have been destroyed by erosion or are buried by later lavas. Large numbers of dikes cut the lavas of the Napali formation along Waimea Canyon and the Napali Coast and along the east edge of the Waialeale massif. Fewer dikes are found in the other members of the series. Some tendency toward radial arrangement of the dikes is present, but the dominant trend all over the island is east-northeastward.

Another great collapse took place on the eastern flank of the volcano at about the time the major shield became extinct, or shortly afterward. A subcircular graben 6 or 7 miles across sank several thousand feet, forming a broad depression between the Waialeale massif on the west and Kalepa and Nonou ridges on the east. This collapsed structure cannot be as clearly demonstrated as the Makaweli graben on the southwest side of the shield, because its walls have been greatly eroded and its floor is deeply buried by lavas of the later Koloa volcanic series. It appears, however, to be the only reasonable explanation of the physiography of the eastern side of the island.

After the completion of the great Kauai shield came a long period of erosion during which no volcanic activity occurred. Waves cut high sea cliffs around the island, and streams cut canyons as much as 3,000 feet deep. Thick soil formed over much of the mountain.

Then volcanism was renewed. Eruption occurred from a series of minor vents arranged in nearly north-south and northeast-southwest lines across the eastern two-thirds of the island. The lavas, cinder cones, and ash beds of this period of volcanism are known as the Koloa volcanic series. Lavas of the Koloa volcanic series include olivine basalt, picrite-basalt (mimosite) with few phenocrysts of olivine, basanite, nepheline basalt, melilite-nepheline basalt, and ankaratrite (nepheline basalt very rich in pyroxene and olivine). Inclusions of dunite, composed almost entirely of olivine, are common in flows of the Koloa. Just before and during the eruption of the Koloa volcanic series, voluminous landslides and mudflows brought down a large amount of rock debris and soil from the steep slopes of the mountainous central upland and deposited it as breccias at the foot of the steep slopes in valley heads and along the border of the marginal lowland. Streams distributed part of the material across the lowland. The breccias and conglomerates thus formed, and later buried by lavas of the Koloa volcanic series, are named the Palikea formation of the Koloa volcanic series.

The structures formed at Koloa vents include cinder cones, one tuff cone, and lava cones. The latter are miniature shields resembling the major shield volcano, formed by repeated outpourings of fluid lava. The tuff cone, at the west side of Kilauea Bay, was formed by phreatomagmatic explosions caused by rising magma coming in contact with water-saturated rocks.

Volcanism during Koloa time continued for a long period but was not continuous over the entire area. Locally, long periods of quiet occurred, allowing streams to re-excavate some of the canyons filled by earlier flows of the Koloa volcanic series, and weathering to form soils later buried by new flows. Some of the canyons thus formed during the time when the Koloa was being deposited were several hundred feet deep. Volcanism probably continued throughout most of the Pleistocene epoch. The latest flow of the Koloa volcanic series appears very recent, and rests on lithified calcareous dunes formed during one of the Pleistocene low stands of the sea.

During the Pleistocene epoch stream valleys and sea cliffs were eroded to base levels governed by one or more stands of the sea more than 100 feet below present sea level. Beaches of calcareous sand were formed, and the sand blown inland to form calcareous dunes, now lithified. A test boring near Moloaa penetrated calcareous sand 160 feet below sea level, at the foot of a high sea cliff. Coral reef also was built around part or all of the island, and in part buried by lavas of the Koloa volcanic series. The explosions that built the tuff cone at Kilauea Bay threw up fragments of limestone from a buried reef. Much of the apron of lavas of the Koloa series around the northeastern side of the island probably rests on a platform formed below present sea level by wave erosion and the growth of coral reef.

As the sea rose around the island, the valley mouths were alluviated. Several levels of the sea higher than the present one probably are represented. Some stream terraces may be graded to a stand of the sea as high as 260 feet above present sea

level, but no positive evidence for stands higher than 25 feet have been found. Well-preserved shorelines are recognized approximately 25 and 5 feet above sea level. Much of the present coral reef appears to have been formed when the sea stood about 5 feet higher than now, and reduced to its present level by solutional weathering and wave erosion.

The lavas of the Napali formation of the Waimea Canyon volcanic series are highly permeable. They carry basal water over much of the island, and yield it freely to wells. This water is fresh everywhere except very close to the coast on the leeward side of the island. In some areas they may contain water confined at high levels between dikes. The lavas of the Olokele and Haupu formations are moderately to poorly permeable. They probably contain fresh water at sea level, but would not yield it readily to wells. Locally, ash beds perch small bodies of fresh water at high levels in the lavas of the Olokele formation, but these are of no economic importance. The lavas of the Makaweli formation also are moderately to poorly permeable. They carry fresh or brackish water at sea level. In general, they yield water to wells less readily than the lavas of the Napali formation, but more readily than the lavas of the Olokele. The conglomerates and breccias of the Mokuone member are poorly permeable, but are not known to perch more than a slight amount of water in the overlying lavas.

The lava flows of the Koloa volcanic series are poorly to moderately permeable. They carry fresh or brackish water at sea level, but generally yield it slowly to wells. Locally, small bodies of fresh water are perched at high levels in the lavas of the Koloa by beds of ash and soil and by breccia and conglomerate of the Palikea formation.

Both the older and the younger alluvium generally are poorly permeable, but contain small amounts of fresh or brackish water. The lithified calcareous dunes are permeable, but they appear to contain only brackish water. Lagoon deposits on the Mana plain are poorly to moderately permeable and yield brackish water to wells.

INTRODUCTION

Scope of investigation and report.—The investigation covered by this report is a part of a program of systematic studies of the geology and ground-water resources of the islands of Hawaii carried on by the United States Geological Survey in cooperation with the Hawaii Division of Hydrography. This volume dealing with the island of Kauai completes a phase of the program in which the objective has been the mapping and description of the geologic units in the islands and the qualitative determination of the occurrence and availability of ground water. This report presents a geologic map of Kauai, describes the geology of the island, and summarizes the petrography of the volcanic rocks. It describes the water-bearing characteristics of the rocks and the occurrence and availability of ground water, and presents records of most of the wells in the island.

Previous reports of the series are as follows:

Bulletin 1, Geology and ground-water resources of the island of Oahu, Hawaii, by Harold T. Stearns and Knute N. Vaksvik, 479 p., 1935.

Bulletin 2, Geologic map and guide of the island of Oahu, Hawaii, by Harold T. Stearns, 75 p., 1939.

Bulletin 3, Annotated bibliography and index of the geology and water supply of the island of Oahu, Hawaii, by Norah D. Stearns, 74 p., 1935.

Bulletin 4, Records of the drilled wells on the island of Oahu, Hawaii, by Harold T. Stearns and Knute N. Vaksvik, 213 p., 1938.

Bulletin 5, Supplement to the geology and ground-water resources of the island of Oahu, Hawaii, by Harold T. Stearns; with chapters on Resistivity survey of Schofield Plateau by Joel H. Swartz, and Petrography of the Waianae Range by Gordon A. Macdonald, 164 p., 1940.

Bulletin 6, Geology and ground-water resources of the islands of Lanai and Kahoolawe, Hawaii, by Harold T. Stearns; with chapters on Petrography of Lanai and Kahoolawe by Gordon A. Macdonald, and Geophysical investigations on Lanai by Joel H. Swartz, 177 p., 1940.

Bulletin 7, Geology and ground-water resources of the island of Maui, Hawaii, by Harold T. Stearns and Gordon A. Macdonald, 344 p., 1942.

Bulletin 8, Geology of the Hawaiian Islands, by Harold T. Stearns, 106 p., 1946.

Bulletin 9, Geology and ground-water resources of the island of Hawaii, by Harold T. Stearns and Gordon A. Macdonald, 363 p., 1946.

Bulletin 10, Bibliography of the geology and water resources of the island of Hawaii, by Gordon A. Macdonald, 191 p., 1947.

Bulletin 11, Geology and ground-water resources of the island of Molokai, Hawaii, by Harold T. Stearns and Gordon A. Macdonald, 113 p., 1947.

Bulletin 12, Geology and ground-water resources of the island of Niihau, Hawaii, by Harold T. Stearns; with a chapter on Petrography of Niihau by Gordon A. Macdonald, 53 p., 1947.

Location and area.—Kauai is the fourth largest of the eight major islands of the Hawaiian Archipelago. It lies near the northwest end of the group of Windward Islands, between latitudes 21°52′ and 22°14′

north and longitudes 159°17′ and 159°48′ west. Thus it lies just within the tropic zone, 1°13′ south of the Tropic of Cancer.

Kauai is nearly circular, with a maximum length of 33 miles, a width of 25 miles, a perimeter of 94 miles, and an area of 555 square miles (Wentworth, 1939, p. 13). The central mountain massif rises to an altitude of 5,170 feet above sea level at Kawaikini Peak, and 5,080 feet at the better-known Mount Waialeale, a mile to the north. The high part of the island is gashed by spectacular canyons. The beautiful Waimea Canyon, 2,600 feet deep in its upper part, has often been compared with the Grand Canyon of the Colorado for type and grandeur of scenery. Equally spectacular are the Olokele Canyon, and the Kalalau Valley viewed from the Kilohana Lookout at its south rim. The gorge of Hanapepe River, just below Halulu Falls, resembles a slightly inclined saw kerf, so narrow and deep that sunshine reaches its bottom for only about half an hour each day. Between the heads of the great canyons lies a broad, gently sloping summit plateau, occupied by the Alakai Swamp.

Around the central massif is a broad belt of lowlands, partly the result of erosion and sedimentation but largely the product of late volcanism. Of the total area, 198 square miles lies below an altitude of 500 feet; and 305 square miles, or more than half of the island, below 1,000 feet.

Kauai is separated from Oahu, to the southeast, by the Kauai Channel, 72 miles wide and approximately 10,000 feet deep in its deepest part. To the west, it is separated from Niihau by the Kaulakahi Channel, 18 miles wide and nearly 2,500 feet deep. The prevailing depths in the adjacent ocean are between 12,000 and 15,000 feet, and Kauai thus constitutes a mountain rising nearly 20,000 feet above the surrounding ocean floor, with a volume on the order of 1,000 cubic miles.

History.—The history of Kauai in the period before the arrival of Europeans is largely lost in the mists of unwritten tradition. No doubt the island was occupied by the modern Hawaiians soon after their arrival in the Hawaiian Archipelago, probably from Tahiti, about 1100 A.D.

The following brief summary of the early history of Kauai is taken largely from Alexander (1891) and Kuykendall (1938).

About the end of the 13th century Kalaunuiohua, king of the island of Hawaii, having subjugated Maui, Molokai, and Oahu, landed with an invading army near Koloa, Kauai. He was met by Kukona, at the head of an army of Kauai warriors, and totally defeated. From that time onward Kauai, although at times allied with them, was never conquered by the warlike kings of the southern islands, perhaps largely because of its separation from them by 60 miles of frequently stormy sea.

The existence of the Hawaiian Islands probably was known to the Spanish mariners, who made regular voyages from Acapulco to Manila during the 16th century. An island group is reported to have been shown on manuscript charts in about the correct latitude, but some 10° too far east. No more definite record of Spanish discovery is known, however. The first definite record of a sighting of the Hawaiian Islands by a European explorer is the "discovery" of the islands by Capt. James Cook, R.N., during his third voyage to the Pacific. Both Oahu and Kauai were sighted on January 18, 1778. The next day Cook reached Kauai, and on the 20th his ships anchored in Waimea Bay and Cook went ashore. After obtaining water and food at Kauai and Niihau, the expedition proceeded to the northwestern coast of North America. In late February 1779, after the death of Cook on the island of Hawaii, the island was again visited by the expedition, under the command of Captain Clerke.

The Cook expedition showed that a profit could be made by bartering for furs along the west coast of North America, and selling the furs in China. Captains Portlock and Dixon, who had been officers under Cook, reached Hawaii in 1786 in command of the ships *King George* and *Queen Charlotte*. They spent the winter of that year taking on provisions and water at Oahu and Kauai. They again visited Kauai in the winter of 1787. Other fur traders followed. Captain Meares spent a month on Kauai in 1787 and took one of the chiefs, Kaiana, as a passenger to China. The prestige of this trip greatly aided Kaiana's later advancement in the court of the rising king, Kamehameha. In October 1791, Captain Kendrick of Boston left three sailors on Kauai to collect sandalwood and pearls to be delivered to him on his next trip.

George Vancouver, who had been an officer under Cook, returned to the Pacific a dozen years later in command of a British expedition to receive from a Spanish officer the cession of lands in the Nootka Sound area and continue the exploration of the Pacific islands. He visited the Hawaiian group three times, in 1792, 1793, and 1794. On each visit he stopped at Kauai. Vancouver was sincerely interested in the welfare of the Hawaiian people. At considerable trouble, he brought cattle and sheep from North America and introduced them to the islands. He strove, unsuccessfully, to bring about peace between Kamehameha, king of Hawaii, and Kahekili, then king of Maui, Molokai, and Oahu. The latter, it may be mentioned, was strongly allied with his brother, Kaeo, king of Kauai. In March 1794 Vancouver presented some sheep to Kaumualii, son of Kaeo, and future king of Kauai. Kaeo was absent, on Oahu or Maui.

Under Vancouver's persuasion, a council of chiefs in the Kona district requested that Hawaii be taken under protection by Great Britain, and Vancouver formally took possession of the island in the name of King George. The agreement was never ratified by the British parliament, but it remained the basis for future close relationships between Hawaii and Great Britain, and the recognition of the close tie with Great Britain may have prevented the seizure of the islands by other great powers.

In the spring of 1796 Kamehameha, having established his rule over all the southern islands, set out with a large army to conquer Kauai, which was in a state of civil war. Keawe, son of the chiefess Kamakehelei, had become king of Kauai in 1779, but shortly afterward was deposed by his stepfather, Kaeo. In 1792 Kaeo left Kauai to aid his half-brother, Kahekili, in his wars with Kamehameha. On Kahekili's death, in 1794, Kaeo became king of Maui, Molokai, and Lanai. He retained the island of Kauai, but left it in direct charge of his son, Kaumualii, the chief Inamoo acting as regent. Toward the end of 1894 Kaeo was killed on Oahu, fighting the king of that island, Kalanikupule; Inamoo died; and Kaumualii became king of Kauai. Keawe quickly engineered a revolt, in an attempt to seize power from his younger half-brother, Kaumualii. Under these conditions of internal conflict Kauai would easily have fallen to the powerful army of Kamehameha. But fortune decreed otherwise. Part way across Kauai Channel Kamehameha's fleet of several hundred canoes encountered a violent storm that swamped many of the canoes and forced the rest to return to Oahu.

Keawe triumphed in the civil war, and by July 1796 was king of Kauai. Surprisingly, Kaumualii did not suffer the usual fate of the vanquished in such wars in old Hawaii, but was permitted to live. Within a year or two Keawe died, and Kaumualii again ascended the throne. His charming personality made him very popular with foreign visitors during the next two decades.

Kamehameha continued to plan for the conquest of Kauai, and in the spring of 1804 had assembled on Oahu another large force for that purpose. Just before he was ready to launch the attack, however, fate again intervened in the form of a violent epidemic (possibly cholera) that killed two of his principal retainers and is said to have decimated his army. Again, Kauai was saved by the ill fortune of the intended invader. Kaumualii recognized, however, that the greatly superior forces of Kamehameha were certain to triumph in the end. In 1810, with Capt. Nathan Winship acting as mediator, Kaumualii went to Honolulu and acknowledged the sovereignty of Kamehameha. Kauai became a tributary kingdom. Kaumualii was to remain king during his lifetime, but on his death Kauai was to become part of the Hawaiian kingdom under the direct rule of Kamehameha or his heirs. Certain of Kamehameha's retainers plotted to kill Kaumualii while he was still in Honolulu, but the execution of the plot was prevented by Isaac Davis. Davis, an Englishman who had escaped the destruction of the schooner *Fair American* in 1790 and for many years had been one of Kamehameha's principal advisors, paid for his good deed with his life. He was poisoned by the same chiefs who had plotted the death of Kaumualii.

In 1814 the ship *Bering* was sent to Oahu to obtain supplies for the settlement of the Russian American Company at Sitka. On her return voyage, on the night of January 31, 1815, she was driven ashore and wrecked at Waimea, Kauai. The cargo was salvaged and left in the care of King Kaumualii. Later in the year, Alexander Baranof, governor of the Russian colony in Alaska, sent Dr. Georg Scheffer to reclaim the cargo. Scheffer stopped first at Kailua, on Hawaii, where Kamehameha gave him a letter instructing Kaumualii to deliver the cargo. He then went on to Oahu. In the spring of 1816 three Russian ships, sent by Baranof to bring back the cargo of the *Bering,* stopped at Honolulu, and then proceeded with Scheffer to Kauai. Scheffer quickly won the friendship of Kaumualii, partly by his skill as a physician, and won from him an agreement which, among other things, granted the Russian American Company the sole right to export sandalwood from Kauai. Also among the agreements were an outright grant to the company of half the island of Oahu and complete control of four harbors on that island. On its part, the company was to furnish 500 men to aid in seizing Oahu from Kamehameha, and supply Kaumualii with an armed vessel. Armed with this treasonable agreement, Scheffer returned to Honolulu, built a small blockhouse, and raised the Russian flag over it. The interlopers were soon run out by an army under Kalanimoku, and Scheffer returned to Kauai. Kaumualii is said to have given him Hanalei Valley, and he built a fort at the east edge of Hanalei Bay, armed with several cannon. Another fort he built for Kaumualii at Waimea. The ruins of these forts are still visible, and their locations are shown on plate 1.

Kaumualii became convinced that Scheffer was actually not a friend, but an ambitious enemy bent on seizing the island. Kamehameha, hearing of events on Kauai, ordered Kaumualii to expel the Russians immediately. This he did, apparently without serious resistance from Scheffer. Scheffer's conduct appears to have been the result of his own ambition. Lt. Otto von Kotzebue, who visited the islands in late 1816 and the fall of 1817 in command of the Russian ship *Rurick,* assured Kamehameha that Scheffer's acts were entirely unauthorized by the Russian government.

The year 1819 saw the death of Kamehameha the Great and succession to the throne of his son, Liholiho (Kamehameha II); the arrival in the islands of the first whaling ships; and the abolition of the ancient religion with its intricate system of tabus. The first Christian missionaries reached Hawaii on March 30, 1820, and accompanying them was George Kaumualii, son of the king of Kauai, who had left home as a sailor and had been studying at the Foreign Mission School in Connecticut. Liholiho granted the missionary company permission to remain in the islands for one year, on trial, so to speak, and to establish stations at Kailua and Honolulu. Messrs. Whitney and Ruggles and their wives went with George Kaumualii to Kauai, where the king urged on them the establishment of a station at Waimea.

In 1824 King Kaumualii died, and Kauai became officially an integral part of the Hawaiian kingdom. A brief rebellion led by George Kaumualii was quickly suppressed by force, the rebels being defeated in a battle near Wahiawa.

The first permanent sugar plantation in the islands was established at Koloa by Ladd and Co. in 1835, on land leased from the Hawaiian Government. Also in 1835, William French set up a sugar mill at Waimea. French was unable to compete with Ladd and Company's Koloa enterprise, and his mill was removed to Oahu in 1838. At the end of the first year of operations at Koloa 25 acres of sugar cane and 5,000 coffee trees had been planted, and a small quantity of molasses manufactured. During 1837, 2.1 tons of raw sugar and 2,700 gallons of molasses were produced. Not all the sugar was grown at Koloa. Some was grown in neighboring districts and transported to Koloa for milling. The Koloa plantation has continued in operation until the present time, having been combined in 1948 with Grove Farm.

In 1836 an attempt was made by Sherman Peck and Charles Titcomb to establish a silk industry on land leased from Ladd and Co. at Koloa. Mulberry trees were planted and silkworm eggs imported. Shortly afterward, Titcomb leased land at Hanalei Valley and started operations there also. In 1839, Stetson and Co. also entered the silk industry at Koloa. In 1840 a severe drought, followed by influx of insect pests, brought disaster to the industry at Koloa. Titcomb continued the attempt at Hanalei until 1844, when he finally abandoned it and turned to coffee growing. A coffee plantation had already been started at Hanalei in 1842, by Bernard and Rhodes.

A small cotton industry existed in the Wailua area in 1848. In 1849, H. A. Peirce and Co. started a sugar enterprise near Nawiliwili that grew into the Lihue Plantation. During the 1850's oranges grown in the Hanalei area were packed with straw in barrels and shipped to California.

Population.—In 1950 the population of the island was 29,683, according to the U. S. Bureau of the Census. The average density of the population is about 50 persons per square mile, but most of the people live in towns and villages in coastal areas, and relatively few permanent habitations are found more than 5 miles from the shore. The largest town on the island is Lihue, which had a population of 3,870 in 1950. Other principal towns and their populations are Kapaa, about 3,170, Waimea, about 1,640, and Hanapepe, about 1,250.

Previous studies.—The first scientists known to have visited the island of Kauai were members of the United States Exploring Expedition, under the command of Lt. Charles Wilkes, U.S.N. Six naturalists of the expedition landed on the south shore, near Koloa, on October 27, 1840. Among them was James D. Dana, who later for nearly half a century, was an outstanding leader among American geologists. The observations of the scientific party are briefly summarized by Wilkes (1845, p. 58-74).

The volcanic nature of the cones in the vicinity of Koloa was immediately recognized. Dana and A. T. Agate, the artist of the expedition, traveled into Hanapepe Valley and described the columnar jointing in lava at Hanapepe Falls. A drawing of the falls by Agate is contained in the Narrative of the expedition (Wilkes, 1845, opp. p. 51). Two members of the expedition, Charles Pickering and W. D. Breckenridge, traveled across the island from Waimea to Wainiha, and along the north shore to Hanalei. They briefly described the Alakai Swamp and the steep cliffs of Wainiha Valley (Wilkes, 1845, p. 66). Dana and Agate, with T. R. Peale and William Rich, traveled around the east side of the island to Hanalei, where all rejoined the ship. Peale and Rich made a side trip up the Wailua River by boat and on foot as far as Wailua Falls, noting numerous dikes in the Kalepa-Nonou Ridge near the river.

The geological observations are more fully stated by Dana himself (1849, p. 262-279). Dana acquired a remarkable fund of knowledge of the geology in his four brief days on the island, almost wholly limited to the marginal lowlands. He considered the entire island to be the eroded remnant of a single big volcano, which he compared with Mauna Kea or Mauna Loa, on the island of Hawaii. He observed the stratified nature of the rocks, and the essential parallelism of the strata to the surface in the lowland areas, the scoriaceous character of some of the lavas, and the presence in many of them of phenocrysts of olivine. He also commented on the much greater average thickness of the lava beds in the central part of the island as compared to those in the marginal parts. He noted the relative recency of the volcanic cones near Koloa, and described in detail the cones, and the fresh ropy surface of the surrounding flows. He noted also the lithified calcareous dunes at the sea coast near Koloa and pointed out their significance as an indication of change of the relative level of land and sea. He appears, however, to have considered them evidence of uplift, rather than subsidence of the island. He described spheroidal weathering in lavas near Nawiliwili, and commented on the deep weathering of lavas over the lowlands in general. He described dikes in Hanapepe Valley as well as in Wailua Valley. In Hanapepe Valley he observed conglomerate underlying columnar lava, but misinterpreted it as indicating the former presence of a lateral vent at that place. The great cliff of the Napali Coast he attributed to faulting that dropped below sea level the northwestern side of the volcanic mountain. Much of the material, in little altered form, is repeated in his later book (Dana, 1890, p. 305-317).

Stearns (1947, p. 7) attributes to Dana the concept that Kauai and Niihau once were joined as a single island, along the Napali coast, and that they have been separated and Niihau shifted southward by faulting. However, although Dana notes the approximate alignment of the Napali Coast with the east coast of Niihau, he does not suggest the separation of the two by lateral faulting. Instead, he suggests that both volcanoes have lost extensive portions by subsidence, vertical displacement on the fault having caused these segments to sink beneath sea level (Dana, 1890, p. 312). Marcuse (1894, p. 6) appears to be the first to mention the possibility that Niihau is a laterally displaced portion of the Kauai shield. The hypothesis was short lived.

Möhle (1902, p. 89) published descriptions of three specimens of olivine basalt collected near Kipukai by Schauinsland, in 1898.

Hitchcock (1909, p. 11-16) called attention to the drowned character of the principal river valleys of Kauai, as evidence of the submergence of the island. He correctly considered the surface of the Lihue basin to have been formed by volcanic rocks erupted by minor volcanic vents, and resting on the eroded flanks of the earlier major volcano. He greatly overemphasized, however, the amount of ash in the later volcanics. He recognized Kalepa-Nonou ridge to be a part of the older major volcano.

Powers (1917, p. 507, 514) considered that Kauai had once been a volcanic doublet, a second volcanic mountain lying northwest of the Napali Coast having been dropped below sea level by faulting, as previously suggested by Dana. Powers attributes to Dana the statement that flows exposed in the Napali cliffs dip inland, away from the supposed offshore center. However, no statement to that effect can be found either in Dana's Exploring Expedition Report or his later book on Hawaiian volcanoes. Powers correctly points out that the scarp bounding Niihau Island on the east is not a continuation of the Napali scarp of Kauai.

Cross (1915, p. 9-17) gave petrographic descriptions of several rocks of Kauai, including olivine basalt, picrite-basalt of the oceanite type, and olivine-poor basalt of the Waimea Canyon volcanic series; and melilite-nepheline basalt, oligoclase gabbro, and "limburgite" of the Koloa volcanic series. Chemical analyses of several of the rock types were presented, and are quoted in the table on page 111. Cross recognized and briefly described the tuff cone at Kilauea Bay. Sidney Powers recognized the great predominance of olivine basalt on Kauai and suggested that the late cones were arranged radially with respect to the volcanic center (1920, p. 259). He noted also the occurrence of dunite nodules in lava along the Koloa Ditch a mile northeast of Puu Kahoaea and northward to Iliiliula Stream, along the Hanapepe River, and near Nawiliwili Bay (1920, p. 275). An inclusion of gabbro in basalt was found in Hanalei Valley. Powers recognized the long erosion interval between the close of the principal volcanism and the revival of activity (1920, p. 279).

Hinds spent 9 months on Kauai in 1921 and 1922 and published several reports dealing with various aspects of the geology of the island

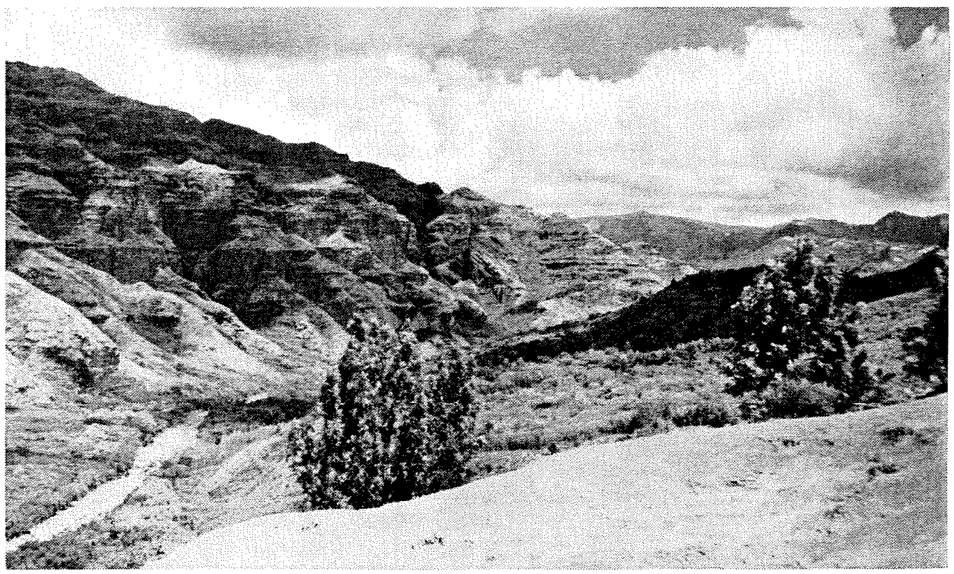


PLATE 3A. View of Waimea Canyon looking north. The high canyon wall on the left is the west boundary of the Makaweli depression. Photo by G. A. Macdonald.

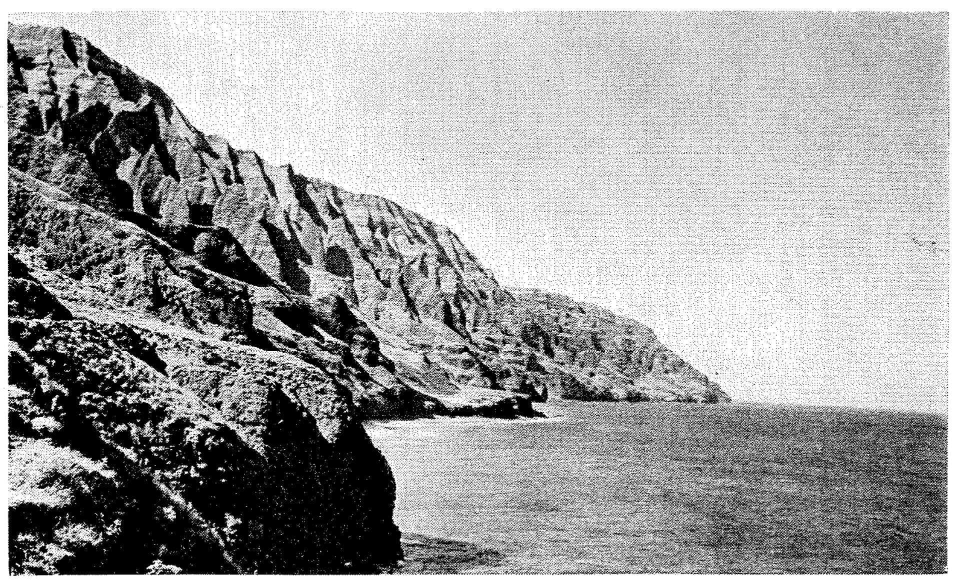


PLATE 3B. View of the Napali Coast from a point between Hanakoa and Kalalau valleys. Alluvial terraces are visible in left foreground and at the mouth of Kalalau valley near the middle of the photograph. Photo by G. A. Macdonald.

(Hinds, 1921, 1925, 1929a, 1929b, 1929c, 1930, 1931). He first clearly recognized (1930, p. 55) the existence of a late period of volcanism (Koloa volcanic episode) separated from the building of the major volcanic mountain by a long period of erosion. He also recognized that nepheline-bearing lavas are much more widespread on Kauai than had been realized by previous workers, though he failed to recognize that they everywhere belong to the post-erosional volcanic rocks of the Koloa volcanic series. He recognized the conglomerates along lower Waimea Canyon, though the erosion that produced them is now known to have been much less important than he believed. Hinds regarded the Lihue basin as formed principally by downfaulting, and the course of the Waimea River to mark a fault line. These conclusions were opposed by Stearns (1946, p. 89-90), but are supported in the present report. Hinds also (1930, p. 79) hypothesized a fault trending north-northeastward along the lower course of Wainiha Canyon, and followed Dana and others in regarding the Napali coast as a fault-line scarp. The latter interpretation was rejected by Stearns (1946, p. 89), who regards the cliff as wholly the result of wave erosion. Evidence on this point is not conclusive, however. Hinds regarded the surface of the Lihue basin and the lowland north and northeast of the Puu Ehu ridge as a somewhat dissected wave-cut platform elevated 500 feet above sea level by diastrophic tilting of the island. This surface, like that along the south shore of the island between Koloa and Hanapepe, is now known to be a constructional surface of lavas of the Koloa volcanic series, which may be underlain by a wave-cut bench.

Clark (1935) clearly recognized that the surface of the Lihue plain is a constructional surface formed by lavas of the Koloa series, and described Kilohana and Hanahanapuni as vents for these lavas. Koluahono, at the south base of the Haupu ridge, also was recognized to be a Koloa vent. Other vents, which he wrongly implied to belong to the Koloa volcanic series, were described along a northwest-trending fault line between the mouths of Poomau and Waialae Streams. Clark also recognized the long duration of Koloa time volcanism and the considerable difference in age of different members of the Koloa volcanic series.

Stearns (1938) described the occurrence of pillow lavas in a late valley-filling flow exposed in Waimea Canyon, and mentioned two other occurrences known to Clark along the Wailua River.

Stearns' reconnaissance map (1946, p. 83) is the first published geologic map of Kauai. Stearns was the first to recognize the presence of the great filled caldera of the Kauai volcano, and the smaller filled caldera at Haupu peak. He did not, however, recognize the Makaweli graben, and considered the Makaweli formation of the Waimea Canyon volcanic series to be part of the Koloa volcanic series. He considered the Haupu ridge to be the eroded remnant of an independent volcano, and termed the rocks composing it the Haupu volcanic series. In the present report it is shown that, although some of the lavas were erupted from the Haupu vent, the ridge as a whole is part of the Waimea Canyon volcanic series. Stearns recognized that the lithified calcareous sand dunes near the south shore of the island were formed during a stand of the sea lower than the present sea level.

Stearns' map indicates vents of the Koloa volcanic series in the headwaters of the North Fork of the Wailua River west of Hanahanapuni, between Keahua and Moalepe Streams north of Hanahanapuni, and between Kealia and Anahola Streams north of Pohakupili. Although it is not improbable that vents once existed in these areas, probably farther inland than those shown on Stearns' map, none of these specific vents could be identified in the field. On the other hand, the Kapaka and Pooku vents, between Hanalei and Kalihiwai Rivers, were not recognized by Stearns. In his report on the geology of Niihau, Stearns points out (1947, p. 10) that the depth (2,550 feet) of the channel between Kauai and Niihau greatly exceeds the depth (1,800 feet) of the deepest submerged shoreline yet recognized in the Hawaiian Islands, and that it is therefore improbable that Kauai and Niihau islands ever were connected above sea level.

History of the investigation.—This report is another unit in the systematic study of the geology and ground-water resources of the Hawaiian Islands by the United States Geological Survey, in cooperation with the Hawaii Division of Hydrography. Its publication marks the completion of the program of areal studies and geologic mapping begun in 1919, with the arrival of W. O. Clark to study the geology and occurrence of ground water in the Kau District on the island of Hawaii. The work begun by Clark has been continued by H. T. Stearns, G. A. Macdonald, and D. A. Davis, for the Geological Survey; and by D. C. Cox, for the Experiment Station of the Hawaiian Sugar Planters' Association.

After a brief visit to the island, the eminent petrographer Whitman Cross wrote (1915, p. 9): "The structure of Kauai is extremely simple and is typical of a basaltic volcano. All the canyons exhibit a series of dark basaltic flows dipping gently away from the general center of the island." This statement is true for the broad features of the original Kauai volcano, but the detailed geology of the island of Kauai has proved to be far from simple. The structure of the island is more complex than that of any other of the Hawaiian Islands, and field work is hampered not only by the heavy vegetative cover common in Hawaii, but over much of the island also by unusually deep weathering. It has required all the experience and knowledge of Hawaiian geology accumulated by the team of investigators on the other islands to decipher the geology of Kauai.

Work on the geology and ground-water resources of Kauai was begun by W. O. Clark in 1930, and continued intermittently until his retirement in 1945. Clark's work was done for the Experiment Station of the Hawaiian Sugar Planters' Association, and was not officially a part of the investigation by the Geological Survey. However, Clark's notes have been available to the writers of this report, and have been of great aid in the investigation.

H. T. Stearns of the Geological Survey devoted brief periods from 1934 to 1945 to study of Kauai; and the knowledge of Kauai geology gained to that time was summarized in his general report on the geology of the Hawaiian Islands (Stearns, 1946, p. 82-90). Stearns' mapping and excellent field notes have been available to the present writers. They have been exceedingly useful both in the field and in the preparation of the report.

Work on Kauai was begun in February 1947 by Macdonald and Davis of the Geological Survey. At the same time Cox, geologist with the Experiment Station, Hawaiian Sugar Planters' Association, joined the investigating team and made available to the Geological Survey the results of his work in the island.

The geologic map.—The existing topographic map of Kauai was made in 1910 by plane-table methods. Because of the extremely rugged topography, dense vegetation, abundant rain, and poor access that exists in many parts of the island, it is not surprising that the map is not of uniform quality throughout the island. On plate 1 the geologic mapping has been fitted to the topography as it is shown on the map, even though in places the depiction of the topography is somewhat inaccurate.

Only the broader topographic features are recognizable along the eastern side of the central mountain massif between the Koloa-Lihue pass and the Hanalei-Wailua divide, adjacent to Halii and Waiahi streams, and considerable adjustment was necessary to fit the geology to the topographic base. The streams shown as southerly large tributaries of the North Fork of Wailua River, 2.7 and 2.9 miles west of Hanahanapuni hill, actually are the headwaters of Waikoko Stream, and should be shown flowing east-southeastward to join that stream near the Waikoko intake of the Lihue ditch. A long, narrow ridge lies between this westward extension of Waikoko Stream and North Fork. The course of the stream has been approximately corrected on plate 1, but the contour lines have not been changed.

The geologic contacts shown on plate 1 have been mapped largely from traverses on foot. Horseback traverses have been used in a few areas, and automobiles have been used along the principal roads. The heavy vegetation over much of the island makes impossible the precise mapping of geologic contacts without the expenditure of much more time, effort, and funds than was deemed justified for this study, except in areas where special problems were involved. For the most part, the map is only of reconnaissance accuracy.

Aerial photographs were used in plotting the eastern boundary of the caldera between Nonopahu Ridge and middle Hanalei Valley. The general position of the boundary is clear from the character and attitudes of the beds, but its exact position is not readily determined in the field. A faint white line, of undetermined origin, is distinguishable in the photographs, following the line shown on plate 1. Some dikes in the area south of Kawaikini peak and along the Napali coast also have been mapped from aerial photographs. The two small patches of lava of the Koloa volcanic series on the end of the ridge between Hanapepe River and Hauhili Stream and near the top of the ridge east of the headwaters of Hanapepe River were mapped from aerial photographs and have not been visited in the field. These patches show in the photographs the same distinct grain of vegetation as do nearby areas of known Koloa. Fragments of lava of the Koloa volcanic series were found in the gravel along Hanapepe Stream just below Halulu Falls. The floor of Lumahai Valley above the falls of Lumahai River has a somewhat similar appearance, and may also be underlain by the Koloa, as is suggested also by the topography. This appears less certain, however, than the patches of Koloa along upper Hanapepe Valley.

Other contacts, such as that bounding the Makaweli graben south of Nonopahu Ridge, are discussed on later pages.

Acknowledgments.—The Geological Survey is indebted to the plantations and ranches of Kauai for assistance and cooperation that made field work possible in the island. The following were very helpful in providing entry to lands, permission to use facilities of their companies, and information on ground-water supplies: Messrs. Aylmer Robinson, Sinclair Robinson, Selwyn Robinson, and Lester B. Robinson of Gay and Robinson; L. A. Faye, manager, and R. C. Williamson, assistant manager, of Kekaha Sugar Co., Ltd.; J. C. Carter, manager of Olokele Sugar Co., Ltd.; John Sandison, manager, and R. H. Cox, engineer, of McBryde Sugar Co., Ltd.; Hector Moir, manager of the former Koloa Sugar Co., Ltd.; W. M. Moragne, manager of Grove Farm Co., Ltd.; C. E. S. Burns, former manager, and Keith Tester, manager, and R. L. Garlinghouse, engineer, of Lihue Plantation Co., Ltd.; Martin Black, manager of Kilauea Sugar Co., Ltd.; and F. B. Conant, manager of Princeville Ranch.

Assistance in entering Territorial Forest Reserve areas and other courtesies were extended by Mr. A. W. Duvel of the Territorial Board of Agriculture and Forestry. Officials and staff members of the water department of the County of Kauai furnished information on public water supplies.

The Experiment Station, Hawaiian Sugar Planters' Association, gave valuable help in granting the use of field notes and manuscript reports on the geology and ground-water supplies of Kauai compiled by the late W. O. Clark during the course of his work as geologist for the Experiment Station.

The illustrations were prepared by James Y. Nitta.

GEOMORPHOLOGY

The ancient Kauai volcano was a roughly circular dome which stood somewhat higher than the present summit of the island. The island still has the roughly circular outline, but collapse, faulting, erosion, and later volcanism have affected its surface profoundly. The only areas that approximate the original surface of the dome are flattish ridges on the west slope of the island and the small area at Wekiu, the summit of the Makaleha Mountains in the northeast part of the island. These areas have been lowered somewhat by erosion, but they have about the same degree and direction of slope as the surface of the ancient dome. Elsewhere, erosion has deeply dissected the dome or faulting and collapse have dropped large segments far below their original levels.

Features associated with calderas.—Ponded lavas which filled to overflowing the main caldera of the Kauai volcano once formed a large, roughly circular area of relatively low relief and gentle slope in the north-central part of the island. The surface of the caldera fill stood 4,000 feet or more above present sea level and, except at places of overflow, was bounded by scarps formed in the lava flows of the original dome when the caldera was formed. Erosion has since destroyed the original surface, but relatively slightly dissected remnants are occupied by Alakai Swamp and form the small flat summits of Laau Ridge and Namalokama Mountain. Kaunuohua Ridge, between Pohakuwaawaa peak and the head of Kalalau Valley, slopes gently to the northwest but steeply to the southeast. The ridge probably is an eroded segment of the northwest rim of the caldera which once stood 400 feet or more above the caldera-filling lavas. No other segments of the caldera-boundary scarp exist.

Haupu peak near the southeast coast of the island is the dissected remnant of massive lavas filling a small caldera. Erosion has destroyed the original surface of the caldera, but the summit of Haupu probably is not far below the original top of the lava fill.

Features caused by faulting and collapse.—East of the Waimea River a depressed area, which Cox (1951) has called the Makaweli depression, is the result of faulting in which a northward-pointing V-shaped section of the original volcanic dome was displaced downward. The high west wall of the Waimea Canyon is an eroded fault scarp which is the west boundary of the depression. The northeast boundary also once was a fault scarp which extended northwestward from the vicinity of Hanapepe to about the junction of Waiahulu and Poomau Streams. That boundary now is obscured by erosion and by lava flows that poured southwestward from vents along the fault and from the main caldera and partly filled the depression.

In the eastern part of the island a large depression, which is called here the Lihue depression, is bounded by the high, steep slopes of the Waialeale massif on the west, by the Makaleha Mountains on the north, by Kalepa-Nonou ridge on the east, and by Haupu ridge on the south. The bounding ridges and mountains all are eroded lava flows of the original dome. The floor of the depression is covered by late lava flows. The explanation offered by Hinds (1930, p. 79) that the depression is the result of collapse of a large nearly circular section of the original dome appears to be correct.

Features caused by late volcanic activity.--Landforms produced by late volcanic activity dominate the lower slopes in most of the northeastern, eastern, and southeastern parts of Kauai. From Hanalei around to Kaumakani relatively slightly dissected and gently sloping lava aprons lie between the shore and the steep mountain slopes of the island. Streams crossing the aprons have cut shallow, narrow valleys, but the surfaces between the valleys are broad flow slopes built by lavas flowing down from vents in the uplands or from scattered vents in the lowlands. The vents in the aprons are marked by numerous cinder and spatter cones and a few small lava shields. The cinder and spatter cones have relatively steep slopes and are small but distinct hills on the lava aprons. Typical cones are Toleau hill south of Kalaheo and the line of hills extending northward from Makahuena Point. The lava shields stand above the aprons as generally gently sloping domes. Puu Auau on the north coast near Moloaa Bay is a low lava shield. The dome just south of Kalaheo and Puu o Papai northeast of Kaumakani are larger and more prominent shields.

The floor of the Lihue depression is formed by late lavas. A conspicuous feature in the depression is the lava shield surrounding Kilohana Crater. The southeastern slope of the shield extends as a lava plain through the gap south of Kalepa Ridge. The eastern, northern, and western slopes of the shield merge into lava plains built by ponded lavas flowing from the Kilohana vent, probably from the vent that built a cinder cone at Hanahanapuni, and from vents high in the north and west walls of the depression. The southern slope of the shield flattens into a lava plain produced by ponding of flows against Haupu ridge.

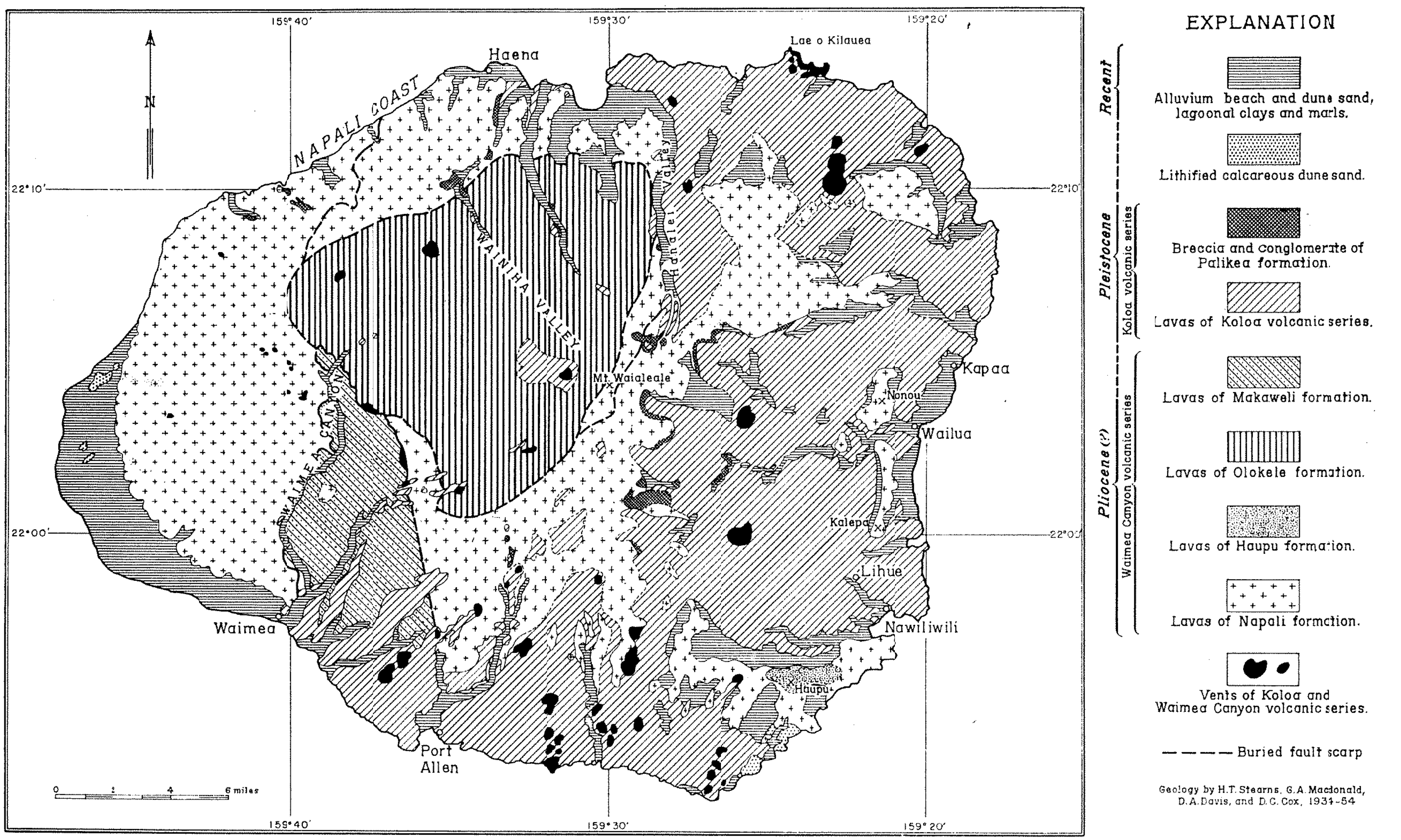
Streams and valleys.—The north-south course of the Waimea River along the base of the eroded fault scarp that bounds the west side of the Makaweli depression was determined by the eastward slope of the fault scarp and the southwestward slope of the depression-filling lava flows which abut against the scarp. The area draining into the Waimea River from the west is small and the tributaries in it are short and generally dry. The tributaries entering from the east, which carry runoff from the wet summit area of the island, are by comparison large and long. The steep west wall of the Makaweli depression and the deep, steep-walled valleys of the lower parts of Waialae, Koaie, and Poomau Streams form the spectacular Waimea Canyon (pl. 3A). Smaller but almost as impressive is Olokele Canyon, through which the runoff from the wet mountains flows southwestward and ultimately into the Waimea River.

On the west slope of the island the drainage lines retain a radial pattern which developed on the flow slope of the original dome. The numerous streams here are in closely spaced small valleys and none are perennial. These small drainage systems developed on a dry leeward segment of the island which was isolated from the rainy central uplands by the faulting that produced the Makaweli depression. As a result of the faulting, runoff from the uplands, which otherwise might have cut larger valleys in the west slope, was diverted southward in the Waimea River. The radial pattern characteristic of the small valleys of the dry west slope continues around the northwest side of the island, but along the Napali Coast where the rainfall is higher most of the streams are perennial and the valleys are larger. The Napali Coast streams, however, are short, their headward extension having been limited by the northwest boundary of the Waimea River basin.

A large section of north-central Kauai is rugged canyon country having deep, steep-walled valleys which were cut by northward flowing streams. The most spectacular of the valleys is the Wainiha River gorge, which is about 11 miles long, 3 miles wide at its widest part, and 2,000 to 3,000 feet deep along much of its length. The valleys of the Wainiha and Lumahai Rivers trend northwestward in their upper parts but bend to the northeast near the coast approximately at their crossing of the north boundary of the main caldera. Structural control of the two streams is not evident now, but their courses probably were determined by the ancient topography that existed after the collapse and subsequent filling of the caldera. Hemmed between the long valleys of Lumahai and Hanalei Streams are the short, deep valleys of Waipa and Waiole streams. Headward erosion in the two small valleys probably was stopped when their ancestral drainage areas were captured by the more rapidly eroding tributaries of Lumahai and Hanalei Streams. The rocks in the high west wall of the Hanalei Stream valley are mostly lava flows of the old Kauai dome, and the rocks in the lower east wall are late lava flows. The Hanalei River possibly was crowded westward to its present course from a northeasterly trend by late lavas erupting from vents east of the present valley. The westward swing of the river near the coast certainly is the result of encroachment of late lavas which now form the apron east and south of the stream.

The rugged Makaleha Mountains and Puu Ehu ridge in the northeastern quarter of the island are deeply dissected segments of the ancient Kauai dome which now are surrounded by late lava flows. These mountains are remnants left after deep erosion of the northern and eastern slopes of the dome, but, except perhaps for that of the Hanalei River valley, the courses of the ancient valleys that they lay between are not apparent in the present topography.

Deep and relatively short gorges, which largely are in lavas of the ancient dome, indent the west wall of the Lihue depression. The gorges were cut by streams flowing from the rainy uplands, and most of them are part of the Wailua River system. East of the gorges the streams flow in relatively shallow valleys across the late lava fill in the Lihue depression. In the gap between Kalepa Ridge and Nonou the Wailua River is incised in late lavas that overflowed from the depression. West of the gap, the headward march of waterfalls in the North and South Forks of the Wailua River has entrenched the lower reaches of the streams in small gorges in the late depression-filling lavas. Runoff from the nearly circular Kilohana lava shield has developed numerous small valleys in a striking radial pattern. Deep stream-cut valleys may have crossed the eastern part of the ancient dome prior to the collapse of the Lihue depression. The gap between the Kalepa Ridge and Nonou, which is older than the late lavas that fill the depression, probably was eroded before or during the formation of the depression. The wide gap south of the Kalepa Ridge



EXPLANATION
Recent
Alluvium beach and dune sand, lagoonal clays and marls.
Lithified calcareous dune sand.
Pleistocene
Koloa volcanic series
Breccia and conglomerate of Palikea formation.
Lavas of Koloa volcanic series.
Pliocene (?)
Waimea Canyon volcanic series
Lavas of Makaweli formation.
Lavas of Olokele formation.
Lavas of Haupu formation.
Lavas of Napali formation.
QUATERNARY
TERTIARY
Vents of Koloa and Waimea Canyon volcanic series.
Buried fault scarp
Geology by H.T. Stearns, G.A. Macdonald, D.A. Davis, and D.C. Cox, 1934-54
N
159°40′
159°30′
159°20′
22°10′
22°00′
Haena
Lae o Kilauea
NAPALI COAST
WAINIHA VALLEY
Hanalei Valley
Mt. Waialeale
WAIMEA CANYON
Kapaa
Nonou
Wailua
Kalepa
Lihue
Nawiliwili
Haupu
Waimea
Port Allen
0 2 4 6 miles

may have been formed, at least in part, by a large stream flowing from the high central part of the island.

Sea cliffs.—High cliffs cut by wave action extend around the west side of the island from Waimea to Hanalei Bay. The cliffs, which are cut in lavas of the ancient dome, range in height from 300 to 2,000 feet and are most scenic along the Napali Coast (pl. 3B). Between Waimea and Polihale on the southwest coast and in the Haena area on the north, coastal plains lie between the cliffs and the shore, but from Polihale to Ka Lae o Kailio marine cutting is still active. Large caves at the base of the cliff near Haena were quarried by wave action, probably at a time when the sea stood about 5 feet higher than the present sea level.

The seaward slopes of Puu Ehu ridge on the northeast coast and Nonou and Kalepa Ridges on the east coast probably were sea cliffs prior to the eruption of the late lavas that now surround or partly surround them. The bases of the cliffs now are buried by the late lavas, and the slopes above the lava fill have been reduced by subaerial erosion.

The steep face of the broad east end of the Haupu ridge is a sea cliff indented by small valleys.

Wave action has cut generally low cliffs in the late-lava platforms that border the north, east, and south sides of the island. The highest of these are on the north shore, where they range from 50 to about 250 feet in height.

Depositional features.—Sedimentary deposits form the Mana plain at the base of the southwest slope of the island (pl. 4A), smaller coastal flats near Haena on the north coast and at the base of the Kalepa Ridge on the east coast, and valley flats at the mouths of the large streams. The Mana plain is built of alluvium washed from the uplands, calcareous and earthy lagoon deposits, and calcareous beach and dune sands. The small flats on the north and east coasts are alluvium and calcareous beach and windblown sands. The valley flats near the mouths of the large streams were built by alluvial fill deposited in valleys which earlier were eroded below present sea level. Well 70 on the flat near the mouth of the Hanalei River (pl. 1) penetrated 173 feet of alluvium before entering lava rock 167 feet below sea level; however, the well may not be in the deepest part of the ancient valley.

THE ROCKS AND THEIR WATER-BEARING PROPERTIES

GENERAL STATEMENT

The rocks of Kauai are all volcanic, except for minor amounts of sediments derived from the volcanic rocks by erosion, and a narrow, discontinuous fringe of calcareous reef and beach deposits. Fundamentally, the island is a single broad dome, built by a typical basaltic shield volcano closely resembling the present active volcanoes, Kilauea and Mauna Loa, on the island of Hawaii. Most of the shield consisted of thin layers of lava rock sloping gently outward from the summit region of the mountain. On the southeastern flank of the mountain a subsidiary vent had

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Figure 1. Generalized geologic map of Kauai.

much the same relationship to the larger shield volcano as Kilauea volcano does to the larger Mauna Loa (Stearns, 1946, p. 43). Collapse of the summit area of the major shield produced a broad depression, or caldera, and in this caldera accumulated thick, massive, nearly horizontal beds of lava, ponded by the walls of the depression. At a slightly later date further collapse produced the Makaweli depression, a downfaulted trough, or graben, on the southwestern flank of the mountain. Lavas poured from the caldera area into the southwestern graben, partly filling it. At about the same time, or a little later, the Lihue depression is believed to have formed by collapse on the eastern flank of the mountain; its walls were greatly eroded, and the floor was deeply covered by volcanic rocks of a later series (the Koloa).

All the rocks of the major shield volcano are included in the Waimea Canyon volcanic series, named for the excellent exposures of most of its members in the walls of Waimea Canyon and its tributaries. For convenience of reference, the several mappable units into which the Waimea Canyon volcanic series has been divided are given separate names. The thin outward-dipping beds of lava that make up the principal part of the volcanic shield, and their associated pyroclastic rocks and breccias, are termed the Napali formation of the Waimea Canyon volcanic series. The thick, nearly horizontal beds of lava and the associated pyroclastics that accumulated in the main caldera are termed the Olokele formation. Similar lavas and breccia that filled the small caldera at the subsidiary vent on the southeastern side of the major shield are termed the Haupu formation. The beds of lava and pyroclastics that accumulated in the graben on the southwestern side of the mountain are named the Makaweli formation; and the breccias and conglomerates at the base of, and interbedded with, lavas of the Makaweli formation are termed the Mokuone member of the Makaweli. All these members are further defined on later pages.

After the long period of inactivity that followed the building of the major shield, volcanism was resumed on Kauai. The lavas and pyroclastic rocks erupted in this second period of volcanism rest with profound erosional unconformity on the rocks of the Waimea Canyon volcanic series. They are known as the Koloa volcanic series. Extensive sedimentary breccias and conglomerates at the base of, and within, the later volcanic succession are known as the Palikea formation.

Sedimentary rocks include calcareous organic ("coral") reefs; marly deposits accumulated in lagoons behind the reef; sand dunes, both lithified and unlithified; beach deposits; and alluvium. Unlithified sand dunes are in general related to the present beaches and sea level. Lithified dunes, however, were formed during earlier times when the relative position of land and sea was different from that of the present. Alluvium, also, is partly related to present conditions of base-level; but in part it accumulated during earlier stages of erosion when baselevels or other local controls of deposition differed from the present ones. The two classes have been differentiated as older alluvium and younger alluvium.

The stratigraphy of Kauai is summarized in the accompanying table. The distribution of the various units is shown on plate 1, and in generalized fashion in figure 1.

Stratigraphic units on the island of Kauai

Age	Major geologic unit	Series	Rock assemblage	Thickness (feet)	Symbol on map (pl. 1)	General character	Water-bearing properties
Recent	Sedimentary deposits.		Beach sand.	5±	Rb	Loose sand, composed chiefly of fragments of calcareous algae, corals, mollusk shells, and skeletons of Foraminifera.	Very permeable; carries brackish or saline water at sea level.
Recent	Sedimentary deposits.		Unconsolidated calcareous dunes.	10-100	Rd	Loose cream-colored crossbedded sand blown inland from the beaches and composed of the same materials.	Very permeable, but almost entirely above water table.
Recent	Sedimentary deposits.		Younger alluvium.	5-200	Ra	Unconsolidated earthy deposits consisting of loose, poorly to moderately well sorted stream-laid gravel, sand, and silt.	Poorly permeable, but contains small amounts of fresh or brackish water.
Local erosional unconformity							
Pleistocene	Sedimentary deposits.	Noncalcareous sediments	Lagoon deposits of Mana plain.	....	Pl	Poorly consolidated earthy and marly sediments accumulated in a lagoon between the volcanic rocks and the beach ridge.	Poorly permeable, but yield brackish water to wells.
Pleistocene	Sedimentary deposits.	Noncalcareous sediments	Older alluvium.	100±	Pa	Poorly to well consolidated earthy deposits consisting of stream-laid gravel, sand, and silt.	Poorly permeable, but locally carries small amounts of fresh or brackish water.
Pleistocene	Sedimentary deposits.		Consolidated calcareous dune sand.	10-100	Pd	Moderately to well cemented crossbedded calcareous sand blown inland from beaches during former lower stands of the sea.	Permeable; contains brackish water at sea level.
Local erosional unconformity							
Pleistocene	Volcanic rocks and associated sedimentary rocks.	Koloa volcanic series	Tuff cone at Kilauea Bay.	350±	Pkt	Moderately to well indurated palagonite tuff containing fragments of basaltic rocks and calcareous reef rock.	Poorly permeable; fractures yield small amounts of fresh water.
Pleistocene	Volcanic rocks and associated sedimentary rocks.	Koloa volcanic series	Ash and tuffaceous soil beds.	1-10	Pka	Fresh to highly decomposed ash and cinder intercalated with lava flows of the Koloa volcanic series.	Locally highly permeable and yield water freely, but mostly poorly permeable and locally perch small bodies of fresh water.
Pleistocene	Volcanic rocks and associated sedimentary rocks.	Koloa volcanic series	Cinder cones.	25-250	Pkv	Heaps of fresh to highly decomposed cinders at vents of lava flows of the Koloa volcanic series.	Moderately to highly permeable, but too small to be important aquifers.
Pleistocene	Volcanic rocks and associated sedimentary rocks.	Koloa volcanic series	Palikea formation.	2-700	Pkp	Masses of poorly sorted breccia and beds of poorly to moderately well sorted conglomerate at the base of, or intercalated with, rocks of the Koloa volcanic series.	Poorly permeable; locally perches small bodies of fresh water.
Pleistocene	Volcanic rocks and associated sedimentary rocks.	Koloa volcanic series	Lava flows.	1,000±	Pkl	Aa and pahoehoe lava flows of nepheline basalt, melilite-nepheline basalt, picrite-basalt, olivine basalt, and basanite.	Poorly to moderately permeable; carry fresh or brackish water at sea level but generally yield it slowly to wells; locally contain small bodies of perched fresh water.
MAJOR EROSIONAL UNCONFORMITY							
Pliocene	Volcanic rocks and associated sedimentary rocks.	Waimea Canyon volcanic series	Makaweli formation, including Mokuone member.	1,500+ (Makaweli fm. proper); 0-1,000 (Mokuone member).	Twm (Makaweli fm. proper); Twmm, Mokuone member.	Aa and pahoehoe lava flows of olivine basalt, basalt, and picrite-basalt accumulated in a graben on the southwest side of the major Kauai shield volcano. Mokuone member, masses of poorly sorted breccia along the contact of lavas of the Makaweli formation with the older rocks, and beds of moderately well sorted conglomerate intercalated with lavas of the Makaweli formation.	Moderately to poorly permeable; carry fresh or brackish water at sea level but generally yield it less readily to wells than the lavas of the Napali formation. Mokuone member, poorly permeable; carries no water.
Pliocene	Volcanic rocks and associated sedimentary rocks.	Waimea Canyon volcanic series	Haupu formation.	1,850+	Twh	Massive flows of olivine basalt and picrite-basalt accumulated in a small caldera on the southeast slope of the major Kauai shield volcano.	Moderately to poorly permeable; may carry fresh water at sea level but would not yield it readily to wells.
Pliocene	Volcanic rocks and associated sedimentary rocks.	Waimea Canyon volcanic series	Olokele formation.	2,600+	Two	Thick, massive flows of olivine basalt, basalt, and picrite-basalt accumulated in a broad caldera at the submmit of the Kauai shield volcano.	Moderately to poorly permeable; lavas probably carry fresh water at sea level, but would not yield it readily to wells. Locally ash beds perch small bodies of fresh water at high levels.
Pliocene	Volcanic rocks and associated sedimentary rocks.	Waimea Canyon volcanic series	Napali formation.	2,700+	Twn	Thin flows of olivine basalt, basalt, and picrite-basalt accumulated on the flanks of the Kauai shield volcano.	Highly permeable; carries fresh water at sea level over much of the island, and yields it freely to wells; may contain water confined at high levels between dikes in some areas.

WAIMEA CANYON VOLCANIC SERIES

GENERAL CHARACTER AND AGE OF THE ROCKS

The Waimea Canyon volcanic series comprises all the rocks of the major volcanic shield that constitutes most of the island of Kauai. The type locality of the series is the walls of Waimea Canyon, where 4 of the 5 mapped units of the series are well exposed. The exposed thickness of the Napali formation, in the west wall of the canyon, in places is as much as 2,400 feet, and in the east wall of the canyon the maximum exposed thickness of the Olokele formation exceeds 2,300 feet. The base of neither formation is exposed. The Napali formation constitutes the great bulk of the mountain from the sea floor to 3,700 feet above sea level in the Kokee area, and the top of the Olokele formation is at an altitude of 5,170 feet at Kawaikini peak. Thus, without allowing for any isostatic sinking of the volcanic mass, the total thickness of the Waimea Canyon volcanic series is about 20,000 feet.

The series consists almost entirely of olivine basalt, with much less abundant basalt poor in olivine, and picrite basalt rich in olivine. A few flows of basaltic andesite have been recognized near the top of the section. Volcanic ash and cinders locally are interbedded with the lava flows, but their total amount in the exposed sections cannot be as much as 2 percent, and probably does not exceed 1 percent of the whole. The lava flows include both pahoehoe and aa types, and vesicularity ranges from very low to very high. Permeability of the lavas varies greatly with the type of flow. The variations are in part related to individual formations of the series, and will be discussed further in later sections. In general, however, the lavas of the Olokele and Haupu formations are the densest and least permeable, and those of the Napali formation are the most vesicular and most permeable of the series.

Small intrusive bodies cut all members of the series, but large intrusive masses are unknown. Dikes are abundant in the Napali formation, especially along the Napali Coast, in the west wall of Waimea Canyon, and in the headwaters of the streams just east of Mount Waialeale (pl. 1). In contrast, they are much less abundant in the Olokele formation, although the latter occupies the central caldera area of the volcano.

Stearns (1946, p. 85) termed the rocks of the main volcanic mass of Kauai the Waimea volcanic series, and subdivided it into an extra-caldera or lower member and a caldera-filling or upper member. However, the stratigraphic name Waimea was found to have been previously used by Hinds (1930, p. 56) for conglomerates interbedded with lavas along Waimea Canyon, and by Wentworth (1938, p. 38) for fragmental volcanics on the island of Hawaii. The new name Waimea Canyon volcanic series was proposed (Macdonald, 1949, p. 1555), in order to create as little change as possible from previous terminology. The lower and upper parts recognized by Stearns are those herein termed the Napali and Olokele formations. The Makaweli formation was not recognized by Stearns.

Stearns (1946, p. 85-87) recognized the massive beds of lava flanked by in-dipping lenses of breccia at Haupu mountain, south of Lihue, as the filling of a small caldera, and considered this vent to have been the source of all the lava flows in the Haupu ridge east of Knudsen Gap. The rocks of this supposedly separate volcanic mountain he termed the Haupu volcanic series. However, southeastward dips of the lava flows in the western part of the ridge indicate at least that part of the ridge to be a continuation of the main volcanic mass. Except for the Haupu mass itself, no structural break can be identified in the ridge. Local westward dips in lavas just west of the Haupu mass indicate that some of the lava flows in the ridge unquestionably came from the Haupu vent. However, they are closely interfingered with the lavas of the main volcanic mass, and the two groups of lavas cannot be satisfactorily separated. It is, therefore, undesirable to apply a separate stratigraphic name to the lavas in the Haupu ridge, and herein they are considered to be merely a part of the Waimea Canyon volcanic series. The massive lava fill and associated breccias of the Haupu caldera are separated as the Haupu formation of the Waimea Canyon volcanic series.

The age of the rocks of the Waimea Canyon volcanic series is not accurately known. No fossils have been found in them, and no age determinations on the basis of uranium-lead ratios, or similar methods, are as yet available.

W. A. Bryan (1915, p. 103) wrote: "The effects of erosion have been considered as perhaps the best evidence of the age of the Hawaiian mountains, and this great mountain [the central massif of Kauai] worn to the core with its one-time lofty crater eaten down to form a slimy bog on its summit, points to the great antiquity of the island. . . ." Even now we have little better information on which to base an opinion of the age of Kauai. On the basis of an estimate of the average rate of reduction of the general land surface of the Hawaiian Islands by stream erosion, Wentworth (1927, p. 132) concluded that the age of the latest lavas of the main shield was approximately 2 million years. Hinds (1931, p. 200) has rightly called attention to the fallacy of applying to the islands of high rainfall a rate of stream erosion determined on the dry island of Lanai, and it is probable that Wentworth's estimate of the age of the Kauai shield on that basis alone should be somewhat reduced. However, other factors probably are of even greater importance and have the effect of greatly increasing, rather than decreasing, an estimate of the age of the Kauai shield.

Both the complications in the geologic history of the island and the amount of reduction of the surface of the Kauai shield are now known to be much greater than Wentworth realized at the time his paper was written. As stated on a later page, even the most recent of the lavas of the Koloa volcanic series were almost certainly extruded during the Pleistocene epoch of geologic time. Deep weathering and erosion within the Koloa volcanic series indicate that the accumulation of the Koloa occupied a long interval. In turn, the Koloa rests on the rocks of the Waimea Canyon volcanic series with profound erosional unconformity, indicating an interval of time between the formation of the two series long enough for stream erosion to cut canyons as much as 3,000 feet deep and carve away a large portion of the Waimea Canyon shield. The general surface of the interfluves west of Waimea Canyon is not essentially uneroded as Wentworth (1928, p. 406, fig. 17) believed, but is now known to have been more or less uniformly stripped to a depth of about 200 feet. Considering the additional erosion now known to have occurred, it appears that Wentworth's estimate of the age of Kauai (assuming his average rate of erosion to be correct) probably should be approximately doubled. This gives the latest lavas of the Waimea Canyon volcanic series an age of approximately 4 million years, and places their extrusion in the Pliocene epoch of the Tertiary period.

The time of beginning of the building of the great Kauai shield volcano at the level of the sea floor can only be surmised, but obviously many eons passed before the extrusion of the rocks now visible above sea level. During the century from 1850 to 1950, Mauna Loa volcano, on the island of Hawaii, liberated approximately 4 billion cubic yards of lava. If extrusion occurred at the same rate on Kauai, without interruption, and if no allowance is made for isostatic sinking of the mass, the entire 1,000 cubic miles of the Kauai shield could have been built in the remarkably short time of 136,000 years! Isostatic compensation very probably did occur, however, increasing the probable bulk of the Kauai shield volcano to something of the order of 3,000 to 6,000 cubic miles, and the time of formation possibly to as much as 800,000 years. Even allowing for some longer periods of quiescence during the building of the major shield, for which evidence is not seen in the exposed part of the section, and for a somewhat lower rate of extrusion than that of Mauna Loa, the time of building probably was not more than 2 to 4 million years. If the activity of the Kauai shield volcano ended in the Pliocene epoch, it probably started in the same epoch.

NAPALI FORMATION

Definition.—The lava flows and associated pyroclastic rocks that accumulated on the flanks of the major Kauai shield volcano, outside the boundaries of the caldera, are herein named the Napali formation of the Waimea Canyon volcanic series. They constitute the major portion of the shield, and extend to its base at the ocean floor. The average depth of the ocean floor in the vicinity of Kauai is approximately 15,000 feet below sea level, and thus the total thickness of the Napali formation is about 19,000 feet. Above sea level the lavas are mostly thin bedded, and dip outward radially from the summit of the mountain at angles of 6° to 12°.

The name Napali formation was adopted because of the extensive and spectacular exposures of these rocks along the Napali Coast on the northwestern side of the island. In that area the exposed thickness of the Napali formation exceeds 2,700 feet. However, the Napali Coast is difficult of access, and therefore undesirable as a type stratigraphic locality. The type locality of the Napali formation is designated as the west wall of Waimea Canyon, where the formation is excellently exposed through thicknesses as great as 2,400 feet.

The Napali formation is separated from the Olokele and Haupu formations of the Waimea Canyon volcanic series by the boundary faults of the calderas. It is separated from the Makaweli formation by the eroded fault scarps at the edge of the Makaweli graben.

The exact age of the Napali formation is not known. The portion exposed above sea level almost certainly was formed during the Tertiary period and probably during the Pliocene epoch.

Distribution and attitude.—The Napali formation is exposed on all sides of the island of Kauai. From Waimea, on the southwestern side of the island, exposures are continuous around the western side to Hanalei Valley at the north. North of the caldera boundary fault, in the segment between Kalalau and Wainiha Valleys, some lavas were ponded against the scarp of a fault diverging from the main caldera fault. These were included by Stearns (1946, p. 83) with the Olokele (caldera-filling) formation. The ponding is only local, however, and there is no structural break between these beds and the thin-bedded outward-dipping lavas that make up the rest of the segment farther north. They are, therefore, considered to be essentially extra-caldera, and are included in the Napali formation.

On the northeastern flank of Kauai, the lavas in the Makaleha Mountains and the ridge just west of Anahola dip away from the center of the island, and for the most part are thin bedded and typical of the Napali formation. Massive, dense beds of picrite-basalt encountered in test hole 14, on a tributary of Papaa Stream, appear to be part of the general series. Their unusual massiveness probably resulted from unusually high viscosity of the flowing magma, which was heavily loaded with crystals of olivine. In the central part of the Makaleha Mountains dips of the lava beds are only 2° to 3° northeastward. The beds appear to be a conformable part of the general Napali formation. Possibly another fault, lying southwest of the Puu Ehu ridge, caused local ponding of the lavas in the Makaleha area. However, similarly low dips are prevalent along the rift zones of the active shield volcanoes Mauna Loa and Kilauea, and it is more probable that the gentle dips in the Makaleha Mountains are simply the result of accumulation of the lavas along a broad northeast-trending rift-zone ridge. Although no concentration of vents or well-defined dike complex has been found in the Makaleha Mountains, the presence of such a rift zone is independently suggested by the general northeast trend of dikes in the area, and the broad northeastward bulge of the island below sea level (fig. 2).

It appears probable that a similar flattening was present in the area now occupied by the broad hollow of the Lihue basin. Lavas exposed in Nonou and Kalepa ridges, at the eastern edge of the basin, closely resemble the lavas of the Napali formation at their type locality, and are included in the Napali formation. However, the average dip of the lava beds in the two ridges is about 10° eastward, a dip somewhat steeper than that commonly occurring on the flanks of Hawaiian shields. If the lavas are projected westward at the same inclination they would rise to an altitude of 9,000 feet at Mt. Waialeale and Kawaikini peak, nearly 4,000 feet above the present summit of the mountain mass. Such a condition is exceedingly unlikely, and probably impossible on the basis of knowledge of the geology of the rest of the island. Possibly the flattening of dip in the area west of the Nonou and Kalepa ridges resulted from a sagging of that portion of the shield, as a precursor of the greater collapse that appears to have contributed to the formation of the Lihue basin.

In the southeastern part of the island, the lavas exposed in the western end of the Haupu ridge are closely similar in character and attitude to those of the main mountain mass just west of Knudsen Gap, and are included as a portion of the Napali formation of the Waimea Canyon

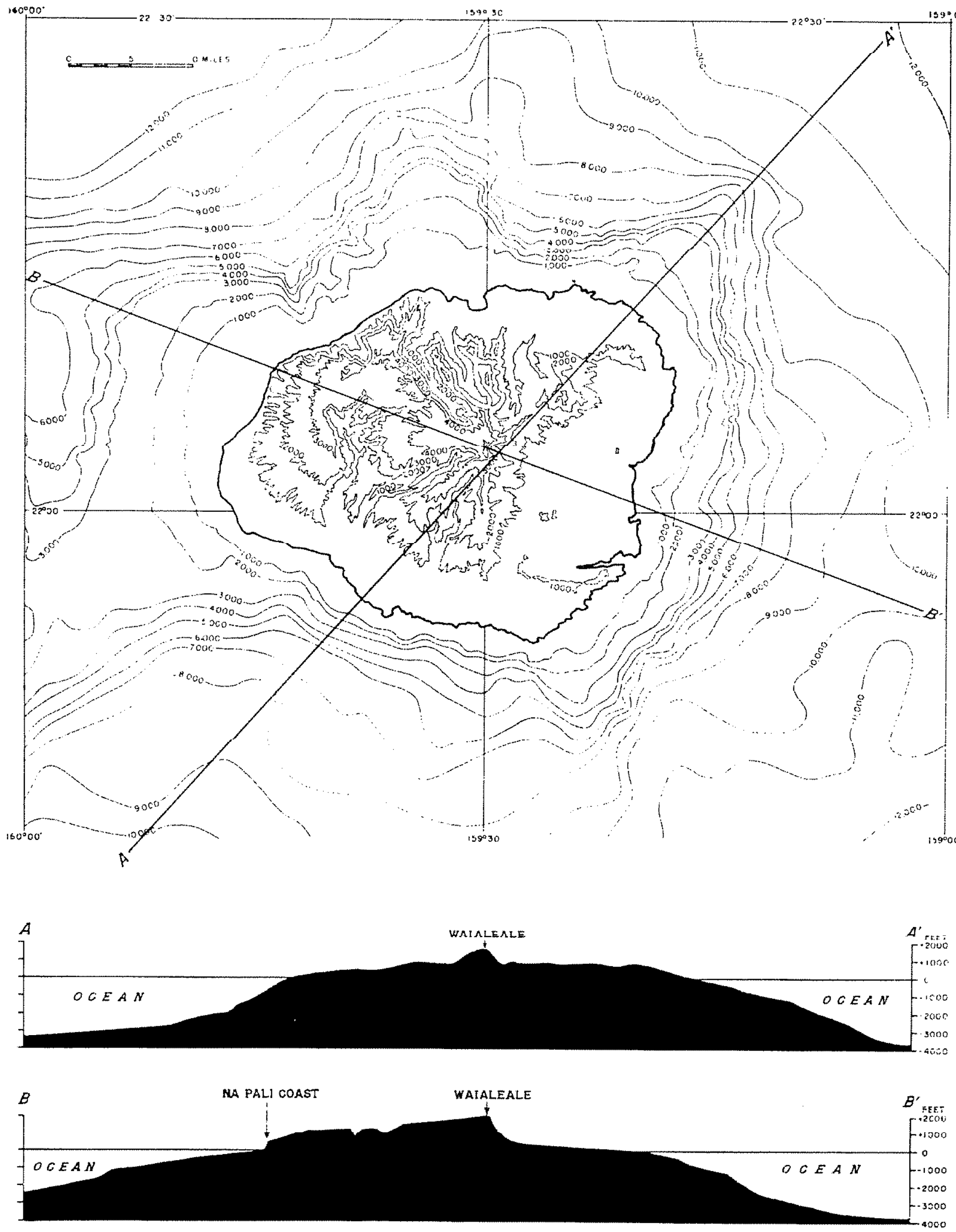

Figure 2. Map of Kauai showing subaerial and submarine contours and profiles of the volcanic dome along lines A-A′ and B-B′.

volcanic series. In the eastern part of the ridge, just west and north of Hokunui peak, the lava beds dip east-southeastward and strike almost directly into the boundary of the adjacent Haupu caldera. There is no apparent reason to suppose that they have any genetic relation to the Haupu vent. They appear rather to be a southward continuation of the lavas of the Napali formation in Kalepa Ridge. On the other hand, just south and west of the Haupu caldera, the lavas dip radially outward from the Haupu mass (pl. 1). Those flows appear quite certainly to have issued from the Haupu vent. Westward and eastward they merge without sharp boundary with the beds dipping southeastward radially away from the central massif of Kauai. The rocks of Haupu ridge, except for those that accumulated within the Haupu caldera, are included in the Napali formation of the Waimea Canyon volcanic series, but with the clear recognition that locally some of them were extruded from the Haupu vent.

Puu Ki is a hill projecting above the general surface of the Makaweli formation, a mile west of Waimea River and 0.6 mile south-southeast of the mouth of Omao Stream. The hill is composed of thin-bedded lavas, closely resembling those of the Napali formation in the nearby western wall of Waimea Canyon and contrasting sharply with the massive beds of the surrounding Makaweli formation. Bedding in the hill dips 7° southwestward, approximately parallel to the beds of the Napali formation west of the canyon, whereas the surrounding beds of the Makaweli formation dip about 3° south-southwest. Puu Ki unquestionably is a mass of lavas of the Napali projecting through the later graben fill of volcanics of the Makaweli formation.

Lava flows.—The Napali formation of the Waimea Canyon volcanic series consists very largely of lava flows. Pyroclastic rocks, including both volcanic ash and cinder, are present locally but constitute probably less than 1 percent of the total mass of the member.

The lavas of the Napali formation are predominantly olivine basalt. Both basalt poor in olivine and picrite-basalt are present, but it is estimated that together they equal less than 10 percent of the whole. The picrite-basalts are of the oceanite type (Macdonald, 1949, p. 1548), containing numerous large crystals of olivine. The olivine phenocrysts may compose more than 50 percent of the rock. The olivine basalts also generally contain phenocrysts of olivine, but less abundantly than the picrite-basalts. Basalts may also contain a few small olivine phenocrysts, but commonly show no crystals visible to the unaided eye. The rocks are described in more detail in the section on Petrography.

The lavas include both pahoehoe and aa, in approximately equal abundance. Pahoehoe may be defined as the variety of lava characterized by smooth, billowy, or ropy surfaces; and aa as that characterized by rough, jagged, spinose, and generally clinkery surfaces. Generally, aa flows have a massive central layer overlain by a nearly continuous layer of clinkery flow breccia, and underlain by a similar but commonly less continuous breccia layer. Pahoehoe and aa are alike in chemical composition, the structural difference being the result of a complex interaction of physical factors during flowage and congelation (Macdonald, 1953). On the basis of knowledge of the behavior of flows on active volcanoes, it is concluded that pahoehoe probably is more abundant in the central part of the shield, and aa more abundant around the edges. However, exposures on Kauai are not sufficiently good, nor have the sections been studied in sufficient detail, to demonstrate this in the field.

In the Napali formation the pahoehoe generally is more vesicular than the massive phase of the aa. The vesicles are shaped like spheroids or complex combinations of spheroids. Vesicularity commonly ranges between 10 and 25 percent but in extreme examples may reach as much as

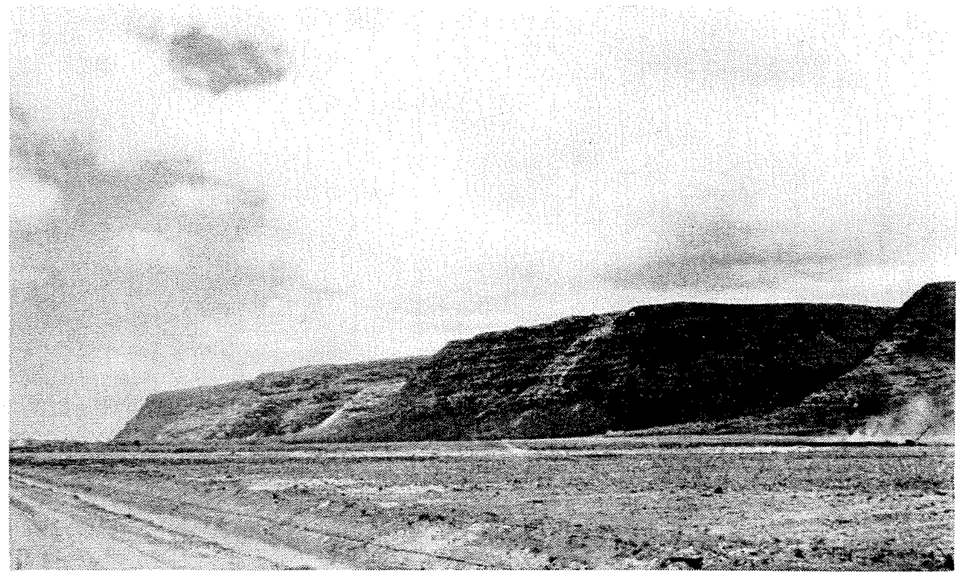

PLATE 4A. Plain formed by sedimentary deposits at foot of ancient sea cliff near Mana. Photo by D. A. Davis.

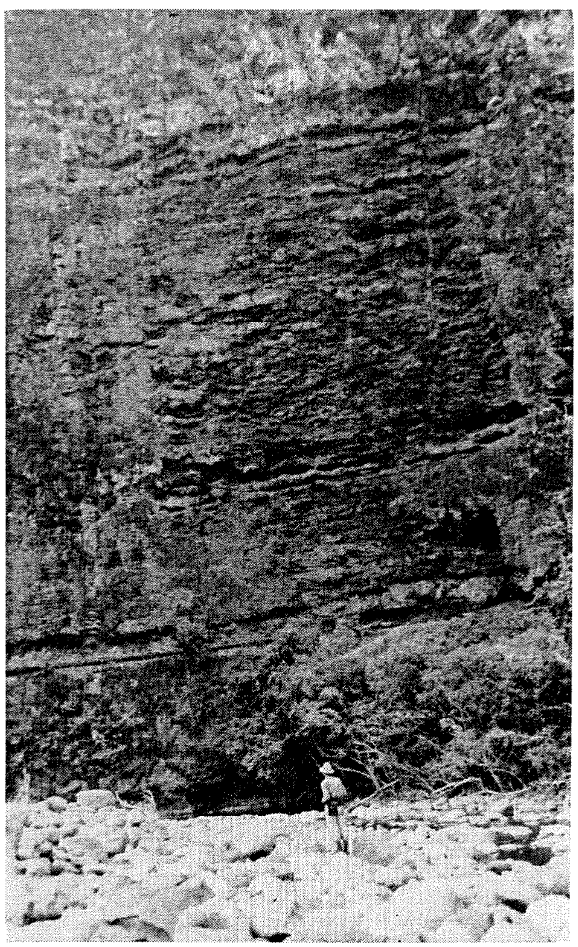

PLATE 4B. Thin-bedded lava flows of the Napali formation in the west wall of Waimea Canyon above the mouth of Mokihana Valley. Two dikes cut the lavas. Photo by G. A. Macdonald.

40 percent. Lava tubes are numerous but generally are partly or entirely filled with congealed lava. Vesicles in the central, massive phase of aa flows are less abundant, on the average, than in pahoehoe, and are much less regular in shape. The clinker phases of aa flows typically comprise from about one-fourth to more than one-half the thickness of the entire flow. Individual fragments of clinker are exceedingly irregular and spinose. In the aa flows of the Waimea Canyon volcanic series the clinker beds are generally well indurated, partly by original welding during emplacement of the flow and partly by later compaction and cementation. The porosity of some beds has been markedly reduced by deposition of secondary materials, predominantly calcareous and clay minerals, by circulating ground water.

Throughout most of the exposed portion of the Napali formation the vesicles in both pahoehoe and aa remain open. In some areas, however, they are partly filled with clay minerals, chlorite, and silica. This condition is especially prevalent in the headwaters of Waiahi, Iole, and Iliiliula Streams and the North Fork of the Wailua River east and southeast of Mount Waialeale, near the boundary of the caldera. Similar rocks are exposed along the Hanalei River near and above the intake of the Hanalei tunnel. Vesicle filling of this sort is characteristic of some areas within and near calderas (Stearns and Macdonald, 1947, p. 19, 92), and apparently results from deposition by rising gases and hot solutions in vent areas of volcanoes.

Most of the individual lava flows are thin (pl. 4B). Single flows commonly are between 4 and 15 feet thick. Pahoehoe flows tend to be thinner than aa flows. A few flow units of pahoehoe are less than a foot thick. In contrast, a few aa flows are as much as 50 feet thick. Individual flow units commonly can be followed for several thousand feet in canyon walls parallel to the dip of the beds. Indications of even minor erosional gullying between flows are rare, as also are intercalated soil or ash beds of significant thickness. This continuity in a section composed of uniform thin flow units is the characteristic result of the rapid accumulation of lavas of uniform basaltic composition on the unobstructed flanks of a highly active shield volcano.

The following stratigraphic section, measured along the Kukui trail on the west wall of Waimea Canyon, is typical of the rocks of the Napali formation.

Stratigraphic section of the Napali formation of the Waimea Canyon volcanic series along the Kukui trail, on the west wall of Waimea Canyon.

TOP	Thickness (feet)
Canyon rim. Upper beds much decomposed	100
Unexposed	150
Olivine basalt pahoehoe, with moderately abundant phenocrysts of olivine up to 4 mm across. Top not exposed	65
Aa clinker	4
Olivine basalt aa, with moderately abundant phenocrysts of olivine up to 3 mm across	10
Aa clinker	0–3
Olivine basalt pahoehoe, with moderately abundant phenocrysts of olivine up to 7 mm across	20
Picrite-basalt pahoehoe, with very abundant phenocrysts of olivine up to 7 mm across	10

	Thickness (feet)
Olivine basalt pahoehoe, with abundant phenocrysts of olivine up to 7 mm across, but mostly less than 4 mm	25
Aa clinker	3
Olivine basalt aa, with abundant phenocrysts of olivine up to 7 mm across, but mostly less than 4 mm	3
Aa clinker	5
Basalt aa, nonporphyritic	12
Unexposed	50
Thin bedded olivine basalt pahoehoe, with moderately abundant phenocrysts of olivine up to 1 mm across. Individual beds average about 3 feet thick	130
Aa clinker	4–6
Olivine basalt aa, with moderately abundant phenocrysts of olivine up to 2 mm across. A heavy moderately dense bed	30
Aa clinker	5
Olivine basalt aa, like the bed above	4–6
Olivine basalt pahoehoe, with moderately abundant phenocrysts of olivine up to 2 mm across. A single heavy bed	35
Basalt pahoehoe, with a few phenocrysts of olivine up to 1 mm across. Individual flows average about 3 feet thick	150
Aa clinker	6
Basalt aa, with a few phenocrysts of olivine up to 1 mm across	15
Aa clinker	5
Basalt pahoehoe, with a few phenocrysts of olivine less than 1 mm across. Individual flow units average 3 to 4 feet thick	130
Unexposed	45
Basalt pahoehoe, like the group just above	7
Aa clinker	3±
Dike of olivine basalt, with moderately abundant phenocrysts of olivine up to 1.5 mm across	4
Basalt aa, nonporphyritic	12
Aa clinker	3
Basalt aa, with rare phenocrysts of olivine up to 1 mm across	6
Aa clinker	3–5
Olivine basalt pahoehoe, with moderately abundant phenocrysts of olivine up to 3 mm across. A single heavy bed	25
Olivine basalt pahoehoe, like the bed above but thin bedded. Individual flow units average about 3 feet thick. Base not exposed	55+
Total, measured section	1,140

An exception to the absence of erosional features between flows of the Napali formation is a lava-filled valley exposed in a road cut on the south side of Haupu ridge, a few hundred yards east of the Grove Farm haulage tunnel. The valley fill is slightly more resistant to erosion than the surrounding rocks, and the crest of a small ridge now follows the axis of the former valley. The trend of the former valley axis was S. 5° E. The buried valley walls have average slopes of about 15° and are exposed for a vertical distance of about 25 feet (pl. 5A). The rocks of the valley walls are decomposed to clay minerals for an average depth of 2 feet. It is not certain, however, whether this weathering occurred before the filling of the valley, or was caused by water circulating along the local unconformity at a later date.

Sedimentary material has been found interbedded with the lavas of the Napali formation at only one locality. The intake of the pipeline that supplies water to Moloaa Camp is in a plunge-pool at the base of a 50-foot waterfall on the north fork of Papaa Stream, at an altitude of approximately 750 feet. In the face of the waterfall is exposed a 20-foot bed of well-cemented breccia containing angular to subangular fragments of lava of the Napali formation. The breccia is poorly bedded and probably was formed by deposition by a stream after the material had been transported only a short distance. It is overlain by a lava flow of the Napali formation.

Massive, nearly horizontal lava flows, estimated from a distance to reach thicknesses as great as 200 feet, are exposed in the upper part of the northeast and east walls of Kalalau Valley. These flows were ponded against the inward-facing scarp of a fault that diverges from the caldera boundary fault near Pohakuwaawaa peak. Northeastward, the dip of the layers steepens and the beds become thinner, until they appear to merge into the normal thin-bedded flows of the Napali formation. The section therefore presents a gradation in character of the flows from the thin flank flows of the Napali member to the thick, nearly horizontal, ponded flows of the Olokele formation.

Puu Opae, 6 miles northwest of the town of Waimea, is a prominent hill 0.2 mile across, standing about 200 feet above the general slope of the surrounding area. It resembles superficially the hills Puu Lua and Puu Ka Pele, described on later pages, that have resulted from differential erosion of resistant crater fills. There is, however, no definite indication that Puu Opae occupies the site of a former vent. No cinder or breccia is exposed in the vicinity. The rock forming the summit of the hill is a hard fine-grained nonporphyritic olivine basalt showing no sign of coarsening of granularity such as would be expected in a slowly cooling thick pool of lava accumulated in a crater of the dimensions of the Puu Opae mass. The hill appears to be simply an erosional remnant. Small residual patches of similar dense nonporphyritic olivine basalt are present on Makahoa and Kaunalewa Ridges 1 to 2 miles west and southwest of Puu Opae. On Pulehu Ridge, 1.6 miles S. 30° W. of Puu Opae, this lava rests on 2 to 6 feet of soil, baked at the top. The soil in turn rests on typical thin porphyritic olivine basalt flows of the Napali formation.

The soil beneath the uppermost flow remnants in the area southwest of Puu Opae indicates a moderately long period of weathering, during which that segment of the shield received no new flows of lava. The lack of flows during that interval probably resulted from the formation of the caldera fault scarp, which prevented flows from the central portion of the volcano from reaching the lower southwestern flanks of the mountain. The flow represented by the remnants above the soil bed probably issued on the flank outside the caldera boundary during the period of eruption of the lavas of the Olokele formation. The location of the vent from which it issued is not known. Possibly it is buried beneath the lava cap of Puu Opae.

Ash beds.—Thin films of ash and reddish ashy soil are found between the lava flows at many places, but ash beds more than a few millimeters thick are rare. A layer of reddish ash a few inches thick is exposed in the falls about 200 feet above stream level at the head of the lower gorge of Nualolo Valley and for a quarter of a mile along the southwest side of the gorge.

In the east bank of Manuahi Stream, 1.1 miles above the point where the stream enters the Hanapepe River, a lens of red ash and cinder is intercalated with lavas of the Napali formation. Its maximum thickness is only about 2 inches, and it pinches out in both directions within 100 feet. Farther up Manuahi Stream, at its confluence with Kawaipuua Stream, a bed of red ash 6 to 18 inches thick is exposed. This may be at the same horizon as the bed that crops out downstream.

Vents.—Few of the vents from which the lavas of the Napali issued have been recognized. Eruptions of the type that built the major portion of the Kauai shield volcano do not build large cinder cones. Small cinder and spatter cones and spatter ramparts form around the vents, but they cover only small areas and are not conspicuous in cross sections exposed by erosion. Furthermore, many of them probably were situated in the crest region of the volcano, and were dropped down by the faulting that formed the caldera and deeply buried beneath caldera-filling lavas.

Most of the eruptions undoubtedly were of the fissure type, like those now building the shields of Mauna Loa and Kilauea volcanoes, on the island of Hawaii. Of the hundreds of dikes exposed in the cliffs and canyons along the Napali coast, in the west wall of Waimea Canyon, and around the other sides of the island, many undoubtedly reached the surface and served as feeders for the Napali flows. None of them has actually been found passing into the flows they fed. However, in a quarry just south of the jail near Wailua, a dike of picrite-basalt 35 feet thick passes at the seaward edge of the excavation into a mass of clinkery breccia cut by stringers of dense lava. The breccia mass shows the same crosscutting relationships to the surrounding flows as does the more massive portion of the dike. It is believed that this portion of the dike was emplaced essentially at the surface, and was autobrecciated to form typical aa-type clinker. Almost certainly, the magma spilled out at the surface to feed a lava flow.

On the southwest wall of Hoolulu Stream, 3.5 miles southwest of Haena, a small segment of cinder cone is exposed in the cliff above the trail. The dip in the immediately overlying lava flow is locally reversed close to the inland side of the cone. The size of the cinder mass has been exaggerated on plate 1.

Near the top of the west wall of Waimea Canyon, 0.3 mile south of the lookout point, a mass of breccia occupies a pit nearly 300 feet deep in the lavas of the Napali formation. The breccia is cut by dikes of olivine basalt. It appears formerly to have been covered by lavas of the Napali formation, but this is uncertain. The breccia appears to have accumulated in a pit crater. The pit crater might have formed during Koloa time, but much more probably it was nearly contemporaneous with the accumulation of the associated lavas of the Napali formation. Masses of breccia near the head of Nualolo Valley, and in the southeast wall of Honopu Valley 0.3 to 0.5 mile above the valley mouth, also may be fillings of pit craters.

Puu Lua, a steep-sided hill just west of the west rim of Waimea Canyon, is an eroded remnant of an ancient filled crater. On its lower northeastern slope poorly bedded breccia dips southwestward, toward the hill, at an angle of about 30°. The breccia consists of angular fragments of olivine basalt in an earthy matrix. A stratigraphic thickness of 40 feet of the breccia is exposed. Above it, 5 feet of thin-bedded olivine basalt pahoehoe dips approximately parallel to the bedding in the breccia. The summit of the hill is composed of massive coarse-grained olivine basalt. Dikes cutting the breccia resemble the massive rock at the summit. The crater probably was a pit crater, formed by collapse, rather than an explosion crater, because the breccia appears to be talus rather than explosive debris. The massive crater fill was more resistant to erosion than the surrounding thin-bedded Napali lavas, and has been left standing above the adjacent region by removal of the surrounding rocks. The two hills respectively 0.25 mile S. 30° E. and 0.4 mile S. 70° E. of Puu Lua appear to be similar in origin, although exposures on them are poorer.

Puu Ka Pele, at the rim of Waimea Canyon a mile southeast of Puu Lua, also appears to be a remnant of a crater fill left standing in relief by differential erosion. Its summit consists of massive coarse-grained olivine basalt, probably accumulated as a pool in an ancient pit crater. Rock fragments scattered on the summit of Puu Ka Pele have been fused on the corners and surfaces. The fusion resembles that caused by lightning, but the fused fragments are too abundant for such a fulgaritic origin to be probable. The hilltop was the site of a Hawaiian heiau (temple), and it is more likely that the fusion resulted from fires (probably burning oil) either during ancient temple ceremonies or during celebrations in more recent times.

A small mass of dense lava 0.25 mile S. 30° E., another 1 mile south, and a third on the south wall of Kahelunui Valley 4.3 miles west-southwest of Puu Ka Pele, also appear to be crater fills.

There is no indication that any of these crater fills were formed in explosion craters. No pyroclastic debris of any sort, either essential or accessory, is associated with any of them. The craters must have been of the collapse type, like the pit craters along the east rift zone of Kilauea volcano (Wentworth and Macdonald, 1953, p. 17). Few pit craters are vents from which lava flows issue. It is possible that some may have formed in small lava cones at eruptive centers, but it is probable that few of them were true vents, or that their rims were elevated more than a few feet above the surrounding terrain. The height of the hills above their present surroundings must result largely from slower erosion of the massive crater fillings than of the surrounding thin-bedded lavas. Both Puu Lua and Puu Ka Pele stand approximately 200 feet above the general surface of the surrounding area. Taken in connection with the similar relief of Puu Opae above the general surface farther down the mountainside, it is clear that erosion has stripped the dry southwestern slope of the Kauai shield to an average depth of some 200 feet. The large number of dikes which reach the surface at the west rim of Waimea Canyon also indicate a considerable erosional lowering of the surface in that area.

Water-bearing properties.—In their original, fresh condition the lavas of the Napali formation are highly permeable. This feature is well illustrated by the closely similar lavas of Mauna Loa and Kilauea volcanoes, where infiltration is so great that despite heavy rainfall normally not a single stream reaches the sea (Stearns and Macdonald, 1946, p. 220). The permeability of the upper portion of the Napali formation has, however, been greatly reduced by weathering. Even in relatively dry portions of the island, the fresh lavas are covered with many feet of soil and subsoil. Partly by compaction, partly by development of new minerals, and partly by deposition of secondary materials in open spaces, the break-down of the rocks into soil greatly reduces the size and continuity of the openings through which water circulates in the fresh rocks. As a result of the deep weathering, Kauai is the only island of the Hawaiian group on which surface storage of water in unlined reservoirs behind dams has thus far been successful.

Locally, the permeability of the Napali has been reduced also by deposition of secondary minerals in openings by rising volcanic gases and solutions. This effect is, however, restricted to small areas close to the margin of the caldera, and is of small importance to the island as a whole.

Water moves readily through the fresh lavas of the Napali formation. The openings that serve as channels include joints, irregular cracks, lava tubes, and interstices between fragments in the clinker portions of aa flows. Below the water table, vesicles in the rocks generally are filled with water. However, the vesicles do not commonly coalesce to any great extent, and it is doubtful that the vesicles serve as an important avenue for movement of ground water except where they are interconnected by cracks.

Open lava tubes constitute natural pipes and may yield very large flows of water. In general, however, they are not of great importance. Large open tubes are so few in number that it is unlikely they will be encountered in a well or infiltration tunnel. Of much greater practical importance as water yielders are joints and other cracks, and the clinker portions of aa flows. In general, the latter yield the greatest unit flows in wells and tunnels.

Except where dikes impound the ground water at high levels, the lavas of the Napali formation are saturated at and near sea level with basal water. Throughout much of the island the basal water is fresh, but it may be brackish at points near the shore in drier parts of the island.

In areas of abundant dikes, the lavas of the Napali formation between the dikes may be highly permeable but the yield of water low because the poorly permeable dikes restrain the movement of water through the rock.

OLOKELE FORMATION

Definition.—The lava flows and associated pyroclastic rocks that accumulated within the boundaries of the major caldera of the Kauai shield volcano are herein named the Olokele formation of the Waimea Canyon volcanic series. The name Olokele formation was selected because of the excellent exposures of the caldera-filling rocks along the walls of upper Olokele Canyon. The type sections of the Olokele formation are designated as the walls of upper Olokele Canyon, and of Poomau, Koaie, and Waialae Streams, tributaries of the Waimea River.

The total thickness of the Olokele formation is not known. The base of the formation is nowhere exposed. In the walls of Poomau, Koaie, and Waialae Canyons the thickness of the exposed portion of the member reaches 2,000 feet, and near the head of Olokele Canyon it is 2,600 feet.

The Olokele formation is separated from the Napali formation of the Waimea Canyon volcanic series by the buried fault scarps marking the edge of the ancient caldera, and locally by masses of talus breccia that accumulated along the fault scarp before it was buried by the later lavas. The volcanics of the Olokele are separated from the Makaweli formation in part by the fault scarp at the head of the Makaweli graben. In part, however, there is no definite sharp line of demarcation between the Olokele and Makaweli formations. Volcanism was still active within the caldera when the Makaweli graben was formed, and lava flows erupted within the caldera poured over the fault scarp into the graben. Thus the Makaweli formation is coeval with the upper portion of the Olokele formation.

Individual flows within the Olokele formation are generally much thicker and more massive than those of the Napali formation. Dips in them for the most part are low, because of the ponding effect of the caldera walls. Few of them are truly horizontal, however. Eruption within the caldera built a broad, gently sloping shield, much like that built in Kilauea caldera and culminating at the rim of the principal active vent, Halemaumau. On all flanks of the shield the lavas dip outward at low angles, generally 2° to 3°.

The Olokele formation of the Waimea Canyon volcanic series is believed to have formed during the Pliocene epoch, in the late part of the Tertiary period. No closer assignment of age can be made as yet.

Distribution.—The Olokele formation of the Waimea Canyon volcanic series occupies the central portion of the main mountain mass of Kauai. It is exposed along the upper stretches of all the major tributaries of the Waimea and Makaweli Rivers in southwestern Kauai; and of the Wainiha, Lumahai, and Waioli Rivers and in the east wall of the Hanalei Canyon in the northern part of the island. The imposing massif of Namolokama, between Hanalei and Lumahai Canyons, is an erosional remnant composed of lavas of the Olokele formation, and its surface is a little-modified portion of the intracaldera shield. Laau Ridge, between Lumahai and Wainiha Canyons, is a similar but smaller remnant.

Flows in the area between the main caldera fault and the fault branching northward from it near Pohakuwaawaa are placed in the Napali formation because they grade northward into thin-bedded flows dipping outward at angles of 6° to 10°, and locally even more. At the head of Kalalau Valley, however, and northwestward as far as the gorge of Hanakoa Stream near the coast, these flows were locally ponded against the scarp of the more northerly fault, and are thick and nearly horizontal like the beds typical of the Olokele formation.

The caldera boundary.—The ancient caldera of the Kauai shield volcano is ovoid, approximately 12 miles long northeast-southwest, and 10 miles wide northwest-southeast. It is the largest caldera known in the Hawaiian Islands. Its linear dimensions are more than twice those of its closest competitor, Mokuaweoweo on Mauna Loa. Mokuaweoweo caldera proper is only 3 miles long and 2 miles wide, but around the central caldera is a broader, slightly sunken zone 4 miles long and 3 miles wide. The Koolau caldera, on the northeastern side of the Koolau range, on Oahu, may have been some 6 miles long and 4 miles wide (Stearns and Vaksvik, 1935, pl. 1; Stearns, 1940, p. 48-50), but its boundaries are not accurately known. Lavas in the Koolau caldera were mapped largely on the basis of the presence of hydrothermal alteration in them, but it is known that such alteration may not be entirely limited to the area of the caldera.

In some areas lavas filled the caldera to its brim and spilled out onto the outer slopes of the volcano. Along Nonopahu Ridge late flows of the

Olokele formation overlie lavas of both the Napali and the Makaweli formations. In such areas the caldera boundary is indefinite. Flows that spilled out of the caldera onto the outer slopes are mapped on plate 1 with the Napali formation, and those that entered the Makaweli graben are mapped with the Makaweli formation. Thus in part, the lavas of the Olokele are contemporaneous with some of the latest flows of the Napali formation.

On the other hand, it appears that at its northwest edge the caldera was not completely filled, and part of the boundary scarp remains unburied. This scarp is still visible as the southeast face of the Kaunuohua Ridge, between Pohakuwaawaa peak and the head of Kalalau Valley. This ridge stands 300 to 400 feet above the general surface of the land to the southeast. Beyond its summit, undoubtedly somewhat lowered by erosion, the land slopes gently northwestward. The gently sloping surface of the Olokele southeast of the scarp appears to have been lowered very little by erosion. The present height of the scarp is, therefore, probably somewhat less than its original height. A road cut 0.4 mile southwest of Pohakuwaawaa peak reveals a breccia containing rounded, apparently spheroidally weathered boulders, overlapped by olivine basalt and andesite of the Olokele formation. The breccia appears to be talus accumulated along the foot of the scarp. The major fault is nowhere exposed along this ridge. However, on the basis of geomorphology, there appears to be no other satisfactory explanation for the ridge, cutting across the general grain of the major drainage and standing well above the level of the terrain southeast of it. Southwestward, the ridge leads directly into the demonstrable caldera boundary in the valley of Halemanu Stream. Northeastward it is prolonged as a less pronounced drainage divide to the west edge of Wainiha Canyon, where again the line is associated with the demonstrable edge of the caldera.

The actual buried scarp of the ancient Kauai caldera is exposed in the valley of Halemanu Stream, half a mile northeast of Puuhinahina. At that locality thin-bedded westward-dipping lavas of the Napali formation in the bottom and west wall of the gulch are overlain by 40 to 50 feet of talus breccia resting on an irregular surface that dips steeply eastward. The breccia is overlain in the upper part of the east wall by nearly horizontal layers of lava belonging to the Olokele formation. The surface beneath the breccia appears to have been eroded, and unquestionably it represents the battered face of the caldera fault scarp. The breccia is exposed also in the head of the canyon of Waiahulu Stream just east of Halemanu Falls. In this area the caldera boundary is exposed through a vertical distance of nearly 2,000 feet. The change in dip of the lava beds on the two sides of the caldera boundary is shown in plate 5B.

In the valleys of Poomau and Waialae Streams the lavas of the Olokele formation lie directly against those of the Napali formation without any intervening breccia. In the wall of Poomau Valley the contact is steep, dipping approximately 80° for 200 feet above stream level. In Waialae Valley the contact dips northeastward at an angle of only 10°. This unusual flatness of the contact is associated with an unusual degree of weathering of the underlying rocks, which are slightly reddened through a depth of several feet. No well-developed soil bed is present, however. At most localities the lavas of the Napali beneath the contact

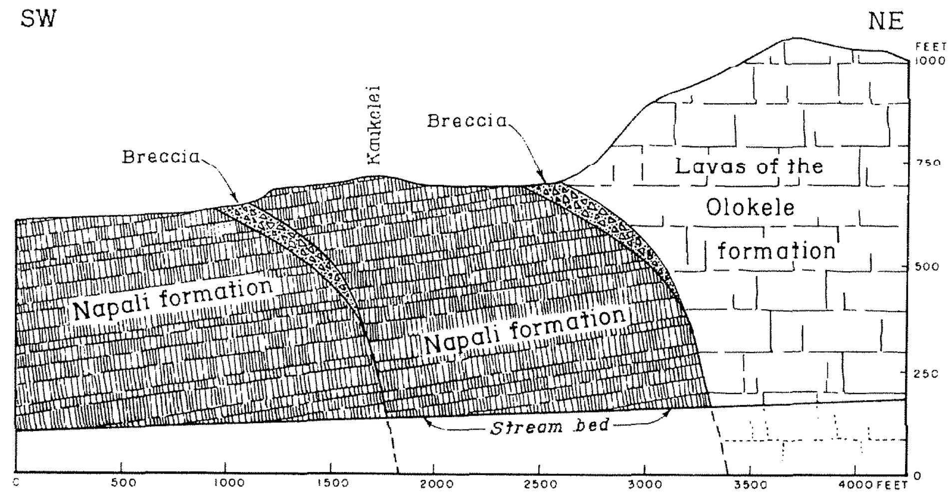

Figure 3. Idealized cross section in the northwest wall of Olokele Canyon, showing breccia masses along the buried fault scarps at and near the margin of the caldera filled with lavas of the Olokele formation.

appear to have been practically unweathered at the time they were buried by the Olokele lavas. This fresh condition is entirely consonant with their exposure on the face of an unstable steep cliff where weathered material could not accumulate. The gently sloping surface beneath the Olokele in Waialae Valley may be the surface of a step-fault block dropped only part way down on the edge of the caldera.

The most spectacular exposure of the caldera boundary is in the northwest wall of Olokele Canyon, 2 miles above the junction of Olokele and Kahana Streams (pl. 6A). Figure 3 is an idealized section illustrating the relationships there. In the upper part of the canyon wall a mass of breccia, averaging approximately 50 feet thick, dips 30° northeastward between thick, massive beds of the Olokele formation above and thin beds of the Napali formation below. Beds of the Napali formation dip 6°

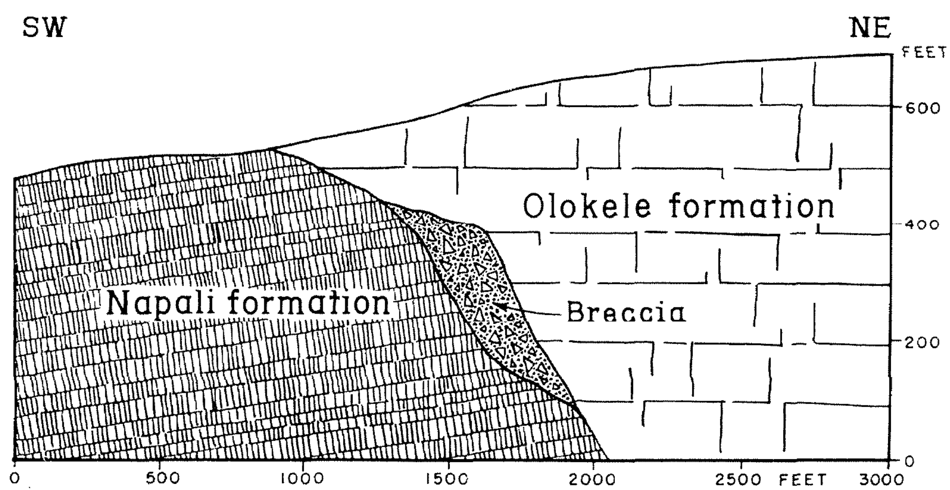

Figure 4. Diagrammatic section across the caldera boundary in the northwest wall of Mokuone Valley.

southwestward, but those of the Olokele formation are nearly horizontal. The breccia is firmly cemented unsorted talus breccia, composed of angular fragments of rocks common in the Napali formation. Downward in the cliff the breccia pinches out and the contact steepens to about 80°. Close to the contact the Olokele beds are curved slightly upward, in a manner suggesting drag along a fault. There does not, however, appear to have been any slippage along the present contact. Probably the drag resulted from a slight sinking of the caldera floor in relation to the less mobile caldera walls.

A second band of breccia is exposed in the canyon wall 1,500 feet downstream. Again the breccia is exposed in the upper part of the cliff, and pinches out downward. The block between the two breccia masses is a step-fault block on the edge of the caldera, like those on the edge of Kilauea caldera (Stearns and Macdonald, 1946, p. 29, pl. 16). The lavas in it belong principally to the Napali formation, although the uppermost beds may be part of the caldera fill.

Both breccia bands continue northwestward across the ridge into Kahana Valley, but again pinch out downward. The southwestern breccia does not reappear farther west, but the northeastern breccia again appears in the north wall of Kahana Valley and can be followed across the ridge into Mokuone Valley. There at stream level the contact is again nearly vertical, with thick beds of the Olokele formation lying directly against thinner Napali beds. An impassable waterfall 200 feet high tumbles down the disinterred edge of the massive caldera fill. In the upper part of the west wall of Mokuone Valley the dip of the contact decreases and a mass of breccia lies between the lavas of the two members. Still higher, the breccia is overlapped by lavas of the Olokele which, at the top of the ridge, lie in direct contact with those of the Napali on a surface that dips about 25° northeastward (fig. 4).

Beyond Mokuone Valley exposures are poorer and the edge of the caldera has not been traced with certainty. It appears to trend west-northwestward, disappearing beneath lavas of the Makaweli formation in the south fork of Mokihana Valley.

Southeast of Olokele Canyon also, exposures are poorer and the caldera boundary is less distinct. On the southeast wall of Olokele Canyon well-indurated breccia is poorly exposed above the old road 2,000 feet northwest of Kapuaa peak, and the lavas in Nonopahu Ridge near Kapuaa peak and farther northeast are massive horizontal beds clearly belonging to the Olokele formation.

Equally clearly, the thin-bedded lavas dipping southward along the upper reaches of Manuahi and Koula streams belong to the Napali formation. The caldera boundary must lie between the upper Hanapepe valley and Nonopahu Ridge. The area is heavily vegetated and very difficult of access, however. Partly on physiographic grounds, the caldera boundary has been mapped trending northeastward along the upper slope of the ridge between upper Hanapepe and Olokele Canyons. This line coincides in part with an otherwise unexplained lineament that is clearly visible on aerial photographs.

Masses of breccia crop out on the projected trend of the caldera boundary near Mauna Hina, in Wainiha Canyon. This breccia consists of angular and subangular fragments of rocks resembling those of the

Napali formation, is better indurated than the breccias of the Palikea formation (described on a later page), and lacks the small proportion of rounded fragments commonly present in the Palikea along Wainiha Canyon. Breccias of the Palikea formation also commonly contain fragments of lava of the Koloa, which are absent in the breccia near Mauna Hina. The latter is cut by a 3-foot dike of picrite-basalt of the oceanite type, a rock type elsewhere found only in the Waimea Canyon volcanic series. There appears little question that this is another mass of talus breccia formed along the fault scarp bounding the ancient caldera. Lavas in the upper walls of Wainiha Canyon south of Kilohana and Kamakeanu peaks are thick, massive caldera-filling flows having a northward dip of only about 2°. In contrast, flows in the ridge north of Pali Eleele are thin, and dip northward at angles as high as 13°. The caldera boundary must lie between these two areas, but it is surprisingly indistinct in the west wall of Wainiha Canyon.

Eastward from Wainiha to Hanalei valley, the general position of the caldera boundary is clear. The edge of the massive caldera fill towers above the lowland to the north, in an imposing erosional escarpment culminating in Iliahi, Mamalahoa, and Hihimanu peaks. South of this lineament the lava beds are thick and dip northward at angles of 1° to 4°. North of it the flows are thin and dip at angles of 7° to 10°. Dikes are much more abundant in the extra-caldera lavas to the north than in the caldera-filling lavas to the south. Clear as the boundary is in a general way, it is exceedingly obscure in detail. At only a single point between Wainiha and Hanalei canyons has it been possible to identify the exact position of the caldera boundary. On the ridge between Wainiha and Lumahai Canyons a small body of breccia marks the position of the caldera fault scarp. Nowhere else have we found breccia, or a clear contact between the Olokele and Napali formations. The line on plate 1 indicates only the approximate position of the contact.

Southward along the west side of Hanalei valley the exact position of the boundary is again obscure. In a small tributary gulch just west of Hihimanu peak, massive lavas of the Olokele formation rest against thinner bedded lavas that appear probably to belong to the Napali formation. A small, isolated outcrop of breccia may lie on the contact. Beyond that point the contact disappears beneath old alluvium on the floor of the valley. Along the Hanalei River and the lower part of the west wall of the valley, in the vicinity of the mouth of Kaapahu Stream, the lavas are fairly thin bedded and are cut by many dikes. Similar conditions are encountered along Kaapoko Stream and along the Hanalei River south of the mouth of Kaapoko Stream. These rocks are similar to those typical of the Napali formation, yet the rocks near the top of the ridge to the west are clearly caldera-filling lavas of the Olokele formation.

Between the Hanalei River and the top of the ridge to the west two distinct lines are visible in aerial photographs, although they are not apparent in the field. These are shown on plate 1 as the caldera boundary and a subsidiary buried fault scarp nearly parallel to it. The more westerly of the two lines passes just west of Mount Waialeale and joins the caldera boundary as mapped on the western slope of upper Hanapepe canyon. This appears to be the principal caldera-boundary fault.

The easterly line crosses just east of Mount Waialeale. In that area the lavas exposed in the headwaters of Iliiliula Stream and the North Fork of the Wailua River are thin bedded and transected by numerous thin dikes. In contrast, the flows forming the upper 500 to 1,000 feet of the escarpment between Kawaikini peak and the peak half a mile northeast of Waialeale are thick and massive. The latter unquestionably were ponded, probably against a subsidiary fault scarp diverging slightly from the main caldera boundary. In this respect they resemble the massive beds exposed in the head walls of Kalalau Valley. On plate 1 the fault is shown passing through the escarpment below Waialeale and Kawaikini and extending northward essentially parallel to the main caldera boundary into the head of Hanalei valley. The rocks between it and the caldera-boundary fault are shown as part of the Napali formation.

Lava flows.—The flows of the Olokele formation of the Waimea Canyon volcanic series include, for the most part, the same rock types as those found in the Napali formation. Olivine basalt is greatly predominant, but both olivine-poor basalt and picrite-basalt with very abundant phenocrysts of olivine are common. A single flow of basaltic andesite has been found.

The lava flows are in general much thicker and more massive than those of the Napali formation (pl. 6B). Along Waialae, Poomau, and Koaie Streams individual flows or flow units average about 30 feet in thickness. Many of them are 40 to 50 feet thick and a few are as much as 100 feet. In upper Olokele Canyon the average thickness is somewhat less, probably 20 to 25 feet, but some flows reach thicknesses as great as 75 feet. Dips are low, seldom exceeding 3°. The low dips are the result of ponding within the ancient caldera. The greater thickness of the flows results partly from impounding of the lava as pools within the caldera, and partly from the very gentle slopes over which the flows spread. Because of their greater thickness, the flows remained hot and fluid longer than those poured down the outer slopes of the shield. This in turn allowed time for more of the gas to escape from the magma before its consolidation, and brought about greater average density of the flows.

Both pahoehoe and aa flows are present. In the area near Waimea Canyon aa is more abundant than pahoehoe. In the walls of upper Olokele Canyon, however, pahoehoe is more abundant than aa. In the thick aa flows, the clinker phase constitutes a smaller portion of the whole, and the massive central phase a proportionately greater portion, than in the typically thinner aa flows of the Napali formation. In the Olokele formation clinker seldom exceeds 15 percent of the total thickness of the flow, whereas in the flows of the Napali formation it commonly exceeds 25 percent and may reach 50 or 60 percent.

Basaltic andesite comprises the surface flow along the trail across the Alakai Swamp, 1.25 to 1.55 miles S. 63° W. of Kilohana peak on the west rim of Wainiha Canyon. The flow is poorly exposed but appears to be aa, about 100 to 150 feet thick, underlain by several feet of weathered basalt. The entire section exposed in the walls of the shallow gulches is much decomposed.

Ash and soil beds.—As is usual, even in the caldera areas of basaltic shield volcanoes, ash beds are rare. A few thin layers of reddish ash are intercalated with the lavas of the Olokele formation. Most of these have been seen only from a distance on the face of steep, inaccessible cliffs. In the west bank of Kauaikinana Stream, 1.4 miles S. 80° E. of Pohakuwaawaa Peak, a 6-inch layer of red weathered vitric ash is interbedded with the lavas. In the same bank, 150 to 200 feet stratigraphically higher, two similar beds, each about a foot thick, are associated with aa clinker. These two upper beds may represent the same horizon as a 2-foot bed of red ash exposed on the trail 0.2 mile farther south.

Throughout most of the period of accumulation of the Olokele formation, volcanism was too active to permit the formation of soil within the caldera. The only soil beds found within the Olokele formation are close to the top, and probably formed at a time when volcanic activity was waning. The weathered basalt beneath the basaltic andesite in the Alakai Swamp has already been mentioned. Farther west, in an area within a mile south and southeast of Pohakuwaawaa peak, several exposures have been found in which dense nonporphyritic basalt rests on 3 inches to 3 feet of red soil. The soil may be tuffaceous, but it is too much decomposed to permit certain recognition of the ash grains. The soil and overlying basalt flow are at approximately the same stratigraphic position as the andesite and underlying soil farther east, and probably are of about the same age.

Vents.—Few vents of the Olokele formation have been recognized. Undoubtedly most of them were fissure vents, around which no large cone was built. A cinder cone is exposed in cross section high in the south wall of Olokele Canyon, half a mile N. 80° E. of Rainbow Falls (pl. 1). Blocks of well-indurated cinder, probably from that cone, are scattered along the canyon floor to the north. The cinder is moderately fine, fresh, and red to reddish brown in color. The fragments range up to about 2 inches across. The thickness of the exposed cross section of the cone is about 500 feet.

Partly decomposed olivine basalt cinders were found by H. T. Stearns on the summit of a hill 1.2 miles S. 37° E. of Pohakuwaawaa peak. The hill is almost surely a cinder cone, but exposures on its flanks are so poor that it cannot be mapped accurately.

A mile south of Kilohana, on the west rim of Wainiha Canyon, a broad cone is clearly revealed by the contours on the map and in aerial photographs. No cinder has been found on the cone, and it probably was built of lava during the late stages of caldera filling. The cone appears to have been partly buried by later flows, but re-excavated by stream erosion.

Water-bearing properties.—The great average density of the lava flows of the Olokele formation make them less permeable than the flows of the Napali formation. They would, therefore, yield less water to wells and tunnels than the lavas of the Napali formation under similar conditions of recharge and extent of the zone of saturation.

Most of the water that enters the lavas of the Olokele formation probably descends to the basal water table. A part of it is diverted by relatively impermeable beds to numerous high-level seeps and a few small springs in the walls of valleys, but the bodies of perched water are discontinuous and generally thin, and none contains large supplies of water.

Probably little water is held at high levels by the few dikes that cut the lava flows of the Olokele formation. The relatively impermeable breccia associated with the buried scarp of the caldera, by retarding the escape of water, may cause high basal-water levels in some places.

HAUPU FORMATION

Definition.—The Haupu volcanic series of former usage (Stearns, 1946) is restricted herein to the rocks occupying the small filled caldera in the Haupu ridge, on the southeastern part of the island of Kauai, and named the Haupu formation of the Waimea Canyon volcanic series. The name is taken from Haupu peak, known also as Hoary Head, the culminating peak of the ridge (pl. 7A). The type locality is the southern side of Haupu ridge between Haupu peak and a point 0.3 mile east of Kamaulele peak.

The rocks of the Haupu formation are surrounded by lavas of the Napali formation, and separated from them by the buried caldera walls. The base of the member is not exposed, and its total thickness is unknown. Its maximum exposed thickness, on the northern side of the peak, is 1,850 feet.

The formation and filling of the Haupu caldera are believed to have taken place contemporaneously with the eruption of the upper portion of the Napali formation, or the Olokele formation, of the Waimea Canyon volcanic series. The rocks are therefore probably of Pliocene age.

Distribution.—Rocks of the Haupu formation crop out along Haupu ridge for 2.6 miles westward from a point a quarter of a mile west-southwest of Hokunui peak (pl. 1). On the northern side they extend to the foot of the ridge, where they disappear beneath an apron of old alluvium. On the southern side they lie against the edges of lavas of the Napali formation. For the most part, the contact is the irregular surface of the cliff bounding the former caldera depression, but northeast of Kipu Kai a lens of breccia lies between the lavas of the two series. At its west end, the Haupu formation is bounded by a thick mass of breccia that forms prominent outcrops on the ridge.

Stearns (1946, fig. 22, p. 83) placed the eastern boundary of the Haupu caldera at the low pass just north of Kipu Kai. However, he gives no reasons for so doing, and the writers can find no evidence of the boundary in that area. Despite the steep topographic rise from the pass to Haupu peak, the caldera-filling lavas appear to extend eastward across the pass. Beds in the peak east of the pass are massive and nearly horizontal, like those in Haupu itself. These nearly horizontal attitudes extend eastward for about 0.8 mile beyond the pass. Half a mile east of the pass breccia is exposed in a gulch on the south side of the ridge. This breccia is thinner and less extensive than, but otherwise closely resembles, that at the west edge of the Haupu caldera.

The eastern boundary of the caldera is vague where it crosses the ridge, possibly because that edge of the caldera was low, like the southwestern rim of Kilauea caldera on the island of Hawaii. Flows near the eastern end of the area of nearly horizontal bedding are thinner and less massive than those in the main Haupu mass. Flows poured in that direction may not have been effectively ponded by the low caldera rim, and to some extent may have escaped from the caldera and merged with the gently dipping flank flows. The eastern boundary of the Haupu caldera has been placed 0.25 mile S. 58° W. of Hokunui peak (pl. 1) because the first definite dips of magnitudes expectable in the flank flows were found just beyond that point.

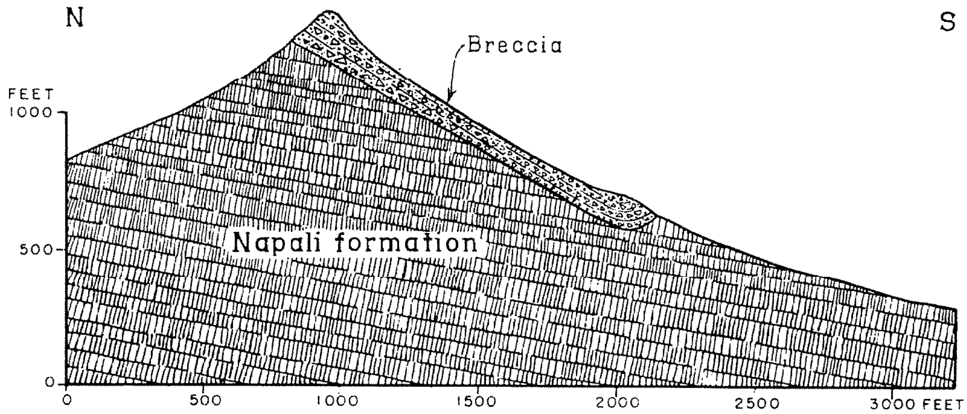

Figure 5. Diagrammatic section across the Haupu ridge 1 mile west of Haupu peak.

Character of the rocks.—The lavas of the Haupu formation closely resemble those of the Olokele formation. The beds are massive and distinctly thicker than the flank flows of the Napali formation. Attitudes in them are essentially horizontal, though locally in the easternmost part of the caldera they appear to dip 1° or 2° eastward. The lavas are predominantly olivine basalt, with a little picrite-basalt rich in olivine. Basalt poor in olivine has not been found.

The breccia exposed along the ridge a mile west of Haupu peak is well consolidated. Bedding in it ranges from very poor to moderately well defined. It is almost unsorted, grading from blocks as much as 5 feet across through intermediate sizes to the impalpable powder of the matrix. The blocks are angular to subangular and consist of vesicular lava of types resembling the adjacent lavas of the Napali. The breccia is typical of talus breccias that accumulate at the foot of lava cliffs in Hawaii. Several dikes 6 inches to 5 feet thick cut the breccia.

From the point where the breccia crosses the ridge the contact with the underlying lavas of the Napali trends eastward along the north side of the ridge for 1,000 feet. There the massive lavas of the Haupu overlap the breccia and rest directly on the thin-bedded lavas of the Napali. The breccia does not extend down the north side of the ridge as shown by Stearns (1946, fig. 22). The basal contact of the breccia dips southward at an angle of about 30°. On the south side of the ridge the contact trends southward to an altitude of about 475 feet, then turns sharply eastward (pl. 1). The bench at an altitude of 400 feet at the head of Mahaulepu Valley is cut across the breccia. Bedding in the breccia on the south side of the ridge dips approximately 20° southward, parallel to the contact. Large masses of breccia have broken loose and slid down along bedding planes toward the floor of Mahaulepu Valley. Near the southern edge of the breccia the dips appear to reverse, suggesting that the deepest portion of the pit in which the breccia accumulated lay low on the northern slope of Haupu ridge. (See fig. 5.)

Northeast of Kipu Kai a thin lens of breccia is exposed at the base of the Haupu. The stratigraphic thickness of the breccia ranges from about 5 to 30 feet. The breccia dips about 10° northward, beneath nearly horizontal lavas of the Haupu. Sorting is poor. Angular to subangular boulders in the breccia have been somewhat rounded by exfoliation in the outcrop. They range in size up to 2.5 feet and include both vesicular and dense olivine basalt. The latter resembles the dense rock common in dikes.

No ash beds, soil beds, or accumulations of cinder or spatter have been recognized in the Haupu formation.

Water-bearing properties.—Like those of the Olokele formation, the lavas of the Haupu formation are poorly permeable. The area occupied by them is too small to catch much rainfall; and slopes are steep, promoting surface runoff. Ground-water recharge probably is small. The Haupu formation is not a favorable terrane for future groundwater development.

MAKAWELI FORMATION

Definition.—The volcanic rocks that accumulated in the Makaweli depression, on the southwestern side of the major shield of the Kauai volcano, are herein named the Makaweli formation of the Waimea Canyon volcanic series. The west wall of the canyon of the Makaweli River and the east wall of Waimea Canyon between the mouth of Omao Stream and the confluence of the Waimea and Makaweli Rivers are designated as type localities.

Along Waimea Canyon the Makaweli formation is separated from the Napali formation to the west by the scarp formed by erosion of the fault scarp that bounded the graben. Lavas that poured into the graben from the northeast were successively ponded against this scarp as it was pushed slowly westward by erosion. On the northeast, the edge of the Makaweli formation is determined by the boundary fault of the graben, over which the lavas poured from vents in the caldera area farther northeast. Southeastward the boundary of the Makaweli formation becomes less definite. The height of the boundary fault appears to have decreased in that direction, and the lavas may have overflowed it and spread without marked structural break over the flank flows of the Napali formation.

The base of the Makaweli formation is not exposed except along its thin northeastern and eastern edges, and the total thickness of the formation is unknown. It is believed to rest with erosional unconformity on the Napali and Olokele formations of the Waimea Canyon volcanic series. In places it is overlain with erosional unconformity by rocks of the Koloa volcanic series. The greatest exposed thickness of the Makaweli formation is 1,500 feet, on the east side of Waimea Canyon just south of the mouth of Waialae Stream.

The Makaweli graben appears to have formed late in the period of eruption of the volcanics of the Olokele formation. Late flows of the Olokele formation spilled southwestward into the graben to constitute the Makaweli formation. Thus the Makaweli formation is coeval with the upper part of the Olokele formation, and probably of middle or late Pliocene age. Flows in the area between Nonopahu and Aaka Ridges appear to have spilled out of the caldera onto the outer slope of the volcano and then into the graben. Thus locally parts of the same flow may belong respectively to the Olokele, Napali, and Makaweli formations.

Breccia masses at the contact of the volcanics of the Makaweli formation with the older rocks, and sedimentary breccia and conglomerate beds intercalated with the lavas of the Makaweli are herein named the Mokuone member. The name is taken from the type locality in Mokuone

PLATE 5A. Erosional unconformity in lava flows of the Napali formation exposed in a road cut on the south side of Haupu ridge. Lava flows fill an ancient gully cut in earlier lavas. A baked soil marks the top of the older rock. Photo by D. A. Davis.

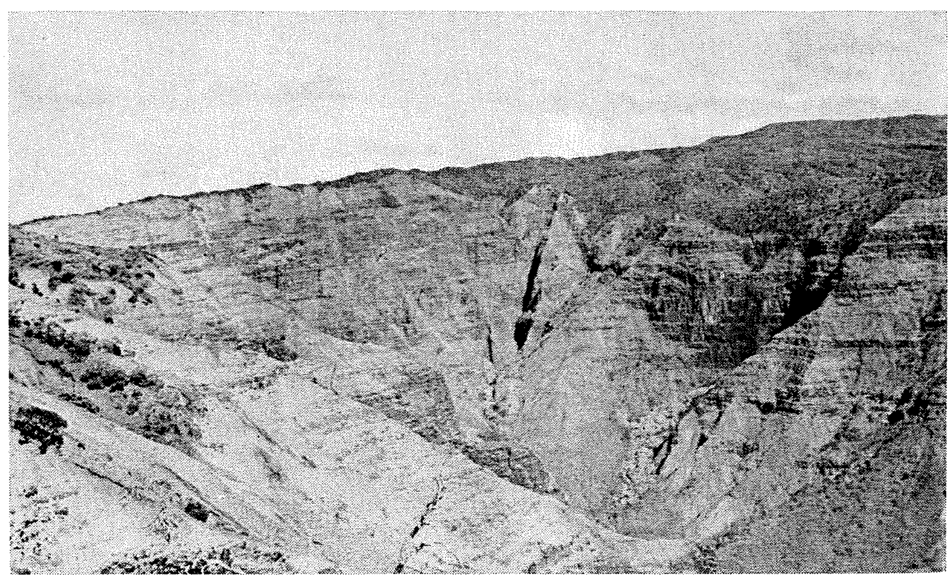

PLATE 5B. View of upper Waimea Canyon looking northward up Waiahulu Stream and showing nearly horizontal caldera-filling lava flows of the Olokele formation on the right and westward dipping extra-caldera flows of the Napali formation on the left. Photo by H. T. Stearns.

Canyon, where both the breccia and the conglomerates are well exposed. Lenses of breccia at the lower contact of the Makaweli formation along Waimea Canyon range from a few feet to several hundred feet in thickness. In the end of the spur below Puu Ka Pele the stratigraphic thickness of the breccia is about 1,000 feet. Conglomerate beds exposed along Waimea Canyon and Makaweli and Mokuone Canyons range from 1 or 2 feet to 25 feet in thickness. The age of the Mokuone member is, of course, the same as that of the lavas of the Makaweli formation with which it is associated.

Distribution and attitude.—The Makaweli formation crops out in the area between Waimea Canyon on the west and the Hanapepe River on the east, and from near the southern edge of the island to altitudes of about 2,000 feet at the northwest. It lies largely east of the Waimea River, but several residual masses have been left by erosion on the west wall of Waimea Canyon (pl. 1). A steptoe of lavas of the Napali formation projects through the Makaweli formation at Puu Ki, just east of Waimea Canyon and half a mile south of Omao Stream. Puu Ki is an erosional hill, possibly an eroded horst, projecting upward from the floor of the Makaweli graben.

Close to the buried scarp at the northeast edge of the graben the lavas of the Makaweli and associated cinders and breccias of the Mokuone member dip steeply southwestward. Locally these dips are as steep as 30°. The breccias of the Mokuone member along Waimea Canyon also dip at angles of 20° to 30° eastward, under the graben-filling lavas of the Makaweli. Throughout most of their extent, however, the lavas of the Makaweli and conglomerate of the Mokuone member dip southwestward at angles of only 3° or 4°.

The southeastern boundary of the Makaweli formation is somewhat vague. The last definite exposure of the lava-mantled cliff along the northeastern edge of the graben is in Kahana Valley, where breccia of the Mokuone is locally overlain by steeply dipping lavas. Farther southeast the contact is poorly exposed. However, a marked topographical discontinuity exists along the projected line of the graben boundary as far as Aakukui Valley. A structural discordance also is present in the headwaters of Waipau Valley, where beds near the projected graben boundary dip southwestward at angles as high as 15°, whereas those farther southwest dip 4° or less. It is unlikely that dips as high as 15° would occur anywhere except in flows mantling a steep scarp such as the graben boundary. On that basis the approximate contact is extended with fair certainty as far as Aakukui Valley, beyond which it disappears beneath a capping of lava of the Koloa volcanic series. The lower course of Kapahili Gulch lies directly in line with the projected northeastern edge of the graben northwest of Aakukui Valley, and diverges markedly from the general southwestward course of most of the adjacent streams. It may have been controlled by erosion along the graben boundary. The lavas in the ends of the spurs west of Puulani probably belong to the Makaweli formation (pl. 1).

Between Nonopahu and Aaka Ridges, lavas southwest of the graben boundary belong to the Makaweli formation. However, the same lava flows poured over the edge of the graben from the northeast, and northeast of the boundary they are part of the Napali formation. Moreover, it appears unlikely that the vents for many of these flows, if any, were situated in the narrow strip between the graben boundary and the edge of the caldera. Most or all of the flows probably spilled onto the outer slopes of the volcano from sources within the caldera, and thus in their headward portions they belong to the Olokele formation. It is obvious, therefore, that locally portions of all three major formations of the Waimea Canyon volcanic series may be correlative in time.

The graben boundary.—The surface underlying the edge of the Makaweli formation along the northeastern edge of the graben is an eroded fault scarp that slopes southwestward at angles as high as 75° but averaging about 30°. In places the lavas of the Makaweli rest directly against the edges of lavas of the Napali and Olokele formations in the scarp, but at many places they are separated from the older lavas by masses of breccia or cinder. The lavas resting directly on the scarp, or on breccia or cinder, dip southwestward at angles as high as 30° (pl. 7B), but the flows flatten to dips of 2° to 4° within a few hundred feet from the scarp. The breccia and cinder commonly are poorly bedded, but where bedding is visible the dips are southwestward at approximately 30°. These represent the slopes of equilibrium for material falling from the face of the scarp above or washed into the graben from the higher area northeast and banked against the cliff.

At its type locality, in Mokuone Valley, talus breccia of the Mokuone member of the Makaweli formation resting against the boundary scarp of the graben is interbedded with cinder and thin clinkery beds of lava that spilled over the cliff from the caldera to the northeast. The beds dip 30° southwestward. The assemblage is cut by dikes of olivine basalt and picrite-basalt. A quarter of a mile to the southeast, just south of the rim of Kahana Valley, tuff-breccia containing moderately abundant large olivine crystals rests against the scarp and dips 25° southwestward. It is overlain by clinkery aa lava dipping in a similar manner. Half a mile farther south-southwest, on the floor of Kahana Valley, poorly bedded breccia contains angular blocks of porphyritic olivine basalt and nonporphyritic basalt up to 4 feet across.

High in the wall of Poomau Canyon, half a mile west of Kahililoa peak, cinder with thin interbeds of clinkery lava rests against the scarp and dips beneath beds of lava of the Makaweli formation. No talus is associated with the cinder at that locality.

In the north wall of Waialae Canyon, 0.4 mile northeast of the junction of Waialae Stream with the Waimea River, the basal contact of the lavas of the Makaweli dips 30° southwestward. In the lower part of the wall 25 feet of talus breccia underlies the lavas, but higher in the wall the breccia lenses out and the lavas of the Makaweli rest directly against lavas of the Napali formation. The lavas of the Napali below the contact show little or no evidence that they were weathered before they were buried. The breccia is cut by a 4-foot dike of olivine basalt.

The most complex conditions along the graben boundary are exposed along the gorge of Nawaimaka Stream, a tributary of Waialae Stream. Figure 6 illustrates the apparent relationships. About 500 feet above the junction of Waialae and Nawaimaka Streams poorly bedded and unsorted breccia contains angular blocks of olivine basalt up to 3 feet across. It dips 30° southwestward and rests against a cliff of lavas of the Olokele

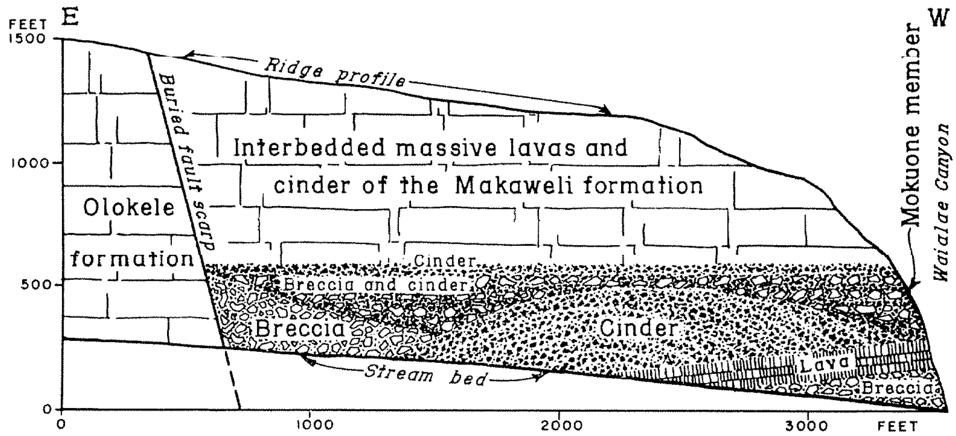

Figure 6. Diagrammatic section in the south wall of Nawaimaka Canyon, just above the junction with the Waialae Canyon.

formation that rises with a slope of 75° just northeast of the stream. The breccia is overlain 250 feet upstream by thin-bedded clinkery olivine basalt lava with about a foot of reddish lapilli tuff at the contact. This group of lava flows appears to be about 100 feet thick. Above them is a segment of cinder cone composed predominantly of well-cemented fine cinder and spatter, individual cinders ranging up to about 2 inches across and a few bombs up to a foot or more, and thin, lenticular flows probably formed on the flanks of the cone by the conflux of copious showers of fluid spatter. Some of the bombs produced well-defined sags in the underlying cinder, indicating that they were deposited from the air. Unquestionably, the cinder was not washed over the cliff but resulted from eruption in place. The rise of magma probably was guided, at least in part, by the boundary fault of the graben.

Higher up Nawaimaka Stream the cinder cone is overlain by talus breccia, dipping southwestward, and banked against the cone on one side and the cliff of lavas of the Olokele on the other. This breccia is in turn overlain by more cinder, apparently washed over the cliff from the higher area to the northeast. Overlying the upper cinder is massive lava of the Makaweli formation. The entire complex along Nawaimaka Stream is cut by dikes, most of them of olivine basalt but a few of picrite-basalt.

The breccia masses beneath the lavas of the Makaweli along the west side of Waimea Canyon appear to be entirely talus formed by debris falling from the face of the cliff above. Three-quarters of a mile east of Kukui peak well-cemented breccia dips 30° to 35° eastward and rests against the face of an unweathered cliff of the Napali. It is overlain by nearly horizontal massive beds of lava of the Makaweli that were confined in their westward spread against the talus at the foot of the ancient cliff. Southward the breccia pinches out, and 0.1 mile west of the intake of the Kekaha Ditch lava of the Makaweli rests directly against lavas of the Napali in the cliff. Dikes in the underlying lavas of the Napali do not cut the breccia or the lavas of the Makaweli. Similar relationships exist to the north as far as the mouth of Poomau Stream, and southward to the mass of breccia of the Mokuone member and lava of the Makaweli formation on the west wall of Waimea Canyon just north of the mouth of Omao Stream.

There is no evidence of renewal of movement along the graben faults after the deposition of the breccias or associated lava flows.

Lava flows.—The lavas of the Makaweli formation of the Waimea Canyon volcanic series resemble closely those of the Olokele formation. Olivine basalt predominates. Most of the flows contain phenocrysts of olivine, commonly up to 3 mm and rarely up to nearly a centimeter across. Picrite-basalt of the oceanite type, containing very abundant olivine phenocrysts, have been observed at several localities. Nonporphyritic basalts poor in olivine also are found. The latter two rock types together probably constitute less than 10 percent of the total. A single flow of andesite has been found.

The flows include both pahoehoe and aa. Aa greatly predominates over pahoehoe. Mechanical stirring is known to promote the change from pahoehoe to aa (Macdonald, 1953, p. 184, 187), and no doubt the predominance of aa over pahoehoe among the lavas of the Makaweli formation resulted partly from the violent mechanical agitation of the liquid lava as it poured over the cliff at the head of the graben.

The flows of the Makaweli formation range from a few feet to 100 feet in thickness. The steeply dipping flows close to the northeastern boundary scarp of the graben commonly are less than 10 feet thick and contain a large proportion (in some places more than 50 percent) of clinker. Southwestward the dips quickly flatten, the average thickness of the flows increases, and the proportion of clinker to massive lava decreases. Along lower Waimea Canyon and the canyon of the Makaweli River they average about 50 feet thick (pl. 8A), and clinker commonly constitutes only 10 or 15 percent, or even less, of the total thickness of the flows. The great average thickness and small proportion of clinker undoubtedly resulted from the very gentle gradients of only 3° or 4° over which the flows spread. As in the Olokele formation, the massive central portions of the thick aa flows are less vesicular than the average of flows of the Napali formation, because of the escape of a larger portion of the gas before final consolidation.

A cut on the road up Nonopahu Ridge on the south side of Olokele Canyon, 1.15 miles N. 63° E. of Camp Nine, exposes platy gray nonporphyritic basaltic andesite resting on a layer of red soil 1.5 to 2 feet thick. Beneath the soil is olivine basalt typical of the Makaweli formation. The andesite layer is approximately 100 feet thick. Under the microscope the rock closely resembles the basaltic andesite at the top of the Olokele formation. It is probable that the flow came from a vent in the caldera area, possibly close to the outcrop of basaltic andesite in the Alakai Swamp.

Pyroclastic rocks.—The cinder cone exposed in the gorge of Nawaimaka Stream, and the accumulations of cinders banked against the buried graben fault scarp, have already been mentioned. The Nawaimaka cone appears to mark an eruptive vent. The other cinders banked against the scarp appear, however, to have originated in the caldera area northeast of the scarp, and to have been washed over the cliff by running water or blown by the prevailing northeasterly wind to accumulate in the lee of the cliff. Rocks of the Makaweli formation are cut by a moderately large number of dikes, especially in the northeastern part of their area of outcrop, and it is possible that other vents existed within the graben. However, no others have been recognized.

Layers of ash are interbedded with the lavas of the Makaweli in lower Waimea Canyon. Just south of the mouth of Mokihana Stream a 3-foot bed of red ash is exposed between massive layers of lava about 100 feet above stream level. What appears to be the same bed crops out just above the Kekaha Ditch half a mile south of the mouth of Omao Stream.

On the west side of Waimea Canyon, 0.1 mile west of the intake of the Kekaha Ditch, pahoehoe lava of the Makaweli formation lies on 2 to 4 inches of baked red tuffaceous soil. Just above the soil the lava contains molds of fallen trunks or branches of trees.

Low in the east bank of Waimea Canyon midway between the mouths of Waialae and Koaie Streams a 2-foot bed of red ash contains lapilli up to 3 centimeters across. The ash rests on the clinkery top of a thick aa flow of the Makaweli formation and is overlain by another thick, massive aa flow. The lower flow is underlain by 25 feet of conglomerate of the Mokuone member. The entire assemblage is cut by a 4-foot dike of olivine basalt.

The soil beneath the flow of basaltic andesite on Nonopahu Ridge also probably was tuffaceous.

Mokuone member.—The Mokuone member includes talus breccia at the contact of the Makaweli formation with older rocks, and layers of conglomerate interbedded with the lavas of the Makaweli formation.

The breccia of the Mokuone member crops out along the eroded fault scarps that bounded the Makaweli graben on the northeast and west. The blocks in the breccia include representatives of all the rock types exposed in the scarps. Olivine basalt is most abundant, as it is also among the older lavas from which the breccia is derived. Dense nonporphyritic basalt is fairly common in the breccia derived from the lavas of the Olokele formation along the northeastern scarp.

The blocks in the breccia are mostly angular, though some are subangular. They commonly attain diameters of 2 to 4 feet, and sometimes as much as 8 feet. Bedding is moderately good to poor. Sorting generally is almost lacking. The debris ranges in size from fragments several feet across to fine dust. The fine debris is generally the product of breaking up of the accompanying larger fragments, but along the northeastern edge of the graben it is locally tuffaceous. The breccia is generally well consolidated, though somewhat less so than the breccias along the edges of the Olokele and Haupu calderas.

At the type locality of the Mokuone member, along Mokuone Valley, two layers of conglomerate are intercalated with lavas of the Makaweli formation. In the southeast wall of the valley, 1.7 miles above the junction of Mokuone and Makaweli Streams, a bed of coarse conglomerate is exposed 75 feet above stream level. The bed is approximately 25 feet thick. Another bed of conglomerate, 10 feet thick, is exposed 25 feet higher in the same wall. The conglomerate is moderately well cemented. The cobbles in the conglomerate are mostly subrounded, but some are well rounded and some are subangular. In the lower bed a few cobbles are as much as a foot in diameter, but most of them are less than 8 inches. They grade in size into a poorly sorted matrix of sand and silt. The cementing material appears to be clay. In the upper bed the largest cobbles are about 8 inches in diameter. In both beds the predominant rock type in the cobbles is porphyritic olivine basalt, but nonporphyritic basalt also is fairly common, and a few fragments of picrite-basalt were noted.

The conglomerate beds can be followed along the canyon walls in both directions. Seaward the beds become thinner and the average size of the constituent fragments decreases. Upstream the beds thicken rapidly. Half a mile to the northeast a bed of conglomerate 75 feet thick is exposed in the northwest wall of the valley, its base being 100 feet above stream level. This appears to be the same bed as the lower bed at the first-described locality.

At some places close to the edge of the Makaweli graben the cobbles in the conglomerate of the Mokuone member become more angular and the rock grades in texture toward that of breccia. On the west bank of the Waimea River, half a mile above its confluence with Waialae Stream, is exposed a small mass of well-consolidated poorly sorted conglomerate. This exposure is at the foot of the scarp bounding the Makaweli formation. Fragments in the conglomerate are mostly less than a foot in diameter. Most of them are subangular, but some are angular and some are subrounded. In the midst of this material is a big block of thin-bedded lavas of the Napali, 30 feet long, 15 feet wide, and 15 feet high. This block probably slid from the scarp above.

The rapid increase in maximum size and angularity of the cobbles in the conglomerate as the edge of the Makaweli formation is approached indicates that much of the material originated from the scarp at the edge of the graben, and was spread away from the foot of the scarp by stream action. The presence of some well-rounded cobbles in the conglomerate close to the scarp indicates, however, that even at the base of the scarp some of the debris had been transported by streams for at least a moderate distance. That material originated in the caldera area to the northeast.

In the walls of the canyon of the Makaweli River and of Waimea Canyon south of the mouth of Omao Stream, the conglomerates appear to be replaced in part by water-laid tuffs and tuffaceous sands and silts. Apparently gradients across the floor of the Makaweli graben were so gentle that only rarely could the streams transport coarse gravel to its southern edge.

Water-bearing properties.—The lavas of the Makaweli formation are intermediate in water-bearing character between those of the Napali and Olokele formations. They are less permeable than the lavas of the Napali because of the smaller proportion of clinker to massive lava in aa layers, and because of the greater massiveness of the flows in general. The massive, rather dense central portions of the flows are poor water yielders. On the other hand, less massive portions of the formation yield water readily. The Olokele shaft (shaft 7) produces from relatively thin-bedded, permeable flows of the Makaweli formation.

Breccias of the Mokuone member are poorly sorted, contain a large proportion of fine material, and hence are poorly permeable. Sedimentary breccia, conglomerate, and tuffaceous sands of the Mokuone member, and the tuff beds in the Makaweli formation, also are much less permeable than the enclosing lavas. In an area of higher rainfall they would result in many perched springs. That they do not do so results from the rather low rainfall and consequent low infiltration into the Makaweli, and the low dip of the strata. The small amount of water entering the lavas of the Makaweli above the conglomerate and ash beds is able to seep through them more rapidly than it moves laterally along them, and therefore does not emerge as perched springs on the walls of the canyons.

INTRUSIVE ROCKS

Dikes intrude all formations of the Waimea Canyon volcanic series, but they are far more numerous in the Napali formation than in any of the others. The petrographic varieties are present in approximately the same abundance as in the flows. Olivine basalt is by far the most common. Nonporphyritic basalt and picrite-basalt containing abundant large phenocrysts of olivine together constitute less than 10 percent of the whole. Dikes of basaltic andesite, or intrusive bodies of any composition larger than dikes, have not been found.

The dikes range in thickness from a few inches to 40 feet. Few exceed 10 feet, however, and the average thickness is about 2 feet. Some dikes are moderately vesicular, but most are dense. Many have glassy selvages, from a millimeter or less to a centimeter thick, caused by chilling against the colder enclosing rock. Typically, the dikes are broken by joints approximately normal to their edges, and in many the joint pattern is strongly developed and regularly columnar. Generally, however, the joints are tight and allow only moderately free passage of water.

No well-developed dike complexes similar to those on other islands (Stearns and Vaksvik, 1935, p. 77, 95; Stearns and Macdonald, 1947, p. 17-19) have been recognized, although the common northeast and west-southwest trends of dikes and the bulges of the island mass in those directions, shown by the submarine contours (fig. 2), suggest rift zones extending northeastward and west-southwestward from the volcanic center. Dikes are very abundant in the west wall of Waimea Canyon and along the Napali coast (pl. 1), but nowhere are they as closely spaced as in the dike complexes of Oahu (Wentworth and Macdonald, 1953, p. 89-91). To some extent the dikes appear to radiate from the central zone of the volcano, as they do in West Maui volcano (Stearns and Macdonald, 1942, p. 163). Along Waimea Canyon the predominant trend is west-southwestward, and along the eastern face of the principal mountain mass the predominant trend is nearly east-west. These predominant trends are clearly shown in the star diagrams in figure 7, where diagram A represents the dikes measured along the eastern edge of the central highland from Waiahi Stream to the North Fork of the Wailua River, and diagram C represents the dikes measured along the west side of Waimea Canyon. In other areas the radial arrangement is much less marked. On the Napali coast (fig. 7, diagram D) the radial trend is represented by dikes striking west-northwestward, but much stronger is a west-southwestward trend parallel to the dominant trend in Waimea Canyon. This trend is present, although less strongly developed, in the area along the east side of the main mountain mass, and also in the Kalepa and Nonou Ridges (fig. 7, diagram B). It is a general trend over the entire island.

Both along the east side of the main mountain mass and in the Kalepa-Nonou ridge another sharply defined group of dikes trends approximately

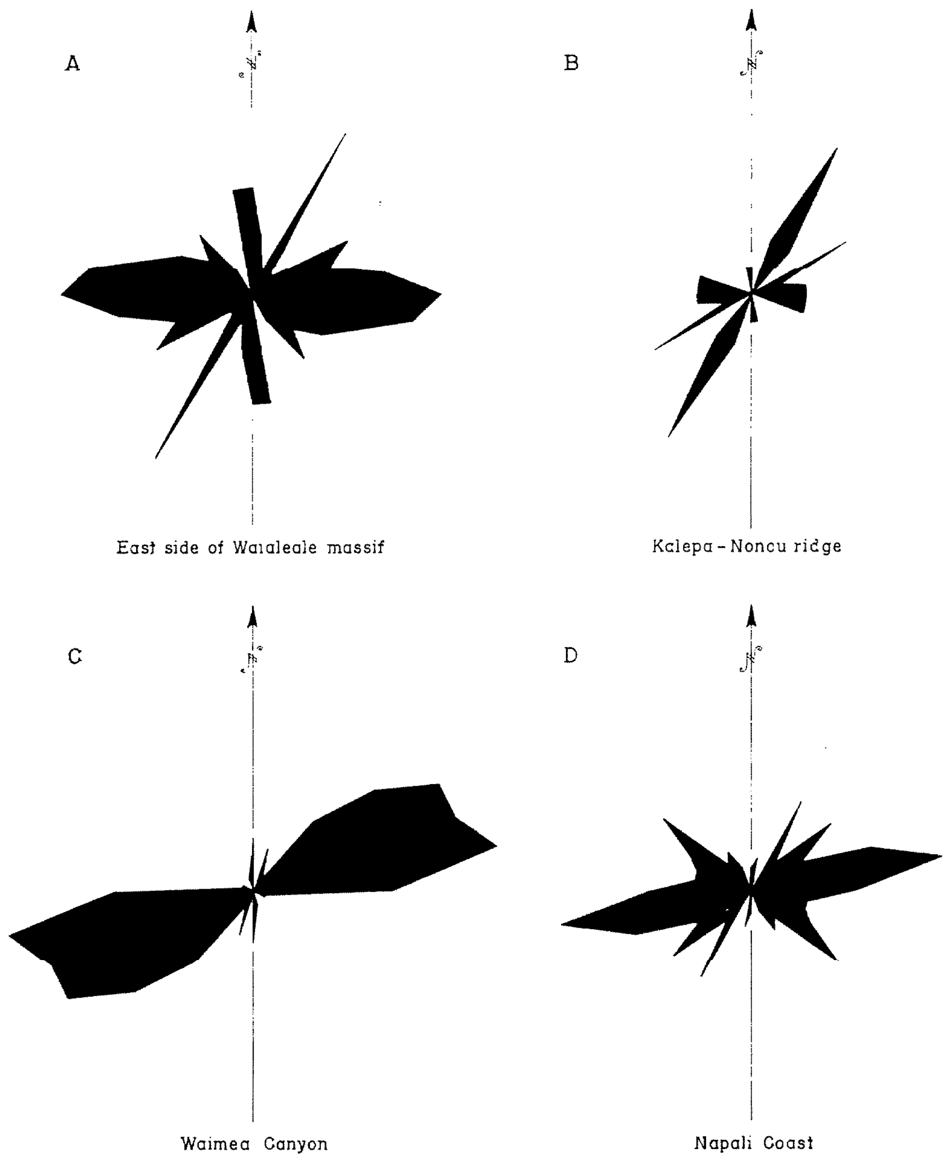

Figure 7. Diagrams showing the trends of dikes in several areas on Kauai.

N. 35° E. (fig. 7, diagrams A and B). The east-west trend prominent along the east side of the main mountain mass is present also in the Kalepa-Nonou ridge, but less strongly developed. A north-south trend that is fairly common on the east side of the main mountain mass (fig. 7, diagram A) is weakly represented in all the other areas.

The reason for the prevailing west-southwestward trend of dikes on Kauai is not clear. Approximately the same trend is represented in the dominant rift zones of Niihau, West Molokai, East Maui, Kahoolawe, Mauna Loa, and Kilauea volcanoes, on other islands of the Hawaiian chain. Unquestionably it is a trend of great structural significance. It makes an angle of approximately 50° with the general trend of the southeastern portion of the Hawaiian Archipelago, and with the trend of the principal rift zones of the Waianae, Koolau, Lanai, Kohala, and Hualalai volcanoes. Possibly this west-southwestward trend represents a series of tensional fractures pulled open in the manner of gash fractures by horizontal movement of the southwesterly block northwestward along a master transcurrent fault (similar in trend and movement to the great San Andreas fault in California) that has governed the location of the entire Hawaiian volcanic ridge. The other rift-zone trend, approximately parallel to the Hawaiian ridge, may be the result of shearing along the same master fault zone. It is represented weakly on Kauai by the northwesterly trends shown on the Napali coast and along the east side of the main mountain mass (fig. 7, diagrams A and D).

Many of the north-northeast trending dikes along the Kalepa-Nonou ridge dip west-northwestward at low angles, averaging about 45°. Such low dips are unusual in Hawaiian volcanoes, most dikes dipping more than 70°. Along the Napali coast and in Wainiha Valley some dikes dip southeastward at low angles, although most of them are nearly vertical. These dikes dipping at low angles toward the center of the volcanic mass resemble cone-sheets, except that no tendency toward arcuate form has been detected in them. Probably the fractures occupied by the dikes to some extent resulted from upward thrust in the central area of the volcano, as do the fractures occupied by cone sheets (Anderson, 1937, p. 36). Some dikes in the ridge west of Kipu Kai also dip westward at low angles. They may be related to the same set of forces that caused the low-dipping fractures in Kalepa-Nonou ridge, or they may be related to the Haupu volcanic center rather than to the main Kauai mass.

In the headwaters of Huleia Stream, south of Kahili peak, a group of dikes averaging 3 feet thick strike east-northeastward and dip southeastward at angles of 50° to 60°. These may be similar in origin to ring dikes, filling fractures related to a decrease of pressure beneath the center of the volcano.

Sills are fairly common along the Napali coast and in the Kalepa-Nonou ridge, and especially in the area along the eastern edge of the main mountain mass. They are thin, commonly ranging between 1 and 6 feet in thickness. Texturally and structurally they closely resemble the dikes with which they are associated. Some can be seen passing into dikes. It is not uncommon for a dike to cut sharply across the bedding in the enclosing lavas for many feet, then turn abruptly and become a sill concordant with the bedding for a few feet, and then resume its upward discordant course cutting sharply across the bedding (fig. 8).

In general, the dikes are less permeable than the enclosing lavas. In regions of high rainfall, recharge by surface infiltration results in water accumulating in the masses of permeable lavas between the less permeable dikes. Where dikes are sufficiently numerous, the water in the inter-dike compartments may be confined many feet above sea level. Where erosion cuts into these compartments high-level springs may result. Such springs occur along the walls of Wainiha Canyon. They are not, however, numerous on Kauai, partly because of the absence of any true dike complex like those of some of the other Hawaiian Islands. It is possible that high-level water could be developed by a tunnel cutting the interdike compartments in the area just northwest of the northwestern boundary of the

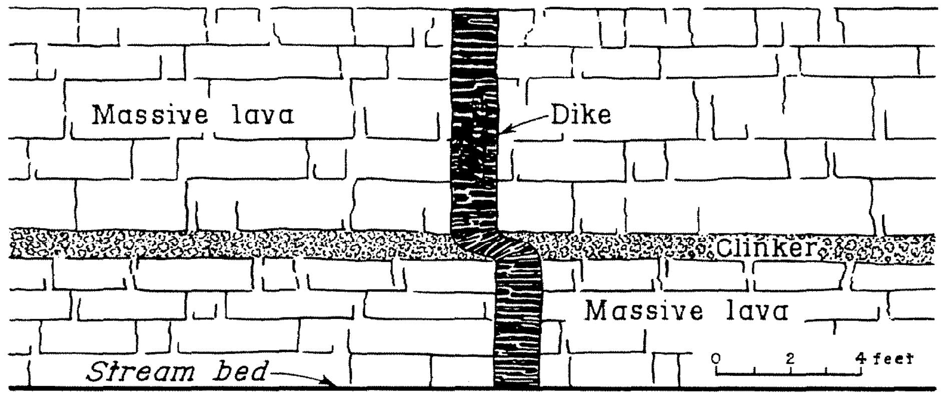

Figure 8. Sketch showing a dike in the west wall of Waimea Canyon 1.9 miles above the junction with Makaweli Canyon.

caldera. Within the caldera, the Olokele lavas are for the most part too massive and impermeable, and dikes are too few, for such a tunnel to have any high expectation of success. The area west of Waimea Canyon is not favorable for dike-tunnel development because of the low rainfall and consequent low recharge, and because the deep gorge of the Waimea River has already cut deeply into the interdike compartments, draining the adjacent portions of them to low levels. Along the eastern side of the main mountain mass the lavas are commonly altered and former spaces in them filled by deposition of secondary minerals, resulting in reduction of permeability to such a degree that prospects for development of high-level water in interdike compartments are not hopeful.

KOLOA VOLCANIC SERIES

DEFINITION

The name Koloa volcanic episode was proposed by Hinds (1930, p. 57) for the period of volcanic activity that occurred long after the volcanism that built the main mass of Kauai had ended and erosion had cut deeply into the Kauai shield. Stearns (1946, p. 87) used the name Koloa volcanic series for the rocks accumulated during that late period of volcanism, and his usage is followed in this report.

The Koloa volcanic series is herein defined as the series of volcanic rocks and closely associated sedimentary rocks laid down on the rocks of the Waimea Canyon volcanic series after a long period of erosion and, thus, separated from them by a profound erosional unconformity. The name is taken from the Koloa District, in the southeastern part of the island, where late volcanics of the series are excellently displayed.

GENERAL CHARACTER AND AGE OF THE ROCKS

The rocks of the Koloa volcanic series include lava flows of olivine basalt, nepheline basalt, melilite-nepheline basalt, and basanite, related cinder and tuff cones and ash beds, and closely associated or intercalated sedimentary breccias and conglomerates. The unconformity between them and the earlier Waimea Canyon volcanic series is an erosional surface marked by canyons several thousand feet deep.

The greatest exposed thickness of the Koloa volcanic series is approximately 2,100 feet, in the east wall of Hanalei valley near Hanalei peak. The base of the Koloa volcanic series is unexposed in the Lihue basin between the Waialeale massif and Kalepa Ridge, in the Koloa District along the southern edge of Kauai, and along the northeastern shore of the island, and the total thickness of the Koloa volcanic series in those areas is unknown. Including the portion of the series below sea level, it may exceed the exposed thickness in Hanalei valley.

Unquestionably, a large part of the Koloa volcanic series was erupted during the Pleistocene epoch. Some of the flows on the southeastern part of the island, notably that from Kaluahono crater, are little weathered and their surface features are almost unaltered. They appear quite recent. However, as indicated elsewhere in this report, ancient shorelines at approximately 5 and 25 feet above sea level and 60 feet below sea level are found on them. Those shorelines are regarded quite definitely as of late Pleistocene age (Stearns, 1947, p. 12), and therefore the lavas on which they were formed certainly are not younger than Pleistocene. Projections of the exposed walls of valleys cut in the Waimea Canyon volcanic series and later partly buried by the Koloa volcanic series indicate that these valleys probably extended several hundred feet below present sea level. They may have been graded to a minus-1,200-foot stand of the sea recognized on the island of Oahu (Stearns, 1935, p. 1930). (That extremely low stage of sea level relative to the height of the island may, however, have resulted from isostatic sinking of the island of Oahu rather than from a eustatic shift of sea level, in which case there may be no closely corresponding low level on Kauai.) The age of the minus-1,200-foot stand of the sea on Oahu is not definitely known, but it is probably either early Pleistocene or late Pliocene. Long periods of erosion, with cutting of deep canyons, occurred within the period of eruption of the Koloa volcanic series. It is possible, therefore, that the Koloa eruptions began during the Pliocene epoch.

DISTRIBUTION

The Koloa volcanic series is widely distributed in eastern Kauai. A small patch of melilite-nepheline basalt is present near the summit of the mountain 1 to 3 miles west of Waialeale. Because of heavy vegetation and swamp conditions, it has not been feasible to map its boundaries accurately, but its presence is shown by several specimens from residual cobbles collected in the swamp, and was known to Hinds (1925, p. 533). Residual masses of canyon-filling flows from other, unknown vents in the central part of the island are scattered along Olokele, Manuahi, Hanapepe, and the lower part of Waimea canyons. Other residual masses of lava of the Koloa are present along the lower courses of Lumahai and Wainiha canyons. The patch shown in the head of Lumahai canyon (pl. 1) is mapped on the basis of its similarity of appearance in aerial photographs to known rocks of the Koloa volcanic series, and of the presence of fragments of lava of the Koloa in the gravel of the Lumahai River upstream from the residual masses of Koloa lava 5 miles from the mouth of the stream.

Along the south side of the island west of the Makaweli River (pl. 1), and along the northeastern coast from Hanalei Bay to Wailua, the Koloa volcanic series forms a broad apron extending outward from the eroded slopes of the Waimea Canyon shield volcano. A broad tongue of lavas of the Koloa occupies the former valley of the Hanalei River between Namolokama Mountain and the Makaleha Mountains. The entire Lihue basin between the foot of the Waialeale massif on the west and the Kalepa-Nonou ridge on the east, the Makaleha Mountains on the north, and the Haupu ridge on the south, is floored with volcanic rocks of the Koloa except for two small steptoes of lavas of the Waimea Canyon series at Aahoaka and Puu Pilo. Bands of lava of the Koloa separate Haupu and Puu Ehu ridges from the main mass of the Waimea Canyon volcano.

No rocks of the Koloa have been recognized in the sector west of Waimea and lower Wainiha Canyons, although some well-cemented breccia along the Napali Coast probably was formed at the same time as the Palikea formation of the Koloa volcanic series.

In the steep-walled canyons, and at other places where rocks of the Koloa rest against steep slopes of the Waimea Canyon volcanic series, the rocks beneath the unconformity are generally fresh. This is to be expected, because weathered materials cannot accumulate in any significant amount on such steep slopes as those displayed by the walls of the lava-buried canyons. Most of the present-day walls of Olokele Canyon, if buried by lavas, would appear fresh beneath the unconformity like those beneath the canyon-filling lavas of the Koloa.

At places where the pre-Koloa slopes were gentler, lavas of the Waimea Canyon volcanic series beneath the unconformity are weathered to depths of a few feet or a few tens of feet, and commonly are covered with several feet of soil. Thus, in the area between Makaweli and Hanapepe Valleys, where lavas of the Koloa rest on a surface of older rocks that slopes southwestward at an average angle of about 5°, the underlying lavas of the Waimea Canyon volcanic series are partly decomposed to a depth of 25 to 50 feet and capped by 2 to 6 feet of brownish-red soil.

At some localities lavas of the Koloa rest directly on the surface of the underlying Waimea Canyon volcanic series, but elsewhere they are separated from them by a few inches or feet of ash or cinder. At an altitude of 900 feet in the north fork of Moalepe Stream, 0.7 mile northwest of Kapukaiki, 40 feet of poorly bedded tuff and tuff-breccia rests on moderately weathered lavas of the Waimea Canyon volcanic series. The tuff-breccia contains fragments of rocks of the Koloa volcanic series, some cinder and some dense material, up to 10 inches across but mostly less than 1.5 inches. A few of the fragments resemble lavas of the Waimea Canyon series, and may have been derived from the basement underlying the erupting vent. In places a thin bed, up to 4 feet in thickness, of conglomerate of the Palikea formation lies at the base of the tuff. The tuff is overlain by lavas of the Koloa.

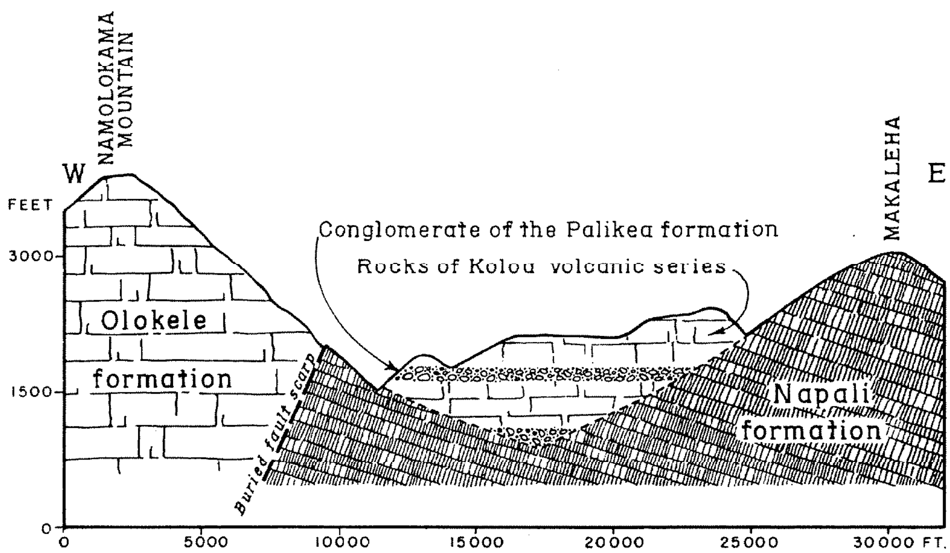

Figure 9. Generalized section across upper Hanalei valley.

RELATION TO OLDER ROCKS

The rocks of the Koloa volcanic series rest on a deeply eroded and weathered surface of the Waimea Canyon volcanic series. The larger canyons cut into the slopes of the Waimea Canyon shield volcano before the eruption of the Koloa volcanic series ranged from 1,000 to more than 3,000 feet in depth. The base of the Koloa exposed in Hanalei valley just south of the mouth of Kaapahu Stream is 3,800 feet below the top of the lavas of the Waimea Canyon series in nearby Namolokama Mountain, just west of Hanalei valley, and the lowest part of the valley-filling mass of the Koloa may be appreciably deeper (fig. 9). Throughout much of their lengths, the Olokele, Koula (Hanapepe), and lower Waimea Canyons were cut nearly to their present depths at the time they were filled with rocks of the Koloa volcanic series. The floor of the lava-filled ancient Olokele Canyon is 1,700 feet below the adjacent ridge half a mile northeast of Kaukelei peak; and the base of the lava-filled ancient Koula Valley near Hanapepe Falls is 2,600 feet below the lavas of the Waimea Canyon in Kapalaoa peak, less than 2 miles to the east-northeast. The bottom of the exposed portion of the small isolated mass of lava of the Koloa in Waimea Canyon, 2.1 miles above the mouth of the Makaweli River, is 1,150 feet below the adjacent western rim of the canyon, and its actual base, hidden by aluvium, is somewhat deeper. However, it is only about 500 feet below the top of the lavas filling the Makaweli graben to the east.

On the south side of Olokele Canyon, 0.4 mile southeast of Kaukelei peak, lava of the Koloa rests on 4 to 6 feet of cinder. This cinder undoubtedly came from the Koloa vent 0.3 mile to the west-southwest.

At many places the rocks of the Koloa volcanic series are separated from the rocks of the Waimea Canyon volcanic series by breccia or conglomerate of the Palikea formation. The Palikea rocks are described at length on a later page, and only brief mention of their relationships to the Koloa and Waimea Canyon volcanic series is made here. At many localities breccia of the Palikea formation appears to be simply the debris shed from steep adjacent slopes of Waimea Canyon rocks. Thus on the southeast wall of Olokele Canyon, half a mile southwest of Rainbow Falls, lava of the Koloa rests on 0 to 5 feet of hill-wash that fills a small lateral gulch on the side of the pre-Koloa valley. Much of the breccia of the Palikea formation along the eastern side of the Waialeale massif was formed by mudflows rushing down the steep slopes of the massif. These breccias grade seaward into conglomerates, partly at the base of the Koloa volcanic series and partly interfingered with them.

Wave erosion also made great inroads on the Kauai shield before it was interrupted by Koloa volcanism. Along the northeastern side of the Puu Ehu ridge a high sea cliff was cut. A drill hole (test hole 15), started at the base of that ridge only 200 feet from the outcrop of the lavas of the Waimea Canyon volcanic series, at a depth of 510 feet penetrated talus breccia formed at the foot of the ancient sea cliff. A similar cliff appears to be present along the southern side of the island in the vicinity of Lawai, where test hole 23 was still in lava of the Koloa volcanic series at a depth of 750 feet, although it is only 750 feet south of lavas of the Waimea Canyon volcanic series at the surface. Extending seaward from the base of these cliffs there probably is a broad wave-cut bench, now deeply buried by lavas of the Koloa. This bench has not yet been demonstrated by drilling, but fragments of calcareous reef rock in the tuff of Kilauea cone (p. 71) indicate the presence along the northeastern side of the island of ancient reefs in that area. The reefs probably grew on a platform cut by wave erosion.

UNCONFORMITIES WITHIN THE KOLOA VOLCANIC SERIES

The accumulation of the rocks of the Koloa volcanic series locally was interrupted by long periods of weathering and erosion. This does not necessarily indicate that volcanism was inactive everywhere on the island, but only that for long periods certain areas were not invaded by new lavas. Considering the island as a whole, periodic eruptions may have continued essentially uninterrupted throughout Koloa time.

Although, for the most part, erosion between successive flows of the Koloa produced only shallow dissection of the pre-existing surface and cut gulches only a few tens of feet deep, in a few areas canyons several hundred feet deep were incised before cutting was halted by a new invasion of lava. In the head of Hanalei canyon a mass of lava of the Koloa occupies a valley cut far below the base of the earlier Koloa valley fill. The early lavas of the Koloa volcanic series filled the ancient Hanalei valley to the level of the divide that separated it from the Wailua drainage basin to the southeast, and some flows appear to have spilled over the divide into the headwaters of Keahua and Uhau Iole Streams. The early fill in Hanalei valley forms a moderately dissected surface that slopes gently downward from the divide to the north shore of the island. The base of the fill lies at an altitude of 1,750 feet on the east side of the present valley, 0.4 mile west of Maheo peak, and is marked by a band of breccia and conglomerate. Later, stream erosion excavated a new canyon slightly west of the earlier one, apparently along the contact between the early valley fill and the rocks of the Waimea Canyon volcanic series. The new canyon was in turn partly filled with lavas of the Koloa, erupted from an unknown vent in the central part of the island. The second canyon-filling mass also rests on conglomerates, but at a level approximately 750 feet below the base of the earlier valley fill.

In Hanapepe-Koula Valley also, a flow of the Koloa volcanic series occupies a valley cut well below the level of the base of nearby earlier lavas of the Koloa. The base of the lava-filled valley along the present Koula Valley near Hanapepe Falls lies 200 feet below the base of the earlier lavas of the Koloa at the falls, and 350 feet below the base of those on the ridge between Koula and Manuahi Valleys.

Many lesser interruptions in volcanic activity are found within the Koloa volcanic series. They are particularly well shown on the southern side of the island but have been recognized on the eastern and northern sides also. Some are marked only by a layer of soil between the flows; others are indicated by erosional unconformities with or without soil. Thin residual soils are found at some localities, but the thicker buried soils are tuffaceous. Layers of vitric ash weather quickly in the wet, warm climate of the lowlands of Kauai, and the formation of a few feet of soil and subsoil may require only a very few hundreds of years. Thus the intercalated layers of tuffaceous soil may represent geologically only a very short interval of time between successive flows.

On the east side of Kalihiwai valley, at the base of the second small waterfall inland from the highway, lava of the Koloa rests on 8 feet of tuffaceous soil. The base of the soil is not exposed. The lower 2 feet of the lava flow is conspicuously columnar, and passes upward into a layer 10 feet thick containing poorly developed pillow structure. The lava probably flowed over wet, swampy ground. A mile farther north-northwest, in a road cut at the coast near the western edge of Kalihiwai Bay, lava that may be the same flow rests on the gullied surface of a deposit of deeply weathered gravel, 20 to 30 feet thick, that in turn rests on an older flow of the Koloa volcanic series.

In cuts where the highway crosses Hanamaulu gulch, a mile north of Lihue, the upper 25 feet of lava rests on 6 feet of red soil, which in turn grades downward into much decomposed lava. The thickness of the zone of decomposition below the soil is somewhat indefinite but exceeds 30 feet.

In road cuts at the head of Nawiliwili Bay, 0.4 mile north of the mouth of Huleia Stream, columnar lava of the Koloa fills a gully cut in older lava of the same volcanic series. In places the later flow rests directly on the earlier one, but elsewhere a thin layer of gravel intervenes.

Unconformable relationships within the Koloa volcanic series are most easily seen in cuts along the highway on the south side of the island. On the ridge 0.3 mile west of the Lawai Stream the cut at the north side of the highway exposes 35 feet of poorly bedded and very poorly sorted conglomerate, resembling hill-wash, banked against a cliff that truncates lavas of the Koloa. Both the lava and the conglomerate are beveled by an erosional surface marked by 6 inches to 2 feet of red soil.. The soil is overlain by a later flow of lava (fig. 10). About 0.1

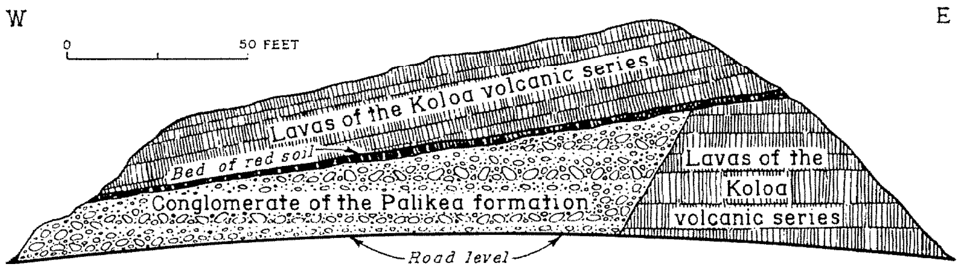

Figure 10. Sketch showing relationships in highway cut 0.3 mile west of Lawai Stream. Vertical scale is the same as horizontal.

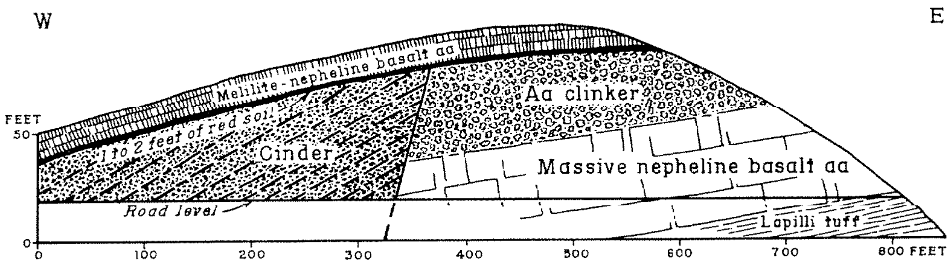

Figure 11. Section along the highway at the ridge 0.2 mile west of Lawai Stream.

mile closer to Lawai Stream similar relationships are displayed, except that, in place of the hill-wash, partly decomposed red cinder is banked against the buried cliff. In the cut at the south side of the road the older lava of the Koloa is underlain by red partly decomposed lapilli tuff (fig. 11).

In cuts along the highway where it ascends the east wall of Hanapepe valley is exposed an unconformable contact that strikes approxi-

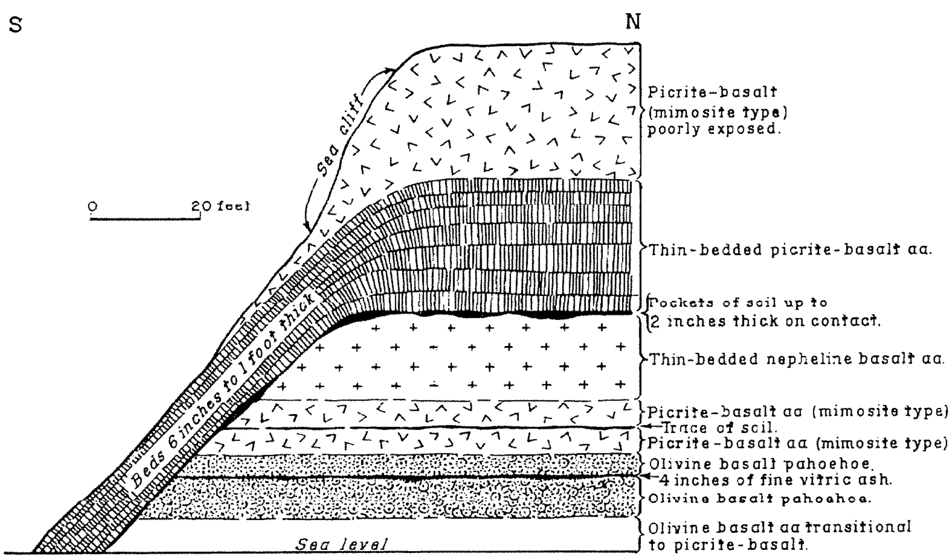

Figure 12. Section at the lava-mantled sea cliff 0.25 mile east of Koheo Point. (Modified after Stearns, unpublished notes.)

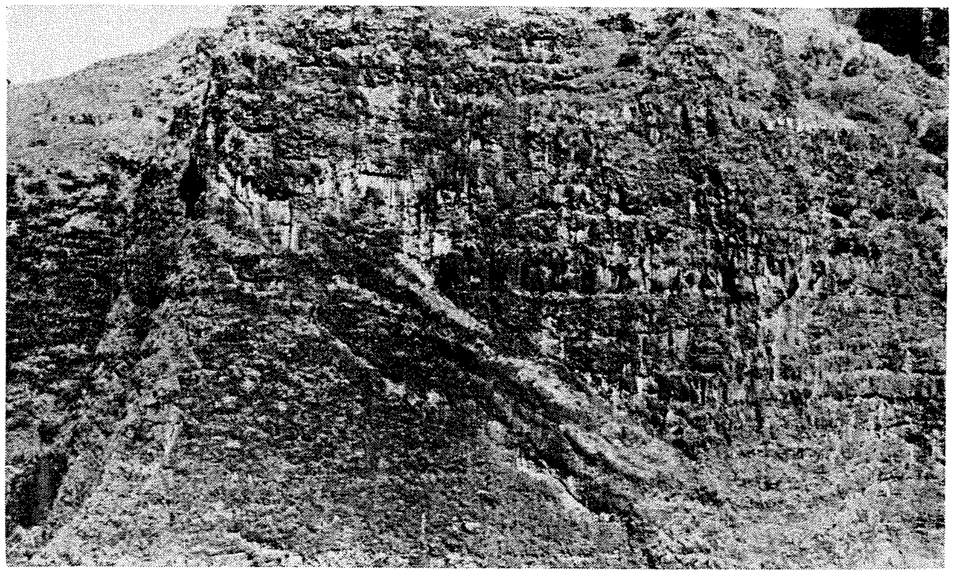

PLATE 6A. Trace of caldera boundary in the north wall of Olokele Canyon. A breccia streak marking the boundary dips to the right. Thick-bedded horizontal lavas of the caldera-filling Olokele formation are on the right of the breccia and thinner bedded lavas of the Napali formation are on the left. Photo by G. A. Macdonald.

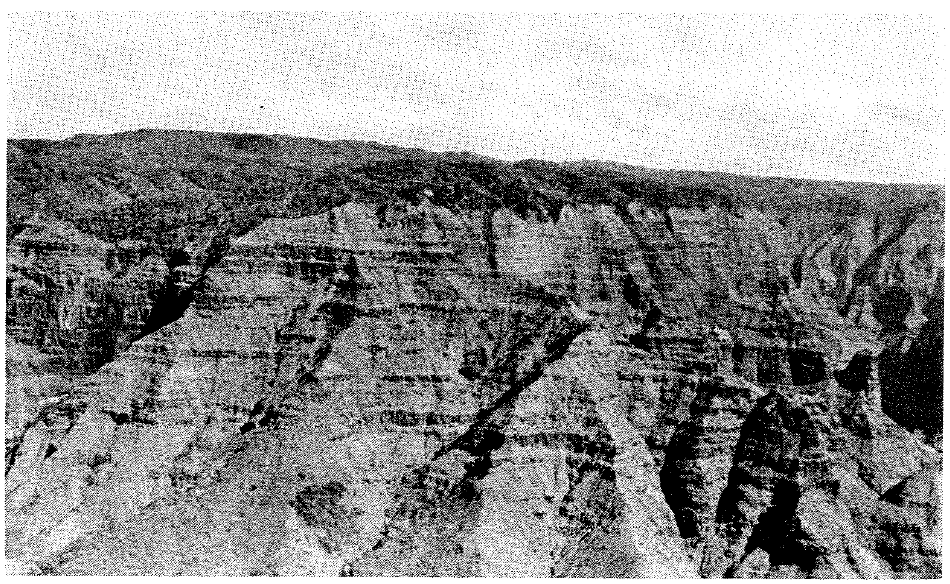

PLATE 6B. Thick-bedded lava flows of the Olokele formation in the east wall of upper Waimea Canyon. The Alakai Swamp occupies the relatively undissected surface beyond the canyon wall. Photo by H. T. Stearns.

mately N. 70° E., and dips 20° to 30° northward. It appears to be the southeast wall of an ancestral Hanapepe valley, later filled with lavas. The rocks on both sides of the unconformity belong to the Koloa volcanic series.

A quarter of a mile east of the Makaweli post office a highway cut exposes another unconformity within the Koloa volcanic series. A valley cut into thin-bedded moderately to highly vesicular pahoehoe is filled with denser, more massive pahoehoe and aa. The contact is marked by a foot of red soil. At the west end of the cut water-laid lapilli tuff just below the contact grades into poorly sorted conglomerate.

Not all the unconformities within the Koloa volcanic series are the result of stream erosion. At the south coast, 0.3 mile east of Koheo Point, an ancient sea cliff cut in Koloa lavas is mantled by newer lavas of the same series (fig. 12). Isolated pockets of soil, up to 3 or 4 inches thick, occur along the unconformity. The beds mantling the face of the cliff are thin, as is usual in this situation. They disappear beneath sea level.

These are only some of the better exposed and accessible examples of erosional unconformities within the Koloa volcanic series. Others are known, but there is no reason to describe more. In addition, there are many localities where, although clear-cut erosional unconformities are absent, a time hiatus is indicated by soil beds between the lava flows. At some places several soil beds are present in a single exposed section. Thus on the eastern edge of Lawai Bay a flow of picrite-basalt exposed at water level is overlain by 0 to 6 inches of red soil. This is overlain by a flow of olivine basalt containing molds of logs at its base. This in turn is overlain by a foot of baked red soil and a flow of nepheline basalt. Similarly, at 575 feet altitude in Wahiawa valley, 3 feet above the level of the ditch, a layer of red tuffaceous soil 1 to 1.5 feet thick is underlain by olivine basalt and overlain by 6 to 8 inches of relatively fresh yellow and gray sandy tuff, which in turn is overlain by massive olivine basalt.

VOLCANIC ROCKS

Lava flows.—The lavas of the Koloa volcanic series include olivine basalt, nepheline basalt, melilite-nepheline basalt, picrite-basalt of the mimosite type, and analcime basanite. Their mineralogical and chemical composition is described in more detail in the section on Petrography (p. 103).

The lavas of the Koloa generally are dark gray to black when they are fresh, changing to paler gray, buff, brown, or reddish brown with increasing weathering. Most are dense to moderately dense. Most contain phenocrysts of olivine, but the phenocrysts are small, sparse, and commonly very dark colored as compared to those in the lavas of the Waimea Canyon volcanic series. Some of the olivine basalts contain green or brownish-green olivine phenocrysts, but in nearly all the nepheline-bearing lavas and many of the olivine basalts the olivine phenocrysts are nearly black. They are always small, in no instance exceeding 5 mm across and in few instances exceeding 2 mm. No phenocrysts other than olivine have been observed. In addition to being commonly very dense, the nepheline-bearing lavas in hand specimen typically exhibit a fracture that is more smoothly conchoidal than the hackly fracture typical of most of the feldspathic rocks, combined with a peculiar pitchlike luster on the freshly fractured surfaces. The combination of conchoidal fracture, pitchlike luster, and dark small phenocrysts of olivine gives the nephelinic rocks a characteristic appearance. After a little field experience with them, they commonly can be recognized with a high degree of accuracy in hand specimen, without the use of even a hand magnifier.

Inclusions of dunite are very common in lavas of the Koloa volcanic series. They are composed almost entirely of grains of bright-green to brownish-green olivine, with a few tiny black grains of magnetite, forming a medium-grained, sugary textured rock. The inclusions commonly are angular, less commonly subangular or subrounded. They range in size from less than half an inch to 8 inches across. Dunite inclusions are well shown in the lava in the Grove Farm quarry, near Halfway Bridge, 5 miles west-southwest of Lihue.

The lavas of the Koloa volcanic series include flows of both pahoehoe and aa types, but aa is the more abundant. Thin flow units of pahoehoe, averaging only 1 to 2 feet thick, occur in the immediate vicinity of some vents. At greater distances from the vents the pahoehoe flow units increase in thickness to an average of several feet, and the proportion of aa increases. Aa flow units average about 25 feet but vary greatly in thickness because of varying degrees of ponding. The average and maximum thicknesses are distinctly greater than in the Napali formation of the Waimea Canyon volcanic series, and are more like those in the Olokele and Makaweli formations. As in the earlier volcanic rocks, the greater thicknesses are largely the result of ponding or confinement of the flows, not in a caldera as were the flows of the Olokele formation, or in a graben like those of the Makaweli formation, but in erosional valleys. Some flows reach thicknesses of 500 feet, or even more, where they have been confined in narrow canyons. Thus the residual mass of the latest flow to descend Hanapepe valley is 600 feet thick on the shoulder just south of the mouth of Manuahi Stream, and the Olokele Canyon flow filling is approximately 1,000 feet thick just north of Kapuaa peak. Very thick flows generally consist of several flow units, but others, such as the late flow in Hanapepe valley, locally consist of a single strikingly massive flow unit.

Clinker layers form the top, and commonly also the base, of aa flow units. In the thinner units clinker commonly composes 25 to 50 percent of the whole. In thicker units the proportion of clinker generally is smaller. Its proportion in the very thick canyon-filling flows of Olokele and Hanapepe canyons is unknown, because the original tops of the flows have been removed by erosion. Probably, however, it was less than 10 percent.

Lava flows of the Koloa volcanic series tend to be notably less vesicular than those of the Waimea Canyon volcanic series. The thin pahoehoe flows near vents generally are moderately, or even highly, vesicular. However, at distances of a mile or two from the vents even pahoehoe flows commonly are only sparingly vesicular, and the centers of aa flows generally are dense. The centers of very thick flows are generally very dense. This denseness, together with fine, uniform grain and sparsity of phenocrysts, resulted in the common use of this rock for the manufacture of stone adzes and axes by the ancient Hawaiians.

Locally, the porosity of the lavas is still further reduced by filling of the vesicles and some other spaces with secondary minerals. Along Hanalei valley, particularly between Pekoa and Kaapahu Streams, some of the lavas are amygdaloidal. The most easily accessible locality at which amygdaloidal lavas can be found is along the road 1.9 miles N. 13° W. of Koloa. The amygdules commonly consist of zeolite minerals, and in some instances also of calcite.

The general character of the lavas of the Koloa volcanic series is illustrated in the following stratigraphic section, along a plantation road up the west side of Lawai gulch half a mile from the ocean.

Stratigraphic section of the Koloa volcanic series along the road up the western side of the Lawai gulch

	Thickness (feet)
TOP	
Mafic olivine basalt aa, with moderately abundant phenocrysts of olivine less than 1 mm across. Alternate beds of dense lava and beds and pockets of clinker. Upper 15 feet weathered to soil and subsoil. This aa fills a valley cut into the underlying lavas	0–55
Gravel, with cobbles up to 10 inches across, subangular to subrounded, in matrix of sand and silt; sorting very poor. The gravel layer parallels the side slope of the buried valley	0–1
EROSIONAL UNCONFORMITY	
Aa clinker	0–2
Mafic olivine basalt aa, much weathered	0–10
Mafic olivine basalt pahoehoe, with moderately abundant dark olivine phenocrysts less than 1 mm across; thin bedded, with individual beds ranging from 2 to 5 feet thick	40–45
Aa clinker	0–3
Olivine basalt aa, with moderately abundant dark phenocrysts of olivine up to 1 mm across; grades into pahoehoe	10
Aa clinker	0–2
Olivine basalt pahoehoe, with moderately abundant olivine phenocrysts up to 1 mm across; lenses out in road cut	0–5
Aa clinker	1–4
Nepheline basalt aa, with moderately abundant olivine phenocrysts less than 1 mm across. Rests directly on underlying ash with no intervening clinker	6–8
Reddish-brown lapilli ash, composed largely of lapilli from 1 to 8 mm across but with some finer ash matrix. The lapilli are glassy essential lava-fountain ejecta	1–3
Aa clinker	8
Nepheline basalt aa, with moderately abundant olivine phenocrysts up to 1.5 mm across, and abundant dunite inclusions up to 3 inches across. The inclusions are regular to subrounded	11
Aa clinker	1–2
Nepheline basalt aa, with moderately abundant phenocrysts of olivine less than 1 mm across, and many inclusions of dunite up to 8 inches across. The inclusions are largely subrounded. Lenticular beds of clinker 0-3 feet thick occur within the massive lava	21
Aa clinker	1–4
Melilite-nepheline basalt aa, with abundant olivine phenocrysts less than 1 mm across, and scattered small inclusions of dunite. Pinches out in the roadcut, allowing the next higher aa to rest directly on the underlying pahoehoe	0–6
Melilite-nepheline basalt pahoehoe, with a few small olivine phenocrysts, and moderately abundant inclusions of dunite	4

	Thickness (feet)
Tuffaceous soil, grading from lapilli ash with lapilli up to 0.25 inch in diameter at the bottom to fine-grained silty ash at the top	0.25
Basaltic gravel, weathered, with cobbles up to 8 inches in diameter in a fine earthy matrix	1
Picrite-basalt aa (mimosite type), with moderately abundant small olivine phenocrysts, and a few small dunite inclusions. Poorly exposed. Top 10 feet weathered to red soil and subsoil. Base not exposed	30
STREAM LEVEL	
Total	155

Many of the valley-filling flows show strongly developed columnar jointing. Columns range from about 4 inches to 18 inches, and rarely 24 inches, in diameter. They tend to be hexagonal in cross section, but many irregularities are present. Near the lower edge of the flow the columns are approximately normal to the contact with the underlying rock, but in the center of the flow they are nearly vertical. Thus, in a cross section of a small valley fill there is a downward-divergent fan-like arrangement of the columns. Close to the contact the large columns of the interior of the flow commonly give place to a much larger number of smaller and less regular columns. Some flows are strongly jointed in their basal portions, the columns passing upward within 3 to 6 feet into massive poorly jointed lava. Thus, in the flow forming the upper portion of the falls on the west side of Kalihiwai valley, a mile above the mouth of Kalihiwai River, the lower 4 feet is highly columnar, but the upper 26 feet is massive and poorly jointed.

Columnar flows are well exposed along Waimea, Olokele, and Hanapepe canyons on the south side of the island; the Wailua valley on the east side; and the Wainiha, Lumahai, and Hanalei valleys on the north. A conspicuous flow of columnar lava is exposed at the head of Nawiliwili Bay just north of Puali Stream. Exceptionally well-developed columnar jointing is shown at the ditch intake on Waikoko Stream. Other examples are widespread, and too numerous to mention individually.

Some of the flows on the southern side of the island are still so fresh that surface features are preserved. The freshest is that from Kaluahono crater, which reaches the sea at Koloa Landing and near Kapunakea Pond (Clark, 1935). The flow is largely pahoehoe, and displays both larger features typical of pahoehoe, such as tumuli and pressure ridges, and locally also smaller surface details such as ropy structure and traces of filamented surface (Wentworth and Macdonald, 1953, p. 35).

Pillow lavas have been found in flows of the Koloa volcanic series at several localities. The best-known and most easily accessible is that at Kamenehune Ditch (pl. 8B), on the west side of the Waimea River 1.3 miles above its mouth (Stearns, 1938). Lava "pillows" are ball-like or spheroidal masses formed where pahoehoe lava flows into water or over very wet, swampy ground. Because of the restricted environment in which they can form, they are useful as indicators of the geographical conditions at the time they developed. In cross-section they are ellipsoidal, and may superficially resemble cross-sections of pahoehoe toes, which have no such environmental significance. However, careful examination generally serves to distinguish the two without question (Macdonald, 1953, p. 173-174).

At the Waimea Canyon locality the base of the pillow lavas is not exposed. The visible section is approximately 50 feet thick. The lava is olivine basalt. The pillows are nearly spherical and range from less than a foot to about 10 feet in diameter. Some are well formed, but others are poorly formed and merge somewhat with adjacent pillows. The small pillows are better formed and more discrete than the large ones. Most of them have a rim of black glass, 1 to 6 mm thick. Each shows weakly to moderately well-developed radial jointing (pl. 8B). The vesicles locally show some radial elongation, or a tendency to radial alignment, but in most of the pillows they are evenly distributed without radial arrangement. Many of the interstices between the pillows are filled with white or pale-gray marl. The pillow-lava flow is overlain by 1 to 10 inches of vitric ash, largely altered to palagonite. The ash appears to have been less scoriaceous than that typical of primary vent explosions, and probably was formed by littoral explosions where either the pillow flow or the overlying flow entered water (Macdonald, 1949b, p. 72). Similar pyroclastic debris resulting from explosions accompanying the entry of lava into water has been described by Fuller (1931, p. 281-284), in the lavas of the Columbia River Plateau. The flow above the ash contains poorly formed pillows near its base, passing upward into massive columnar jointed lava.

An equally good display of pillow lava is found at the base of Wailua Falls (pl. 1). The flow of olivine basalt occupies a former small valley cut into mudflow deposits of the Palikea formation, which in turn rest on lava of the Koloa series that was somewhat spheroidally weathered before burial. Stream gravel in the bottom of the ancient valley is overlain by a few inches of mudstone and peaty material, then 2 inches of sandy ash overlain by a layer of thinly laminated fine water-laid ash from 1 to 4 feet thick. This in turn is overlain by pillow basalt containing individual pillows as much as 15 feet in diameter. The pillows are moderately vesicular to dense, many of them with a shell of glass 1 to 10 mm thick. Roughly columnar joints radiate from the center of each pillow. The surfaces of some pillows show an irregular checking resembling the cracking of old leather. At many places the underlying muddy ash has been squeezed up between the pillows. The zone of pillows is 10 to 25 feet thick, and passes upward into dense blocky lava without pillows. This in turn is overlain by a flow of aa, platy at the top, and by old alluvium. The relationships are shown in figure 13.

Farther downstream the walls of the Wailua gorge expose several flows with moderately well to poorly developed pillows in their basal portions. The same is true of flows exposed in Kalihiwai, Iliiliula, and Olokele valleys. This upward gradation of pillow basalt into massive, sometimes columnar jointed lava is common also among lavas of the Columbia Plateau (Fuller, 1931, p. 287-292).

As pointed out by Stearns (1953), the formation of pillow lavas only where pahoehoe flows enter water or very wet ground is now well established. For the most part, it appears unlikely that the pillow lavas of the Koloa volcanic series were formed by entrance of the flows into

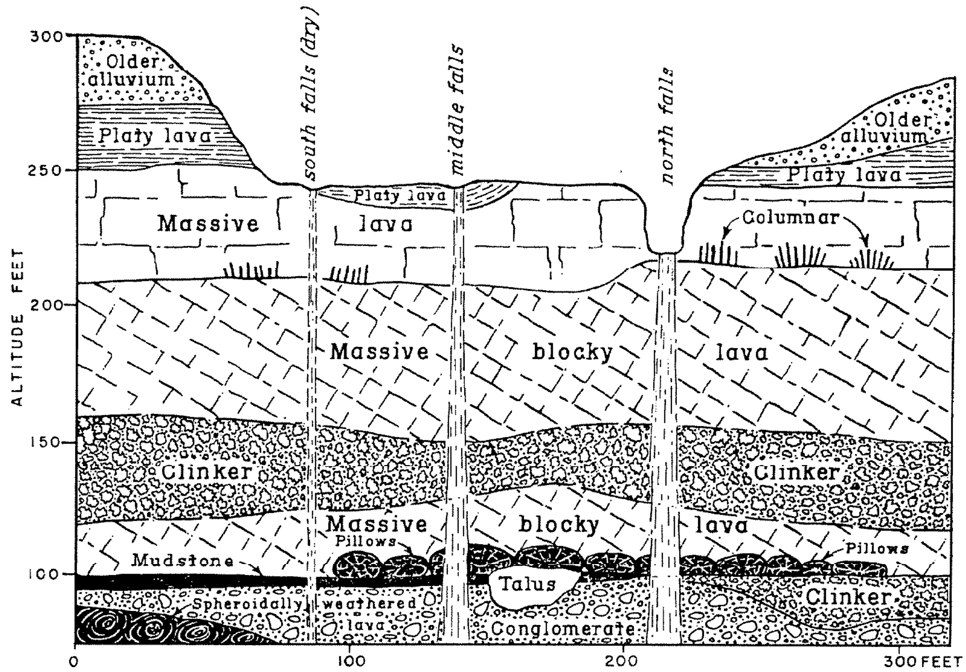

Figure 13. Sketch showing geological relationships at Wailua Falls.

the open ocean or bays. Such may have occurred, but if so the pillow lavas formed at those localities were trimmed away by wave erosion, buried by later lavas, or drowned by subsequent relative rise of sea level. The pillow lavas at the known localities appear to have formed in valleys above sea level. The flow at Wailua Falls spread over the swampy flood plain of the ancestral Wailua River. The marly material between the pillows at Kamenehune Ditch probably was squeezed up by the weight of the lava from unconsolidated lagoonal deposits in the estuary of the ancient Waimea River. Locally, Koloa flows may have blocked valleys and created temporary lakes, and the entrance of later units of these flows into the lakes may have formed pillow lavas. Thus, the flow exposed along Olokele Canyon appears to have issued from a vent part way up the canyon, and probably obstructed the drainage, with resultant formation of a lake in the upper part of the canyon. Weakly developed pillows are present in the flow near the head of the canyon but have not been found in the portion of the flow downstream from the vent.

No molds of standing trees have been found in the lavas of the Koloa volcanic series, but molds of fallen trunks and branches have been found at several localities. All are associated with pillow lavas. A nearly horizontal mold of a log 5 inches in diameter is exposed in the pillow lavas at Kamenehune Ditch (pl. 9A). Others are found in pillow lavas along the South Fork of the Wailua River below the falls. The largest log mold thus far known was discovered by W. O. Clark on the north bank of the South Fork of the Wailua River, 1 mile above its junction with the North Fork. The mold is 30 feet above river level, 20 feet above an abandoned irrigation ditch, and about 3 feet above the base of the flow unit in which it occurs. It is 35 feet long, 4 by 5 feet in diameter at its larger end, tapering to 3 feet at the smaller end. Several small branches diverge from it at the small end. The mold is nearly horizontal, and lies with the butt end of the log at the river bank and the other end pointing northwestward, away from the river. Lava pillows are packed closely around it.

Lavas of both the Koloa and the Waimea Canyon volcanic series may show strongly developed pits and fluting resulting from solution by rainwater trickling down over boulders or outcrops. Such flutings are known as lapies (Palmer, 1927). Lapies are well developed on olivine basalt of the Waimea Canyon volcanic series at Pohakuwaawaa, near the head of Waimea Canyon. They are present elsewhere on olivine basalt in both the Waimea Canyon and Koloa volcanic series. Nepheline basalts are even more subject to rainwater solution than are olivine basalts, and the best lapies observed were on nepheline basalt. Similar lapies have been described (Stearns and Vaksvik, 1935, p. 59) on nepheline basalts and other rocks on the island of Oahu. Some boulders have acquired a series of strong flutings in one direction, only to roll over and acquire a new series at a distinct angle to the first. As many as three distinct sets of flutings have been seen on a single boulder.

Ash and cinder beds.—Many beds of ash and cinder are intercalated with the lavas of the Koloa volcanic series (pl. 9B). Most are less than a foot thick, but some are as much as 10 feet. They range from fine silty ash through lapilli beds to coarse cinders as much as 4 inches in diameter. Cinder deposits directly associated with known vents are discussed in the next section.

Cinder resting on an erosional surface exposed in highway cuts near Lawai has been mentioned on page 58. It is probably correlative with cinder exposed along the upper branches of Lawai Stream. At the intake of the county pipeline, 0.3 mile east of Kapohakau peak, 10 feet of coarse cinders are exposed beneath thin-bedded nepheline basalt. Most of the cinders are less than half an inch across, but some are as large as 4 inches. The same cinder is exposed at intervals for 0.2 mile downstream and about the same distance along the stream to the northwest. Similar cinder is exposed 0.65 mile N. 14° W. of Kapohakau peak, and 500 feet farther upstream, resting on conglomerate, and cut by a 6-foot dike of nepheline basalt. The presence of the dike suggests that this may be a vent area, but there is no indication of the thickening of the cinder into a cone. The cinder is well bedded and appears to grade into the conglomerate. It is probable that all the cinder in the upper Lawai area is water or wind laid, and derived from the vent area to the north. A 3-foot bed of coarse cinder exposed near stream level in Lawai valley just east of Camp Eleven also probably is water laid.

At 575 feet altitude on the west bank of Wahiawa Stream, 3 feet above the Eleele Ditch, 6 to 8 inches of yellow and gray fresh sandy ash rests on 1 to 1.5 feet of red weathered tuffaceous soil. The ash and soil are overlain and underlain by lava flows of the Koloa volcanic series. All the rocks are cut by a 3-foot dike. At the ditch intake the same ash is about 7 feet above water level. The surface on which the ash rests dips gently westward. The ash and immediately overlying lava appear to be older than the nearby Pohakea cone.

Small residual patches of ash and fine cinder lie on red residual soil at and near the east rim of Hanapepe canyon. The cinder is fresh or only moderately weathered. It probably was blown by the wind from the Pohakea cone, which lay to the northeast.

In a road cut near the Hanapepe Ditch on the east bank of Hikiula Gulch, half a mile west of Hanapepe canyon, 30 to 40 feet of coarse cinder underlies lava of the Koloa. The cinder is much decomposed. Bombs up to a foot across contain numerous small phenocrysts of olivine. The abundant olivine in the bombs and extreme decomposition of the cinder suggest that it might belong to the Waimea Canyon volcanic series. However, the overlying and surrounding rocks belong definitely to the Koloa volcanic series, and the decomposed cinder is included with them on plate 1. At the top of the cinder, 5 feet of red soil is overlain by 10 to 15 feet of only slightly weathered black vitric ash containing lapilli up to 1 inch in diameter. This, in turn, is overlain by 35 feet of thin-bedded lava of the Koloa with a bed of vitric lapilli ash 6 to 18 inches thick near the center of the section.

Where the road crosses Papalu Gulch, 0.4 mile farther west, 20 feet of black vitric lapilli ash is overlain by 6 feet of tuffaceous soil. The soil appears to be at least in part residual, derived by decomposition of the underlying ash. In the next gulch to the west road cuts expose 12 feet of similar ash, the upper 10 feet of which are weathered to residual soil. The ash probably is correlative with thick lapilli ash above the soil bed in Hikiula Gulch. In a small gully 0.3 mile S. 27° E. of Ahuaeliku peak, 3 feet of weathered vitric ash rests on red soil covering nepheline basalt of the Koloa volcanic series, and grades upward into 2 feet of residual tuffaceous soil. This ash also may be the correlative of the thick ash layers in Hikiula and Papalu Gulches, as the lava overlying the ash in Hikiula Gulch probably is one of the group of later flows that descended Hanapepe valley.

Beds of vitric ash, in varying stages of decomposition, are intercalated with Koloa lavas in the walls of Hanapepe valley. In the low bluff on the west side of the valley, 0.3 mile above the junction of the road with the main highway, 18 inches of reddish ash is exposed in the lower part of the road cut. On the west wall of Hanapepe gorge, 0.95 mile S. 23° E. of Ahuaeliku peak, a 10-foot layer of fresh well-bedded cinder, with individual fragments reaching one-half inch across, is intercalated with thick, massive flows of olivine basalt. A few feet lower in the section a bed of fine cinder and ash 1 to 2 feet thick rests on residual soil 3 to 15 feet thick formed on thin-bedded olivine basalt of the Waimea Canyon volcanic series. Traced upstream, the eroded surface at the base of the Koloa volcanic series slopes abruptly downward and disappears below the level of the alluvial fill in the floor of the valley. This slope appears to be the southern side of a pre-Koloa valley that entered the ancestral Hanapepe valley from the northwest. The relationships are shown in figure 14.

In Manuahi Valley, 2.1 miles above its junction with Hanapepe valley, columnar lava rests on 3 to 4 feet of red ash and cinder, which in turn rests on more than 100 feet of conglomerate of the Palikea formation.

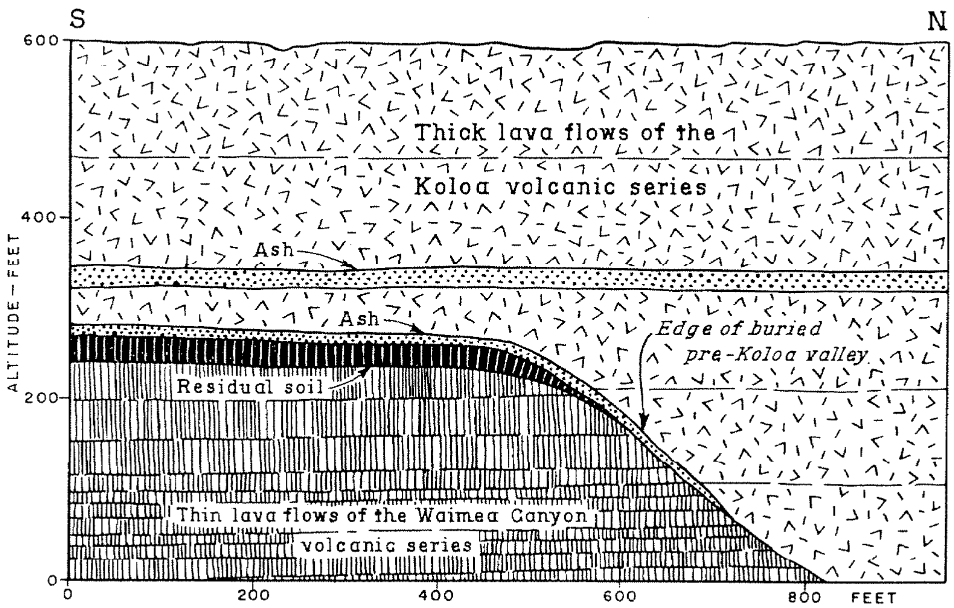

Figure 14. Diagrammatic section in the west wall of Hanapepe valley 1.7 miles below the confluence of Hanapepe and Manuahi valleys.

Along the trail on the south wall of Olokele Canyon, 0.7 mile N. 33° E. of Kapuaa peak, lava of the Koloa rests on more than 4 feet of deeply weathered cinder. The base of the cinder is not exposed. The cinder probably is related to the vent shown on the map (pl. 1) 0.3 mile to the west-southwest.

Beds of ash intercalated with Koloa lavas at Wailua Falls have already been mentioned on page 63. Similar thin beds are exposed at other places along the South Fork of the Wailua River as far as the confluence with the North Fork. At 37 feet altitude on Opaikaa Stream, on the south bank just above the ditch intake, lava of the Koloa rests on a 5-foot bed of cinder. The cinder is very well bedded, possibly water-laid, containing fragments up to 1 inch in diameter in a matrix of finer cinder and ash. The cinder bed pinches out about 125 feet upstream from the intake.

Forty feet of poorly bedded, much decomposed vitric ash is exposed in the north bank of the north fork of Moalepe Stream at 900 feet altitude (pl. 1). The ash contains some angular fragments up to 10 inches across, though most of them are less than 1.5 inches. Most of the fragments are of Koloa lava, some of them probably bombs ejected by the explosions that formed the ash. Others, however, are fragments of older lavas of the Waimea Canyon volcanic series. The ash rests in places on lavas of the Waimea Canyon volcanic series, but in other places it is separated from them by 1 to 4 feet of conglomerate of the Palikea formation. The source of this ash is unknown, but the large size of some of the fragments contained in it suggests that the vent was nearby, possibly somewhere on the Kamalii Ridge, and has been destroyed by erosion.

At 900 feet altitude, approximately 500 feet upstream from the ditch intake on Anahola Stream, more than 5 feet of lapilli ash is exposed. The top of the ash is hidden by vegetation and hill-wash. The ash rests on olivine basalt pahoehoe believed to belong to the Waimea Canyon volcanic series. About 300 feet farther upstream the same ash grades downward into coarse, conglomerate of the Palikea formation. Good bedding in the ash parallels the surface of the underlying conglomerate. The ash probably was deposited by running water. It is overlain by columnar lava of the Koloa volcanic series.

At the base of the waterfall on the east side of Kalihiwai valley, 0.4 mile southwest of the highway bridge, 8 feet of red tuffaceous soil underlies lava of the Koloa, with the base of the soil not exposed. On the west side of the valley, 1 mile southwest of the bridge, 4 to 5 feet of ash rests on pahoehoe at the base of the waterfall. Above this is 25 feet of poorly columnar lava of the Koloa volcanic series, on top of which lies another 4-foot bed of ashy soil, leached in its upper part, and containing thin lenses of iron hardpan. This in turn is overlain in the upper part of the falls by columnar lava.

Vents.—Vents of the Koloa volcanic series are scattered over the eastern two-thirds of Kauai. About 40 vents have been recognized. Some, however, such as the row just north of Makaokahai point, south of Kalaheo, form very closely associated and related groups probably formed at or about the same time, in which it is difficult to distinguish one vent as entirely independent from the others. Most are marked by cinder cones, but a few are the eruptive centers of lava cones, and one is a tuff cone. Other vents must have existed in the central part of the island, to explain the known distribution of lavas of the Koloa. That they have not been found may be partly the result of heavy vegetation and soil cover, but more probably cones built at vents of early flows of the Koloa in the mountainous central part of the island have been destroyed by erosion.

Pyroclastic cones at vents range from typical cinder cones, composed of discrete and essentially unwelded cinders of Strombolian type, to spatter cones of Hawaiian type, resembling those commonly found on Kilauea and Mauna Loa volcanoes on the island of Hawaii. In the latter the lava shreds fall to the ground in so fluid a condition that they stick together and form a mound of thoroughly welded agglutinate (Wentworth and Macdonald, 1953, p. 22).

The two vents near Makahuena Point, southeast of Koloa, are good examples of cinder and spatter cones of the latter type. Puu Wanawana, 0.75 mile from the sea, is typical of all four vents. The cone rises 75 to 125 feet above its surroundings. It consists largely of spatter of Hawaiian type but contains a little unwelded cinder and a few Strombolian fusiform (spindle-shaped) bombs. At its summit is a partially collapsed crater with an average depth of about 75 feet. Outcrops at Pihakekua cone, 0.15 mile from the sea, expose only welded spatter, but blocks of little-welded cinder in the talus suggest the possibility that the welded spatter may be only a veneer. Not uncommonly in Hawaii the nature of the ejecta changes during late stages of an eruption, and a cone built largely of unwelded cinder is covered with a shell of welded spatter. Puu Hunihuni, half a mile north-northeast of Puu Wanawana, consists largely of cinder, which is being quarried for use as road metal. Puu Hi, the northernmost cone of the line, appears to be largely lava. On its north side, a quarter of a mile southwest of Koloa Mill, there are exposed very thin beds, 6 to 8 inches thick, of highly scoriaceous lava dipping steeply eastward. These layers probably veneered the inner slopes of an elongated crater. Puu Ainakoa, 0.6 mile east-southeast of Puu Wanawana, also appears to be largely a lava cone, though some welded spatter is present.

The Nomilo cone, at the coast south of Kalaheo, is composed largely of cinder, partly weakly welded and partly cemented with calcium carbonate deposited by percolating water. Some firmly welded spatter also is present. A lava flow is interbedded with the cinder along the west side of the crater. Kapeku cone, just to the north, also appears to be a cinder cone. Exposures are poor, but cinder is exposed in ditches on the sides of the cone. The cone 0.4 mile northeast of Kapeku is a cinder cone with a well-preserved crater. Ioleau cone, 0.6 mile north of Kapeku, also is a cinder cone. Residual blocks of lava on the lower slopes of the cone are picrite-basalt transitional to olivine basalt.

The cones just east of Lawai Stream appear to be principally cinder cones, although exposures are poor. The cone 0.7 mile southeast of Camp Twelve is composed of cinder, partly veneered with a flow of picrite-basalt of mimosite type (see page 104). The cones built against eroded ridges of lavas of the Waimea Canyon volcanic series, 1.5 miles N. 60° E. and 2.5 miles N. 40° E. of Lawai, are cinder cones. Massive black nepheline basalt near the southwest edge of the more northerly cone probably is a pool of lava accumulated in one of the craters of a compound cone. Pohakea, a mile east of Hanapepe valley, is a large cinder cone partly buried by later lavas from the Black Swamp area to the northeast.

Puulani, 2.5 miles north of Hanapepe, is a cinder cone partly veneered by a thin flow of lava. It lies on the projection of the Makaweli graben fault, and the rise of magma may have been localized by the fault. The vent at Kahipa, 1.5 miles farther northeast, probably is principally a cinder cone, but it is poorly exposed and deeply weathered. Decomposed fragmental material exposed in gullies on its southwestern side appear to be partly cinder. Near the top of the cone cinder and cored lapilli were found. The cores of some of the lapilli are fragments of olivine basalt probably derived from the Waimea Canyon lavas beneath. The cone has been deeply eroded, exposing a thick dike of coarse nepheline basalt.

The vent on the ridge between Manuahi and Koula valleys, a mile east-northeast of Aawela peak, is very deeply weathered and poorly exposed. Its general shape suggests that it is a cinder cone, and material resembling highly decomposed cinder was seen in the soil.

On the northwest wall of Kahana Valley, 0.6 mile above its junction with Olokele Canyon, the remnants of a dissected cinder cone are exposed. The material of the cone is mostly fine cinder, less than 1 inch in diameter, but the cinder encloses some angular blocks of lava as much as 10 inches across. The cone lies on the line of the east fault Makaweli graben, and the rising magma may have been guided by the fault. There is, however, no question that the cone belongs in the Koloa volcanic series. Although some of the enclosed blocks are porphyritic olivine basalt, probably derived from the underlying Waimea Canyon volcanic series, others are nepheline basalt. The cone unquestionably was the source of the nearby patches of lava of the Koloa, and may have been the source also of some of the lava of the Koloa along the Makaweli River.

Hanahanapuni, near the North Fork of the Wailua River, is a cinder cone. It is deeply weathered, but the form of the cone is well preserved. The crater is breached on the north-northeast side. The breach has been enlarged by stream erosion but appears probably to have been original.

The cone containing Ka Loko Reservoir, 3 miles southeast of Kilauea, consists largely of cinders, with some intercalated thin beds of scoriaceous spattery lava. The large cone just to the south, and Kamoku cone to the north, also appear to be cinder cones, although exposures are poor. At Kapaka cone, a mile east of Hanalei valley, weathered cinder was found in a shallow stream gully, but the cone appears to be essentially a lava vent. Exposures are very poor because of deep weathering and dense vegetation.

Pooku hill, at the eastern edge of Hanalei valley 2 miles east of Hanalei, was recognized by W. O. Clark (unpublished notes) as a vent of the Koloa volcanic series, but was regarded by Stearns (1946, fig. 22) as an erosional residual of rocks of the Waimea Canyon volcanic series protruding through rocks of the Koloa. It is unquestionably a vent of the Koloa volcanic series. A road cut on the southwest side of the hill exposes red cinders, apparently overlain by a thin cap of lava. The lava is olivine basalt but contains the purplish pyroxene characteristic of many rocks of the Koloa volcanic series and unknown in lavas of the Waimea Canyon volcanic series. Pooku was the vent for a broad, gently sloping fan of lavas that spread northward and northwestward, causing the abrupt westward swing of the course of the Hanalei River.

Kaluahono crater, 2.5 miles northeast of Koloa, is essentially a collapse crater, approximately 1,000 feet across and 100 feet deep, from which issued a lava flow that is probably the youngest on Kauai. There appears to have been very little cinder or spatter formed at the vent, although some of the pahoehoe lava at the southern lip of the crater is very scoriaceous. The northern wall of the crater is composed of ancient lavas of the Waimea Canyon volcanic series. The Kaluahono lava flow is younger than the cones southeast of Koloa, and swept around both sides of them to the sea.

Several vents of the Koloa volcanic series lie at the summit of broad, gently sloping domical accumulations of lava known as lava shields. These shields are replicas in miniature of the giant shields of the major Hawaiian volcanoes, Mauna Loa and Kilauea on the island of Hawaii, as well as that built by the lavas of the Waimea Canyon volcanic series before it was deeply dissected by erosion. Of the small shields in the Koloa volcanic series, the most spectacular is that which occupies most of the southern part of the Lihue basin and culminates at Kilohana Crater. The Kilohana shield has a diameter of nearly 6 miles and rises to an altitude of 1,134 feet. It is composed very largely of lava flows. The crater at the summit, which is half a mile across and as much as 250 feet deep, is breached on the north side.

Other lava shields are Manuhonohono cone, a mile west of Koloa; Kukuiolono cone, half a mile south of Kalaheo; Puu o Papai and Manienieula cones, northeast of Kaumakani; and Puu Auau, just south of Moloaa Bay.

Kilauea cone, on the west side of Kilauea Bay, on the northeastern side of Kauai, is a broad tuff cone overlain by a cap of thin-bedded spattery lava. The tuff cone is closely similar to such cones as Diamond Head and Punchbowl on the island of Oahu (Stearns and Vaksvik, 1935, p. 15, 133, 145) and Kapoho cone on the island of Hawaii (Stearns and Macdonald, 1956, p. 106), and like them resulted from explosion of the rising magma on encountering water-saturated rocks. The tuff consists of brown to buff palagonitized vitric ash, containing many angular blocks up to 18 inches in diameter, and many bombs and fragments of bombs of melilite-nepheline basalt. The blocks include several different types of lava, probably all derived from underlying flows of the Koloa volcanic series, and also many fragments of reef limestone. The latter are clear evidence that the lavas of the Koloa along the northeastern shore of Kauai overlie submerged fringing reefs. Between an abandoned quarry and the old landing at the head of Kilauea Bay the tuff rests on massive lava containing vesicles lined with calcite and many calcite veinlets. At sea level the lava rests on an older flow, with an intervening layer of red soil. At Mokolea point the bottom 2 feet of the cone consists of coarse, poorly sorted breccia containing many fragments up to 1.5 feet across, resting on the lava and grading upward into the tuff. This basal breccia was formed by the first violent explosion at the beginning of the eruption that built the cone. Makapili head is a tombolo, formed of two large slumped blocks of tuff tied to the shore by a sand bar. A sea arch has been cut through the headland at the contact of the two slumped blocks (fig. 15).

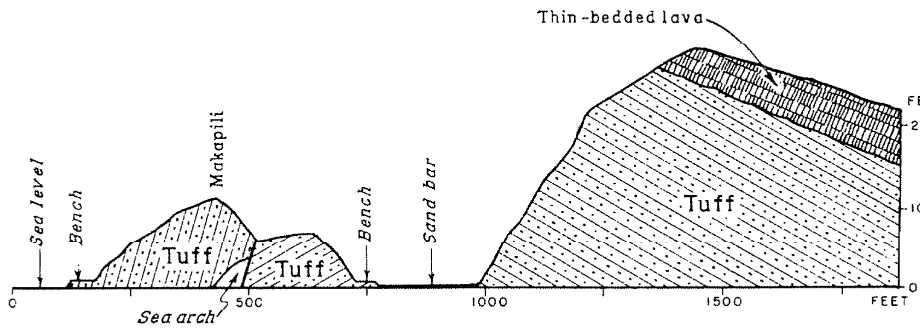

Figure 15. Diagrammatic section through Kilauea tuff cone, showing Makapili tombolo and the unconformable relationship of the lavas capping the tuff cone.

Between Makapili head and Lae o Kilauea the tuff is overlain unconformably by thin-bedded spattery lava. The contact between them is gullied by channels as much as 20 feet deep, and marked by a foot of red soil. Obviously, the capping lava is of later date than the underlying tuff. Two small lava shields lie just west of the crest of Kilauea cone, and a third, similar lava vent probably existed higher on the slope of the tuff cone and supplied the flows that now cap the cone. Both the upper part of the tuff cone and the third lava vent have been destroyed by erosion.

It has been pointed out on an earlier page that other vents must have existed in the interior part of the island, to account for the known distribution of Koloa lavas. The lavas farthest up the Olokele and Kahana canyons may have been, and probably were, derived from known vents in those canyons. The top of the Koloa near the Olokele Ditch intake is lower than the top of the lava near the vent on the south wall of the canyon 3 miles to the southwest. Lavas erupted from that vent undoubtedly blocked the lower portion of the canyon, and probably forced part of the flow to spread upstream.

In Waimea Canyon residual masses of lava of the Koloa volcanic series occur up to 3 miles above the junction with Makaweli canyon. The top of these residuals is 150 to 200 feet higher than that of the canyon-filling flow at the junction of the two valleys. Even allowing for some lowering of the surface at the latter locality by erosion, it is unlikely that the lava of the Koloa in lower Waimea Canyon could have spread back up the canyon from the flow or flows moving down the Makaweli canyon. Furthermore, the residuals north of the mouth of Kunini Gulch are nepheline basalt, whereas only olivine basalt has been found in the lavas of the Koloa at the junction of Waimea and Makaweli canyons. The small residual masses of lava of the Koloa along Koaie valley are nepheline basalt (ankaratrite), very poor in feldspathoid minerals and resembling neither the residuals lower down Waimea Canyon nor the nepheline basalt in the Alakai Swamp at the heads of Waialae and Koaie Streams. It appears certain that vents of the Koloa volcanic series must have existed somewhere in the Waimea drainage basin. That which liberated the lava of the residuals below the mouth of Omao Stream may have been in the vicinity of the body of oligoclase gabbro near the mouth of Waialae Stream, discussed in the next section. The ankaratrite in Koaie canyon resembles that in Wainiha canyon, though it is somewhat more mafic. They may have come from a common vent, in the vicinity of the Koaie-Wainiha divide.

The uppermost residuals of the Koloa in Manuahi Valley also appear to be too high to have come from the known vents on the ridge between Manuahi and Koula Valleys. Another vent must once have existed in the Manuahi drainage basin above the mouth of Kawaipuaa Stream. The vent must have been east of the Manuahi-Kawaipapa divide, because no indication of Koloa lavas has been found in Kawaipapa Valley.

The broad bench of lavas of the Koloa above Hanapepe and Kahili Falls, and the small residuals higher up Hanapepe valley, indicate the presence of a vent higher in the Hanapepe drainage. Similarly, lavas of the Koloa west of the Kilohana shield indicate the presence of vents in the headwaters of the drainage basins of the South Fork of the Wailua River and the northern branches of Huleia Stream. Thus it appears certain that one or more vents must have existed in the vicinity of the Hanapepe-Wailua divide. The general position of this hypothetical vent area is shown in figure 16.

A similar situation exists northeast of Mount Waialeale, where the vents for the Koloa flows in upper Hanalei valley and in the drainage basin of the North Fork of the Wailua River have not been found. The vents must have been somewhere in the vicinity of the Hanalei-Wailua divide (fig. 16). As already pointed out, the cinder at the base of the lavas of the Koloa along the north fork of Moalepe Stream suggest the former presence of a vent above them on Kamali Ridge. The source of lavas of the Koloa along both major branches of Anahola Stream also is unknown. One or more vents must formerly have existed in the Ma-

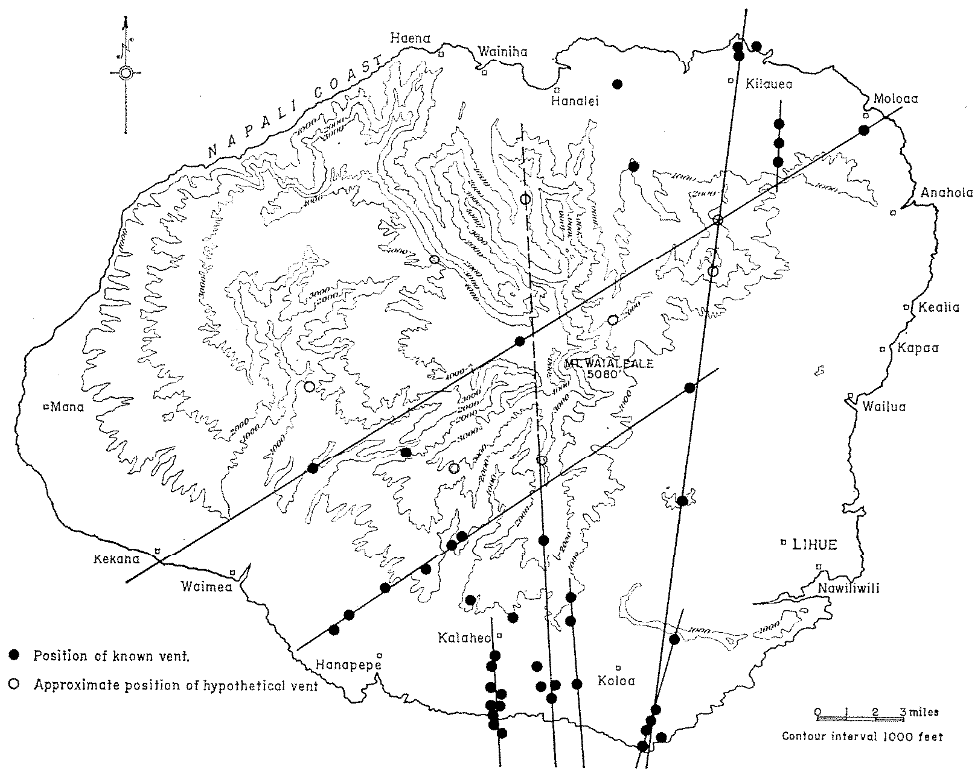

Figure 16. Map of Kauai, showing the distribution of vents of the Koloa volcanic series.

kaleha Mountains north of Puu Ehu. This vent may also have poured lavas westward into the Hanalei-Kalihiwai basin.

Lavas of the Koloa along Wainiha valley may, at least in part, have originated at the vent on the summit plateau west of Waialeale (pl. 1). Other vents may also have existed, however. Lavas of the Koloa along Lumahai Stream could not have come from the summit vent. There must also have been a vent in the upper part of Lumahai valley.

The distribution of known and hypothetical vents of the Koloa volcanic series is shown in figure 16. The figure shows that there is a strong tendency for the vents to lie along lines, presumably marking the course of fissures that guided the rise of magma from depth. It is noteworthy, however, that even along short segments of the lines the vents are seldom closely related in time of formation or composition of the erupted lavas. The five vents in the group southeast of Koloa appear to be of nearly the same age, but some of them liberated nepheline basalt, and others mafic olivine basalt. Kaluahono crater, apparently on the same line farther north, liberated mafic olivine basalt but appears to be distinctly younger than the Koloa cones. The vents in the row south of Kalaheo all liberated picrite-basalt of mimosite type or mafic olivine basalt transitional toward picrite-basalt, but the Kukuiolono-Wahiawa lava shield appears to be somewhat younger than the Ioleau, Kapeku, and Nomilo cinder cones. The group of vents just east of Lawai gulch produced both picrite-basalt and nepheline basalt. Thus the fissures that determined the lineaments apparently guided the rise of differing magmas, over a considerable period of time.

Two main trends of lineaments can be distinguished: one nearly north-south, and the other approximately N. 60° E. Both are approximately parallel to prominent trends among the dikes of the Waimea Canyon volcanic series. Thus the fundamental forces that governed the directions of fissures that guided the rise of magma appear to have remained essentially unchanged throughout the entire history of Kauai.

Intrusive rocks.—Intrusive bodies in the Koloa volcanic series include dikes of olivine basalt and nepheline basalt and small bosses of oligoclase gabbro. Neither are numerous. At 1,145 feet altitude on Iliiliula Stream an 18-inch dike of nepheline basalt cuts Koloa lava. On nearby Waiahi Stream, at 900 feet altitude, a 10-inch dike of nepheline basalt cuts a conglomerate of the Palikea formation. These dikes may be feeders for some of the nepheline basalt flows in the drainage basin of the South Fork of the Wailua River. If so, however, the cones built at the vents have been eroded away.

In the west bank of Wahiawa Stream, below the intake of the Eleele Ditch, a 3-foot dike cuts lavas and intercalated ash of the Koloa volcanic series. This dike may be related to the nearby Pohakea vent. On the east fork of Lawai Stream, 0.65 mile N. 13° W. of Kopahakau peak, a dike of nepheline basalt, 1 foot thick, cuts conglomerate associated with cinder of the Koloa volcanic series. About 500 feet farther upstream, a 6-foot dike of nepheline basalt cuts the cinders. The dikes and abundant cinder, with fragments up to half an inch across, suggest the proximity of a vent.

Several dikes cut conglomerate of the Palikea formation along the upper course of the Hanalei River a quarter of a mile above the intake of the ditch leading to the Hanalei tunnel. These dikes are irregular and average about 8 inches in thickness. Approximately 0.1 mile farther upstream the conglomerate in the northwest wall of the canyon is cut by a thick vertically banded dike. This may be the feeder of the flow that filled the second canyon cut by the Hanalei River.

Oligoclase gabbro has been found at only three localities. One is just southeast of the top of Papapaholahola hill, north of Kalaheo. The gabbro comprises a subcircular boss, about 700 feet in diameter. The gabbro matrix is crowded with partly assimilated xenoliths of dunite. (See section on Petrography.) The other occurrences of gabbro are as boulders scattered along the Waimea River and the lower portions of Waialae and Koaie Streams. This so-called "lightning-stone" was mentioned briefly by Lindgren (1903, p. 15), and described in detail by Cross (1915, p. 14). Gabbro float was followed up a gully on the southeast side of Waialae Canyon 0.15 mile above its mouth, to an altitude of 1,650 feet, near the top of the ridge. Above that no more fragments of gabbro could be found. The intrusive mass from which the gabbro was derived must be nearby, but it could not be located. Mr. Selwyn Robinson has informed us that many years ago he found a fragment of rock resembling the Waialae "lightning-stone" in Olokele Canyon near its junction with Mokuone Valley. Another mass of oligoclase gabbro must therefore crop out somewhere in the headwaters of Olokele River. Because of the general chemical composition of the rock, particularly the high titanium content of

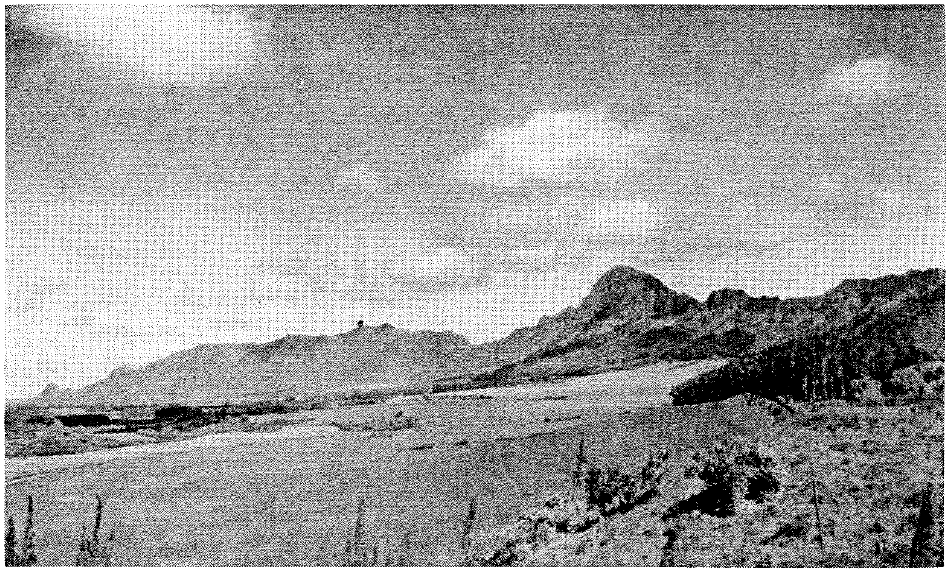

PLATE 7A. View of Haupu ridge from the north. Haupu (Hoary Head), the highest peak in the ridge, is composed of lavas of the Haupu formation. Photo by D. A. Davis.

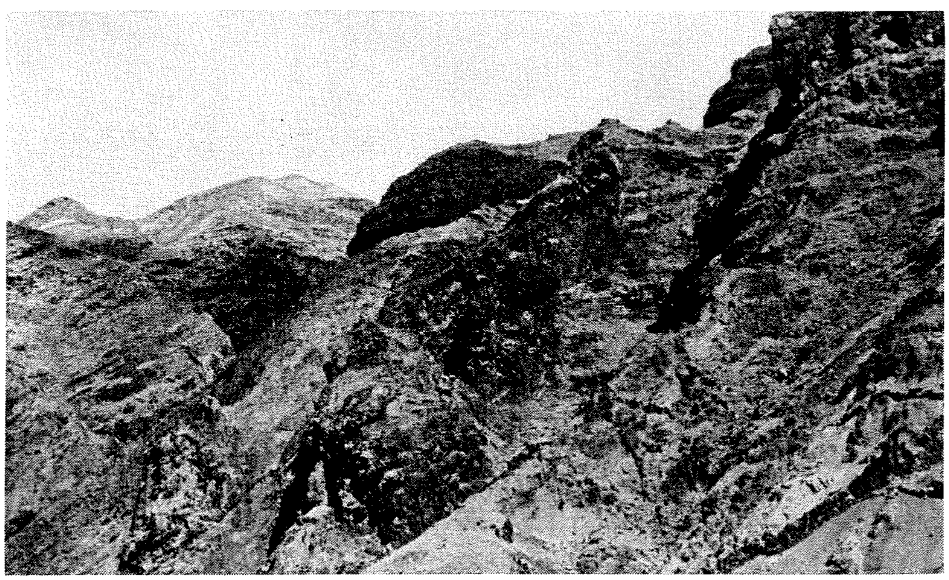

PLATE 7B. Steeply dipping beds of lava, cinder, and breccia on the east boundary of the Makaweli graben in Mokuone Valley. Photo by G. A. Macdonald.

the pyroxene, and the presence of nepheline in some specimens, the oligoclase gabbro is believed to belong to the Koloa volcanic series.

The masses of oligoclase gabbro represent shallow-seated intrusives that nevertheless cooled slowly enough to develop coarse granularity. Similar masses are known in West Maui volcano (Stearns and Macdonald, 1942, p. 164). The location of the mass near Kalaheo, and the approximate location of the mass near the mouth of Waialae Canyon, are shown as vents of the Koloa volcanic series in figure 16.

Water-bearing properties.—Lavas of the Koloa volcanic series are for the most part poorly to moderately permeable. In fresh uncompacted aa clinker water moves freely, but in many areas the amount of pore space in the clinker has been reduced by compaction, cementation, and weathering. In the massive central portions of aa flows water moves largely through joints and other fractures. Most pahoehoe flows are moderately permeable, but pahoehoe is much less abundant than aa in the Koloa volcanic series.

The fine-grained pyroclastic rocks are generally very poor water-bearing materials. Beds of ash and tuffaceous soil are commonly less permeable than the associated lava flows, and they tend to produce perched-water bodies wherever they occur in the lavas of the Koloa. Fractures in some thick tuff deposits contain water, but only in small amounts. Locally, beds of cinder may serve as aquifers where they overlie less permeable material.

Basal water occurs in the rocks of the Koloa where they extend below sea level, and in areas of high rainfall it is fresh.

PALIKEA FORMATION

Definition.—At the base of the Koloa volcanic series, and intercalated with them, are sedimentary breccias and conglomerates. These are herein named Palikea formation. The Palikea formation is defined as those conglomerates and breccias directly underlying or interbedded with the lavas of the Koloa volcanic series; or, if not directly associated with lavas, so well indurated that they are believed to be correlative with the pre and inter-lava conglomerates. The name is taken from Palikea ridge, 3.2 miles S. 20° E. of Kawaikini peak, where the thickest known mass of the breccia is exposed. The type locality of the breccia is designated as Palikea ridge; and that of the conglomerate as the walls of Hanalei valley, where the conglomerates are well exposed from a point east of Hihimanu peak to the valley head.

At its type locality, in Palikea ridge, the breccia has a stratigraphic thickness of approximately 700 feet. At no other place, however, does it exceed 200 feet. The conglomerate beds in the walls of upper Hanalei valley are as much as 100 feet thick, but they thin rapidly seaward.

The breccias of the Palikea formation generally rest directly on an eroded surface of the Waimea Canyon volcanic series, although locally they rest on lavas of the Koloa volcanic series. They are overlain by lavas of the Koloa. The conglomerates generally are interbedded with lavas of the Koloa, though locally they lie at the contact between the Koloa volcanic series and the Waimea Canyon volcanic series. The age of the Palikea formation is the same as that of the Koloa volcanic series.

Well-cemented conglomerates along the Napali coast undoubtedly are correlative at least in part with the conglomerates of the Palikea and volcanic rocks of the Koloa. They are better cemented than the associated old alluvium, and in part obviously belong to an older stage of erosional development of the surrounding topography. They are shown on plate 1 as conglomerates of questionable Palikea age (Pkp?) because, although they probably are of the same age as Palikea rocks elsewhere on the island, their relationship to the Koloa volcanic series is uncertain.

Distribution.—Rocks of the Palikea formation are essentially coextensive with the lavas of the Koloa volcanic series. The breccias are, for the most part, restricted to the immediate vicinity of the foot of the steep eroded slopes on the Waimea Canyon volcanic series, against which the Palikea and Koloa rocks rest. A few breccia bodies are found far out from those cliffs, apparently as the result of mudflow transportation. The conglomerates, in contrast, are widespread in the Koloa volcanic series all the way to the coast.

Thick deposits of breccia extend along the eastern foot of the central massif of Kauai almost continuously from Palikea ridge northward to the main branch of the North Fork of the Wailua River. Thence to the northern branch of North Fork no breccia is exposed, but probably is buried by alluvium. From the north branch of North Fork to Keauhua Stream breccia is again exposed. A small patch of conglomerate underlies tuff-breccia on Moalepe Stream.

Along the northeastern edge of the Puu Ehu ridge no breccia or conglomerate is exposed. However, a test hole on a branch of Papaa Stream 1.3 miles south-southeast of Moloaa Bay penetrated a thick breccia at the foot of the steep slope cut across the Waimea Canyon volcanic series, about 200 feet below sea level. This appears to be a talus breccia that accumulated at the foot of a sea cliff cut across the Waimea Canyon rocks during an ancient stand of the sea lower than the present one, and later buried by lavas of the Koloa.

Coarse breccias lie along the edge of the Waimea Canyon series at their contact with the lavas of the Koloa along Hanalei valley. They grade into moderatly well-sorted and bedded conglomerates. Thick conglomerates underlie lavas of the Koloa in Lumahai and Wainiha valleys. Thick conglomerates also are present beneath and intercalated with lavas of the Koloa in Hanapepe, Manuahi, Olokele, Kahana, and Mokuone valleys, and along Waimea Canyon, on the south side of the island. They are well displayed in cuts along the highway between Hanapepe valley and Omau Stream.

On the south side of Carter Point, just south of Nawiliwili Bay, lava of the Koloa is underlain by 4 to 5 feet of coarse talus breccia derived from the adjacent rocks of the Waimea Canyon volcanic series.

Nature of the rocks.—The breccias of the Palikea formation are for the most part chaotic assemblages of angular to subangular rock fragments grading into an earthy matrix. At most places the matrix is largely or entirely erosional debris, but at a few places it appears to be partly tuffaceous. A part of the breccia is somewhat friable, but most is well cemented. In places it is so well cemented that hammer blows causes it to break through the larger fragments almost as readily as around them. The cement appears to be very largely clay, but locally some calcareous material may be present. The angular fragments range in size from as much as 8 feet across to the very fine material of the matrix. Bedding is generally poor. Commonly, sorting is very poor or totally absent, though in some places there is moderately good sorting. At the latter localities the rock generally also shows better bedding and some rounding of the fragments, representing a graduation into conglomerate.

Most of the fragments in the breccia are olivine basalt or related rock types derived from the Waimea Canyon volcanic series. Commonly, however, a few are of lavas of the Koloa. Angular pieces of nepheline basalt are present in the breccias in Wainiha valley and along the eastern foot of the central massif.

The breccias are intergradational with conglomerates in which fragments of the same types of rocks form subrounded to well-rounded cobbles and pebbles (pl. 10A). As in the breccias, the matrix of the conglomerates is earthy. The cement is largely clay. Many of the conglomerates are very well indurated, yielding large blocks that may travel several miles downstream without disintegrating. Sorting and bedding are better in the conglomerates than in the breccias, but in few places are they really good. The proportion of rounded cobbles, and the perfection of the sorting and bedding, increase with increasing distance from the central massif of the island. Many of the conglomerates are restricted to narrow bands, representing former stream channels. All of the conglomerates appear to be of fluviatile origin. None believed to be of marine origin have been found. No fossils other than carbonaceous decomposed plant material have been found in them.

Along Waiole Stream south of Iole peak, close to the type locality of the Palikea formation, massive unbedded breccia contains angular to subangular fragments of olivine basalt and basalt up to a foot across. It rests on thin-bedded olivine basalt with an undulating contact that slopes east-northeastward at an angle of about 65°. There is no sign of soil on the contact; but neither is there any indication of any fault movement along it. The breccia is cut by two dikes of olivine basalt, one 10 feet and the other 2 feet thick. Just east of that locality, the breccia in Palikea ridge is approximately 700 feet thick. Exposures are poor, but for the most part the breccia appears to be poorly bedded and sorted. Locally, poorly sorted conglomerates are present, as in the cliffs just southwest of the upper powerhouse. At these places there has obviously been some stream transportation of the material. Most of it, however, shows little or no evidence of any effects of running water. It is very largely talus accumulated at the foot of the steep cliffs cut across lavas of the Waimea Canyon volcanic series.

Along Kaulu Stream, 4,000 feet east of Palikea peak, the breccia consists of fragments of all sizes up to 4 feet across, though mostly less than 1 foot. Almost all of them are angular, but a few are subangular. The matrix is fine grained, dense, and earthy. The fragments in the breccia are porphyritic olivine basalts, most of them vesicular flow rock but some of them dense dike rock, derived from the Waimea Canyon volcanic series. A 10-inch dike cuts the breccia.

Along Iliiliula Stream, approximately 800 feet upstream from the ditch intake, breccia of the Palikea formation at least 100 feet thick is exposed in the north bank with its base 20 feet above stream level. The contact with underlying lavas of the Waimea Canyon volcanic series dips eastward at an angle only slightly greater than the gradient of the present stream bed. The breccia is exposed again in windows along Iliiliula Stream below the ditch intake. There the rock fragments are mostly found in types of the Waimea Canyon volcanic series, but some are nepheline basalt from the Koloa volcanic series. The rock in these exposures may not be the basal breccia, but may instead be lenses of Palikea formation intercalated with the Koloa lavas. The breccia is poorly bedded. Most of the fragments are angular or subangular, but some are subrounded. The matrix is earthy. In general texture, the material closely resembles some glacial tills. It is very probably the product of mudflows.

In the ridge between Iole and Iliiliula Streams the contact between the breccia of the Palikea formation and the underlying lavas of the Waimea Canyon dips east-southeastward at an average angle of approximately 18°, and the breccia is 100 to 150 feet thick.

Along the North Fork of the Wailua River, at 1,470 feet altitude, well-cemented breccia contains fragments of lavas of the Waimea Canyon, some of them amygdaloidal. It is cut by two dikes. Southward the breccia continues into the valley of Waikoko Stream, along the south side of which it is exposed in tributary gullies (pl. 1). The ridge between North Fork and Waikoko Stream appears to consist entirely of lava of the Koloa overlying breccia of the Palikea formation.

Breccia transitional to conglomerate is exposed along Uhau Iole Stream, 0.1 mile above Uhau Iole Falls. In the banks of the valley a few feet above stream level it is overlaid by lava of the Koloa that rests on a surface showing minor gullying. The contact dips gently southeastward, alternately dropping below stream level and rising a few feet above it. Thus, as on Iliiliula Stream, the top of the breccia approximates the present grade and level of the stream. The lower surface is less well exposed, but because the basal breccia probably is less than 100 feet thick over nearly all of this area, the pre-Palikea surface must also have been approximately the same in grade and level as the present valley bottoms.

Farther east the Palikea formation gradually loses the character of breccia and becomes more largely conglomerate, generally well cemented. Where the Kauai Electric Power Line crosses the Lihue Ditch and the South Fork of the Wailua River, conglomerate is exposed in the walls of both the ditch and the river valley. It contains subrounded to well-rounded cobbles of olivine basalt up to 10 inches in diameter in a sandy matrix. In places the conglomerate is well bedded, layers of sandstone nearly free from pebbles lying between beds of coarse conglomerate. The sandstone consists of basaltic erosional debris, and may be classed as greywacke. Some of it may contain some tuffaceous material. Elsewhere bedding is lacking and the conglomerate is massive. The basal contact is poorly exposed, but the conglomerate is overlain by dense olivine basalt of the Koloa volcanic series. The contact is disconformable, with a local relief of at least 15 feet produced by gullying of the conglomerate before it was covered by the lava.

Still farther east, along the valley of South Fork below Wailua Falls, conglomerate of the Palikea formation occupies the bottom of an ancient valley cut into breccia lavas of the Koloa. The conglomerate is overlain by a 2-inch bed of tuffaceous sandstone, and that in turn by 2 to 4 feet of thinly laminated silty ash. The ash is overlain by the pillow basalt flow that crops out in Wailua Falls. The conglomerate at the valley bottom consists of subrounded to rounded cobbles and pebbles in a sandy to silty matrix. Most of the cobbles are less than 1 foot in diameter, and only two greater than 3 feet have been observed. Near the base of the falls a boulder 12 by 6 by 4 feet in dimensions, composed of basaltic flow-breccia, is embedded in the conglomerate. Another is approximately 5 feet in diameter. Most of the boulders and cobbles consist of olivine basalt similar to that of the Waimea Canyon volcanic series. A few blocks of breccia of the Palikea formation exposed in the valley walls are found in the conglomerate.

Breccia of the Palikea formation exposed below Wailua Falls is widely distributed along the walls of South Fork valley and its tributary gulches for more than a mile below the falls. On the west side of the valley 500 feet south of the falls it is 45 feet thick. It consists of angular to subangular, and less abundant subrounded, fragments of vesicular to dense olivine basalt similar to that in the Waimea Canyon volcanic series in a silty or muddy matrix. A few dense fragments may have been derived from the Koloa volcanic series. The material is believed to have been transported from the edge of the exposures of Waimea Canyon rocks 6 miles to the west, and deposited in its present position, as a mudflow. The criteria that point to its mudflow origin are: The nearly complete lack of bedding within the layer; the lack of sorting; the large variety of types of rock represented among the fragments; the angular or subangular shape of most of the fragments, associated with some subrounded and a few well-rounded cobbles; the abundant earthy matrix; the wide areal distribution of the layer, which is not confined to narrow stream channels; the flatness of the basal contact, which slopes only a few feet per mile; and the absence of any nearby cliff to supply talus.

Thin beds of conglomerate are present at some places between lava flows of the Koloa volcanic series in the area south and southwest of Lihue. At Carter Point, just south of Nawiliwili Bay, where lava of the Koloa rests against steep slopes of lavas of the Waimea Canyon, 4 to 5 feet of coarse talus breccia lies at the basal contact of the Koloa volcanic series.

On the west bank of Hanalei River, 1 mile S. 35° E. of Hihimanu peak, a thick mass of breccia is plastered against the wall of ancestral Hanalei valley. It consists of angular to subangular blocks of lavas from the Waimea Canyon volcanic series, up to 5 feet across but mostly less than 1 foot, in an earthy matrix. Cobbles and pebbles are much more abundant than the matrix. Sorting and bedding are very poor, but the material is so well indurated that it breaks up as large blocks of breccia that are transported as boulders more than 2 miles downstream. The breccia is more than 50 feet thick, its base being hidden by recent alluvium. On the west side of the valley 1.5 miles farther upstream the breccia is overlain by a small patch of lava of the Koloa. The material appears to be largely talus accumulated at the foot of the west wall of the ancient Hanalei valley later filled with lavas of the Koloa volcanic series.

Between 750 and 900 feet altitude conglomerate of the Palikea formation is exposed along the bed of Hanalei River. The fragments are subrounded to subangular, and the material is transitional toward breccia.

Another bed of conglomerate is exposed 100 to 150 feet above stream level in the east wall of the valley. The bed in the east wall is at the base of the earlier valley-filling lavas; the bed at stream level is at the base of the later valley fill. The older bed extends southward for 0.7 mile, gradually climbing higher on the east wall of the present valley. Between the two major forks of Hanalei River, 0.2 mile southwest of Hanalei tunnel intake, conglomerate underlies the Koloa lavas of the later valley fill.

Near the north coast the Palikea formation is largely conglomerate, containing subrounded to rounded pebbles and cobbles. At the north edge of the Hanalei estuary, close to the edge of Hanalei Bay, conglomerate underlies the Koloa. The base of the conglomerate is not exposed. Just west of Kalihiwai Bay a bed of deeply weathered conglomerate 20 feet thick lies between lava flows of the Koloa volcanic series.

Conglomerate is exposed as a narrow band along Kalihiwai River for nearly a mile upstream from a point east of Kapaka hill. It is overlain by lava of the Koloa, which forms the bed of the stream just below Hoopouli Falls. In the face of the falls another 10-foot bed of conglomerate is exposed between lavas of the Koloa. The bed is very lenticular, pinching out within about 100 feet in the walls of the plunge pool. At about the same stratigraphic level, at the foot of a waterfall on a branch of Kalihiwai River, a mile N. 87° W. of Haleone peak, 50 feet of conglomerate is exposed. The base of the bed is hidden. It is overlain by massive lava that forms the lip of the lower falls. Above the massive flow is a 10-foot bed of greywacke, possibly tuffaceous, which in turn is overlain by a 10-foot bed of conglomerate. The sequence is capped by lavas of the Koloa.

Conglomerates of the Palikea formation are exposed beneath Koloa lavas along both Lumahai and Wainiha valleys. The cobbles in them are for the most part subrounded, but range from well rounded to angular. Most are derived from the Waimea Canyon volcanic series, but in Wainiha valley some cobbles of lava of the Koloa volcanic series are present.

Conglomerates of the Palikea formation are widely distributed on the southern side of this island. Those exposed in highway cuts near Lawai have already been mentioned (p. 57). Similar conglomerate is exposed beneath the end of the spillway at the Alexander Dam. The new Hanapepe tunnel, in the ridge between Koula and Manuahi Valleys, cut 6 feet or more of conglomerate containing boulders up to 2.5 feet in diameter, overlain by 0.5 to 3 feet of red tuffaceous soil, at the base of columnar lava of the Koloa. What appears to be the same conglomerate is exposed along Manuahi Valley. In the east wall of the valley, 1.5 miles above its junction with Koula Valley, columnar lava of the Koloa volcanic series is underlain by several feet of very poorly sorted breccia, probably hillwash, the base of which is not exposed. About 0.65 mile farther upstream the lava rests on 3 to 4 feet of red ash and cinder, which in turn rests on more than 100 feet of conglomerate. The base of the conglomerate is not exposed. This great thickness of conglomerate may have resulted from interruption of the drainage by blocking of the lower portion of the ancient canyon by a flow of lava of the Koloa volcanic series.

In road cuts on the southeast side of Makaweli Valley, 0.75 mile above the confluence of Makaweli and Waimea Rivers, 3 feet of conglomerate containing well-rounded boulders up to 1 foot in diameter is overlain by 10 feet of poorly sorted talus breccia. Above this is 15 feet of water-deposited ash, some layers of which contain rounded pebbles, with fresh fine black cinder near its base. The conglomerate rests on lavas of the Makaweli formation. Lava of the Koloa overlies what probably is the same conglomerate 0.4 and 0.7 mile upstream. In the end of the ridge between Mokuone and Makaweli valleys 100 feet of conglomerate of the Palikea formation underlies lava of the Koloa. Conglomerate is exposed beneath lava of the Koloa in places along Kahana Valley, from 0.2 to 2.0 miles above its mouth. In the northwest wall of Olokele Canyon, 0.5 mile above the mouth of Kahana Valley, conglomerate is overlain 100 to 120 feet above stream level by the dense columnar canyon-filling flow that descended the ancient Olokele Canyon. Similar conglomerate, apparently filling the base of the ancient canyon, underlies lava of the Koloa 300 feet downstream from the intake of the Olokele Ditch.

Origin of the Palikea formation.—There can be little question as to the manner of deposition of the several types of rock in the Palikea formation. The poorly sorted breccias, from 100 to 700 feet thick, found immediately adjacent to the central mountain mass of the island have all the characteristics of talus and chaotic mudflow deposits. They were formed by rock falls, soil avalanches, and mudflows rushing down the steep slopes of the central highland and coming to rest on the inner edge of the more gently sloping marginal lowland. As commonly happens, these deposits grade distally into slightly sorted breccias in which the work of running water becomes more evident, and finally into moderately well-sorted conglomerates composed of subrounded to rounded cobbles and pebbles, with a matrix of sand and silt. The latter conglomerates, such as those interbedded with lavas of the Koloa volcanic series in the walls of the lower portions of Hanalei and Kalihiwai valleys, are clearly the deposits of moderately overloaded streams.

However, although the direct agents of deposition of the Palikea formation are clear, the causes underlying its origin are less evident. It is reasonable to expect that streams rushing down the steep highland slopes over this accumulation of debris, and then moving outward over the relatively very gentle and moderately permeable slopes on the lavas of the Koloa, would be overloaded and deposit their excess load to form the conglomerates. That would be the normal regime under the conditions that obviously existed at that time. But what are the reasons for the development of the thick masses of mudflow and avalanche breccia around the base of the central highland? These do not represent any ordinary regime. Deposits similar in composition to the breccias of the Palikea formation are rare in the Hawaiian Islands, and the writers know of no others that are equal to them in thickness or extent. The development of the breccias must have depended on special conditions that occurred only on the island of Kauai. A favorable locus for their deposition and preservation was, of course, provided by the gentle slopes of the marginal lowland of lavas of the Koloa abutting against the steep highland slopes. The principal problem appears to be the origin of the abundant supply of loose debris that (literally) poured down the flanks of the central massif. In the Hawaiian Islands such debris generally is well anchored in place by the abundant vegetative cover. What caused it suddenly to be released in mudflows and avalanches that deposited the material at the foot of the slope too rapidly for it to be carried away by the streams?

The features of the breccias of the Palikea formation that appear important in considering their origin are as follows:

1. They are largely the result of mudflows and soil avalanches.
2. They are restricted to the zone adjacent to the steep slopes of the central highland.
3. They grade outward into ordinary stream deposits.
4. They consist largely of debris derived from the Waimea Canyon volcanic series, but contain also some debris from the Koloa volcanic series.
5. The period in which they were formed was relatively short.
6. They are closely associated with the other rocks of the Koloa volcanic series.
7. They are almost surely of Pleistocene age.

Let us consider next the possible causes that might make available, relatively suddenly, large amounts of loose debris on the upper portion of the central highland, and cause this debris to move down the slopes. The unusualness of deposits of this type in the Hawaiian Islands indicates that the cause or causes were probably "catastrophes", or volcanic or climatic "accidents" not ordinarily encountered, at least on such a large scale.

In Hawaii, the only deposits of definitely known origin that resemble closely in character the breccias in the Palikea formation are landslide breccias along the Hamakua and Kohala coasts of the island of Hawaii (Stearns and Macdonald, 1946, p. 51), and the deposits of the great mudflow of 1868 (Hitchcock, 1909, p. 105) and a lesser mudflow in 1945 on the southern part of the same island. The landslides along the coast appear to result from oversteepening of the sea cliff by wave erosion at its base. Headward stream erosion in the amphitheater-headed valleys of the Hawaiian Islands produces similar oversteepening of the head-walls of the valleys, and many small landslides result (Wentworth, 1943). These do not, however, produce accumulations of debris even approaching the breccias of the Palikea formation in volume. Moreover, the poor but distinct bedding in these breccias of the Palikea indicates mudflow, rather than landslide origin for most of the breccias. It is probable that some of the breccia in the Palikea formation was formed by landslides on oversteepened valley head-walls, but for most of it some other origin must be sought.

The direct cause of the mudflow of 1868 was a series of heavy earthquakes. In the vicinity of Wood Valley, in the Kau District of the island of Hawaii, the lavas that form the bulk of Mauna Loa volcano are covered with a thick mantle of volcanic ash (Pahala ash), on which is developed a moderately thin layer of soil and a heavy vegetative cover (largely forest in 1868). The ash and soil have very high potential moisture contents, some similar ash deposits along the Hamakua coast having been found by laboratory tests to contain as much as 600 per cent moisture, expressed as percentage of the dry weight of the rock. A block of such highly saturated ash maintains its form when undisturbed, but flows under its own weight when shaken. In the spring of 1868 heavy rains had saturated the ashy soil of the Wood Valley area. On April 2, violent earthquakes shook the Kau District, doing extensive damage to structures. In the area near Wood Valley it is reported that the quakes were so strong that men and horses were unable to stand. The water-soaked soil on the slopes just south of Wood Valley was so agitated that it turned to fluid mud, and swept down the hillside. The mudflow carried with it everything movable, killing many animals and some persons. The deposits extend for more than 2 miles, and are as much as 100 feet thick.

The mudflow of April 8, 1945, resulted from the sudden release of a large volume of water temporarily impounded during an exceptionally heavy rain by cane trash accumulated along a wire fence. Release of the water by collapse of the fence resulted in a rush of mud and water down the mountainside, carrying boulders, trees, and other debris. Although much damage was done at the Kapapala Ranch, the flow was small in volume and the deposits minute compared to those of the great mudflow of 1868.

Another possible cause of abundant mudflows and soil avalanches is the sudden destruction of the vegetative cover that normally retards the removal of weathered debris by erosion. The uplands of Kauai are covered with a large amount of soil and partly weathered rock fragments that are held in place largely by the vegetation. No doubt a similar condition existed at the beginning of Koloa volcanism. Any destruction of the vegetation would allow this debris to move rapidly down the steep highland slopes and accumulate at their feet at a rate faster than it could be removed by streams. Such destruction of the vegetation could result from either a drastic change of climate or a volcanic event.

The probable late Pliocene or Pleistocene age of the breccias of the Palikea formation immediately suggests the possibility of a climatic change related to the great continental glaciations. Either a marked cooling or a marked drying of climate would greatly reduce the amount of vegetative cover in the areas now covered by tropical rain-forests. However, it appears unlikely that such a change would take place rapidly enough to cause the deposition of material at the base of the highland slopes at a rate much greater than it could be spread over the lowlands by streams. Furthermore, there is no apparent reason, other than mere chance, why the event should be closely associated with the beginning of volcanic activity in Koloa time. Climatic change, resulting in destruction of the vegetative cover and rapid removal of weathered debris from the highlands, cannot be ruled out as a cause of the formation of the breccias, but it appears unlikely.

Another possible cause of destruction of the vegetation is voluminous pyroclastic activity at the beginning of volcanism in Koloa time. Heavy ash and cinder showers, accompanied by volcanic fume, might kill the vegetation and allow the removal of the weathered debris from the uplands. This cause would account for the close association of the breccias with the beginning of Koloa volcanism. However, Hawaiian volcanism does not normally produce sufficient pyroclastic debris to kill vegetation over large areas. Furthermore, pyroclastic debris is not present in most of the breccia of the Palikea formation, as surely it would be if ash falls heavy enough to kill large areas of vegetation had occurred. Locally, destruction of vegetation by ash falls and volcanic fumes may have played a part in the formation of the breccias, but in general it appears to have had little importance.

We conclude, therefore, that the most probable cause of the formation of the breccias in the Palikea formation was a series of strong earthquakes that made the water-soaked regolith on the upland slopes unstable and precipitated it down the slopes in a series of mudflows and soil avalanches, to accumulate at the base of the slopes more rapidly than it could be removed by streams. Such a series of earthquakes might well be expected to accompany the renewal of volcanism after a long period of quiet like that represented by the great pre-Koloa erosional unconformity. Locally, the accumulation may have been aided by destruction of vegetation by contemporary ash falls.

Water-bearing properties.—The poor sorting and abundant silty and clayey matrix of the breccias and conglomerates of the Palikea formation make them relatively impermeable. Locally they act as perching members and hold small amounts of water at high levels in the lava flows of the Koloa volcanic series.

SEDIMENTARY DEPOSITS

Older Alluvium

Moderately well-cemented alluvium graded to base levels other than those of the present time is widespread on Kauai. Much of it is poorly sorted stream gravel and associated sand and silt, but accumulations of ancient talus also have been recognized. The deposits of both sorts are now being dissected by streams. In the drier areas the alluvium is quite fresh, and it is distinguished from modern alluvium only by its generally better cementation and its disconsonant relationship to modern streams. In wetter areas it is commonly somewhat decomposed, and may be so rotten that a pick can be driven easily through matrix and cobbles alike.

A broad apron of old alluvium lies along the northern foot of the Haupu ridge, and smaller patches lie at the head of Mahaulepu Valley and the Kipu Kai embayment on the south side of the ridge. Most of the alluvium in that area is thoroughly decomposed. It is well exposed in cuts along the new road to Kipu Kai on the north side of the ridge. Similar aprons of somewhat fresher old alluvium lie along the base of Kalepa, Nonou, and Puu Ehu ridges.

Extensive deposits of ancient stream alluvium lie on terraces along both forks of the Wailua River. This aggradation of the ancient Wailua valley may have been caused by a rise of sea level to about 200 feet above that of the present time. Similar gravel-covered terraces along Kapaa Stream and other streams may also be graded to a plus-200-foot stand of the sea.

The principal gravel-covered terrace at the mouth of Kalalau Valley intersects the sea cliff at an altitude of approximately 110 feet. It may have been graded to plus-100-foot stand of the sea. A smaller, lower terrace may have been graded to the plus-25-foot stand of the sea.

A mile northeast of the mouth of Kalalau Valley poorly sorted gravel rests against a buried cliff that slopes 40° seaward (pl. 3B). Boulders in

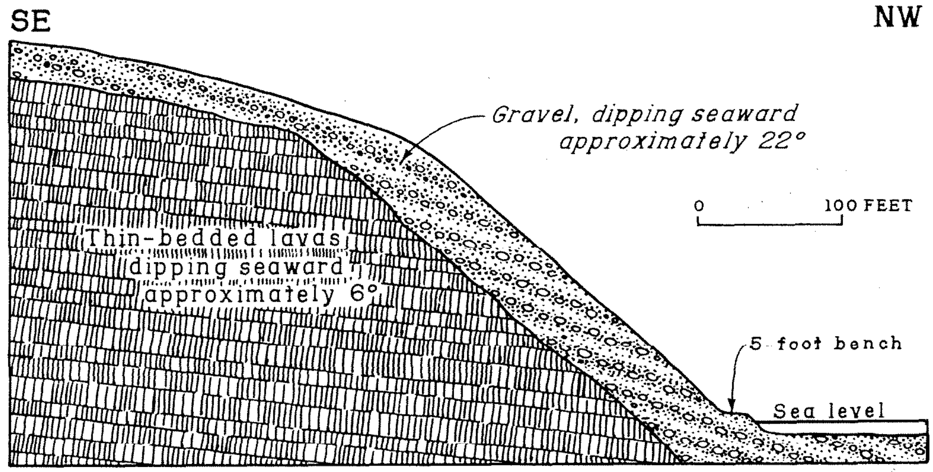

Figure 17. Section at the Napali Coast 1.25 miles northeast of the mouth of Kalalau Stream, showing old alluvium extending below sea level.

the gravel range from subrounded to angular and up to 4 feet in diameter. It is moderately well cemented, but not as well as typical conglomerate of the Palikea formation. Bedding in the gravel dips seaward 20° to 25°. Both the degree of rounding of the cobbles and the perfection of the bedding appear to be too great for an ordinary talus deposit. The material appears to be an alluvial fan deposited against an ancient sea cliff. About 200 feet above sea level the gravel overlaps the top of the cliff. In places it extends below sea level, and both a narrow bench about 5 feet above sea level and a bench at least 500 feet wide just below sea level are cut across it (fig. 17).

Just southwest of the mouth of Kaahole Valley, at the end of Milolii Ridge, and half a mile south of the mouth of Makaha Valley masses of ancient talus (shown on pl. 1 as older alluvium) extend below sea level.

The generally poor sorting of the old alluvium makes it for the most part poorly permeable. In addition, much of it lies well above the basal water table. Locally, enough water is perched in it by less permeable layers to produce small high-level seeps, but it has little importance as a water-bearing formation.

Lithified Dune Sands

Deposits of calcareous dune sand in various stages of consolidation occur in scattered patches on the Mana plain and along the southeast coast between Makahuena Point and Kipu Kai (pl. 1). On the southeast coast the lithified dunes extend below sea level and, in places, as much as 500 feet above sea level. Apparently they were formed when sea level was about 60 feet below present level, in common with similar dunes elsewhere in the Hawaiian Islands. The deposits consist of fragments of shells and coral and the skeletons of Foraminifera blown inland from beaches. They range from slightly cemented, friable sandstone to firmly consolidated, fairly dense rock. In some deposits distinct cross-bedding is visible; in others solution and redeposition of calcium carbonate has obscured or destroyed the bedding.

Lagoonal Deposits of the Mana Plain

Poorly consolidated sediments probably deposited in a shallow lagoon form a curved band on the Mana plain between Kekaha and Barking Sands (pl. 1). The deposits consist of calcareous sand and gravel, marl, and clay. On their inland edge the lagoonal deposits are earthy, are overlain by younger alluvium, and probably grade into or interfinger with older alluvium. On the seaward side the deposits are mostly calcareous and probably grade into barrier-beach deposits. Clay beds contain gypsum in places.

Younger Alluvium

Poorly sorted and essentially unconsolidated gravel, sand, and silt occur along present stream channels, in equilibrium with the present stream regimen. In part the alluvium represents local, temporary deposists of material periodically in transit to the sea. Much of it, however, represents the aggradation of the floors of slightly drowned valley mouths. Calcareous beach sand is interbedded with terrigenous detritus near the mouth of Hanalei River.

The total thickness of the alluvium in these drowned valley mouths is unknown, but at some places, such as the mouths of Lumahai, Hanapepe, and Waimea valleys, it may be several hundred feet. No deep wells have been drilled in it, nor are there any geophysical data on its depth. The existence of drowned and alluviated valley mouths indicates sinking (of unknown amount) of the island in relation to sea level. In the mouth of Hanalei valley well 70 encountered lava at a depth of 167 feet.

Much of the younger alluvium lies close to sea level and extends below the water table. At many places shallow wells in it will yield water, but its generally poor sorting results in generally low permeability, and the low rates of yield. Water in it is commonly fresh, but on the dry leeward side of the island it may be brackish.

Beach Deposits

Sand and gravel consisting mostly of fragments of shells and coral and the skeletons of Foraminifera and calcareous algae form discontinuous beach deposits around the shore of the island. The largest beaches are between Haena and Lumahai and at Hanalei Bay on the north side of the island; at Kapaa and Wailua on the east side; and on the long stretch of shore between Waimea and Polihale on the west side. Most of the beach deposits consists of cream-colored to white calcareous material, but volcanic debris makes up a noticeable part of the deposits locally. At Ka Lae o Kailio near Haena, for example, the beach contains sufficient olivine to give the sand a greenish tinge. At numerous places the beach deposits are consolidated into bedded calcareous sandstone called "beachrock" (Emory and Cox, 1956). The beachrock generally has the same seaward dip as the unconsolidated deposits and extends from a few feet above sea level to a few feet below. Where it is exposed, the beachrock commonly is being broken down by solution and wave action.

Unconsolidated Dune Sand

Dunes of unconsolidated sand form a narrow band adjacent to and parallel with the shore between Nohili and Polihale on the west side of Kauai (pl. 1). Other dunes cover smaller areas on the southeast shore at Makahuena Point, Kamala, and Kipu Kai, and a band of low dunes border the shore east of Kalepa Ridge. The dune sand is mostly fine- to medium-grained calcareous debris derived from beaches.

GEOLOGIC STRUCTURE

General features.—The island of Kauai consists essentially of a single deeply dissected constructional dome. Lava flows dip outward at angles of 2° to 10° in all directions from the principal volcanic center near Mount Waialeale. The dome is slightly elongated in a northeast-southwest direction, and a slight bulge was produced on the southeastern slope of the dome by the lesser eruptive center of Haupu. The smooth profile of the dome was further marred by the great depression of the summit caldera; the smaller Haupu caldera; a structural trough (the Makaweli depression) on the southwest side; and a nearly circular basin (the Lihue depression), probably also of structural origin, on the east side. Within the main caldera, eruptions built a smaller constructional dome, similar to the major dome but with much gentler slopes.

The absence of well-defined rift zones has already been mentioned (p. 49). The closest approach to a true dike complex, such as those in most Hawaiian volcanoes (Wentworth and Macdonald, 1953, p. 89-81), is furnished by the abundant dikes trending west-southwestward in the west wall of Waimea Canyon (pl. 1). This rift zone probably is responsible for the submarine ridge extending to the submerged saddle between Kauai and Niihau (fig. 2). Similar but smaller submarine ridges extend northwestward, northward, and northeastward from Kauai, and probably are the result of minor concentrations of dikes in those directions. In general, however, the distribution of dikes is more evenly radial than in any other Hawaiian volcano except West Maui.

Folding is absent on the island of Kauai, except for minor drag along the caldera boundary fault in Olokele Canyon, and on minor faults 1.5 miles east-southeast of Pohakuwaawaa peak.

Caldera boundary faults.—The principal faults on the island are those forming the boundary of the main caldera, the Haupu caldera, and the Makaweli graben; and the hypothetical faults bounding the Lihue depression. The nature of the caldera boundary has already been discussed (p. 33). The actual plane of the caldera boundary fault is not exposed. The contact between the caldera-filling and extra-caldera lavas is a buried fault scarp that slopes toward the center of the caldera, generally at angles greater than 50°. Hawaiian calderas appear to have resulted from sinking of the summit portion of the volcanic shield, caused by large scale stoping and fluctuation of magmatic pressure beneath it. The boundary faults are unquestionably high-angle faults, probably essentially vertical. The visible scarps around the calderas of Kilauea and Mauna Loa, on the island of Hawaii, and the buried scarps of calderas such as that of Kauai, slope inward at angles less than those of the faults

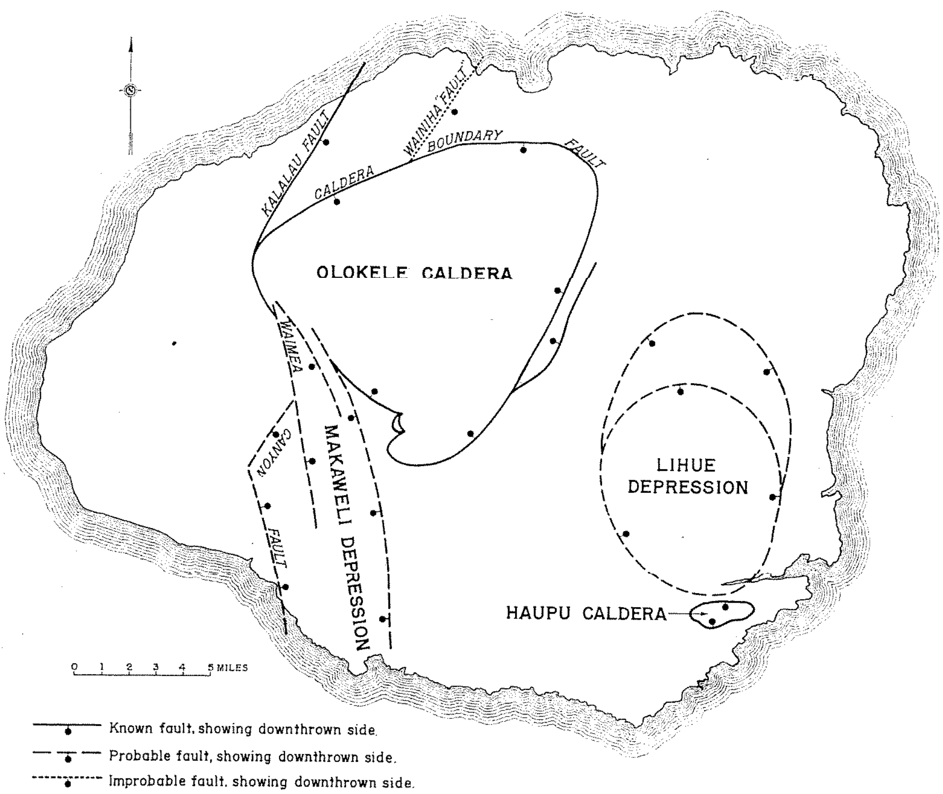

Figure 18. Map of the island of Kauai, showing the approximate position of the principal faults.

themselves because of reduction of the original slopes by gravity and rainwash.

Kalalau fault.—A mile southwest of Pohakuwaawaa peak a fault branches northward from the main caldera boundary fault (pl. 1). The trace of the fault scarp is exposed in the head of Kalalau Valley and along the cliffs of the Napali Coast for 2 miles northeast of the valley. The name Kalalau fault is suggested for it. The block southeast of the fault was dropped in relation to that northwest of it, and lava flows of the Napali formation were ponded against the ancient fault scarp. The buried fault scarp is exposed over a vertical distance of 2,700 feet in the head of Kalalau Valley. The Kalalau fault is believed to have formed at essentially the same time as the caldera boundary fault, and in the same manner.

Wainiha fault.—Hinds (1930, p. 80) suggested the possibility of faulting along the lower part of Wainiha canyon. Approximately 4 miles above its mouth the Wainiha River makes an abrupt bend of 70°, and from that point to the ocean its course is discordant with the courses of adjacent streams that are more nearly consequent on the original constructional slope of the shield. In addition, the average altitude of the northern ends of the ridges east of the canyon is more than 1,000 feet lower than that of the ridges directly opposite them to the west of the canyon.

No fault has been found along the lower part of the canyon north of the caldera boundary fault. It is possible, however, that a fault with downthrow to the east may branch northward from the caldera fault along Wainiha canyon (fig. 18) as does the Kalalau fault farther southwest. Poor exposures along the lower course of the valley could account for failure to identify the fault in the field. There is, however, no evidence of ponding of the lavas exposed in the ridge just east of the mouth of Wainiha canyon, such as is found along the Kalalau fault in the head of Kalalau Valley.

The abrupt bend in Wainiha canyon may be explained by control of stream erosion by the line of weakness afforded by the caldera boundary fault, which follows the course of the canyon for about 2 miles just below the bend. The lower ridge altitudes east of the valley probably are simply the result of more rapid lateral lowering of the terrain by the big, closely set master streams of that area. Streams west of the mouth of Wainiha River are small and short, because of diversion of the drainage southwestward by the unburied portion of the caldera rim along Kaunuohua Ridge. On the whole, the existence of the Wainiha fault appears improbable.

Napali fault.—Dana (1849), and later Powers (1917) and Hinds (1930), considered the cliffs of the Napali Coast to be the result of wave erosion of a high northwest-facing fault scarp. Stearns (1946) considered them to be wholly the result of wave erosion and rejected the hypothesis of an offshore fault. It is difficult to rule out the possibility of a tangential fault of small displacement, but certainly there is no necessity of a fault to explain the existence of the cliffs. Wave erosion is a wholly adequate cause. The cut bench at the foot of the cliffs is 2 miles wide, and projection upward of the slopes of the shield below the level of the bench easily carries the surface to the top of the cliffs without interposition of any faulting. If the Napali fault exists at all, it cannot have any large displacement.

Minor faults.—Few other faults have been found on the island. In a quarry beside the old railroad about 1.8 miles south of Wailua a minor normal fault strikes N. 60° E. and dips 60° SE. The amount of apparent displacement in the quarry face is approximately 8 feet.

In a highway cut north-northwest of Omoe peak a fault strikes N. 57° W. and dips 80° SW. The apparent displacement in the road cut is a downthrow of the footwall block of about 3 feet. However, slickensides on the fault surface indicate nearly horizontal displacement, and the apparent thrust nature of the fault in the outcrop probably is illusory. The movement appears to have been largely transcurrent, the block south of the fault moving southeastward. A zone of minor faulting at the south end of the same roadcut strikes N. 17° E. and dips 75° SE., and slickensides indicate a direction of displacement pitching 40° SW.

About 2.5 miles farther south-southeast a fault is prominently displayed in a deep road cut about 1,000 feet southeast of the south portal of the Grove Farm tunnel. The fault strikes N. 70° E. and dips 61° SE. As much as 2.5 inches of gouge are present locally along the fault surface. Grooves in slickensides indicate dip-slip motion. The direction and amount of displacement are unknown, but the displacement is probably normal and small. In the same road cut, 300 feet farther southeast, a zone of normal faults contains three principal fault planes and many lesser ones, striking N. 40-50° E. and dipping 40-55° SE. These faults may be related to the collapse of the Haupu caldera; or they may represent a tendency for the central portion of the volcanic mass to be uplifted in relation to the marginal portions in the manner illustrated by the Hilina fault system on the island of Hawaii (Wentworth and Macdonald, 1953, p. 21).

In Manuahi Valley, 0.3 mile below the mouth of Kapohakukilomanu Stream, a fault strikes N. 30° E. and dips 35° NW. Along the fault plane is 1 to 2 inches of gouge and fine breccia. Displacement on the fault probably was small in amount, but related in cause and mechanism to the much larger displacement on the caldera boundary fault a little more than a mile to the northwest.

A zone of faults is exposed in cuts along the road up the east bank of the valley of Kauaikinana Stream, 1.5 miles S. 72° E. of Pohakuwaawaa peak. A dozen or more faults can be recognized. Most of them strike from N. 10° W. to N. 20° E., and dip eastward at angles of 55° to 87°, but one strikes N. 50° E. and dips 50° NW. There is much shattering and brecciation within the fault zone. The direction of offset is difficult to ascertain, but apparent drag in beds adjacent to some of the faults indicates that the rocks to the east were displaced downward. The fault zone probably is related to the caldera boundary a mile to the northwest. Another minor fault a mile farther east shows downthrow in the opposite direction.

Three small faults in older alluvium exposed in a road cut 0.4 mile east of the mouth of Lumahai River strike nearly east-west and dip 45° northward. One of them shows a displacement of the material north of it downward about 1 foot. The faults probably are merely the result of slumping in the alluvium.

The steeply sloping buried surface separating rocks of the Waimea Canyon volcanic series from those of the Koloa volcanic series in the vicinity of Lawai may be an eroded fault scarp trending nearly eastward across the south slope of the island, similar to the faults of the Hilina system on the island of Hawaii (Stearns and Macdonald, 1946, p. 129). However, it appears more probable that the scarp is an ancient sea cliff.

The Makaweli depression.—The name Makaweli depression is applied to a roughly triangular area east of Waimea Canyon and southwest of a line extending from near Puulani northwestward to the mouth of Poomau Stream. The average altitude of the surface within this area is distinctly lower than that either west or northeast of it. There can be no question that it represents a topographic depression partly filled with rocks younger than those west of Waimea Canyon and most of those northeast of the Puulani-Poomau line. The unconformable relationships are clearly shown along Waimea Canyon and in the valleys of streams crossing the northeast border of the depression, and have already been described (p. 44). The writers believe the Makaweli depression to be a graben, formed by sinking of a segment of the southern side of the Kauai shield between two major faults or fault zones. The evidence is discussed in detail elsewhere (Cox, in preparation), and is only briefly summarized here.

Stearns (1946, p. 82-90) considered the Makaweli depression to have

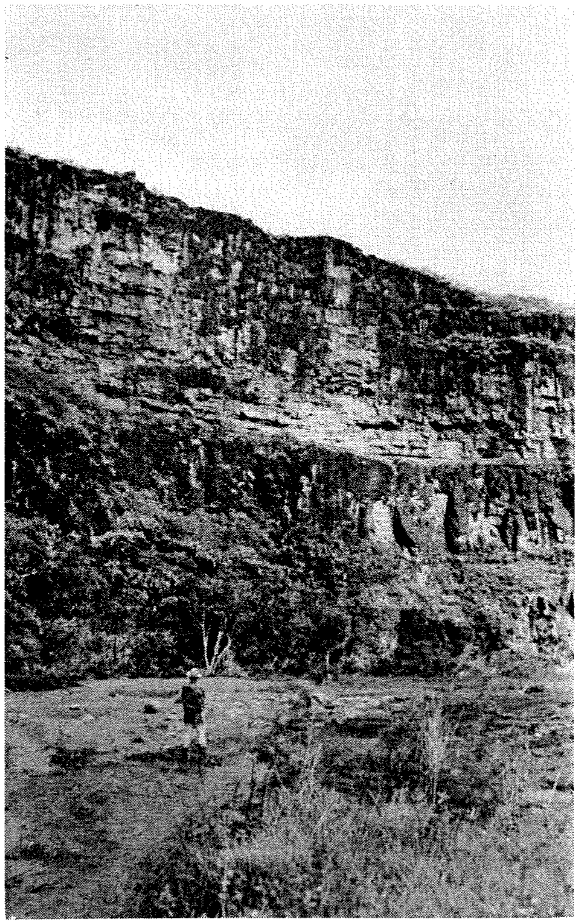

PLATE 8A. Thick, massive, graben-filling lava flows of the Makaweli formation in east wall of Waimea Canyon below the mouth of Mokihana Valley. Photo by G. A. Macdonald.

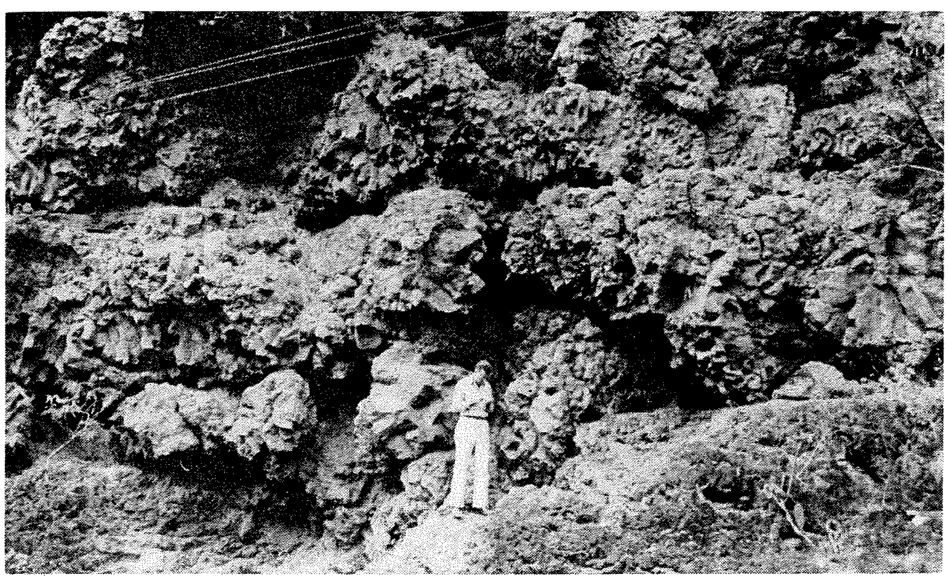

PLATE 8B. Pillow lavas in the Koloa volcanic series at Kamenehune Ditch near Waimea. Photo by D. A. Davis.

been formed by stream erosion, and the lavas filling it to belong to the Koloa volcanic series. The profound erosional unconformity separating the Koloa from the Waimea Canyon volcanic series has been described on pages 55-56. It can be shown, however, that the great majority of the lavas within the depression belong to the Waimea Canyon volcanic series. At several places the uppermost flows in the section can be traced back across the boundary of the depression into the area farther northeast, where the rocks unquestionably belong to the Olokele formation of the Waimea Canyon volcanic series, as indicated on Stearns' map (1946, fig. 22) as well as on plate 1 of the present report. The assignment of the rocks in the depression to the Waimea Canyon volcanic series on the basis of field mapping is confirmed by the petrographic studies. The rocks are of types common in the Olokele formation, and several of the types are unknown in the Koloa volcanic series. Several flows of picrite-basalt of the oceanite type have been found, and olivine basalts containing moderately abundant large phenocrysts of green to brownish-green olivine are common. Near Olokele Canyon the uppermost flow is andesite. All these types are absent from recognized portions of the Koloa volcanic series. (See Petrography, p. 98.) Flows belonging to the Koloa volcanic series also are present within the depression, but they are much later in date than the main mass of rocks filling the depression and are separated from the latter by erosional unconformities.

If the main mass of lavas occupying the Makaweli depression belongs to the Waimea Canyon volcanic series, the depression cannot be attributed to erosion during the long interval between Waimea Canyon and Koloa time. On the other hand, it is highly unlikely that erosion during the major (Waimea Canyon) period of volcanism could have continued long enough in that area, without major interruptions by lava flows, to have formed a valley of such large size. No important erosional unconformities are known within the Waimea Canyon volcanic series elsewhere, and it is more reasonable to seek some other origin for the Makaweli depression.

The nature of the northeast boundary of the depression seems to provide the essential clue to its origin. The now exposed, but formerly buried portion of the boundary is a steep scarp, in part more than 800 feet high, sloping southwestward at angles at high as 75°, but averaging about 30°. Although minor irregularities are present, the scarp is essentially straight. The only major irregularity in the course of the scarp is the sharp offset of the northern portion to the west in the vicinity of Waialae Stream—an offset that is more easily explained as the result of an arrangement en echelon of two major faults (fig. 18) than as the result of erosion. Such en echelon faults, with the throw on one fault gradually decreasing and that on the other increasing in proportion, are common along the edges of grabens on Kilauea volcano. The trend of the scarp as a whole is nearly at right angles to normal stream courses consequent on the original slope of the volcanic shield. Could this be an erosional scarp?

Obviously, the position of the scarp along the northeast edge of the depression, protected by the high land area west of Waimea Canyon, is such that the scarp could not be the result of erosion by ocean waves. If it is the result of stream erosion the course of the stream must have been guided by some structure, presumably a fault, trending south-south-

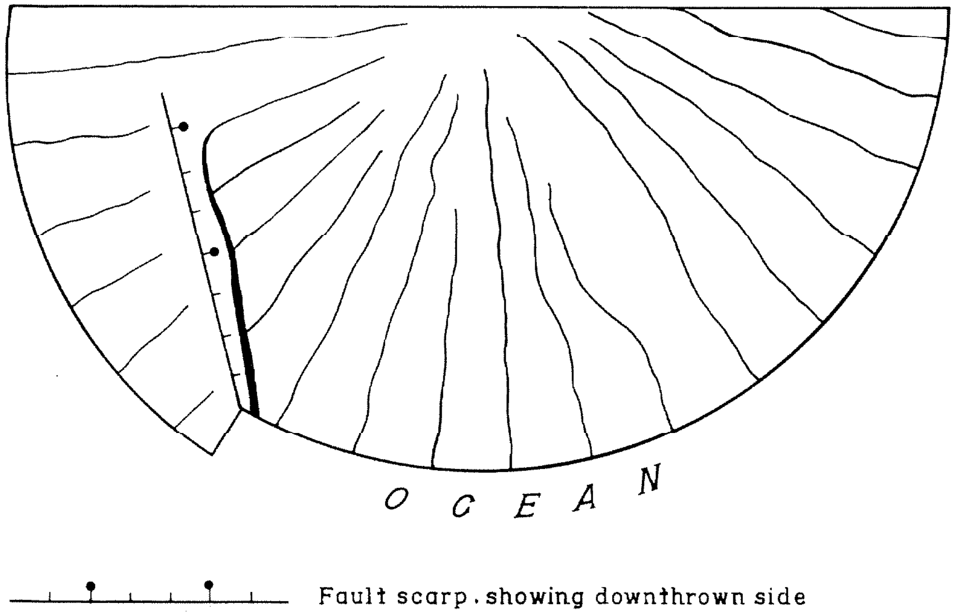

Figure 19. Diagram illustrating the manner in which a fault crossing diagonally the slope of a volcanic shield may concentrate and change the direction of the major drainage lines, beheading small valleys farther downslope. (Slightly modified after Palmer, 1947, fig. 4.)

eastward diagonally across the slope of the shield. If that guiding structure was a fault, the downthrown side must have been to the northeast. At one time the caldera boundary fault probably did provide such an escarpment approximately along the edge of the Makaweli depression between Halemanu and Kaluokalani Streams and, although no evidence of it has been found farther southeast, the visible scarp may have been cut back by erosion some distance northeast of the actual position of the fault that guided the stream, and the fault itself buried beneath the later fill of lavas.

To account for the Makaweli depression, a stream valley with its eastern wall along the line of the scarp at the eastern edge of the depression would have to be as much as 5 miles wide. A normal valley of such width, with side slopes of 30° (the average slope of the northeastern scarp) would have had a depth of approximately 7,000 feet, and would have extended more than a mile below present sea level. The assumption of any such amount of submergence of the island appears wholly unreasonable. It is conceivable, however, that the valley was widened without being cut to anything remotely approaching so great a depth, by lateral cutting of the stream as a result of lava flows entering the depression from the northeast gradually crowding the stream southwestward. That, indeed, appears to be essentially the contention of Stearns (1946). The evidence against it, or any other hypothesis of erosional origin of the northeast boundary of the depression, is the straightness of the boundary scarp, the lack of any large stream valleys intersecting it from the northwest, and the absence of erosional unconformities within the principal mass of depression-filling lavas.

Lateral erosion great enough to shift the valley wall well back from the fault would be expected also to produce more irregularity in the course of the wall. Even more, it would be expected that streams entering the valley from the northeast would have cut deep gorges in an attempt to remain accordant in level with the master stream. That is particularly true because the major source of water from precipitation would have been to the northeast, and streams entering from that direction should at least have approached in size the master stream, and have had much steeper average gradients. No such valleys are found.

The westward displacement of the stream by lava flows would not be expected to be regular, particularly as the flows would have entered the upper portion of the valley at different points and at irregular intervals of time. Irregular westward shifting of the stream should have produced a series of erosional unconformities within the depression-filling lavas, but in most of the mass such unconformities are absent. The only one found is exposed in Mokihana Valley 0.75 mile above the Waimea River. It is possible, of course, that other unconformities may lie below the level exposed by stream dissection (a depth of 1,000 feet or more in much of the northern part of the depression), but there is no evidence that such is the case. The unconformity in Mokihana Valley suggests that there actually was some local westward displacement of the stream in that area. That displacement may account for the considerable irregularity of the western margin of the depression as compared to the northeastern margin.

Finally, the volume of material that would have had to be removed by stream erosion to account for the Makaweli depression wholly by the westerward displacement of the present Waimea River is far too large as compared with that removed by other large rivers of the island in approximately the same length of time.

The course of the Waimea River is highly discordant with the normal courses of streams consequent on the original constructional slope. Its canyon sharply truncates the heads of consequent streams flowing down the western side of the shield. This discordant relationship was recognized by Hinds (1930, p. 79-80), who advanced the hypothesis that the course of the Waimea River had been guided by an eastward-facing fault scarp approximately along the line of the present canyon.A similar situation has been postulated by Palmer (1947) to explain the discordant drainage pattern and offset of surface levels at Waimea on Oahu. Figure 19, slightly modified after Palmer, clearly shows how such a fault would concentrate and change the direction of the major drainage lines, beheading small valleys farther down slope. As has already been mentioned, Stearns (1946, p. 90) considers that the Waimea River has been crowded westward to its present position by lava flows entering an erosional valley from the northeast. This, however, depends on the hypothesis that the northeastern border of the Makaweli depression is the edge of an erosional valley. If instead, the northeastern border is a fault scarp, the fault origin of the western edge of the depression, along Waimea Canyon, also is demanded. The approximate position of the probable Waimea Canyon fault is shown in fig. 18.

It should be noted that the erosional hypothesis for the origin of the Makaweli depression requires that the former trend of the Waimea

River along the eastern edge of the depression be controlled by a hypothetical fault. However, there is no other evidence for the existence of such a fault, the scarp of which would have faced in a direction opposite to that of the great buried escarpment known to have existed along the same line! Under the graben hypothesis the faults along the northeast side of the depression have scarps facing in the same direction as this great known escarpment, and the hypothetical east-facing fault scarp lies along the western edge of the depression near the Waimea River in the position logically demanded of it by the physiography, as was recognized many years ago by Hinds.

The established facts, together with the large amount of special pleading required to explain the northeastern scarp and the broad valley by erosion, militate strongly against the acceptance of the erosional hypothesis. The simpler hypothesis of a southwest-facing fault scarp along the northeast boundary of the depression appears preferable. This hypothesis is strengthened by the existence of several cinder cones along the scarp and partly mantling it. A major high-angle fault extending far into the interior of the shield might be expected to approach or even reach the underlying magma chamber, and furnish an avenue for liquid rock to reach the surface.

It does not appear possible, at least at the present stage of knowledge, to prove definitely the origin of the Makaweli depression. The present writers feel, however, that the graben hypothesis is by far the more probable.

Lihue depression.—On the eastern side of the island, north of the Haupu ridge, lies a spectacular, nearly circular basin. It is well shown in plate 10B. The rim of the basin is formed by the Haupu ridge on the south, the main mountain mass of central Kauai on the west, the Makaleha Mountains on the north, and Nonou and Kalepa ridges on the east. The basin rim thus consists of rocks of the Waimea Canyon volcanic series (pl. 1), but the basin is wholly floored with lavas of the Koloa volcanic series. Some of the latter escaped from the basin through gaps in the rim at the northeast and southeast edges, and to a lesser degree through the gap between the Kalepa and Nonou ridges. Two vents of the Koloa volcanic series, Kilohana Crater and Hanahanapuni cinder cone, lie within the basin.

The circular shape of the basin immediately suggests its origin by caldera collapse, and that is the origin advocated for it by Hinds (1930, p. 79). Stearns (1946, p. 89) discarded the hypothesis of caldera collapse, and believed the basin to be wholly the result of stream erosion. Neither writer presented any particular evidence for his belief. Indeed, other than the circular shape, there appears to be little evidence available on the origin of the basin. Koloa lavas have buried any faults that may be present, and likewise have hidden all conclusive evidence of erosional origin. There is, of course, no question whatever that very extensive erosion has taken place. Rather, the question is whether erosion alone was responsible for the excavation of the basin, or whether erosion merely modified pre-existing fault scarps.

The only recognized evidence bearing the origin of the Lihue basin, other than its circular shape, is the nearly north-south trend of the Kalepa-Nonou ridge. This trend is at right angles to the general trend of ridges that normally would be left by erosive action of consequent streams. It is possible to conceive of the north-south ridges being formed by stream erosion as a result of continuous crowding of streams laterally out of their normal courses by repeated lava flows. But such an explanation is far less simple than the assumption of caldera collapse as the cause of the basin. In the absence of evidence against it, the simpler explanation appears preferable. The abnormally steep dips locally present in the Kalepa and Nonou ridges also suggest structural complication possibly related to the sinking of the basin.

Puu Pilo and Aahoaka hill are steptoes of older rocks projecting through the lavas of the Koloa volcanic series. Under the erosional hypothesis of origin of the Lihue basin they are merely high points on the inter-valley ridges buried by the Koloa lavas. Under the hypothesis of origin by faulting they remain partly buried erosional remnants of the older rocks, but probably are located on a block that did not sink as far as the central block farther southwest.

The probable approximate positions of the faults bounding the Lihue basin are shown in figure 18. The scarps are assumed to have been battered back considerably by erosion before they were buried by lavas of the Koloa volcanic series.

GEOLOGIC HISTORY

At some time during the latter part of the Tertiary period, probably in the Pliocene epoch, a fissure opened on the floor of the Pacific Ocean and volcanic eruptions began the building of the island of Kauai. Because of the very high pressure of the overlying water (approximately 7,800 pounds per square inch at a depth of 18,000 feet) the early activity probably was entirely nonexplosive, lacking even the very minor amount of explosive activity characteristic of subaerial Hawaiian volcanism. The early flows spread very quietly from vents, probably distributed principally along a rift zone that extended in an ENE-WSW direction across the growing shield. Even vesiculation probably was greatly reduced by the high water pressures, and thus the early flows were essentially dense and nonvesicular.

Similar conditions prevailed until the top of the shield reached comparatively shallow water, though the confining pressure of the water became progressively less effective in restraining vesiculation and explosive gas release. As very shallow depths were reached, the contact of the hot (approximately 2000° F.) magma with the sea water undoubtedly resulted in violent boiling and hydro-magmatic explosions, for a time increasing the amount of pyroclastic material far beyond that normally associated with Hawaiian volcanism.

Finally, as the shield rose above the ocean surface, the volcanism assumed the characteristics well-known in the activity of Mauna Loa and Kilauea on the island of Hawaii. Eruptions along rift-zone fissures produced long lines of lava fountains, which built around themselves long, low ramparts of agglutinated spatter, and small cinder and spatter cones. Flows were principally pahoehoe close to the vents, changing to aa as they advanced down the mountainside. Pyroclastic material again became very small in amount, averaging less than 1 percent of the total erupted material. The slopes of the shield averaged approximately 6°, and individual lava flows averaged 10 to 20 feet in thickness.

Toward the end of its growth, the summit of the shield collapsed to form a caldera 10 to 12 miles across. The total sinking of the caldera floor exceeded 2,000 feet. The collapse almost surely was gradual, however, and the depression was filled with new flows at nearly the same rate as its floor subsided. A high wall along the northwest side stood well above the gently domed floor of the caldera, but on the southeast side, and possibly elsewhere, flows spilled over the caldera rim onto the outer flank of the volcano. At about the same time another, much smaller caldera formed on the southeastern flank of the shield and, like the major caldera, became filled probably to overflowing with, thick massive lava flows.

Late in the history of the major Kauai volcano still more collapse of the shield occurred. On its southwestern flank was formed a graben 4 miles across that cut partly into the area of the caldera. Lava flows erupted within the caldera spilled over the boundary cliff at the northeastern edge of the graben and spread over its floor. They were joined by other flows erupted at vents along the northeastern boundary of the graben. At the west and southwest the flows were ponded by a high fault-line scarp bounding the graben. Probably at about the same time, another roughly circular graben formed on the eastern flank of the shield. The development of these grabens probably was related to a general decrease of pressure in the underlying magma reservoir as the end of the volcanic cycle drew near.

The time occupied by the growth of the Kauai shield from the sea floor to its final height above sea level can be estimated only roughly. The bulk of the mass above the sea floor was approximately 1,000 cubic miles. During recent years Mauna Loa volcano has poured out vesicular lava at a rate of approximately four-fifths of a cubic mile per century. Assuming eruption at the same rate, and allowing for the greater denseness of the lavas in the lower portion of the Kauai shield and the additional volume of lava poured into the sinking calderas and graben, the 1,000-cubic-mile bulk of the visible shield could have been built in the short time of 175,000 years! The rate of lava production may have been even greater during early stages. On the other hand, the apparent bulk of the shield probably is only a portion of the actual bulk. The accumulation of so vast a pile of heavy basaltic rock almost surely produced an overloading of the earth's crust and resultant isostatic sinking. This sinking may have been as much as 3 miles, more than doubling the total bulk of the Kauai shield and the time required for its growth. At any rate, the building of the shield probably started and was completed within the Pliocene epoch.

There ensued a long period of volcanic quiet, during which erosion cut deeply into the Kauai dome. Wave erosion produced a broad wave-cut platform and high sea cliffs around the edges of the island. Coral reefs probably grew on the eroded platform. In the central highlands streams cut canyons as much as 3,000 feet deep, developing a submature topography similar to that of the present.

Finally, probably still within the Pliocene epoch, there began a new period of volcanic activity. Lavas of the Koloa volcanic series, from about 40 vents scattered over the eastern part of the island, partly buried the erosional topography developed during the preceding period of volcanic quiescence. Volcanism probably continued throughout most of the Pleistocene epoch. At any one place it was intermittent, however, and locally stream canyons several hundred feet deep and sea cliffs as much as 40 feet high were cut in Koloa lavas and buried by later Koloa lavas.

During the Pleistocene epoch the shifting sea levels that attended changes in volume of the glaciers undoubtedly affected Kauai, but evidence of only a few of the shorelines recognized on the other islands of the Hawaiian group has been found. However, this evidence occurs on some of the latest lavas of the Koloa volcanic series, showing that Koloa volcanism terminated before the end of the Pleistocene. Since then, erosion has been dominant, but most of the areas underlain by rocks of the Koloa volcanic series still are in a youthful stage of the erosion cycle.

The geological history of Kauai can be summarized as follows:

1. Opening of a fissure on the ocean floor during late Tertiary (probably Pliocene) time, and beginning of building of the major Kauai shield volcano.

2. Emergence of the summit of the shield above sea level, during Pliocene time.

3. Formation of the Olokele and Haupu calderas, and progressive filling of them with lava.

4. Formation of the Makaweli graben and Lihue depressions, and partial filling of the Makaweli graben with lavas.

5. Cessation of Waimea Canyon volcanism, during middle or late Pliocene time.

6. Erosion forming high sea cliffs, broad wave-cut platforms, and canyons as much as 3,000 feet deep.

7. Beginning of Koloa volcanism, probably during late Pliocene time, and ensuing burial of part of the erosional topography.

8. Intermittent erosion forming inter-Koloa canyons; shifting sea levels accompanying Pleistocene glaciation on the continents.

9. Cessation of Koloa volcanism.

10. During the remainder of the Pleistocene epoch, formation of shorelines both above and below the present sea level, cutting of canyons to a depth at least 100 feet below present sea level, and alluviation of the canyon mouths at sea level rose again; formation of lagoonal sediments along the southwestern side of the island.

11. Erosion re-excavating canyons filled with Koloa lavas to levels nearly the same as those they had attained before Koloa time, and formation of low sea cliffs on Koloa lavas and general dissection of Koloa volcanics to a late youthful stage in the erosion cycle.

PETROGRAPHY

By Gordon A. Macdonald

Introduction

Approximately 480 rock specimens from Kauai have been studied in thin section under the microscope, and many more have been examined in hand specimen. Only a summary of the petrography is given here. The rocks will be described in detail elsewhere (Macdonald, in preparation), and brief statements of the results have already been published (Macdonald, 1948; 1949a, p. 1555-1558).

Funds to pay for 7 of the chemical analyses in the table on page 110 were provided by a grant to the Committee on Hawaiian Petrology from the Penrose Fund of the Geological Society of America. The writers wish to thank the Society and the Committee for this aid. Four new analyses, given in the table on page 112, were made in the laboratory of the U. S. Geological Survey.

WAIMEA CANYON VOLCANIC SERIES

Description of rocks.—The rocks of the Waimea Canyon volcanic series closely resemble those that make up the great bulk of the other Hawaiian volcanoes (Macdonald, 1949a, p. 1556). They are predominantly olivine basalt, with lesser amounts of basalt and picrite-basalt of the oceanite type. A small amount of basaltic andesite is present among the latest rocks. No oligoclase andesite (mugearite) or trachyte has been found.

The rocks are named according to the same classification used in previous reports of this series. Those in which the average modal feldspar is labradorite or bytownite are called *basalt* if they are fine grained and *gabbro* if they are coarse grained. Rocks in which the average feldspar is andesine are called *andesine andesite*. Basaltic rocks containing less than 30 percent feldspar are called *picrite-basalt*. If the phenocrysts in the latter are nearly all olivine and the ultramafic character of the rock is the result of an abundance of phenocrysts, the rock is called picrite-basalt of the *oceanite* type. The ankaramite type of picrite-basalt, in which the phenocrysts include abundant augite as well as olivine, has not been found on Kauai. Basaltic rocks containing less than 5 percent olivine are called *basalt*, in distinction from *olivine basalt*, which generally contains 5 to 15 percent olivine.

The use of the name "andesite" for Hawaiian lavas in which the dominant feldspar is andesine or oligoclase has resulted in some confusion. Although on the basis of feldspar composition they are indeed andesites, they are very different from the andesites typical of continental orogenic regions (Macdonald, 1957), and doubtless some other name should be used for them. *Mugearite* may be used for those in which the feldspar is oligoclase, and for those in which it is andesine the most appropriate name appears to be *hawaiite*, proposed by Iddings (1913,

p. 198). However, for the sake of uniformity with earlier reports of this series, the name "andesine andesite" is retained herein.

Most of the rocks of the Waimea Canyon volcanic series appear to belong to the tholeiitic basalt group (Kennedy, 1933; Tilley, 1950), but some belong to the group of alkali basalts. The latter are known to be present in the latest part of the series, but their distribution in the earlier parts of the series is still inadequately known and is receiving further study. Some flows of alkali basalt occur among the latest rocks in the Napali formation, west of Waimea Canyon, but these may have been contemporary with rocks of the Olokele and Makaweli formations farther east and southeast.

Most of the olivine basalts are porphyritic, containing phenocrysts of olivine from less than a millimeter to about 8 mm in diameter. Very commonly the olivine phenocrysts are rounded and embayed by resorption, and the edges of the partly resorbed crystals commonly are altered to iddingsite. In some rocks a later period of crystallization has formed a shell of fresh olivine around the iddingsite. Rarely, the resorbed phenocrysts are surrounded by a rim of finely granular magnetite. Rarely also, the olivine phenocrysts are enclosed in reaction rims of finely granular pyroxene.

A very unusual type of alteration of the olivine was found in a rock cropping out at an altitude of 1,300 feet on Pulehu Ridge, west of Waimea Canyon. Sparse phenocrysts of olivine up to 1.5 mm long are partly resorbed, and considerably altered to strongly pleochroic greenish-brown biotite. Most of the altered crystals retain cores of fresh olivine. The alteration is shown to have been magmatic by the fact that the olivine and other minerals of the surrounding groundmass are not affected. In weathered specimens the biotite is altered to chlorite.

Phenocrysts of plagioclase are common, though less abundant than those of olivine. In the rocks of Kauai their size range is about the same as that of olivine phenocrysts. They generally are zoned, with cores of intermediate or sodic labradorite surrounded by rims in which the composition changes rapidly to that of the feldspar in the groundmass.

In several of the alkali olivine basalts of the Waimea Canyon volcanic series, and many of the Koloa volcanic series, the monoclinic pyroxene has a small optic axial angle and has been called *pigeonite*. It should be emphasized, however, that the mineral has been identified wholly on the basis of the small optic axial angle, and that it may not be a true pigeonite in the sense of being poor in lime. In this report "pigeonite" means simply a monoclinic pyroxene with small optic axial angle.

Pyroxene phenocrysts are rare in the lavas of Kauai. In a few rocks phenocrysts of augite or pigeonitic augite up to about 1.5 mm long have been found. Microphenocrysts, less than 0.5 mm long, are common and include both monoclinic and orthorhombic pyroxenes. The monoclinic pyroxene ranges from augite with an optic axial angle greater than 55° to pigeonite with an optic axial angle approaching 0°. In a specimen from the top of the ridge 0.8 mile N. 64° E. of Kukui Peak, phenocrysts of augite are enclosed in narrow coronas of pigeonite.

The orthorhombic pyroxene is hypersthene, commonly extremely poikilitic, but in other instances forming well-defined grains commonly rounded by resorption and generally enclosed in coronas of monoclinic pyroxene. In a specimen collected by H. T. Stearns at the top of Puu Opae, west of Waimea Canyon, rounded and embayed microphenocrysts of hypersthene are partly altered to brown biotite. Microphenocrysts of magnetite are present in some rocks, but rare.

The groundmass of the olivine basalts is generally intergranular, but less commonly is intersertal, and rarely diabasic. It consists predominantly of plagioclase, monoclinic pyroxene, olivine, and opaque iron oxides, with less abundant hypersthene, interstitial biotite, and glass. The core of the plagioclase grains generally is intermediate to calcic labradorite, rarely labradorite-bytownite, commonly passing outward into sodic labradorite or even calcic andesine. The monoclinic pyroxene generally is pigeonite or pigeonitic augite, but in some rocks it is augite. In most rocks the olivine of the groundmass is fresh, but in some it is partly or even wholly altered to iddingsite and finely granular iron ore. The ore minerals of the groundmass include both magnetite and ilmenite. Interstitial glass commonly is clouded with finely dispersed opaque oxides. Tiny highly acicular grains of apatite are enclosed in the feldspar, and less commonly in the glass.

Hypersthene is present in small amounts in the groundmass of many olivine basalts of Kauai. In this abundance of hypersthene, the rocks resemble those of the Koolau volcano on Oahu (Wentworth and Winchell, 1947, p. 66), and many of the historic lava flows of Mauna Loa volcano on the island of Hawaii (Macdonald, 1949b, p. 54, 57).

Picrite-basalts of the oceanite type differ from the olivine basalts only in the abundance of phenocrysts of olivine. The latter commonly attain lengths of 5 to 8 mm, and rarely as much as 1 cm. They commonly comprise 25 to 30 percent of the rock, and in some specimens as much as 55 percent. Augite and plagioclase phenocrysts occur in a few specimens, but even in those they form only a very few percent of the total phenocrysts. Phenocrysts of hypersthene up to 1.3 mm long are present in a specimen collected at an abandoned quarry in huge boulders at the intrusive plug of 0.35 mile S. 65° E. of Puu Lua. The grains are so extremely irregular and poikilitic, however, that it is probable they were formed during the period of groundmass crystallization rather than intratellurically. Microphenocrysts of hypersthene up to about 0.6 mm long occur in some specimens. The groundmass of the picrite-basalts of oceanite type show the same range of texture and composition as do those of the olivine basalts.

The basalts are mineralogically the reciprocal of the picrite-basalts of oceanite type. Whereas the latter differ from the olivine basalts only in the greater abundance of olivine, the former differ in the sparsity of olivine. It appears probable that gravitative differentiation in the magma column was responsible for the formation of both types, subtraction of olivine phenocrysts from olivine basalt magma resulting in basalts, and addition of the sunken crystals to a lower portion of the magma body resulting in the picrite-basalts of oceanite type. Even in the basalts, some olivine generally is present. Only two specimens appear to be totally devoid of olivine. One of these is an unusually coarse grained basalt cropping out at the north side of the dam at the reservoir just south of Puu Lua. The rock is interesting also in containing moderately abundant small anhedral grains of sanidine. In other respects, the description given for the olivine basalts applies equally well to the basalts.

The andesine andesites of Kauai generally are much like the basalts in texture and composition, except that feldspar is somewhat more abundant and its average composition is more sodic. In the field, most of the andesites are paler gray than the basalts, and dense portions of the flows commonly have moderately to well developed platy jointing parallel to the nearly horizontal flow planes. In some specimens parallel orientation of the mineral grains, particularly the feldspars, results in trachytic texture in place of the intergranular texture characteristic of the basalts. All of the andesites found on Kauai are nonporphyritic. The rocks consist of fine grained mixtures of plagioclase and monoclinic pyroxene, with smaller proportions of magnetite and ilmenite, and generally olivine. Interstitial flakes of pale reddish-brown biotite may be present. Some specimens also contain interstitial chlorite. In those specimens in which its nature could be determined, the pyroxene is augite. The feldspar comprises 50 to 60 percent of the rocks, and ranges in composition from medium andesine to oligoclase-andesine. In an andesite exposed in a road cut 0.3 mile S. 19° W. of Pohakuwaawaa peak the feldspar is principally calcic to intermediate andesine, but some interstitial medium oligoclase also is present. The latter has a small positive optic axial angle, from about 10° to 45°, and probably is potassic (Macdonald, 1942).

Pebbles of fine-grained gabbro have been found along several of the stream beds on Kauai, but few of the intrusive bodies have been found in place. It is difficult to be certain whether the gabbros represented in the pebbles belong to the Waimea Canyon or to the Koloa volcanic series. In general, those of normal gabbro or olivine gabbro composition probably belong to the Waimea Canyon volcanic series, and those of more sodic composition to the Koloa volcanic series. A few specimens of olivine diabase represent gradations from the olivine basalts to the olivine gabbros. For the most part the gabbros are fine to medium grained, with granitoid texture. An open miarolytic structure is common, as in those of the other Hawaiian volcanoes (Stearns and Macdonald, 1942, p. 328-331), and apparently is the result of consolidation at shallow depths under relatively small pressure from the weight of overlying materials. The rocks consist predominantly of feldspar (commonly zoned, from calcic or intermediate labradorite to sodic labradorite or calcic andesine), and monoclinic pyroxene (augite or pigeonitic augite); with lesser amounts of magnetite, ilmenite, and apatite. Olivine is present in some specimens, but absent in others. Small amounts of alkalic feldspar are present in some rocks. Thus, in a 30-foot dike exposed in a waterfall at 750 feet altitude on Hanakapiai Stream interstitial feldspar includes both albite and sanidine, the two being clearly distinguishable by their different optical properties. Sanidine is estimated to comprise 2 to 3 percent of the rock.

Of particular interest is the grabbo that makes up the intrusive plug of Puu Lua. The mass has a fine-grained porphyritic contact phase containing partly resorbed phenocrysts of olivine. Most of the plug consists of a medium-gray nonporphyritic finely granular granitoid rock containing many minute miarolytic cavities. The average grain size is about 0.7 mm. The rock is composed largely of plagioclase and augite, with smaller amounts of iron ore and an interstitial material with low birefringence and low relief. Highly acicular crystals of apatite occur in the interstitial material and to a lesser extent in the plagioclase. The plagioclase is zoned from calcic labradorite to sodic andesine. Both magnetite and ilmenite are present, and range from euhedral to anhedral, indicating a long range of crystallization. The interstitial material has a refractive index near 1.52 and a negative optic axial angle close to 0°. It is probably sanidine. Olivine is absent in this phase of the plug, presumably because of complete resorption. An even coarser phase of the gabbro is present locally. In it the interstitial feldspar is unquestionably sanidine, which in many places is perthitically intergrown with plagioclase. In some places it appears to have partly replaced earlier plagioclase crystals. Wedge-shaped twins of tridymite project into the miarolytic cavities. This coarsest phase of the gabbro probably represents portions of the magma that were especially rich in gas, and the formation of perthite and tridymite may be regarded as deuteric phenomena.

A few dunite inclusions are found in the lavas of the Waimea Canyon volcanic series, but they are much less abundant than in those of the Koloa volcanic series. Particularly noteworthy is a dunite breccia occurring as huge boulders along the upper Hanalei Stream at and near the intake of the Hanalei tunnel. The source of the boulders is unknown, and it is quite possible that the rock belongs to the Koloa volcanic series. However, the matrix containing the dunite fragments is a normal olivine diabase resembling other intrusive rocks of the Waimea Canyon volcanic series. The dunite fragments are angular to subrounded, up to 6 inches across, and constitute approximately 80 percent of the rock of the boulders. They are allotriomorphic granular, with an average grain size varying in different parts from about 1 mm to 0.1 mm. They consist very largely of olivine ($2V = 90°$), with a few anhedral grains of iron ore. One fragment, of unique structure and probably different in origin from the rest, shows distinct radial structure and is much richer in magnetite than the others. At its core is a frayed remnant of a grain of hypersthene.

Distribution of rock types.—The accompanying table shows the distribution of rock types in the igneous formations of the Waimea Canyon volcanic series. All three of the major rock types are present in the Napali, Olokele, and Makaweli formations. Basalt has not been found in the Haupu formation, but it is present in about normal abundance among the lavas in adjacent parts of the Haupu Range. Andesite has been found only in the uppermost parts of the Olokele and Makaweli formations.

Occurrence of rock types in the Waimea Canyon volcanic series

Stratigraphic unit	Olivine basalt	Picrite-basalt of oceanite type	Basalt	Andesine andesite	Explanation of symbols
Makaweli formation...	●	O	O	X	● =Abundant
Haupu formation........	●	O			O=Moderately abundant
Olokele formation.......	●	O	O	X	
Napali formation........	●	O	O		X=Sparse

KOLOA VOLCANIC SERIES

Description of rocks.—The lavas of the Koloa volcanic series are principally olivine basalt, nepheline basalt, melilite-nepheline basalt, and picrite-basalt of mimosite type. A small amount of analcime basanite and ankaratrite also are present. Inclusions of peridotite are very common in them. Gabbros, some of them of unusual composition, also are present. The olivine basalts probably all belong to the alkali olivine basalt group.

Some of the olivine basalts of the Koloa volcanic series closely resemble in hand specimen some of those of the Waimea Canyon volcanic series. For the most part, however, they have a sufficiently different appearance to make their recognition in the field fairly easy and definite. Those that cannot be identified with certainty in hand specimen generally can be in thin section. In some of the rocks the olivine phenocrysts are green or brownish green in hand specimen, like the characteristic phenocrysts of the Waimea Canyon volcanic series, but in most they are darker brown, and in some they are nearly black. They probably are somewhat richer in iron than those in the rocks of the Waimea Canyon volcanic series. Also, the average size of the phenocrysts in the rocks of the Koloa volcanic series is distinctly smaller than that of those in the Waimea Canyon volcanic series. None have been found exceeding 5 mm in average diameter, and in few specimens do they exceed 2 mm. Phenocrysts of plagioclase up to 3 mm long have been found in a few olivine basalts. Microphenocrysts of pyroxene are fairly common, but true phenocrysts of pyroxene are very rare in the lavas of the Koloa volcanic series. In that respect the rocks differ from those of the otherwise similar Honolulu volcanic series on the island of Oahu, in which pyroxene phenocrysts are common (Winchell, 1947, p. 21-23).

In many of the olivine basalts of the Koloa volcanic series, the pyroxene (both augite and pigeonite) of both microphenocrysts and groundmass, has in thin section a marked purplish tinge that becomes more pronounced in the later crystallized material. It probably is titanian. Similar purplish pyroxene is absent in rocks of the Waimea Canyon volcanic series, but it is interesting to note that it is present in many of the olivine basalts of the Kiekie volcanic series on the island of Niihau, which bears the same stratigraphic and structural relationship to the rocks that form the principal Niihau shield as do those of the Koloa volcanic series to the Waimea Canyon volcanic series (Macdonald, 1947, p. 46).

Analcime basanite has been definitely identified only at two localities —one on the southeast side of the small ridge at the east side of Wainiha Bay, on the north side of the island; the other on the south side of the island, in a road cut 0.35 mile southeast of the Makaweli postoffice. The rock from the first locality (analysis 9, p. 110) contains about 8 percent of analcime. Lack of alteration of the associated feldspars indicates that the analcime probably is of primary igneous origin. In other respects the rock closely resembles the olivine basalts. A few olivine basalts contain a very small amount of interstitial isotropic material with refractive index less than 1.54, which probably is analcime. These rocks resemble those in the Honolulu volcanic series termed "linosaite" by

Winchell (1947, p. 28). Nepheline basanites have not been found on Kauai.

There is a complete gradation from the olivine basalts to the picrite-basalts of mimosite type. The latter rocks conform to the definition of picrite-basalts, in that they contain less than 30 percent feldspar, but they differ from those of oceanite and ankaramite type in that their ultramafic character is not merely the result of an abundance of mafic phenocrysts. All specimens contain phenocrysts of olivine, but the phenocrysts are small, and rarely more than moderately abundant. In most, the olivine phenocrysts are less than 1.5 mm long, and in none do they exceed 4 mm. Augite phenocrysts are very rare, and none have been found exceeding 1 mm in length. Microphenocrysts of pyroxene are present in about a third of the specimens, and grade in size into the groundmass. The latter consists largely of pyroxene, with less abundant plagioclase, olivine, and opaque oxides. Apatite occurs as inclusions in the feldspar. Interstitial glass is present in some specimens, and a few contain small interstitial flakes of brown biotite. Rarely, a few small grains of what appears to be analcime are present. Both microphenocrysts and groundmass pyroxene generally are pigeonite, but rarely they are augite. In one specimen, from a residual boulder at the top of the sea cliff 0.27 mile east of Koheo Point, the larger grains of groundmass pyroxene contain cores of augite surrounded by pigeonite, whereas the smaller grains are entirely pigeonite. In most specimens the pigeonite is colorless to pale brown in thin section; but in some, in the vicinity of vesicles or in small pegmatitoid patches, it has purplish-brown titanian borders.

The plagioclase of the picrite-basalts of mimosite type is intermediate or calcic labradorite. In some rocks it forms anhedral grains interstitial to subhedral grains of monoclinic pyroxene, olivine, and magnetite. In others it forms large anhedral poikilitic grains that enclose the mafic minerals. The feldspar makes up 20 to 25 percent of most specimens, but in some it is as low as 10 percent.

The nepheline basalts are porphyritic, containing phenocrysts of olivine. The phenocrysts are small, generally less than 2 mm long, but rarely as much as 6 mm. In some specimens only a few phenocrysts are present, but in others they comprise as much as 20 percent of the rock. They generally are rounded and embayed by resorption, and in many specimens they are partly altered to iddingsite. In some, the iddingsite is surrounded by a thin jacket of fresh olivine. In some rocks the partly resorbed olivine phenocrysts are surrounded by a thin zone of finely granular exsolved magnetite, and in a few they have narrow reaction coronas of monoclinic pyroxene mixed with magnetite. Phenocrysts of purplish brown titanian augite are rare, but microphenocrysts of pigeonite are present in several specimens. Nepheline phenocrysts, much rounded by resorption, have been found at three localities, at one of which (the summit of Papapaholahola hill) they attain a maximum diameter of 1.5 mm.

The groundmass of the nepheline basalts consists essentially of nepheline, pigeonite, and iron ore. Olivine is present in the groundmass of some rocks, but absent in others. In the melilite-nepheline basalts melilite also is present. Among the specimens studied, melilite-nepheline basalt is about one-fifth as abundant as nepheline basalt.

Melilite is neither as abundant, nor present in as large grains, in the lavas of Kauai as it is in some of the lavas of the Honolulu volcanic series of Oahu. Phenocrysts have not been found, though some microphenocrysts reach a length of 0.3 mm. Melilite in a lava exposed in a road cut 1.7 miles southwest of Koloa is optically negative, uniaxial, and has a refractive index of $\omega = 1.659$, indicating a composition of about 33 percent ackermanite and 67 percent gehlenite. Peg structure is rarely seen. In some rocks the melilite is altered to pale honey-yellow or brown isotropic material.

In some of the nepheline basalts and melilite-nepheline basalts the pyroxene is very pale brown or colorless, but more commonly it is purplish, with strong dispersion, and probably is titanian. Rarely, it passes outward into borders of green aegirine-augite. The opaque oxide is largely magnetite, but considering the titanian character of the pyroxene, the magnetite also is probably titanian. Ilmenite is present also in some specimens. Minute highly acicular crystals of apatite are common, generally enclosed in the nepheline. Irregular interstitial flakes of reddish-brown or purplish biotite also are common. Together with rare small grains of brown hornblende, they are of late crystallization, probably formed during very late magmatic or deuteric stages. Perovskite is present in a few specimens. Interstitial chlorite and serpentine are present in a few rocks, and some contain a small amount of interstitial glass. Calcite and zeolite occur quite commonly in vesicles. Analcime is present in a few rocks. In most it appears to be primary, but in others it is an alteration product of nepheline.

The commonest groundmass texture of the nepheline and melilite-nepheline basalts consists of subhedral grains of monoclinic pyroxene, iron ore, and sometimes olivine, between which lie small anhedral grains of nepheline. Less widespread, but still common, are rocks in which large anhedral grains of nepheline enclose smaller subhedral grains of the other minerals. Least common is a texture in which the abundant small grains of nepheline are subhedral, showing nearly square cross sections, with the grains of other minerals partly enclosed in them and partly lying between them.

The nepheline basalts grade, by a decrease in the proportion of nepheline, into ankaratrite, in which the mafic minerals constitute as much as 80 to 85 percent of the rock. The ankaratrites bear the same relationship to the nepheline basalts as do the picrite-basalts of mimosite type to the olivine basalts. Ankaratrite has been found at only three localities on Kauai. Of the rocks at these three localities, only that at 1,325 feet altitude on Kuilau Ridge contains melilite.

Peridotite inclusions are common in the lavas of the Koloa volcanic series, especially in the nepheline basalts and picrite-basalts of mimosite type. They are green to greenish-brown granular nodules, angular to subrounded in outline, ranging in size from less than a centimeter to 10 cm or even more in diameter. Many of them obviously were undergoing mechanical disintegration in the magma at the time of its eruption. Some of them consist almost wholly of olivine, with only a small proportion of a metallic mineral of the spinel group, possibly magnetite, or possibly chromite or a chrome spinel. Most of them, however, contain some pyroxene. An inclusion in olivine basalt collected on the west side of Kilauea Point consists of anhedral grains of olivine and bronzite, up to about 1 mm across. The inclusion is surrounded by a reaction corona of augite and iron ore about 0.2 mm thick. On the east slope of Papapaholahola hill, north of Kalaheo, very abundant peridotite nodules are enclosed in oligoclase gabbro. They range in composition from dunite, containing only a very few tiny grains of pyroxene, to harzburgite containing about 25 percent bronzite. Reaction rims 1 to 2 mm thick around the nodules consist largely of anhedral olivine and augite, with a smaller proportion of euhedral to subhedral grains of metallic spinel. Beyond that distance the proportion of feldspar in the rock gradually increases to that of the normal gabbro, ranging from 40 to 50 percent.

Ross, Foster, and Myers (1954, p. 697-698) have studied peridotite inclusions from the Grove Farm quarry, 5 miles west-southwest of Lihue, and from boulders along Kapohakukilomanu Stream on the south side of the island. Some of the latter are almost pure olivine, but others contain pale green chromian diopside. Enstatite (bronzite) is sparse in all the specimens. The inclusions from the Grove Farm quarry are dominantly olivine and enstatite (bronzite), with less than 1 percent of chromian spinel. No diopside was observed in them. Chemical analyses of the principal minerals are given below.

Composition of minerals from peridotite inclusions in nepheline basalt from Grove Farm Quarry
(After Ross, Foster, and Myers, 1954, pp. 707-714)

Major oxides (weight percent) (M. D. Foster, analyst)				Minor elements (weight percent) (Spectrographic determination by A. T. Myers)			
Oxide	Olivine	Enstatite (bronzite)	Chromian spinel	Element	Olivine[1]	Enstatite (bronzite)[2]	Chromian spinel[3]
SiO_2	41.16	54.85	0.22	Mn	0.13	0.08	0.15
Al_2O_3	0.00	2.18	19.29	Ni	0.35	0.050	0.10
Fe_2O_3	0.00	0.00	15.62	Cr	0.015	0.35	....
FeO	8.89	5.99	16.68[4]	Co	0.018	0.005	0.020
TiO_2	0.015	0.033	1.60	Ti	0.002	0.02	0.4
Cr_2O_3	0.02	0.80	34.87	V	....	0.008	0.04
CaO	0.07	1.72	0.08	Ca	0.05	1.2	0.07
MgO	49.56	33.72	12.14	Al	0.024	....	....
Na_2O	0.03[5]	0.08[5]	....	Ga	....	....	0.002
K_2O	0.00[5]	0.07[5]	....	Zr	....	....	0.0X
MnO	0.15	0.09	0.18				
CoO	0.010	....	....				
NiO	0.30	0.08	....				
V_2O_5	....	....	....				
H_2O	0.10	0.18	....				
Total	100.30	99.79	100.68				
Specific gravity at 4° C	3.334	3.291	4.395				

[1] Looked for but not found: Ag, As, B, Ba, Be, Bi, Cd, Ga, Ge, In, La, Li (present at about the 0.000X order), Mo, P (not present at 0.5 percent or more), Pb, Sb, Sr, Y, Zn, and Zr.
[2] Looked for but not found: Ag, As, B, Ba, Be, Bi, Cd, Ga, Ge, In, La, Li, Mo, P (not present at 0.5 percent or more), Pb, Sb, Sr, Y, Zn, and Zr.
[3] Looked for but not found: Ag, As, B, Ba, Bi, Cd, Ge, In, Li, Mo, P (not present at 0.5 percent or more), Pb, Sb, Sr, Y, and Zn.
[4] Calculated to give 1:1 ratio of $FeO:Fe_2O_3$.
[5] Determined with flame photometer by S. M. Berthold.

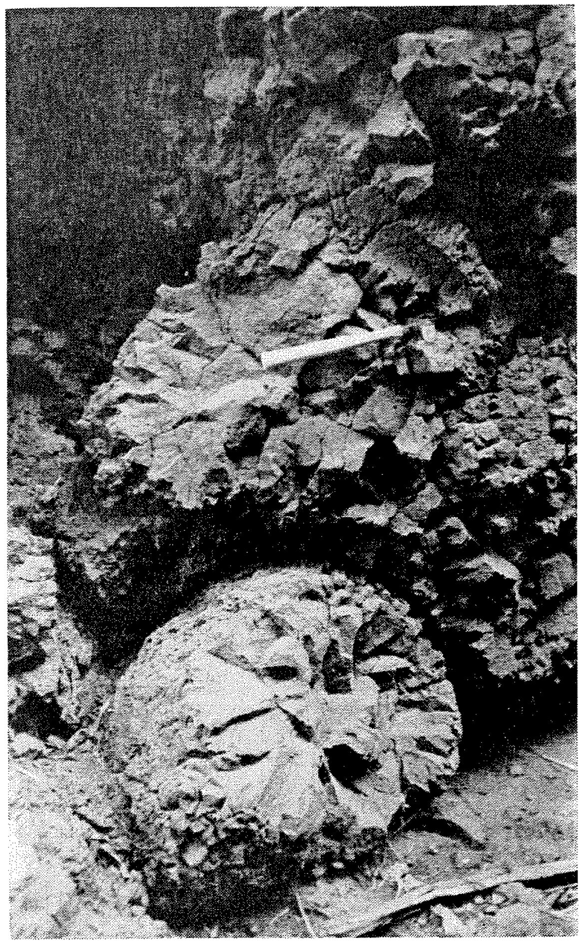

PLATE 9A. Log mold, just above hammer, in pillow lavas at Kamenehune Ditch. Photo by H. T. Stearns.

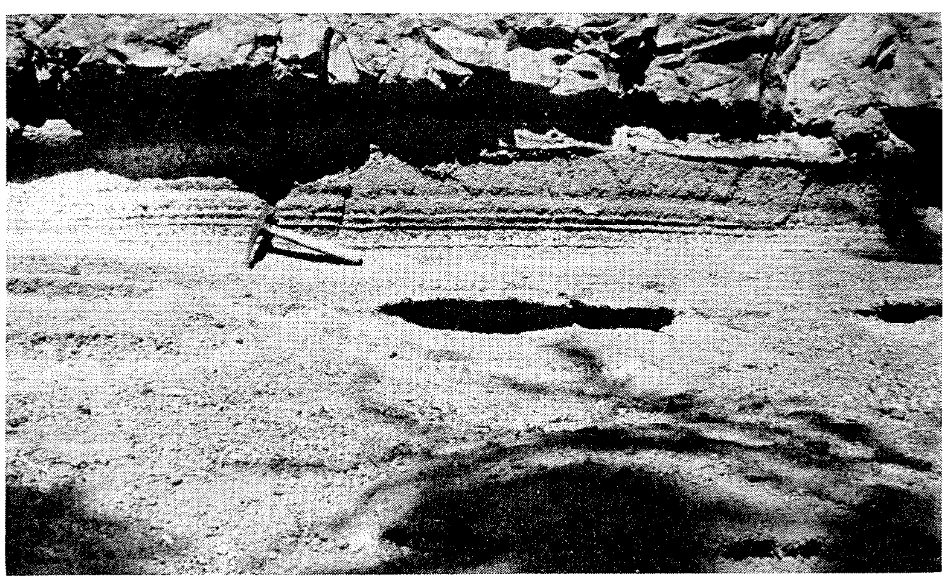

PLATE 9B. Ash bed overlain by lava flow in the Koloa volcanic series in the west wall of the Hanapepe River valley. Photo by D. A. Davis.

A boulder of oligoclase gabbro lying in the bed of Waialae Stream about a quarter of a mile above its junction with the Waimea River, and locally known as the "lightning stone", has been described in detail by Cross (1915, p. 14). The modal feldspar is labradorite, in part intergrown with alkalic feldspar, probably anorthoclase. The normative feldspar is oligoclase (see analysis 11 in the table on page 110). A little olivine is present. The dominant mafic mineral is pink or violet titanian augite, commonly with borders of green aegirine-augite or aegirine. Apatite and titanomagnetite are accessory constituents. Like many Hawaiian gabbros, the rock is open textured, with many miarolytic cavities. The forms of crystals of orthoclase, apatite, and augite projecting into the cavities have been described by W. T. Schaller (1923, p. 85-87). Cross suggested the name "kauaiite" for this rock.

A boulder of similar rock was found by George Hirashima in Koaie Stream half a mile above its mouth. As in the rock from Waialae Stream, grains of titanian augite commonly have thin irregular rims of green aegirine-augite. The few small grains of olivine are largely altered to serpentine. The augite and large grains of sodic labradorite are surrounded by smaller grains of anorthoclase and perthite composed of sodic oligoclase and alkalic feldspar, and a little partly altered nepheline.

Other boulders of gabbroic rock are scattered along the lower course of Waialae Stream, and Waimea River below the mouth of Waialae Stream. They are similar in texture and general appearance to the rock described by Cross, and many of them almost surely came from the same source. Some of them contain several percent of nepheline, in grains ranging from anhedral to euhedral, and from fresh to much altered. C. E. Tilley (personal communication, May 8, 1959) points out that these rocks can be considered olivine-bearing essexites.

A finer grained oligoclase gabbro, exposed on the eastern slope of Papapaholahola hill north of Kalaheo, consists largely of euhedral crystals of augite in a confused matrix of lath-shaped subhedral to anhedral grains of sodic oligoclase containing feathery skeleton growths of red hematite and green monoclinic pyroxene, with many euhedral grains of magnetite. Some interstitial material may be much-altered nepheline. The very abundant peridotite inclusions in this rock have already been mentioned.

Distribution of rock types.—The major rock types appear to be distributed more or less uniformly through the Koloa volcanic series. No concentration of specific types at different stratigraphic levels has been recognized.

The Koloa flows in Wainiha canyon include both nepheline basalt and ankaratrite (analysis 3, p. 110). Lava at the mouth of the adjacent Lumahai Valley is analcime basanite (analysis 9, p. 110). The mass of lavas filling the ancient Hanalei valley are principally olivine basalts, but some nepheline basalts also are present. The similar mass of lavas that spilled southeastward into the Uhau Iole area, possibly from the same vents as the flows in Hanalei valley, also are largely olivine basalts, but ankaratrite was found at their eastern edge on Kuilau Ridge. Olivine basalt, nepheline basalt, and melilite-nepheline basalt have been found in the coastal platform of Koloa lavas between Hanalei and Moloaa Bays. Melilite-nepheline basalt crops out beneath the tuff of the Kilauea cone at the northwest side of Kilauea Bay (analysis 2, p. 110). The Puu Auau shield, just south of Moloaa Bay, is olivine basalt.

Olivine basalt, picrite-basalt or mimosite type, and nepheline basalt all are present in the Anahola drainage basin. The flows exposed along Wailua River are mostly olivine basalt, but both nepheline basalt and melilite-nepheline basalt have been found along Iliiliula Stream and the North Fork of Wailua River. The pillow lavas at the base of Wailua Falls are olivine basalt.

The Kilohana cone, just west-northwest of Lihue, consists of olivine basalt and unquestionably was the source of some of the flows exposed along the South Fork of the Wailua River and in the vicinity of Nawiliwili. Nepheline basalt also occurs in the vicinity of Nawiliwili, and westward along the valley of Huleia Stream.

Nepheline basalt and melilite-nepheline basalt occur along the upper part of Komooloa Stream, and both nepheline basalt and picrite-basalt of the mimosite type (analysis 5, p. 110) have been found in the area just northeast of Kahoaea hill. In that area picrite-basalt containing very abundant inclusions of peridotite has been excavated in the Grove Farm quarry and along the Koloa ditch. Nepheline basalts occur also in the Knudsen Gap between Kahoaea hill and Puu Kolo. Both nepheline basalt and melilite-nepheline basalt issued from the vents just southeast of Puu Kolo, and are exposed between there and Koloa.

The northernmost and southernmost of the so-called "Koloa craters" (Puu Hi and Pihakekua), 2 miles southeast of Koloa, produced olivine basalt; but the second cone from the north in the same line (Puu Hinahina) and the small vent just southeast of the main line (Puu Ainakoa) produced nepheline basalt (analysis 6, p. 110). The latest flow on the island, which issued from Kaluahono Crater, is olivine basalt.

The Manuhonohono lava shield consists of melilite-nepheline basalt (analysis 1, p. 110). Its edges are overlapped by picrite-basalts that appear to have come from a vent between Omau and Poeleele Streams a mile northwest of Puu o Hewa. These in turn are overlain by nepheline basalt from the vent half a mile south of Lawai and the two vents a mile west-southwest of Manuhonohono hill. The picrite-basalt (analysis 7, p. 110) overlain by nepheline basalt at the northwest edge of Kukuiula Bay probably belongs to the flow from the vent between Omau and Poeleele Streams. The vent 1.4 miles south of Lawai produced picrite-basalt, which at the east side of Lawai Bay underlies the nepheline basalt from the more southerly vents.

The mass of lavas that fills the ancient valley south of Black Swamp, between Puu Kolo and Puu Aukai (just east of Hanapepe Valley) consists principally of nepheline basalt (analysis 4, p. 110) and melilite-nepheline basalt, but includes also picrite-basalt and olivine basalt. They came in part from one or more vents at the upper edge of Black Swamp, just south of Kahili peak, but probably came in part also from vents now eroded away that were situated near the ridge line in the vicinity of Kapalaoa peak, which probably also gave rise to the flows along Komooloa Stream.

Papapaholahola cone consists partly of melilite-nepheline basalt and partly of nepheline basalt. The line of cones south of Kalaheo consists mostly of picrite-basalt; but olivine basalt, possibly from the cone containing Nomilo Fishpond, is exposed at Makaokahai point. Picrite-basalt from the Kukuiolono vent, just south of Kalaheo, forms the rim rock along the western edge of Lawai Gulch between Camp Twelve and the sea. Along the road descending the west wall of the gulch half a mile from the sea it is underlain successively by flows of olivine basalt, nepheline basalt, melilite-nepheline basalt, nepheline basalt, and melilite-nepheline basalt.

In the sea cliff 0.3 mile east of Koheo Point a later flow of picrite-basalt overlies unconformably a series of flows consisting, from the top down, of nepheline basalt, picrite-basalt, and olivine basalt (fig. 12). The upper picrite-basalt is in turn overlain a short distance inland by the olivine basalt from Pohakea cone.

The flows that descended the ancient gorge of Koula Stream appear to have been largely picrite-basalts, but one specimen of melilite-nepheline basalt was found by George Hirashima in the area half a mile northeast of Hanapepe Falls, and Hinds (1925, p. 532) reports finding melilite-nepheline basalt in Koula Valley a short distance below Hanapepe Falls. Boulders of nepheline basalt in the headwaters of Manu ahi Stream indicate that rocks of that composition must be present in the region of the divide between Manuahi Valley and Olokele Canyon, but the valley-filling flow in the lower part of Manuahi Valley is olivine basalt. Both olivine basalt and picrite-basalt are present along the Hanapepe River, and where the highways ascends the eastern wall of Hanapepe Valley two series of picrite-basalt flows separated by an unconformity are in turn overlain by the fairly recent olivine basalt flow from Pohakea cone. The peninsula west of Hanapepe Bay consists of olivine basalt, and probably is part of the flow from Pohakea cone.

The area west of the Hanapepe River and south of Kahipa hill is covered mainly by nepheline basalts, but olivine basalt and ankaratrite also are present. Olivine basalts are exposed along Aaka Ridge 1.5 mile northeast of Camp Six, but just east of Mahinauli Gulch half a mile from the ocean nepheline basalt is unconformably overlain by basanite.

Flows along the top of Nonopahu Ridge near Camp Nine include both nepheline basalt and olivine basalt. The later inter-canyon flow in Olokele Canyon is olivine basalt (analysis 10, p. 110), but that in Kahana Valley is nepheline basalt. The flows that descended Waimea Canyon include both olivine basalt and nepheline basalt. The pillow lavas exposed at the Menehune Ditch 0.4 mile northwest of the confluence of the Waimea and Makaweli Rivers are olivine basalt (analysis 8, p. 110).

Hinds (1925, p. 533) reported melilite-nepheline basalt in the summit region about 4 miles east-northeast of Kaholuamanu. Nepheline basalt was collected by Donald Richardson in the same region. Melilite-nepheline basalt reported by Hinds about 2 miles above the mouth of Koaie Stream probably was float from the same general summit region.

CHEMICAL ANALYSES

In the accompanying table are listed the chemical analyses and calculated normative mineral composition of 15 rocks from the island of Kauai. Five of the analyses are quoted from previously published sources. The other 10 are new, and represent rocks studied during the present

Chemical analyses of rocks of the Koloa volcanic series

	1	2	3	4	5	6	7	8	9	10	11
SiO_2	35.84	37.50	39.44	40.30	40.56	40.80	41.96	45.18	45.30	45.48	45.81
Al_2O_3	9.76	9.12	10.24	9.72	8.81	10.68	11.82	11.64	11.76	11.87	11.90
Fe_2O_3	5.09	5.59	6.52	5.73	5.98	7.64	5.17	3.98	3.98	1.98	4.62
FeO	9.59	8.81	7.02	8.16	8.23	6.58	9.02	8.60	8.80	9.87	8.09
MgO	13.98	13.72	14.14	14.79	16.33	13.13	11.68	12.89	12.88	13.28	5.39
CaO	13.78	13.85	12.32	12.72	11.77	12.72	11.52	11.04	10.72	10.97	10.67
Na_2O	2.22	2.69	2.67	3.21	3.13	3.54	3.25	2.45	2.36	2.21	4.28
K_2O	0.83	0.63	1.21	0.96	1.19	0.82	0.57	0.62	0.72	0.77	1.40
H_2O+	3.59	2.35	2.31	0.88	0.27	0.88	0.97	1.30	0.67	0.74	0.53
H_2O-	0.00	1.05	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.23	0.47
TiO_2	3.68	3.21	3.30	2.46	2.73	2.58	2.58	2.08	2.30	1.90	4.05
P_2O_5	1.05	0.90	0.78	0.80	0.82	0.65	0.45	0.36	0.31	0.25	2.20
MnO	0.10	0.15	0.09	0.09	0.15	0.11	0.12	0.11	0.11	0.16	0.17
BaO	0.16	0.07	0.11	0.19	n.d.	0.17	0.21	0.00	0.13	0.04	0.04
SrO	0.00	0.05	0.00	0.00	n.d.	0.00	0.00	0.00	0.00	n.d.	tr.
Cr_2O_3	0.00	0.07	0.00	0.00	n.d.	0.00	0.00	0.00	0.00	0.08	n.d.
CO_2	0.09	0.27	0.00	0.05	n.d.	0.00	0.38	0.00	0.00	0.00	n.d.
SO_3	0.00	tr.	0.03	0.04	n.d.	0.00	0.06	0.00	0.00	n.d.	0.07[a]
Total	99.76	100.19[b]	100.18	100.10	100.03	100.30	99.76	100.25	100.04	99.94[c]	99.69

[a] Reported as S=0.03.
[b] Total includes ZrO_2—0.02, V_2O_3—0.05, NiO—0.04, Cl—0.05.
[c] Total includes ZrO_2—0.00, V_2O_3—0.04, NiO—0.04, FeS_2—0.03.

Norms

	1	2	3	4	5	6	7	8	9	10	11
or	....	....	....	....	....	5.00	3.34	3.34	3.89	4.45	8.34
ab	....	....	....	....	....	....	7.86	16.77	16.77	12.84	29.34
an	14.46	11.12	12.23	8.90	6.39	10.84	16.12	19.18	19.74	20.57	9.17
lc	3.92	2.62	5.67	4.80	5.67	....	....	....	....	....	....
ne	9.94	12.21	12.21	14.77	14.20	16.19	10.51	1.99	1.70	2.92	3.69

	1	2	3	4	5	6	7	8	9	10	11
cs	6.45	....	....	1.11	....	....	....	....	....	....	....
di { wo	11.37	16.39	18.10	18.91	19.49	20.42	16.01	13.69	13.22	13.46	12.41
di { en	8.60	12.47	15.00	14.40	15.10	17.00	11.50	9.70	9.40	8.80	8.50
di { fs	1.58	2.18	0.79	2.51	2.24	0.79	3.04	2.77	2.64	3.70	2.90
ol { fo	18.48	15.32	14.28	15.82	17.99	11.06	12.39	15.75	15.96	17.08	3.50
ol { fa	4.49	3.24	1.02	2.96	2.75	0.61	3.77	4.90	5.00	7.55	1.43
mt	7.42	8.12	9.51	8.35	8.82	11.14	7.66	5.80	5.80	3.02	6.73
il	6.99	6.08	6.23	4.71	5.17	5.02	5.02	3.95	4.41	3.65	7.60
ap	2.35	2.12	2.02	2.02	2.02	1.34	1.01	1.01	0.67	0.47	5.04
cs	....	3.61	....	....	....	....	....	....	....	....	....

1. Melilite-nepheline basalt; Koloa volcanic series, 375 feet altitude in a small canyon on the south slope of Manuhononohono hill. F. A. Gonyer, analyst.

2. Melilite-nepheline basalt; Koloa volcanic series, near old landing on the north shore of Kilauea Bay. W. F. Hillebrand, analyst. Cross, 1915, p. 17.

3. Ankaratrite (mafic nepheline basalt); Koloa volcanic series, at 250 feet altitude on the west wall of Wainiha Canyon, 0.15 mile N 14° W of the power house. F. A. Gonyer, analyst.

4. Biotite-bearing nepheline basalt; Koloa volcanic series, residual boulders at the mouth of a water-transportation tunnel on the east side of the road up Lawai Gulch, 0.18 mile N 4° E of benchmark 436 at Lawai. F. A. Gonyer, analyst.

5. Picrite-basalt of mimosite type; Koloa volcanic series, a dark gray basaltic rock crowded with peridotite inclusions, along the Koloa ditch about one mile northeast of Puu Kahoaea. H. S. Washington, analyst. Washington and Keyes, 1926, p. 343-344; Powers, S., 1920, p. 275.

6. Nepheline basalt, transitional to ankaratrite; Koloa volcanic series, just north of the top of the Koloa lava shield, 0.74 mile N 46° E of Makahuena Point lighthouse. F. A. Gonyer, analyst.

7. Picrite-basalt of mimosite type; Koloa volcanic series, on the south coast, 0.2 mile west of the head of Kukuiula Bay. F. A. Gonyer, analyst.

8. Olivine basalt (pillow lava); Koloa volcanic series, on the west bank of the Waimea River just above Kamenehune Ditch, 0.3 mile northwest of the confluence with Makaweli River. F. A. Gonyer, analyst.

9. Analcime basanite; Koloa volcanic series, southeast side of the small ridge at the east side of Wainiha Bay, 0.3 mile S 37° W of Lae o Kolokolo. F. A. Gonyer, analyst.

10. Olivine basalt; Koloa volcanic series(?), on the east wall of Olokele Canyon at the south end of tunnel 20 of the Olokele Ditch. W. F. Hillebrand, analyst. Cross, 1915, p. 11.

11. Oligoclase gabbro (kauaiite); Koloa volcanic series(?), boulder in Waialae Stream about 0.25 mile above the confluence with Waimea River. W. T. Schaller, analyst. Cross, 1915, p. 15.

Chemical analyses of rocks of the Waimea Canyon volcanic series, Kauai

	1	2	3	4	5	6	7	8	9
SiO_2	47.32	48.06	48.44	48.99	49.34	49.57	50.26	49.95	50.89
Al_2O_3	11.00	11.36	12.11	13.73	13.14	13.26	13.52	12.80	13.22
Fe_2O_3	6.45	4.30	2.33	1.60	2.69	4.01	3.74	1.86	2.03
FeO	6.30	7.88	9.63	10.46	9.09	7.69	7.61	9.70	9.12
MgO	14.55	13.41	14.00	13.53	9.75	9.09	7.88	9.51	8.02
CaO	8.51	9.26	9.22	7.34	10.31	10.24	10.86	10.41	10.56
Na_2O	1.78	1.85	1.85	1.62	2.02	2.30	2.18	2.16	2.17
K_2O	0.28	0.26	0.22	0.27	0.34	0.30	0.34	0.47	0.43
H_2O+	0.67	0.36	0.15	0.27	0.45	0.37	0.38	0.17	0.27
H_2O-	0.44	0.34	0.11	0.10	0.34	0.76	0.34	0.05	0.11
TiO_2	2.33	2.24	1.46	1.73	2.24	2.22	2.44	2.63	2.79
P_2O_5	0.19	0.23	0.19	0.13	0.19	0.18	0.14	0.28	0.27
MnO	0.17	0.19	0.18	0.20	0.17	0.16	0.17	0.16	0.14
BaO	......	0.01	0.03	tr.	......	......	0.02	......	......
Cr_2O_3	......	......	......	0.02	......	......	......	......	......
CO_2	0.01	0.06	0.03	0.24	0.01	0.02	0.03	......	......
Cl	......	0.06	0.00	......	......	......	0.16	......	......
S	......	0.03	0.00	0.04	......	......	0.00	......	......
F	0.02	......	......	......	0.03	0.03	......	......	......
Total	100.02	99.90	99.95	100.38[a]	100.11	100.20	100.07	......	......

[a] Total includes ZrO_2—0.00, V_2O_3—0.06, NiO—0.05, BaO—tr.

Norms

	1	2	3	4	5	6	7	8	9
Q	......	......	......	......	0.66	2.10	4.38	0.12	3.40
or	1.67	1.67	1.11	1.67	1.67	1.67	1.67	2.78	2.56
ab	15.20	15.72	15.72	13.62	16.77	19.39	18.34	17.82	18.35
an	21.13	21.96	24.19	29.19	25.85	25.02	26.13	23.91	25.06
di wo	8.47	9.28	8.58	2.65	10.21	10.44	11.25	10.90	10.75
di en	6.90	6.80	5.70	1.69	6.60	7.30	7.60	6.80	6.57
di fs	0.53	1.58	2.24	0.78	2.90	2.24	2.77	3.43	3.61
hy en	27.20	21.80	15.90	25.20	17.80	15.40	12.10	17.00	13.40
hy fs	1.85	5.15	6.34	11.62	8.05	4.88	4.49	8.71	7.12
ol fo	1.61	3.43	9.38	4.86	......	......	......	......	......
ol fa	0.30	0.71	3.88	2.35	......	......	......	......	......
mt	9.28	6.26	3.25	2.32	3.94	5.80	5.34	2.78	2.94
il	4.41	4.26	2.89	3.19	4.26	4.56	4.56	5.02	5.30
ap	0.34	0.67	0.34	0.30	0.34	0.34	0.34	0.67	0.66
plagioclase	Ab_{42}	Ab_{42}	Ab_{39}	Ab_{32}	Ab_{39}	Ab_{44}	Ab_{41}	Ab_{43}	Ab_{42}

1. Olivine basalt; Napali formation massive phase of aa flow, 0.2 mile south of southernmost hairpin turn on road from Kekaha to Kokee. Analyst, M. Balazs, U. S. Geological Survey.

2. Olivine basalt; Napali formation of Waimea Canyon volcanic series, west wall of Waimea Canyon, 0.27 mile northwest of junction of Mokihana Stream, 4 feet above stream level. Analyst, V. C. Smith, U. S. Geological Survey.

3. Olivine basalt; Makaweli formation of Waimea Canyon volcanic series, east side of Waimea Canyon, on road 0.22 mile northeast of junction of Omao Stream. Analyst, V. C. Smith, U. S. Geological Survey.

4. Olivine basalt; Olokele formation of Waimea Canyon volcanic series, east wall of Olokele Canyon near tunnel 24 on Olokele Ditch. Analyst, W. T. Schaller, U. S. Geological Survey.

5. Basalt; Napali formation of Waimea Canyon volcanic series, dikelet in west wall of Waimea Canyon 500 feet south of Kauai County well. Analyst, M. Balazs, U. S. Geological Survey.

6. Basalt; Napali formation of Waimea Canyon volcanic series, massive phase of lava flow in west wall of Waimea Canyon 500 feet south of Kauai County well. Analyst, M. Balazs, U. S. Geological Survey.

7. Basalt; Napali formation of Waimea Canyon volcanic series, west wall of Waimea Canyon 0.27 mile northwest of junction of Mokihana Stream, at line of old ditch 50 feet above stream level. Analyst, V. C. Smith, U. S. Geological Survey.

8. Tholeiitic basalt; average lava of Kilauea volcano, island of Hawaii. (Average of 43 analyses, partly unpublished.)

9. Tholeiitic basalt; average of 32 analyses of Hawaiian rocks. Kuno, *et al*, 1957, p. 213.

investigation. For the latter, the actually observed modal mineral compositions also are given. It is not wholly certain to which stratigraphic unit the rock of analysis 10 belongs, but from the description given by Cross (1915, p. 11) it is believed that the specimen probably came from a remnant of the late inter-canyon flow of Koloa age in Olokele Canyon. For comparison with the Kauai rocks, there is given in column 8 of the table on page 112, the average composition of 43 basaltic rocks from Kilauea volcano, on the island of Hawaii.

The most striking feature of the analyses is the extreme poorness in silica of many of the lavas of the Koloa volcanic series (analyses 1 to 11). Analysis 1 shows 0.5 percent less silica than any other modern analysis of any Hawaiian lava. Several of the analyzed rocks are unusually rich in titania and phosphorus pentoxide. Several of them are lower in alumina than the average of other Hawaiian rocks except the oceanite type of picrite-basalt. The nepheline basalts, and especially the melilite-nepheline basalts, are richer in lime than the average of any other Hawaiian rock type, and richer in alkalies than any other type more mafic than andesite.

GROUND-WATER RESOURCES

CLIMATE

Kauai lies just south of the Tropic of Cancer in the belt of the northeast trade winds. Its mild and generally uniform climate is determined largely by the latitude, the oceanic environment, and the effect of the mountains of the island on the moist trade winds. Occasional deviations from uniformity are caused by cyclonic storms associated with cold fronts moving from the north and disturbances of tropical origin moving from the east, south, or west. The description here of the various aspects of the climate of the island are based on the climatological data of the U. S. Weather Bureau.

Temperature, wind, and humidity.—The records of 9 stations tabulated below show that at altitudes below about 300 feet the mean monthly temperatures range from about 69°F in February and March to about 77°F during August through October. Differences in exposure to the trade winds apparently have no consistent effect on mean temperatures in the lowlands. Records are not available for higher altitudes, but the mean temperature decreases with height, probably dropping about 3°F for each 1,000-foot increase in altitude. Extreme temperatures

Mean monthly and annual temperatures at 9 stations on Kauai in degrees Fahrenheit
(Data from U. S. Weather Bureau, Climatological Data)

	Station	Altitude (feet)	Years of record	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
927	Eleele	163	34	71.0	71.1	71.4	72.4	74.4	76.2	78.6	77.6	77.4	76.7	74.4	72.1	74.3
936	Koloa	241	48	69.5	69.8	70.4	71.6	73.5	75.4	76.2	76.8	76.4	75.6	73.2	71.1	73.3
965	Makaweli	140	45	70.9	71.3	71.8	73.1	75.0	77.0	78.2	78.7	78.2	77.0	74.6	72.4	74.8
1013	Puhi	329	18	69.6	69.8	69.6	71.0	72.4	74.7	75.4	76.1	75.6	74.6	72.7	70.7	72.7
1020	Lihue	207	47	69.4	73.5	70.0	71.3	73.4	75.3	75.9	76.9	76.7	75.3	72.8	70.9	73.1
	Lihue Airport	115	4	70.1	70.1	70.6	72.0	71.5	76.2	77.4	78.1	77.8	76.5	73.6	71.5	74.0
1026	Mana	11	42	70.1	70.7	71.0	72.4	74.6	76.4	77.4	78.1	77.6	76.3	73.8	71.4	74.2
1112	Kealia	11	43	70.9	71.1	71.6	73.2	75.0	77.1	78.1	78.9	78.6	77.4	74.9	72.7	75.0
1134	Kilauea	317	48	69.4	69.6	69.7	71.1	72.9	75.0	75.7	76.3	76.0	74.9	72.7	70.4	72.8

recorded at Lihue airport, which is on the east coast, are 51° and 88°. Lower temperatures occur in the mountains.

The prevailing winds are the northeast trade winds, which are maintained by the permanent high-pressure cell north of the Hawaiian Islands and which blow about 80 percent of the time. The trade winds are interrupted at intervals, mostly during the winter months, by the cyclonic disturbances passing over or near the island, which are known as kona storms. Sultry calms occur during these storms, which usually last a few days, or the winds are variable, blowing mostly from the south to west.

The average relative humidity at Lihue Airport is 82 percent in the early morning hours and 67 percent in the middle of the afternoon. On the dry leeward side of the island the humidity usually is about 10 percent lower.

Rainfall.—Records of mean monthly and mean annual rainfall at 60 stations on Kauai are given in the following table, and the distribution of rainfall over the island is shown in figure 20. The outstanding feature of the rainfall is the great range over short distances, which is illustrated by a comparison of the mean annual figure of 466 inches at Mount Waialeale with that of 21 inches at Mana, 18 miles to the southwest. The high rainfall in the mountainous areas is the result of persistent precipitation from the moist trade-wind air as it is cooled in flowing upward and over the mountains. Rain from cyclonic storms falls at random over the island, and in the long term its areal distribution apparently is relatively uniform in contrast with the strong orographic pattern that dominates the isohyets in figure 20. A comparison of the monthly distribution of rainfall in various parts of the island is shown in figure 21. The cyclonic component is greatest during winter months and makes up a large part of the rainfall on the coast and on leeward slopes where trade-wind rainfall is low. Cyclonic rainfall is the cause of the winter maximum and summer minimum which the graphs show for coastal and leeward areas. The cyclonic component also contributes materially to the rainfall in the wet uplands, but it is masked by the high summer trade-wind rainfall.

Severe storms.—Storms that interrupt the trade-wind regimen occasionally bring very heavy rains, strong winds, and high seas to the island. In November 1955 an extra-tropical storm dropped almost 20 inches of rain at Kilauea in 13½ hours, and in January 1956 more than 40 inches fell in 30 hours at Kilauea from a storm moving with a cold front from the northwest. Between 1950 and 1957 at least three tropical storms of hurricane intensity passed near Kauai. In August 1950 hurricane Hiki hovered north of the island and caused winds of 68 miles per hour at Kilauea lighthouse and 52 inches of rainfall in 4 days at Kalanahuluhulu ranger station in the north part of the island. Hurricane Della, in September 1957, passed a few hundred miles west of Kauai and caused heavy surf on the south shore. Early in December 1957, Hurricane Nina, moving northward from the vicinity of Palmyra Island, passed 120 miles southwest of Kauai and caused very high surf on the south shore. During the passing of the storm, wind speeds of 90 miles per hour were recorded at Kilauea lighthouse, and 20 inches of rain fell in 14 hours at Wainiha on the north side of the island.

Mean monthly and annual rainfall on Kauai through 1956 in inches
(From U. S. Weather Bureau, Climatological Data, and records of Pineapple Research Institute, Hawaiian Sugar Planters' Association, and U. S. Geological Survey)

	Station	Altitude	Years of Record	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1007	Aakukui	345	47	7.98	5.52	6.29	4.91	4.62	3.36	4.82	5.04	4.41	5.46	5.55	6.70	64.66
1111	Anahola	40	26	6.43	5.80	6.01	4.56	3.27	1.87	2.28	2.83	2.28	4.56	4.26	4.90	49.05
	Brydeswood	720	47	7.16	5.08	5.66	3.62	3.56	3.06	4.04	4.44	3.59	4.41	4.80	6.49	55.91
934	East Lawai	441	55	7.80	5.65	6.08	4.47	4.18	3.66	5.17	5.29	3.98	4.97	5.22	6.66	63.13
927	Eleele	163	56	4.82	3.63	3.12	1.83	1.33	1.12	1.27	1.71	1.55	2.32	2.52	3.92	29.14
1021	Grove Farm	200	72	7.01	5.28	5.20	4.02	3.93	2.27	2.33	3.27	2.91	4.59	4.80	6.17	51.78
1110	Halaula	253	55	6.58	4.54	5.05	4.11	2.84	1.72	2.50	2.35	2.22	3.79	4.65	5.16	45.51
1006	Halenanaho	490	25	7.33	6.98	6.78	4.89	4.69	4.17	4.93	6.02	4.81	5.64	6.23	6.69	69.16
1053	Hanalei tunnel	1218	29	15.04	14.02	14.79	15.25	12.78	10.41	13.19	15.29	12.25	12.30	14.33	15.19	164.84
1022	Hanamaulu	175	60	7.80	4.92	4.85	3.97	3.80	1.99	3.10	2.54	2.96	4.29	4.99	6.11	51.32
945	Hukipo	800	16	4.98	3.28	3.01	2.26	.94	.23	.43	1.21	.50	1.56	2.18	4.79	25.37
1050	Iliiliula Intake	1070	22	14.80	13.34	16.18	14.17	14.03	11.55	14.99	17.18	10.98	12.78	13.50	15.37	168.87
1086	Intake Wainiha Power Co.	700	50	17.85	13.43	19.53	18.47	12.88	7.86	12.44	12.17	8.08	11.39	15.13	20.83	170.06
1077	Kalalau	850	18	......	......	......	......	......	......	......	......	......	......	......	......	69
1005	Kaluahonu	330	33	7.02	6.21	6.88	5.96	6.01	4.33	6.09	6.17	4.73	5.59	6.36	8.24	73.59
1104	Kapaa Stable	175	16	6.36	5.91	6.14	4.47	2.64	2.03	4.46	2.82	2.41	4.81	5.95	6.21	52.21
1112	Kealia	9	57	6.04	4.22	4.50	3.67	2.33	1.74	2.56	2.18	2.18	3.45	4.21	4.86	41.94
1044	Keanakua	4450	31	......	......	......	......	......	......	......	......	......	......	......	......	134
944	Kekaha	9	62	3.70	2.83	2.16	1.21	.79	.61	.60	1.09	.77	1.62	1.55	3.44	20.37
1134	Kilauea	317	71	7.60	5.42	6.59	6.29	5.16	3.26	4.39	4.48	4.12	5.18	6.13	7.20	65.82
1135	Kilauea Field 17	415	26	9.13	8.07	9.63	9.04	8.56	5.50	6.79	7.94	5.81	6.59	7.36	9.27	93.69
1084	Kilohana Alakai	4032	15	......	......	......	......	......	......	......	......	......	......	......	......	188
1033	Kolo	36	20	4.64	2.92	3.03	1.79	1.12	.54	.60	1.10	1.04	2.06	1.58	3.55	23.97
936	Koloa	240	70	7.79	5.38	6.30	4.86	4.43	3.57	5.01	5.20	4.06	4.72	5.27	7.03	63.62
995	Koloa Field 52	600	10	6.02	5.53	11.83	7.95	7.63	8.64	11.74	7.16	6.64	9.82	13.61	18.94	115.51
994	Koloa Mauka	640	52	11.33	8.51	9.29	8.12	7.59	6.35	8.40	8.82	7.31	8.12	8.69	10.20	102.73

937	Koloa Mill	155	32	5.46	4.97	4.87	3.64	2.30	1.88	2.93	3.48	2.64	3.44	4.13	5.89	45.63
1137	Koloko Reservoir	737	23	9.50	7.83	10.04	8.86	7.64	5.55	6.03	7.38	4.99	7.22	7.50	9.31	91.85
935	Kukuiula	104	54	5.69	4.08	4.17	2.52	2.03	1.55	2.20	2.69	2.08	3.04	3.30	5.39	38.74
1020	Lihue	207	52	7.00	5.22	5.03	4.04	4.12	2.39	3.20	3.24	3.01	4.79	4.71	5.88	52.63
	Lihue Airport	115	6	6.23	4.44	4.07	3.03	2.51	1.65	1.87	2.27	2.20	4.63	4.24	5.35	42.49
941	Mahaulepu	98	52	7.38	5.49	6.01	4.51	3.90	2.58	3.52	3.86	3.41	3.94	4.84	6.97	56.51
965	Makaweli	140	65	3.73	3.45	2.34	1.31	.99	.53	.65	1.14	.98	1.93	1.97	3.52	22.54
1017	Malumalu	250	16	5.62	6.32	6.22	4.42	4.02	2.38	2.57	3.41	2.67	4.14	6.12	7.62	55.61
1026	Mana	11	52	3.77	2.53	2.23	1.41	.99	.82	.79	1.23	.97	1.63	1.84	3.37	21.58
1083	Mohihi upper	3500	28	......	......	......	......	......	......	......	......	......	......	......	......	82
1085	Mohihi Koaie	3920	18	......	......	......	......	......	......	......	......	......	......	......	......	89
1145	Moloaa	330	30	6.31	5.40	5.94	4.68	3.40	1.78	2.58	2.77	2.08	4.18	4.81	5.21	49.14
1047	Mt. Waialeale	5075	34	......	......	......	......	......	......	......	......	......	......	......	......	466
1035	Niu Ridge	1250	17	5.55	2.90	3.04	2.13	1.42	.81	.80	1.12	1.03	2.25	1.91	4.56	27.52
1051	N. Wailua Ditch	1110	29	14.62	14.82	14.81	15.65	13.63	11.62	14.80	17.19	13.66	12.78	14.12	15.26	172.96
997	Papuaa	548	41	10.22	6.89	8.29	7.16	6.66	5.68	7.53	8.12	6.59	7.21	7.62	9.82	91.79
1080	Paukahana	3732	30	......	......	......	......	......	......	......	......	......	......	......	......	80
1115	Powerhouse Wainiha	101	49	12.12	8.34	13.28	12.80	8.56	5.86	9.35	9.47	6.13	7.46	9.67	12.62	115.66
1117	Princeville Ranch	295	47	9.89	6.59	8.85	8.85	6.73	5.17	6.11	6.87	5.44	6.56	7.76	8.91	87.73
1040	Puehu Ridge	1660	17	6.04	3.44	3.10	2.76	2.01	.97	1.13	2.10	1.18	2.55	2.19	5.11	32.58
1013	Puhi	329	21	6.83	6.94	6.93	5.30	5.09	3.18	4.00	4.88	3.85	5.98	5.17	7.11	65.26
940	Puuhi	80	50	5.11	3.94	3.61	2.20	1.83	1.18	1.64	2.02	1.75	2.57	2.80	4.38	33.03
1011	Reservoir 5	385	21	6.80	4.56	7.00	5.17	4.99	3.36	4.44	5.41	3.96	6.13	5.28	6.73	63.83
1004	Reservoir 6	420	43	7.93	5.90	6.59	5.16	4.63	3.75	5.14	5.60	4.86	5.40	6.09	7.10	68.15
930	Wahiawa	213	52	5.02	3.78	3.42	2.25	1.63	1.33	1.77	2.16	1.75	2.73	2.64	4.25	32.73
990	Wahiawa Mtn	2100	56	14.58	10.68	13.16	12.65	12.36	10.68	14.04	14.15	10.89	11.11	11.32	14.14	149.76
1054	Waiahi lower	550	27	10.21	7.86	10.95	8.78	9.21	8.39	9.46	10.86	8.95	9.14	10.90	10.79	115.50
1052	Waiahi upper	780	24	11.53	10.25	12.31	10.81	9.96	9.85	11.79	13.35	9.22	9.91	10.10	12.19	131.27
1082	Waiakoali	3450	31	......	......	......	......	......	......	......	......	......	......	......	......	77
943	Waiawa	38	62	3.42	2.47	1.75	1.36	.79	.77	.64	1.19	.74	1.77	1.45	3.19	19.54
947	Waimea	20	44	3.18	3.09	2.01	1.22	.87	.44	.57	1.03	.74	1.64	1.47	3.40	19.66
931	West Lawai	210	55	5.83	4.27	4.45	2.67	2.24	1.92	2.64	2.81	2.48	3.31	3.57	4.96	41.15

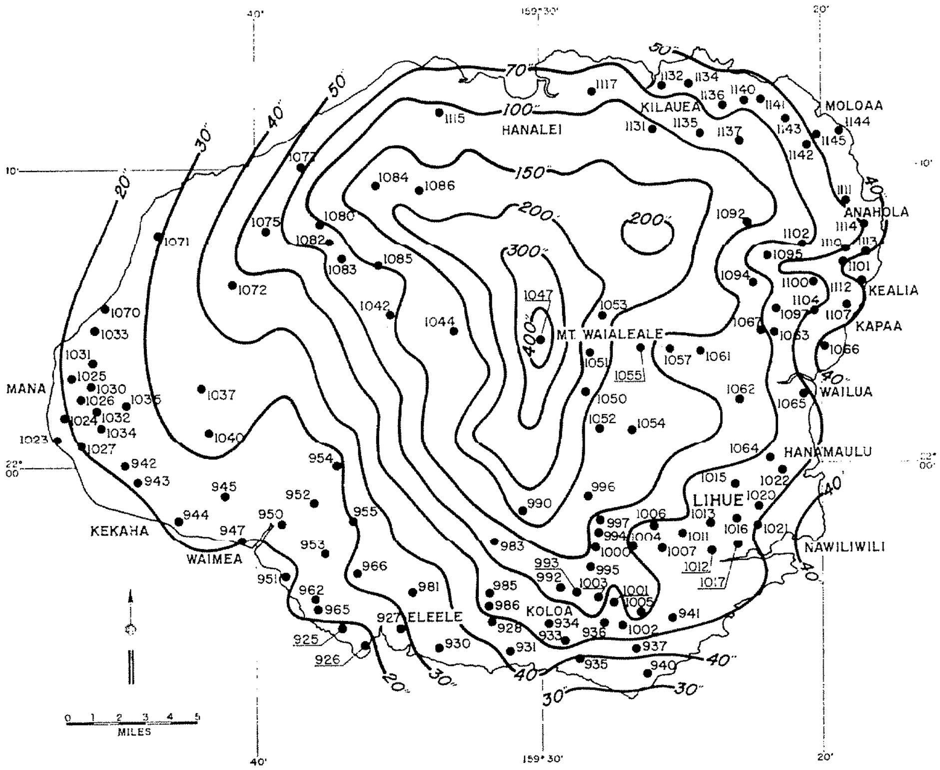

Figure 20. Map of Kauai showing distribution of rainfall and rain gages. Isohyetal lines by U. S. Weather Bureau.

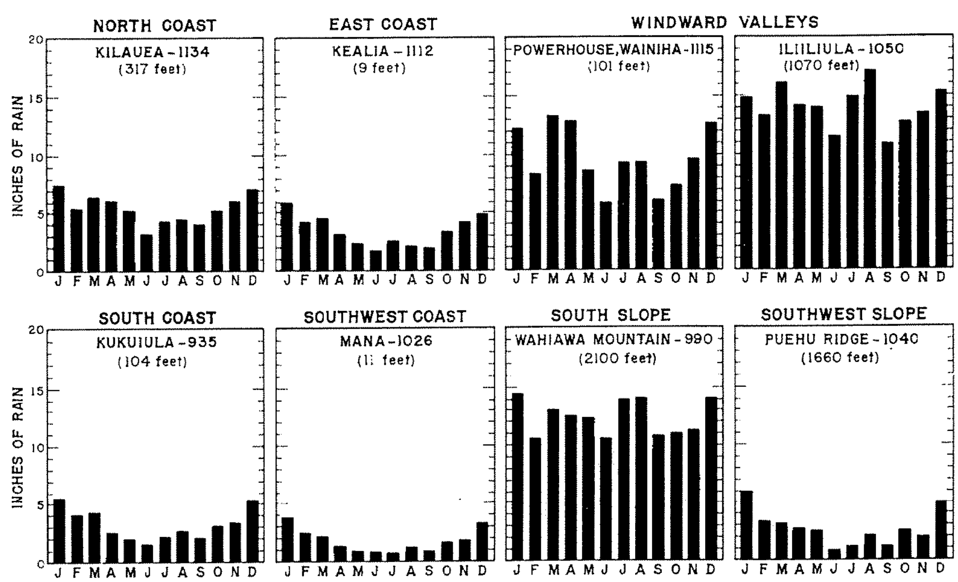

Figure 21. Comparative monthly distribution of rainfall on Kauai.

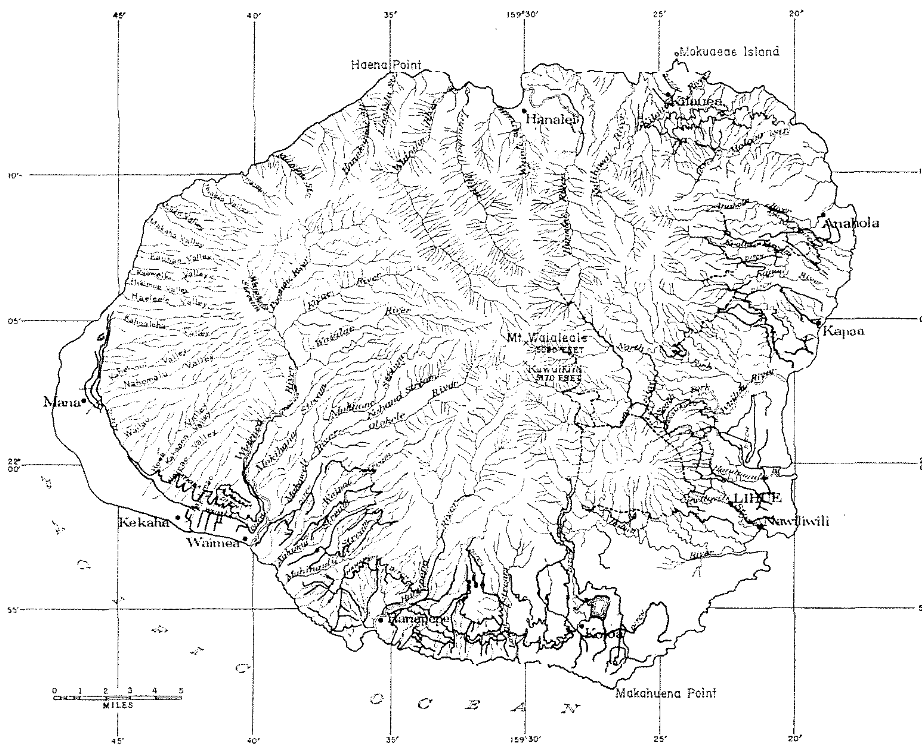

Figure 22. Map of Kauai showing streams and main ditches.

SURFACE WATER

Perennial streams flow to the sea in all parts of Kauai, except in the sector west of the Waimea Canyon (fig. 22). The major streams are large and have relatively uniform flow in comparison with those of the other islands of Hawaii. All the large streams head in the rainy uplands, and, in at least their upper reaches, they flow in deep, steep-walled valleys. The low flow of the streams is maintained by direct run-off from persistent rainfall in the mountains and by the discharge of water from high-level springs and seeps. Water in the streams is extensively developed for sugar-cane irrigation and is transported long distances through complex ditch and tunnel systems to the irrigated fields (fig. 22). Daily discharges of many of the streams and ditches of Kauai are published in the annual surface water supply papers of the U. S. Geological Survey.

Numerous small reservoirs, which are mostly parts of the ditch systems in the lowlands, provide short-term storage of irrigation water during its flow from points of diversion to the sugar-cane fields. Two relatively large reservoirs are the Alexander Reservoir, which is formed by a dam across Wahiawa Stream and which has a capacity of about 800 million gallons, and the Koloa Reservoir near the town of Koloa, which holds 2,500 million gallons and which stores water diverted from streams, mostly from tributaries of the Wailua River.

A 3,600-kw hydroelectric power plant is operated on the north side of the island by water from the Wainiha River, and a 1,000-kw plant by water from the Alexander Reservoir. Several smaller plants, ranging from 120 to 700 kw in capacity, operate at drops in the irrigation ditch systems.

GROUND WATER

Source and Occurrence of Ground Water

Rainfall is the source of all fresh water in Kauai. A part of the rainfall runs off directly to the sea in streams, a part escapes into the atmosphere by evaporation and transpiration, and a part moves downward through the soil and rocks to the zone of saturation and becomes ground water. The ground water moves slowly through the rocks and eventually reaches points of discharge at springs and seeps in stream valleys and along the shore.

The principal aquifers, or water-bearing rocks, of Kauai are the lava flows that make up the bulk of the island. The openings in the lavas, which contain the ground water and through which water moves, consist of interstitial openings in the clinker associated with aa flows, cracks and fissures in lava beds formed by the shrinking and collapse of the beds during or soon after placement and by cooling of the lava, openings between lava flows, lava tubes, openings along joints and faults, and gas vesicles.

In unweathered rocks water moves freely through the openings in clinker and between lava flows and those formed by shrinkage and collapse of beds; these openings are the most important to the ground-water supply. Lava tubes usually are capable of transmitting large quantities of water, but the tubes apparently are not common in the rocks of Kauai. Openings along joints and faults are very small and are not significant in the ground-water supply. Vesicles form a large part of the total volume of openings in many lava flows, but, because of their lack of connection, they contribute little to the water-bearing capacity of rocks.

Thin-bedded lava flows are the best aquifers in the island. These flows occur mostly in the extra-caldera lavas in the flanks of the island where the lavas moved down relatively steep slopes. In thick-bedded flows the relative amounts of clinker and the size and frequency of cracks and other openings that transmit water freely are less than in thin flows, and the water-bearing capacity of thick-bedded sections of lava is comparatively low. Thick flows are most common in the large caldera and in other places where lavas ponded or accumulated on surfaces of gentle slope.

In the process of weathering the mineral constituents of volcanic rocks expand during chemical decomposition. This expansion reduces the sizes of openings in the rocks, and weathering usually is accompanied by a considerable reduction in permeability and a decrease in the water-bearing capacity of the rocks.

Pyroclastic rocks have a minor role in the ground-water supply of Kauai. Unweathered cinder has high permeability, but this material does not occur in significant volume in the zone of saturation. Most ash and tuff deposits are fine grained and moderately to thoroughly weathered and have very low permeability. Joints in tuff locally may carry small amounts of water. In some places, weathered ash beds between more permeable lava flows hold up bodies of perched water in the overlying lavas.

Basal Ground Water

The basal ground water in an island was described by Meinzer (1930) as the great body of water below the main water table that lies near sea level. Because of more or less continuous recharge of water from rainfall, the upper part of this great body of water is fresh or relatively fresh water which floats on heavier sea water which saturates the rocks to an unknown depth below sea level.

The Ghyben-Herzberg lens.—The fresher part of the basal ground-water body is commonly called the Ghyben-Herzberg lens, or the Herzberg lens, after W. Badon Ghyben (1888-1889) and Alexander Herzberg (1901), who described the occurrence of fresh water floating in and displacing sea water in permeable rocks in the coastal area of the Netherlands and in islands of the North Sea, respectively. This type of occurrence of fresh water in Hawaii was recognized many years ago by Andrews (1909) and possibly by others, but it was first fully appreciated in Hawaii by H. S. Palmer (1927 and 1957) in his study of the geology of the Honolulu artesian system. Subsequent studies by Wentworth (1947, 1948, 1951), Stearns and Vaksvik (1935), Stearns and Macdonald (1942), and Cox (1954) have added much to the understanding of the occurrence of basal ground water in Hawaii and the hydrologic and geologic factors that promote and control the existence of the Ghyben-Herzberg lens in volcanic islands.

Under the assumptions of static conditions which were implicit in the early enunciations of the behavior of the Ghyben-Herzberg lens, the formula $h = \frac{t}{g-1}$ defines the location of the bottom of the fresh-water lens floating in sea water. In this equation, h is the distance to which the fresh water extends below sea level; t is the height of the free fresh-water surface above sea level; g is the specific gravity of sea water; and 1 is the specific gravity of the fresh water. When the commonly used value of 1.025 for the specific gravity of sea water is placed in the equation the value of h becomes 40t, that is, the depth of the base of the fresh water below sea level is 40 times the height of the water table above sea level.

This expression for a static balance between fresh and sea waters takes into consideration the difference in the specific gravities of the two waters, which is a principal factor in the thickness and behavior of a Ghyben-Herzberg lens. The lens is, however, a dynamic system through which fresh water moves from an area of recharge to points or zones of discharge, and the energy involved in this movement affects the shape of the lens and the depth of the fresh water. Theoretical aspects of the depth and shape of a dynamic lens are discussed by Hubbert (1940) in his treatise on the motion of ground water. In the practical matter of water supplies in the Ghyben-Herzberg lens, the most important factors are the rate of recharge of fresh water, the permeability of the rocks that contain the water and control its movement, and the effects of mixing of the fresh water with the sea water in which the lens floats.

Fresh water enters the lens by intermittent recharge from rainfall and moves through it to the sea where continuous, but fluctuating, discharge occurs at springs and seeps in a narrow zone at the shore. In an aquifer of a given uniform permeability the thickness of the lens varies with the amount of water moving through it; that is, the thickness increases as the rate of recharge increases. In the case of a fixed rate of recharge the lens is thinner in an aquifer having high permeability than in one having low permeability.

The thickness of a lens may be affected also by relatively impermeable deposits that overlie the aquifer above and below sea level and separate it from the sea water. These deposits form a caprock on the aquifer which retards the escape of water from the lens and causes the fresh water to be thicker than it would be if the deposits were absent. The magnitude of the effect can range from the minor local thickening caused by sandy beach deposits having permeabilities only a little less than the underlying lava flows to the formation of a very thick lens as the result of the presence of a caprock of extensive coastal deposits of tight alluvium.

The complexity of the geology of Kauai and the wide range in the permeability of the lava flows are not favorable for the formation of large, well-developed Ghyben-Herzberg lenses, such as those in the islands of Oahu and Maui. In much of Kauai the rocks above and below sea level are thick bedded, massive, dense, and of generally low permeability. In these rocks the fresh water may not occur as buoyant systems that are characteristic of well-developed Ghyben-Herzberg lenses in rock of higher permeability. In some areas of higher permeability the aquifers are cut by dikes or other structures that limit the extent of the fresh-water lenses. In other areas, where the extent of permeable rock is large, the recharge of fresh water apparently is too small to maintain well-developed lenses of fresh water.

A zone of transition always exists between the fresh part of the Ghyben-Herzberg lens and the sea water under the lens. This zone is produced by mixing that occurs during movement of the interface between the fresh and salt waters, and its thickness is dependent largely on the magnitude of the movement of the interface. Under natural conditions the principal causes of the movement are the rise and fall of tides in the ocean that are transmitted into the sea water in the rocks, and the fluctuations in the thickness of the fresh-water lens that accompany changes in the rate of recharge of fresh water. Changes in recharge result from seasonal and long-term fluctuations in rainfall, during which the lens shrinks or expands as the recharge from rainfall decreases or increases. Pumping from wells in the lens at rates that are sufficient to affect the thickness of the lens also causes movement of the interface. The combined effects of the tide and the fluctuations in the thickness of the lens are greatest near the shore, and in some coastal areas, especially where the permeability of the rock is high, the transition zone may be so thick that the near-shore part of the lens is largely brackish.

High-Level Ground Water

High-level ground water is water that occurs above the basal aquifers and is perched or impounded by relatively impermeable rocks. Lava

Plate 10A. Base of a lava flow of the Koloa volcanic series resting on conglomerate of the Palikea formation in the south wall of Kahana Valley. Photo by G. A. Macdonald.

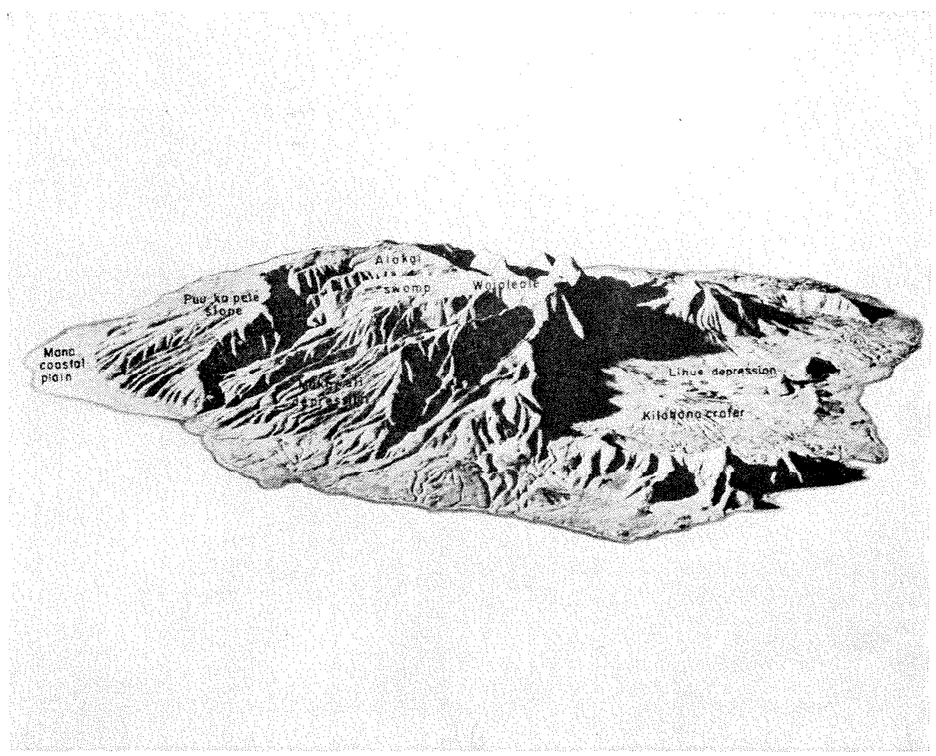

Plate 10B. Photograph of a topographic model of Kauai at the University of Hawaii. The model is viewed from the south and shows the Lihue depression at the right on the eastern side of the island. In the left center is the Makaweli depression with the Waimea Canyon at its western edge. Photo by Experiment Station, Hawaiian Sugar Planters' Association.

flows are the principal high-level aquifers, but in a few places perched water occurs in unweathered alluvial fill in valleys, and meager amounts are contained locally in pyroclastic rocks.

The perched water in lava flows is held up mainly by beds of ash, soil, and dense lava flows, and less commonly by weathered or consolidated alluvium. Perched water in appreciable bodies is rare in the lava flows in the uplands of Kauai, where it is apparent only in seeps and a few small springs in valley walls. It occurs more extensively in the lava flows under the lower slopes of the island, but many of the saturated zones are thin, or, where the aquifers are thick, the permeability generally is low.

Dikes cutting lava flows are relatively impermeable barriers to the movement of ground water, and in some places their spacing and orientation is such that they form compartments that impound high-level ground water. The dike-impounded water bodies are roughly prismoidal, and they may have vertical dimensions that are as great or greater than the horizontal. Some leakage probably occurs through the dikes, but most of the water discharging from the compartments flows over the crests of the dikes. This overflow commonly appears in springs at notches cut in the dikes by streams.

High-level water impounded by dikes occurs notably along the Napali Coast and in the Makaleha Mountains of Kauai, but in most of the island dikes are absent or their orientation and spacing are not favorable for the confining of large supplies of high-level water. In some places dikes cutting basal aquifers retard the seaward movement of ground water and probably cause the basal water table to stand somewhat higher than it would if the dikes were absent.

HANALEI DISTRICT

The north boundary of the Hanalei District is the section of the north shore of Kauai lying between Awaawapuhi Valley and Moloaa Bay (pl. 1). The boundary on the south runs in an easterly direction from the mouth of Awaawapuhi Valley to Kilohana, and thence southeastward along Wainiha Pali to Mount Waialeale. At Mount Waialeale it turns about 90 degrees and extends northeastward to Moloaa Bay.

West of the Hanalei River the rocks are deeply eroded lava flows of the Waimea Canyon volcanic series (pl. 1). The flows of the Napali formation form a band 3 to 4 miles wide along the coast from Awaawapuhi Valley to the Hanalei River valley. In the part of the southern salient of the district lying between the valleys of the Wainiha and Hanalei Rivers the rocks are mostly caldera-filling lavas of the Olokele formation. East of the Hanalei River the lavas of the Koloa volcanic series underlie the areas of relatively gentle slope. These lavas of the Koloa abut against the steep west and north faces of the Makaleha Mountains, which are made up of rocks of the Napali formation.

Basal ground water.—Along the Napali coast numerous dikes cutting the lava flows of the Napali formation prevent the occurrence of basal ground water, except possibly in small bodies. Considerable quantities of ground water undoubtedly discharge near sea level from springs along the rocky coast, but the flow is largely from dike compartments that have been breached by marine erosion and into which high-level ground water moves from adjacent inland compartments. Because of the rugged, generally inaccessible character of the coast, none of this water can be developed readily.

The lava flows of the Napali formation along the coast between Ka Lae o Kailio and Hanalei also are cut by dikes, but in much of this area sedimentary deposits underlying the coastal flats retard the seaward flow of ground water from the lava flows. Consequently, the small bodies of basal water here have higher levels than those along the Napali coast. In the sea cave at Ka Lae o Kailio, which extends below the water table, the water level is about 5 feet above sea level. At well 70 on the east side of Hanalei Bay (pl. 1) the basal water is under artesian pressure and rises to 10 feet above sea level. Lower water levels occur at the ends of spurs where the coastal plain is very narrow or is absent. A part of the seaward discharge of the basal water probably occurs through the coastal-plain deposits; however, none of it causes large visible springs. Discharge probably occurs along parts of the inland edge of the coastal plain into marshy areas and in stream channels cut below the basal-water level, but this also apparently is diffused flow.

The only development of basal water in this area is at well 70, which struck artesian water in lava underlying alluvial fill in Hanalei Valley at 167 feet below sea level, and which flows at the rate of about 20 gallons per minute (gpm) at the ground surface, 6 feet above sea level. The water has a chloride content of about 90 parts per million (ppm). Basal water of this quality probably can be found under most of the coastal plain, but the depths to water-bearing lava flows are variable and unpredictable. The best sites for wells probably are at the inland edge of the coastal plain at places where dikes are most widely spaced.

The inland extent of the basal ground water west of the Hanalei River valley cannot be defined clearly, but it ranges from a few hundred feet to a few thousand, depending on the presence of dikes. Probably no basal water occurs in the lavas of the Olokele formation.

The lava flows of the Napali formation in the west and south slopes of the Makaleha Mountains, which lie east of the Hanalei River, may contain basal ground water, but no wells have been drilled into these rocks.

The lava flows of the Koloa volcanic series underlying the broad, relatively gently sloping surface between Hanalei Bay and Moloaa Bay probably have generally low permeability. The basal water table in these rocks, therefore, may stand relatively high above sea level, except at the shore. No wells have been drilled in these rocks.

High-level ground water.—Water confined by dikes occurs extensively in the lava flows of the Napali formation along the Napali Coast, where it supplies numerous, mostly small springs that flow in the steep-walled valleys. Some streams in the Kalalau Valley are fed by high-level ground water impounded by the relatively impermeable breccia associated with the fault trending northeastward across the valley.

The low flow in some tributaries to the northern reach of the Wainiha River is maintained largely by springs rising from dike compartments in the Napali formation. Studies made by Cox show that high-level water might be developed in the west wall of the valley north of the caldera boundary, but the capacities of individual dike compartments probably are small. Tunnels 2,000 to 3,000 feet long probably would be necessary to intercept the spring water in the tributaries. The lava flows of the Napali formation in the ridges east of the Wainiha River valley contain some high-level water, but none apparently is in compartments having large capacity. Water confined by dikes occurs in the Napali lava flows in Kekoiki ridge east of Kalihiwai River. It is estimated that dike water flowing in Halaulani Stream on the north slope of the ridge might be developed by means of one or more tunnels 1,000 to 5,000 feet long.

Only a few dikes cut the caldera-filling lava flows of the Olokele formation, and probably very little high-level water confined by dikes occurs in these rocks. Some perched-water bodies are held up by thick, dense lava flows, but the water discharging from them is diffused in small springs and seeps in valley walls and stream channels.

Water perched above sea level on soil or ash beds and on dense lava flows probably occurs extensively in the rocks of the Koloa volcanic series in the Hanalei District, but most of these water bodies probably are discontinuous and probably none could be the source of large quantities of water. This perched water is the source of supply for two small communities (tunnels 1 and 2, pl. 1). The water developed in the tunnels is perched on soil or ash. Deeper perched water probably occurs in the rocks of the Koloa, but no wells have been drilled into it.

KAWAIHAU DISTRICT

The Kawaihau District is a roughly triangular area bordered on the east by the section of the shoreline lying between Moloaa Bay and Lae Alakukui and on the northwest and southwest by irregular boundaries running northeastward and southeastward to the shore from Kekoiki peak. The rocks of the rugged Makaleha Mountains and Puu Ehu ridge are lava flows of the Napali formation of the Waimea Canyon volcanic series. The more gentle slopes bordering the mountains are underlain by lava flows of the Koloa volcanic series (pl. 1).

Basal ground water.—The records of test hole T-14 and well 80 (see pl. 1 and the records of wells) at the foot of the northeast slope of Puu Ehu ridge indicate that basal water having a head about 50 feet above sea level occurs in the ridge in lava flows of the Napali formation. This relatively high head is caused by the confining or impounding effect of the lava flows of the Koloa volcanic series, which were deposited against the steep, northward sloping, eroded and weathered surface of the Napali lavas. The results of a 110-hour pumping test at well 80 suggest that this basal aquifer is divided into compartments, possibly by dikes that cut the Napali formation. The continuing drawdown in test hole T-14 and well 80 during pumping, which is shown in figure 23, indicate that a pumping rate of about 300 gpm probably exceeds the capacity of the aquifer in the vicinity of well 80. Areas having higher capacities than that supplying well 80 may exist in the Puu Ehu ridge, but finding them would require the drilling and pumping of test wells. The water in the aquifer probably discharges into the overlying rocks of the Koloa volcanic series, in which the basal heads appear to be lower than those in the Napali lava flows.

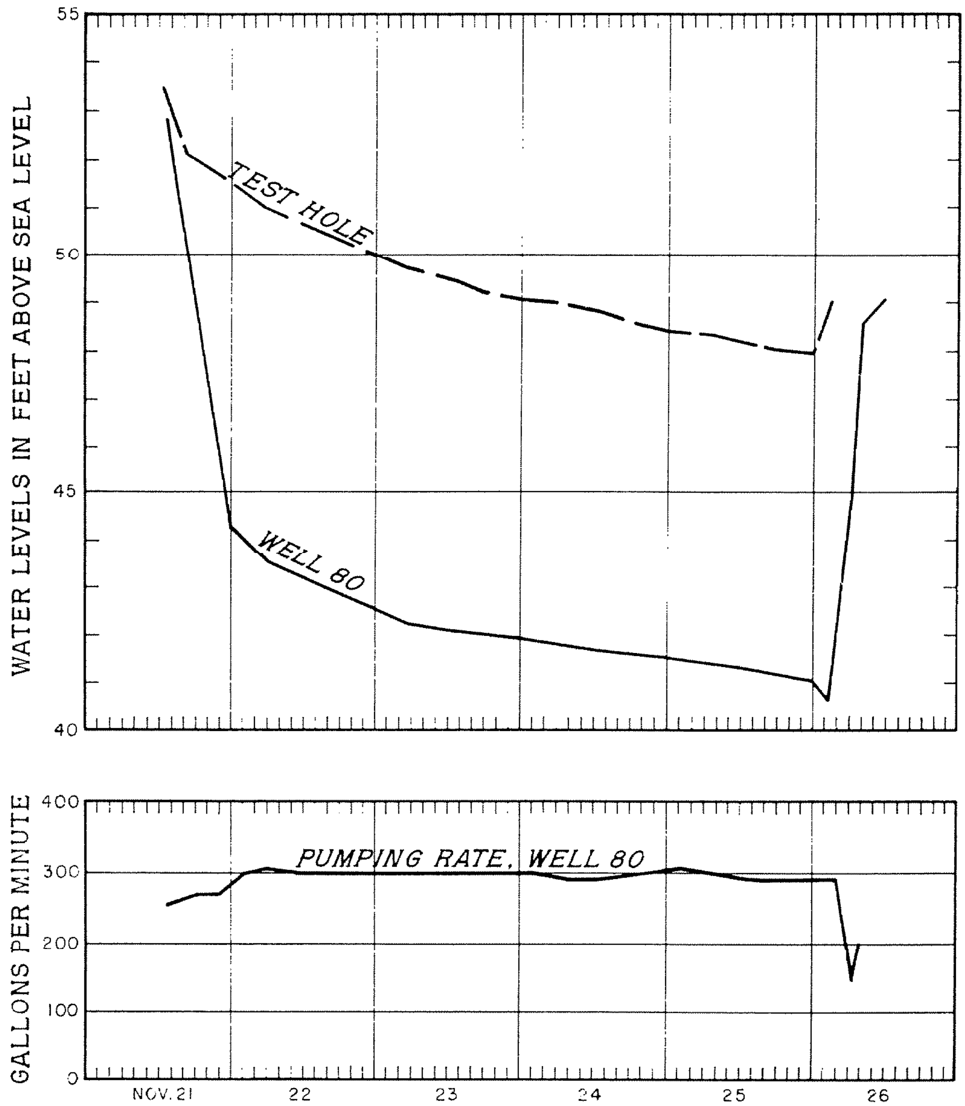

Figure 23. Graphs showing the drawdown in well 80 and test hole T-14 and the pumping rate during a test of well 80.

Basal water occurs in the rocks of the Napali formation that underlie the easternmost ridge of the Makaleha Mountains. Test holes T-10 and T-13 drilled near the end of the ridge struck basal water in Napali lava flows having a head of about 66 feet. Here also the high head is due to the confining effect of the rocks of the Koloa volcanic series which overlie the older lavas.

In the coastal part of the Kawaihau District the lava flows of the Koloa volcanic series contain basal ground water having heads ranging from 7 to 10 feet. Farther inland the Koloa rocks are saturated with fresh water to considerable depths below sea level, but clear identification of the basal aquifers is not always possible. In some inland areas rocks lying at a considerable distance below sea level contain what appears to be basal water but are overlain by aquifers having heads that are several times the supposedly basal heads. Locally, underlying Koloa lavas also appear to have heads markedly higher than those that are considered to be representative of basal aquifers. A mile or more inland from the shore the apparent basal heads measured in wells and test holes range from 7 to 30 feet. The differences between the heads in the basal aquifers of the Koloa and those in the overlying lavas of the series decrease in a shoreward direction, and at the shore the basal heads generally are equal to or higher than those in the overlying rocks.

Recharge to the basal aquifers occurs mainly in inland areas from overlying rocks that have higher heads. Discharge takes place near the shore into overlying rocks in which the heads are lower, and into the sea at invisible submarine springs.

The records of test hole T-15 on the northeast side of Puu Ehu ridge show that an apparent basal-water head of about 7 feet exists in the Koloa rocks lying about 180 feet below sea level. At greater depths, however, higher heads occur, ranging from 7 up to about 130 feet. In test holes T-11 and T-12 on Homaikawaa Stream northeast of Kealia the apparent basal heads are 13 to 17 feet and 30 feet, respectively. In both holes the tops of the basal aquifers are below sea level and are overlain by lavas in which the heads are more than 200 feet above sea level. In well 90, near Anahola, the basal head appears to be about 15 feet. At well 1, near Halaula, the top of the basal aquifer is about 212 feet below sea level and the head is about 10 feet. The head in the rocks just above the basal aquifer is about 100 feet.

Basal ground water in the rocks of the Koloa series has been developed in drilled wells at Anahola, Kealia, and Kapaa. Wells 90A and 90B at Anahola, which were drilled in 1957 for domestic supplies, produce basal water containing about 30 ppm of chloride. When they are pumped for short periods at about 220 gpm, well 90A has a drawdown of about 2.6 feet and well 90B a drawdown of about 6.5 feet. The wells are 65 feet apart. Well 90A is 433 feet deep, 43 feet deeper than well 90B, but the depths to the water-bearing rocks is not known for either well. Pumping of these wells has not been at rates large enough or prolonged enough to enable a quantitative estimate of the productivity of the basal aquifer they tap.

Seven drilled wells (2A to 2G) at Kealia tap basal ground water in a near-shore section of the lavas of the Koloa volcanic series. The basal head at Kealia is about 10 feet, and at the time they were drilled three wells (2A, 2E, and 2F) each were reported to flow at the rate of 0.75 to 1 mgd, presumably at levels only slightly above sea level. Wells 2A to 2F, each of which extends to a little more than 200 feet below sea level, produced water having a chloride content of about 60 ppm or less. However, well 2G, which originally extended to about 400 feet below sea level, produced water of much higher salinity, even in shallow parts of the aquifer. Figure 24, which shows the variation of chloride content with depth in well 2G during drilling, indicates that the well entered the transition zone between the fresh basal water and sea water at a relatively shallow depth, probably at about 150 feet. A local zone of

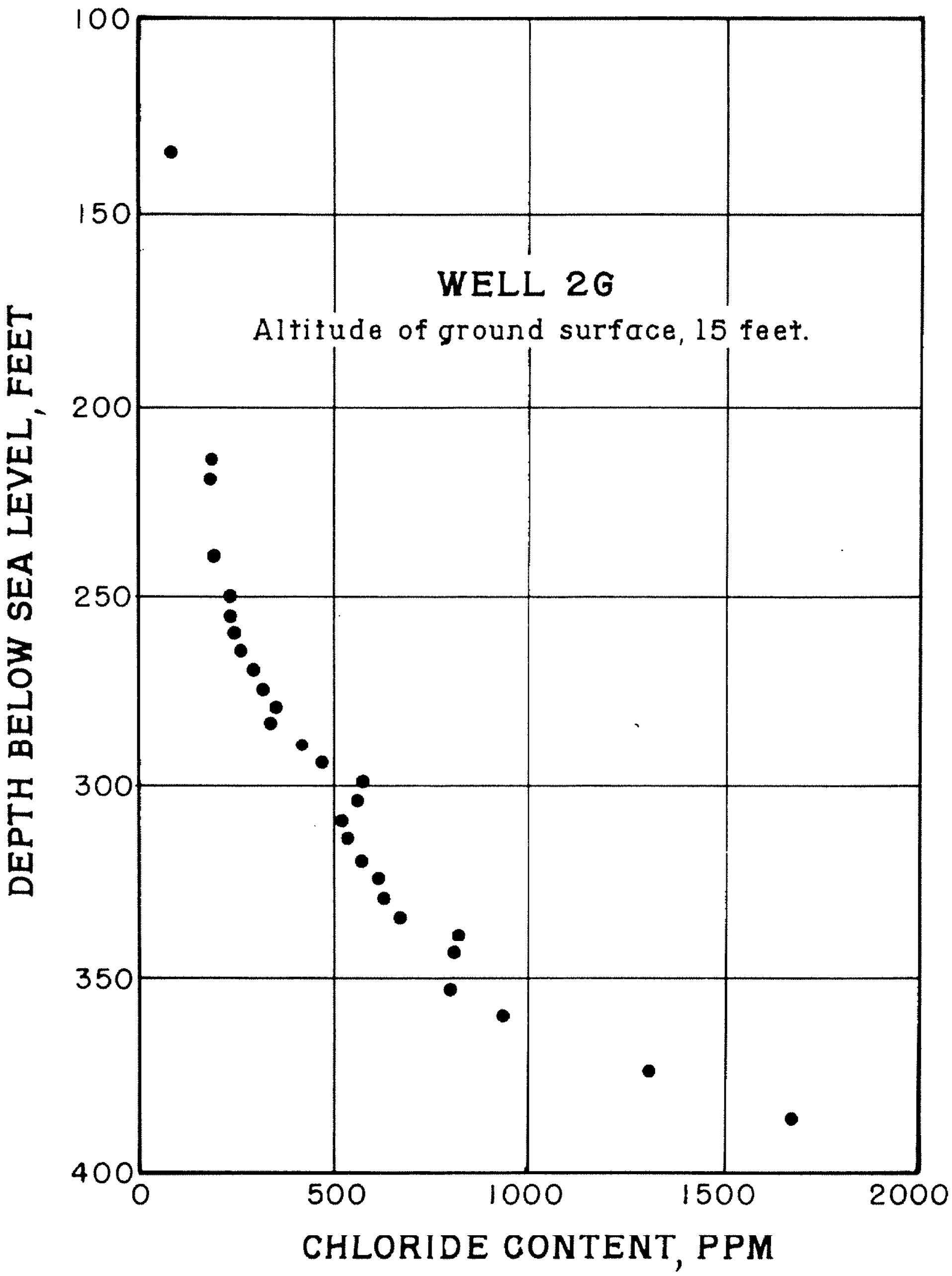

Figure 24. Graph showing the variation of chloride content of water in well 2G with depth during the drilling of the well.

high permeability extending into sea water probably is the cause of the shallow depth to the transition zone in this well.

The wells at Kealia apparently have not been pumped heavily enough to indicate the capacity of the basal aquifer. Since about 1935 well 2F has been used to supply an average of about 0.5 mgd for local domestic use, and since about 1934 the other wells have been idle. The graph of the chloride content of well 2F in figure 25 indicates that there was very little change, if any, in the quality of the basal water in the 12-year period between 1937 and 1948 and suggests that there probably has been very little change since the first well was drilled. The slight downward trend of the head in well 2F, which is apparent in figure 26, has not effected the salinity of the water in the well during the period of record. Lower heads and higher salinity undoubtedly would result from heavy pumping of the aquifer at Kealia. The maximum amount of water of acceptable quality that is available can be determined only by experiment.

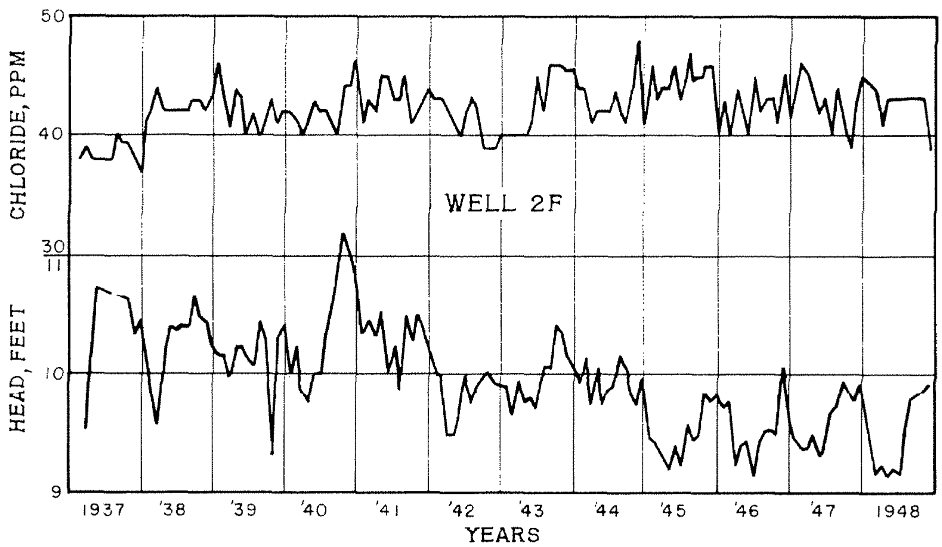

Figure 25. Graph showing variations in chloride content of water and head in well 2F during the 12-year period 1937-48.

Well 6, which is about 500 feet from the shore in Kapaa, has a head of 6 to 7 feet above sea level, but it produces water having a chloride content of 700 to 800 ppm. At the time it was drilled the well entered basal water containing about 130 ppm of chloride at about 150 feet below sea level, and at the final depth of about 240 feet below sea level it was in water containing about 500 ppm. During pumping the chloride content of the water rose to about 1,000 ppm, but after 50 feet of backfill was placed in the hole the chloride content during pumping dropped to about 700 ppm. This well is at the seaward edge of the fresh-water lens where the top of the transition zone is shallow and where pumping can cause a rapid and substantial increase in the salinity of the water.

An attempt was made in 1938 to develop basal water in Koloa lava flows at the southwest side of Kapaa by means of a tunnel at the bottom of an inclined shaft. The shaft (shaft 1, pl. 1) was about 20 feet above sea level and was on a slope of approximately 15 degrees down to the tunnel invert at about 15 feet below sea level. The tunnel, which was about 30 feet long, produced water containing 30 to 40 ppm of chloride.

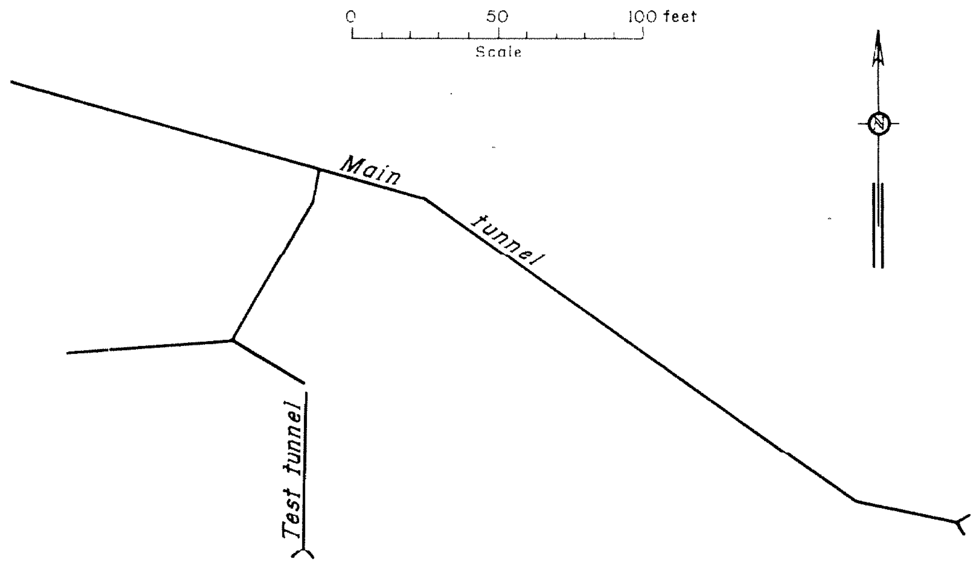

Figure 26. Plan of tunnel 6, Kauai County Akulikuli tunnel.

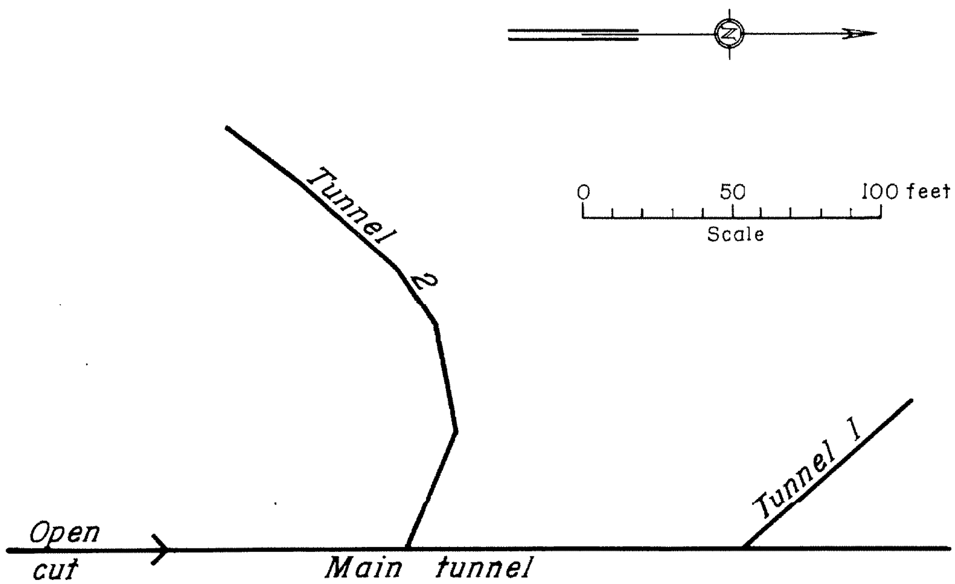

Figure 27. Plan of tunnel 7, Kauai County Moalepe tunnel.

The static water level in the shaft was about 13 feet above sea level. The water level was lowered to the tunnel invert at a pumping rate of only 50 gpm, and the installation was abandoned. At this locality the lava flows generally are thoroughly weathered to depths of several tens of feet below sea level and, therefore, have very low permeabilities.

High-level ground water.—Scattered dikes cut the lava flows of the Napali formation in Puu Ehu ridge, but there probably is very little high-level water in the ridge. All streams flowing from the ridge are small and most are intermittent. If large bodies of water are impounded by dikes, none of the valleys is deep enough to intersect them.

The numerous streams flowing from the Makaleha Mountains suggest that large quantities of high-level water occur in the rocks dissected by the streams. The flow of three large springs at the base of the southeast slope of the mountains has been developed in horizontal tunnels (tunnels 5, 6, and 7, pl. 1). The altitudes of the tunnels range from 360 to 568 feet, and all are in lava flows of the Napali formation. Plans of tunnels 6 and 7 are shown in figures 26 and 27. The water probably is impounded partly by dikes, but older alluvium and lava flows of the Koloa volcanic series, which lie against the eroded surface of the Napali lavas, also probably are effective in holding the water at a high level. No records of discharge of the tunnels are available, but the flow of Akulikuli spring, which was partly intercepted by tunnel 5, was reported to range from about 0.6 to 4 mgd and to average about 1 mgd during a 2½-year period from 1911 to 1913.

Small perched water supplies in the lava flows of the Koloa volcanic series are developed in short tunnels near the villages of Moloaa and Anahola (tunnels 3 and 4). These tunnels tap relatively shallow water held up on soil or ash beds that lie 150 to 200 feet above sea level. Records of test holes in the Koloa rocks in the Kawaihau District indicate that water also is perched above the basal aquifers on impermeable beds lying at considerable depth, in some places below sea level. The graph in figure 28, which shows the heads in test hole T-12 at various depths during drilling, is representative of water levels in test holes in the lava flows of the Koloa. This perched water apparently saturates a

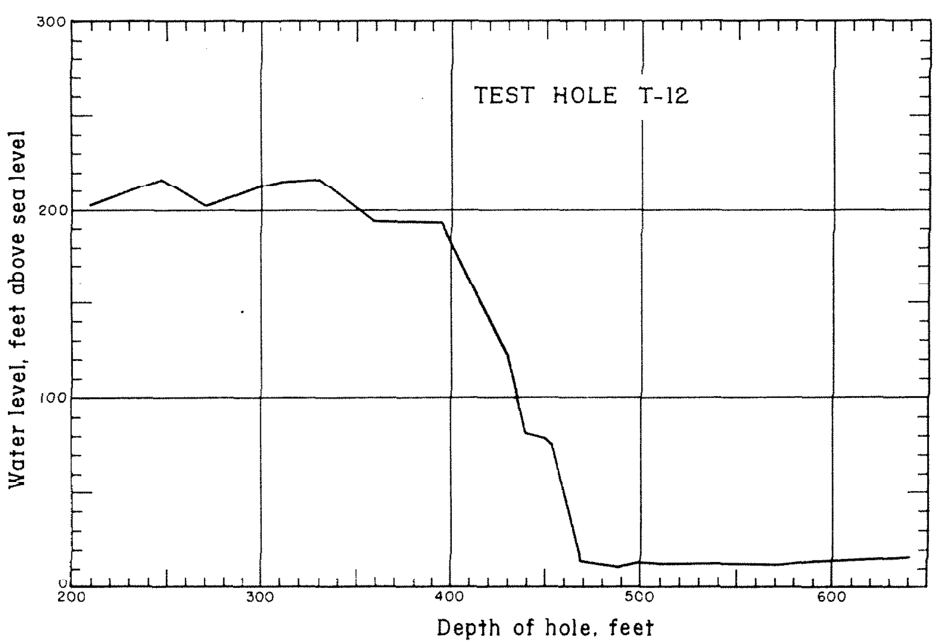

Figure 28. Graph showing heads in test hole T-12 at various depths during drilling of the hole.

considerable thickness of rock, perhaps as much as 200 feet in test hole T-12, but no tests of the capacity of the aquifer have been made.

LIHUE DISTRICT

The east boundary of the Lihue District is the east shore of the island between Wailua and Kawelikoa. The northeast boundary runs from Wailua through Nonou peak and along Kuilau and Kamoohoopulu Ridges to Wekiu peak. The west boundary is a broad arc running southwestward from Wekiu to Mount Waialeale then southward to Kahili peak and southeastward along Haupu ridge to Kawelikoa (pl. 1).

The rocks in the upper slopes on the rugged west side of the area, in Nonou and Kalepa Ridge, and in a large part of Haupu ridge are lava flows of the Napali formation. A part of the rocks in Haupu ridge are caldera-filling flows of the Haupu formation. The remainder of the area is underlain by rocks of the Koloa volcanic series, which are mostly lava flows.

Basal ground water.—Basal ground water occurs in the lava flows of the Napali formation in Kalepa Ridge, in most of Haupu ridge, and probably in Nonou ridge.

Wells in Kalepa ridge have basal heads ranging from about 10 to 16 feet, which are produced by the impounding effects of lava flows of the Koloa volcanic series surrounding the ridge. Dikes in the ridge probably divide the basal aquifer into compartments, but wells are too few for estimating the size of the compartments and their water-bearing capacities. Wells 7 and 8, which are a few hundred feet apart on the east side of the ridge, extend nearly 200 feet below sea level. The range of fluctuation of the chloride content of the water in these wells is about 40 ppm. When the head drops more than about 3 feet the chloride content increases markedly (fig. 29). This increase in salinity indicates that the bottoms of the wells are near the top of the transition zone, which rises when the fresh-water lens shrinks and the head drops. In the south end of the ridge, well 10 also entered the transition zone in lava flows about 200 feet below sea level. At the time the well was drilled, the water at 150 feet below sea level contained 23 ppm of chloride; however, after the well was deepened to 238 feet below sea level the water pumped during a 100-gpm test contained about 180 ppm of chloride.

The bottom of well 9, which is on the east slope of Nonou ridge, is about 140 feet below sea level, and the well probably penetrates more than 100 feet of lava flows, of the Napali formation. However, the flows are thoroughly weathered and have low permeability, and the water level in the well stands about 55 feet above sea level. Basal water having a head of 10 to 20 feet above sea level probably occurs in more permeable rock beneath the weathered zone in well 9 and in other parts of Nonou ridge where the lava flows are not weathered. Dikes in the ridge may divide the basal aquifer into compartments.

Well 12 at Kipu Kai on the southeast side of Haupu ridge is in lava flows of the Napali formation and taps basal water having a head of about 5 feet and a chloride content of about 60 ppm. Lower heads and higher salinities very likely prevail in the basal water in the east end of the ridge, and higher heads probably occur in the relatively impermeable

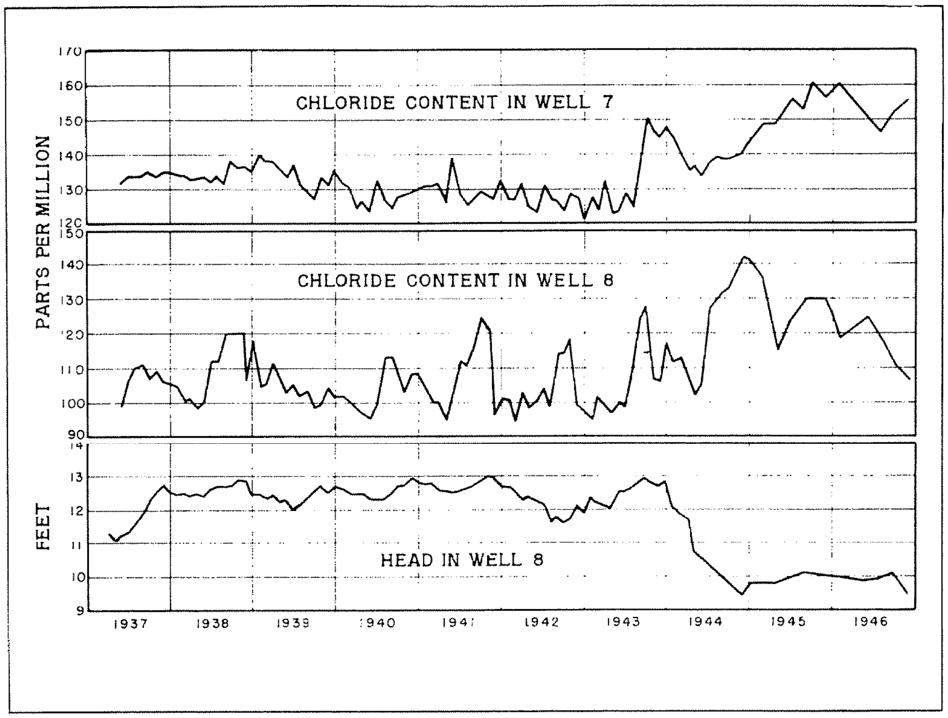

Figure 29. Graphs showing chloride content of water in wells 7 and 8 and head in well 8 during 10-year period 1937-46.

lava flows of the caldera-filling Haupu formation that make up Haupu peak. High heads and low salinities undoubtedly exist in the lava flows under the northeast slopes of the ridge lying east of Haupu peak, but the aquifer may be cut by dikes that limit its capacity to yield water to individual wells.

The extent of the occurrence of basal ground water in the rocks of the Koloa volcanic series in the Lihue District is practically unexplored. At shaft 2, near Hanamaulu, shallow tunnels develop a small amount of basal water in lava flows of the Koloa, but no deep wells have been drilled into the rocks. Near the shore the basal water may be brackish like that in well 6 at Kapaa, but at a distance of half a mile inland the rocks probably are saturated with fresh water to depths of several hundred feet below sea level. The capacities of wells may be low, however, because of the generally poor permeability of the lava flows of the Koloa.

High-level ground water.—A large amount of high-level ground water may discharge into streams from the lava flows of the Napali formation that make up the high west wall of the Lihue depression, but its occurrence is such that it does not appear favorable for easy development. High-level water issues from small perched bodies and dike reservoirs, but it can be seen only in seeps and small springs distributed along the stream channels and valley walls. No flow from dike reservoirs occurs at large springs that would encourage attempts at development of high-level water in tunnels.

High-level water is absent or occurs only in meager amounts in the lavas of the Napali formation in Nonou, Kalepa, and Haupu ridges.

Water perched on soil, ash, or dense lava flows occurs widely in the Koloa volcanic series in the Lihue District. The water discharges mostly in seeps and small springs in the valleys cut into the rocks of the Koloa, but in a few places it occurs in quantities adequate for municipal supplies.

Tunnel 8, which is west of Lihue on Nawiliwili stream, was excavated by the Lihue Plantation Co. in 1935 at a site selected by W. O. Clark, where the flow of the stream increased from 0.25 mgd to about 2.4 mgd in a distance of about 1,000 feet. The tunnel is about 790 feet long and follows roughly the course of the stream (fig. 30). The floor of the tunnel is 187 feet above sea level. The perching bed under the lava-flow aquifer is red clay. At the time the tunnel was constructed the zone of saturation above the perching member was 15 to 20 feet thick. Water is pumped from the tunnel into the Lihue Plantation Co. domestic-water system at the average rate of about 1.2 mgd.

Tunnel 9 was excavated in 1928 to intercept the water flowing from springs at an altitude of about 300 feet in a tributary to Huleia Stream. The aquifer is lava flows of the Koloa volcanic series, and the water apparently is perched on a red soil. The tunnel is in three sections which have a total length of nearly 1,600 feet. Most of the water discharged by the tunnel seems to come from the sections marked tunnel 1 and tunnel 2 on the sketch in figure 31. The tunnel supplies about 0.6 mgd to the Kauai County water systems in Lihue and Nawiliwili. About half a mile west of tunnel 9 a perched spring discharges 0.13 to 0.15 mgd

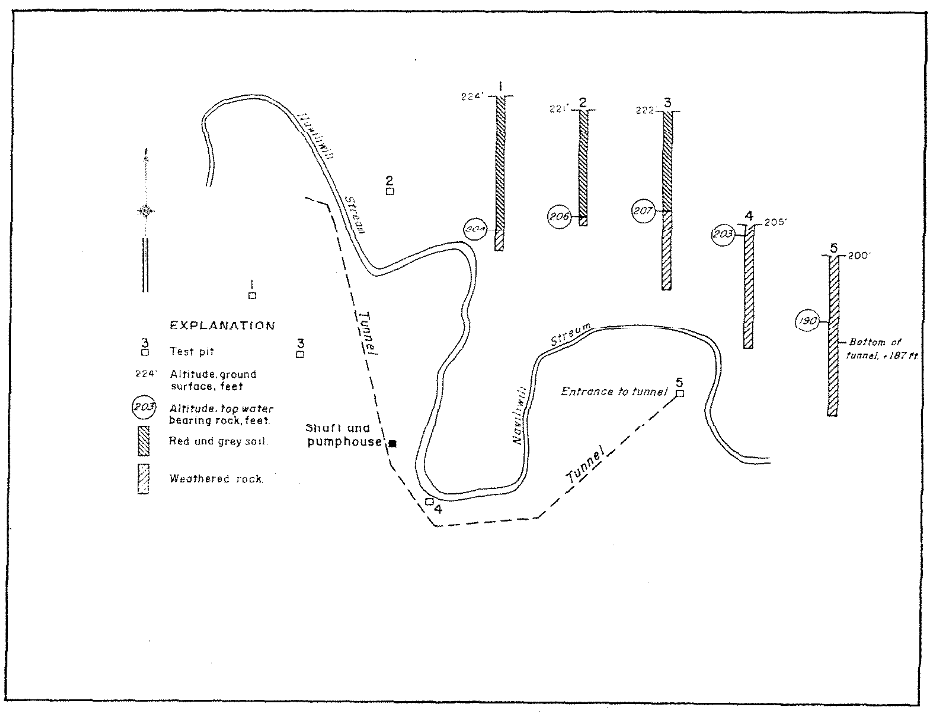

Figure 30. Plan of tunnel 8, Lihue Plantation Co. Nawiliwili tunnel.

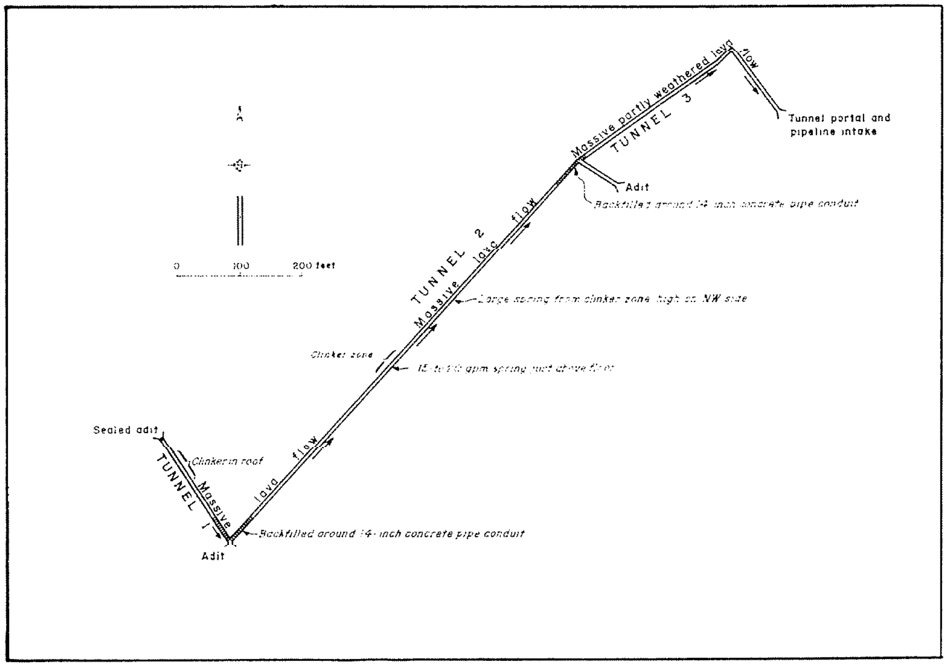

Figure 31. Plan of tunnel 9, Kauai County Enoka tunnel.

from lava flows. Test holes 7 to 9 in the vicinity of the spring penetrated a red soil that probably is the perching bed under the aquifer. Development of this water in a tunnel might be possible.

KOLOA DISTRICT

The Koloa District is a triangular area lying west of the Lihue District and east of the Hanapepe River. Lava flows of the Napali formation make up the southwest slopes of Haupu ridge and most of the east slope of the upper two-thirds of the Hanapepe River valley. The flows crop out also in irregular north-south bands in the central part of the district. Lavas of the Koloa volcanic series underlie the coastal part of the area, irregular bands extending northward from the coast and detached patches being present in the upper part of the Hanapepe River valley.

Basal ground water.—The lava flows of the Napali formation in the south slopes of the Haupu ridge contain basal water having heads of 30 to 45 feet and chloride contents of 25 to 45 ppm. The wells at the Grove Farm Co.'s Mahaulepu pump (wells 14A to 14N) apparently struck the basal aquifer at about 250 feet below sea level. The head of basal water in the wells is about 30 feet. Records of wells 14K to 14N, which were drilled in 1927-28, show that the basal water in the wells had a chloride content of 50 to 90 ppm at the time of drilling. Subsequently, however, determinations made over a period of several years in well 14N showed a chloride content of about 45 ppm. The higher early salinity may have been due to contaminating effects of more saline water occurring above the basal aquifer, which later was sealed out of the wells by casing. The wells have been used to supplement surface-water supplies for the irrigation of sugar cane, and the average pumping rate at the station during years of highest use was 2.5 to 3.5 mgd.

Well 16, which is just north of Koloa on the slope of Waihohonu hill, penetrates 455 feet of lava flows of the Napali formation to a depth of 210 feet below sea level. The well taps basal water having a head of about 45 feet above sea level and a chloride content of about 25 ppm. The specific capacity of the well is about 100 gpm per foot of drawdown. The well supplies about 0.2 mgd to the Kauai County water system at Koloa.

The records of wells 14 and 16 indicate that basal water of good quality in Napali lava flows is available under the southerly slopes of Haupu ridge that lie west of Mahaulepu, but they give no suggestion of the total amount of basal water that can be pumped. Development of the water in amounts of half a million gallons or more probably would require deep wells extending at least 200 feet below sea level.

The records of wells 20 and 23 and test holes 2 and 6, which are in the vicinity of Lawai, show that basal water occurs in the lava flows of the Napali formation in the central part of the Koloa District. The basal water levels stand 60 to perhaps 140 feet above sea level, but the depth to the basal aquifer is 300 feet or more, depending on the altitude of the ground surface. Wells producing as much as 1 mgd may have to penetrate several hundred feet of the aquifer. Because of the steep seaward dip of the eroded surface of the Napali formation beneath the rocks of the Koloa volcanic series south of Lawai, the rocks of the Napali probably lie too deep for practical development of the basal water. A

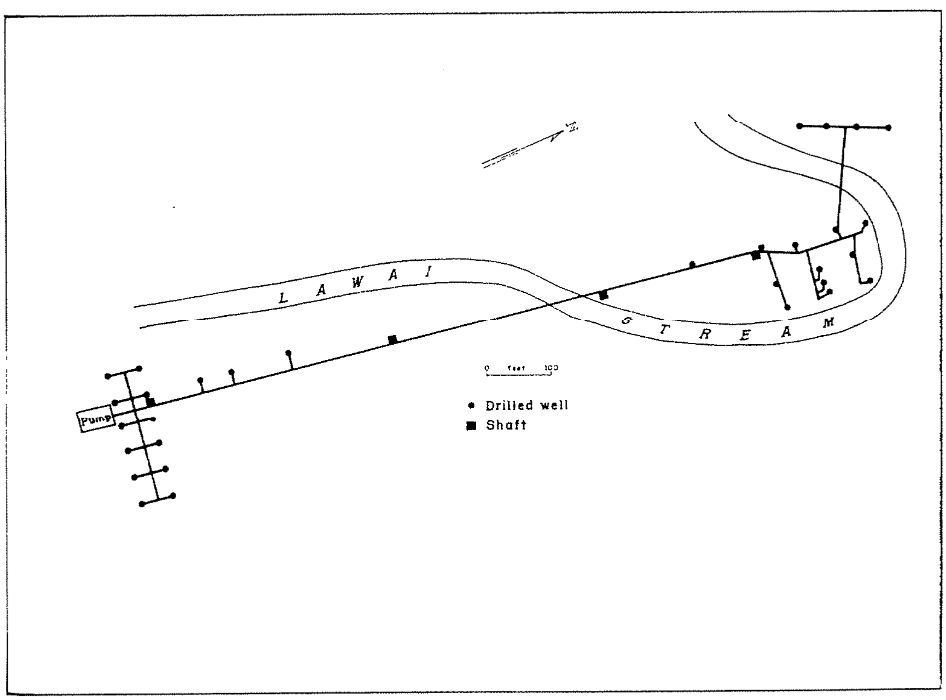

Figure 32. Plan of the tunnel system at shaft 3, McBryde Sugar Co. Lawai pump.

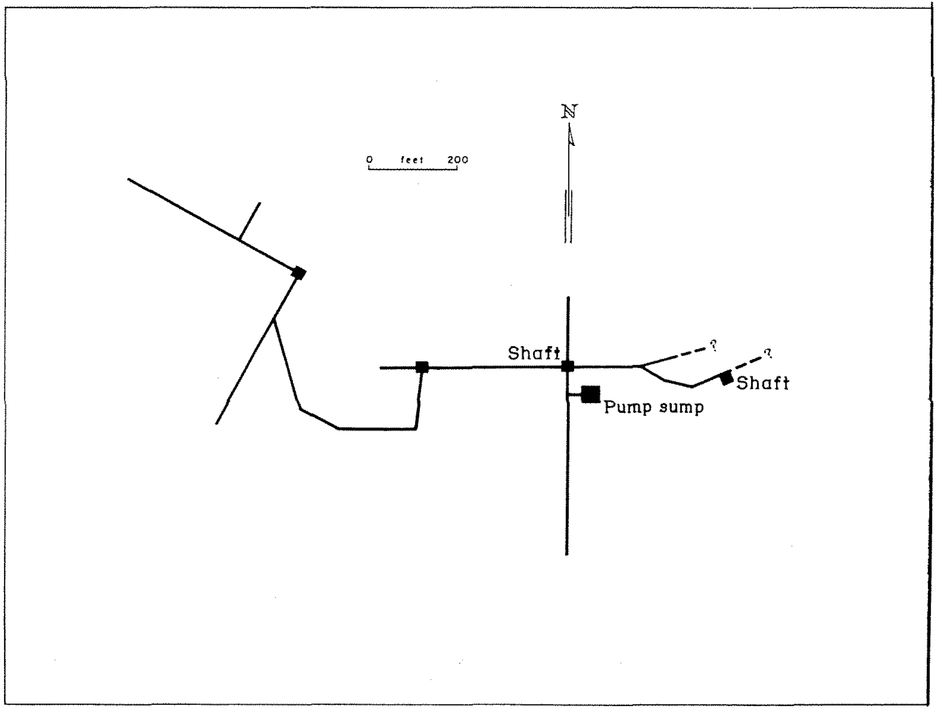

Figure 33. Plan of tunnel system at shaft 4, McBryde Sugar Co. pump 1.

mile southwest of Lawai in test hole 4 the rocks at 600 feet below the surface, or 228 feet below sea level, are of the Koloa volcanic series.

The high basal heads in the Napali formation are the result of the impounding effects of the rocks of the Koloa volcanic series, which lie on the weathered surface of the Napali lavas and which dip seaward.

Basal water in the lava flows of the Koloa volcanic series is developed at shaft 3 in the valley of Lawai Stream and at shafts 4, 5, and 6 in the valley of the Hanapepe River. These installations were started about 1899 as batteries of drilled wells in which the wells were connected by tunnels to sumps equipped with steam-driven suction pumps.

The Lawai station has about 2,200 feet of tunnel excavated in lava flows and pyroclastic deposits. The floors of the tunnels ranged in altitude from about 10 to 15 feet below sea level, and the tunnels originally carried water from 31 drilled wells to the pump sump (fig. 32). The tunnels also receive surface water from Lawai Stream, however, and sediment carried by the surface water has partially filled the tunnels and probably has plugged many of the wells. The maximum pumpage from shaft 3 is about 2.3 mgd and the average is about 1.2 mgd.

The shafts in the Hanapepe River valley have complex tunnel systems (fig. 33, 34, and 35) which apparently were originally laid out to connect drilled wells with pump sumps. The tunnels draw water partly from lava flows of the Koloa volcanic series, partly from alluvium, and partly from the Hanapepe River from which surface water drains into sumps connected with the tunnels.

The tunnels of shaft 4 are 45 to 55 feet below sea level, and the ground

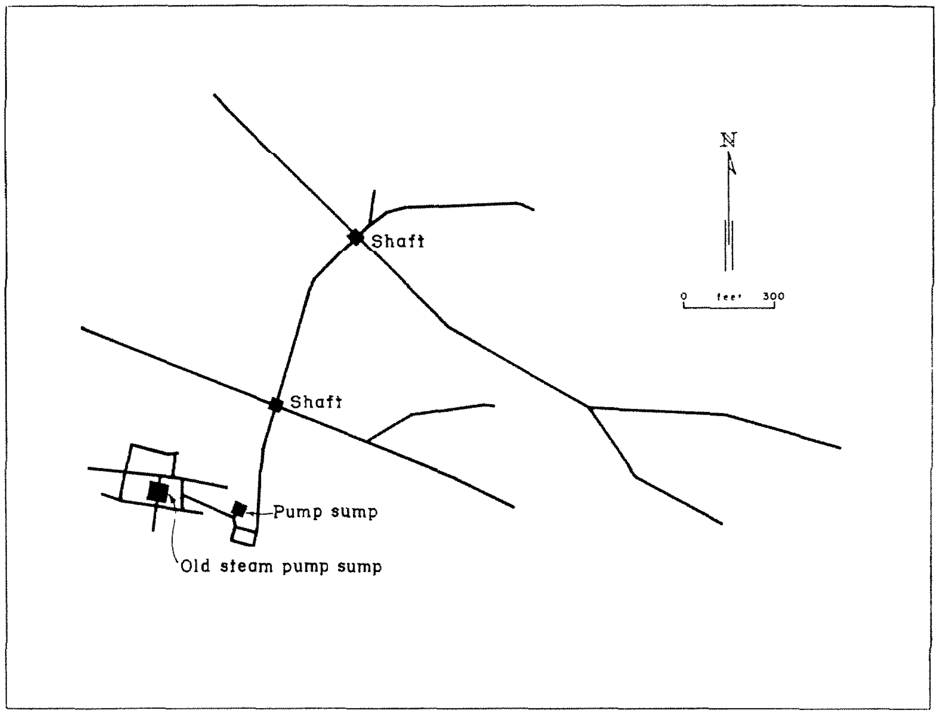

Figure 34. Plan of tunnel system at shaft 5, McBryde Sugar Co. pump 2.

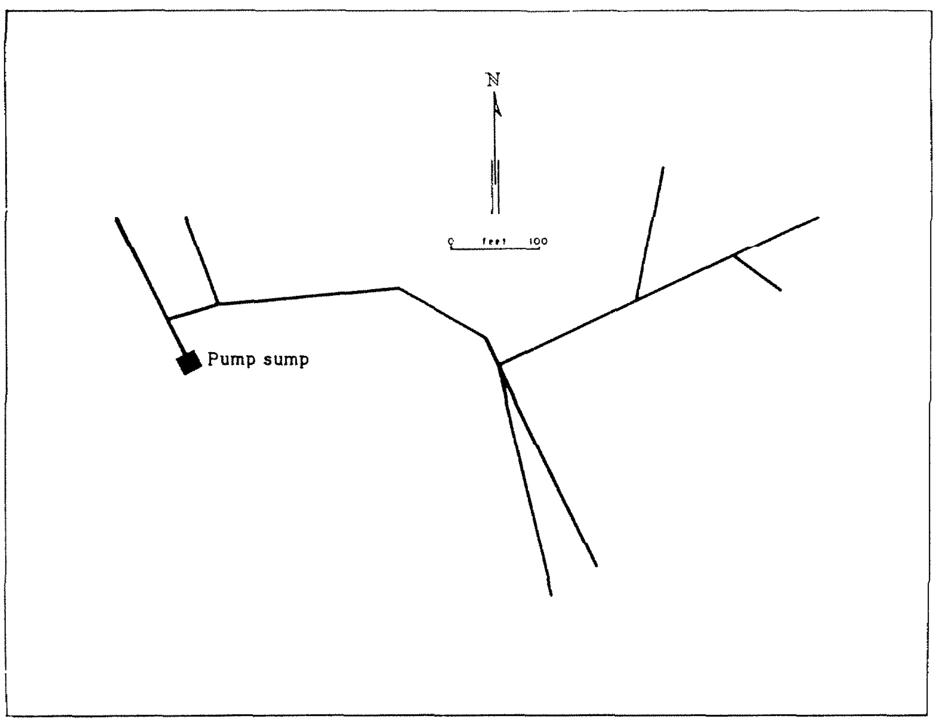

Figure 35. Plan of tunnel system at shaft 6, McBryde Sugar Co. pump 3.

water produced from them comes mainly from clinkery parts of lava flows and from a large lava tube which was intersected during the extension of one of the tunnels in 1928. The total length of the tunnels is about 8,000 feet, probably only a small part of that length produces appreciable ground water. Since 1928 the average pumpage from shaft 4 has been about 10 mgd of ground water and 7 mgd of surface water. The chloride content of the ground water entering the tunnels ranges from about 100 to nearly 1,300 ppm, and the average in the ground water pumped from the shaft is about 850 ppm.

High-level ground water.—The driller's records of wells 14K to 14L suggest that some perched water may occur in the lava flows of the Napali formation in Mahaulepu, but the amount is minor, and there is no other evidence of high-level water in Haupu ridge. In test hole T-6 near Lawai a perched water table standing 120 feet above sea level was struck at a depth of about 390 feet in the Napali formation, but the supply of water in the perched aquifer probably is small.

High-level water confined by dikes may exist in the lavas of the Napali formation in the mountainous north part of the district, but its location would require a search of the rugged valleys for springs and the confining dikes.

Perched water in the rocks of the Koloa volcanic series occurs in discontinuous bodies which probably vary greatly in thickness and areal extent. Numerous seeps and small springs discharge from shallow and generally thin perched bodies that are intersected by stream valleys. A few of these springs provide small supplies of domestic water. Deeply buried perching beds also exist in the rocks, and in some places they apparently hold up thick bodies of water. At test hole T-3, for example, a perching bed at some depth below sea level causes the water level to stand about 360 feet above sea level. The poor permeability of the rocks of the Koloa is not favorable for the development of large supplies of water in the perched aquifers.

WAIMEA DISTRICT

The east boundary of the Waimea District follows the Hanapepe River northeastward from Hanapepe Bay to Mount Waialeale. From Mount Waialeale the north boundary runs along the Wainiha Pali to Kilohana and thence through Pohakuwaawaa to the mouth of Awaawapuhi Valley. The shoreline between Awaawapuhi Valley and Hanapepe Bay forms the west and south boundaries.

Lava flows of the Napali formation of the Waimea Canyon volcanic series underlie the section lying west of the Waimea Canyon and a smaller area lying west of the Hanapepe River (pl. 1). Caldera-filling lava flows of the Olokele formation make up the part of the central upland lying southwest of the Wainiha Pali, and the graben-filling lava flows of the Makaweli formation occupy a triangular segment in the central part of the district east of the Waimea River. Between the Waimea and Hanapepe Rivers lava flows of the Koloa volcanic series form a coastal band from which irregular salients projects northeastward. These lavas also underlie small scattered patches in the valleys of the Waimea, Makaweli, and Olokele Rivers. Sedimentary deposits underlie the Mana plain, which borders the southwest side of the island.

Basal ground water.—The rocks of the Napali formation in the area west of the Hanapepe River have not been explored by wells or test holes, but they undoubtedly contain basal ground water. These rocks are bounded on the southwest by the lava flows of the Makaweli formation that bury the fault scarp marking the east side of the Makaweli graben. On the southeast side the southerly slopes of the eroded Napali formation are overlain by thick deposits of the Koloa volcanic series. The impounding effects of the poorly permeable rocks of the Makaweli formation and the Koloa volcanic series probably cause the basal water to stand high in the rocks of the Napali, perhaps 50 feet or more above sea level. Most of the area is too high and rugged for economic development of the basal water. Probably the most favorable place for exploration is on the west side of the Hanapepe River half a mile south of the mouth of the Manuahi Valley, where the lava flows of the Napali crop out at about 200 feet above sea level, and where the depth to the basal water probably is about 150 feet. In 1939 this locality was proposed to Kauai County by W. O. Clark as a favorable site for a shaft and basal tunnel development.

An extensive body of basal water is contained in lavas of the Napali formation in the area lying west of Waimea Canyon. Along the rocky coast from Awaawapuhi Valley to Polihale, where the lava flows are exposed at the shore, the basal water escapes through sea-level springs, and the heads probably are low. From Polihale to Waimea the sedimentary deposits of the Mana plain retard the escape of the ground water and cause basal-water heads ranging 8 to 12 feet above sea level.

Development of the basal water by means of drilled wells in the lava flows under the Mana plain began probably in the early 1880's. From the time of the first well until about 1906 perhaps 50 or more wells were drilled throughout the plain for the irrigation of rice and sugar cane. The last wells were drilled in 1929 and 1930, when 9 wells were finished. Some of the early wells were abandoned and now are lost. At the present, 52 numbered wells exist in the plain, but the locations of even some of them are uncertain. The first shaft and basal tunnel was constructed in 1931 at the base of the cliff near Kekaha (shaft 11). Between 1931 and 1957 six additional shafts were installed along the inland edge of the plain to supply irrigation and domestic water.

According to records of wells, the sedimentary deposits under the Mana plain consists of clay, sand, gravel and boulders, and coral (fig. 36). The sediments, on the whole, are less permeable than the underlying lava flows of the Napali formation and form a caprock that causes relatively high heads in the basal water in the flow rock. However, the beds of sand, gravel, and coral produce zones of relatively high permeability in the caprock, and leakage from the basal aquifer occurs wherever they are in contact with the lava flows. This leakage, rising to the surface through the caprock, probably maintained the marshy areas that once existed in parts of the Mana plain but now are drained and converted to sugar-cane lands. In addition to this natural escape of basal water through the caprock, leakage of considerable magnitude may take place through abandoned wells.

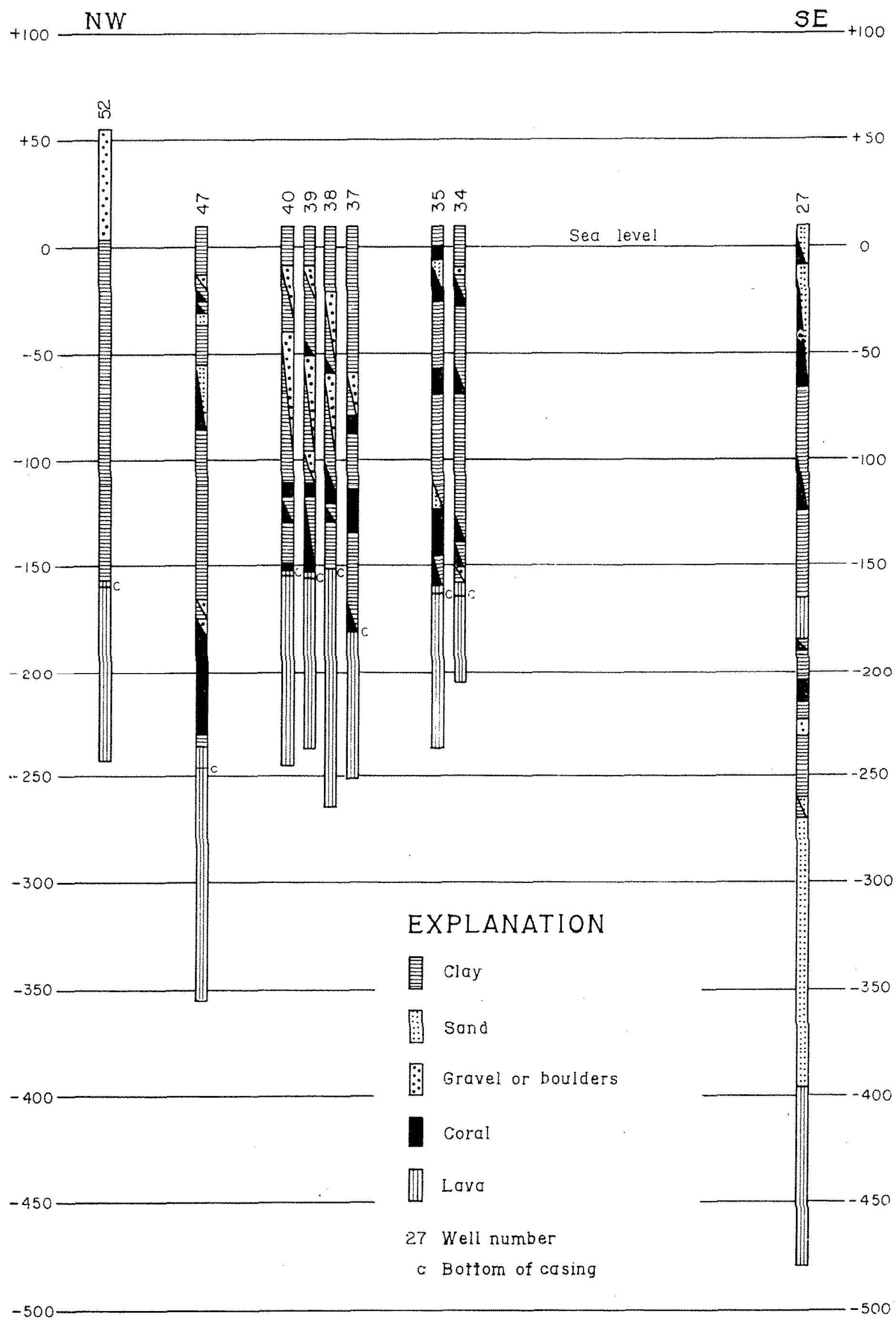

Figure 36. Graphic representation of driller's logs of wells in the Mana plain. The wells are approximately spaced according to their distribution along a line through wells 27 and 52.

The contact between the sedimentary deposits and the underlying eroded surface of the lava flows has a seaward dip of 300 to 700 feet to the mile. Consequently, wells drilled in low parts of the plain enter the water-bearing lava flows at depths ranging from 150 to 400 feet below sea level and extend to total depths ranging from 200 to 475 feet below sea level. There are no records of the salinity of the water found in the first wells in the plain at the time they were drilled. The maximum chloride contents of the basal water in the wells drilled in 1929 and 1930, as reported in the driller's records, ranged from about 80 ppm at 206 feet below sea level in well 34 to about 500 ppm at 355 feet below sea level in well 47. These chloride contents possibly are representative of the original quality of the basal water at similar depths in all wells in the plain, but draft on most wells has been accompanied by large fluctua-

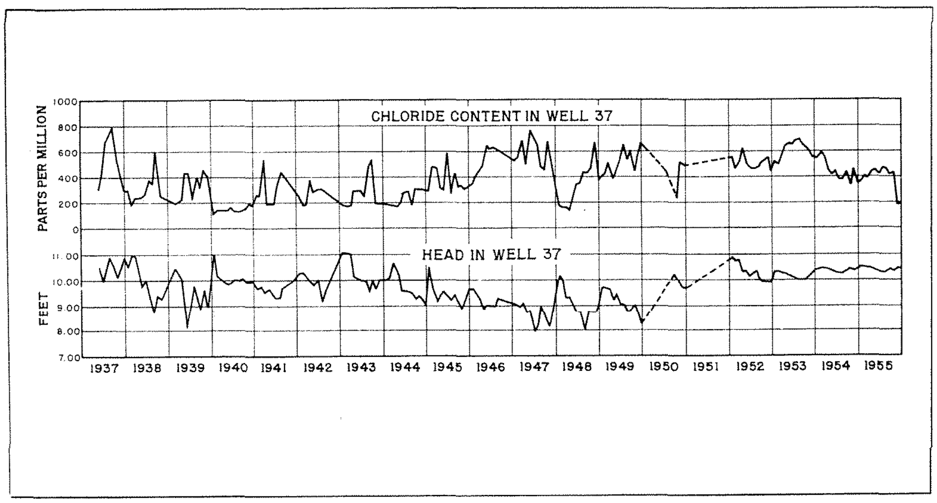

Figure 37. Graphs showing variation of chloride content and head at well 37, 1937-55.

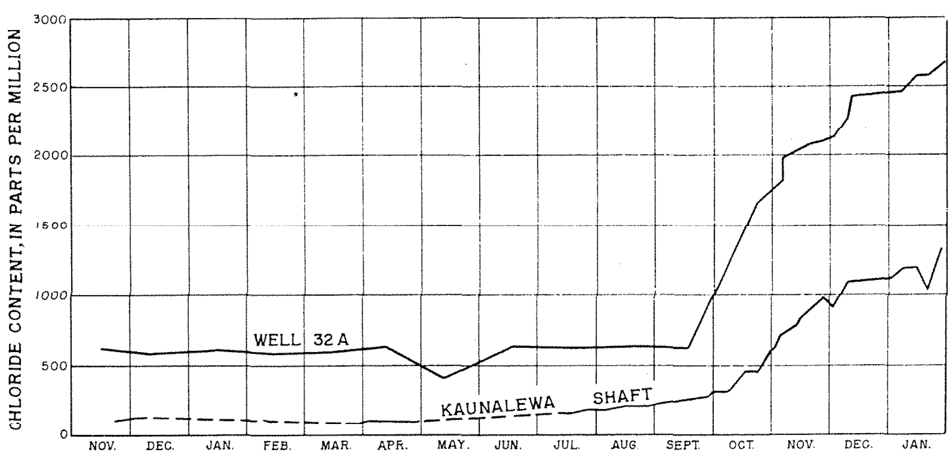

Figure 38. Graphs showing variation in chloride content at well 32A and Kaunalewa shaft, November 1956-January 1958.

tions in chloride content. The graphs in figure 37 of the chloride content and head in well 37 during a 19-year period show a pattern of fluctuation that is representative of most drilled wells in the Mana plain, although the range of the chloride content in well 37 is smaller than that in many other wells. The wide range in the fluctuations in chloride content indicate that most of the drilled wells enter the transition zone.

The results of a local rise of the top of the transition zone caused by heavy pumping is shown in figure 38 by the sharp upward breaks in the graphs of chloride content of the water in well 32A and shaft 14 during the construction of the shaft. The basal aquifer in the well lies under the caprock about 150 feet below sea level; the floor of the infiltration tunnel at the shaft is in the aquifer at about sea level. The shaft is about 1,500 feet inland from the well. During the first 10 of the 14 months covered by the graph, the pumping rate at the shaft increased gradually from 0.5 mgd to nearly 5 mgd; during the remaining 4 months, the period of rapidly rising salinity, the pumping rate increased to about 9 mgd.

Shaft-type wells at the inland edge of the Mana plain have the advantage of developing basal water as high as possible above the transition zone. Locally, the transition zone may rise high enough in response to pumping to affect the quality of the water in a shaft, as in the case of shaft 14 described above, but the shafts normally produce water having better and more uniform quality than the deep drilled wells.

The average daily pumpage of basal water from drilled wells and shafts in the Mana plain since about 1940 has ranged from 6.5 to 14 million gallons a day. About three-fifths of the water is pumped from drilled wells. Some of the water is used for domestic and sugar-mill purposes, but most is used to irrigate sugar cane on the plain. In addition to the pumped water, an undetermined amount discharges at the surface from flowing wells that are used or have been used for irrigation.

Outside the Mana plain no basal water is developed in the lavas of the Napali formation, except in shaft 9 in the west wall of the Waimea River valley. This shaft, which was constructed by the county of Kauai at a site selected by W. O. Clark, supplies about 0.4 mgd to the town of Waimea. The maximum pumping rate during the excavation of 225 feet of tunnel that leads from the shaft was about 2 mgd. The water contained about 20 ppm of chloride.

The occurrence of basal ground water in the lava flows of the caldera-filling Olokele formation has not been explored. Because of the generally low permeability of these thick-bedded flows, and possibly because of impounding effects of the buried caldera fault scarp that bounds them, the basal water table undoubtedly stands very high in the Olokele formation, perhaps 100 feet or more above sea level. Owing to their poor permeability and their occurrence in the remote, rugged central part of the island, development of basal ground water from the lava flows of the Olokele formation does not appear feasible.

Basal ground water in lava flows of the Makaweli formation has been developed at only one place, in shaft 7 about 2 miles north of Hanapepe. The water-bearing rock in the shaft is pahoehoe lava, which is thinner bedded and probably more permeable than the bulk of the lava flows of the formation. The water level in the shaft is about 20 feet above sea level. The shaft supplies domestic water to Kaumakani village at the average rate of about 1.4 mgd.

Basal water probably occurs in the lava flows of the Makaweli formation throughout the area of outcrop shown in plate 1. The coastal band of lavas of the Koloa volcanic series, overlying the eroded and commonly weathered surface of the Makaweli formation, forms a caprock which probably causes the basal water table to stand 20 feet or more above sea level throughout the formation. The most favorable locations for wells in the lavas of the Makaweli are in the ends of spurs such as that in which shaft 7 was dug. Exploratory borings or test wells to determine the water-bearing character of the lavas would be advisable at prospective well sites.

The only known attempt to develop basal ground water in the lavas of the Koloa volcanic series in the Waimea District was at shaft 8 in Mahinauli Gulch. The basal head in this locality is about 9 feet above sea level. Two tunnels extending from the shaft at about 16 feet below sea level and totaling about 220 feet in length produced a little more than 3 mgd when the water level was lowered by pumping to about 16 feet below sea level. During a period of about 4 months, in which the construction pumping rate ranged from 0.8 to 1.7 mgd, the chloride content of the water from the tunnels fluctuated between 400 and 800 ppm. A test hole drilled in the bottom of the shaft to about 40 feet below sea level yielded no water. The ground-water conditions disclosed by shaft 8 probably are representative of those throughout the Koloa volcanic series in the Waimea District.

High-level ground water.—In the area of lava flows of the Napali formation lying west of the Hanapepe River, dikes and perching beds are scarce or absent, and there probably is very little high-level ground water. In the larger area west of the Waimea River, dikes in the lavas of the Napali are numerous, but the absence of springs in the west wall of the Waimea Canyon indicates that high-level supplies in the area probably are very small. There appear to be no favorable sites for development of water by high-level tunnels.

Most of the water that enters the lavas of the Olokele formation probably descends to the basal water table. High-level springs in them are rare in most areas, because of the scarcity of dikes and the absence of beds that are much less permeable than the average of the section. A soil bed near the top of the section of lava flows south of Pohakuwaawaa peak is less permeable than the overlying flows and is responsible for small perched springs and seeps. Rarely and locally, water may be perched by unusually dense beds of lava. In a small tributary gulch on the southeast side of Olokele Canyon, 1.65 miles northeast of Kapuaa peak, a group of small springs having an aggregate flow of about 0.3 mgd lies about 140 feet above the level of the Olokele Ditch. The springs issue at or near the top of a massive bed of dense lava, and the water probably is perched by that bed. A few springs may issue from behind dikes, but because of the relatively low permeability of the lava flows and the scarcity of dikes, the development of any large amount of water in high-level tunnels in the Olokele formation is unlikely.

A few small perched springs or seeps flow from the rocks of the Makaweli formation, but the development of high-level water from these rocks in amounts of more than a few gallons a minute would not be possible at any place.

The lava flows of the Koloa volcanic series undoubtedly contain some water perched on soil beds or dense lava flows, but the total supply of high-level water in these rocks probably is very small.

Tunnel 10 in the valley of the Hanapepe River at about 196 feet above sea level develops high-level water contained in unconsolidated alluvium. The water, which is perched by less permeable, probably weathered, lava flows, enters the alluvium from the channel of the Hanapepe River. The tunnel supplies water at an average rate of about 0.3 mgd to the town of Hanapepe.

RECORDS OF DRILLED WELLS, TEST HOLES, SHAFTS, AND TUNNELS

The records of drilled wells, test holes, shafts, and tunnels that follow were compiled from information furnished by the owners of the installations; from logs and reports furnished by well drillers; and from data in the files of the Experiment Station, Hawaiian Sugar Planters' Association; the Hawaii Division of Hydrography; and the U. S. Geological Survey. Locations of the installations are shown on plate 1.

1 (Lihue Plantation Co. well 8) In Kumukumu Gulch. 22°6′45″N, 159°18′55″ W. Owner, Lihue Plantation Co. Drilled, 1929 by G. B. Primmer for Makee Sugar Co. Altitude, 130 ft. Original depth, 342 ft., backfilled to 321 ft. Diameter, 12 in. Casing 114 ft. Not in use. Head (ft.), Sept. 1929, 99.65; Aug. 3, 1954, 98.6.

Driller's log

	Depth (ft.)		Depth (ft.)		Depth (ft.)
Brown and red clay	0-68	Blue lava, broken	144-150	Brown lava	228-245
Boulders and red clay	68-90	Hard blue lava	150-162	Rotten rock and rubble	245-254
Boulders and broken lava	90-102	Brown porous lava	162-173	Brown lava, porous and hard streaks	254-266
Blue rock	102-126	Hard brown lava	173-176	Brown rotten rock	266-272
Blue lava	126-130	Red and brown porous lava	176-200	Brown porous lava	272-295
Red porous lava and sandstone	130-134	Red, brown and blue lava, some porous streaks	200-212	Brown and blue broken lava	295-330
Hard blue lava	134-138	Waxy red clay	212-228	Hard blue lava, full of olivines	330-342
Red clay and rotten rock	138-144				

At 342 ft. entered lava tube or broken lava and water level dropped from about 100 ft. to about 10 ft. above sea level. Backfilled to 321 ft. with cement and water level recovered to about 100 ft. above sea level.

Chloride content of water during drilling

Depth (ft.)	Chloride (ppm)	Depth (ft.)	Chloride (ppm)	Depth (ft.)	Chloride (ppm)
175	66	250	37	300	37
190	34	260	37	325	39
210	35	275	37	342	42
240	39				

2A (Lihue Plantation Co. well 7) Kealia. 22°6′5″N, 159°18′35″W. Owner, Lihue Plantation Co. Drilled 1928 by G. B. Primmer for Makee Sugar Co. Altitude, 6 ft. Depth, 225 ft. Diameter, 12 in. Casing, 140 ft. Not in use.

Driller's log

	Depth (ft.)		Depth (ft.)		Depth (ft.)
Black sandy clay	0-6	Gray sandy clay	90-105	Brown hard lava	140-186
Red clay and large boulders	6-18	Grayish brown sandy clay	105-126	Brown lava with streaks of red waxy clay	186-205
Gray clay	18-30	Greenish gray sandstone and sea shells	126-140	Hard blue and brown lava with olivines	205-225
Light brown clay	30-50				
Brown sandy clay	50-90				

Chloride content of water during drilling

Depth (ft.)	Chloride (ppm)	Depth (ft.)	Chloride (ppm)
175	42	215	45
200	42	225	45

2B (Lihue Plantation Co. well 6) Kealia. 22°6′5″N, 159°18′35″W. Owner, Lihue Plantation Co. Drilled, 1928 by G. B. Primmer for Makee Sugar Co. Altitude, 6 ft. Depth, 220 ft. Diameter, 12 in. Casing 123 ft. Not in use. Flow at time of completion, 0.75 mgd.

Driller's log

	Depth (ft.)		Depth (ft.)		Depth (ft.)
Black sandy clay	0- 6	Brown lava	122-140	Conglomerate consisting of blue, brown, and red lava, coral, and waxy clay	180-188
Red clay and large lava boulders	6- 18	Hard brown and blue lava. Flow of 0.5 mgd carrying pieces of rotten wood between 148 ft. and 180 ft.	140-180	Hard brown lava, olivines	188-220
Gray clay	18- 30				
Light brown clay	30- 55				
Brown sandy clay	55-100				
Gray sandy clay	100-122				

Chloride content of water during drilling

Depth (ft.)	Chloride (ppm)	Depth (ft.)	Chloride (ppm)
150	67	200	67
160	67	210	57
175	62	220	57

2C (Lihue Plantation Co. well 4) Kealia. 22°6′5″N, 159°18′35″W. Owner, Lihue Plantation Co. Drilled, 1905 by McCandless Bros. for Makee Sugar Co. Altitude, 8 ft. Depth, 225 ft. Diameter, 12 in. Casing, 85± ft. Not in use.

2D (Lihue Plantation Co. well 3) Kealia. 22°6′5″N, 159°18′35″W. Owner, Lihue Plantation Co. Drilled, 1905 by McCandless Bros. for Makee Sugar Co. Altitude, 8 ft. Depth, 210 ft. Diameter, 12 in. Casing, 85± ft. Not in use.

2E (Lihue Plantation Co. well 2) Kealia 22°6′5″N, 159°18′35″W. Owner, Lihue Plantation Co. Drilled, 1898 by McCandless Bros. for Makee Sugar Co. Altitude, 8 ft. Depth, 213 ft. Diameter, 12 in. Casing, 95 ft. At time of completion well flowed 1 mgd.

2F (Lihue Plantation Co. well 1) Kealia. 22°6′5″N, 159°18′35″W. Owner, Lihue Plantation Co. Drilled, 1898 by McCandless Bros. for Makee Sugar Co. Altitude, 8 ft. Depth, 213 ft. Diameter, 10 in. Casing, 95 ft. Use, domestic supply. Well reported to flow 1 mgd. at time it was drilled.

Observations
(Bench mark, top of door sill in pump house, 2 ft. above ground surface; altitude 10.05 ft.)

Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)
Mar. 23, 1937	....	38	Oct. 22	10.65	43	May 23	9.76	41
Apr. 22	9.49	39	Nov. 19	10.49	43	June 19	10.07	43
May 15	10.15	38	Dec. 21	10.42	42	July 20	10.01	42
June 16	10.74	38	Jan. 24, 1939	10.20	43	Aug. 19	10.32	42
July 21	....	38	Feb. 20	10.15	46	Sept. 23	10.59	41
Aug. 23	....	38	Mar. 21	10.15	43	Oct. 3	11.15	....
Sept. 17	....	40	Apr. 21	9.99	41	Oct. 21	10.88	40
Oct. 18	....	39	May 22	10.22	44	Nov. 20	11.17	44
Nov. 17	10.61	39	June 20	10.21	43	Dec. 20	11.01	44
Dec. 21	10.36	97	July 21	10.15	40	Jan. 21, 1941	10.74	46
Jan. 20, 1938	10.40	39	Aug. 25	10.09	42	Feb. 20	10.36	41
Feb. 26	....	41	Sept. 25	10.44	40	Mar. 25	10.46	43
Mar. 21	....	42	Oct. 26	10.28	41	Apr. 21	10.32	42
Apr. 26	9.57	44	Nov. 27	9.32	43	May 21	10.52	45
May 21	10.22	42	Dec. 22	10.30	41	June 21	10.04	45
June 21	10.40	42	Jan. 20, 1940	10.38	42	July 25	10.24	43
July 23	10.38	42	Feb. 22	10.01	42	Aug. 20	9.89	43
Aug. 20	10.40	42	Mar. 26	10.24	41	Sept. 22	10.48	45
Sept. 20	10.40	42	Apr. 23	9.86	40	Oct. 20	10.39	41

Observations—Well 2F (Continued)

Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)
Nov. 19	10.50	42	Mar. 18	10.11	44	July 26	9.15	45
Dec. 22	10.36	43	Apr. 20	9.75	41	Aug. 27	9.44	42
Jan. 21, 1942	10.20	44	May 19	10.06	42	Sept. 25	9.52	43
Feb. 23	10.01	43	June 20	9.72	42	Oct. 24	9.52	43
Mar. 23	9.99	43	July 19	9.86	42	Nov. 26	9.50	41
Apr. 18	9.47	42	Aug. 24	9.88	44	Dec. 27	10.07	45
May 19	9.47	41	Sept. 23	10.15	42	Jan. 20, 1947	9.63	42
June 20	9.66	40	Oct. 24	10.07	41	Feb. 27	9.44	44
July 22	9.98	41	Nov. 21	9.80	44	Mar. 25	9.38	46
Aug. 22	9.77	43	Dec. 30, 1944	9.76	48	Apr. 29	9.37	45
Sept. 24	9.90	42	Jan. 24, 1945	9.92	40	May 28	9.49	44
Oct. 22	9.99	39	Feb. 24	9.44	46	June 30	9.32	42
Nov. 24	10.09	39	Mar. 21	9.42	43	July 24	9.34	43
Dec. 19	9.96	39	Apr. 21	9.32	44	Aug. 26	9.70	40
Jan. 20, 1943	9.80	40	May 24	9.20	44	Sept. 24	9.74	44
Feb. 23	9.81	40	June 20	9.40	46	Oct. 23	9.92	40
Mar. 20	9.68	40	July 24	9.34	43	Nov. 26	9.83	39
Apr. 20	9.93	40	Aug. 29	9.58	47	Dec. 22	9.78	43
May 20	9.78	40	Sept. 22	9.44	45	Jan. 20, 1948	9.86	45
June 22	9.79	41	Oct. 22	9.49	45	Mar. 24	9.17	44
July 21	9.73	45	Nov. 23	9.82	46	Apr. 22	9.24	41
Aug. 18	10.06	42	Dec. 22	9.77	46	May 26	9.16	43
Sept. 24	10.05	46	Jan. 22, 1946	9.82	40	June 24	9.20	43
Oct. 20	10.41	40	Feb. 26	9.70	43	July 22	9.17	43
Nov. 24	10.32	46	Mar. 28	9.72	40	Aug. 24	9.50	43
Dec. 21	10.17	45	Apr. 29	9.24	44	Sept. 23	9.77	43
Jan. 19, 1944	10.03	45	May 23	9.40	42	Nov. 5	9.82	43
Feb. 22	9.94	44	June 19	9.43	40	Dec. 3	9.90	39

2G (Lihue Plantation well 5) Kealia. 22°6′5″N, 159°18′35″W. Owner, Lihue plantation Co. Drilled, 1928 by G. B. Primmer for Makee Sugar Co. Altitude, 15 ft. Depth 402 ft., backfilled to 250 ft. Diameter, 12 in. Casing, 112 ft. Head, 8 ft., when well was completed.

Driller's log

	Depth (ft.)		Depth (ft.)		Depth (ft.)
Dry yellow sand	0- 12	Hard brown lava	123-130	Brown and red lava, some porous	208-250
Quicksand, blue	12- 65	Red and brown lava	130-133	Brown lava and sand	250-265
Black sandy clay	65- 80	Hard black lava	133-154	Hard brown and blue rock full of olivines	265-325
Brown clay and coral	80- 95	Brown lava	154-192	Blue and black lava, olivines	325-402
Rotten rock	95-112	Very hard brown lava	192-208		
Hard blue rock	112-123				

Hole backfilled with brick and cement from 402 to 250 ft. and crushed rock from 250 to 224 ft.

Observations
Chloride content of water during drilling

Depth (ft.)	Chloride (ppm)	Depth (ft.)	Chloride (ppm)	Depth (ft.)	Chloride (ppm)
150	74	295	348	340	607
230	177	300	328	345	624
235	182	305	410	350	753
255	192	310	452	355	810
265	234	315	560	360	815
270	229	320	550	370	780
275	234	325	500	375	925
280	254	330	525	390	1300
285	280	335	566	402	1660
290	306				

6 Kapaa. 22°4′35″N, 159°19′15″W. Owner, Hawaiian Canneries Co. Drilled, 1928 by G. B. Primmer. Altitude, 7 ft. Original depth, 250 ft., backfilled to 200 ft. Diameter, 12 in. Casing, 160 ft. Use, industrial.

Driller's log

	Depth (ft.)		Depth (ft.)		Depth (ft.)
Yellow sand	0- 16	Reddish brown clay	115-140	Brown lava, very hard	192-202
Loose Coral and Sand	16- 50	Hard brown lava	140-155	Black lava	202-210
Grayish brown clay	50- 60	Red brown and black lava with loose coral and sea shells	155-158	Hard brown lava	210-224
Brown sandy clay	60- 82	Blue and black lava	158-192	Red, blue, and brown lava, broken and full of olivines	224-250
Gray clay and boulders	82- 90				
Brown sandy clay and rubble	90-115				

Chloride content of water during drilling

Depth (ft.)	Chloride (ppm)	Depth (ft.)	Chloride (ppm)
155	128	250	530
195	385	250 (pumping)	1075
215	447	200 (after backfill)	707

Date	Head (ft.)	Chloride (ppm)
Mar. 16, 1937	6.48	883
May 7	7.1	760

7 2 mi N Hanamaulu. 22°01′25″N, 159°20′55″W. Owner, Territory of Hawaii. Drilled, 1897 or 1899 by McCandless Bros. Altitude, 10 ft. Reported original depth, 250 ft. Measured depth 1925, 192 ft.; 1954, 182 ft. Diameter, 12 in. Casing, about 60 ft. Use, intermittent domestic and irrigation.

Observations

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
May 15, 1937	132	June 17, 1940	124	May 15, 1943	124
June 16	134	July 17	133	June 15	129
July 15	134	Aug. 15	127	July 16	124
Aug. 16	134	Sept. 17	124	Aug. 16	139
Sept. 17	135	Oct. 17	128	Sept. 16	150
Oct. 16	134	Nov. 18	129	Oct. 15	146
Nov. 16	135	Dec. 16	130	Nov. 16	145
Jan. 15, 1938	134	Jan. 16, 1941	131	Dec. 16	148
Feb. 16	134	Feb. 18	131	Jan. 16, 1944	145
Mar. 16	133	Mar. 17	132	Feb. 17	139
Apr. 16	133	Apr. 15	126	Mar. 18	135
May 16	134	May 16	140	Apr. 15	137
June 16	132	June 16	128	May 16	134
July 16	134	July 15	125	June 15	138
Aug. 16	131	Aug. 15	128	July 15	140
Sept. 16	139	Sept. 16	130	Aug. 15	139
Oct. 16	136	Oct. 16	128	Sept. 4	139
Nov. 16	137	Nov. 17	127	Nov. 2	140
Dec. 17	135	Dec. 16	132	Dec. 29	154
Jan. 16, 1939	140	Jan. 17, 1942	127	Feb. 25, 1945	149
Feb. 16	138	Feb. 17	127	Apr. 27	149
Mar. 16	138	Mar. 16	132	June 30	156
Apr. 17	136	Apr. 16	126	Aug. 11	153
May 17	133	May 15	124	Sept. 30	161
June 16	138	June 16	132	Nov. 28	156
July 15	131	July 14	127	Jan. 25, 1946	161
Aug. 15	129	Aug. 17	127	May 9	152
Sept. 19	127	Sept. 15	124	July 26	146
Oct. 16	134	Oct. 15	129	Sept. 26	153
Nov. 16	131	Nov. 17	128	Nov. 23	156
Dec. 16	135	Dec. 16	122	Jan. 20, 1947	158
Jan. 16, 1940	132	Jan. 15, 1943	128	Mar. 29	155
Mar. 19	131	Feb. 16	124	June 4	156
Apr. 15	123	Mar. 15	134	July 16	154
May 16	127	Apr. 16	123	Nov. 19	157

8 *2 mi N Hanamaulu. 22°01′25″N, 159°20′55″W.* Owner, Territory of Hawaii. Drilled, 1897 or 1899 by McCandless Bros. Altitude, 12 ft. Reported original depth, 240 ft.; measured depth 1955, 211 ft. Diameter, 12 in. Casing, about 60 ft. Use, intermittent domestic and irrigation. Discharge, July 1924, 0.6 mgd; Oct. 1925, 0.4 mgd.

Observations

Benchmark, top of casing, 2 ft. above ground; altitude, 13.95 ft.

Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)
Mar. 16, 1937	11.25	......	Apr. 15, 1940	12.47	96	Apr. 16, 1943	12.02	97
Apr. 16	11.16	......	May 16	12.45	95	May 15	12.52	100
May 15	11.25	99	June 17	12.36	100	June 15	12.50	99
June 16	11.39	107	July 17	12.30	113	July 16	12.59	111
July 15	11.67	110	Aug. 15	12.45	113	Aug. 16	12.79	125
Aug. 16	11.95	111	Sept. 17	12.70	108	Sept. 16	12.88	128
Sept. 17	12.36	107	Oct. 17	12.77	103	Oct. 15	12.78	107
Oct. 16	12.59	109	Nov. 18	12.95	108	Nov. 16	12.72	106
Nov. 16	12.67	106	Dec. 16	12.81	108	Dec. 16	12.89	117
Dec. 16	12.60	......	Jan. 16, 1941	12.75	105	Jan. 15, 1944	12.06	112
Jan. 15, 1938	12.45	105	Feb. 18	12.74	100	Feb. 17	11.83	113
Feb. 16	12.49	100	Mar. 17	12.54	100	Mar. 18	11.70	108
Mar. 16	12.40	101	Apr. 15	12.53	95	Apr. 15	10.76	102
Apr. 16	12.47	99	May 16	12.50	......	May 16	10.49	105
May 16	12.41	100	June 16	12.58	112	June 15	10.39	127
June 16	12.51	112	July 15	12.61	111	July 15	....	130
July 16	12.72	112	Aug. 15	12.69	116	July 21	10.35	......
Aug. 16	12.72	120	Sept. 16	12.85	125	Aug. 15	....	132
Sept. 16	12.76	120	Oct. 16	12.99	122	Sept. 4	9.78	134
Oct. 15	12.85	120	Nov. 17	12.93	97	Nov. 2	9.45	142
Nov. 17	12.83	106	Dec. 16	12.72	101	Dec. 29	9.77	141
Dec. 17	12.53	118	Jan. 17, 1942	12.70	100	Feb. 27, 1945	8.49	135
Jan. 16, 1939	12.47	104	Feb. 17	12.53	95	Apr. 27	9.81	115
Feb. 16	12.38	105	Mar. 16	12.37	103	June 30	9.95	124
Mar. 16	12.41	111	Apr. 16	12.39	99	Aug. 11	10.10	130
Apr. 17	12.23	107	May 15	12.26	100	Nov. 28	10.05	130
May 17	12.23	103	June 16	12.15	104	Jan. 25, 1946	10.00	119
June 16	12.08	105	July 14	11.60	99	May 9	9.87	125
July 15	12.19	102	Aug. 17	11.75	114	July 26	9.88	118
Aug. 15	12.28	103	Sept. 15	11.61	114	Sept. 26	10.07	111
Sept. 16	12.55	98	Oct. 15	11.75	118	Nov. 23	9.52	107
Oct. 16	12.67	99	Nov. 17	12.05	99	Jan. 20, 1947	10.07	117
Nov. 16	12.56	104	Dec. 15	11.95	97	Mar. 29	9.96	102
Dec. 16	12.63	102	Jan. 15, 1943	12.33	95	June 4	10.23	105
Jan. 16, 1940	12.60	102	Feb. 16	12.19	102	July 16	10.35	110
Feb. 19	12.49	......	Mar. 15	12.17	99	Nov. 19	10.52	111

9 2 mi SW Kapaa. 22°3′35″N, 159°20′45″W. Owner, Board of Agriculture and Forestry, Territory of Hawaii. Drilled, 1952 by Samson and Smock, Ltd. Altitude, 90 ft. Depth, 230 ft. Diameter, 6 in. Head, about 55 ft. Drilling of 6-in. well was preceded by a diamond-drill core test to depth of 136 ft.

Description of cores from test hole

	Depth of Hole (ft.)	Length of Core (ft.)
Brown soil	0- 5	0.8
Reddish brown clay	5- 26	0.7
No core	26- 30	0
Medium gray, fine-grained basalt, moderately vesicular, flattened vesicles	30- 33	1.1
Dark gray, fine-grained basalt, moderately vesicular, flattened vesicles	33- 61	2.6
Same as 33-61 but less vesicular, dense toward bottom	61- 72	3.8
Dark gray, fine-grained basalt, moderately vesicular, generally very small vesicles	72- 86	7.9
Dark gray, fine-grained basalt, similar to 72-86 but fewer vesicles	86-103	13.7
Very dark brown nonplastic clay, many small light-colored veinlets	103-104	0.2
Dark reddish brown plastic clay	104-118	0.5
Dark gray, fine-grained basalt with numerous small olivine crystals, vesicular in part with very small vesicles, somewhat weathered	118-124	2.9
Basalt, moderately vesicular with flattened vesicles, many small olivine crystals, thoroughly weathered	124-133	1.9
Basalt, generally dense with a few vesicles, many small olivine crystals, thoroughly weathered	133-136	1.9

Driller's log

	Depth (ft.)		Depth (ft.)		Depth (ft.)
Brown soil	0- 12	Soft brown rock	104-107	Medium hard rock	170-177
Soft decayed mud rock	12- 33	Medium hard brown clay	107-118	Soft rock	177-184
Soft pukapuka rock	33- 47	Medium hard rock	118-125	Medium hard rock	184-187
Medium hard pukapuka rock	47- 61	Soft reddish rock	125-137	Soft rock	187-191
Hard gray rock	61- 78	Soft gray rock	137-142	Medium hard rock	191-197
Hard rock	78- 84	Medium hard rock	142-148	Soft rock	197-201
Medium hard rock	84- 88	Hard rock	148-154	Brown clay	201-204
Hard rock	88-102	Soft rock	154-157	Medium hard rock	204-207
Medium hard pukapuka rock	102-104	Hard rock	157-161	Medium hard cracked rock	207-213
		Medium hard rock	161-167	Medium hard rock	213-214
		Soft rock	167-170	Yellow clay	214-230

10 South end Kalepa ridge, Hanamaulu. 21°59′50″N, 159°21′45″W. Owner, County of Kauai. Drilled Aug. to Dec. 1954 by Samson and Smock, Ltd. Altitude, 302 ft. Depth, 540 ft. Diameter, 14 in. Casing, 315 ft. Head. 16 ft. Chloride, 23 ppm when hole was 452 ft. deep; 182 ppm at 540 ft. after pumping 9 hours at 100 gpm. Abandoned.

Driller's log
(Petrographic interpretation of cuttings by G. A. Macdonald in parentheses)

	Depth (ft.)		Depth (ft.)		Depth (ft.)
Sticky brown clay	0- 15	Medium hard olivine rock	242-259	Medium hard rock	329-367
Sticky brown clay with decomposed rock	15- 57	Hard olivine rock	259-260	Hard rock	367-376
Medium hard olivine rock	57-140	Medium hard olivine rock. Reamed, 255 to 261 ft.	260-261	Medium hard olivine rock	376-390
Hard olivine rock	140-145	Medium hard rock	261-263	Soft pukapuka olivine rock	390-405
Medium hard rock	145-149	Medium hard olivine rock	263-264	Medium hard olivine rock	405-411
Hard rock (olivine basalt of Waimea Canyon volcanic series, 57-153 ft.)	149-155	Medium hard rock with red rock. Reamed, 260 to 270 ft.	264-275	Soft pukapuka olivine rock	411-418
Medium soft rock	155-157	Hard olivine rock, soft on one side. Reamed	275-278	Medium hard pukapuka rock	418-465
Medium hard olivine rock	157-176	Hard olivine rock	278-279	Soft pukapuka rock	465-476
Soft olivine rock	176-181	Medium hard olivine rock	279-280	Medium hard pukapuka rock	476-489
Hard olivine rock	181-185	Hard olivine rock	280-282	Soft pukapuka rock with red rock	489-501
Medium hard rock	185-194	Medium hard olivine rock	282-286	Medium hard rock	501-505
Hard rock	194-198	Medium hard olivine rock, soft on one side	286-290	Medium hard rock (picrite-basalt of Koloa volcanic series. 524-526 ft. Probably a dike)	505-526
Medium hard rock (olivine basalt of Waimea Canyon volcanic series, 170-200 ft.)	198-201	Medium hard olivine rock	290-299	Clinker (olivine basalt of Waimea Canyon volcanic series)	**526-529**
Medium hard porous olivine rock	201-205	Soft olivine rock	299-303	Medium hard rock	529-535
Medium hard rock	205-210	Hard olivine rock. Reamed	303-305	Hard rock	535-537
Medium hard olivine rock	210-217	Medium hard olivine rock	305-307	Hard rock. Bit sheared off at 540 ft. (olivine basalt of Waimea Canyon volcanic series)	537-540
Medium hard rock	217-225	Hard rock	307-309		
Hard rock	225-235	Very hard rock. Reamed	309-314		
Hard porous rock	235-237	Hard rock	314-329		
Hard rock	237-242				

Water-level measurements during drilling

Depth (ft.)	Head (ft.)	Depth (ft.)	Head (ft.)	Depth (ft.)	Head (ft.)
290	15.97	317	15.3	529	16.3
300	15.3	418	16.05	535	16.3
305	14.97	476	16.3	537	16.8
307	14.97	501	16.47	540	16.9
309	14.97	505	16.3		

12 Kipukai. 21°55′20″N, 159°23′15″W. Owner, J. T. Waterhouse. Drilled, 1950 by Samson and Smock, Ltd. Altitude, 27 ft. Depth, 107 ft. Diameter, 8 in. Casing, 34 ft. Use, domestic. Head, Aug. 9, 1954, 4.8 ft. Chloride, Aug. 9, 1954, 60 ppm.

Driller's log

	Depth (ft.)		Depth (ft.)		Depth (ft.)
Soil	0- 3	Hard rock	34- 40	Soft brown rock	78- 86
Soft rock	3- 8	Very hard rock	40- 46	Soft brown and gray rock	86- 89
Medium hard rock	8- 13	Soft gray rock	46- 58	Soft gray rock	89- 96
Hard rock	13- 27	Soft brown rock	58- 70	Medium hard gray rock	96-107
Medium hard rock	27- 34	Hard gray rock	70- 78		

14A to **N** Mahaulepu. 21°54′50″N, 159°25′20″W. Owner, Grove Farm Co. Wells A to J drilled by McCandless Bros. Wells K to N drilled by G. B. Primmer. Wells A to J were drilled between 1897 and 1899 (or 1901) and connected by a 4 ft. by 5 ft. concrete or masonry lined tunnel about 50 below ground surface. Header pipe in tunnel connected wells to a steam pump installed in a pit 35 ft. deep. Slumping of walls of pit eventually destroyed pump house, which was replaced with a concrete structure, access to which was through a shaft. Wells A to J were abandoned about 1928. Use, irrigation.

Well	Date Drilled	Altitude (ft.)	Depth (ft.)	Diameter (in.)	Casing (ft.)
A	1897	85	303	12	242
B	1897	85	300	12	242
C	1897	85	300	12	220
D	1897	85	301	12	224
E	1897	85	300	12	210
F	1897	85	304	12	212
G	1899	85	300	12	215
H	1899	85	300	12	215
I	1901	85	300	12	215
J	1901	85	300	12	215
K	1927	85	505	12	245
L	1927	85	506	12	301
M	1927	85	510	12	309
N	1928	85	526	12	315

Well 14K

Driller's log

	Depth (ft.)		Depth (ft.)
Clay	0- 60	Blue and red porous lava. Water at about same level to 330 ft. where it rose to 30 ft. above sea level. Does not bail down	261-342
Brown and blue lava. Struck water at 64 ft. which rose to 31 ft. below ground. Can bail water down	60- 69	Hard lava and blue stone	342-345
Red clay, caving and sticky	69- 85	Porous lava	345-352
Red, blue, and brown clay	85-120	Hard lava and blue stone	352-358
Purple clay, sticky	120-165	Hard blue and red porous lava	358-370
Brown sandy clay	165-192	Blue stone and brown lava	370-385
Rotten rock and rubble. Some water at about 198 ft. standing about 26 ft. above sea level, but could bail it down to below sea level	192-248	Blue and red porous lava with small streaks of blue stone. At 390 ft. water stands 32 ft. above sea level	385-475
Porous lava	248-252	Hard brown lava full of olivines	475-483
Hard blue stone	252-261	Red porous lava and volcanic ash and brown burnt porous clay	483-486
		Blue and brown and red lava; blue and brown lava with olivines and very hard	486-506

Chloride content of water during drilling

Depth (ft.)	Chloride (ppm)	Depth (ft.)	Chloride (ppm)	Depth (ft.)	Chloride (ppm)
330	100	400	77	460	72
347	114	410	77	470	72
358	107	420	77	480	70
365	78	430	79	490	69
380	79	440	75	500	67
390	74	450	73	506	69

Well 14L

	Depth (ft.)
Red, blue, and brown clay	0- 54
Hard blue lava	54- 60
Brown and gray rotten lava	60- 63
Hard blue lava	63- 64
Rotten brown lava, some black sand	64- 67
Hard blue lava	67- 76
Reddish brown clay	76- 99
Red, blue, and brown clay	99-114
Purple and brown clay	114-159
Greenish brown clay, sandy	159-184
Brown clay and rotten rock	184-236
Blue and brown lava, hard	236-243
Brown clay and rotten rock	243-252
Blue and brown lava	252-264
Rotten rock	264-292
Red, blue, and brown porous lava, some hard streaks, water	292-319
Red lava, some porous	319-324
Red lava, very hard	324-334
Red, blue, and brown lava, some porous. At 369 ft. water stands 29 ft. above sea level	334-384
Very hard brown lava	384-396
Blue and brown porous lava, some hard streaks	396-434
Red, blue, and brown porous lava	434-449
Blue and brown porous lava	449-479
Hard blue lava full of olivines	479-491
Brown porous lava, some hard streaks. At 501 ft. water stands 32 ft. above sea level	491-502
Hard, brown lava full of olivines. At 506 ft. water stands 31 ft. above sea level	502-506

Chloride content of water during drilling

Depth (ft.)	Chloride (ppm)
346	52
369	55
394	58
419	59
444	63
469	63
494	66
506	65

Well 14M

	Depth (ft.)
Red and blue clay	0- 43
Blue clay	43- 62
Rubble and brown clay. At 72 ft. brown sandy mud thin enough to bail rose to 44 ft.	62- 72
Hard lava, blue and brown	72- 75
Reddish brown clay	75- 97
Brown and purple sandy clay	97-128
Light brown clay, sticky	128-148
Chocolate brown clay, sticky	148-189
Greenish brown clay, very tough and sticky	189-215
Blue clay and rotten rock	215-257
Volcanic ash, cinders, and fine sand, all colors	257-273
Brown clay and lava sand	273-299
Hard red lava. Water stands 25 ft. above sea level	299-311
Hard brown lava	311-326
Hard blue rock. At 328 ft. water stands 27 ft. above sea level	326-330
Hard, red, blue and brown lava, some porous	330-335
Greenish gray sandstone	335-343
Red, blue, and brown lava. At 348 ft. water stands 28 ft. above sea level	343-368
Red lava, porous streaks, some hard streaks	368-373
Brown lava, some porous. At 383 ft. water stands 28 ft. above sea level	373-383
Very hard brown lava	383-395
Brown lava, porous	395-401
Small hard streak	401-402
Red, brown, and greenish sandy lava, porous	402-440
Brown and gray lava, very hard	440-447
Red and brown porous lava	447-459
Red, blue and brown lava; some porous streaks and some very hard streaks full of olivines. At 510 ft. water stands 31 ft. above sea level	459-510

Chloride content of water during drilling

Depth (ft.)	Chloride (ppm)
343	55
393	58
398	62
418	62
443	65
468	67
493	71
510	72

Well 14N

	Depth (ft.)
Red, blue, and brown clay	0- 72
Lava	72- 75
Reddish brown clay	75-124
Purple and brown clay	124-209
Brown clay and rotten rock	209-302
Red lava	302-322
Brown porous lava	322-359
Hard blue lava	359-374
Red, blue, and brown porous lava, hard streaks	374-404
Brown porous lava, some hard streaks	404-434
Hard brown lava, porous streaks	434-454
Red, blue, and brown porous lava	454-462
Blue and brown hard lava full of olivines	462-479
Red and blue hard lava full of olivines	479-489
Red lava full of olivines	489-496
Red and blue hard lava full of olivines	496-502
Red, blue, and brown porous lava full of olivines	502-510
Blue rock and porous lava	510-526

Chloride content of water during drilling

Depth (ft.)	Chloride (ppm)	Depth (ft.)	Chloride (ppm)	Depth (ft.)	Chloride (ppm)
394	92	454	93	494	82
419	94	469	83	504	67
444	89	484	81	514	75
				526	75

Date	Head (ft.)	Chloride (ppm)
Mar. 30, 1937	31.10	....
Apr. 29	31.27	....
June 1	31.19	....
Aug. 2	30.31	....
Aug. 28	31.23	....
Sept. 27	31.27	....
Nov. 5	31.35	....
Nov. 19	31.35	....
Dec. 22	31.27	....
Jan. 20, 1938	31.27	45
Feb. 26	31.44	46
Apr. 18	31.27	46
May 16	31.19	42
June 15	31.35	42
July 28	31.52	44
Aug. 30	31.52	45
Sept. 26	[a]22.02	41
Oct. 31	[a]11.10	42
Nov. 22	[a]13.22	41
Dec. 27	[a]12.35	44
Jan. 26, 1939	30.52	45
Feb. 28	[a]12.85	43
Mar. 27	31.02	44
Apr. 28	31.35	....
May 29	31.52	45
June 29	31.52	43
July 31	31.52	43
Aug. 31	[a]11.15	44
Sept. 29	[a] 9.77	44
Oct. 30	29.94	44
Nov. 29	30.60	43
Dec. 29	31.02	44
Jan. 30, 1940	31.27	42
Feb. 27	[a]12.02	42
Mar. 29	[a]10.94	42
Apr. 29	[a]11.69	42
May 25	29.94	42
June 25	[a]11.94	43
July 25	[a]11.02	43
Aug. 28	[a]11.52	42
Sept. 26	[a]10.27	42

Date	Head (ft.)	Chloride (ppm)
Oct. 29, 1940	30.52	42
Nov. 26	[a]12.20	44
Dec. 24	30.44	42
Jan. 30, 1941	[a]11.94	45
Feb. 27	[a]10.85	45
Mar. 28	[a]10.10	45
Apr. 28	[a]10.69	45
May 10	[a]10.69	45
June 26	[a] 8.77	45
July 30	[a]10.02	46
Aug. 29	[a] 8.19	45
Sept. 29	[a] 8.35	45
Oct. 30	28.60	45
Nov. 27	[a]11.27	43
Feb. 14, 1942	30.35	42
Mar. 11	30.19	42
Apr. 30	30.52	42
June 25	[a]17.35	42
July 27	[a]16.69	42
Aug. 25	[a]17.52	42
Sept. 26	31.44	42
Oct. 22	[a]13.52	43
Nov. 26	30.35	40
Dec. 29	31.10	40
Jan. 26, 1943	31.27	39
Feb. 25	30.94	41
Mar. 25	31.02	....
Apr. 26	[a]19.10	42
May 28	28.69	42
June 26	[a]13.52	41
June 27	[a]12.19	43
Aug. 28	30.77	41
Sept. 28	[a]14.10	41
Oct. 28	[a]13.52	42
Nov. 29	30.85	41
Dec. 28	30.85	....
Jan. 29, 1944	30.94	....
Feb. 28	30.94	....
Mar. 30	31.02	....
Apr. 29	30.52	41
May 29	[a]15.10	39

Date	Head (ft.)	Chloride (ppm)
June 26, 1944	[a]12.77	42
July 27	30.85	42
Aug. 30	[a]15.85	42
Sept. 30	[a]13.77	42
Oct. 28	[a]13.52	42
Nov. 28	[a]10.02	43
Dec. 29	29.77	42
Jan. 31, 1945	[a]10.02	44
Feb. 28	[a] 8.85	41
Mar. 31	[a] 9.60	43
Apr. 27	30.02	42
May 29	29.70	....
June 28	[a] 9.85	42
July 27	[a] 9.85	45
Aug. 29	[a] 9.85	44
Sept. 28	[a] 9.02	45
Oct. 31	28.69	43
Nov. 30	26.94	....
Dec. 31	29.69	....
Jan. 31, 1946	29.94	41
Feb. 27	29.02	....
Mar. 31	30.19	41
Apr. 30	30.19	41
May 31	30.19	39
July 1	30.19	42
Oct. 15	30.52	39
Nov. 29	30.35	39
Dec. 31	30.77	42
Jan. 28, 1947	30.77	41
Feb. 28	30.77	41
Apr. 19	[a]10.35	42
May 6	[a]10.77	41
June 10	29.02	43
July 2	[a] 8.22	42
Aug. 5	[a] 8.02	42
Sept. 3	28.22	42
Oct. 28	30.02	41
Dec. 3	29.32	41
Dec. 31	30.22	....

[a] Adjacent wells pumping.

15A (Koloa mill well 1). Koloa mill. 21°54′15″N, 159°26′50″W. Owner, Grove Farm Co. Drilled, 1927 by G. B. Primmer for Koloa Sugar Co. Altitude, 190 ft. Depth, 191 ft. Diameter, 12 in. Casing, unknown. Static water level, 118.5 ft., 1927. Drawdown, 19.25 ft. when pumping at 1.5 mgd, Aug. 13-20, 1937. Abandoned.

Driller's log

	Depth (ft.)		Depth (ft.)
Soil and boulders	0- 35	Yellow clay and large hard boulders	112-117
Blue lava	35- 50	Hard blue lava, possibly a boulder	117-120
Pink and blue lava	50- 72	Red clay and boulders	120-125
Hard blue lava	72- 75	Blue lava, hard	125-127
Chocolate brown lava, very hard	75- 92	Red clay. Bailing does not lower water level	127-145
Clay and boulders	92- 98	Brown clay	145-175
Hard blue lava	98-104	Gray sandy clay. Drilling stopped because of caving clay and boulders	175-191
Clay and boulders	104-108		
Blue lava	108-112		

15B (Koloa mill well 2). Koloa mill. 21°54′15″N, 159°26′50″W. Owner, Grove Farm Co. Drilled, 1927 by G. B. Primmer for Koloa Sugar Co. Altitude, 209 ft. Depth, 340 ft.; cement plugs 320 ft. to 340 ft. and 200 ft. to 215 ft. Diameter, 12 in. Casing, 176 ft. Head, 1927, 119.5 ft. Chloride, 1927, 43 ppm. Abandoned.

Driller's log

	Depth (ft.)		Depth (ft.)
Soil	0- 1	Sandy brown clay and boulders, caving	178-185
Hard blue lava, full of crevices and cracks; caving in large blocks, slow drilling	1- 35	Rubble and porous lava, boulders	185-190
Red lava	35- 41	Hard blue lava	190-195
Blue lava	41- 63	Chocolate brown sticky clay	195-202
Red and blue lava, some porous streaks	63- 88	Light brown clay, sticky	202-211
Chocolate brown lava, hard, porous streaks	88-103	Hard sandstone	211-213
Black or blue-black lava, very hard; porous streaks	103-106	Hard reddish brown lava	213-244
Clay and boulders	106-109	Hard fine-grained blue and brown lava	244-262
Hard purple lava	109-114	Clay and gravel; shells	262-264
Clay and boulders	114-120	Blue and brown lava, very hard	264-269
Hard blue lava	120-124	Clay and gravel; shells	269-278
Yellow clay and boulders	124-125	Blue and brown lava	278-282
Hard blue rock	125-142	Yellow and red clay and gravel; shells; some boulders	282-330
Boulders and loose rock, caving	142-148	Blue and brown porous lava, large olivines. At 340 ft. water dropped from 122 ft. to 110 ft. above sea level. Cemented hole from 340 ft. to 320 ft. and water came back to 122 ft. Also cemented hole from 215 ft. to 200 ft.	330-340
Hard blue lava, caving	148-155		
Chocolate brown clay, sticky	155-161		
Brown clay, caving	161-168		
Blue clay and brown clay in streaks, sticky	168-178		

16 Koloa. 21°54′45″N, 159°27′40″W. Owner, County of Kauai. Drilled, 1953 by Samson and Smock, Ltd. for Kauai County Water Works Board. Altitude, 245 ft. Depth, 455 ft. Diameter, 12 in. Casing, 277 ft. Cement grout outside of casing, surface to 103 ft.; sand and crushed rock backfill outside of casing, 103 ft. to metal shoe around casing at 215 ft. Bottom 60 ft. of casing perforated; 15-in. diameter open hole 277 ft. to 353 ft.; 11½-in. diameter open hole 353 ft. to 455 ft. Use, municipal. Capacity, 342 gpm with 3.5 ft. drawdown.

Driller's log

	Depth (ft.)		Depth (ft.)		Depth (ft.)
Dirt	0- 8	Medium hard rock	178-182	Hard rock	329-343
Sticky red clay	8-108	Soft rock	182-222	Medium hard rock	343-347
Brown clay with small rocks	108-127	Medium hard rock	222-227	Hard rock	347-355
Small boulders	127-128	Hard rock	227-233	Hard rock	355-359
Sticky clay	128-131	Medium hard rock	233-240	Medium hard rock	359-377
Brown clay with small rocks	131-140	Soft rock	240-265	Very hard rock	377-398
Hard boulder	140-142	Medium hard rock	265-272	Soft red rock	398-400
Sticky clay	142-153	Hard rock	272-277	Medium hard red rock	400-408
Medium hard rock—boulder	153-160	Soft rock	277-280	Hard rock	408-411
Soft rock	160-177	Medium hard rock	280-292	Medium hard rock	411-420
Hard rock	177-178	Hard rock	292-304	Soft rock	420-426
		Medium hard rock	304-322	Medium hard rock	426-439
		Soft rock	322-324	Soft rock	439-443
		Medium hard rock	324-329	Medium hard rock	443-455

Observations

Date	Chloride (ppm)	Date	Chloride (ppm)
Mar. 13, 1953	25	Sept. 22, 1953	25
Aug. 7	25	Aug. 4, 1954	26

20 Lawai. 21°55′20″N, 159°29′55″W. Owner, McBryde Sugar Co. Drilled, Oct. 1953-Mar. 1954 by Samson and Smock, Ltd. Altitude, 465 ft. Depth, 720 ft. Diameter, 20 in. Casing, 493 ft. Head, Feb. 20, 1954, 58.90 ft.

Driller's log

	Depth (ft.)		Depth (ft.)		Depth (ft.)
Boulders	0- 4	Boulders	170-172	Soft rock	400-437
Hard blue rock	4- 5	Soft rock and clay	172-178	Cavity	437-440
Boulders	5- 11	Boulders	178-180	Soft rock	440-446
Blue boulder	11- 17	Soft rock	180-182	Cavity	446-449
Blasted hole	17- 27	Boulders	182-185	Soft rock	449-453
Hard blue rock	27- 32	Soft rock and clay	185-187	Hard rock	453-457
Very hard rock	32- 34	Hard rock and clay	187-189	Soft rock	457-467
Hard rock	34- 35	Soft rock and clay	189-193	Hard rock	467-471
Hard blue rock	35- 54	Soft rock with clay and small boulders	193-212	Very hard drilling	471-476
Hard rock	54- 55	Soft rock and clay	212-216	Soft rock	476-484
Cinder	55- 56	Small boulder	216-217	Pukapuka rock	484-520
Red clay	56- 65	Cinder	217-223	Soft rock	520-570
Red clay with small boulders	65- 94	Small boulder	223-225	Pukapuka rock	570-605
Boulders	94- 96	Soft rock and clay	225-235	Soft rock	605-616
Hard boulders	96- 99	Boulders and clay	235-238	Pukapuka rock	616-640
Soft rock and clay	99-103	Soft rock and clay	238-305	Soft rock	640-658
Loose boulders	103-105	Soft rock with hard rock on one side	305-311	Hard rock	658-665
Boulders	105-107	Soft rock and clay	311-337	Soft rock	665-677
Boulders and clay	107-144	Soft rock	337-370	Soft pukapuka rock	677-706
Soft rock and clay	144-157	Pukapuka rock	370-400	Hard rock	706-717
Boulders and clay	157-170			Soft rock	717-720

23 Lawai. 21°55′15″N, 159°30′25″W. Owner, Kauai Pineapple Co. Drilled, 1951 by Samson and Smock, Ltd. Altitude, 440 ft. Depth, 750 ft. Diameter of hole, 21¼-in. to 477 ft.; 15½-in. to 750 ft. Casing, 23-in. to 6 ft.; 16-in. to 477 ft.; bottom 168 ft. of 16-in. casing perforated. Use, industrial.

Log
(Driller's terms followed by interpretation by D. C. Cox)

	Depth (ft.)		Depth (ft.)
Sticky clay. Highly weathered flow rock	0- 56	Soft rock. Clinker, possibly soil	350-356
Boulders. Compact flow rock, residual boulder	56- 76	Medium hard to very hard rock. Vesicular to compact flow rock, basalt, olivine basalt, or picritic basalt	356-375
Sticky clay. Highly weathered flow rock	76-116	Soft to medium soft red rock. Highly weathered flow rock or tuff	375-382
Medium soft rock. Partly weathered flow rock	116-130	Medium soft to medium hard rock. Mostly fairly thin and vesicular flow rock, basalt, olivine basalt, or picritic basalt	382-478
Soft material, caving. Highly weathered flow rock	130-139	Medium soft rock with soft cavities. Clinker, possibly weathered flows	478-487
Hard and medium hard pukapuka rock. Mostly thin and vesicular flow rock, basalt and olivine basalt	139-162	Medium hard rock. Mostly thin and vesicular flow rock, basalt, olivine basalt, or picritic basalt	487-514
Hard olivine rock. Mostly fairly massive and compact flow rock, probably picritic basalt	162-177	Medium soft red rock. Highly weathered flow rock or tuff	514-520
Medium hard rock and hard olivine rock. Mostly fairly massive and compact flow rock, basalt, olivine basalt, or picritic basalt	177-215	Medium hard rock. Mostly fairly thin and vesicular flow rock, basalt, olivine basalt, or picritic basalt	520-565
Medium soft to hard red rock. Partly weathered flow rock	215-227	Soft rock. Clinker, possibly soil or tuff	565-575
Medium hard to hard rock. Mostly fairly massive and compact flow rock, basalt, olivine basalt, or picritic basalt	227-288	Medium soft to hard rock. Mostly fairly thin and vesicular flow rock basalt, olivine basalt, or picritic basalt	575-718
Medium soft to medium hard rock. Mostly thin and vesicular flow rock, basalt, olivine basalt, or picritic basalt	288-350	Medium hard to hard rock. Mostly fairly massive and compact flow rock, basalt, olivine basalt, or picritic basalt	718-750

Water levels during drilling

Depth of Well (ft.)	Head (ft.)	Depth of Well (ft.)	Head (ft.)	Depth of Well (ft.)	Head (ft.)
374	154	476	142	580	142
379	154	478	142	600	137
381	154	490	142	600	136
445	142	505	142	639	133
452	142	520	142	650	133
462	142	535	142	687	131
470	142	555	142	700	130
				750	124

Meter tests during drilling

Test No. 1. Date, April 18, 1951. Depth of well, 650 ft. Au 3-inch deep-well meter used. Depth to water 307 ft.

Observations by D. C. Cox.

Depth (ft.)	Revolutions per minute	Approximate velocity (ft. per sec.)	Depth (ft.)	Revolutions per minute	Approximate velocity (ft. per sec.)
423	27	0.17	497	33	0.22
447	34	.23	492	27	.18
472	60	.40	487	45	.30
497	34	.23	477	46	.31
522	65	.43	472	61	.41
547	41	.27	462	83	.55
572	1	.007	455	52	.35
597	0	0	440	32	.21
557	0.8	.005	422	29	.19
547	38	.25	397	16	.11
522	68	.45	382	12	.08
532	66	.44	377	1	.007
503	58	.39			

Test No. 2. Date, May 4, 1951. Depth of well, 750 ft. Au 3-inch deep-well meter used. Water was moving downward. Depth to water, 316 ft.

Observations by D. C. Cox.

Depth (ft.)	Revolutions per minute	Approximate velocity (ft. per sec.)	Depth (ft.)	Revolutions per minute	Approximate velocity (ft. per sec.)
429	13	0.09	528	30	.20
453	16	.11	513	26	.17
478	36	.24	503	0	0
503	0	0	498	0	0
528	33	.22	493	21	.14
553	0	0	483	21	.14
748	0	0	478	36	.24
553	0	0	468	32	.21
543	29	.20	461	19	.19
538	32	.22	446	15	.10
533	28	.19	403	0	0

Infiltration tests during drilling

Date	Depth of Well (ft.)	Rate (gpm)	Length (hours)	Static Head (ft.)	Rise in Water Level (ft.)
Apr. 13, 1951	600	750	1	137.3	6.5
Apr. 14	600	500	....	137.0	0
May 4	750	675	1	124.3	0.3

27 Kekaha. 21°58′05″N, 159°42′45″W. Owner, Kekaha Sugar Co. Drilled, April 17, 1930 to May 29, 1930 by G. B. Primmer. Altitude, 9 ft. Depth, 490 ft. Diameter, 10 in. Casing, 463 ft. Use, industrial, sugar mill.

Driller's log

	Depth (ft.)		Depth (ft.)		Depth (ft.)
Loose sand and coral	0- 38	Brown rotten rock	190-195	Brown sandstone, hard streaks of gypsum 315-340 ft. and 370-385 ft.	280-404
Pink coral and hard sandstone	38- 76	Sandy clay, coral and sea shells	195-199	Hard brown lava	404-410
Chocolate brown clay	76- 91	Hard brown waxy clay	199-215	Red brown lava, some porous	410-440
Light brown and yellow clay	91-115	Coral	215-230	Broken strata, hard brown lava	440-462
Brown clay and coral	115-135	Sticky yellow clay	230-238	Red and brown lava	462-490
Dark brown clay, very tough and sticky	135-175	Boulders	238-242		
Hard blue lava, full of olivines	175-190	Brown sticky clay	242-270		
		Brown sandy clay	270-280		

28 (Limaloa well; camp 5 well) Kaunalewa. 21°59′50″N, 159°45′10″W. Owner, Kekaha Sugar Co. Drilled, about 1899. Altitude, 6 ft. Depth, unknown. Diameter, 10 in. Casing, unknown. Use, stock.

Observations

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
Feb. 26, 1937	360	Mar. 31, 1939	240	July 3, 1946	490
Apr. 9	360	Apr. 28	225	Aug. 22	610
30	345	May 26	225	Nov. 25	610
May 28	200	Aug. 25	255	Dec. 4	610
June 25	235	Sept. 29	255	Jan. 6, 1947	630
July 30	290	Dec. 8	255	Feb. 14	600
Sept. 3	250	Jan. 26, 1940	275	Mar. 17	610
25	240	May 15	255	Apr. 18	580
Oct. 29	240	June 27	275	May 19	720
Nov. 26	240	July 29	275	June 18	670
Dec. 24	240	Aug. 14	290	July 21	620
Jan. 28, 1938	205	Jan. 3, 1941	290	Aug. 8	602
Apr. 29	230	Feb. 7	275	Sept. 19	639
May 27	205	Mar. 17	290	Oct. 16	608
June 24	225	May 10	310	Dec. 4	679
July 29	230	July 12	325	Jan. 30, 1948	660
Sept. 30	230	Oct. 21	310	Mar. 1	640
Oct. 28	250	Aug. 3, 1945	445	Apr. 3	660
Nov. 25	250	Sept. 27	480	May 11	590
Dec. 30	240	May 10, 1946	530		
Jan. 27, 1939	240	June 20	360		

29 (K. S. Co. well 10) Kaunalewa. 21°59′45″N, 159°44′35″W. Owner, Kekaha Sugar Co. Drilled, about 1899. Altitude, 8 ft. Depth, 35 ft. Diameter, 8 in. Casing, unknown. Use, irrigation.

30 (K. S. Co. well 11; field 207 well) Kaunalewa. 21°59′45″N, 159°44′40″W. Owner, Kekaha Sugar Co. Drilled, about 1899 (?). Altitude, 4 ft. Depth, 213 ft. Diameter, 8 in. Casing, unknown, obstructed at 2.5 ft. Use, irrigation.

31 Kaunalewa. 21°59′50″N, 159°44′40″W. Owner, Kekaha Sugar Co. Altitude, 4 ft. Depth, unknown. Casing, unknown. Well is buried; location uncertain.

32A to **H** (K. S. Co. K-1 to 8; Kaunalewa pump) Kaunalewa. 21°59′55″N, 159°44′40″W. Owner, Kekaha Sugar Co. Drilled, about 1890. Altitude, ground surface 10 ft. Wells are in sump into which they flow and from which water is lifted by electric powered pumps. Altitudes shown for individual wells are for tops of casing. Depths shown are below tops of casing. Use, irrigation.

32A (K-1) Altitude, 0.86 ft. Depth, unknown. Diameter, 12 in. Casing, unknown, obstructed at 13.5 ft.

Observations

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
Feb. 12, 1937	805	23	635	26	790
26	1355	30	685	Jan. 14, 1938	630
Mar. 26	975	Aug. 6	615	21	635
Apr. 9	1200	13	670	Jan. 28, 1938	685
16	1215	28	635	Mar. 18	735
23	1335	Sept. 3	670	25	700
May 14	600	18	685	Apr. 15	685
21	635	25	700	22	670
28	635	Oct. 1	875	29	670
June 11	700	8	615	May 6	685
18	635	15	635	13	670
25	670	29	720	20	650
July 2	700	Nov. 5	685	27	615
9	790	12	755	June 10	740
16	465	19	820	17	615

Observations—Well 32A (Continued)

Date	Chloride (ppm)
24	680
July 1	660
15	640
22	640
29	640
Aug. 5	615
26	630
Sept. 2	640
16	680
23	680
30	670
Oct. 7	670
14	615
21	650
28	660
Nov. 25	650
Dec. 2	680
16	835
30	760
Jan. 6, 1939	855
13	840
Jan. 20, 1939	670
27	755
Feb. 3	685
17	650
24	685
Mar. 10	685
31	735
Apr. 14	685
21	635
28	685
May 5	670
19	650
26	720
Aug. 4	700
25	685
Sept. 1	685
15	700
22	685
29	635
Oct. 13	670
20	670
Nov. 10	670
Dec. 8	635
15	670
22	635
Feb. 9, 1940	635
June 27	635
July 29	615
Aug. 14	615
Feb. 15, 1941	700
Mar. 17	700
May 10	685
Sept. 27, 1945	735

Date	Head (ft.)	Chloride (ppm)
Mar. 22, 1950	8.71	890
Apr. 3	8.85	......
10	8.75	980
17	8.97	......
24	8.94	......
May 1	8.57	660
8	8.96	......
15	8.97	......
22	8.97	......
29	8.96	......
June 6	8.96	......
12	8.87	......
July 3	8.82	......
24	8.57	......
31	8.61	......
Aug. 7	8.97	......
14	8.97	......
19	9.13	830
Sept. 8	9.10	......
Oct. 2	8.98	......
Nov. 4	8.96	......
Dec. 11	8.98	......
Jan. 15, 1951	8.80	810
Feb. 15	8.95	560
Mar. 15	9.10	838
Apr. 16	8.98	629
May 18	8.96	713
June 14	8.86	678
July 17	8.59	690
Aug. 16	8.96	722
Sept. 18, 1951	9.08	750
Nov. 16	8.99	802
Dec. 20	9.10	558
Jan. 1952	8.97	866
Feb.	8.83	914
Mar.	8.71	743
Apr.	8.88	971
May	8.89	866
June	8.92	832
July	8.67	962
Aug.	8.97	990
Sept.	8.91	870
Oct.	8.89	859
Nov.	8.97	849
Dec.	8.96	832
Jan. 1953	8.80	866
Feb.	8.76	859
Mar.	8.74	990
Apr.	8.63	866
May	8.60	991
June	8.60	914
July	8.58	986
Aug.	8.56	945
Sept.	8.54	868
Oct.	8.54	880
Nov.	8.60	849
Dec.	8.98	834
Jan. 15, 1954	8.98	801
Feb. 15	8.97	853
Mar. 15	8.97	858
Apr. 15, 1954	8.98	815
May 20	8.96	687
June 16	8.93	760
July 22	8.90	832
Aug. 14	8.93	800
Sept. 20	8.95	849
Oct. 13	8.98	801
Nov. 17	8.95	858
Dec. 16	8.98	818
Jan. 1955	8.96	830
Feb.	8.96	845
Mar.	8.98	840
Apr.	8.98	845
May	8.96	745
June	8.94	1100
July	8.93	1020
Aug.	8.95	900
Sept.	8.96	850
Oct.	8.94	980
Nov.	8.97	......
Jan. 17, 1956	8.96	980
Feb. 23	8.93	780
Mar. 23	8.93	880
Apr. 20	8.95	840
May 25	8.93	845
Sept. 24	8.80	1070
Oct. 30	8.91	1070
Nov. 16	8.96	1000
Dec. 13	8.98	1010

32B (K-2) Altitude, 1.75 ft. Depth, 195 ft. Diameter, 12 in. Casing, 156 ft. Meter test on Feb. 20, 1950, showed no leaks in casing.

Observations

Date	Chloride (ppm)
Feb. 2, 1937	2160
26	1990
Mar. 26	1950
Apr. 9	1920
16	1885
23	1920
May 14	1165
21	1150
28	1165
June 11	1200
18	1200
25	1200
July 2	1180
9	1165
16	1180
23	1200
30	1200
Aug. 6	1165
13	1200
28	1200
Sept. 3	1200
18	1200
25	1200
Oct. 1	1180
8	1215
29	1165
Nov. 5	1200
12	1200
19	1215
26	1180
Jan. 14, 1938	1150
21	1095
28	1150
Mar. 18	1150
25	1150
Apr. 15	1150

Observations—Well 32B (Continued)

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
22	1095	30	1115	Dec. 8	1180
29	1095	Jan. 6, 1939	1095	15	1150
May 6, 1938	1165	13	1070	22	1165
13	1095	20	1095	Feb. 9, 1940	1180
20	1150	27	1095	June 27	1165
27	1165	Feb. 3	1150	July 29	1150
June 10	1100	17	1150	Aug. 14	1115
17	1115	24	1150	Feb. 15, 1941	1165
24	1095	Mar. 10	1095	Mar. 17	1180
July 1	1115	31	1165	May 10	1150
15	1115	Apr. 14	1150	July 12	1150
22	1115	21	1115	Sept. 3	1180
29	1130	28	1200	Oct. 21	1150
Aug. 5	1115	May 5	1165	Aug. 3, 1945	1300
26	1115	May 19, 1939	1095	Sept. 27	1335
Sept. 2	1080	26	1165	May 10, 1946	1370
16	1115	June 16	1115	Aug. 22	950
23	1095	Aug. 4	1115	Nov. 25	930
30	1095	25	1115	Dec. 4	920
Oct. 7	1095	Sept. 1	1150	Jan. 6, 1947	950
14	1130	15	1150	Mar. 17	1430
21	1115	22	1165	Apr. 18	1405
28	1095	29	1150	May 19	1460
Nov. 25	1115	Oct. 13	1150	June 18	1370
Dec. 2	1095	20	1150	July 21	1460
16	1095	Nov. 10	1150		

Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)
Mar. 22, 1950	8.71	1483	Sept. 18, 1951	9.00	990	Apr. 15, 1954	8.97	757
Apr. 3	8.63	......	Nov. 16	8.96	996	May 20	8.96	722
10	8.63	840	Dec. 20	9.06	850	June 16	8.93	832
17	8.63	......	Jan. 1952	8.73	971	July 22	8.91	895
24	8.56	......	Feb.	8.70	815	Aug. 14	8.88	863
May 1	8.57	1000	Mar.	8.72	928	Sept. 20	8.90	849
8	8.64	......	Apr.	8.61	502	Oct. 13	8.97	781
15	8.57	......	May	8.58	842	Nov. 17	8.93	818
22	8.56	......	June	8.68	945	Dec. 16	8.97	803
29	8.54	......	July	8.52	971	Jan. 1955	8.94	695
June 6	8.62	......	Aug.	8.77	1024	Feb.	8.93	805
12	8.74	......	Sept.	8.77	914	Mar.	8.96	680
July 3	8.42	......	Oct.	8.75	861	Apr.	8.95	730
24	8.57	......	Nov.	8.70	914	May	8.94	850
31	8.58	......	Dec.	8.78	832	June	8.92	835
Aug. 7	8.57	......	Jan. 1953	8.73	945	July	8.90	880
14	8.73	......	Feb.	8.74	902	Aug.	8.91	870
19	9.10	1260	Mar. 1953	8.72	936	Sept.	8.92	830
Sept. 8	9.08	......	Apr.	8.60	901	Oct.	8.95	800
Oct. 2	8.75	......	May	8.53	935	Nov.	8.98	......
Nov. 4	8.74	......	June	8.54	815	Jan. 17, 1956	8.96	520
Dec. 11	8.80	......	July	8.52	916	Feb. 23	8.93	800
Jan. 15, 1951	8.64	990	Aug.	8.53	984	Mar. 23	8.90	720
Feb. 15	8.60	650	Sept.	8.52	1020	Apr. 20	8.94	810
Mar. 15	9.09	929	Oct.	8.50	1022	May 25	8.92	780
Apr. 16	8.65	973	Nov.	8.60	979	Sept. 24	8.73	1210
May 18	8.67	860	Dec.	8.93	866	Oct. 30	8.89	1230
June 14	8.70	964	Jan. 15, 1954	8.96	678	Nov. 16	8.96	895
July 17	8.59	1021	Feb. 15	8.95	695	Dec. 13	8.96	805
Aug. 16	8.78	1030	Mar. 15	8.96	707			

32C (K-3) Altitude, 1.09 ft. Depth, unknown. Diameter, 12 in. Casing, unknown, obstructed at 3.5 ft.

Observations

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
Feb. 12, 1937	2140	May 14	1180	July 2	1115
26	1645	21	790	9	1030
Mar. 26	1850	28	1095	16	1285
Apr. 9	1800	June 11	1165	23	1180
16	1505	18	1080	30	1165
23	1780	25	1115	Aug. 6	1355

Observations—Well 32C (Continued)

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
13	1215	Sept. 2	1080	22	1165
28	1215	16	1120	29	925
Sept. 3	1250	23	1130	Oct. 13	1165
18	1080	30	1115	20	1030
25	1115	Oct. 7	1095	Nov. 10	1200
Oct. 1	1095	10	1070	Dec. 8	1150
8	1200	21	1130	15	995
29	1115	28	1120	22	1180
Nov. 5	1115	Nov. 25	1080	June 27, 1940	940
12	1235	Dec. 2	1140	July 29	1215
19	1150	16	1060	Aug. 14	1060
26	1150	30	1115	Feb. 15, 1941	1115
Jan. 14, 1938	1115	Jan. 6, 1939	1115	Mar. 17	1215
21	1062	13	1045	May 10	960
28	1150	20	995	July 12	960
Mar. 18	995	27	1080	Sept. 3	1230
25	1045	Feb. 3	1131	Oct. 21	1270
Apr. 15	1165	17	1200	Aug. 3, 1945	1355
22	1115	24	1165	May 10, 1946	925
29	700	Mar. 10	910	July 3	310
May 6, 1938	1115	31	910	Aug. 22	370
13	1115	Apr. 14	1045	Nov. 25	245
20	1150	21	855	Dec. 4	360
27	1130	28	1130	Jan. 6, 1947	360
June 10	1095	May 5	1115	Feb. 14	1380
17	940	19	1180	Mar. 17	1340
24	1050	May 26, 1939	1165	Apr. 18	1230
July 1	1120	June 16	1060	May 19	1360
15	1115	Aug. 4	995	June 18	1420
22	1165	25	840	July 21	1470
29	1150	Sept. 1	1165		
Aug. 5	1150	15	1062		

32D (K-4) Well is buried under stones.

Observations

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
Feb. 12, 1937	925	May 6, 1938	465	May 26, 1939	515
26	960	13	430	June 16	345
Mar. 26	995	20	430	Aug. 4	445
Apr. 9	1095	27	430	25	430
16	720	June 10	460	Sept. 1	395
23	925	17	465	15	395
May 14	495	24	465	22	395
21	495	July 1	465	29	430
28	465	15	445	Oct. 13	395
June 11	495	22	480	20	465
18	755	29	445	Nov. 10	375
25	550	Aug. 5	480	Dec. 8	225
July 2	480	Sept. 2	445	15	410
9	480	16	465	22	395
16	480	23	445	June 27, 1940	410
23	515	30	445	July 29	395
30	720	Oct. 7	445	Aug. 14	445
Aug. 6	755	14	420	Feb. 15, 1941	345
13	495	21	445	Mar. 17	375
28	615	28	480	May 10	430
Sept. 3	530	Nov. 25	480	July 12	550
18	685	Dec. 2	394	Sept. 3	310
25	550	16	505	Oct. 21	480
Oct. 1	580	30	520	Aug. 3, 1945	345
8	480	Jan. 1, 1939	550	Sept. 27	310
10	515	13	550	May 10, 1946	805
Nov. 5	465	20	410	20	1335
12	465	27	480	July 3	1380
19	615	Feb. 3	395	Aug. 22	250
26	565	17	615	Nov. 25	360
Jan. 14, 1938	480	24	515	Dec. 4	1360
21	480	Mar. 10	565	Jan. 6, 1947	1405
28	430	31	550	Feb. 14	370
Mar. 18	495	Apr. 14	480	Mar. 17	570
25	495	21	375	Apr. 18	460
Apr. 15	465	28	445	May 19	360
22	395	May 5	395	June 18	240
29	530	19	495	July 21	370

32E (K-5) Altitude, 1.62 ft. Depth, unknown. Diameter, 12 in. Casing, unknown, obstructed at 2 ft.

Observations

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
Feb. 12, 1937	1850	May 20, 1938	995	June 16, 1939	960
26	1765	27	995	Aug. 4	940
Mar. 26	1575	June 10	975	25	940
Apr. 9	1730	17	975	Sept. 1	910
16	1835	24	960	15	925
23	1730	July 1	960	22	940
May 14	1028	15	920	29	940
21	975	22	875	Oct. 13	925
28	1010	29	940	20	925
June 11	995	Aug. 5	895	Nov. 10	975
18	1030	Sept. 2	875	Dec. 8	925
25	995	16	770	15	940
July 2	960	23	940	22	925
9	975	30	960	June 27, 1940	1115
16	995	Oct. 7	925	July 29	940
23	770	14	976	Aug. 14	975
30	1030	21	770	Feb. 15, 1941	910
Aug. 6	1045	28	770	Mar. 17	940
13	1060	Nov. 25	995	May 10	925
28	565	Dec. 2	975	July 12	910
Sept. 3	1045	16	820	Sept. 3	875
18	1045	30	1030	Oct. 21	995
Oct. 1	1045	Jan. 6, 1939	1010	Aug. 3, 1945	890
8	1010	13	995	Sept. 27	890
29	1045	20	960	May 10, 1946	910
Nov. 5	1030	27	975	20	1405
12	1045	Feb. 3	975	July 3	1405
19	975	17	1030	Aug. 22	1190
26	1045	24	1045	Nov. 25	1330
Jan. 14, 1938	875	Mar. 10	975	Dec. 4	1420
21	875	31	1030	Jan. 6, 1947	1285
28	975	Apr. 14	975	Feb. 14	230
Mar. 18	960	21	875	Mar. 17	950
25	975	28	995	Apr. 18	940
Apr. 15	940	May 5	975	May 19	950
22	925	19	940	June 18	730
May 13	995	26	995	July 21	920

Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)
Mar. 22, 1950	8.75	580	Aug. 16, 1951	8.86	553	Apr. 15, 1954	8.95	503
Apr. 3	8.72	......	Sept. 18	9.02	570	May 20	8.92	520
10	8.74	510	Nov. 16	8.95	631	June 16	8.86	555
17	8.70	......	Dec. 20	9.08	457	July 22	8.81	560
24	8.69	......	Jan. 1952	8.66	572	Aug. 14	8.83	538
May 1	8.68	580	Feb.	8.72	454	Sept. 20	8.81	558
8	8.69	......	Mar.	8.73	517	Oct. 13	8.95	520
15	8.63	......	Apr.	8.71	502	Nov. 17	8.90	529
22	8.61	......	May	8.65	486	Dec. 16	8.96	527
29	8.64	530	June	8.77	551	Jan. 1955	8.90	540
June 6	8.67	......	July	8.62	507	Feb.	8.91	520
12	8.86	......	Aug.	8.92	568	Mar.	8.92	470
July 3	7.63	600	Sept.	8.73	592	Apr.	8.92	465
24	8.23	......	Oct.	8.79	592	May	8.89	530
31	8.30	647	Nov.	8.78	630	June	8.85	620
Aug. 7	8.23	660	Dec.	8.80	508	July	8.88	575
14	8.81	570	Jan. 1953	8.72	556	Aug.	8.86	605
19	8.73	608	Feb.	8.70	503	Sept.	8.90	540
Sept. 8	8.70	......	Mar.	8.69	488	Oct.	8.95	640
Oct. 2	8.82	720	Apr.	8.63	473	Nov.	8.96	......
9	......	640	May	8.59	508	Jan. 17, 1956	8.93	680
23	......	620	June	8.56	486	Feb. 23	8.94	645
Nov. 4	8.80	......	July	8.54	541	Mar. 23	8.90	460
Dec. 11	8.81	648	Aug.	8.55	570	Apr. 20	8.92	590
Jan. 15, 1951	8.73	550	Sept.	8.53	584	May 25	8.90	560
Feb. 15	8.67	230	Oct.	8.50	606	Sept. 24	8.73	600
Mar. 15	8.92	468	Nov.	8.58	572	Oct. 30	8.85	640
Apr. 16	8.71	452	Dec.	8.90	580	Nov. 16	8.87	630
May 18	8.65	470	Jan. 15, 1954	8.93	562	Dec. 13	8.91	590
June 14	8.84	536	Feb. 15	8.95	548			
July 17	8.36	528	Mar. 15	8.94	524			

32F Altitude, 0.10 ft. (?). Well is buried.

Observations

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
May 14, 1937	260	May 27, 1938	280	Sept. 22, 1939	275
21	275	June 10	280	29	275
28	280	July 22	275	Oct. 13	255
June 11	265	29	275	20	255
18	290	Aug. 5	220	27	275
25	310	Sept. 2	315	Nov. 3	275
July 2	290	16	300	10	275
9	310	23	310	Dec. 8	275
16	285	30	280	15	255
23	310	Oct. 7	275	22	255
30	320	14	280	June 27, 1940	275
Aug. 6	310	21	290	July 29	275
13	300	28	275	Aug. 14	275
28	300	Nov. 25	290	Feb. 15, 1941	255
Sept. 18	300	Dec. 2	275	Mar. 17	275
25	290	16	275	May 10	255
Oct. 1	285	30	275	July 12	155
8	285	Jan. 6, 1939	290	Sept. 3	225
29	290	13	275	Oct. 21	360
Nov. 5	280	20	255	Aug. 3, 1945	255
12	295	27	275	Sept. 27	255
19	280	Feb. 3	290	May 10, 1946	240
26	255	17	290	June 20	515
Jan. 14, 1938	280	24	290	Aug. 22	1440
21	280	Mar. 10	275	Nov. 25	1300
28	260	Apr. 14	310	Dec. 4	325
Mar. 18	280	28	290	Jan. 6, 1947	260
25	315	May 5	275	Feb. 14	960
Apr. 15	315	19	255	Mar. 17	250
22	260	26	325	Apr. 18	250
29	300	Aug. 4	310	May 19	260
May 6	315	25	308	June 18	250
13	275	Sept. 1	275	July 21	260
20	280	15	255		

32G Altitude, 3.18 ft. (?). Well is buried.

32H Well is buried.

33 (K. S. Co. well 12; field 217 old well) Kaunalewa. 22°00′10″N, 159°44′50″W. Owner, Kekaha Sugar Co. Drilled, about 1890. Altitude, 8 ft. Depth, unknown. Casing, unknown, obstructed at 20 ft. below top. Use, irrigation.

Observations

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
Feb. 12, 1937	375	16	465	Dec. 3	360
26	360	23	430	10	375
Mar. 26	465	30	480	17	360
Apr. 9	480	Aug. 6	395	24	345
16	445	13	375	Jan. 7, 1938	377
23	360	20	345	14	265
30	465	Sept. 3	360	21	310
May 7	325	10	395	28	310
14	340	18	430	Feb. 4	310
21	395	25	395	18	310
28	375	Oct. 1	375	25	320
June 4	410	8	320	Mar. 11	300
11	395	29	375	18	360
18	325	Nov. 5	310	25	325
25	410	12	360	Apr. 8	325
July 2	465	19	360	Apr. 15, 1938	345
9	515	26	345	22	310

Observations—Well 33 (Continued)

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
29	310	27	308	9	394
May 6	280	Feb. 3	343	May 15	445
20	320	10	343	June 27	514
27	300	17	325	July 29	548
June 3	320	24	343	Aug. 14	548
10	260	Mar. 10	308	Jan. 3, 1941	308
17	290	31	308	11	343
24	275	Apr. 14	291	17	343
July 1	300	21	274	24	325
15	360	28	291	Feb. 7	325
22	300	May 5	291	13	428
29	245	19	343	Mar. 17	428
Aug. 5	245	26	308	May 10	548
12	320	June 9	377	July 12	685
26	360	16	325	Sept. 3	702
Sept. 2	310	Aug. 4, 1939	445	Oct. 21	617
9	300	25	497	Aug. 3, 1945	651
16	320	Sept. 1	480	Sept. 27	668
23	320	15	463	May 10, 1946	685
30	320	22	463	June 20	1319
Oct. 7	245	29	480	July 3	790
14	310	Oct. 6	497	Aug. 22	780
21	370	13	617	Nov. 25	680
28	360	20	428	Dec. 4	820
Nov. 4	370	27	377	Jan. 6, 1947	790
25	245	Nov. 3	377	Feb. 14	470
Dec. 2	310	10	343	Mar. 17	770
16	420	Dec. 8	445	Apr. 18	770
30	380	15	463	May 19	830
Jan. 6, 1939	343	22	565	June 18	850
13	326	Jan. 26, 1940	343	July 21	880
20	343	Feb. 2	240		

Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)
Mar. 22, 1950	10.36	430	Aug. 16, 1951	10.39	596	Apr. 15, 1954	10.50	507
Apr. 3	9.95	......	Sept. 18	10.42	560	May 20	10.47	601
10	....	450	Nov. 16	10.36	661	June 16	10.41	594
17	10.39	600	Dec. 20	10.43	491	July 22	10.36	601
24	10.32	470	Jan. 1952	10.86	472	Aug. 14	10.38	584
May 1	10.33	600	Feb.	10.46	449	Sept. 20	10.35	609
8	10.38	640	Mar.	10.38	442	Oct. 13	10.43	560
15	10.13	640	Apr.	10.22	445	Nov. 17	10.39	570
22	10.14	640	May	10.22	551	Dec. 16	10.48	524
29	10.13	670	June	10.16	592	Jan. 1955	10.54	540
June 6	10.36	700	July	10.28	567	Feb.	10.56	515
12	10.28	660	Aug.	10.45	596	Mar.	10.55	505
July 3	10.28	660	Sept.	10.28	558	Apr.	10.55	490
24	10.28	......	Oct.	10.36	567	May	10.54	480
31	10.28	670	Nov.	10.27	620	June	10.49	620
Aug. 7	10.03	650	Dec.	10.32	524	July	10.45	635
14	10.36	580	Jan. 1953	10.55	476	Aug.	10.42	635
19	10.74	400	Feb.	10.36	502	Sept.	10.46	580
Sept. 8	10.68	......	Mar.	10.29	512	Oct.	10.47	620
Oct. 2	10.38	540	Apr.	10.26	457	Nov.	10.80	640
9	....	620	May	10.25	524	Jan. 17, 1956	10.53	680
23	....	630	June	10.18	589	Feb. 23	10.55	610
Nov. 4	10.28	......	July	10.14	609	Mar. 23	10.46	640
Dec. 11	10.30	606	Aug.	10.11	570	Apr. 20	10.38	660
Jan. 15, 1951	10.61	460	Sept.	10.08	613	May 25	10.42	630
Feb. 15	10.28	440	Oct.	10.06	680	Sept. 24	10.09	670
Mar. 15	10.75	438	Nov.	10.12	661	Oct. 30	10.10	690
Apr. 16	10.40	421	Dec.	10.56	541	Nov. 16	10.12	700
May 18	10.15	536	Jan. 15, 1954	10.56	527	Dec. 13	10.48	660
June 14	10.28	576	Feb. 15	10.54	534			
July 17	10.25	558	Mar. 15	10.50	520			

34 (Kekaha Sugar Co. well 7) Kaunalewa. 22°00′10″N, 159°44′50″W. Owner, Kekaha Sugar Co. Drilled, Feb. 1930 by G. B. Primmer. Altitude, 8 ft. Original depth, 214 ft.; measured depth, Feb. 1950, 211 ft. Diameter, 12 in. Casing, reported original depth, 173 ft., measured depth, Feb. 1950, 171 ft. Depth to aquifer, 166 ft. Use, irrigation.

Driller's log

	Depth (ft.)		Depth (ft.)
Brown and blue clay	0- 18	Brown clay, sticky	116-135
Boulders	18- 22	Brown clay and coral	135-142
Sand and coral	22- 28	Coral	142-148
Coral	28- 36	Brown clay and coral	148-160
Brown clay	36- 65	Brown sandy clay and rubble. Water started to flow at 166 ft.	160-166
Brown clay and coral	65- 77	Brown and blue lava	166-214
Brown clay	77- 95		
Gray clay, tough	95-116		

Observations

Chloride content of water during drilling

Depth (ft.)	Chloride (ppm)	Depth (ft.)	Chloride (ppm)	Depth (ft.)	Chloride (ppm)
166	72	182	68	205	77
172	68	192	77	210	78
178	68	198	77	214	81

Discharge of well during drilling

Depth (ft.)	Discharge (mgd)	Depth (ft.)	Discharge (mgd)	Depth (ft.)	Discharge (mgd)
173	0.2	203	.7	208	.9
192	.4	205	.8	210	1.1
198	.6				

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
Feb. 12, 1937	480	21	440	13	274
26	463	28	325	20	445
Mar. 26	582	Feb. 4	291	27	343
Apr. 9	737	18	209	Feb. 3	394
16	737	25	260	10	308
23	737	Mar. 11, 1938	565	24	343
30	754	18	590	Mar. 10	308
May 7	480	25	582	31	325
14	497	Apr. 8	274	Apr. 14	360
21	737	15	325	21	377
28	582	22	343	28	377
June 11	514	29	308	May 5	445
18	411	May 6	377	19	394
25	514	13	360	26	394
July 2	719	20	377	June 9	291
9	702	27	360	16	394
16	702	June 3	320	Aug. 4	685
23	514	10	310	25	737
30	565	17	340	Sept. 1	634
Aug. 6	260	24	330	15	428
13	445	July 1	430	22	582
20	173	15	430	Oct. 6	668
28	219	22	445	13	480
Sept. 3	497	29	445	20	360
10	334	Aug. 5	445	27	325
18	250	12	394	Nov. 3	325
25	394	Sept. 2	281	10	480
Oct. 1	445	9	290	Dec. 8	719
8	428	16	380	15	702
22	300	23	440	22	788
29	377	30	411	Jan. 26, 1940	308
Nov. 5	334	Oct. 7	500	Feb. 2	394
12	360	14	411	9	600
19	582	21	560	May 15	343
26	394	28	475	June 27	668
Dec. 3	325	Nov. 4	440	July 29	634
10	257	25	350	Aug. 14	719
17	205	Dec. 2	400	Jan. 3, 1941	428
24	240	16	485	11	308
Jan. 7, 1938	223	30	411	17	308
14	205	Jan. 6, 1939	291	24	257

Observations—Well 34 (Continued)

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
Feb. 7	325	Sept. 27	582	Feb. 14	670
15	291	May 10, 1946	668	Mar. 17	780
Mar. 17	394	June 20	805	Apr. 18	710
May 10	788	July 3	790	May 19	820
July 12	908	Aug. 22	810	June 18	850
Sept. 3	857	Nov. 25	660	July 21	820
Oct. 21	634	Dec. 4	740		
Aug. 3, 1945	651	Jan. 6, 1947	690		

Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)
Mar. 20, 1950	10.78	141	Aug. 16	10.41	384	Mar. 15	10.66	495
Apr. 3	10.73	......	Sept. 18	10.38	470	Apr. 15	10.65	473
17	10.35	560	Nov. 16	10.40	490	May 20	10.58	479
24	10.38	440	Dec. 20	10.38	378	June 16	10.53	490
May 1	10.23	540	Jan. 1952	10.23	356	July 22	10.48	479
8	10.38	540	Feb.	10.25	380	Aug. 14	10.39	505
15	10.78	550	Mar.	10.36	351	Sept. 20	10.40	520
22	10.76	580	Apr.	10.34	397	Oct. 13	10.45	479
29	10.68	600	May	10.36	390	Nov. 17	10.41	507
June 6	10.37	620	June	10.30	387	Dec. 16	10.51	515
12	10.53	580	July	10.28	476	Jan. 1955	10.62	440
July 3	10.30	550	Aug.	10.38	404	Feb.	10.64	430
24	10.38	......	Sept.	10.53	452	Mar.	10.64	400
31	10.42	580	Oct.	10.39	442	Apr.	10.62	575
Aug. 7	10.15	590	Nov.	10.30	490	May	10.55	445
14	10.38	500	Dec.	10.28	421	June	10.48	480
19	10.88	180	Jan. 1953	10.33	401	July	10.47	475
Sept. 8	10.75	380	Feb.	10.29	354	Aug.	10.49	427
Oct. 2	10.39	530	Mar.	10.20	455	Sept.	10.51	380
9	....	580	Apr.	10.18	478	Oct.	10.52	520
23	....	......	May	10.22	401	Nov.	10.66	540
Nov. 4	10.30	......	June	10.18	459	Jan. 17, 1956	10.64	590
Dec. 11	10.29	586	July	10.10	476	Feb. 23	10.51	540
Jan. 15, 1951	10.63	340	Aug.	10.10	558	Mar. 23	10.52	520
Feb. 15	10.26	360	Sept.	10.09	582	Apr. 20	10.46	530
Mar. 15	10.83	330	Oct.	10.10	601	May 25	10.46	525
Apr. 16	10.39	394	Nov.	10.10	596	Sept. 24	10.38	530
May 18	10.64	387	Dec.	10.63	507	Oct. 30	10.36	530
June 14	10.21	389	Jan. 15, 1954	10.65	495	Nov. 16	10.39	540
July 17	10.30	461	Feb. 15	10.63	519	Dec. 13	10.60	515

35 (K. S. Co. well 8) Kaunalewa. 22°00′10″N, 159°44′50″W. Owner, Kekaha Sugar Co. Drilled, Feb. 19 to Mar. 14, 1930, by G. B. Primmer. Altitude, 8 ft. Original depth, 245 ft.; measured depth, Feb. 1950, 241 ft. Diameter, 12 in. Casing, reported original depth, 172 ft; measured depth, Mar. 1950, 164 ft. Depth to aquifer, 167 ft.

Driller's log

	Depth (ft.)		Depth (ft.)		Depth (ft.)
Blue and brown clay	0- 8	Brown clay	40- 66	Brown sandy clay	120-132
Hard coral	8- 15	Hard coral	66- 78	Hard coral	132-152
Sand and coral	15- 25	Brown sticky clay	78- 98	Brown clay, coral and black sand	152-167
Hard coral	25- 35	Gray tough clay	98-110	Blue and brown lava	167-245
Sand, black	35- 40	Brown tough clay	110-120		

Observations
Chloride content of water during drilling

Depth (ft.)	Chloride (ppm)	Depth (ft.)	Chloride (ppm)	Depth (ft.)	Chloride (ppm)
183	67	218	126	233	122
197	67	220	126	237	129
204	94	223	120	241	129
206	110	226	120	245	139
215	126	231	120		

Observations—Well 35 (Continued)

Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)
May 15, 1937	10.53	766	Feb. 15	8.62	1030	Oct. 2	10.38	350
June 15	10.40	635	Mar. 15	8.24	880	9	....	490
July 16	9.15	1150	Apr. 16	8.22	710	23	....	530
Sept. 15	10.82	693	May 15	8.63	548	Nov. 4	10.33	......
Oct. 16	11.07	231	June 15	8.48	1180	Dec. 11	10.35	505
Dec. 20	11.32	330	July 16	8.52	640	Jan. 15, 1951	10.71	320
Jan. 20, 1938	10.24	390	Aug. 17	8.44	860	Feb. 15	10.30	330
Feb. 16	11.20	221	Sept. 17	8.46	860	Mar. 15	10.80	459
Mar. 19	10.11	720	Oct. 15	8.12	620	Apr. 16	10.38	416
May 17	10.02	520	Nov. 17	8.40	630	May 18	10.58	357
June 19	10.92	320	Dec. 18	8.40	760	June 14	10.30	365
July 19	10.12	550	Jan. 15, 1946	8.35	630	July 17	10.32	337
Aug. 18	10.62	290	Feb. 15	8.32	650	Aug. 16	10.40	365
Sept. 19	10.52	380	Mar. 15	8.32	655	Sept. 18	10.40	410
Oct. 15	9.92	550	Apr. 16	8.32	660	Nov. 16	10.39	458
Feb. 15, 1939	10.47	295	May 15	8.07	760	Dec. 20	10.39	362
Apr. 15	10.47	350	June 15	7.82	710	Jan. 1952	10.56	336
May 21	9.92	400	July 16	8.32	730	Feb.	10.39	346
June 14	9.62	440	Aug. 17	8.40	610	Mar.	10.49	421
July 15	9.38	370	Jan. 15, 1947	8.38	570	Apr.	10.40	390
Aug. 19	9.52	710	Feb. 14	8.54	430	May	10.47	370
Oct. 16	9.92	400	Mar. 15	8.24	790	June	10.37	382
Nov. 18	9.72	560	Apr. 16	8.18	770	July	10.38	349
Dec. 19	9.05	440	May 19	7.81	750	Aug.	10.39	380
Jan. 15, 1940	11.28	79	June 14	7.82	860	Sept.	10.39	421
Feb. 16	10.03	600	July 15	7.95	840	Oct.	10.36	397
Apr. 15	10.51	79	Aug. 15	7.77	810	Nov.	10.32	466
May 19	10.74	200	Sept. 16	7.82	860	Dec.	10.35	397
June 16	10.25	280	Dec. 15	9.50	610	Jan. 1953	10.40	351
July 15	10.07	410	Jan. 15, 1948	....	710	Feb.	10.35	378
Aug. 15	10.12	430	Feb. 17	....	370	Mar.	10.30	360
Sept. 15	10.77	240	Mar. 15	....	560	Apr.	10.28	421
Oct. 16	10.42	300	Apr. 20	....	800	May	10.26	395
Nov. 16	10.72	250	May 15	....	781	June	10.20	416
Dec. 15	10.12	280	June 15	....	469	July	10.18	457
Jan. 19, 1941	10.67	320	July 15	....	890	Aug.	10.15	510
Feb. 15	9.80	700	Aug. 16	....	800	Sept.	10.20	539
Mar. 18	9.64	530	Sept. 15	....	930	Oct.	10.18	560
Apr. 22	9.52	690	Oct. 18	....	870	Nov.	10.12	541
June 16	9.22	790	Nov. 15	....	490	Dec.	10.65	479
July 15	9.22	940	Dec. 15	....	430	Jan. 15, 1954	10.65	473
Feb. 16, 1942	10.02	350	Jan. 18, 1949	....	430	Feb. 15	10.60	507
Mar. 18	9.72	410	Feb. 15	....	170	Mar. 15	10.63	476
Apr. 16	10.47	350	Mar. 17	....	580	Apr. 15	10.67	457
May 16	10.17	380	Apr. 18	....	620	May 20	10.58	479
June 15	10.17	590	May 20	....	450	June 16	10.51	491
July 17	9.56	590	June 15	....	461	July 12	10.49	479
Aug. 15	9.57	580	July 15	....	620	Aug. 14	10.43	473
Jan. 15, 1943	10.78	280	Aug. 15	....	650	Sept. 20	10.42	490
Feb. 15	10.39	312	Sept. 15	....	890	Oct. 13	10.47	461
Mar. 15	10.42	312	Oct. 17	....	830	Nov. 17	10.43	457
Apr. 16	9.57	790	Nov. 15	....	880	Dec. 16	10.59	454
June 16	9.55	850	Dec. 15	....	880	Jan. 1955	10.64	360
July 15	9.47	740	Mar. 22, 1950	10.72	230	Feb.	10.66	345
Aug. 14	9.00	770	Apr. 3	10.67	......	Mar.	10.64	387
Sept. 14	9.14	770	10	....	380	Apr.	10.66	410
Oct. 16	9.40	560	17	10.39	550	May	10.62	460
Nov. 15	9.19	580	24	10.40	420	June	10.60	400
Dec. 16	8.96	410	May 1	10.39	530	July	10.60	445
Jan. 16, 1944	9.29	400	8	10.37	530	Aug.	10.56	492
Feb. 15	8.46	600	15	10.54	520	Sept.	10.60	442
Mar. 15	9.52	500	22	10.54	570	Oct.	10.63	460
Apr. 17	7.63	550	29	10.54	590	Nov.	10.70	480
May 16	9.32	500	June 6	10.36	600	Jan. 17, 1956	10.65	510
June 15	9.25	440	12	10.30	550	Feb. 23	10.60	400
July 15	8.50	420	July 3	10.45	530	Mar. 23	10.58	460
Aug. 15	8.13	460	24	10.29	......	Apr. 20	10.49	480
Sept. 15	8.57	720	31	10.41	550	May 25	10.50	485
Oct. 16	8.89	890	Aug. 7	10.09	580	Sept. 24	10.20	430
Nov. 15	8.50	840	14	10.37	360	Oct. 30	10.30	470
Dec. 15	8.49	760	19	10.79	220	Nov. 16	10.40	510
Jan. 15, 1945	8.70	600	Sept. 8	10.73	......	Dec. 13	10.56	477

36 (K. S. Co. well 19) field 216. 22°00′45″N, 159°45′20″W. Owner, Kekaha Sugar Co. Drilled, about 1890. Altitude, 8 ft. Depth, unknown. Diameter, 12 in. Casing, unknown, obstructed at 26 ft. Use, irrigation.

Observations
(Bench mark, top of casing, 5.98 ft. above sea level, 2 ft. below ground surface)

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
Feb. 12, 1937	430	Apr. 8	275	16	428
26	445	15	550	Aug. 4	428
Mar. 26	445	22	565	25	754
Apr. 9	600	29	480	Sept. 1	703
23	720	May 6	205	15	583
30	1010	13	275	22	736
May 7	310	20	495	29	754
14	480	27	430	Oct. 6	736
21	515	June 3	580	13	736
28	465	10	650	20	787
June 4	580	17	480	27	326
11	670	24	580	Nov. 3	343
18	580	July 1	420	10	703
25	685	15	580	Dec. 8	703
July 2	580	22	685	15	703
9	700	29	460	22	685
16	735	Aug. 5	640	Jan. 26, 1940	240
23	615	12	600	Feb. 2	428
30	670	26	620	9	583
Aug. 6	250	Sept. 2	490	May 15	463
13	375	9	380	June 27	428
20	495	16	300	July 29	326
Sept. 3	430	23	280	Aug. 14	206
10	580	30	380	Jan. 3, 1941	583
18	565	Oct. 7	600	11	496
25	550	14	245	17	583
Oct. 1	700	21	430	24	736
8	565	28	390	Feb. 7	463
15	580	Nov. 4	300	15	634
22	670	25	270	Mar. 17	496
29	670	Dec. 2	400	May 10	856
Nov. 5	670	16	580	July 12	874
12	650	30	480	Sept. 3	771
19	700	Jan. 6, 1939	326	Oct. 21	634
26	685	13	308	Aug. 3, 1945	257
Dec. 3	755	20	446	Sept. 27	274
10	600	27	412	May 10, 1946	411
17	685	Feb. 3	343	June 20	496
24	755	10	308	July 3	650
Jan. 7, 1938	580	17	326	Aug. 22	630
14	515	24	343	Nov. 25	740
21	500	Mar. 10	446	Dec. 4	1180
28	480	31	377	Jan. 6, 1947	540
Feb. 4	345	Apr. 14	291	Feb. 14	1120
11	310	21	394	Mar. 17	610
18	345	28	480	Apr. 18	1000
25	320	May 5	583	May 19	1160
Mar. 11	465	19	703	June 18	730
25	515	June 9	685	July 21	640

Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)
Mar. 22, 1950	10.06	250	Oct. 2	9.71	390	Mar.	10.79	438
Apr. 3	10.37	......	9	....	810	Apr.	10.29	464
10	10.45	......	Nov. 4	9.69	......	May	10.33	421
17	10.23	......	Dec. 11	9.72	764	June	10.26	365
24	10.12	......	Jan. 15, 1951	10.46	290	July	10.21	438
May 1	10.16	250	Feb. 15	10.20	387	Aug.	10.45	498
8	10.24	......	Mar. 15	10.42	452	Sept.	9.81	457
15	10.41	......	Apr. 16	10.20	463	Oct.	9.73	467
22	10.40	......	May 18	10.35	399	Nov.	9.70	507
29	10.42	......	June 14	10.02	360	Dec.	9.75	438
June 12	9.20	......	July 17	10.28	458	Jan. 1953	10.46	507
July 24	10.22	......	Aug. 16	10.14	490	Feb.	10.45	377
31	10.20	770	Sept. 18	10.20	440	Mar.	10.35	421
Aug. 7	....	800	Nov. 16	10.13	520	Apr.	10.27	438
14	9.71	767	Dec. 20	10.24	360	May	10.22	526
19	9.71	770	Jan. 1952	10.99	305	June	10.16	520
Sept. 8	10.38	......	Feb.	10.83	336	July	10.15	567

Observations—Well 36 (Continued)

Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)
Aug.	10.13	524	Sept. 20	10.33	510	Oct.	10.40	860
Sept.	10.14	529	Oct. 13	10.49	661	Nov.	10.43	600
Oct.	10.14	479	Nov. 17	10.40	515	Jan. 17, 1956	10.39	500
Nov.	10.15	472	Dec. 16	10.51	526	Feb. 23	10.38	680
Dec.	10.46	558	Jan. 1955	10.43	640	Mar. 23	10.35	517
Jan. 15, 1954	10.44	529	Feb.	10.42	610	Apr. 20	10.30	902
Feb. 15	10.44	526	Mar.	10.42	630	May 25	10.32	902
Mar. 15	10.42	491	Apr.	10.41	677	Sept. 24	9.96	852
Apr. 15	10.43	423	May	10.38	782	Oct. 30	10.08	930
May 20	10.39	360	June	10.33	860	Nov. 16	10.20	630
June 16	10.24	402	July	10.32	835	Dec. 13	10.38	520
July 22	10.28	360	Aug.	10.34	782			
Aug. 14	10.23	404	Sept.	10.38	680			

37 (K. S. Co. well 5) field 216. 22°00′45″N, 159°45′20″W. Owner, Kekaha Sugar Co. Drilled, Dec. 18, 1929 to Jan. 8, 1930 by G. B. Primmer. Altitude, 10 ft. Original depth, 262 ft.; measured depth, Mar. 1950, 253 ft. Diameter, 12 in. Casing, reported original depth, 191 ft.; measured depth, Mar. 1950, 175 ft. Depth to aquifer, 191 ft. Use, irrigation.

Driller's log

	Depth (ft.)		Depth (ft.)		Depth (ft.)
Brown clay	0- 12	Coral	90- 98	Hard blue and brown lava with porous streaks. Water started to flow at 217 ft.	191-262
Gray clay	12- 30	Brown clay, soft	98-125		
Brown sandy clay	30- 45	Coral	125-145		
Red sticky clay	45- 68	Brown sticky clay	145-176		
Boulders and brown clay	68- 90	Brown clay and coral	176-191		

Observations
Chloride content of water during drilling

Depth (ft.)	Chloride (ppm)	Depth (ft.)	Chloride (ppm)	Depth (ft.)	Chloride (ppm)
217	135	235	125	250	125
221	135	240	125	255	125
225	135	245	125	262	135
230	125				

(Bench mark, top of flange on 12-in. tee, 7.48 ft. above sea level, 2.5 ft. below ground surface)

Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)
May 15, 1937	10.55	312	Dec. 19	9.48	410	Apr. 16	9.93	350
June 15	9.94	430	Jan. 15, 1940	10.94	110	May 16	9.82	280
July 16	10.86	675	Feb. 16	10.23	140	June 15	9.98	300
Sept. 15	10.58	790	Apr. 15	9.86	140	July 17	9.39	300
Oct. 16	10.11	495	May 19	9.78	140	Aug. 15	9.50	286
Dec. 20	10.90	298	June 16	9.90	160	Jan. 15, 1943	11.07	165
Jan. 20, 1938	10.48	298	July 15	10.06	130	Feb. 15	11.08	160
Feb. 16	10.94	190	Aug. 15	9.98	125	Mar. 15	10.79	170
Mar. 19	10.90	232	Sept. 15	10.03	140	Apr. 16	10.13	290
May 17	9.78	240	Oct. 16	9.98	150	June 16	9.99	290
June 19	9.98	260	Nov. 16	9.92	190	July 15	9.83	250
July 19	9.48	370	Dec. 15	9.98	180	Aug. 14	9.53	480
Aug. 18	8.68	350	Jan. 19, 1941	9.66	260	Sept. 14	9.88	530
Sept. 19	9.38	580	Feb. 15	9.77	250	Oct. 16	9.64	190
Oct. 15	9.23	240	Mar. 18	9.51	540	Nov. 15	9.93	190
Feb. 15, 1939	10.40	196	Apr. 22	9.63	180	Dec. 16	10.11	190
Apr. 15	10.08	220	June 16	9.32	190	Jan. 16, 1944	10.04	180
May 21	8.13	430	July 15	9.33	320	Feb. 15	10.10	180
June 14	9.08	430	Aug. 16	9.68	430	Mar. 15	10.65	170
July 15	9.78	240	Nov. 20	9.98	320	Apr. 17	10.18	160
Aug. 19	8.88	380	Jan. ...., 1942	10.28	250	May 16	9.60	200
Oct. 16	9.58	320	Feb. 16	10.28	170	June 15	9.56	280
Nov. 18	8.98	440	Mar. 18	10.13	180	July 15	9.56	290

Observations—Well 37 (Continued)

Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)
Aug. 15	9.46	180	July 15	8.68	349	Apr.	10.24	644
Sept. 15	9.27	310	Aug. 16	8.08	440	May	10.19	657
Oct. 16	9.37	300	Sept. 15	8.83	430	June	10.14	644
Nov. 15	9.26	300	Oct. 18	8.76	470	July	10.12	683
Dec. 15	9.09	280	Nov. 15	8.78	670	Aug.	10.10	690
Jan. 15, 1945	10.48	290	Dec. 15	9.02	390	Sept.	10.10	664
Feb. 15	9.57	480	Jan. 18, 1949	9.72	410	Oct.	10.12	610
Mar. 15	9.15	470	Feb. 15	9.68	420	Nov.	10.17	596
Apr. 16	9.42	310	Mar. 17	9.65	510	Dec.	10.38	558
May 15	9.58	300	Apr. 18	9.22	390	Jan. 15, 1954	10.40	553
June 15	9.29	585	May 20	9.40	440	Feb. 15	10.41	592
July 16	9.26	270	June 15	9.06	520	Mar. 15	10.40	560
Aug. 17	9.38	430	July 15	9.02	650	Apr. 15	10.39	457
Sept. 17	9.00	330	Aug. 15	8.72	540	May 20	10.38	406
Oct. 15	8.93	340	Sept. 15	8.91	610	June 16	10.26	438
Nov. 15	9.25	300	Oct. 15	9.06	450	July 22	10.27	372
Dec. 18	9.68	330	Nov. 15	8.59	570	Aug. 14	10.20	380
Jan. 15, 1946	9.63	350	Dec. 15	8.30	650	Sept. 20	10.30	433
Feb. 15	9.51	410	July 31, 1950	......	430	Oct. 13	10.41	349
Mar. 15	9.24	455	Aug. 7	......	450	Nov. 17	10.37	452
Apr. 16	8.88	500	14	......	480	Dec. 16	10.43	344
May 15	9.04	650	Sept. 8	10.20	......	Jan. 1955	10.42	377
June 15	8.98	620	Oct. 2	9.75	220	Feb.	10.42	405
July 16	8.98	630	9	......	490	Mar.	10.42	390
Aug. 17	9.31	610	23	......	510	Apr.	10.40	445
Jan. 15, 1947	9.12	520	Nov. 4	9.71	......	May	10.36	450
Feb. 14	8.99	550	Dec. 11	9.72	492	June	10.36	420
Mar. 15	9.10	680	Jan. 1952	10.83	558	July	10.32	470
Apr. 16	8.68	500	Feb.	10.75	466	Aug.	10.33	465
May 19	8.78	730	Mar.	10.80	524	Sept.	10.39	410
June 14	7.93	710	Apr.	10.31	620	Oct.	10.37	440
July 15	8.23	660	May	10.35	507	Nov.	10.45	180
Aug. 15	8.96	480	June	10.19	472	Jan. 17, 1956	10.42	205
Sept. 16	8.60	450	July	10.26	459	Feb. 23	10.39	410
Oct.	8.10	670	Aug.	10.39	472	Mar. 23	10.34	430
Nov.	8.81	520	Sept.	9.96	510	Apr. 20	10.32	480
Dec. 15	9.93	360	Oct.	9.75	534	May 25	10.34	487
Jan. 15, 1948	10.18	170	Nov.	9.70	553	Sept. 24	9.95	410
Feb. 17	10.95	159	Dec.	9.76	457	Oct. 30	10.00	480
Mar. 15	10.28	159	Jan. 1953	10.36	527	Nov. 16	10.26	475
Apr. 20	10.34	140	Feb.	10.37	508	Dec. 13	10.31	440
June 15	8.69	341	Mar.	10.29	572			

38 (K. S. Co. well 6) Camp 2. 22°00′55″N, 159°45′15″W. Owner, Kekaha Sugar Co. Drilled, Jan. 10 to 30, 1930, by G. B. Primmer. Altitude, 10 ft. Original depth, 275 ft; measured depth, Mar. 1950, 267 ft. Diameter, 12 in. Casing, reported original depth, 162 ft; measured depth, Mar. 1950, 155 ft. Depth to aquifer, 162 ft.

Driller's log

	Depth (ft.)
Reddish brown clay	0- 20
Red sticky clay	20- 32
Boulders and soft red clay	32- 62
Blue clay and coral	62- 68
Blue clay and large boulders	68-104
Brown clay, coral	104-124
Coral	124-132
Brown clay and coral	132-140
Brown sticky clay	140-162
Brown and blue hard lava. At 185 ft. water started flowing over top of casing at 5.5 ft. above sea level	162-233
Light gray hard lava	233-263
Red and brown lava	263-266
Blue lava, broken lava	266-275

Observations
Chloride content of water during drilling

Depth (ft.)	Chloride (ppm)	Depth (ft.)	Chloride (ppm)	Depth (ft.)	Chloride (ppm)
186	166	233	104	262	104
192	166	240	104	265	114
193	166	244	104	270	114
218	166	250	114	275	114
226	104	255	104		

Discharge of well during drilling
(Measured over a 3-ft. weir discharging into a ditch about 8 ft. above sea level)

Depth (ft.)	Discharge rate (mgd)	Depth (ft.)	Discharge rate (mgd)	Depth (ft.)	Discharge rate (mgd)
233	1.1	266	1.2	275	1.8

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
Feb. 29, 1937	290	20	345	July 9	550
Mar. 26	275	27	465	Jan. 3, 1941	410
Apr. 30	650	June 17	320	11	495
May 7	445	24	260	24	495
21	375	July 15	230	Feb. 7	465
28	445	22	377	15	515
July 2	375	29	300	Mar. 17	550
30	430	Aug. 5	395	July 12	515
Aug. 8	465	Sept. 23	370	Sept. 3	495
Sept. 3	445	Jan. 6, 1939	465	Oct. 21	530
18	375	13	480	May 10, 1946	375
25	580	27	495	June 20	465
Oct. 15	685	Apr. 28	500	July 3	470
29	790	May 5	395	Aug. 22	460
Nov. 5	375	June 9	395	Nov. 25	520
26	375	Sept. 1	375	Dec. 4	530
Jan. 21, 1938	330	22	495	Jan. 6, 1947	340
28	345	29	550	Feb. 14	250
Mar. 11	300	Oct. 6	580	Mar. 17	360
25	310	Nov. 10	375	Apr. 18	350
Apr. 15	310	Dec. 22	565	May 19	320
29	325	Feb. 9, 1940	395	June 18	300
May 13	480	June 27	600	July 21	300

(Bench mark, top of flange on 12-in. tee, 7.17 ft. above sea level,
3 ft. below ground surface)

Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)
Jan. 22, 1950	10.63	1120	Sept. 18	10.27	2651	July 22	10.34	....
Apr. 3	10.37	....	Nov. 16	10.08	2686	Aug. 14	10.34	....
10	10.30	1920	Dec. 20	10.18	1920	Sept. 20	10.29	....
17	10.18	2410	Jan. 1952	10.46	2099	Oct. 13	10.35	....
24	10.04	....	Feb.	10.39	2390	Nov. 17	10.37	....
May 1	10.21	2110	Mar.	10.36	1887	Dec. 16	10.56	....
8	10.19	....	Apr.	10.22	2000	Jan. 1955	10.42	....
15	10.41	....	May	10.33	1964	Feb.	10.44	....
22	10.41	....	June	10.21	1921	Mar.	10.43	....
29	10.42	....	July	10.18	2322	Apr.	10.40	....
June 6	10.18	....	Aug.	10.38	2210	May	10.39	....
July 24	9.76	....	Sept.	10.46	2520	June	10.38	....
31	9.67	....	Oct.	10.21	2452	July	10.36	....
Aug. 19	10.05	1980	Nov.	10.16	2698	Aug.	10.35	....
Sept. 8	10.38	....	Dec.	10.26	2219	Sept.	10.39	....
Nov. 4	10.12	....	Jan. 1953	10.45	....	Oct.	10.37	....
Dec. 11	10.14	1887	Feb.	10.39	....	Nov.	10.47	....
Jan. 15, 1951	10.46	2730	Mar.	10.39	....	Jan. 17, 1956	10.46	....
Feb. 15	10.15	2407	Apr.	10.33	....	Feb. 23	10.38	....
Mar. 15	10.09	1920	Jan. 15, 1954	10.45	....	Mar. 23	10.36	....
Apr. 16	10.19	2117	Feb. 15	10.40	....	Apr. 20	10.30	....
May 18	10.38	2008	Mar. 15	10.42	....	May 25	10.33	....
June 14	10.28	1990	Apr. 15	10.40	....	Sept. 24	9.94	....
July 17	9.81	2501	May 20	10.38	....	Oct. 30	10.04	....
Aug. 16	9.96	1208	June 16	10.38	....	Nov. 16	10.31	....
						Dec. 13	10.33	....

39 (K. S. Co. well 3) Camp 2. 22°01′00″N, 159°45′15″W. Owner, Kekaha Sugar Co. Drilled, November 1929, by G. B. Primmer. Altitude, 9 ft. Original depth, 245 ft.; measured depth, March 1950, 240 ft. Diameter, 12 in. Casing reported original depth, 166 ft.; measured depth March 1950, 159 ft. Depth to aquifer, 163 ft. Use, irrigation.

Driller's log

Material	Depth (ft.)
Reddish brown clay	0- 18
Clay and boulders	18- 32
Red sticky clay	32- 52
Clay and coral	52- 60
Blue clay and boulders	60-105
Brown clay and boulders	105-120
Coral	120-126
Sticky brown clay and coral. Well started to flow at 163 ft.; flow about 0.25 mgd.	126-163
Brown and blue lava. Lava seems to be in layers of 2 ft. to 4 ft., with blue very hard and brown soft and easy drilling. No increase in water in blue lava but each brown streak gives more water	163-245

Observations

Chloride content of water during drilling

Depth (ft.)	Chloride (ppm)
163	176
168	166
173	156
185	145
198	135
203	125
208	125
215	114
225	104
229	94
233	94
239	89
245	94

Date	Chloride (ppm)
Mar. 30, 1937	255
July 30	240
Aug. 28	480
Sept. 3	565
25	600
Oct. 15	230
29	230
Nov. 5	550
26	580
Jan. 21, 1938	400
26	1150
Mar. 25	670
Apr. 15	515
29	615
May 20	770
27	685
June 17	560
July 15	730
22	755
29	735
Aug. 5	770
26	790
Apr. 21, 1939	495
28	650
May 5	840
June 9	820
Sept. 29	770
Oct. 6	720
Dec. 10	600
Feb. 9, 1940	820
June 27	805
Jan. 3, 1941	875
11	960
24	960
Feb. 7	975
15	960
Apr. 17	805
July 12	790
Sept. 3	755
Oct. 21	875
Aug. 3, 1945	515
Sept. 27	465
Jan. 6, 1947	250
Mar. 17	570
Apr. 18	540
July 21	480

(Bench mark, top of flange on 12-in. tee, 8.63 ft. above sea level)

Date	Head (ft.)	Chloride (ppm)
Mar. 22, 1950	10.73	310
Apr. 3	10.45	......
10	10.36	310
17	10.20	360
24	10.09	350
May 1	10.19	470
8	10.20	470
15	9.89	476
22	9.92	520
29	9.95	520
June 6	10.19	......
12	....	490
July 3	....	460
24	9.89	......
31	9.78	540
Aug. 7	....	520
14	9 97	520
19	10.76	470
Sept. 8	10.56	......
Oct. 10	10.12	520
23	....	540
Nov. 4	10.09	......
Dec. 11	10.10	481
Jan. 15, 1951	10.39	560
Feb. 15	10.18	576
Mar. 15	10.73	470
Apr. 16	10.18	451
May 18	10.29	490
June 14	10.26	508
July 17	9.85	525
Aug. 16	9.99	611
Sept. 18	10.26	540
Nov. 16	10.02	576
Dec. 20	10.21	451
Jan. 1952	10.56	610
Feb.	10.49	592
Mar.	10.50	507
Apr.	10.28	491
May	10.03	507
June	10.00	517
July	9.92	526
Aug.	10.22	630
Sept.	10.24	610
Oct.	10.06	594
Nov.	10.02	577
Dec.	10.20	524
Jan. 1953	10.44	628
Feb.	10.40	558
Mar.	10.28	508
Apr.	10.26	520
May	10.24	611
June	10.15	555
July	10.10	570
Aug.	10.08	507
Sept.	10.10	606
Oct.	10.10	520
Nov.	10.10	515
Dec.	10.38	587
Jan. 15, 1954	10.63	575
Feb. 15	10.6[illegible]	572
Mar. 15	10.60	630
Apr. 15	10.58	508
May 20	10.56	479
June 16	10.47	510
July 22	10.40	520
Aug. 14	10.38	490
Sept. 20	10.34	508
Oct. 13	10.48	490
Nov. 17	10.43	520
Dec. 16	10.59	515
Jan. 1955	10.46	630
Feb.	10.45	605
Mar.	10.45	510
Apr.	10.41	512
May	10.40	540
June	10.40	500
July	10.37	555
Aug.	10.36	572
Sept.	10.38	540
Oct.	10.40	540
Nov.	10.38	160
Jan. 1956	10.44	205
Feb.	10.41	507
Mar.	10.43	420
Apr.	10.39	630
May	10.41	612
Sept.	9.97	395
Oct.	10.03	552
Nov.	10.20	610
Dec.	10.24	525

40 (K. S. Co. well 4) Camp 2. 22°01′00″N, 159°45′15″W. Owner, Kekaha Sugar Co. Drilled, December 1929 by G. B. Primmer. Altitude, 10 ft. Original depth, 254 ft.; measured depth, Mar. 1950, 249 ft. Diameter, 12 in. Casing, reported original depth, 164 ft.; measured depth, Mar. 1950, 159 ft. Depth to aquifer, 162 ft. Use, irrigation.

Driller's log

	Depth (ft.)		Depth (ft.)		Depth (ft.)
Reddish brown clay	0- 18	Coral	120-128	Hard blue lava	192-211
Brown clay and boulders	18- 40	Brown clay and coral	128-140	Reddish brown lava	211-220
Red sticky clay	40- 50	Sticky brown clay	140-158	Hard blue lava	220-239
Large boulders in brown and blue clay, caving	50-112	White coral	158-162	Brown lava	239-245
Brown clay	112-120	Hard blue lava	162-168	Hard gray lava	245-248
		Red and brown lava	168-192	Brown porous lava	248-254

Observations

Chloride content of water during drilling

Depth (ft.)	Chloride (ppm)	Depth (ft.)	Chloride (ppm)	Depth (ft.)	Chloride (ppm)
176	145	195	125	218	104
184	145	200	114	233	83
187	135	207	104	241	93
				250	93

(Bench mark, top of flange on 12-in. tee, 7.30 ft. above sea level)

Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)
Mar. 22, 1950	10.64	240	Sept. 18	10.31	580	Apr. 15	10.48	572
Apr. 3	10.38	......	Nov. 16	10.10	675	May 20	10.46	560
10	10.32	320	Dec. 20	10.19	474	June 16	10.46	568
17	10.17	......	Jan. 1952	10.07	592	July 22	10.42	560
May 1	10.12	460	Feb.	10.73	572	Aug. 14	10.44	524
8	10.19	490	Mar.	10.21	507	Sept. 20	10.38	570
15	10.37	540	Apr.	10.22	486	Oct. 13	10.45	539
22	10.38	530	May	10.29	527	Nov. 17	10.41	556
29	10.39	550	June	10.20	575	Dec. 16	10.58	520
June 6	10.18	......	July	9.96	678	Jan. 1955	10.48	610
12	....	500	Aug.	10.15	644	Feb.	10.46	587
July 3	....	520	Sept.	10.05	598	Mar.	10.47	605
24	9.95	......	Oct.	10.12	661	Apr.	10.46	620
31	9.85	580	Nov.	10.10	695	May	10.43	600
Aug. 7	....	530	Dec.	10.17	558	June	10.44	580
14	10.07	550	Jan. 1953	10.40	620	July	10.42	630
19	10.49	270	Feb.	10.35	611	Aug.	10.42	607
Sept. 8	10.44	......	Mar.	10.29	644	Sept.	10.46	555
Oct. 2	10.10	550	Apr.	10.27	570	Oct.	10.45	660
23	....	560	May	10.28	620	Nov.	10.56	240
Nov. 4	10.06	......	June	10.13	470	Jan. 17, 1956	10.44	180
Dec. 11	10.08	450	July	10.11	608	Feb. 23	10.47	605
Jan. 15, 1951	10.36	580	Aug.	10.12	572	Mar. 23	10.43	380
Feb. 15	10.13	525	Sept.	10.16	647	Apr. 20	10.44	640
Mar. 15	10.51	460	Oct.	10.18	620	May 25	10.43	660
Apr. 16	10.18	395	Nov.	10.17	611	Sept. 24	9.97	600
May 18	10.32	524	Dec.	10.56	623	Oct. 30	10.00	630
June 14	10.20	632	Jan. 15, 1954	10.57	610	Nov. 16	10.28	605
July 17	9.94	635	Feb. 15	10.52	592	Dec. 13	10.33	500
Aug. 16	10.01	595	Mar. 15	10.50	611			

41 (K. S. Co. well 13) Camp 2. 22°01′00″N, 159°45′15″W. Owner, Kekaha Sugar Co. Drilled, about 1890. Altitude, 10 ft. Depth, 242 ft., measured, Feb. 1950. Diameter, 8 in. Casing, unknown, partly obstructed at 42 ft. below top in 1950. Use, irrigation.

Observations

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
Aug. 13, 1937	175	Apr. 28	240	Oct. 21	480
Oct. 15	230	Sept. 29	290	Aug. 3, 1945	205
29	220	Oct. 27	205	Sept. 27	255
Nov. 26	190	Dec. 8	960	May 10, 1946	325
Dec. 24	170	15	1200	June 20	275
Jan. 28, 1938	180	June 27, 1940	345	July 3	300
Feb. 25	170	July 29	275	Aug. 22	310
May 27	180	Aug. 14	240	Nov. 25	310
June 24	160	Jan. 3, 1941	240	Dec. 4	320
July 29	190	Feb. 7	275	Feb. 14, 1947	485
Dec. 30	240	May 10	225	May 19	620
Jan. 27, 1939	225	July 12	310	June 18	520
Mar. 31	205	Sept. 3	495		

42 (K. S. Co. Camp 3 well; Camp 3 old well) Camp 3. 22°01′20″N, 159°45′30″W. Owner, Kekaha Sugar Co. Drilled, about 1890. Altitude 10 ft. Depth, unknown. Diameter, unknown. Casing, unknown. Unused and covered by stones and debris.

Observations

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
Aug. 28, 1937	120	May 27	110	Jan. 27, 1939	120
Oct. 29	140	June 24	120	Mar. 31	120
Nov. 26	120	July 29	90	Apr. 28	120
Dec. 24	100	Sept. 30	110	Aug. 25	105
Jan. 28, 1938	95	Oct. 28	120	Sept. 29	105
Feb. 25	100	Nov. 25	110	Oct. 27	105
Apr. 29	140	Dec. 30	120	Dec. 8	105

43 (K. S. Co. Camp 3 old sump) Camp 3. 22°01′20″N, 159°45′30″W. Owner, Kekaha Sugar Co. Drilled, about 1890 (?) by McCandless (?). Altitude, 10 ft. Depth, unknown. Diameter, unknown. Casing, unknown. Unused and buried by mud and stone debris.

Observations

Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)
May 15, 1937	9.51	173	Dec. 20	11.26	148	July 15	9.52	100
June 15	9.76	165	Jan. 20, 1938	9.92	109	Aug. 19	9.57	100
July 16	10.61	165	Feb. 16	9.83	109	Oct. 16	9.32	110
Sept. 15	9.96	165	Apr. 15, 1939	9.52	110	Nov. 18	9.57	110
Oct. 16	9.76	182	June 14	10.62	100			

44 (K. S. Co. well 14; field 221 well) Camp 3. 22°01′20″N, 159°45′30″W. Owner, Kekaha Sugar Co. Drilled, about 1890 (?) by McCandless Bros. (?). Altitude, 10 ft. Depth, unknown. Diameter, 8 in. Casing, unknown, obstructed at 6 ft. below top. Unused.

Observations

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
Feb. 26, 1937	123	11	79	Sept. 3	67
Mar. 26	151	18	79	10	96
Apr. 9	130	25	410	18	79
23	140	July 9	130	25	85
30	137	16	85	Oct. 1	103
May 7	115	23	91	8	74
14	80	30	110	22	94
21	75	Aug. 6	91	29	120
28	91	13	77	Nov. 5	79
June 4	85	20	190	12	115

Observations—Well 44 (Continued)

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
19	110	23	110	Nov. 3	86
26	115	30	91	10	86
Dec. 3	85	Oct. 7	99	Dec. 8	103
10	99	14	91	15	103
17	91	21	91	22	86
24	91	28	99	Jan. 26, 1940	86
Jan. 7, 1938	80	Nov. 4	99	Feb. 2	86
14	94	25	99	9	86
21	105	Dec. 2	99	May 15	103
28	91	16	99	June 27	154
Feb. 4	91	30	99	July 29	103
11	91	Jan. 6, 1939	69	Aug. 14	86
18	94	13	103	Jan. 3, 1941	86
25	91	20	86	11	86
Mar. 11	91	27	103	17	86
18	91	Feb. 3	103	24	86
25	91	10	103	Feb. 7	86
Apr. 4	85	17	86	15	86
15	120	24	103	Mar. 17	86
22	91	Mar. 10	103	May 10	86
29	120	31	103	July 12	86
May 6	91	Apr. 14	103	Sept. 3	86
13	80	21	86	Oct. 21	86
20	91	28	103	Aug. 3, 1945	86
27	94	May 5	103	Sept. 27	171
June 3	94	19	120	May 10, 1946	103
10	80	26	103	June 20	120
17	80	June 9	86	July 3	120
24	82	16	103	Aug. 22	99
July 1	99	Aug. 4	103	Nov. 25	89
15	99	Oct. 6	103	Dec. 4	89
22	80	25	103	Jan. 6, 1947	99
29	80	Sept. 1	86	Feb. 14	110
Aug. 5	80	15	103	Mar. 17	99
12	99	22	103	Apr. 18	99
26	120	29	103	May 19	58
Sept. 2	99	13	86	June 18	99
9	91	20	86	July 21	99
16	91	27	103		

45 A-O (K. S. Co. wells M-1 to 15) Near Mana. 22°01′40″ N, 159°45′30″W. Owner, Kekaha Sugar Co. Drilled, about 1890 to 1901 by Olsen. Altitude, ground surface, 27 ft.; altitudes shown for individual wells are for the tops of casing. Depths shown are below tops of casing. All except unused wells are equipped with electric powered deep-well pumps and are pumped for irrigation.

A (M-1) Altitude, 26.47 ft. Depth, 264 ft., measured in 1950. Diameter, 12 in. Casing, 185 ft., measured in 1950. Unused. Meter test, Jan. 30, 1950, showed no movement of water in well. Head, Jan. 30, 1950, 13.98 ft.; Aug. 6, 1954, 9.76 ft.

Observations

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
July 16, 1929	1475	28	1525	July 30	110
19	1060	Sept. 4	1680	Aug. 13	90
30	1060	11	1715	28	90
Aug. 20	1130	18	1715	Sept. 3	80
Sept. 2	1060	25	1745	18	100
16	1045	Oct. 2	1440	25	95
Oct. 1	1165	Nov. 14	1595	Oct. 15	130
11	1235	23	1475	29	140
Nov. 1	1270	28	1475	Nov. 12	135
15	480	Dec. 26	600	26	130
Feb. 24, 1930	465	Aug. 31, 1936	60	Jan. 28, 1938	100
May 5	565	Sept. 25	165	Feb. 18	50
31	755	Oct. 2	145	25	91
July 15	1180	16	250	Apr. 15	99
Aug. 2	1235	Jan. 15, 1937	155	29	91
Aug. 7, 1931	410	Apr. 9	160	May 27	68
17	1200	30	170	June 10	99
22	1370	June 4	85	17	99

Observations—Well 45 (Continued)

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
July 1	99	30	180	22	345
15	120	Jan. 13, 1939	105	Feb. 9, 1940	190
22	120	27	120	June 27	345
29	120	May 5	85	July 29	480
Aug. 5	140	26	103	Jan. 11, 1941	120
12	290	June 9	103	17	105
26	225	16	120	24	85
Sept. 2	255	Aug. 4	137	Feb. 7	170
9	180	25	225	15	225
16	200	Sept. 1	190	Mar. 17	310
23	200	15	290	May 10	465
30	200	22	225	July 12	345
Oct. 14	151	29	310	Sept. 3	600
21	151	Oct. 6	255	Oct. 21	635
28	170	13	310	Aug. 3, 1945	530
Nov. 25	151	Nov. 10	290	Sept. 27	515
Dec. 2	180	Dec. 8	245	Apr. 18, 1947	230
16	159	15	375		

B (M-2) Altitude, 28.67 ft. Depth, 261 ft. Diameter, 12 in. Casing, unknown, obstructed at 26.5 ft. Unused. Head, Mar. 10, 1930, 9.31 ft.; Jan. 30, 1950, 13.93 ft.; Aug. 6, 1954, 9.45 ft.

C (M-3) Altitude, 28.94 ft. Depth, 249 ft., measured in 1950. Diameter, 12 in. Casing, 180 ft., measured in 1950. Unused. Head, Jan. 30, 1950, 14.13 ft.; Aug. 6, 1954, 9.36 ft.

D (M-4) Altitude, 29.45 ft. Depth, 266 ft. Diameter, 12 in. Casing, unknown.

Observations

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
Nov. 1, 1929	2330	Nov. 23	2620	Feb. 9, 1940	290
July 15, 1930	820	28	2670	27	615
July 13, 1931	2430	Dec. 26	1095	Mar. 17, 1941	495
27	2485	Jan. 13, 1939	120	May 10	975
Aug. 1	1165	27	120	Sept. 3	910
7	615	June 16	170	Oct. 21	910
17	2330	Aug. 25	325	Aug. 3, 1945	720
22	2640	Sept. 15	445	Sept. 27	910
28	3510	22	495	May 10, 1946	205
Sept. 4	2605	29	480	June 20	615
11	2655	Oct. 13	615	Aug. 22	810
18	2845	Nov. 10	375	Dec. 4	110
25	2740	Dec. 8	550	Apr. 18, 1947	290
Oct. 2	2810	15	580	May 19	290
14	2280	22	650	June 18	400

E (M-5) Altitude, 29.48 ft. Depth, 283 ft. Diameter, 12 in. Casing, unknown.

Observations

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
June 16, 1939	155	15	685	Sept. 27	1235
Aug. 25	345	22	790	May 10, 1946	205
Sept. 15	580	Feb. 9, 1940	310	June 20	875
22	615	June 27	635	Aug. 22	1030
29	565	Mar. 17, 1941	530	Dec. 4	120
Oct. 6	580	May 10	1080	Apr. 18, 1947	340
13	790	Sept. 3	805	May 19	330
Nov. 10	395	Oct. 21	1030	June 18	550
Dec. 8	615	Aug. 3, 1945	910		

F (M-6) Altitude, 30.77 ft. Depth, 270 ft. Diameter, 12 in. Casing, unknown.

Observations

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
Nov. 1, 1929	225	18	75	16	190
July 15, 1930	890	25	85	Aug. 4	155
July 13, 1931	1030	Oct. 15	90	25	170
27	975	29	100	Sept. 1	205
Aug. 1	1010	Nov. 12	105	15	225
7	275	Jan. 28, 1938	90	22	255
17	890	June 10	80	29	240
22	1130	24	80	Oct. 6	360
28	2210	July 1	100	13	310
Sept. 4	1165	15	110	Nov. 10	155
11	1200	22	110	Dec. 8	255
18	1270	29	100	15	275
25	1200	Aug. 5	120	22	325
Oct. 2	1130	12	140	Feb. 2, 1940	105
Nov. 14	1235	26	130	9	155
23	1060	Sept. 2	155	June 27	225
28	1130	9	165	July 29	310
Dec. 26	430	16	175	Feb. 15, 1941	255
Aug. 28, 1936	125	23	160	Mar. 17	240
Sept. 25	160	30	170	May 10	445
Oct. 2	155	Oct. 14	130	July 12	495
16	235	21	160	Sept. 3	465
Jan. 15, 1937	120	28	155	Oct. 21	430
Apr. 9	130	Nov. 25	120	Aug. 3, 1945	480
30	135	Dec. 2	170	Sept. 27	565
June 4	75	16	130	May 10, 1946	170
25	75	30	150	June 20	410
July 30	90	Jan. 13, 1939	85	Aug. 22	530
Aug. 13	85	27	105	Dec. 4	110
28	85	May 5	85	Apr. 18, 1947	190
Sept. 3	75	June 9	85	May 19	180
				June 18	290

G (M-7) Altitude, 30.45 ft. Depth, 275 ft. Diameter, 12 in. Casing, unknown.

Observations

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
Nov. 1, 1929	170	18	90	Aug. 4	170
July 15, 1930	875	25	100	25	190
July 13, 1931	1130	Oct. 15	105	Sept. 1	190
27	1095	29	120	15	205
Aug. 1	720	Nov. 12	130	22	240
7	274	Jan. 28, 1938	100	29	240
17	995	June 10	80	Oct. 6	255
22	1165	24	80	13	275
28	1420	July 15	130	Nov. 10	190
Sept. 4	1200	22	130	Dec. 8	255
11	1200	29	120	15	255
18	1505	Aug. 5	140	22	275
25	1235	12	151	Feb. 9, 1940	155
Oct. 2	1235	26	159	June 27	255
Nov. 14	1130	Sept. 2	170	Feb. 15, 1941	205
23	875	9	178	Mar. 17	255
28	1230	16	200	May 10	225
Dec. 26	500	23	200	July 12	465
Aug. 26, 1936	145	30	180	Sept. 3	480
Sept. 25	75	Oct. 14	170	Oct. 21	495
Oct. 16	235	21	130	Aug. 3, 1945	465
Jan. 15, 1937	100	28	151	Sept. 27	580
Apr. 9	160	Nov. 25	151	May 10, 1946	170
June 4	95	Dec. 2	180	June 20	430
25	90	30	190	Aug. 22	540
July 30	110	Jan. 13, 1939	137	Apr. 18, 1947	180
Aug. 13	105	27	85	May 19	180
28	105	June 9	135	June 18	290
Sept. 3	95	16	120		

H (M-8) Altitude, 30.60 ft. Depth, 372 ft. Diameter, 12 in. Casing, unknown.

Observations

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
Nov. 1, 1929	445	18	140	June 16	155
July 15, 1930	465	25	115	Aug. 25	255
July 13, 1931	2330	Oct. 15	145	Sept. 1	255
27	2210	29	145	15	325
Aug. 1	720	Nov. 12	150	22	245
17	1810	Jan. 28, 1938	110	29	245
22	2470	June 10	100	Oct. 13	410
28	2640	24	100	Nov. 10	445
Sept. 4	2470	July 15	150	Dec. 8	375
11	2550	22	170	15	410
25	2570	29	170	22	465
Oct. 2	2290	Aug. 5	190	Feb. 9, 1940	255
Nov. 14	2410	12	220	June 27	430
23	2480	26	220	Feb. 15, 1941	430
28	2400	Sept. 2	240	Apr. 17	430
Dec. 26	1045	9	260	May 10	395
Aug. 28, 1936	175	16	260	Sept. 3	890
Sept. 25	200	23	240	Oct. 21	960
Oct. 16	353	30	260	Aug. 3, 1945	820
Jan. 15, 1937	154	Oct. 14	230	Sept. 27	925
Apr. 9	170	21	260	May 10, 1946	205
June 4	104	28	250	June 20	720
25	108	Nov. 25	210	Aug. 22	895
July 30	128	Dec. 2	255	Apr. 18, 1947	210
Aug. 13	130	30	260	May 19	200
28	130	Jan. 13, 1939	154	June 18	180
Sept. 3	91	27	170		

I (M-9) Altitude, 30.53 ft. Depth, 251 ft. Diameter, 12 in. Casing, unknown.

Observations

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
Nov. 1, 1929	225	Sept. 3	100	Jan. 13, 1939	120
July 25	925	18	100	27	135
July 13, 1930	960	25	110	June 16	105
July 27, 1931	855	Oct. 15	115	Aug. 4	135
Aug. 1	600	29	120	Sept. 15	120
17	550	Nov. 12	140	22	155
22	1060	Jan. 28, 1938	110	29	155
28	1130	June 10	90	Oct. 13	190
Sept. 4	1030	24	90	Nov. 10	155
11	1030	July 15	140	Dec. 8	170
18	1165	22	145	15	190
25	1060	29	145	22	190
Oct. 2	890	Aug. 5	150	Feb. 9, 1940	135
Nov. 14	975	12	170	June 27	155
23	995	26	170	Mar. 17, 1941	190
28	855	Sept. 2	170	May 10	240
Dec. 26	345	9	180	Sept. 3	275
Aug. 28, 1936	147	16	180	Oct. 21	275
Sept. 25	158	23	160	Aug. 3, 1945	255
Oct. 16	230	30	170	Sept. 27	325
Jan. 15, 1937	150	Oct. 14	160	May 10, 1946	120
Apr. 9	155	21	170	June 20	225
June 4	100	28	160	Aug. 22	300
25	105	Nov. 25	90	Mar. 17, 1947	110
July 30	110	Dec. 2	165	Apr. 18	160
Aug. 13	110	16	150	May 18	160
28	110	30	160	June 18	190

J (M-10) Altitude, 30.44 ft. Depth, 246 ft. Diameter, 12 in. Casing, unknown.

Observations

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
Nov. 1, 1929	445	Sept. 3	165	June 16	170
July 15, 1930	940	18	155	Aug. 25	190
July 13, 1931	700	25	155	Sept. 15	205
27	700	Oct. 15	150	22	205
Aug. 1	890	29	180	29	205
17	550	Nov. 12	180	Oct. 13	205
22	755	Jan. 28, 1938	160	Nov. 10	205
28	820	June 10	130	Dec. 8	205
Sept. 4	720	24	130	15	205
11	720	July 22	160	22	205
18	790	29	160	Feb. 9, 1940	190
25	755	Aug. 5	160	June 27	205
Oct. 2	1575	12	190	July 29	225
Nov. 14	700	26	180	Feb. 7, 1941	170
23	700	Sept. 2	190	15	205
28	720	9	200	Mar. 17	190
Dec. 26	445	16	200	May 10	255
Aug. 28, 1936	225	23	190	July 12	255
Sept. 25	115	30	200	Sept. 3	170
Oct. 16	275	Oct. 14	200	Oct. 21	290
Jan. 15, 1937	225	21	190	Aug. 3, 1945	225
Apr. 9	205	28	190	Sept. 27	225
30	255	Nov. 25	200	May 10, 1946	205
June 4	130	Dec. 2	200	June 20	205
25	150	16	200	Aug. 22	230
July 30	145	30	210	Mar. 17, 1947	130
Aug. 13	145	Jan. 13, 1939	190	Apr. 18	160
28	145	27	190	May 19	170
				June 18	190

K (M-11) Altitude, 30.58 ft. Depth, unknown. Diameter, 12 in. Casing, unknown. Unused. Filled with debris.

L (M-12) Altitude, 30.65 ft. Depth, 240 ft. Diameter, 12 in. Casing, unknown.

Observations

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
July 13, 1931	565	Jan. 28, 1938	85	Sept. 1	105
27	565	Feb. 18	90	15	135
Aug. 7	205	25	100	22	135
17	480	Apr. 15	110	29	120
22	650	29	100	Oct. 6, 1939	155
28	670	June 10	80	13	135
Sept. 4	685	24	80	Nov. 10	105
11	685	July 1	90	Dec. 8	135
18	755	15	90	15	135
25	720	22	95	22	155
Oct. 2	685	29	95	Feb. 2, 1940	85
Nov. 14	600	Aug. 5, 1938	90	9	105
23	600	12	110	June 27	135
28	615	26	110	July 29	155
Dec. 26	240	Sept. 2	110	Jan. 11, 1941	120
Aug. 28, 1936	116	9	120	17	105
31	123	16	130	24	85
Sept. 25	127	23	120	Feb. 15	120
Oct. 16	164	30	120	Mar. 17	120
Jan. 15, 1937	116	Oct. 14	110	May 10	445
Apr. 9	140	21	110	July 12	205
30	137	28	120	Sept. 3	225
June 4	80	Nov. 25	105	Oct. 21	225
25	80	Dec. 2	120	Aug. 3, 1945	225
July 30	80	30	130	Sept. 27	255
Aug. 13	80	Jan. 13, 1939	85	May 10	105
28	80	27	85	June 20	205
Sept. 3	100	May 5	85	Aug. 22, 1945	260
18	70	26	85	Dec. 4	100
25	80	June 16	85	Feb. 14, 1947	100
Oct. 15	100	Aug. 4	120	Apr. 18	130
Nov. 12	110	25	105	May 19	120
				June 18	170

M Location unknown. Believed to be in vicinity of 45A-O.

N Location unknown. Believed to be in vicinity of 45A-O.

O Location unknown. Believed to be in vicinity of 45A-O.

46 Near Mana. 22°01′35″N, 159°45′45″W. Owner, Kekaha Sugar Co. Drilled, 1891 to 1906 (?) Well is buried and location is uncertain.

47 (K. S. Co. well 1) Near Mana. 22°01′40″N, 159°46′00″W. Owner, Kekaha Sugar Co. Drilled, Oct. 1929, by G. B. Primmer. Altitude, 9 ft. Depth, 365 ft.; backfilled to 346 ft. with crushed rock, sand, and cement. Diameter, 12 in. Casing, 256 ft. Reported abandoned and plugged about 1931 because of high salinity. Head, Mar. 10, 1937, 9.57 ft. Chloride, Oct. 1929, at 365 ft., 956 ppm with pump running; after backfilling to 346 ft., 312 ppm.

Driller's log

	Depth (ft.)		Depth (ft.)
Reddish brown clay	0- 12	Sticky clay and boulders	184-192
Gray clay	12- 22	Coral, some hard streaks	192-240
Boulders and clay	22- 27	Sandy and waxy volcanic ash	240-242
Gray clay and coral	27- 35	Hard blue lava, full of olivine	242-264
Yellow clay and coral	35- 40	Red, brown, and blue lava, some porous streaks	264-292
Loose sand	40- 45	Red, purple and blue lava	292-342
Tough brown clay	45- 64	Gray porous lava, fine pores	342-355
Sandy coral	64- 96	Gray porous lava, large pores	355-365
Sticky brown clay	96-175		
Brown sandy clay and small pebbles	175-184		

Chloride content of water during drilling

Depth (ft.)	Chloride (ppm)	Depth (ft.)	Chloride (ppm)	Depth (ft.)	Chloride (ppm)
150	2650	332	166	360	457
312	166	345	166	365	499
325	166				

48 Near Mana. 22°01′40″N, 159°46′00″W. Owner, Kekaha Sugar Co. Drilled about 1895 by McCandless Bros. Well is buried and location is uncertain.

49 Near Mana. 22°01′30″N, 159°46′00″W. Owner, Kekaha Sugar Co. Drilled, 1895 (?) by McCandless Bros. (?). Well is buried and location is uncertain.

50 Near Mana. 22°01′25″N, 159°46′00″W. Owner, Kekaha Sugar Co. Drilled, 1895 (?) by McCandless Bros. (?). Well is buried and location is uncertain.

51 Near Mana. 22°01′45″N, 159°46′15″W. Owner Kekaha Sugar Co. Drilled, 1895 (?) by McCandless Bros. (?). Well is buried and location is uncertain.

52 (Kekaha Sugar Co. well 2) Near Mana. 22°02′25″N, 159°45′45″W. Owner, Kekaha Sugar Co. Drilled, October 1929, by G. B. Primmer. Altitude, 55 ft. Depth, 298 ft. Diameter, 12 in. Casing, 215 ft. Depth to perched aquifer, 28 ft.; to basal aquifer, 212 ft. Reported yield when pumped, 1.25 mgd. Abandoned. Well is buried and location is uncertain.

Driller's log

	Depth (ft.)		Depth (ft.)
Boulders; similar to river bed boulders and with considerable water, 28 ft. to 36 ft. large boulders, 36 ft. to 52 ft.	0- 52	Sticky brown clay	164-212
Rotten rock, some clay	52-164	Red, brown, and blue lava	212-234
		Blue lava, some porous streaks	234-298

Chloride content of water during drilling

Depth (ft.)	Chloride (ppm)	Depth (ft.)	Chloride (ppm)	Depth (ft.)	Chloride (ppm)
36	83	275	290	290	250
255	395	284	250	298	260
270	332				

53 Saki Mana camp. 22°03′15″N, 159°46′05″W. Owner, Kekaha Sugar Co. Drilled, 1891-1906 (?). Well is buried, location uncertain.

54 (K. S. Co. well 15) Saki Mana camp. 22°03′25″N, 159°46′00″W. Owner, Kekaha Sugar Co. Drilled, 1891-1906 (?). Altitude, 11 ft. Depth, 271 ft. Diameter, 8 in. Casing, unknown. Well is buried and location is uncertain.

55 (K. S. Co. well 16)Saki Mana camp. 22°03′30″N, 159°45′45″W. Owner, Kekaha Sugar Co. Drilled, 1891 to 1906 (?). Altitude, 13 ft. Depth, 70 ft. (?). Diameter, 8 in. Casing, unknown. Use, domestic.

Observations

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
Feb. 12, 1937	395	Nov. 25	240	May 10	205
26	410	Dec. 30	240	July 12	205
Mar. 26	395	Jan. 27, 1939	240	Sept. 3	205
Apr. 30	395	Mar. 31	225	Oct. 21	225
June 25	255	Apr. 28	205	Aug. 3, 1945	205
Sept. 3	240	May 26	225	Sept. 27	205
25	260	Aug. 25	225	May 10, 1946	205
Oct. 29	260	Sept. 29	205	June 20	325
Nov. 26	270	Oct. 27	240	July 3	490
Dec. 24	240	Dec. 8	225	Aug. 22	450
Jan. 28, 1938	255	Jan. 26, 1940	225	Nov. 25	220
Feb. 25	240	May 15	205	Dec. 4	200
Apr. 29	260	June 27	225	Jan. 6, 1947	220
May 27	225	July 29	225	Feb. 14	210
June 24	255	Aug. 14	225	Mar. 17	200
July 29	240	Jan. 3, 1941	205	Apr. 18	200
Sept. 30	240	Feb. 7	225	May 19	190
Oct. 28	225	Mar. 17	240	June 18	210
				July 21	210

56 (K. S. Co. well 17; field 250 well) Saki Mana camp. 22°03′35″N, 159°45′55″W. Owner, Kekaha Sugar Co. Drilled, 1891 to 1906 (?). Altitude, 12 ft. Depth, reported, 262 ft.: measured, Feb. 1950, 258 ft. Casing, 183 ft. Unused.

Observations

Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)
May 15, 1937	9.13	830	Feb. 15, 1939	9.42	480	Aug. 15	9.52	440
June 15	9.25	585	Apr. 15	9.57	480	Sept. 15	9.72	320
July 16	9.29	595	May 21	9.42	490	Oct. 16	9.52	370
Sept. 15	9.25	595	June 14	9.62	480	Nov. 16	9.94	360
Oct. 16	9.25	610	July 15	9.72	460	Dec. 15	9.82	370
Dec. 20	9.34	610	Aug. 19	9.57	480	Jan. 19, 1941	9.89	360
Jan. 20, 1938	9.09	360	Oct. 16	9.57	484	Feb. 15	9.96	360
Feb. 16	9.34	360	Nov. 18	9.52	440	Mar. 18	9.52	380
Mar. 19	9.34	360	Dec. 19	9.55	550	Apr. 22	9.70	340
May 17	9.32	435	Jan. 15, 1940	9.96	400	June 16	9.55	195
June 19	9.37	420	Feb. 16	9.96	720	July 15	9.52	360
July 19	9.42	440	Apr. 15	9.71	350	Aug. 16	9.52	320
Aug. 18	9.17	420	May 19	9.52	370	Nov. 20	9.72	350
Sept. 19	9.22	460	June 16	9.58	390	Jan. ...., 1942	9.72	360
Oct. 15	9.42	460	July 15	9.42	350	Feb. 16	9.72	370

Observations—Well 56 (Continued)

Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)	Date	Head (ft.)	Chloride (ppm)
Mar. 18	9.62	370	Nov. 15	9.29	410	Dec. 15	9.17	420
Apr. 16	9.57	370	Dec. 16	9.28	400	Jan. 15, 1945	......	470
June 15	9.12	400	Jan. 16, 1944	9.24	400	Feb. 15	......	600
July 17	9.12	380	Feb. 15	9.22	400	Mar. 15	......	480
Aug. 15	9.07	380	Mar. 15	9.69	410	Apr. 16	......	440
Feb. 15, 1943	9.64	440	Apr. 17	9.37	400	May 15	......	290
Mar. 15	9.47	400	May 16	9.12	390	June 15	......	825
Apr. 16	9.47	410	June 16	9.19	410	July 16	......	620
June 16	9.47	400	July 15	9.25	410	Aug. 17	......	620
July 15	9.37	400	Aug. 15	9.15	390	Sept. 17	......	460
Aug. 14	9.25	400	Sept. 15	9.17	420	Oct. 15	......	460
Sept. 14	9.39	400	Oct. 16	9.12	420			
Oct. 16	9.32	390	Nov. 15	9.19	460			

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
Jan. 18, 1949	550	May 20	550	Sept. 15	560
Feb. 15	550	June 15	580	Oct. 17	520
Mar. 17	570	July 15	570	Nov. 15	540
Apr. 18	560	Aug. 15	600	Dec. 15	550
				Aug. 5, 1954	464

57 (K. S. Co. 18; field 247 well) Saki Mana camp. 22°03′45″N, 159°46′00″W. Owner, Kekaha Sugar Co. Drilled, 1891-1906 (?). Altitude, 11 ft. Depth, 165 ft. Diameter, 8 in. Casing, unknown, obstructed 14 ft. below top. Use, irrigation. Head, Mar. 10, 1937, 6.35 ft.

Observations

Date	Chloride (ppm)	Date	Chloride (ppm)	Date	Chloride (ppm)
Feb. 26, 1937	910	Jan. 27, 1939	910	Sept. 3	910
Mar. 26	890	Mar. 31	925	Oct. 21	735
Apr. 30	875	Apr. 28	995	Aug. 3, 1944	820
May 28	345	May 26	975	Sept. 27	790
June 25	580	Aug. 25	1010	May 10	820
July 30	580	Oct. 27	995	June 20	755
Dec. 24	875	Dec. 8	910	July 3	820
Jan. 28, 1938	890	Jan. 26, 1940	960	Aug. 22	640
Feb. 25	910	May 15	840	Nov. 25	560
Apr. 29	755	June 27	805	Dec. 4	530
May 27	855	July 29	790	Jan. 6, 1947	590
June 24	800	Aug. 14	805	Feb. 14	540
July 29	790	Jan. 3, 1941	1115	Mar. 17	550
Sept. 30	900	Feb. 7	1150	Apr. 18	570
Oct. 28	920	Mar. 17	1030	May 19	510
Nov. 25	910	May 10	1030	June 18	490
Dec. 3	900	July 12	840	July 21	470

70 Hanalei. 22°12′45″N, 159°29′50″W. Owner, G. P. Wilcox. Drilled, April 1940 by W. M. Mullin. Altitude, 6 ft. Depth, 175 ft. Diameter, 6 in. Casing, 170 ft. Use, supply for fish pond. Head, June 26, 1949, 10.0 ft. Chloride (ppm), June 26, 1949, 88; Aug. 2, 1954, 91. Flow, June 26, 1949, 38,600 gpd.

Driller's log

	Depth (ft.)
Beach sand	0- 50
Beach sand and gray mud	50- 90
Black sand with some rotten wood and small gray pebbles at 110 ft	90-120
Mud and sand	120-150
Mud with pieces of blue rock with coral-like branches and small gray rocks	150-165
Black gravel with shells and black sand	165-173
Rock full of olivines	173-175

71 Hanalei. 22°12′30″N, 159°29′50″W. Owner, G. P. Wilcox. Drilled, May 1940, by W. M. Mullin. Altitude, 7 ft. Depth, 170 ft. Diameter, 6 in. Casing, 135 ft. Abandoned. Head, 6 ft. Flow, very small.

Log
(Compiled from record kept by G. P. Wilcox)

	Depth (ft.)		Depth (ft.)
Sand, thin layer of sandstone at 20 ft.	0- 30	Small shot-like gravel	132-139
Coarse gravel	30- 50	Mud and gravel	139-160
Sand, gravel, and mud	50- 70	Rock	160-164
Black sticky mud; pieces of rotten wood at 102 ft.	70-132	Rocky gravel	164-170

80 Papaa. 22°9′55″N, 159°19′45″W. Owner, Lihue Plantation Co. Drilled, Oct. 1955, by Pacific Drilling Co. Altitude, 285 ft. Depth, 700 ft. Diameter of open hole, 9 in. Casing, none. Abandoned because of low yield.

Driller's log

	Depth (ft.)		Depth (ft.)
Broken pukapuka lava and clay	0- 8	Hard pukapuka lava, olivine	429-454
Soft pukapuka rock	8- 13	Medium hard pukapuka lava, olivine	454-500
Medium hard lava	13- 69	Hard lava	500-545
Hard pukapuka rock	69- 79	Hard black lava	545-592
Medium hard pukapuka lava	79-250	Soft red lava	592-606
Soft pukapuka lava	250-254	Hard lava	606-624
Hard pukapuka lava	254-310	Soft red lava	624-626
Medium hard pukapuka lava	310-375	Hard lava	626-629
Soft pukapuka lava	375-427	Hard pukapuka lava	629-700
Volcanic ash	427-429		

90A Anahola. 22°08′15″N, 195°19′00″W. Owner, Hawaiian Homes Commission. Drilled, 1956, by Nat Whiton. Altitude, 270 ft. Depth, 433 ft. Diameter, 10 in. Casing, 295 ft. Use, domestic. Head, ?

Driller's log

	Depth (ft.)		Depth (ft.)		Depth (ft.)
Sticky brown clay	0- 7	Hard rock and clay	82- 93	Medium hard rock	267-286
Compact brown clay	7- 18	Hard rock and red soil	93-109	Decomposed rock	286-290
Soft brown clay	18- 28	Hard rock and clay	109-117	Medium hard rock	290-295
Soft gray rock	28- 34	Decomposed rock and hard rock	117-122	Medium hard rock with soft streak	295-314
Red-gray rock	34- 40	Decomposed red rock	122-132	Decomposed rock	314-321
Brown soil	40- 44	Red rock	132-137	Medium hard rock	321-325
Boulder	44- 55	Hard rock	137-152	Hard rock	325-337
Rock ledge	55- 60	Red rock	152-172	Medium hard rock	337-399
Decomposed rock	60- 66	Decomposed gray rock	172-178	Hard rock	399-415
Decomposed rock and medium hard rock	66- 75	Hard rock	178-250	Compact black sand	415-433
Hard rock and red soil	75- 82	Decomposed rock	250-267		

90B Anahola. 22°08′15″N, 159°19′00″W. Owner, Hawaiian Homes Commission. Drilled, 1957 by Nat Whiton. Altitude, 270 ft. Depth, 486 ft.; filled by caved material to 390 ft. Diameter, 10 in. Casing, 295 ft. Use, domestic.

Driller's log

	Depth (ft.)		Depth (ft.)		Depth (ft.)
Compact brown clay	0- 15	Medium hard decomposed rock	118-135	Decomposed rock with hard streaks	351-364
Soft brown clay	15- 18	Decomposed soft rock	135-138	Hard rock	364-367
Soft decomposed rock	18- 26	Medium hard decomposed rock	138-140	Medium hard rock	367-381
Soft brown decomposed rock	26- 46	Hard rock	140-155	Brown clay	381-390
Soft gray decomposed rock	46- 56	Red rock, very sticky	155-189	Hard rock	390-395
Soft brown decomposed rock	56- 63	Hard rock	189-245	Soft rock	395-400
Soft gray decomposed rock	63- 76	Medium hard rock	245-271	Very hard rock	400-413
Boulder	76- 78	Hard rock	271-299	Medium hard rock	413-427
Boulder and clay	78- 94	Medium hard rock	299-326	Very hard rock	427-439
Sticky clay	94-105	Hard rock	326-328	Soft rock	439-442
Soft decomposed rock	105-112	Soft rock	328-331	Soft rock	442-456
Soft sticky clay	112-115	Hard rock	331-336	Soft rock and clay	456-481
Red clay	115-118	Medium hard rock	336-341	Soft gray rock	481-485
		Soft rock with hard streaks	341-351	Medium hard gray rock	485-486

Cored material, probably from brown clay layer between 381 and 390 ft. filled hole from bottom to 390 ft.

T-1 (Kauai Pineapple Co. Lawai Cannery test hole) 21°55′20″N, 159°30′25″W. Owner, Kauai Pineapple Co. Drilled, April to June 1950, by Samson and Smock, Ltd. Altitude, 499 ft. Depth, 622 ft. Casing, 2 in. to 160 ft.; ¾ in. to 350 ft. Use, exploratory and observation.

Log

(Driller's terms followed by core descriptions by D. C. Cox.)

	Depth (ft.)	Length of core (ft.)
Clay. Probably highly weathered olivine basalt	0 -20	0
Soft formation. Probably highly weathered olivine basalt	20-160	0
Medium hard pukapuka rock. Picrite basalt, generally moderately vesicular	160-274	40.0
Medium hard pukapuka rock, soft in places. Olivine basalt, pahoehoe and aa, vesicular with generally fine vesicles, clinkery in part, generally small olivine grains	274-329	35.5
Olivine basalt, as above, 7.2 ft.; picrite basalt, pahoehoe, fairly vesicular, rich in large olivine grains, 2.4 ft	329-349	9.6
Medium hard to soft rock. Olivine and picrite basalt, pahoehoe, moderately to highly vesicular, variable olivine content	349-466	53.1
Soft to medium soft pukapuka rock. Olivine basalt, moderately to highly vesicular, generally moderate olivine content	466-527	22.9
Medium soft to soft rock. Picrite basalt, pahoehoe, brown, moderately vesicular, partly weathered	527-570	4.6
Medium soft to soft rock. Olivine basalt, mostly very vesicular with fine vesicles but some patches moderately vesicular with coarse vesicles	570-622	13.2

Water-level measurements during drilling

Depth (ft.)	Effective casing (ft.)	Head (ft.)	Depth (ft.)	Effective casing (ft.)	Head (ft.)	Depth (ft.)	Effective casing (ft.)	Head (ft.)
499	0	152.38	615	547	64.55	615	527	78.35
615	0	165.61	615	507	144.92	615	517	136.32
						615	615	61.9

T-2 (Kauai Pineapple Co. Macadamia Nut Farm test hole) 21°56′05″N, 159°30′30″W. Owner, Kauai Pineapple Co. Drilled, Aug. 11 to Oct. 5, 1950 by Samson and Smock, Ltd. Altitude, 626 ft. Depth, 625 ft. Casing, ¾ in. to 624 ft., bottom 42 ft. perforated. Use, exploration and observation.

Log
(Driller's terms followed by core descriptions by D. C. Cox.)

	Depth (ft.)	Length of core (ft.)
Clay	0- 14	0
Boulders and clay. Boulders of basalt, very dense, fine-grained, fairly massive, with plentiful small dark olivine phenocrysts	14- 49	2.7
Waimea clay. Gray, partly weathered rock	49- 79	0.2
Boulders, clay and blue rock. Boulders of fairly vesicular basalt and very dense basalt: small amounts of yellow, fine-grained, alluvial material adhering to some fragments	79-105	5.2
Blue rock and medium hard rock, soft in places. Cobbles and boulders of basalt, with fine alluvium and yellow soil adhering to fragments	105-119	1.9
Hard rock soft in places. Olivine basalt, pahoehoe, irregularly vesicular, fairly plentiful small olivine phenocrysts	119-128	1.2
Medium soft broken rock. Olivine basalt, fairly dense, probably aa	128-154	1.9
Medium soft rock, soft in places. Olivine basalt, fairly dense, conspicuous feldspars, probably aa, 2.4 ft.; olivine basalt, pahoehoe, highly vesicular, 0.4 ft.; olivine basalt, fairly dense, probably aa, 0.7 ft	154-174	3.5
Hard rock. Olivine basalt, aa, dense	174-194	16.1
Hard rock, soft rock with cavities, and soft pukapuka rock. Olivine basalt, dense, grading downward to fairly and irregularly vesicular	194-234	4.7
Soft pukapuka rock. Olivine basalt, pahoehoe, highly vesicular with fine vesicles, 8.7 ft.; picrite basalt, pahoehoe, moderately and coarsely vesicular, 0.8 ft	234-290	9.5
Soft rock and medium hard pukapuka rock, soft in places. Picrite basalt, pahoehoe, moderately and coarsely vesicular, 1.1 ft.; olivine basalt, pahoehoe, highly and finely vesicular, slightly weathered flow surface at top, 2.5 ft	290-305	3.6
Medium soft pukapuka rock. Olivine basalt, frothy pahoehoe, 2.3 ft., moderately to highly vesicular, 2.8 ft.; picrite basalt, pahoehoe, highly vesicular, 1.2 ft	305-336	6.3
Medium soft and soft pukapuka rock. Picrite basalt, pahoehoe, highly vesicular, 0.7 ft.; olivine basalt, pahoehoe, moderately to highly vesicular, 6.4 ft	336-369	7.1
Medium soft rock and medium hard rock, soft in places. Olivine basalt, pahoehoe, moderately and coarsely to highly vesicular, some clay-like material in amygdules	369-400	5.3
Medium soft pukapuka rock, soft rock and soft pukapuka rock. Olivine basalt, pahoehoe, moderately to highly vesicular, becoming dense in bottom 0.1 ft	400-449	7.7
Not logged	449-464	......
Medium soft rock and soft pukapuka rock. Olivine basalt, pahoehoe, moderately to highly vesicular, high in olivine	464-504	4.2
Soft pukapuka rock. Olivine basalt, pahoehoe, moderately and coarsely vesicular to highly vesicular, high in olivine	504-545	3.9
Hard, medium hard and soft rock. Olivine basalt, pahoehoe, highly to moderately vesicular	545-601	2.7
Medium soft rock and hard rock. Olivine basalt, pahoehoe, moderately to highly vesicular, becoming dense in bottom 0.5 ft	601-625	8.8

Water-level measurements during drilling

Depth (ft.)	Head (ft.)	Depth (ft.)	Head (ft.)	Depth (ft.)	Head (ft.)
400	250.59	483 below	155	591	64.02
449	211.30	520	118.45	603	63.78
464 below	173	580	64 ±	624	63.87

Water-level measurements after completion of hole
(Measuring point, top of ¾-in. coupling, altitude, 627.94 ft.)

Date	Head (ft.)	Date	Head (ft.)	Date	Head (ft.)
Oct. 9, 1950	63.79	Apr. 18, 1951	63.21	May 16, 1951	64.13
13	63.68	19	63.21	18	64.17
20	63.68	20	63.15	19	64.17
28	63.66	21	63.86	22	64.25
Nov. 14	63.78	27	63.92	25	64.32
21	63.59	28	63.99	29	64.36
29	63.64	30	64.16	June 1	64.36
Dec. 4	63.55	May 1	64.14	8	64.51
Jan. 13, 1951	63.45	2	64.06	16	64.16
20	63.45	7	64.09	27	64.76
Feb. 6	63.45	9	64.04		
27	63.25	10	64.01		

T-3 (McBryde Sugar Co. test hole 1) *21°54′55″N, 159°30′20″W.* Owner, McBryde Sugar Co. Drilled, Dec. 7, 1949 to January 9, 1950, by Samson and Smock, Ltd. Altitude, 386 ft. Depth, 394 ft. Casing, temporary during drilling to 140 ft. Use exploratory.

Log

(Driller's terms followed by core description by D. C. Cox.)

	Depth (ft.)	Length of core (ft.)
Sticky clay	0- 7	0
Hard rock. Basalt, dark, fine-grained, extremely dense, containing a dunite segregation; possibly a boulder	7- 10	1.2
Soft clay	10- 12	0
Hard rock. Basalt, dark, fine-grained, extremely dense, containing dunite segregations	12- 25	4.9
Yellow sticky clay. Weathered tuff or flow rock	25-139	0
Medium hard rock. Olivine basalt, gray amygdaloidal, with 4-mm. round, fresh olivine grains, probably a bomb, 0.2 ft.; tuff, black except at top which is brown, very massive	139-149	9.3
Soft rock, gray in color. Probably tuff; at 153 ft. a 0.3 ft. core of olivine basalt, probably a bomb	149-157	0.1
Medium hard rock. Tuff, black, very massive, composed of black glassy, 1 to 10 mm., fragments, and white cement; some vesicular lava bombs	157-167	9.8
Medium hard rock and soft rock in places. Black tuff	167-215	....
Soft dirty rock. Hard red soil, 0.3 ft.; olivine basalt, residual boulder, 0.3 ft.; hard red soil, 0.3 ft.; hard red soil with small residual fragments of weathered olivine basalt, 0.9 ft.	215-218	2.0
Soft dirty rock. Probably weathered rock	218-220	0
Medium hard rock, soft in places. Basalt, aa, fairly dense, very massive, amygdaloidal, with 3 mm. olivine grains, 6.9 ft.; hard red soil with fragments of weathered olivine basalt, 0.2 ft.; olivine basalt as above, 2.8 ft.	220-233	9.9
Medium hard rock, soft in places. Olivine basalt, mostly massive and dense, vesicular and amygdaloidal in places, weathered in places	233-243	10.0
Medium hard rock, soft in places. Olivine basalt, amygdaloidal, stained reddish or weathered in part	243-253	8.7
Medium hard rock, soft in places. Olivine basalt, amygdaloidal, dense to vesicular; vesicular sections are reddish	253-263	9.9
Medium hard rock and soft dirty rock in places. Olivine basalt, amygdaloidal, very massive, and dense at top, becoming fairly vesicular at bottom, 5.2 ft.; olivine basalt, amygdaloidal, vesicular to rubbly, 2.1 ft.; olivine basalt, amygdaloidal, finely vesicular with 5 mm. olivine grains, 1.0 ft.; olivine basalt, amygdaloidal, rubbly, 0.5 ft.	263-273	8.8
Medium hard rock and soft dirty rock in places. Olivine basalt, partly amygdaloidal, clinkery, possibly pyroclastic, partly weathered, 5.1 ft.; olivine basalt, dense, massive, partly amygdaloidal, slightly weathered in top foot; 5 mm. olivines common; fine feldspar grains, 4.0 ft.	273-283	9.1
Medium hard rock and soft dirty rock in places. Basalt, olivine, dense, massive, 4.4 ft.; olivine basalt, amygdaloidal, clinkery, 1.3 ft.	283-289	5.7
Medium hard rock, soft dirty rock in places. Olivine basalt, amygdaloidal, clinkery, weathered, 0.9 ft.; olivine basalt, partly amygdaloidal, fairly massive, finely vesicular, 5.0 ft.; olivine basalt, amygdaloidal, vesicular, clinkery, 0.4 ft.	289-297	6.3
Medium hard rock, soft dirty rock in places. Olivine basalt, aa, amygdaloidal, coarsely and irregularly vesicular, 2.3 ft.; olivine basalt, partly amygdaloidal, very massive, finely vesicular, 4.4 ft.; basalt, clinkery or coarsely vesicular, amygdaloidal with white and red filling material, 1.8 ft.	297-309	8.5
Medium hard rock. Olivine basalt, amygdaloidal, dense, massive, with 1 mm. to 3 mm. olivine grains	309-319	8.7
Soft rock. Mostly clinker, some clinkery olivine basalt, partly amygdaloidal, partly weathered	319-339	6.2
Medium hard rock. Olivine basalt, fairly massive, finely and sparsely vesicular	339-342	2.8
Soft rock. Pyroclastic material, red, weathered, 0.6 ft.; olivine basalt, fairly massive, moderately vesicular and partly amygdaloidal at top, dense below	342-355	2.2
Soft rock. Olivine basalt, partly amygdaloidal and moderately vesicular with 2 mm. rusty olivine grains, 6.3 ft.; olivine basalt, amygdaloidal, rubbly, 2.2 ft.	355-364	8.5
Soft rock. Olivine basalt, amygdaloidal, rubbly, 2.1 ft.; basalt, moderately and coarsely vesicular, small olivine and feldspar grains, 2.2 ft.	364-384	4.3
Soft rock. Basalt, red, weathered, possibly pyroclastic in part, 1.0 ft.; olivine-augite basalt, vesicular, somewhat amygdaloidal; plentiful 3 mm. olivine grains; sparse 2 mm. green augite grains, 2.5 ft.	384-394	3.5

Water-level measurements during drilling

Depth (ft.)	Effective casing (ft.)	Head (ft.)	Depth (ft.)	Effective casing (ft.)	Head (ft.)
263	140	363	394	140	366

T-4 (McBryde Sugar Co. Keke Gulch test hole) 21°54'40"N, 159°29'55"W. Owner, McBryde Sugar Co. Drilled, Jan. 13 to Mar. 11, 1950 by Samson and Smock, Ltd. Altitude, 372 ft. Depth, 600 ft. Casing, ½ in. to 600 ft., perforated from 411 ft. to 432 ft. Hole cemented and redrilled, 145 ft. to 301 ft. Use, exploratory and observation.

Log
(Driller's terms followed by core description by D. C. Cox.)

	Depth (ft.)	Length of core (ft.)
Soil. Soil and weathered rock	0- 20	0
Clay and soft dirty rock. Weathered rock	20-141	0
Hard broken rock. Olivine basalt, very dense, apparently closely jointed; very pale, 2 mm. olivine grains; rubbly, 169 ft. to 170 ft.	141-181	37.8
Red clay. Probably soil or weathered pyroclastic material	181-184	0
Medium hard pukapuka rock. Olivine basalt, vesicular, with 2 mm., rusty olivine grains	184-189	3.7
Soft clay. Probably soil or rotten clinker	189-197	0
Hard broken rock. Olivine basalt, very dense	197-202	5.9
Medium hard rock, soft in places. Olivine basalt, moderately vesicular, partly weathered in places with clay-like vesicle filling	202-213	9.4
Medium hard rock, soft in places. Basalt, very dense, very massive	213-222	2.8
Medium hard rock, soft in places. Basalt, very dense, very massive	222-236	5.4
Soft rock. Olivine basalt, rubbly	236-239	2.7
Medium hard rock, soft in places. Olivine basalt, vesicular at top, dense at bottom	239-254	9.1
Medium hard rock, soft in places. Olivine basalt, generally dense, vesicular in part	254-268	9.5
Hard rock. Basalt, very dense, very massive	268-276	6.7
Soft clay	276-286	0
Soft rock, very soft in places. Basalt, vesicular to rubbly, partly weathered	286-290	1.8
Medium hard rock. Basalt, very dense to fairly dense jointed, plentiful small olivine grains altered to red color	290-301	10.9
Medium hard rock, soft in places. Olivine basalt, moderately vesicular, clinkery near bottom, with few 4 mm. olivine grains altered to red color	301-305	2.9
Hard rock. Olivine basalt, moderately vesicular at top to dense at bottom, massive	305-315	10.0
Medium hard rock and hard rock. Olivine basalt, vesicular to dense, jointed	315-387	29.0
Medium hard rock, soft in places or hard rock. Olivine basalt, jointed to clinkery, possible pyroclastic in part, white amorphous filling in openings	387-400	1.1
Hard broken rock and medium hard rock, soft in places. Olivine basalt, dense to vesicular, highly and coarsely vesicular 416 ft. to 418 ft., jointed	400-426	8.2
Medium hard clay with a few cavities	426-432	0
Medium hard red clay, soft in places. Red and yellow soil	432-456	0.3
Medium soft yellow clay. Weathered tuff and one lava fragment, possibly a bomb	456-466	0.1
No core	466-474	0
Medium hard mud rock. Tuff, black and well consolidated, except at 475 ft. to 477 ft., which is gray and poorly consolidated; space between fragments filled with secondary mineral	474-481	6.0
Medium hard mud rock. Tuff brown to gray, well consolidated	481-494	8.2
Hard rock. Tuff, brown to gray with a bomb of gray, dense, somewhat amygdaloidal bomb	494-495	0.7
Mud rock. Tuff, brown, well consolidated	495-589	61.9
Medium soft blue rock. Basalt, highly vesicular, with small calcite amygdules; sharp fresh contact with tuff above	589-594	1.6
Hard rock. Basalt, moderately vesicular	594-600	4.9

Water-level measurements during drilling

Depth (ft.)	Head (ft.)	Depth (ft.)	Head (ft.)	Depth (ft.)	Head (ft.)
426	11.8	481	12.0	589	11.8

Recharge test
Depth of hole, 600 ft. Casing, ½ in. to 600 ft., perforated 411 ft. to 432 ft.

Time	Depth to water (ft.)	
7:15	....	Began recharge at 13.5 gpm
9:30	....	End of recharge
9:35	364.4	
11:34	364.3	

T-5 (McBryde Sugar Co. Kalawai test hole) 21°55′05″N, 159°29′50″W. Owner, McBryde Sugar Co. Drilled, Mar. 13 to May 1, 1951 by Samson and Smock, Ltd. Altitude, 510 ft. Depth, 533 ft. Casing, ½ in. to 531 ft., bottom 42 ft. perforated. Use, exploratory. Head, Apr. 12, 1954, 11 ft. depth of hole, 533 ft.

Log
(Driller's terms followed by core description by D. C. Cox.)

	Depth (ft.)	Length of core (ft.)
Clay, soft in places. Soil and weathered rock	0-106	0
Medium hard rock boulders. Basalt, extremely dense and massive, broken at top	106-110	2.7
Soft clay. Probably weathered rock	110-130	0
Hard rock. Basalt, extremely dense and massive	130-196	53.2
Red clay	196-206	0
Soft rock. Olivine basalt, dense and massive, weathered, small olivine grains	206-213	1.7
Medium hard rock, soft in places. Olivine basalt, extremely dense and massive, weathered in places	213-236	22.9
Clay. Probably soil and weathered rock	236-242	0
Soft rotten rock. Olivine basalt, vesicular, weathered	242-253	1.9
Medium soft pukapuka rock, soft in places. Olivine basalt, fine-grained, vesicular and weathered at top, becoming dense and fresh at bottom	253-273	6.2
Medium hard pukapuka rock. Olivine basalt, fine-grained, top 4 ft. dense and massive, lower part moderately vesicular	273-293	19.9
Medium hard pukapuka rock. Olivine basalt, fine-grained, moderately vesicular	293-364	29.7
Hard pukapuka rock. Olivine basalt, fine-grained, fairly dense, jointed	364-374	6.6
Medium hard pukapuka rock, soft in places. Olivine basalt, fairly dense and massive in top half, becoming moderately vesicular in lower half	374-398	10.0
Hard rock. Olivine basalt, fairly dense, jointed to fairly massive	398-415	2.4
Soft pukapuka rock. Probably vesicular basalt	415-427	0
Hard to medium hard pukapuka rock. Olivine basalt, fairly dense to moderately vesicular	427-470	20.4
Soft rock. Olivine basalt, fairly dense, 2.8 ft.; olivine basalt, moderately vesicular, 1.1 ft.; olivine basalt, with red coarse olivine grains, highly weathered; probably talus or conglomerate boulder, 0.5 ft.	470-493	4.4
Soft rock. Olivine basalt, vesicular, partly weathered	493-506	1.3
Soft rock and medium hard rock, soft in places. Olivine basalt, vesicular and broken, 1.5 ft., fairly dense and massive with inclusions of highly vesicular material, 3.9 ft., and vesicular, 1.2 ft.	506-522	6.6
Soft rock and medium hard rock, soft in places. Olivine basalt, vesicular to dense	522-533	6.6

T-6 (McBryde Sugar Co. Reservoir 18 test hole) 21°55′15″N, 159°29′55″W. Owner, McBryde Sugar Co. Drilled, May 16 to July 26, 1950, by Samson and Smock, Ltd. Altitude, 511 ft. Depth, 530 ft. Casing, 2 in. to 3 ft.; ¾ in. to 530 ft. Hole cemented and redrilled 0-100 ft. Use, exploration and observation.

Log
(Driller's terms followed by core descriptions by D. C. Cox.)

	Depth (ft.)	Length of core (ft.)
Boulders. Olivine basalt, massive and extremely dense, fine-grained, probably residual boulders	0- 10	2.7
Clay	10- 15	0
Boulders and clay. Olivine basalt, fine-grained, very dense, massive, dunite segregations near top; brown soil at bottom, 0.4 ft.	15- 72	22.0
Clay	72- 88	0
Clay and boulders. Olivine basalt, fine-grained, dense, jointed in part, weathered in places	88-108	5.3
Hole abandoned because of lost tools. New hole drilled a few feet from that logged above	......-......	......
Soft red formation	110-114	0
Medium soft, sandy formation. Olivine, basalt, fine-grained, weathered	114-172	0.1
Boulder. Olivine basalt, fine-grained, very dense, 1.7 ft.; olivine basalt, somewhat vesicular, partly weathered; 1.0 ft., possibly boulders in gravel	172-176	2.7

Log—Well T-6 (Continued)

	Depth (ft.)	Length of core (ft.)
Soft pukapuka rock. Basalt, brown, very vesicular, amygdaloidal filling of white, clay-like material, partly weathered, 2.9 ft.; basalt, pahoehoe, gray, finely vesicular, 2.7 ft.	180-202	5.6
Soft pukapuka rock. Basalt, pahoehoe, moderately and coarsely vesicular to finely vesicular with some white, clay-like amygdaloidal filling and mostly weathered, 8.8 ft.; picrite basalt, finely vesicular	202-232	10.4
Soft rock and medium soft rock. Picrite basalt, pahoehoe, moderately and irregularly vesicular, olivine content variable	232-277	16.2
Medium soft rock and soft rock. Olivine basalt, moderately and irregularly vesicular with less olivine than above, 18.9 ft.; picrite basalt, similar to olivine basalt above but less vesicular and with more olivine, 2.5 ft	277-344	21.4
Medium soft to medium hard rock. Olivine basalt, pahoehoe, possibly aa at top, slightly to moderately vesicular, high in olivine at top	344-368	6.7
Medium hard rock. Olivine basalt, slightly to moderately and irregularly vesicular, patches high in olivine	368-385	4.8
Medium hard rock. Olivine basalt, pahoehoe, moderately and irregularly vesicular, 1.0 ft.; reddish-brown weathered clinker or pyroclastic material, 0.5 ft.; clinker, 0.5 ft.	385-390	2.0
Medium hard rock. Olivine basalt, pahoehoe, irregularly vesicular	390-394	0.6
Medium hard rock and soft rock. Olivine basalt, 2.1 ft., grading to picrite basalt, 2.0 ft., grading to olivine basalt, 6.1 ft., slightly to moderately vesicular	394-434	10.2
Medium hard rock and soft rock, cavities in places. Olivine basalt, pahoehoe, moderately and irregularly vesicular	434-530	12.6

Water-level measurements during drilling

Depth (ft.)	Head (ft.)	Depth (ft.)	Head (ft.)	Depth (ft.)	Head (ft.)
348	165 –	404	122.0	508	63.3
371	142 –	451	67.3	530	63.3
390	124.4	461	64.1		

Observations
Measuring point, top of ¾-in. tee, altitude 513.02 ft.

Date	Head (ft.)	Date	Head (ft.)	Date	Head (ft.)
Aug. 10, 1950	65.00	Aug. 31, 1950	65.31	Sept. 19, 1950	65.38
17	65.06	Sept. 7	65.33	27	65.27
24	65.14	14	65.30	Oct. 3	65.08

Measuring point, top of ¾-in. coupling, altitude, 512.90 ft.

Oct. 13, 1950	64.98	Nov. 14, 1950	65.11	Jan. 13, 1951	64.75
20	64.88	21	64.86	20	64.77
28	64.93	29	64.93	Feb. 6	64.77
Nov. 6	64.94	Dec. 4	64.84	27	64.50

T-7 (Kauai County Huleia test hole 1) 21°57′30″N, 159°25′50″W. Owner, Kauai County. Drilled, Apr. 1953 by Samson and Smock, Ltd. Altitude, 341 ft. Depth, 44 ft. Casing, none. Use, exploratory.

Log
(Driller's terms followed by core description by D. C. Cox.)

	Depth (ft.)	Length of core (ft.)
Medium hard rock. Sludge sample, soil and weathered rock	0- 6	0
Soft gray sandy mud rock. Sludge sample, weathered basalt	6- 17	0
Soft brown mud rock. Sludge sample, weathered basalt	17- 24	......
Cavity	24- 25	......
Medium hard gray rock, soft in places. Slightly vesicular olivine basalt	25- 31	1.1
Hard rock. Basalt as above	31- 39	3.3
Hard rock. Basalt as above but more compact	39- 41	0.9
Hard rock. Basalt as above but very compact; one large dunite inclusion	41- 43	1.9
Ash bed rock and brown clay. Weathered rock and yellowish brown clay	43- 44	0.4

T-8 (Kauai County Huleia test hole 2) 21°57′30″N, 159°25′50″W. Owner Kauai County. Drilled, Apr. 1953 by Samson and Smock, Ltd. Altitude, 423 ft. Depth, 101 ft. Casing, none. Use, exploratory.

Log
(Driller's terms followed by core description by D. C. Cox.)

	Depth (ft.)	Length of core (ft.)
Top soil	0- 11	0
Brown sandy mud rock. Sludge sample, weathered rock	11- 20	0
Small boulders with clay. Sludge sample, weathered rock	20- 24	0
Soft sandy mud rock. Sludge sample, weathered rock	24- 47	0
Hard rock. Fresh olivine basalt with numerous dunite inclusions, fairly compact	47- 57	5.2
Medium hard rock. Fresh basalt as above, 0.1 ft.; partly weathered, very compact basalt, numerous dunite inclusions, 0.9 ft.	57- 61	1.0
Soft rock. Basalt as above, partly weathered at top, becoming fresh with depth, fairly vesicular	61- 67	2.1
Soft rock, 6 ft.; medium hard rock, soft in places, 8 ft. Fresh basalt as above; small feldspar grains conspicuous in some zones	67- 81	2.8
Medium hard pukapuka rock. Basalt as above, fairly vesicular to fairly compact	81- 90	6.8
Soft red ash rock. Fairly vesicular, partly weathered basalt, 0.1 ft.; fairly compact, partly weathered basalt, 0.3 ft.; reddish, partly weathered basalt, 0.1 ft. Probably a weathered flow with a soil bed at the top. Possibly a weathered conglomerate with a soil bed at the top	90- 92	0.5
Medium hard pukapuka rock. Fairly compact, partly weathered basalt, 0.2 ft.; vesicular partly weathered basalt, dunite inclusion, 0.8 ft.; fairly compact, partly weathered basalt, dunite inclusion, 1.2 ft. Possibly a conglomerate, but probably a weathered lava flow	92-101	2.2

T-9 (Kauai County Huleia test hole 3) 21°57′30″N, 159°25′50″W. Owner, Kauai County. Drilled, Apr. 1953 by Samson and Smock, Ltd. Altitude, 421 ft. Depth, 98 ft. Casing, none. Use, exploratory.

Log
(Driller's terms followed by core description by D. C. Cox)

	Depth (ft.)	Length of core (ft.)
Clay or top soil. Sludge sample, soil	0- 8	0
Clay or sandy mud rock with small boulders. Sludge sample, weathered rock	8- 18	0
Soft mud rock. Sludge sample, weathered rock	18- 24	0
Soft sandy mud rock. Sludge sample, weathered rock	24- 48	0
Hard gray rock. Fresh olivine basalt, fairly compact	48- 61	7.8
Hard gray cracked rock, 4 ft.; soft dirt pocket, no sample, 2 ft.; hard rock, 3 ft. Compact olivine basalt	61- 70	1.5
Medium hard cracked rock, 6 ft.; soft rock, poor recovery, 3 ft. Compact olivine basalt, few dunite inclusions	70- 79	1.6
Cracked rock. Compact olivine basalt	79- 85	0.6
Hard cracked rock. Very compact olivine basalt with olivine inclusions	85- 90	4.7
Soft rock or ash bed. Weathered, vesicular olivine basalt	90- 91	0.4
Drive pipe sample. Weathered, vesicular olivine basalt, 0.3 ft.; yellowish brown soil, 1.0 ft.; highly weathered rock, 1.2 ft.	91- 94	2.5
Brown sandy clay with small rocks mixed. Highly weathered rock	94- 97	2.3
Soft gray sandy rock with small rocks mixed. Gray, highly weathered, olivine basalt	97- 98	1.0

T-10 (Lihue Plantation Co. test hole 1) 22°07′05″N, 159°20′45″W. Owner, Lihue Plantation Co. Drilled, 1953 by Samson and Smock, Ltd. Altitude, 352 ft. Depth, 414 ft. Diameter of hole, 2⅞ in. to 114 ft.; 1½ in. to 414 ft. Casing, ¾ in. to 413 ft., bottom 21 ft. perforated, cemented to 119 ft. Use, exploration and observation.

Log
(Driller's terms followed by core description by D. C. Cox.)

	Depth (ft.)	Length of core (ft.)
Brown soil and soft mud rock. Sludge sample, soil	0- 14	0
Soft brown clay. Sludge sample, highly weathered basalt	14- 25	0
Soft sandy soil or mud rock. Sludge sample, highly weathered basalt	25- 35	0
Soft sandy red clay. Sludge sample, highly weathered basalt	35- 64	0
Soft brown sandy clay. Sludge sample, highly weathered basalt	64- 79	0
Soft clay. Sludge sample, highly weathered basalt	79-111	0
Medium hard rock. Sludge sample, partly weathered amygdaloidal basalt	111-114	0
Soft pukapuka rock. Fairly vesicular, somewhat amygdaloidal basalt, pahoehoe	114-126	2.7
Medium hard pukapuka rock, soft in places. Fairly vesicular to very vesicular, somewhat amygdaloidal basalt and olivine basalt, pahoehoe	126-139	7.5
Hard rock. Moderately vesicular to fairly compact olivine basalt	139-143	4.5
Medium hard pukapuka rock. Fairly vesicular to very vesicular somewhat amygdaloidal basalt and olivine basalt	143-153	5.5
Medium hard pukapuka rock. Very vesicular olivine basalt, pahoehoe, with some vesicles filled with white clay-like material	153-165	9.9
Hard pukapuka rock, soft reddish rock and medium hard pukapuka rock. Very vesicular olivine basalt, pahoehoe, with some vesicles filled with white clay-like material	165-174	7.8
Medium hard pukapuka rock. Very vesicular olivine basalt, pahoehoe, with some vesicles filled with white clay-like material	174-184	5.5
Hard pukapuka rock, soft in places. Fairly vesicular olivine basalt	184-194	4.5
Medium hard pukapuka rock. Moderately vesicular olivine basalt and very vesicular olivine basalt with some vesicles filled with white clay-like material	194-205	9.7
Medum hard pukapuka rock, soft in places. Very vesicular olivine basalt with amygdaloidal patches as above	205-214	1.7
Medium hard pukapuka rock, soft in places. Moderately to very vesicular olivine basalt	214-223	1.7
Hard pukapuka rock, soft in places. Moderately vesicular olivine basalt, fine-grained, possibly aa. 3.9 ft.: very vesicular basalt, pahoehoe, 1.0 ft	223-231	4.9
Medium hard pukapuka rock. Very vesicular basalt, pahoehoe	231-237	3.7
Hard pukapuka rock. Very vesicular basalt	237-244	4.9
Hard pukapuka rock. Vesicular to very vesicular basalt, pahoehoe, 3.6 ft., grading to very vesicular olivine basalt, pahoehoe, 2.2 ft	244-250	5.8
Hard brown pukapuka rock, soft in places. Reddish, fine-grained, moderately vesicular olivine basalt, pahoehoe	250-254	1.6
Medium hard pukapuka rock, soft in places. Very vesicular olivine basalt	254-264	4.2
Hard pukapuka rock, soft in places. Very vesicular to moderately vesicular olivine basalt	264-274	6.2
Medium hard pukapuka rock, soft in places. Moderately vesicular picritic basalt	274-284	1.1
Soft pukapuka rock. Moderately to very vesicular olivine basalt	284-292	0.8
Medium hard pukapuka rock. Moderately vesicular olivine basalt	292-303	2.7
Soft pukapuka rock, no recovery	303-308	0
Medium hard pukapuka rock. Very vesicular olivine basalt, sparse small olivine grains	308-346	13.1
Medium hard pukapuka rock, soft in places. Very vesicular olivine basalt	346-353	2.5
Soft pukapuka rock. Moderately to very vesicular basalt and olivine basalt, pahoehoe	353-362	2.0
Medium hard pukapuka rock, soft in places. Moderately to very vesicular olivine basalt, 0.5 ft., and moderately vesicular olivine basalt with more olivine, coarse vesicles, 2.6 ft.	362-373	3.1
Soft reddish pukapuka rock. Somewhat reddish, very vesicular olivine basalt, 1.0 ft., and moderately vesicular olivine basalt with sparse olivine grains, 1.1 ft	373-383	2.1
Medium hard pukapuka rock, soft in places. Moderately vesicular olivine basalt with more olivine than above	383-414	3.7

Water levels during drilling

Date	Depth of hole (ft.)	Head (ft.)	Date	Depth of hole (ft.)	Head (ft.)	Date	Depth of hole (ft.)	Head (ft.)
Nov. 21, 1953	153	271.2	Nov. 26, 1953	231	169.6	Dec. 9, 1953	383	67.3
23	153	268.5	27	254	104.6	10	383	67.3
23	174	259.3	27	274	102.3	10	414	69.8
24	174	256.5	30	274	97.3	10	414	70.3
24	205	233.6	30	292	97.3	11	414	70.3
25	205	227.3	Dec. 1	292	67.3			
25	231	169.6	9	334	67.3			

Observations
(Data for May 3-Aug. 29, 1954 from pressure-type recording gage)

Date	Head (ft.)	Date	Head (ft.)	Date	Head (ft.)
Dec. 23, 1953	69.37	Feb. 24, 1954	67.03	June 7, 1954	65.4
28	69.26	Mar. 3	66.70	14	65.3
31	69.18	10	66.53	21	65.2
Jan. 4, 1954	69.96	20	66.27	28	65.1
9	68.93	26	66.18	July 2	65.0
11	68.90	Apr. 1	66.07	9	65.0
14	68.73	10	65.91	15	64.9
18	68.74	13	65.57	23	64.9
23	68.49	22	65.82	30	64.7
25	68.47	May 3	65.8	Aug. 2	64.7
28	68.41	10	65.8	9	64.7
Feb. 2	68.20	17	65.7	12	64.61
11	67.85	25	65.5	22	63.91
17	67.20	31	65.5		

T-11 (Lihue Plantation Co. test hole 2) *22°07′25″N, 159°19′10″W.* Owner, Lihue Plantation Co. Drilled, 1954 by Samson and Smock, Ltd. Altitude, 209 ft. Depth, 367 ft. Diameter of hole, 6 in. to 4 ft.; 2⅞ in. to 60 ft.; 1½ in. to 367 ft. Casing, 6 in. to 4 ft.; 2 in. to 67 ft.; ⅛ in. to 214.7 ft., with packers at 111 ft., 112 ft., and 113 ft. Use, exploration and observation.

Log
(Driller's terms followed by core description by D. C. Cox.)

	Depth (ft.)	Length of core (ft.)
Medium hard brown mud rock. Sludge sample, brown soil	0- 20	0
Soft mud rock. Sludge sample, red soil	20- 45	0
Soft mud rock. Sludge sample, highly weathered, probably amygdaloidal basalt	45- 60	0
Boulders. Fairly compact fresh olivine basalt with plentiful 1 mm. olivine grains mostly altered to iddingsite (?)	60- 72	0.5
Medium hard rock. Olivine basalt as above	72- 92	14.1
Soft rock. Highly weathered, fairly vesicular, olivine basalt, pahoehoe	92-102	3.2
Soft rock. Highly weathered vesicular olivine basalt, as above, becoming less vesicular and less weathered in depth	102-108	1.7
Hard rock. Fairly compact olivine basalt, probably aa, olivine fairly plentiful and altered	108-113	3.2
Hard rock. Very compact olivine basalt, probably aa; some fresh dark olivine; some 1 cm. feldspathic segregations	113-123	8.0
Hard rock. Olivine basalt as above, compact, jointed	123-135	2.1
Soft rock. Compact, fresh olivine basalt as above, 0.2 ft.; very highly weathered, red, olivine basalt, 1.0 ft.; moderately vesicular olivine basalt, weathered in places, with olivine grains up to 5 mm., possibly aa, 3.0 ft.	135-143	4.2
Medium hard rock, soft in places. Moderately vesicular olivine basalt as above, nearly picritic in part, weathered in places	143-153	4.2
Hard rock. Fairly compact to moderately vesicular olivine basalt as above but with less olivine	153-159	3.9
Hard rock. Moderately compact olivine basalt, possibly aa	159-164	6.1
Soft rock. Compact red soil with some residual pebbles of highly weathered olivine basalt	164-170	2.5
Soft gray rock. Compact olivine basalt, probably aa, weathered throughout	170-180	6.1
Medium hard rock. Fairly compact olivine basalt	180-186	2.5
Soft pukapuka rock. Compact olivine basalt, 0.5 ft.; very vesicular olivine basalt, olivine content very high, picritic in places; probably pahoehoe, 1.9 ft.	186-189	2.4
Medium hard rock. Moderately vesicular to fairly compact olivine basalt with less olivine than above, pahoehoe	189-196	4.0
Medium hard pukapuka rock. Olivine basalt as above	196-202	3.7
Hard rock. Fairly compact olivine basalt	202-216	7.3
Medium hard rock. Fairly vesicular olivine basalt, possibly aa	216-220	0.3
Hard cracked rock. Fairly compact to moderately vesicular olivine basalt, possibly aa	220-236	9.7
Soft brown pukapuka rock. Very vesicular olivine basalt; olivine very common in small grains	236-241	1.9
Medium hard rock. Fairly compact olivine basalt, olivine plentiful in small grains	241-249	3.8
Soft brown pukapuka rock. Weathered vesicular olivine basalt with less olivine than above	249-254	2.2
Medium hard brown rock and hard rock. Fairly compact olivine basalt, weathered in places	254-277	19.8
Hard rock. Very compact and fairly massive olivine basalt, except bottom 0.1 ft. which is fairly vesicular	277-288	7.7

Log—Well T-11 (Continued)

	Depth (ft.)	Length of core (ft.)
Medium hard pukapuka rock, cavity at 298 ft. Fairly vesicular olivine basalt, 3.2 ft.; compact olivine basalt, 1.3 ft.	288-298	4.5
Medium hard cracked rock, soft in places. Fairly compact olivine basalt	298-311	0.9
Cavities in places. Olivine basalt as above	311-317	0.3
Medium hard pukapuka rock, soft in places. Fairly fresh vesicular to compact basalt, 1.0 ft., grading to weathered basalt, 1.3 ft.	317-326	2.3
Medium hard rock. Fairly compact basalt with very large vesicles	326-332	5.7
Cavity	332-333	0
Medium hard rock, soft in places. Fairly compact basalt	333-337	1.2
Medium hard rock. Fairly compact basalt grading to olivine basalt	337-347	6.0
Soft brown pukapuka rock. Weathered, moderately vesicular olivine basalt	347-354	0.4
Medium hard pukapuka rock. Fairly compact olivine basalt with pale olivines	354-357	0.5
Medium hard pukapuka rock, soft in places. Moderately vesicular olivine basalt	357-367	3.4

Water-level measurements during drilling

Depth (ft.)	Effective casing (ft.)	Head (ft.)	Depth (ft.)	Effective casing (ft.)	Head (ft.)	Depth (ft.)	Effective casing (ft.)	Head (ft.)
82	0	209.7+	266	0	214.45	357	0	181.0
113	0	209.7+	277	277	209.7—	367	367	51.2
143	0	209.7+	277	0	214.11	367	318	37.7
159	0	209.7+	288	288	145.3	367	268	57.9
180	0	214.5	288	0	208.1	367	218	75.5
196	0	215.2	298	298	43.7	367	198	79.2
206	0	215.4	298	0	200.1	367	178	81.3
216	0	215.7	317	317	97.7	367	158	81.5
230	0	214.7	317	0	199.2	367	138	107.7
241	236	214.2	337	141	69.1	367	118	102 —
241	0	214.9	337	0	191.5	367	128	92 —
254	254	216.1	337	337	66.2	367	138	113.2
254	0	215.85	354	354	47.3	367	88	183.5
266	266	209.7—	354	0	191.5	367	108	183.7
266	110	209.7	357	357	36.4	367	118	109.2

Date	Head, ft.	Date	Head, ft.
Mar. 5, 1954	23.18	Apr. 1, 1954	22.21

T-12 (Lihue Plantation Co. test hole 3) 22°07′35″N, 159°19′35″W. Owner, Lihue Plantation Co. Drilled, 1954 by Samson and Smock, Ltd. Altitude, 316 ft. Depth, 642 ft. Diameter of hole, 2⅞ in. to 117 ft.; 1½ in. to 525 ft. Casing, 2 in. to 116 ft.; ¾ in. to 470 ft., with bottom 20 ft. perforated and with improvised rubber packers outside of pipe at 258 ft., 298 ft., and 449 ft. Hole cemented and redrilled, 116 ft. to 137 ft., 440 ft. to 455 ft., and 490 ft. to 511 ft. Use, exploration and observation.

Log
(Driller's terms followed by core description by D. C. Cox.)

	Depth (ft.)	Length of core (ft.)
Brown soil. Sludge sample, brown soil	0- 6	0
Red soil. Sludge sample, red soil	6- 13	0
Soft mud rock. Sludge sample, weathered basalt	13- 21	0
Boulders. Probably residual boulders	21- 25	0
Soft mud rock	25- 33	0
Boulders. Probably residual boulders	33- 34	0
Soft brown clay and soft mud rock. Sludge sample, weathered basalt	34- 75	0
Red soil. Sludge sample, weathered basalt	75- 94	0
Soft mud rock. Weathered basalt	94-112	0
Medium hard rock. Vesicular olivine basalt, partly weathered	112-117	0.2
Ran 2-in. casing to 116 ft.	......	......
Medium hard rock. Fairly compact olivine basalt, partly weathered, plentiful 1 mm. olivine grains altered to orange and red color, few large vesicles	117-140	5.7
Medium hard cracked rock. Fairly compact olivine basalt as above, partly weathered in places	140-151	3.5

Log—Well T-12 (Continued)

	Depth (ft.)	Length of core (ft.)
Hard rock. Fresh, fairly compact olivine basalt, very pale olivine	151-156	2.9
Soft	156-169	0
Medium hard cracked rock, soft in places. Moderately vesicular to fairly compact olivine basalt, slightly weathered, fairly plentiful 1 mm. and occasional 5 mm. olivine grains, altered to orange color	169-183	5.7
Hard cracked rock, soft in places. Fairly compact olivine basalt, slightly weathered; in top 0.5 ft. olivine altered to orange color, pale olivine in remainder	183-192	3.4
Hard rock. Fairly compact, fresh, olivine basalt with small, pale olivine grains	192-197	2.0
Small cavity	197-200	0
Soft rock. Highly weathered, red, vesicular olivine basalt, 0.1 ft.; partly weathered, vesicular olivine basalt, 0.3 ft.; nearly fresh, vesicular olivine basalt, 1.1 ft	200-210	1.4
Medium hard brown rock. Fairly compact to compact olivine basalt, weathered in upper part	210-223	4.1
Medium hard cracked rock. Fairly compact, massive olivine basalt, probably aa	223-230	2.1
Soft pukapuka rock, brown. Weathered vesicular olivine to picrite basalt, pahoehoe	230-239	1.9
Medium hard rock, soft in places. Fairly vesicular to vesicular olivine to picrite basalt, pahoehoe, partly weathered in places	239-247	6.4
Medium hard cracked rock, soft in places. Vesicular, olivine to picrite basalt, partly weathered, 0.7 ft., and fairly compact olivine basalt nearly fresh with less olivine, 3.0 ft.	247-253	3.7
Medium hard cracked pukapuka rock. Olivine basalt as above; fairly compact, 2.4 ft.; vesicular to very vesicular, 1.8 ft.; fairly compact with large vesicles, 2.3 ft	253-260	6.5
Medium hard cracked rock, soft in places. Fairly compact olivine basalt	260-263	0.5
Cavity, rough drilling	263-264	0
Medium hard cracked rock, soft in places. Vesicular to fairly compact olivine basalt	264-270	0.8
Medium hard rock	270-271	0
Soft pukapuka rock. Vesicular olivine basalt	271-281	0.5
Medium hard rock, soft in places. Moderately vesicular to compact olivine basalt	281-291	2.7
Medium hard pukapuka rock, soft in places. Moderately to fairly vesicular, partly weathered olivine basalt, 2.8 ft.; fairly compact to moderately vesicular, nearly fresh olivine basalt, 2.5 ft	291-300	5.3
Medium hard rock, soft in places. Fairly compact olivine basalt, 1.5 ft.; vesicular olivine basalt, partly weathered, 0.1 ft	300-310	1.6
Medium hard pukapuka rock, soft in places. Vesicular, partly weathered olivine basalt	310-314	1.1
Soft brown rock. Fairly vesicular to compact olivine basalt, partly weathered to very thoroughly weathered, some sections completely weathered to soil, 3.9 ft.; fairly fresh, 0.2 ft	314-325	4.1
Medium hard rock. Moderately vesicular olivine basalt, 1.0 ft.; fairly compact olivine basalt with large vesicles, 1.0 ft	325-330	2.0
Medium hard rock, soft in places. Moderately vesicular olivine basalt with conspicuous small feldspars	330-340	1.1
Medium hard rock, soft in places. Fairly vesicular olivine basalt	340-352	1.9
Medium hard rock, soft in places. Moderately vesicular olivine basalt	352-360	2.0
Medium hard rock, soft in places. Fairly compact olivine basalt	360-372	4.6
Medium hard pukapuka rock. Many cavities in places. Fairly compact to fairly vesicular olivine basalt with large vesicles	372-385	1.7
Cavity	385-387	0
Moderately vesicular olivine basalt, 0.7 ft.; compact olivine basalt, 2.2 ft.; moderately vesicular olivine basalt, 1.0 ft	387-395	3.9
Medium hard brown rock, soft in places. Fairly compact olivine basalt, bottom 1.3 ft. thoroughly weathered	395-405	1.4
Medium hard brown rock, soft in places. Moderately to fairly vesicular olivine basalt with large vesicles, slightly weathered	405-412	2.5
Medium hard pukapuka rock, soft in places. Moderately compact olivine basalt with conspicuous small feldspars at base, slightly weathered, 2.3 ft.; fairly compact, fresh olivine basalt with small pale olivine grains, 0.8 ft	412-420	3.1
Cracked pukapuka rock. Vesicular olivine basalt with small pale olivine grains, some sections partly weathered	420-425	0.6
Soft rock. Partly altered, amygdaloidal olivine basalt, 0.3 ft.; compact olivine basalt, 0.1 ft.	425-429	0.4
Hard to medium hard cracked rock. Moderately vesicular to compact olivine basalt with small, pale olivine grains	429-444	3.0
Medium hard cracked rock. Vesicular to fairly compact olivine basalt	444-454	2.0
No record	454-455	0
Medium hard cracked rock. Fairly compact to moderately vesicular olivine basalt, jointed, 1.5 ft.; very vesicular olivine basalt with pale olivine grains, 0.8 ft	455-469	2.3
Medium hard cracked rock, soft in places. Very vesicular olivine basalt, 0.4 ft.; fairly compact olivine basalt with small pale olivine grains in almost glassy groundmass	469-473	2.3
Hard cracked rock. Fairly compact olivine basalt as above but with some olivine or dunite segregations	473-489	3.1
Hard cracked rock. Compact olivine basalt as above, massive at top, jointed at bottom	489-495	3.1
Very soft drilling	495-500	0
Hard cracked rock. Olivine basalt as above, very compact except for some large vesicles	500-511	3.1
Hard rock and hard cracked rock, soft in places. Fairly compact olivine basalt with aphanitic groundmass and small pale olivine grains and occasional large olivines	511-519	1.7
Hard cracked rock, soft in places, and yellow clay. Fairly compact olivine basalt as above, 0.5 ft.; light brown waxy clay with calcareous sand grains, 0.1 ft	519-525	0.6
Soft yellow clay	525-535	0

Log—Well T-12 (Continued)

	Depth (ft.)	Length of core (ft.)
Soft yellow sandstone or clay. Coarse-grained calcareous beach rock, soft with occasional large concretionary fragments	535-540	2.5
Soft yellow sandstone. Calcareous beach rock, soft, 0.2 ft.; beach rock with 1 to 2 mm. soft concretionary fragments, 0.4 ft.; brown waxy clay with calcareous sand and concretions, 0.1 ft.; brown waxy clay, 0.1 ft	540-546	0.8
Soft sandstone or coral. Calcareous beach rock, harder than above, with embedded coral fragments, or reef rock with enclosed cemented sand	546-561	1.4
Soft sandstone or coral. Calcareous beach rock or reef rock, soft, with few fragments or fresh aphanitic basalt, 0.4 ft.; highly altered amygdaloidal basalt, 0.2 ft	561-568	0.6
Medium hard rock. Fairly compact aphanitic basalt	568-571	0.4
Medium hard pukapuka rock. Moderately vesicular olivine basalt, with small pale olivine grains in aphanitic groundmass	571-580	8.0
Soft rock. Fairly compact holocrystalline olivine basalt with conspicuous fine feldspars, partly weathered in places	580-620	8.0
Medium hard pukapuka rock. Olivine basalt as above, fairly compact, 0.2 ft.; vesicular and slightly weathered, 1.3 ft.; moderately vesicular, 0.2 ft.; vesicular, 1.5 ft.; moderately vesicular, 0.8 ft.; vesicular, 1.0 ft	620-635	5.0
Medium hard rock. Moderately vesicular basalt	635-642	3.6
Measured water levels and ran ¾-in. casing to 470 ft	......-......	......

Water-level measurements during drilling

Depth (ft.)	Effective casing (ft.)	Head (ft.)	Depth (ft.)	Effective casing (ft.)	Head (ft.)	Depth (ft.)	Effective casing (ft.)	Head (ft.)
210	116	203.6	473	116	182.7	577	570	15.1
247	116	216.6	475	470	16.1	590	590	14.7
270	116	203.5	489	480	10.4	600	600	15.6
300	116	213.2	489	116	180.2	610	610	15.1
310	116	215.4	500	500	14.1	620	620	15.2
330	116	216.1	500	116	180.7	620	116	214.2
360	116	209.5	507	500	13.2	635	630	17.2
360	360	193.2	507	116	180.7	635	116	183.2
395	390	193.1	511	510	13.1	642	640	17.2
395	116	215.5	511	116	180.4	642	610	17.2
420	116	216.6	525	520	13.4	642	560	13.7
431	430	121.5	525	116	179.2	642	500	14.8
444	440	82.4	540	540	13.2	642	550	14.8
444	116	199.4	540	116	179.5	642	490	14.7
451	450	79.4	546	540	13.5	642	330	32.2
451	116	199.3	546	116	179.5	642	250	146.9
454	450	75.7	561	560	12.4	642	220	146.2
454	116	198.8	561	116	172.8	642	210	148.2
469	460	13.6	571	570	12.2	642	190	145.4
469	116	185.2	571	116	172.5	642	170	179.2
473	470	13.2	573	570	12.4	642	160	179.0

Observations

(Basal water levels measured in ¾-in. casing; measuring point, top of ¾-in. casing, altitude, 317.29 ft. High-level water levels measured in 2-in. casing; measuring point top of 2-in. casing, altitude, 317.15 ft.)

Date	Head (ft.) High-level water	Head (ft.) Basal water	Date	Head (ft.) High-level water	Head (ft.) Basal water
Mar. 3, 1954	206.57	11.56	Apr. 28, 1954	208.95	11.31
4	206.82	11.46	May 12	208.65	11.39
5	206.32	10.48	June 19	209.96	11.21
8	206.98	11.31	26	210.21	10.29
19	207.73	11.23	July 2	210.19	10.39
26	207.73	11.06	10	209.99	10.39
Apr. 4	207.72	11.01	17	211.49	11.29
9	208.15	11.01	23	211.19	11.04
13	208.32	10.92	Sept. 23	211.24	11.09

T-13 (Lihue Plantation Co. test hole 4) 22°07′15″N, 159°20′25″W. Owner, Lihue Plantation Co. Drilled, March 29 to April 19, 1954, by Samson and Smock, Ltd. Altitude, 262 ft. Depth, 580 ft., backfilled to 576. Diameter of hole, 3⅛ in. to 8 ft.; 1⅞ in. to 156 ft.; 1½ in. to 580 ft. Casing, ⅜ in. to 160 ft. connected to ¼ in., 160 to 270 ft., perforated 249 ft. to 270 ft.; ⅜ in. to 270 ft. connected to ¾ in., 270 to 576 ft., perforated 555 ft. to 576 ft. Two parallel casings to 270 ft. Liner 80 ft. to 160 ft.

Log
(Driller's terms followed by core description by D. C. Cox.)

	Depth (ft.)	Length of core (ft.)
Clay and boulders	0- 8	0
Boulders. Compact fairly massive, fine-grained basalt	8- 27	15.3
Soft pukapuka rock or boulders. Vesicular, medium-grained basalt, 1.2 ft.; vesicular picritic basalt, 0.3 ft.; very weathered basalt, probably boulders, 0.1 ft	27- 38	1.6
Soft gray clay. Gray clay	38- 50	0.5
Soft mud rock. Muddy conglomerate or talus with variety of cobbles to 0.3 ft. diameter	50- 58	6.7
Soft pukapuka rock. Partly weathered, vesicular olivine basalt	58- 67	2.3
Soft rock. Slightly weathered clinker with red clay in interstices near bottom	67- 76	1.7
Soft rock. Partly weathered clinker with red and brown clay in interstices, 1.8 ft.; fairly compact aa basalt, veins of brown clay, 2.0 ft.; clinker with brown clay in interstices, partly weathered, 1.0 ft	76- 86	4.8
Soft rock. Muddy conglomerate, 0.1 ft.; vesicular basalt boulder, 1.0 ft.; muddy conglomerate, 0.4 ft	86- 96	1.5
Soft rock. Vesicular picritic basalt boulder, 1.2 ft.; variety of boulders in a muddy matrix, 3.3 ft	96-112	4.5
Medium hard rock, soft in places. Variety of cobbles, 0.6 ft.; vesicular basalt, possibly a boulder, 0.6 ft.; basalt, once very vesicular, now filled with soft white, amorphous, amygdaloidal mineral, 1.4 ft	112-119	2.6
Medium hard pukapuka rock. Very vesicular pahoehoe basalt, amygdaloidal in places, becoming less vesicular with larger vesicles and with large olivine phenocrysts at bottom	119-130	3.5
Medium hard pukapuka rock. Fairly compact to moderately vesicular pahoehoe basalt with amygdaloidal patches and soft, white, amygdaloidal masses in large openings and joints	130-139	8.4
Soft pukapuka rock. Vesicular, pahoehoe basalt, extremely vesicular and red in part, amygdaloidal in places	139-146	5.8
Soft pukapuka rock. Very vesicular basalt, amygdaloidal in places	146-180	16.0
Hard pukapuka rock, soft in places. Very vesicular basalt as above, 3.1 ft.; moderately vesicular basalt grading to olivine basalt, possibly aa, 4.2 ft	180-189	7.3
Medium hard pukapuka rock. Very vesicular pahoehoe basalt, slightly amygdaloidal	189-212	16.2
Soft yellow rock. Vesicular pahoehoe basalt with waxy, yellowish-brown, amygdaloidal material	212-213	1.2
Medium hard to soft pukapuka rock. Moderately to very vesicular pahoehoe basalt, partly amygdaloidal	213-238	14.0
Medium hard rock. Fairly compact to fairly vesicular basalt, partly amygdaloidal	238-255	9.5
The amygdaloidal filling between 213 ft. and 255 ft. is mostly in large openings, small vesicles being empty. Some larger openings show two stages of filling, an outer layer of waxy yellowish-brown amorphous material, as at 212-213 ft., and an inner filling of gray, clay-like, amorphous material. The yellowish, waxy material forms the filling in smaller openings that are filled, but a white clay-like material is found in some.		
Hard rock. Fairly compact to compact aa basalt becoming moderately vesicular at bottom	255-265	10.0
Soft red rock. Fairly compact, reddish, olivine basalt, probably aa, with olivine phenocrysts. Amygdaloidal, with white clay-like mineral	265-270	2.2
Soft red rock. Reddish, amygdaloidal, aa, olivine basalt, 2.6 ft.; fine-grained, brown, olivine-bearing ash, 0.1 ft.; vesicular, amygdaloidal, pahoehoe basalt, 0.5 ft.; ash parting, 0.02 ft.; vesicular pahoehoe basalt, 0.2 ft	270-273	3.4
Soft pukapuka rock. Moderately to very vesicular pahoehoe basalt, partly amygdaloidal	273-281	7.2
Medium hard rock. Moderately vesicular to fairly compact, aa, olivine basalt with sparse small olivine grains at top increasing in size and number downward, partly amygdaloidal	281-295	12.5
Medium hard rock, soft in places. Fairly compact to clinkery olivine basalt, aa, 2.0 ft.; moderately vesicular, massive olivine basalt, pahoehoe, with plentiful coarse olivine, 2.4 ft.	295-300	2.4
Medium hard pukapuka rock, soft in places. Olivine basalt, pahoehoe, as above but less massive	300-313	8.0
Soft pukapuka rock. Moderately to very vesicular basalt, pahoehoe, with amygdaloidal patches	313-332	10.1
Soft red rock. Red flow top of olivine basalt, 0.2 ft.; vesicular olivine basalt, pahoehoe, 0.8 ft.; vesicular basalt, pahoehoe, 0.4 ft	333-336	1.4
Soft red pukapuka rock. Vesicular to compact basalt	336-349	0.7
Soft pukapuka rock. Very vesicular to compact basalt, pahoehoe, amygdaloidal in places	349-410	21.4
Soft pukapuka rock. Vesicular basalt, pahoehoe, amygdaloidal in places, 3.5 ft.; reddish, compact, olivine basalt, pahoehoe, vesicular in places, picritic at base, 1.7 ft.; vesicular basalt, pahoehoe, 0.1 ft	410-420	5.3
Soft pukapuka rock. Very vesicular basalt, pahoehoe, amygdaloidal in places	420-430	1.3
Soft red pukapuka rock. Red, vesicular olivine basalt, pahoehoe, amygdaloidal	430-436	4.1
Medium hard to soft pukapuka rock. Moderately to very vesicular olivine basalt, pahoehoe	436-556	40.7
Medium hard cracked pukapuka rock, soft in places. Moderately compact basalt, pahoehoe, 1.8 ft.; very vesicular basalt, pahoehoe, 0.1 ft	556-567	1.9
Soft pukapuka rock. Very vesicular basalt, pahoehoe, 2.3 ft.; moderately vesicular basalt, pahoehoe, 1.0 ft	567-580	3.3

Water-level measurements during drilling

Depth (ft.)	Effective casing (ft.)	Head (ft.)	Depth (ft.)	Effective casing (ft.)	Head (ft.)	Depth (ft.)	Effective casing (ft.)	Head (ft.)
180	180	119.4	480	160	125.6	580	490	71.4
228	228	141.0	480	220	71.6	580	470	71.5
250	160	162.4	480	260	67.4	580	450	71.2
270	160	162.4	480	300	70.3	580	430	71.7
290	160	162.4	480	340	65.7	580	410	69.0
290	290	162.4	480	400	65.0	580	390	70.9
315	315	162.4	480	479	80.4	580	370	64.3
360	360	162.4	526	520	68.8	580	350	71.5
390	160	158.6	526	160	119.6	580	330	71.5
410	160	158.3	556	520	65.8	580	310	71.4
410	410	131.4	556	550	65.4	580	290	70.2
436	160	152.4	580	160	121.2	580	270	68.1
470	470	83.6	580	560	64.6	580	250	66.7

Observations

(High-level water levels measured through ⅜-in. pipe connected at bottom end to ¼-in. pipe which extends to 270 ft. Basal water levels measured through ⅜-in. pipe connected at bottom end to ¾-in. pipe which extends to 576 ft. Measuring point, top of ⅜-in. coupling, altitude, 263.10 ft.)

Date	Head (ft.) High-level water	Head (ft.) Basal water	Date	Head (ft.) High-level water	Head (ft.) Basal water
June 17, 1954	138.10	66.35	17	138.44	66.14
26	138.77	66.27	23	138.80	66.09
July 2	138.60	66.23	Aug. 24	138.10	65.90
10	138.46	66.19			

T-14 (Lihue Plantation Co. test hole 6). Papaa. 22°09′55″N, 159°19′50″W. Owner, Lihue Plantation Co. Drilled, June 29 to Aug. 2, 1954 by Samson and Smock, Ltd. Altitude, 281 ft. Depth, 496 ft. Diameter of hole, 3½ in. to 31 ft.; 1⅞ in. to 496 ft. Casing, 2 in. to 31 ft.; ¾ in. to 280 ft., bottom 20 ft. perforated. Use, exploration and observation.

Log

(Driller's terms followed by core description by D. C. Cox.)

	Depth (ft.)	Length of core (ft.)
Brown clay	0- 20	0
Boulders	20- 31	0
Pukapuka rock. Holocrystalline basalt with small olivine grains, pahoehoe, very vesicular, partly amygdaloidal, 2.5 ft., grading to massive and moderately vesicular with fine vesicles, 1.0 ft.; very vesicular, partly amygdaloidal, 1.0 ft.	31- 40	8.7
Pukapuka rock. Basalt, pahoehoe, as above; vesicular, amygdaloidal in places, 4.0 ft.; moderately vesicular to fairly compact, massive, 3.5 ft.	40- 50	7.5
Pukapuka rock. Basalt, pahoehoe, as above, mostly massive, compact to moderately vesicular, amygdaloidal in patches	50- 60	7.2
Soft red pukapuka rock. Basalt, pahoehoe, as above, massive, moderately vesicular, slightly reddish at top	60- 70	9.1
Soft pukapuka rock. Basalt, pahoehoe, as above, moderately vesicular to very compact, very massive, fine vesicles in places, large vesicles at bottom	70- 85	15
Medium hard rock and pukapuka rock. Basalt, pahoehoe, as above, mostly massive, moderately vesicular to fairly compact, amygdaloidal in few places	85-187	90.3
Pukapuka rock. Basalt, pahoehoe, as above, massive and fairly compact to moderately vesicular, 6.5 ft.; picrite basalt, pahoehoe, moderately vesicular with flow contact at top, 3.3 ft.	187-200	9.8
Pukapuka, olivine rock. Picrite basalt, pahoehoe, massive, mostly moderately compact, moderately and irregularly vesicular at bottom; flow contact at bottom	200-248	47.3
Pukapuka rock and medium hard to hard pukapuka rock. Basalt, pahoehoe, moderately vesicular to compact	248-290	30.0
Hard rock. Basalt, pahoehoe, very compact and massive	290-318	17.7
Soft pukapuka olivine rock. Olivine and picrite basalt, moderately vesicular to compact, generally massive	318-370	45.4
Soft rock. Olivine basalt, pahoehoe, irregularly and moderately vesicular to compact, 0.9 ft.; red, olivine-bearing tuff, 0.2 ft.; olivine basalt, moderately vesicular, 0.3 ft.	370-380	1.4
Soft pukapuka rock. Olivine basalt, pahoehoe, moderately vesicular to fairly compact, massive in places	380-400	14.7
Soft pukapuka olivine rock. Basalt, pahoehoe with small amount of olivine, 1.9 ft., grading to picrite basalt, massive and fairly compact, 6.2 ft., grading to olivine basalt, massive and compact, 1.9 ft.	400-410	10

Log—Well T-14 (Continued)

	Depth (ft.)	Length of core (ft.)
Soft pukapuka olivine rock. Olivine basalt, fairly compact, 0.1 ft., grading to picrite basalt, pahoehoe, fairly compact, 4.8 ft.; basalt, pahoehoe, moderately vesicular to fairly compact, 3.9 ft.	410-420	8.7
Soft pukapuka olivine rock, soft in places. Basalt, pahoehoe, moderately to very vesicular, 3.1 ft.; picrite basalt, compact to moderately vesicular, 0.8 ft.; basalt, pahoehoe, fairly vesicular to fairly compact, some small olivine grains, 3.1 ft.	420-430	7.0
Soft pukapuka olivine rock. Basalt, pahoehoe, moderately vesicular, 1.0 ft.; olivine basalt, pahoehoe, moderately vesicular to fairly compact and massive, 4.9 ft.; basalt, pahoehoe, moderately vesicular, 0.3 ft.	430-440	6.2
Soft pukapuka olivine rock. Basalt, pahoehoe, moderately vesicular, 2.6 ft.; olivine basalt, pahoehoe, moderately vesicular, 0.3 ft.; basalt, pahoehoe, moderately vesicular to very compact and massive, 5.1 ft., grading to picrite basalt, very compact and massive, 2.0 ft.	440-450	10.0
Soft pukapuka olivine rock. Picrite basalt, massive and compact	450-460	9.9
Soft pukapuka rock. Olivine basalt, pahoehoe, compact to moderately vesicular	460-480	4.4
Soft pukapuka rock. Olivine basalt, fairly compact, 1.2 ft.; basalt, pahoehoe, vesicular to fairly compact, 1.5 ft.	480-490	2.7
Soft pukapuka rock. Basalt, moderately vesicular to fairly compact, compact and massive	490-496	2.5

Water-level measurements during drilling

Depth (ft.)	Effective casing (ft.)	Head (ft.)	Depth (ft.)	Effective casing (ft.)	Head (ft.)	Depth (ft.)	Effective casing (ft.)	Head (ft.)
50	31	252.2	300	300	49.7	410	410	50.0
90	31	241.2	300	31	49.7	440	31	50.0
90	50	229.2	305	31	49.7	440	440	50.0
140	31	201.2	305	300	49.7	470	470	50.0
140	140	146.2	340	340	49.7	471	31	50.0
240	240	84.7	340	31	49.7	496	490	50.1
265	31	89.2	380	380	49.8	496	31	51.0
265	260	84.7	380	0	50.2	496	250	51.0
290	290	51.2	410	31	50.0			
290	31	55.0	410	410	49.8			

Observations

Date	Head (ft.)	Date	Head (ft.)
Aug. 13, 1954	51.4	Aug. 27, 1954	51.0
17	51.4	Sept. 12	51.0
20	51.4	Oct. 12	51.0
23	51.4		

T-15 (Lihue Plantation Co. test hole 5) Moloaa camp. 22°10′30″N, 159°20′20″W. Owner, Lihue Plantation Co. Drilled, April 16 to June 15, 1954 by Samson and Smock, Ltd. Altitude, 280 ft. Depth, 620 ft. Diameter of hole, 3 in. to 105 ft.; 2½ in. to 200 ft.; 1⅞ in. to 281 ft.; 1½ in. to 620 ft. Casing, 2½ in. to 155.7 ft.; ¾ in. to 615 ft., bottom 21 ft. perforated. Cemented and redrilled, 395 ft. to 497 ft.

Log
(Driller's terms followed by core description by D. C. Cox.)

	Depth (ft.)	Length of core (ft.)
Clay and small boulders. Soil and weathered rock	0- 8	0
Boulders	8- 11	0
Soft clay or mud rock. Cuttings of brown weathered rock and soil	11- 50	0
Soft clay or mud rock	50- 62	0
Boulders or hard rock. Cuttings of brown weathered rock and soil	62- 67	0
Boulders, soft in places. Very fine-grained, compact, massive basalt, probably flow rock, 5.2 ft.; basalt and olivine basalt boulders, 1.4 ft.	67- 80	6.6
Boulders, soft in places. Boulders, cobbles and pebbles of basalt, olivine basalt, and picrite basalt	80-100	10.8
Boulders, soft in places. Miscellaneous small boulders and cobbles; last 0.1 ft., muddy conglomerate	100-110	2.2
Brown clay, soft. Probably muddy conglomerate, weathered rock and soil	110-145	0
Soft rock. Olivine basalt, vesicular to fairly compact	145-178	15.6
Soft pukapuka rock. Olivine basalt, very vesicular with large vesicles	178-189	0.6
Medium hard to soft pukapuka rock. Olivine basalt, moderately to very vesicular	189-216	10.0

Log—Well T-15 (Continued)

	Depth (ft.)	Length of core (ft.)
Hard rock. Olivine basalt, compact, jointed in places	216-272	15.5
Medium hard pukapuka rock. Olivine basalt, very vesicular	272-280	3.2
Medium hard pukapuka rock. Olivine basalt, pahoehoe, moderately vesicular; plentiful small olivine grains and some small augite (?) grains in a holocrystalline matrix with conspicuous feldspar	280-290	1.7
Soft pukapuka rock. Olivine basalt, pahoehoe, moderately to very vesicular, reddish alteration in places	290-320	13.4
Medium hard rock. Olivine basalt, pahoehoe, gray, moderately vesicular, 0.7 ft.; gabbro, fairly compact, mostly augite or hornblende and feldspar, 0.2 ft.; olivine basalt, pahoehoe, moderately vesicular, 0.8 ft.	320-330	1.7
Medium hard rock. Olivine basalt, moderately vesicular to compact	330-340	2.5
Medium hard rock. Olivine basalt, compact, olivine fresh and light colored, holocrystalline matrix, 3.0 ft., grading to fairly compact with very fine matrix	340-350	4.3
Hard rock. Olivine basalt, fairly compact, vesicular in places, massive, pahoehoe, with fine matrix	350-380	9.0
Hard rock. Olivine basalt, as above, probably clinker, 0.9 ft.; fairly compact, 0.7 ft.	380-390	1.6
Hard rock. Olivine basalt, clinkery in places, generally compact, vesicular in places	390-428	11.6
Hard rock. Olivine basalt, very dense and massive, jointed and possibly clinkery at bottom	428-441	8.9
Sandstone with mudrock and hard rock. Tuff, consisting of cinder, ash and pumice fragments mixed with calcareous sand becoming very compact and firmly consolidated, and with less sand at bottom, crude bedding at angle of 75° to 90° with core, 1.0 ft.; cobble of olivine basalt coated with algal limestone at contact with tuff above, 0.4 ft.; olivine basalt pebble coated with algal limestone at contact with tuff below, 0.1 ft.; sandy tuff with very fine brown mudstone layers, bedding at angle of 60° with core, 0.1 ft.; agglomerate of basalt cobbles in fine cinders, 0.3 ft.; conglomerate of basalt pebbles in weakly consolidated yellow beach rock becoming gray in lower part, 3.7 ft.; boulder of picrite basalt, 0.3 ft.; conglomerate of basalt pebbles in yellow beach rock, 1.4 ft.	441-450	7.3
Mud rock and soft rock. Conglomerate of basalt cobbles and boulders in brown to white sandy or tuff matrix	450-480	15.7
Mud rock and soft pukapuka rock. Conglomerate of basalt pebbles, cobbles, and boulders in compact muddy matrix	480-520	22.6
Pukapuka olivine rock mix with soft rock. Boulders of olivine and picrite basalt, probably a coarse talus	520-546	11.7
Pukapuka olivine rock mix with soft rock. Picrite basalt boulder, 2 ft.; red clinkery basalt with white clay and patches of fine altered material which may be clinker but appears to be sedimentary, 0.6 ft.; basalt and olivine basalt with patches of white and gray waxy clay and occasional basaltic pebbles and conglomerates, 7.0 ft.	546-557	9.6
Pukapuka rock. Basalt, pahoehoe, with small olivine grains, generally vesicular, amygdaloidal near bottom	557-567	5.5
Pukapuka rock. Olivine basalt, pahoehoe, vesicular with large vesicles	567-576	1.6
Pukapuka rock. Olivine basalt, pahoehoe, moderately vesicular to very compact, amygdaloidal in places	576-610	17.0
No core recovery	610-620	0

Water-level measurements during drilling

Depth (ft.)	Effective casing (ft.)	Head (ft.)	Depth (ft.)	Effective casing (ft.)	Head (ft.)	Depth (ft.)	Effective casing (ft.)	Head (ft.)
165	156	196.7	497	209	70.6	576	570	86.7
200	200	100.3	497	390	8.7	587	209	79.7
210	156	123.9	510	500	12.7	587	580	86.7
240	209	194.0	510	209	69.9	610	209	15.0
250	250	80.9	520	520	14.7	610	610	83.2
280	209	131.4	540	540	86.7	616	209	120.5
310	310	15.5	546	209	129.9	616	610	11.2
320	209	69.9	546	290	6.8	620	600	11.2
350	209	72.1	546	310	6.8	620	590	13.5
350	350	13.7	546	330	6.8	620	580	13.6
360	360	13.5	546	350	6.8	620	560	14.0
360	209	72.5	546	370	6.8	620	540	21.2
370	370	13.5	546	390	6.8	620	530	21.2
380	380	11.3	546	410	7.8	620	520	19.9
390	209	71.3	546	430	24.4	620	510	19.0
400	400	25.3	546	430	24.6	620	507	18.9
400	209	85.4	546	450	30.7	620	490	18.5
420	209	72.4	546	450	40.9	620	470	18.2
420	420	7.9	546	470	41.7	620	430	15.0
428	420	8.1	546	490	47.0	620	410	8.6
428	209	68.8	546	510	47.8	620	390	7.5
440	440	7.2	546	530	24.4	620	370	7.5
451	209	68.5	546	545	89.4	620	350	7.5
451	450	9.5	546	536	97.2	620	330	7.5
467	460	14.6	546	528	97.0	620	310	7.0
467	209	69.9	546	530	98.5	620	209	73.7
480	480	8.7	557	550	83.8			
480	209	70.6	557	209	8.7			

Observations

(Water levels measured through ¾-in. casing. Measuring point, top of ¾-in. coupling, altitude, 280.82 ft.)

Date	Head (ft.)	Date	Head (ft.)	Date	Head (ft.)
June 15, 1954	11.72	July 2, 1954	11.02	July 23, 1954	12.02
19	11.90	10	11.12	27	12.32
26	11.02	17	12.32	Sept. 24	12.32

Tunnels developing high-level ground water in Kauai
(Data furnished by owners)

No.	Name	Owner[a]	Altitude (ft.)	Length of tunnel (ft.)	Aquifer
1	Wanini	C. of K.	28	......	Koloa basalt
2	Kalihiwai	do.	190	......	do.
3	Moloaa	do.	250	......	do.
4	Anahola	do.	200	150	do.
5	Akulikuli	do.	360	360	Waimea Canyon basalt
6	Makaleha	do.	574	67	do.
7	Moalepe	do.	568	550	do.
8	Nawiliwili	L. P. Co.	187	1,000	Koloa basalt
9	Kokolau	C. of K.	300	1,575	do.
10	Hanapepe	do.	138	......	Alluvium

[a] C. of K.: County of Kauai. L. P. Co.: Lihue Plantation Co.

SHAFTS IN KAUAI
(Data furnished by Owners)

Number	Name	Owner[a]	Date Installed	Altitude of Shaft Collar (ft.)	Depth of Shaft (ft.)	Altitude of Floor of Tunnel or Pump Sump (ft.)	Number of Tunnels	Length of Tunnels (ft.)	Pump Capacity (mgd.)	Aquifer
1	Kapaa	L. P. Co.	1938	25	40	—15	1	25	....	Koloa basalt
2	Hanamaulu	do.	....	10	12	— 1	1	200	....	do.
3	Pump 6	McB. S. Co.	1899	26	41	—15	1	2,200	1.5	do.
4	Pump 3	do.	1899	28	68	—40	5	8,000	30	Alluvium and Koloa basalt
5	Pump 2	do.	1899	24	54	—30	4	3,000	11	do.
6	Pump 1	do.	1899	21	40	—19	4	1,800	5	do.
7	Domestic	O. S. Co.	1947	376	364	12	0	0	1.4	Waimea Canyon basalt
8	Mahunauli	G. & R.	1933	43	56	—18	2	220	....	Koloa basalt
9	Waimea	C. of K.	1932	40	43	0	1	80	0.5	Waimea Canyon basalt
10	Huluhulunui	K. S. Co.	1949	45	48	0	1	66	15	do.
11	Kekaha domestic	do.	1932	60	57	4.5	1	250	4.0	do.
12	Kekaha	C. of K.	1948	57	55	....	0	0	0.5	do.
13	Waiawa	K. S. Co.	1935	57	57	0	1	15	7.5	do.
14	Kaunalewa	do.	1957	54	60	— 3	1	572	12	do.
15	Mana	do.	1938	102	105	— 1.5	1	180	2.5	do.
16	Saki-Mana	do.	1957	57	62	— 3	1	578	12	do.

[a] L. P. Co.: Lihue Plantation Co. McB. S. Co.: McBryde Sugar Co. O. S. Co.: Olokele Sugar Co.
G. & R.: Gay and Robinson. C. of K.: County of Kauai. K. S. Co.: Kekaha Sugar Co.

Ground-water pumped from principal wells, tunnels, and shafts in Kauai, 1940-1958, in millions of gallons
(Data furnished by owners)

	Drilled Wells						High-level tunnels	
Year	2	11	16	27	32	45	8	10
1940	210	494	......	519	1,018	1,357	488	......
1941	200	978	......	516	764	1,743	467	104
1942	142	144	......	630	627	1,368	416	87
1943	200	107	......	470	667	1,280	480	95
1944	200	260	......	555	764	1,990	500	98
1945	150	569	......	512	922	1,577	420	89
1946	213	37	......	512	600	1,087	470	91
1947	200	......	......	525	350	1,267	499	93
1948	200	......	......	650	386	1,533	508	96
1949	200	......	......	623	867	1,425	550	98
1950	200	......	......	524	235	1,268	550	100
1951	150	......	......	75	568	1,164	500	69
1952	150	......	......	0	644	1,315	500	76
1953	150	......	......	1	1,147	1,999	500	71
1954	100	......	22	106	1,170	1,323	500	65
1955	......	......	67	0	1,310	1,845	......	83
1956	......	......	70	......	1,056	1,114	......	68
1957	150	......	66	......	1,232	1,808	225	69
1958	......	......	71	......	1,112	1,379	......	71

Shafts

Year	2	7	9	11	12	13	14	15	16
1940	......	......	......	730	......	887	......	91	......
1941	......	......	155	730	......	623	......	118	......
1942	......	......	138	730	......	603	......	118	......
1943	13	......	144	730	......	308	......	91	......
1944	6	......	165	726	......	462	......	90	......
1945	6	......	173	732	......	682	......	98	......
1946	10	......	139	535	......	268	......	68	......
1947	10	228	173	366	......	471	......	92	......
1948	10	527	188	714	......	377	......	89	......
1949	10	520	190	730	......	309	......	182	......
1950	10	511	182	730	......	315	......	183	......
1951	3	500	106	730	27	227	......	182	......
1952	3	510	106	454	15	760	......	110	......
1953	3	450	113	558	47	1,362	......	120	......
1954	3	540	107	298	42	1,179	......	120	......
1955	......	500	124	467	45	1,208	......	142	......
1956	......	475	129	434	47	1,173	......	474	......
1957	......	689	167	434	54	1,177	......	362	......
1958	......	699	147	351	76	1,212	1,593	373	1,438

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