DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
STATE OF HAWAII, DEPARTMENT OF LAND AND NATURAL RESOURCES
DIVISION OF WATER AND LAND DEVELOPMENT

HYDROLOGIC INVESTIGATIONS
ATLAS HA–358 (SHEET 1 OF 2)

OCCURRENCE AND QUALITY OF GROUND WATER AS RELATED TO GEOLOGY

INTRODUCTION

The principal ground-water reservoir in the Waianae District is the middle and lower members of the Waianae Volcanic Series. Ground-water movement within the reservoir is partly controlled by dikes and breccia. The largest user of ground water in the area at the present time is a phreatophytic growth called kiawe. Future development of the ground-water reservoir by man depends, in large part, on depriving the extensive kiawe growth from using the ground water in the intermontane valleys.

The author wishes to acknowledge the Honolulu Board of Water Supply, Waianae Development Co., and Austin, Smith, and Associates, Inc., who furnished data included in the report.

BRIEF GEOLOGIC SKETCH OF THE WAIANAE RANGE

The island of Oahu was built by the coalescence of two shield volcanoes; Waianae and Koolau. The Waianae Range forms the western part of the island and is the eroded remnant of Waianae volcano. Its eastern slope is overlapped by lava flows of Koolau, which remained active after Waianae became dormant. The Waianae Range is composed of three groups of lava flows erupted during Tertiary time. A few secondary eruptions occurred during Pleistocene time, but lava flows and cinders of this epoch have been deeply weathered and eroded.

The stratigraphy of principal rock units (after Stearns 1939, 1966, and Macdonald 1940) is summarized below, and their distribution is shown on the geologic map; except for the lower and middle members of the Waianae Volcanic Series, which are shown as a unit. In general, flows of the lower member occur outside the curvilinear line of faults and flows of the middle member occur inside the line. Macdonald (1940, p. 66) reported that flows of the middle member are largely caldera-filling and are, therefore, nearly horizontal and thicker and more massive than flows of the lower member, which everywhere dip gently away from the caldera.

STRUCTURAL FEATURES AND THEIR EFFECT ON THE MOVEMENT OF GROUND WATER

RIFT ZONES

The Waianae shield volcano was built up by repeated fissure eruptions within three rift zones, which met at the central vent near the summit of the original dome. As in most volcanoes in Hawaii, two principal rift zones and a subordinate zone radiate from the central vent, and the subordinate one approximately bisects the external angle between the other two. The principal rift zones of the Waianae volcano, which trend roughly northwest and south, determined the elongate shape of the dome. The subordinate zone trends roughly northeast from the central vent area. The rift zones are roughly outlined on the structural map. The central vent area is probably associated with the highest gravity anomalies.

A rift zone of an active volcano is characterized by parallel to subparallel fissures and a line of cinder and spatter cones. These features are absent or scarce in extinct volcanoes, such as the Waianae, where erosion has cut deep into the dome, and the rift zones are marked by exposed dikes. Dikes exercise major controls in the movement and storage of ground water because they are less permeable than the rocks they intrude. Where they are few and mostly parallel, they channel ground water along their trend. Where they are numerous and intersect, they form compartments and reduce lateral movement of ground water and impound it at altitudes higher than those in surrounding dike-free or sparsely dike-intruded rocks. The height to which water is stored depends on the dike pattern and the ability of the dikes to retain water.

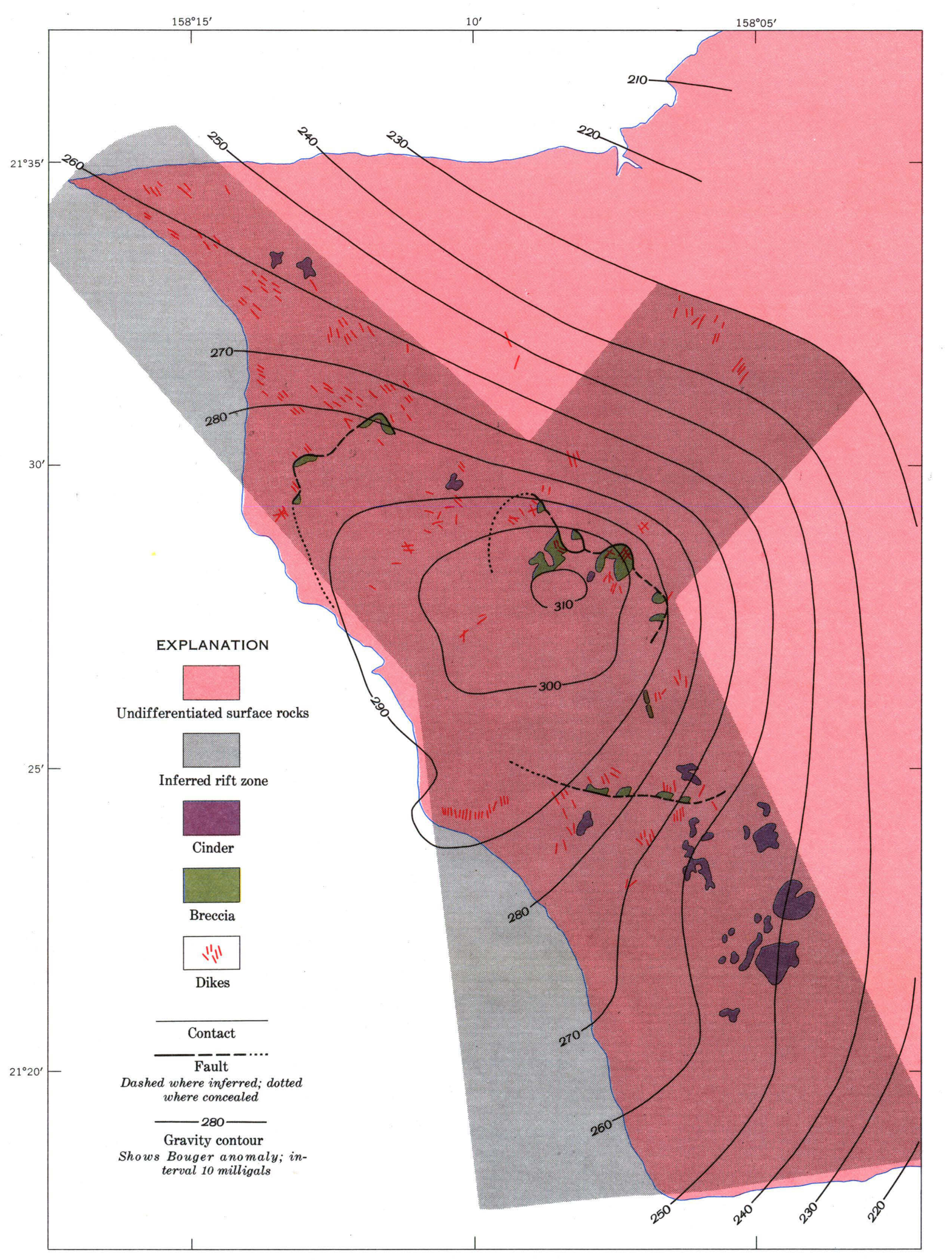
Dikes intrude most of the volcanic rocks in the Waianae District. They are sparse in the poorly permeable, massive, thick-bedded flows of the upper member and are numerous in the highly permeable, thin-bedded flows of the lower and middle members of the Waianae Volcanic Series.

BRECCIA AND FAULTS

Narrow strips of breccia crop out across the heads of Nanakuli, Lualualei, and Keaau Valleys. Stearns wrote in considerable detail of the origin, significance, and effect on ground-water movement of the breccia (Stearns and Vaksvik, 1935, p. 80–86). He described the breccia as poorly bedded, unsorted, well cemented, and practically impermeable. He believed that the breccia accumulated at the foot of high cliffs, which may have been caused by faulting in the lower member of the Waianae Volcanic Series. Stearns showed that, except in a few places, the breccia indicated a profound angular unconformity between flows of the lower and middle member. He concluded also that the breccia forms a barrier to ground water percolating seaward and to sea water migrating inland.

STRATIGRAPHIC UNITS, WAIANAE RANGE

PERIOD	GEOLOGIC UNIT	ROCK ASSEMBLAGE	WATER-BEARING PROPERTIES
QUATERNARY	Calcareous sedimentary material	Coral, coral rubble, and beach sand.	Generally highly permeable. Water from wells likely to be brackish when wells are pumped heavily.
	Noncalcareous sedimentary material	Older alluvium: Moderately to well-consolidated and weathered in its entirety. Younger alluvium: Reworked older alluvium in and near stream channels and overlying older alluvium. Mainly reworked fragments of older alluvium. Talus: Mainly poorly consolidated gravel and boulders.	Older alluvium: Generally poorly permeable; acts as confining member where it overlies more permeable saturated rocks. Younger alluvium: Poorly to moderately permeable; yield from wells is small, but quality is generally fair to good even near coast. Talus: Highly permeable, but storage is generally small.
TERTIARY	Waianae Volcanic Series	Upper member: About 2,300 feet thick, mostly massive aa andesite flows that issued from large cinder cones. Flows sparsely intruded by dikes. Middle member: Exposed part about 2,000 feet thick; resembles lower member but more aa than in lower member. Mostly dike-intruded in Waianae District. Separated from lower member in most places by angular unconformity and breccia and in few places by erosional unconformity. Includes 400-foot thick trachyte flow at Mount Kuwale between Waianae and Lualualei Valleys. Lower member: Exposed part nearly 2,000 feet thick, mostly thin-bedded pahoehoe. Mostly dike-intruded in Waianae District.	Upper member: Generally poorly permeable owing to massive nature of flows. Acts as perching member of marsh on Kaala. Cinders generally permeable but drain quickly after heavy rains. Middle member: Permeability highly variable, depending on number and nature of dike intrusions. In Waianae District nearly all flows of the middle member are dike-intruded. Breccia generally poorly permeable and is probably barrier to movement of ground water. Trachyte flows are poorly permeable. Lower member: Permeability highly variable, depending on number and nature of dike intrusions. Permeability decreases with increasing number of dike intrusions. In Waianae District nearly all flows of lower member are dike-intruded.



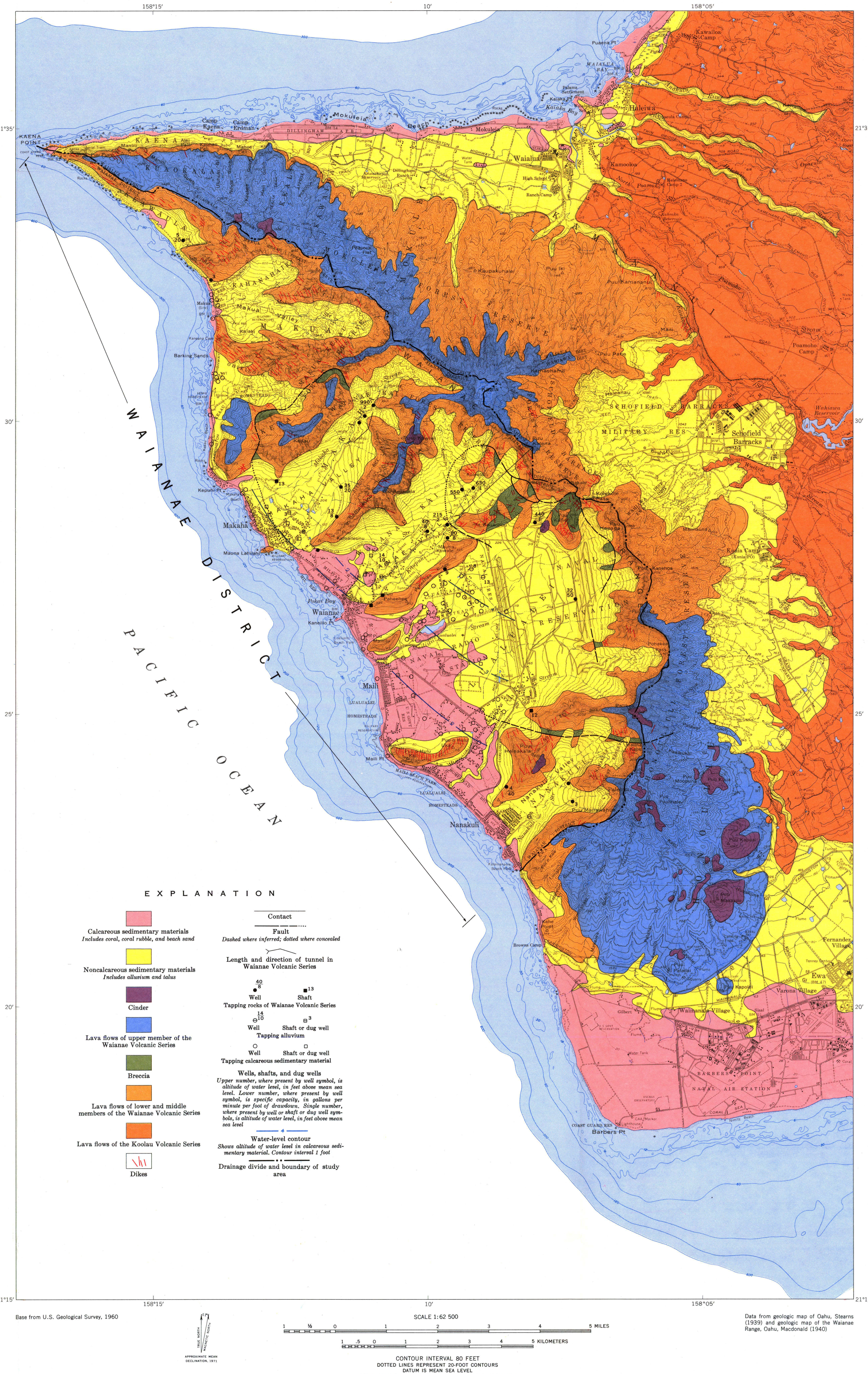
EXPLANATION

- 🟥 Undifferentiated surface rocks
- ▨ Inferred rift zone
- ■ Cinder
- ■ Breccia
- Dikes
- Contact
- Fault — *Dashed where inferred; dotted where concealed*
- 280 Gravity contour — *Shows Bouger anomaly; interval 10 milligals*

0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS

Gravity data from Bouguer anomaly map of the island of Oahu, Hawaii (Strange, Machesky, and Woollard, 1965)

STRUCTURAL MAP OF WAIANAE RANGE



E X P L A N A T I O N

- 🟥 Calcareous sedimentary materials — *Includes coral, coral rubble, and beach sand*
- 🟨 Noncalcareous sedimentary materials — *Includes alluvium and talus*
- 🟪 Cinder
- 🟦 Lava flows of upper member of the Waianae Volcanic Series
- 🟩 Breccia
- 🟧 Lava flows of lower and middle members of the Waianae Volcanic Series
- 🟧 Lava flows of the Koolau Volcanic Series
- Dikes

Contact

Fault — *Dashed where inferred; dotted where concealed*

Length and direction of tunnel in Waianae Volcanic Series

● 40/8 Well ■ 13 Shaft — Tapping rocks of Waianae Volcanic Series

⊖ 14/10 Well ⊟ 3 Shaft or dug well — Tapping alluvium

○ Well □ Shaft or dug well — Tapping calcareous sedimentary material

Wells, shafts, and dug wells — *Upper number, where present by well symbol, is altitude of water level, in feet above mean sea level. Lower number, where present by well symbol, is specific capacity, in gallons per minute per foot of drawdown. Single number, where present by well or shaft or dug well symbols, is altitude of water level, in feet above mean sea level*

—4— Water-level contour — *Shows altitude of water level in calcareous sedimentary material. Contour interval 1 foot*

Drainage divide and boundary of study area

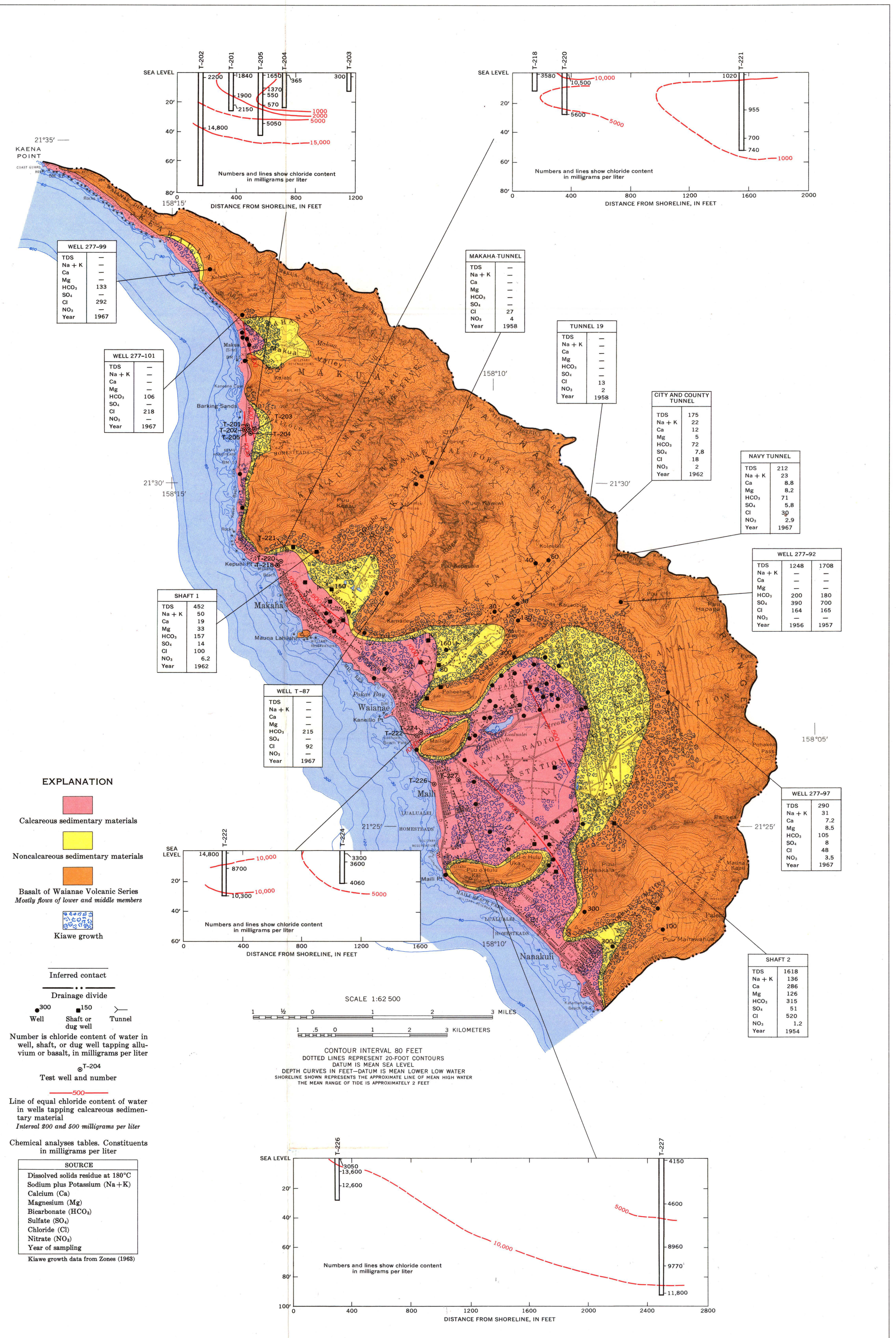
Base from U.S. Geological Survey, 1960

SCALE 1:62 500
1 ½ 0 1 2 3 4 5 MILES
1 .5 0 1 2 3 4 5 KILOMETERS

CONTOUR INTERVAL 80 FEET
DOTTED LINES REPRESENT 20-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL
DEPTH CURVES IN FEET—DATUM IS MEAN LOWER LOW WATER
SHORELINE SHOWN REPRESENTS THE APPROXIMATE LINE OF MEAN HIGH WATER
THE MEAN RANGE OF TIDE IS APPROXIMATELY 2 FEET

Data from geologic map of Oahu, Stearns (1939) and geologic map of the Waianae Range, Oahu, Macdonald (1940)

GEOLOGIC MAP OF WESTERN OAHU SHOWING AREA OF STUDY, LOCATIONS OF WELLS, SHAFTS, AND TUNNELS ALTITUDE OF WATER LEVELS, AND SPECIFIC CAPACITIES OF WELLS,(1967), IN WAIANAE DISTRICT



EXPLANATION

- 🟥 Calcareous sedimentary materials
- 🟨 Noncalcareous sedimentary materials
- 🟧 Basalt of Waianae Volcanic Series — *Mostly flows of lower and middle members*
- Kiawe growth

Inferred contact

Drainage divide

●300 Well ■150 Shaft or dug well ≻— Tunnel

Number is chloride content of water in well, shaft, or dug well tapping alluvium or basalt, in milligrams per liter

⊙T–204 Test well and number

—500— Line of equal chloride content of water in wells tapping calcareous sedimentary material — *Interval 200 and 500 milligrams per liter*

Chemical analyses tables. Constituents in milligrams per liter

SOURCE
Dissolved solids residue at 180°C
Sodium plus Potassium (Na+K)
Calcium (Ca)
Magnesium (Mg)
Bicarbonate (HCO_3)
Sulfate (SO_4)
Chloride (Cl)
Nitrate (NO_3)
Year of sampling

Kiawe growth data from Zones (1963)

SCALE 1:62 500
1 ½ 0 1 2 3 MILES
1 .5 0 1 2 3 KILOMETERS

CONTOUR INTERVAL 80 FEET
DOTTED LINES REPRESENT 20-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL
DEPTH CURVES IN FEET—DATUM IS MEAN LOWER LOW WATER
SHORELINE SHOWN REPRESENTS THE APPROXIMATE LINE OF MEAN HIGH WATER
THE MEAN RANGE OF TIDE IS APPROXIMATELY 2 FEET

QUALITY-OF-WATER MAP SHOWING PROBABLE DISTRIBUTION OF ROCKS AT SEA LEVEL AQUIFERS TAPPED BY WELLS, SHAFTS, TUNNELS, AND AREAS OF PHREATOPHYTES

GROUND WATER

WHERE AND HOW IT OCCURS

Most of the fresh ground-water supply in the Waianae District occurs in flows of the lower and middle members of the Waianae Volcanic Series. Flows of the upper member are mostly above the water table and contain only a small perennial supply. Some fresh ground water occurs in sedimentary materials, but development of this supply is generally limited by the low permeability of alluvium, the restricted storage available in talus, or by sea-water intrusion in coral or coral rubble.

The ground-water reservoir in the volcanic rocks is large. The top of the reservoir extends from an altitude of a few feet near the coast to more than 1,800 feet near the crest of the range at Kaala. Although the reservoir seems to be continuous, it is far from being homogeneous (having a uniform water-level gradient). Instead, as shown by water levels in wells (geologic map), the gradient is steplike, reflecting the damming effects due to local changes in permeability, caused by variations in dike density and in number of dike intersections, and to breccia. Local changes in permeability are reflected also in the wide range of specific capacities shown in the geologic map.

Springs, which discharge at altitudes as high as 1,800 feet in Waianae and Makaha Valleys, contribute to perennial flow of streams. Most of the flow disappears below an altitude of 1,000 feet in both valleys. These and other deep valleys that breach dikes and breccia deposits act as line sinks. Water in wells drilled near stream channels is either artesian or occurs at shallow depths. Artesian conditions prevail where wedges of poorly permeable older alluvium and weathered rock overlie the aquifer.

Ground water also occurs in highly permeable coral and coral rubble near sea level. Information from drillers' logs indicates that coralline rocks extend at least 3 miles inland in Lualualei Valley and about 1 mile inland in Waianae and Makaha Valleys (quality-of-water map). About 100 wells have been drilled into this aquifer, but most have been abandoned because of an increase in chloride content of the water with continued pumping. Water levels in wells tapping the coralline aquifer are shown by contours on the geologic map.

Several wells have been dug or drilled in younger alluvium adjacent to inland extensions of the coralline material. Water levels in those wells are somewhat higher than those in wells tapping the coralline material (geologic map). Prospects are good for developing small supplies of fresh water in younger alluvium.

Talus deposits apparently do not form ground-water reservoirs of any significance because most of them lie above the main water table. However, because of the high permeability of the deposits and their location at the base of cliffs, they provide excellent catchments during periods of heavy rainfall. Lack of heavy vegetation on most talus slopes indicates that they are quickly drained after rains.

QUALITY

Data on ground-water quality are given on the quality-of-water map which also shows probable distribution of the principal aquifers at sea level. The map was prepared from drillers' logs and by projecting slopes of outcrops.

The quality of water from wells tapping the volcanic aquifer is generally good, except in near-shore areas and areas abutting landward edges of the coralline aquifer, where the major contaminant is sea water. Other contaminants result from leaching of hydrothermally altered volcanic rocks in the central vent area and of carbonate rocks above or adjacent to the volcanic aquifer. Most of the coralline aquifer is intruded by sea water, so the volcanic aquifer is highly susceptible to sea-water intrusion where it is in contact with the coralline aquifer.

The low overall permeability of volcanic rocks, which is mostly caused by dike intrusions, is the principal deterrent to sea-water encroachment. Where dike intersections are numerous, landward movement of sea water is almost completely retarded. Where dikes are mostly parallel, permeability is much greater along the trend of the dikes than it is at right angles to them. Where they are parallel to the shoreline, dikes channel fresh water along their trend by retarding its flow across them, thereby also retarding sea-water intrusion. The chloride content of water from wells 277–99 and 277–101, 292 and 218 mg/l (milligrams per liter), respectively, is unusually low for ground water near the coast and may reflect water channeling and sea-water exclusion by dikes.

The high dissolved-solids content of more than 1,700 mg/l and sulfate content of 700 mg/l (well 277–92) probably reflects leaching of hydrothermally altered rocks in an area where the permeability of the altered rocks is further reduced by intersecting dikes. The temperature, 26.6°C (Celsius), of water from this well compared with that of water from tunnels in upper Waianae Valley, 18.3°C, water from the City and County tunnel, 21.1°C, and water from well 277–97, 23.9°C, is further evidence of sluggish movement of water and effects of hydrothermal activity on the aquifer tapped by well 277–92.

Water in the coralline aquifer ranges widely in chloride concentration. The lines of equal chloride content shown on the map represent only the fresher upper part of a lenslike water body that floats on sea water. Because recharge from rainfall and underflow from other water bodies is small, the fresh-water lens is thin and unstable. It is subject to rapid contamination by sea water if wells tapping it are pumped heavily.

The lack of fresh water needed to develop a thicker lens is at least partly due to a luxuriant growth of algaroba, or kiawe (*Prosopis chilensis*), a close relative of mesquite. Transpiration by this plant, from shallow water bodies in volcanic rock and alluvium, reduces underflow that would otherwise recharge the coralline aquifer. Where kiawe growth is most luxurious on the coralline aquifer, transpiration constitutes the main discharge of ground water.

Ground water in the alluvium is generally fresh. Sea-water intrusion is limited to near-shore areas and to areas abutting edges of the coralline aquifer.

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D.C.—1971—W69340

GROUND WATER IN THE WAIANAE DISTRICT, OAHU, HAWAII

By
Kiyoshi J. Takasaki
1971

For sale by the U.S. Geological Survey, price $1.50 per set