Drilling and Construction Data for the Waiohuli Exploratory Well (State Well 6-4421-01), Island of Maui, Hawaii

By Stephen B. Gingerich and David R. Sherrod

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CONTENTS

FIGURES

TABLES

CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
cubic foot per minute (ft^3/min)	0.02832	cubic meter per minute
gallon per minute (gal/min)	3.785	liter per minute
mile, statute (mi)	1.609	kilometer

Abbreviations
µS/cm, microsiemens per centimeter at 25 degrees Celsius
mg/L, milligrams per liter

Datums
Vertical coordinate information is referenced relative to mean sea level.
Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

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Abstract

The Waiohuli exploratory well, located on the western slope of Haleakala, Maui, Hawaii, was drilled in 2001 to investigate the hydrology and geology in an area where other well information was not available. The well was drilled from a ground altitude of about 1,864 feet and penetrated a 1,940-foot section of subaerial lava flows (consisting of basanite, hawaiite, and alkalic basalt) with interbedded tephra. Water levels measured in the well ranged from about 5 to 6 feet above sea level.

INTRODUCTION

The Waiohuli exploratory well was drilled during April to August 2001 by the U.S. Geological Survey (USGS) in cooperation with the State of Hawaii Department of Hawaiian Home Lands to explore the availability of ground water and the geology on the western slope of Haleakala (also known as East Maui Volcano) (fig. 1). The objectives for drilling the well include determining (1) the water-table altitude in the area, (2) the salinity of water in the aquifer at the well, and (3) the subsurface geology of the area. The Department of Hawaiian Home Lands considers the Waiohuli area a potential site for future ground-water development.

This report documents (1) the well location, (2) drilling and well-construction information from the drillers, (3) geologic descriptions of the rock cuttings brought to the surface during drilling, (4) available water-level information, and (5) chloride concentration, specific conductance, and temperature of water in the well.

Site Selection

The exploratory well was sited in an area where no wells had been drilled and no subsurface information was available and is at least 5 mi from the nearest pumped wells. Site selection was also guided by (1) the need to have the well on public land for future access, (2) the need to have the well near a road for drilling equipment access, and (3) the need to avoid drilling near Puu O Kali because of the potential effects of drilling activity on threatened or endangered species and the possible geologic complications associated with the volcanic feature.

Location

The Waiohuli exploratory well is on ranchland leased from the State of Hawaii Department of Hawaiian Home Lands, about 1.7 mi west and downhill from the Kula Highway (State Road 37) on the western flank of Haleakala (fig. 2). The well is about 2,000 ft downslope from the downhill end of Laueie Road, a new subdivision road not yet shown on the topographic map. The well was assigned the well number 6-4421-01 by the State of Hawaii Commission on Water Resource Management using the State well-numbering system (table 1).

No perennial surface-water bodies lie within at least 4 mi of the well. The nearest intermittent stream valley is Waiohuli Gulch, about 0.1 mi south of the well. The well is about 5.4 mi inland from the western coast of east Maui.

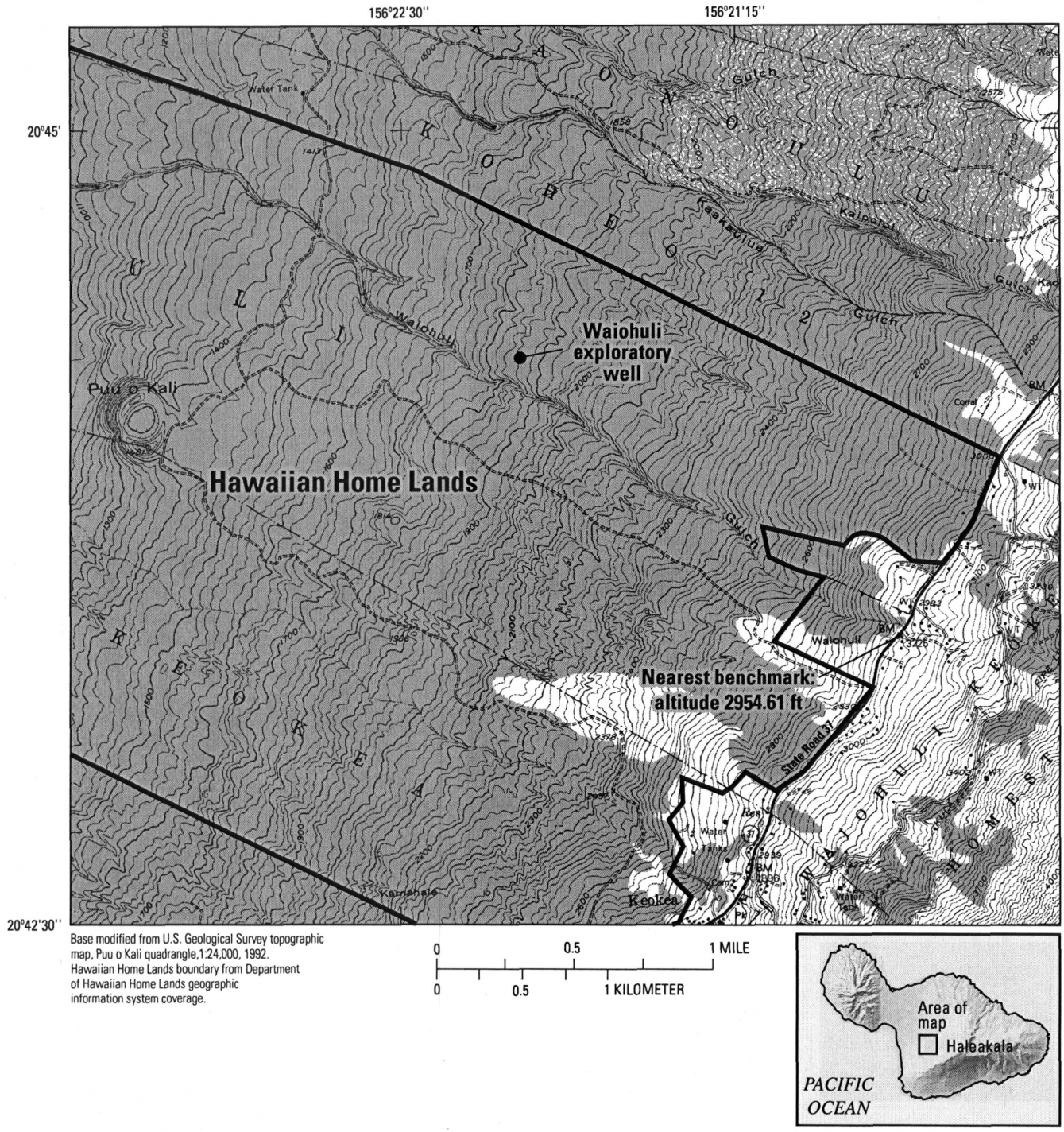

Figure 1. Location of the Waiohuli exploratory well (State well 6-4421-01), Maui, Hawaii.

Table 1. Location, altitude, and State number of the Waiohuli exploratory well, Maui, Hawaii

[Vertical datum is mean sea level; latitude and longitude measured using GPS (global positioning system) and referenced to NAD83 datum]

Latitude	20°44′07″N
Longitude	156°21′55″W
Ground altitude at brass plate in concrete pad	1,864.33 feet
Measuring-point altitude at top of 4-inch well casing	1,867.56 feet
Distance and direction from Keokea	2.2 miles north-northwest
Distance and direction from nearest shoreline	5.4 miles east
State well number	6-4421-01

Geologic Setting

The Waiohuli exploratory well is located on the western flank of Haleakala, a broad shield volcano that forms the eastern part of the island of Maui. Haleakala was built chiefly by thousands of pahoehoe and aa lava flows erupted during the past 2 million years, the last 1 million years of which the flows erupted above sea level (Stearns and Macdonald, 1942). Consequently the drill hole penetrates almost entirely through lava flows. Additionally, tephra deposits are interbedded among the lava flows. Though generally thin, these deposits are as thick as 6 to 9 ft.

Two major stratigraphic units, the Kula Volcanics and the Hana Volcanics, are mapped at the surface on Haleakala's west flank (Stearns and Macdonald, 1942) (fig. 2). The Kula Volcanics comprises chiefly basanite and hawaiite lava in flows that were emplaced as aa. Pahoehoe is sparse. The Kula Volcanics unit represents the alkalic-cap stage of Hawaiian volcano evolution (Langenheim and Clague, 1987). Hana Volcanics is not found at the drill site.

A third stratigraphic unit, the Honomanu Basalt, is inferred to underlie the Kula Volcanics. Though not exposed on the volcano's west flank, the Honomanu Basalt is found in deep canyons on the north and possibly the southeast side (Stearns and Macdonald, 1942). The Honomanu Basalt, containing both pahoehoe and aa lava flows, was emplaced as Haleakala progressed from its shield-building to alkalic-cap stage (Langenheim and Clague, 1987).

Acknowledgments

The drilling and construction of the Waiohuli exploratory well was made possible with the cooperation and assistance of Darrell Yagodich, Carolyn Darr, and Daniel Ornellas of the Department of Hawaiian Home Lands and David Craddick of the Maui Department of Water Supply.

DRILLING METHODS AND CONSTRUCTION

The well was bored by rotary drilling with an 7-7/8-in.-diameter tungsten-carbide bit. Air and foam were injected down through the hollow drill stem and circulated back up the space between the stem and the well bore to remove water and cuttings from the hole. The Waiohuli exploratory well was drilled to a depth of 1,940 ft from an altitude of about 1,864 ft.

A 1,924-ft solid steel casing with a 4-in. inner diameter was installed and the bottom 90 ft was hand perforated to create a well screen. The altitude of a brass plate in a concrete pad surrounding the well is 1,864.33 ft and the altitude of the measuring point notched in the top of the steel well casing is 1,867.56 ft. The well altitude was determined by leveling survey from a benchmark (National Geodetic Survey No. P23; alt. 2,954.61 ft) on the east side of a bridge along State Road 37 (fig. 1). Construction details of the finished well are shown in figure 3. Kimo Akina was the head of the USGS drill crew for well construction.

GEOLOGIC LOG

The geologic log (fig. 4) of the Waiohuli exploratory well was compiled from cuttings brought to the surface by the air and foam circulated through the well bore. Samples were collected at 5-ft depth intervals, then rinsed and dried before being examined at low-power magnification with a binocular microscope. Lithologic descriptions appear in table 2. The following terms refer to the percentage of phenocrysts found in the samples: slightly porphyritic, 1 to 3 percent; moderately porphyritic; 3 to 10 percent; highly porphyritic, 10 to 25 percent.

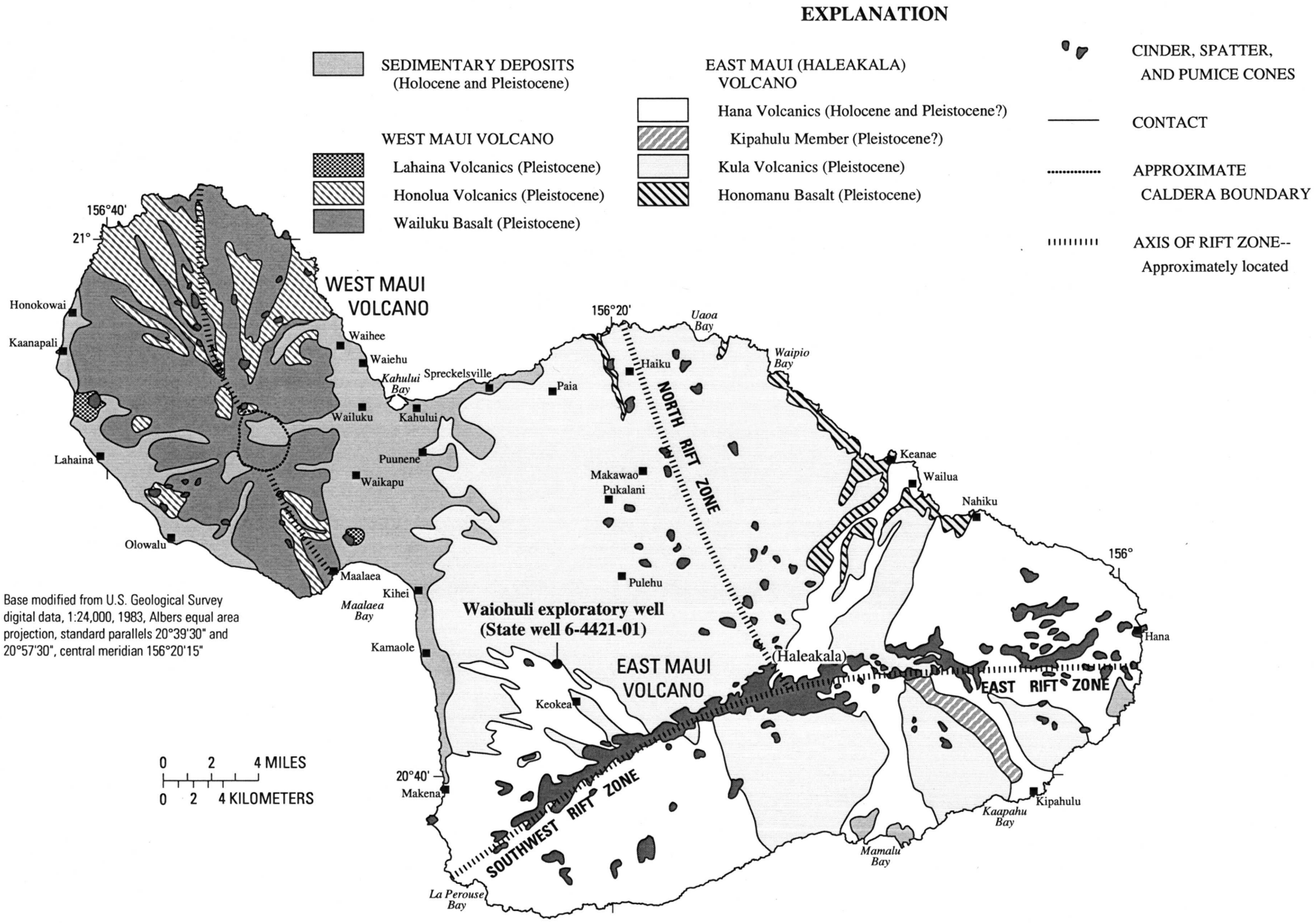

Figure 2. Generalized surficial geology, Maui, Hawaii (modified from Langenheim and Clague, 1987).

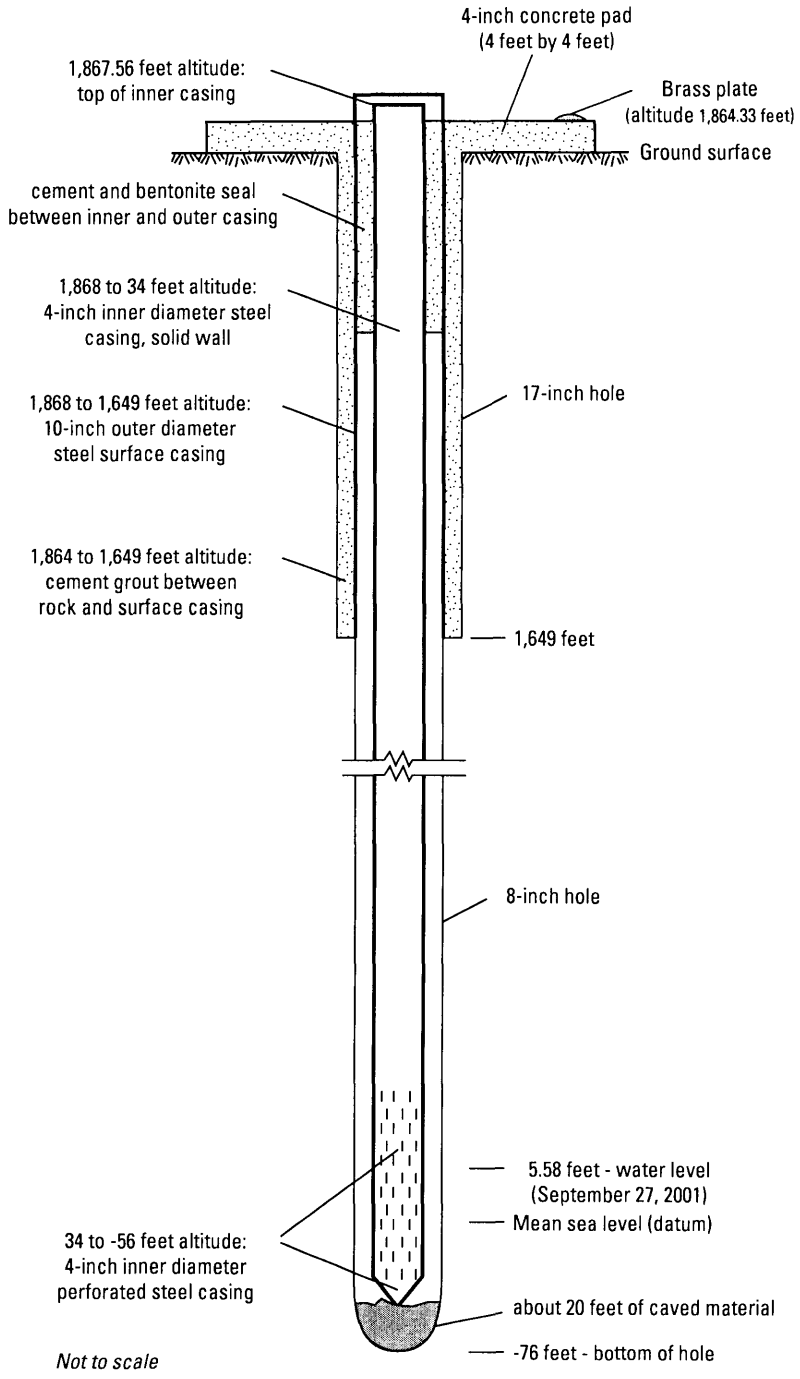

Figure 3. Diagram showing construction details of the Waiohuli exploratory well (State well 6-4421-01), Maui, Hawaii.

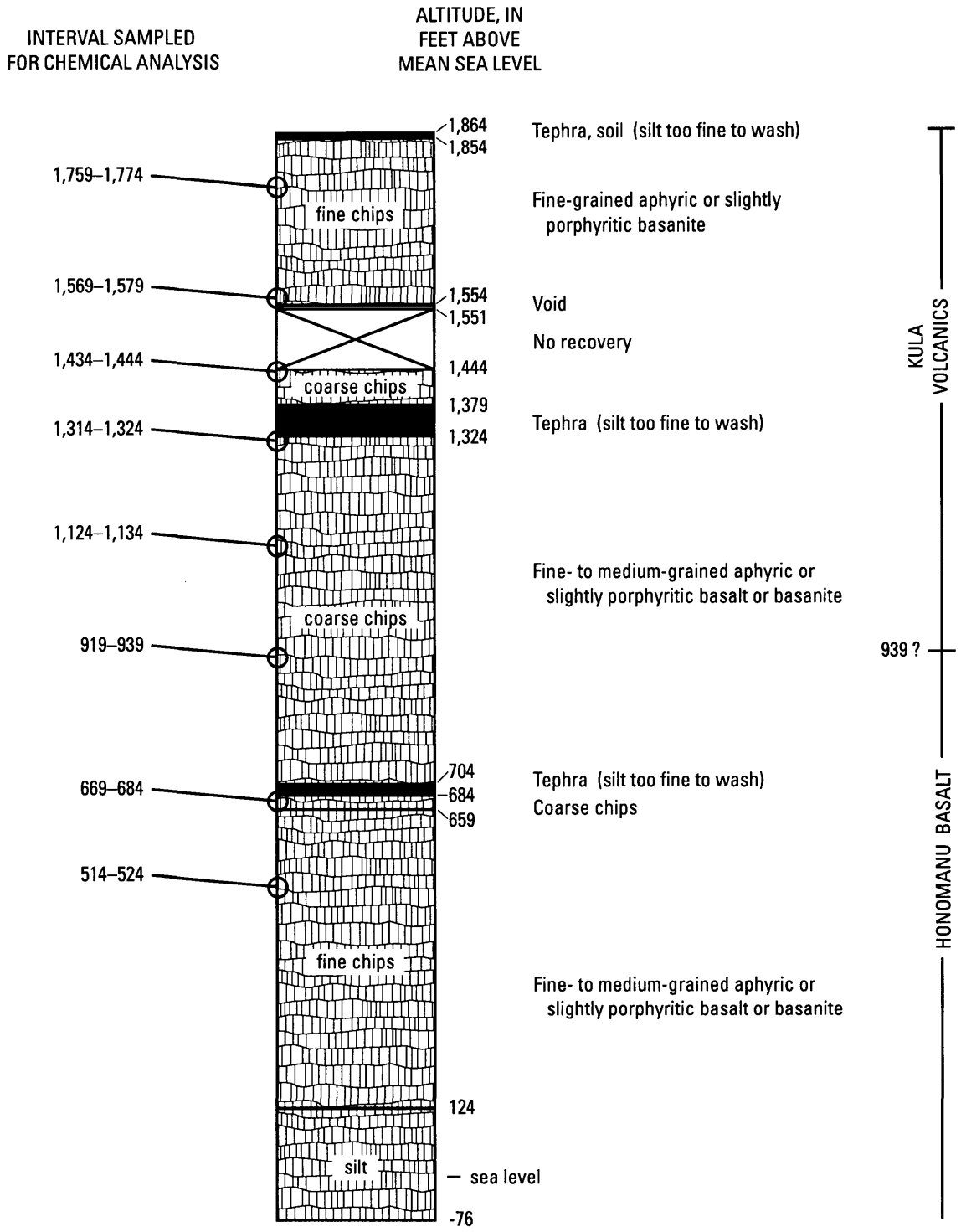

Figure 4. Geologic log for the Waiohuli exploratory well (State well 6-4421-01), Maui, Hawaii.

Table 2. Lithologic descriptions of drill cuttings from Waiohuli exploratory well (State well 6-4421-01), Maui, Hawaii

[Datum is mean sea level; depth measured from 1,864 feet above sea level; slightly porphyritic, 1 to 3 percent phenocrysts; moderately porphyritic, 3 to 10 percent phenocrysts; highly porphyritic, 10 to 25 percent phenocrysts]

Altitude (feet)			Depth (feet)			Sample description[1]
1,864	to	1,859	0	to	5	dark-brown soil
1,854	to	1,554	10	to	310	dark-gray fresh aphyric to slightly porphyritic lava
1,554	to	1,444	310	to	420	No recovery due to void between 1,551-ft and 1,544-ft altitude
1,444	to	1,384	420	to	480	Medium-gray aphyric lava
1,384	to	1,379	480	to	485	Light-brownish gray grit-size lava chips
1,379	to	1,324	485	to	540	Light-brownish gray silt- to sand-size chips, probably weathered tephra
1,324	to	1,124	540	to	740	Medium-gray aphyric lava; some chips with sparse small olivine
1,124	to	1,119	740	to	745	Medium-gray lava; slightly olivine-bearing chips more abundant
1,119	to	1,114	745	to	750	Medium-gray lava; slightly olivine-bearing chips more abundant
1,114	to	1,109	750	to	755	Medium-gray lava, several chips moderately to highly porphyritic with olivine and clinopyroxene
1,109	to	1,104	755	to	760	Medium gray lava, 70 percent of chips aphyric, 30 percent moderately to highly porphyritic
1,104	to	964	760	to	900	Chiefly medium-gray aphyric lava, 20 percent with olivine phenocrysts 1 to 2 mm; rarely plagioclase- or clinopyroxene-bearing
964	to	954	900	to	910	Medium-gray lava; 50 percent aphyric and 50 percent moderately plagioclase-phyric
954	to	944	910	to	920	Chiefly medium-gray aphyric lava, 20 percent porphyritic lava
944	to	914	920	to	950	Medium-gray lava, many chips moderately plagioclase-phyric, phenocrysts 1 to 2 mm
914	to	884	950	to	980	Medium-gray lava; abundance of plagioclase-bearing chips diminishes
884	to	704	980	to	1,160	Chiefly medium-gray aphyric lava; 10-20 percent moderately olivine-phyric lava and only scant plagioclase-phyric chips
704	to	684	1,160	to	1,180	Medium-gray silt- and sand-size matter
684	to	584	1,180	to	1,280	Chiefly medium-gray aphyric lava; 20 to 30 percent moderately olivine-phyric lava with scattered clinopyroxene phenocrysts
584	to	524	1,280	to	1,340	Chiefly medium-gray aphyric lava; 10 to 20 percent moderately olivine-phyric lava with scattered clinopyroxene phenocrysts
524	to	504	1,340	to	1,360	Medium-gray aphyric lava; 20 to 30 percent chips with small plagioclase phenocrysts
504	to	124	1,360	to	1,740	Medium-gray aphyric lava; 5 percent chips with plagioclase phenocrysts, 10 percent chips with olivine and clinopyroxene phenocrysts
124	to	-76	1,740	to	1,940	gray silt-size matter

[1] Rotary-drilling cuttings lifted with air, foam, and polymer. Sample repository: U.S. Geological Survey, Hawaii District office.

The Waiohuli well penetrates a 1,940-ft section of subaerial lava flows with interbedded tephra. The cuttings, generally fresh, range from massive to slightly vesicular basanite, hawaiite, and alkalic basalt. Specific compositions are not discernible in hand specimen but are based on chemical analyses from selected cuttings (table 3). Cuttings typically are medium gray in color, indicating that groundmass glass has not degraded extensively to clay minerals. Olivine phenocrysts range from oxidized to fresh, plagioclase is generally unaltered. Secondary mineralization is sparse to absent; opaline silica lightly coats some vesicle and fracture surfaces below 1,444-ft altitude. Tests using hydrochloric acid indicate almost no calcium carbonate as a secondary mineral.

Aphyric and slightly porphyritic lava predominate among the lava flows. Olivine-bearing lava, some moderately to highly porphyritic, forms less than 20 percent of the sequence. Clinopyroxene accompanies olivine as a phenocryst phase in some flows. Moderately plagioclase-bearing flows form less than 5 percent of the stratigraphic section penetrated by the drill stem. The porphyritic flows occur sporadically, never forming thick, homogeneous sequences as judged by their scant representation among cuttings from all depths.

Two discrete tephra sequences are presumed from cuttings collected at altitude intervals 1,379 to 1,324 ft and 704 to 684 ft. Material from these intervals is entirely silt to sand in size. In contrast, chips are commonly as large as 1 in. from other depth intervals where lava flows presumably dominate the sequence. Thin individual tephra beds between lava flows would be impossible to recognize in the drill cuttings. One void is mentioned in the driller's notes between altitudes of 1,551 to 1,544 ft.

Medium-gray silt-sized cuttings were the only material returned from the 124- to –76-ft altitude interval, the bottom 200 ft in the drill hole. It is unlikely that this extensive return of fine material represents 200 ft of tephra accumulation. The material is not beach sand or other fluvial or marine sediment. The driller's log shows no change in drilling procedures. Conceivably, the sequence below the 124-ft altitude comprises thin vesicular pahoehoe lava flows pulverized by drilling. This extensive return of fine material is otherwise unexplained.

Eight chemical analyses were obtained from cuttings at selected intervals (table 3). Rock chips were hand picked to obtain a petrographically uniform sample. However, the samples were composites and can not be shown to correspond to any single lava flow from the stratigraphic section. The sample collected from 524- to 514-ft altitude is slightly porphyritic with small phenocrysts of plagioclase and olivine. Similar chips are sparse to lacking from cuttings immediately above and below those depths, so this sample may come closest to representing a single lava flow. The sample collected from 1,324- to 1,314-ft altitude is from coarse chips collected beneath a zone of silt-size cuttings (tephra?). These aphyric chips are larger than those from shallower parts of the hole and may therefore be from one or two flows at that depth. The boundary between the Kula Volcanics and the Honomanu Basalt is probably about 925 ft deep in the Waiohuli drill hole, or about the 939-ft altitude, on the basis of the chemical analyses (David R. Sherrod, U.S. Geological Survey, Hawaiian Volcanoes Observatory, written commun., 2002).

WATER-LEVEL AND WATER-QUALITY MEASUREMENTS

Water-level measurements made in the Waiohuli exploratory well between September 2001 and April 2002 ranged from 5.58 ft to 6.11 ft above sea level (table 4). A water sample, collected from the well on April 3, 2002, had a chloride concentration of 65.9 mg/L. The specific conductance of the water sample was 442 µS/cm and the temperature was 19.3°C. The sample was collected from several feet below the water surface using a bailer attached to a steel cable on an electric reel. The water-level altitude, measured with a 2,000-ft graduated electric tape just prior to sampling, was 5.91 ft.

SUMMARY

The Waiohuli exploratory well (State well number 6-4421-01) is located on ranchland owned by the Department of Hawaiian Home Lands on the western slope of Haleakala. The well was constructed during April to August 2001 to study the hydrology and geology in an area where no other well information was available. The altitude of a brass plate embedded in the concrete pad at the well is 1,864.33 feet above mean sea level and the well is 1,940 feet deep (bottom is at –76 feet altitude) and has a bore diameter of 7-7/8 in. A 1,924-ft solid steel casing with a 4-in. inner diameter

Table 3. Chemical analysis of selected rock cuttings collected during drilling of the Waiohuli exploratory well (State well 6-4421-01), Maui, Hawaii

[Major- and trace-element data were determined by X-ray fluorescence methods using an automated Rigaku 3370 spectrometer at Washington State University (WSU) Geoanalytical Laboratories; accuracy and precision are discussed fully by Johnson and others (1999). Accuracy for major elements is better than 0.5 percent. For the trace elements, accuracy is better than 10 percent and commonly in the range 3 to 5 percent except for those elements in concentrations less than 10 ppm (parts per million), in which case the precision may exceed 50 percent. Sc is only semiquantitative below the 30-ppm concentration. La and Ce concentrations are qualitative only. Major-element analyses normalized to 100 percent with all iron as Fe^{2+}. Also shown are prenormalized oxide totals. Sample numbers indicate downhole depth, in feet. Altitude describes the range from which cuttings were gathered for each sample.]

Sample number	WAIO-95	WAIO-285	WAIO-420	WAIO-540	WAIO-730	WAIO-925	WAIO-1180	WAIO-1340
Altitude (ft)	1,774–1,759	1,579–1,569	1,444–1,434	1,324–1,314	1,134–1,124	939–919	684–669	524–514
Sample weight (g)	12.5	14.4	17.5	17.5	15.4	11.1	16.5	13.4
Formation	Kula Volcanics	Kula Volcanics	Kula Volcanics	Kula Volcanics	Kula Volcanics	Honomanu Basalt	Honomanu Basalt	Honomanu Basalt
Rock type	Hawaiite	Basanite	Hawaiite	Hawaiite	Hawaiite	Alkali basalt	Alkali basalt	Alkali basalt
Major-element analyses, normalized water-free (weight percent)								
SiO_2	45.76	45.90	48.26	47.73	49.71	47.12	46.02	47.50
Al_2O_3	16.73	16.84	16.62	16.50	17.68	16.42	12.45	15.29
TiO_2	3.85	3.89	3.75	3.70	3.52	3.33	3.221	4.10
FeO	13.12	12.92	11.82	12.60	10.96	12.02	12.71	12.76
MnO	0.220	0.218	0.242	0.237	0.243	0.174	0.171	0.18
CaO	9.34	9.08	8.56	8.63	7.97	11.79	10.42	10.88
MgO	5.09	5.01	4.56	4.53	3.28	5.06	11.85	5.080
K_2O	1.35	1.41	1.38	1.34	1.70	0.89	0.63	0.79
Na_2O	3.94	4.12	4.19	4.12	4.17	2.76	2.16	3.030
P_2O_5	0.61	0.61	0.61	0.61	0.76	0.446	0.359	0.40
Original oxide total	98.75	99.20	99.69	99.28	98.70	99.43	99.46	99.63
Trace-element analyses (parts per million)								
Ni	2	6	0	2	0	66	328	51
Cr	9	10	6	5	2	132	698	61
Sc	14	11	18	11	13	18	31	27
V	281	261	208	232	196	301	31	378
Ba	595	618	506	491	674	299	188	199
Rb	28	29	28	26	34	16	11	12
Sr	963	992	843	859	933	666	550	639
Zr	235	241	273	273	306	232	172	213
Y	31	32	34	35	38	29	23	31
Nb	51.1	51.3	49.6	48.5	61.7	30.6	19.2	22.6
Ga	23	23	24	25	25	23	19	24
Cu	5	7	0	0	0	67	48	65
Zn	122	115	114	122	136	99	108	114
Pb	1	3	0	3	5	2	0	3
La	24	23	15	45	28	7	21	30
Ce	74	71	86	74	91	46	55	29.0
Th	2	5	4	3	4	1	3	3

was installed and the bottom 90 ft was hand perforated to create a well screen. The Waiohuli exploratory well penetrated a 1,940-ft section of subaerial lava flows with interbedded tephra. On the basis of chemical analyses of eight samples of drill cuttings, the Honomanu Basalt/Kula Volcanics contact is placed at 939-ft altitude.

Water-level measurements between September 2001 and April 2002 ranged from 5.58 ft to 6.11 ft above sea level. Water sampled from the well on April 3, 2002 had a specific conductance of 442 µS/cm, a temperature of 19.3°C, and a chloride concentration of 65.9 mg/L.

Table 4. Water-level measurements from the Waiohuli exploratory well (State well 6-4421-01) Maui, Hawaii between September 2001 and August 2002
[Datum is mean sea level]

Date and time	Water level (feet)
September 27, 2001; 14:09	5.58
December 18, 2001; 11:10	6.11
February 14, 2002; 13:20	6.05
April 3, 2002; 11:25	5.91
June 18, 2002; 11:20	5.71
August 22, 2002; 11:30	5.73

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