HIG-79-7

TEMPERATURE PROFILES IN WELLS ON THE ISLAND OF HAWAII

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Geothermal Resources Exploration in Hawaii:
Number 7

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HAWAII INSTITUTE OF GEOPHYSICS
UNIVERSITY OF HAWAII

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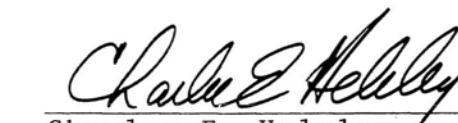

Charles E. Helsley
Director
Hawaii Institute of Geophysics

ABSTRACT

We report temperature versus depth for 21 wells on the Island of Hawaii. The highest temperatures were measured in wells on Kilauea's east rift zone in the Puna area. Temperatures decrease rapidly north and south of the rift zone. Above-average temperatures were observed in two wells in the south Kohala area.

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ACKNOWLEDGMENTS

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INTRODUCTION

As part of the Hawaii Geothermal Project, temperature versus depth profiles were obtained for 21 wells on the island of Hawaii. Three of the wells (GTW-1, 2 and 3) had been drilled on the Puna rift in 1961 for geothermal exploration purposes (Stearns, 1966). The others are wells or test holes drilled for water, which now either are dry holes, contain brackish water, or are unused for some other reason. Wells that are presently being pumped on a regular basis were not measured because the water column is not in thermal equilibrium with the surrounding country rock. Individual temperature measurements for these latter wells can be found in the Division of Water and Land Development Report R34 (1970).

METHOD OF MEASUREMENT

Temperature was measured by sensing the electrical resistance of a thermistor (Fenwall Electronics, 15K Isocurve) that is housed in a water-tight, stainless steel tube. Two housings were used: one with an outside diameter of 0.32 cm, and the other with an outside diameter of 0.56 cm. Four-conductor cable connected the thermistor to the resistance-measuring multimeter on the surface and lowered the thermistor into the well; the use of four-conductor cable permits the elimination of the resistance of the wire. The resistance of the thermistor was measured with a Data Precision digital multimeter.

The thermistors were calibrated by use of a constant temperature water bath and Brooklyn Thermometer Co. calorimeter and precision thermometers. The calibration is accurate to 0.05°C and ±1.0 ohm. Near 50°C the resistance of the thermistor varies by ∿200 ohm/°C, so the accuracy of the calibration is limited by the accuracy of the temperatures measured with the thermometer in the bath.

The accuracy of the well temperatures reported here is limited by temperature variations in the well. Diment (1967) and Gretener (1967) have shown that large-diameter (greater than 10 cm), fluid-filled holes subjected to a thermal gradient are generally unstable and that the fluid in the hole will convect. When the hole is full of water the convection forms small cells whose vertical extent is several times the diameter of the hole. In most of the wells measured, the temperature variation due to convection was from 0.1° to as much as 1.0°C, with a period of several minutes. In wells

where this convection was apparent, the maximum and the minimum temperature was recorded over at least one cycle of the convection cell at each depth where a temperature is reported. A mean of the maximum and minimum is the temperature reported in the tables (Appendix). In some cases, no convection was apparent, inasmuch as no temperature variation was observed.

A more serious problem was encountered in trying to measure temperatures in the air above the water. Most of the wells measured are unused and are opened only for periodic water level measurements. When a well is opened, the air column is disturbed, and consequently, accurate temperature measurements in the air column are difficult unless the well is opened a day or so before measurement to allow the air column to stabilize. This phenomenon, present to some extent in almost all the wells measured, was most pronounced in the high-temperature wells. The temperature in GTW-2 was measured four times. Previous to the 4 Sept. 1974 measurement, the well had been tightly capped, preventing steam from escaping. Thus when the well was opened for the 4 Sept. 1974 measurement, thermal equilibrium was disturbed in the upper part of the hole and high temperatures were recorded in the upper 70 m of the hole. The 4 Oct. 1974 values were obtained after the hole had been open for about 28 hours. After that measurement, a loose cap was installed that allows steam to escape from the well, and it is apparent from the measurement one year later, 3 Sept. 1975, that a new thermal equilibrium had been established in the upper 70 m of the hole.

In some wells, accurate temperature values were obtained in the air column, and these values are reported in the tables (Appendix). It appears that in some wells the air is also convecting; unfortunately, the vertical extent of these convection cells in unknown.

The depths in the tables were determined from marks at one-meter intervals placed on the wire prior to the measurements. The depths were measured from the top of the casing or the top of the nipple in the casing cover and are accurate to 0.2 m. It should be remembered, however, that because of convection, the temperature values are an average of temperatures over some vertical range about the reported depth.

TEMPERATURE DATA

Figure 1 shows the location of wells on the island of Hawaii. The U.S. Geological Survey well numbers are shown adjacent to the wells measured. Locations, depths, and other

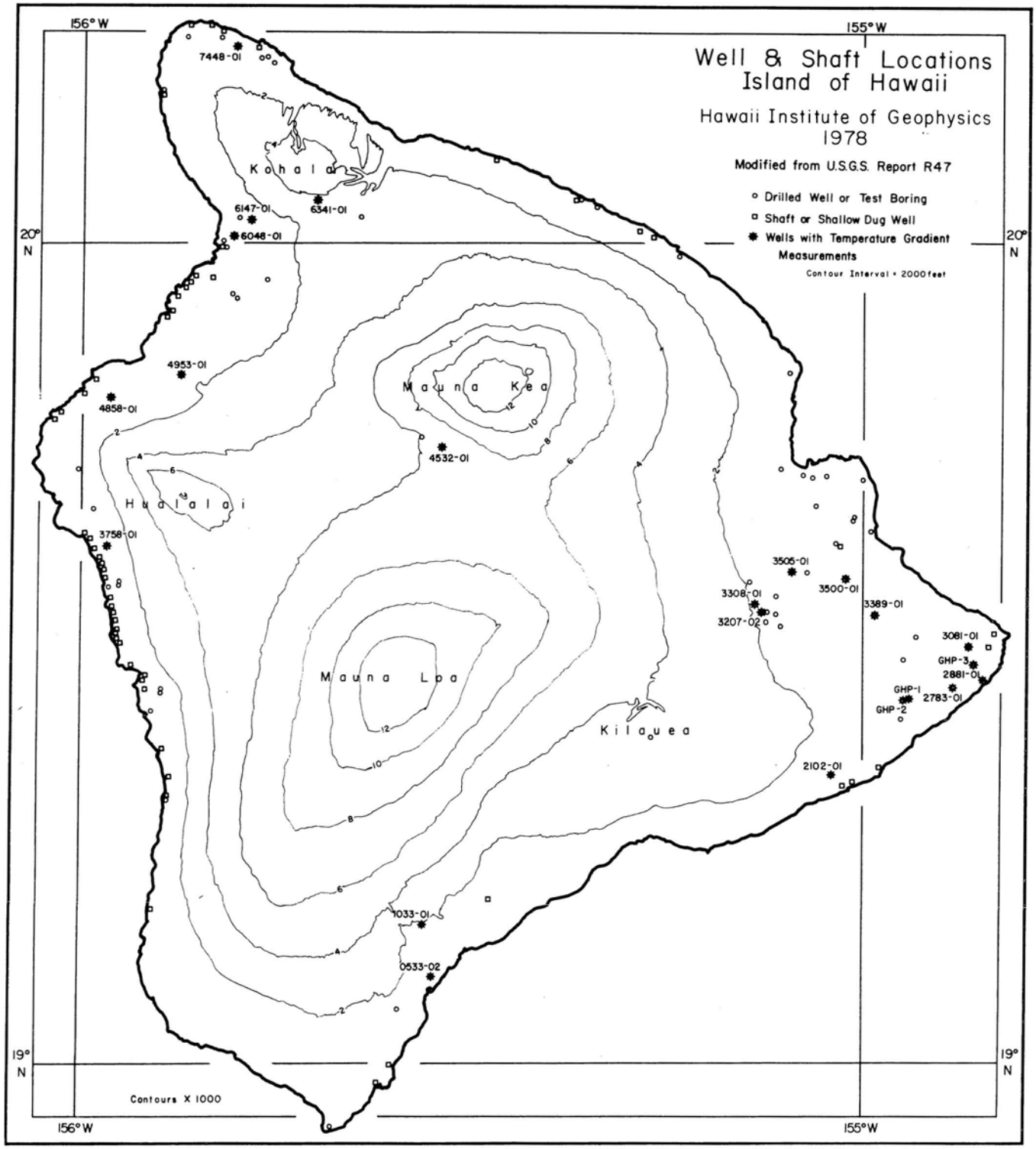

Fig. 1. Well and shaft locations for the island of Hawaii. Wells measured are those with adjacent well numbers. (From Davis and Yamanaga, 1973).

information for these wells are given in the Division of Water and Land Development Report R34 (1970). Table 1 in the Appendix lists data for the wells measured. The remainder of the Appendix contains temperature versus depth profiles and tables for these wells. In the temperature versus depth profiles, the dashed line gives the depth to water. These profiles show that there is often a change in temperature and temperature gradient across the air-water interface. This change is probably caused by more rapid circulation in the air column.

Figure 2 shows the maximum temperature measured in each well. The highest temperatures were recorded in the wells on the Puna rift zone (Fig. 3). Temperatures in 3389-01 (9-4) and 2102-01 (9-10) are considerably lower than temperatures in wells closer to the rift zone, indicating that the temperature decreases rapidly to the north and south of the rift zone.

The elevation of the ground surface at GTW-2 is about 315 m, and the well is dry. Since it was drilled, the hole has caved in at a depth of about 110 m, 60 m above the original bottom. Below 75 m, the temperature increases with depth, and at 110 m it reaches 97°C. The temperature at the bottom of the hole at the time of drilling was 102°C, which suggests that the temperature continues to increase below 110 m. The temperature profile in this well shows discontinuities at 75 m, 90 m, and 105 m, which probably occur at the boundaries of lava flows.

The other wells in the Puna rift, which penetrate the water table, are characterized by an increase in temperature at the water table; the increase is most pronounced in GTW-3. In Figure 4, the temperatures in these wells are plotted relative to mean sea level. GTW-3, and to a lesser extent 2783-01 (9-9, Malama-Ki), show a decrease in temperature near the bottom of the hole, which suggests that the upper water layer in this area has passed through a high-temperature region located upslope from these wells.

Temperature measurements were repeated in four of the high-temperature wells on the Puna rift: GTW-2, GTW-3, 3081-01 (9-6, Kapoho), and 2783-01 (9-9, Malama-Ki); and at one well south of the rift: 2102-01 (9-10, Pulama). There is very little temporal variation in the temperature in GTW-2 and GTW-3 (except for the upper 75 m of GTW-2, which is explained above). Temporal changes of 2 to 5°C were measured in 3081-01 (9-6, Kapoho) and 2783-01 (9-9, Malama-Ki). The cause of those changes in unknown. Data are insufficient to relate the changes to some specific magmatic event or to a change in the pattern of groundwater movement.

Fig. 2. Maximum temperature (°C) measured in each well.

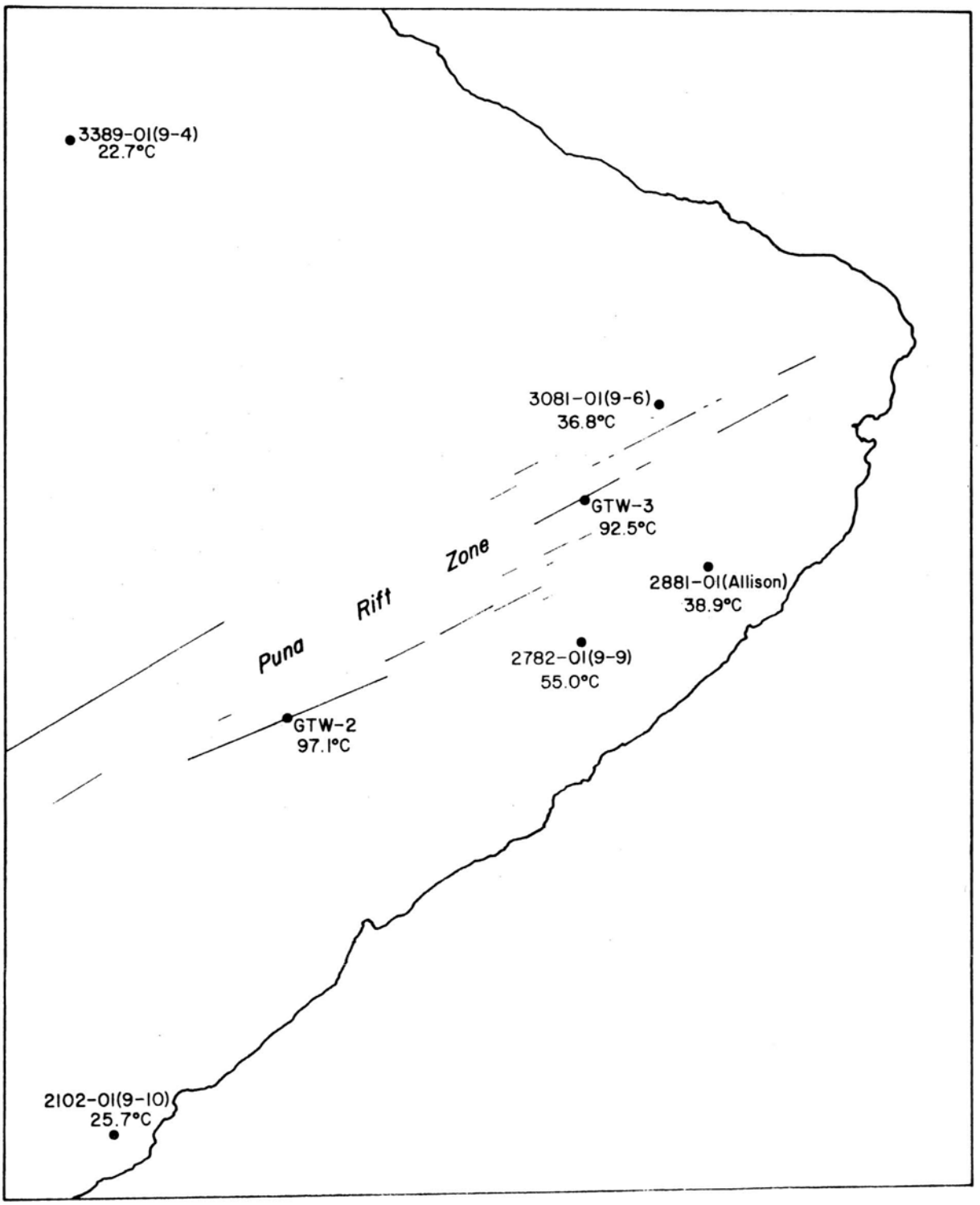

Fig. 3. Location of wells relative to the Puna rift zone. Maximum temperatures are shown below the well numbers.

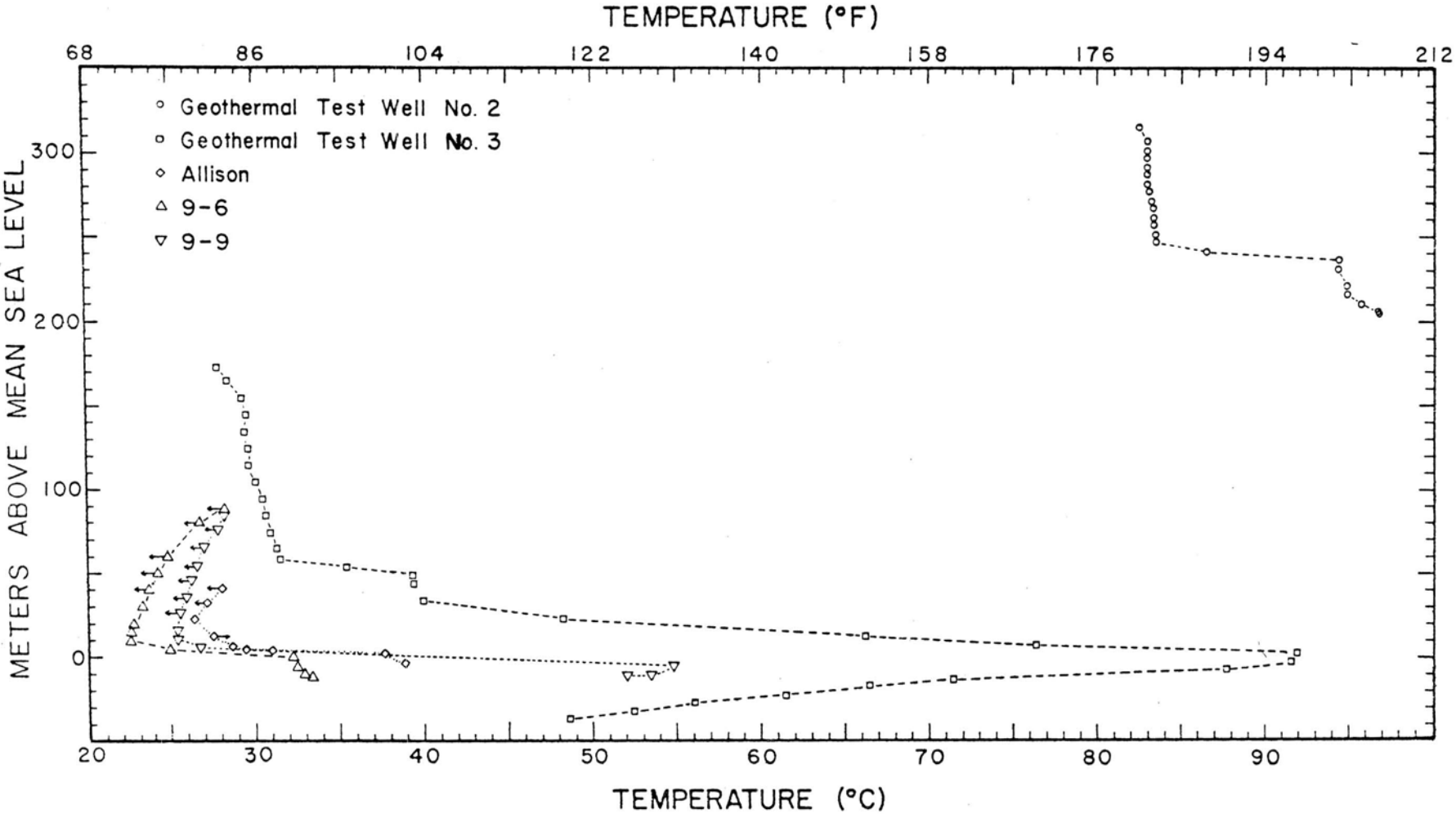

Fig. 4. Temperature in Puna rift wells plotted relative to mean sea level. The arrows indicate nonequilibrium values.

The high temperatures in wells in the east rift zone obviously reflect the continuing volcanic activity along the rift zone. Since these wells are unlikely to be connected directly to the geothermal reservoir located below 1200 m in the rift zone, the presence of temperatures in excess of 90°C within 150 to 200 m of the surface of the rift zone implies that there is some residual heat within the upper few hundred meters of the rift zone. The data also indicate that the temperature, and the amount of heat, vary along the rift zone.

Outside the Puna district, only wells 6048-01 (15) and 6147-01 (16), in the Kawaihae area, have temperatures above 25°C. The water in well 6147-01 has a temperature of 35°C, which increases to 36.6°C in the bottom 10 m of the hole, suggesting higher temperatures at greater depths. Well 6048-01 (15) is located in prehistoric Mauna Kea lava flows, and 6147-01 (16) is located near the contact between Mauna Kea and Kohala flows. The last volcanic activity in that area was the 1859 Mauna Loa flow that came from a vent high in the flank of Mauna Loa and entered the ocean about 16 km south of well 6048 (15), but that flow could not have provided the heat necessary to produce the anomalous temperatures observed in the wells. The heat source must be located in the old Mauna Kea or Kohala lavas. It may be shallower than heat sources in other old regions of the island, or it may be associated with some geologic structure that permits a deeper circulation of groundwater.

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Gretener, P. E., 1967. On the thermal instability of large diameter wells--An observational report. Geophysics, v. 32, p. 727-738.

Stearns, H. T., 1966. Geology of the State of Hawaii. Pacific Books, Palo Alto.

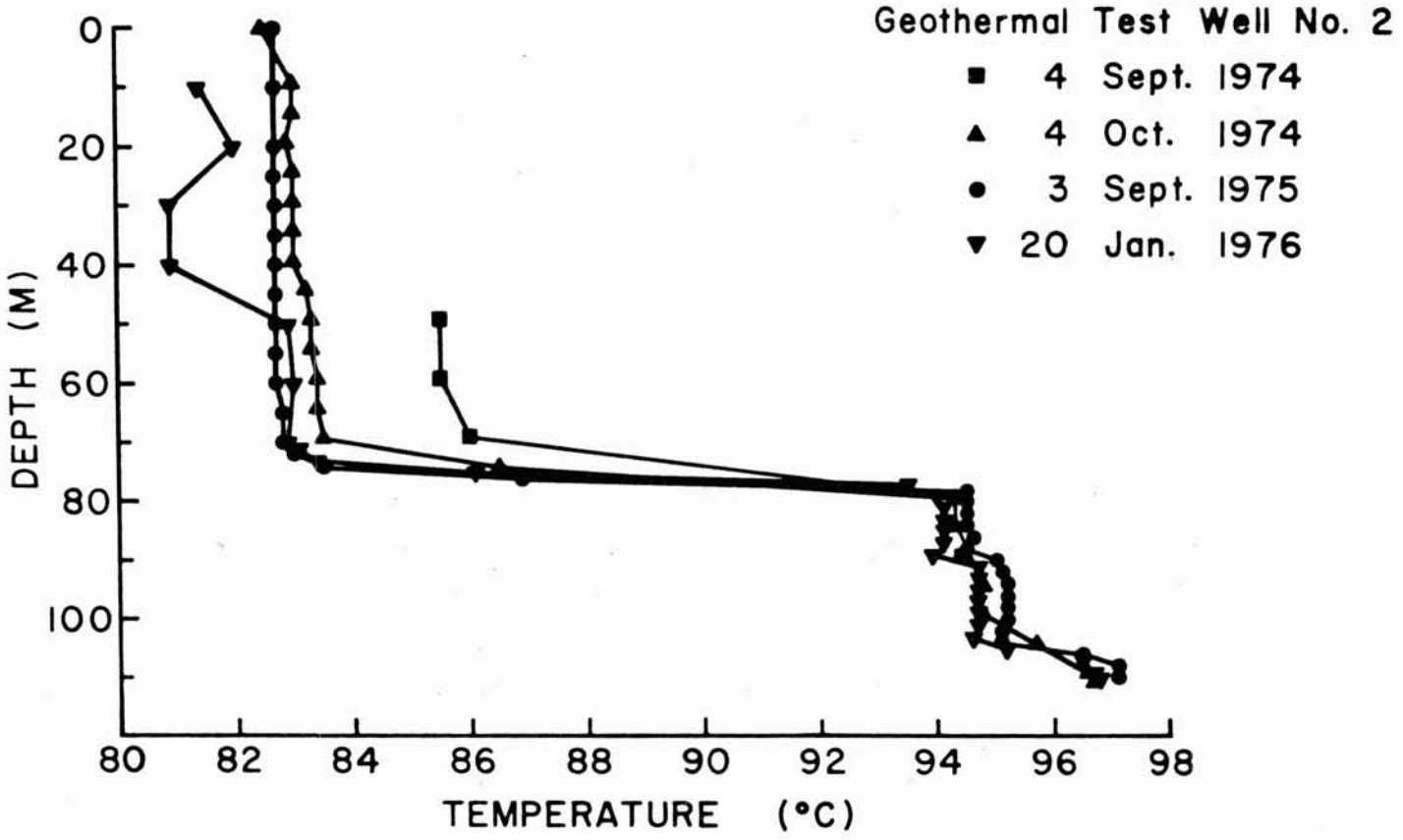
APPENDIX

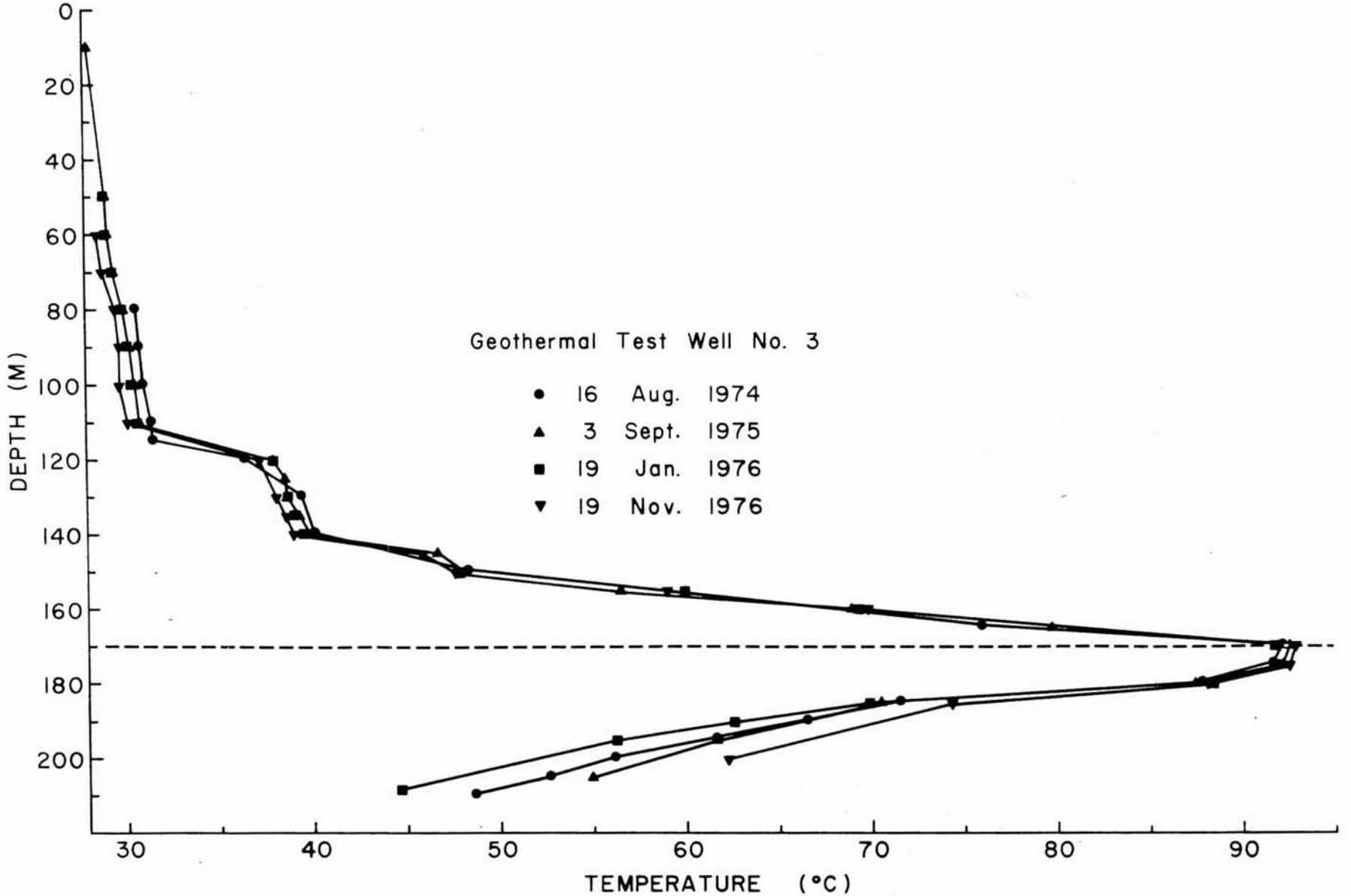
Table 1. Temperature data from wells on the island of Hawaii

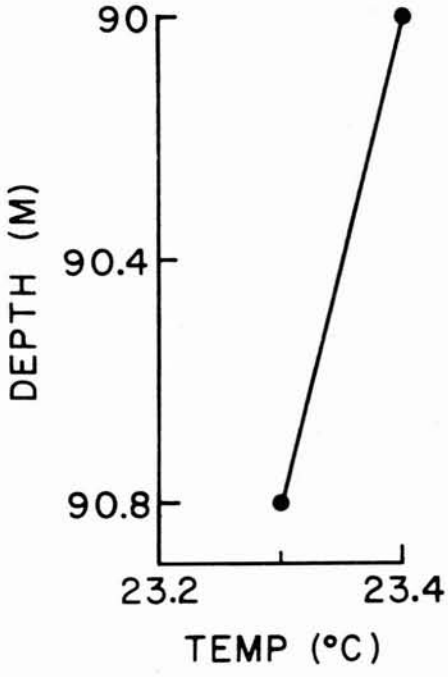
Well Number*	Location	Elevation (m)	Depth to water (m)	Highest Temp Measured (°C)
Geothermal Test Well No. 1	Puna Rift	307.5	**	68.8
Geothermal Test Well No. 2	Puna Rift	315.5	**	97.1
Geothermal Test Well No. 3	Puna Rift	171.6	170.0	92.5
7748-01 and 02 (2 and 2-2)	N. Kohala	94.8	93.0	23.4
3389-01 (9-4)	Keaau - Pahoa	130.1	124.3	22.7
3081-01 (9-6)	Kapoho (Airport)	87.4	86.4	36.8
3500-01 (9-8)	Keaau - Pahoa	94.7	89.8	22.5
2783-01 (9-9)	Malama-Ki	83.5	83.3	55.0
2102-01 (9-10)	Puna	70.1	69.1	25.7
2881-01 (Allison)	Pohoiki (Puna)	39.3	37.8	38.9
0533-02 (10-1)	Kau	25.9	17.7	18.0
1033-01	Kau	609.16	--	19.0
3758-01 (12)	N. Kona	181.4	180.8	20.8
4858-01 (12-7)	N. Kona	152.7	152.5	21.9
6048-01 (15)	Kawaihae	119.5	117.9	26.0
6147-01 (16)	Kawaihae	299.4	297.8	36.6
3505-01 (T1)	Kurtistown	342.9	101.4	15.6
3207-02 (T3)	Mountain View	559.3	104.2	17.4
3308-01 (T4)	Mountain View	580.6	83.0	18.6
6341-01 (T19)	S. Kohala	1101.2	**	16.6
4532-01 (T20)	Saddle	1943.1	**	18.6

* U.S.G.S. numbers with the old U.S.G.S. number in parentheses.

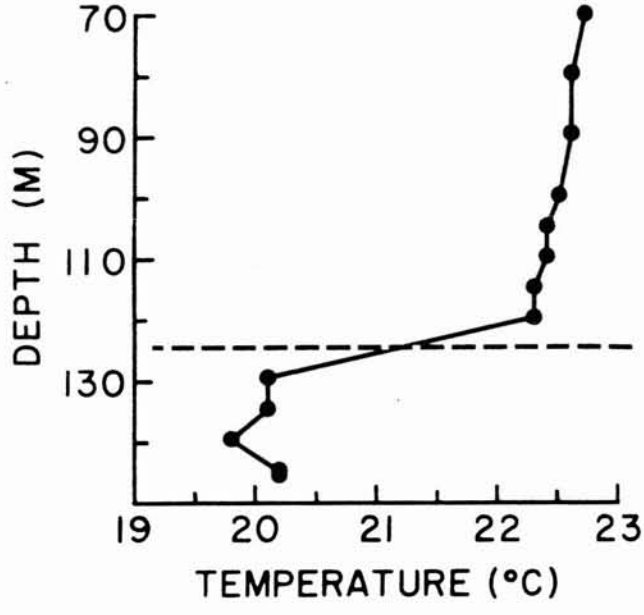
** Does not penetrate water level.


Geothermal Test Well No. 2
4 Sept. 1974
4 Oct. 1974
3 Sept. 1975
20 Jan. 1976
DEPTH (M)
0
20
40
60
80
100
80
82
84
86
88
90
92
94
96
98
TEMPERATURE (°C)

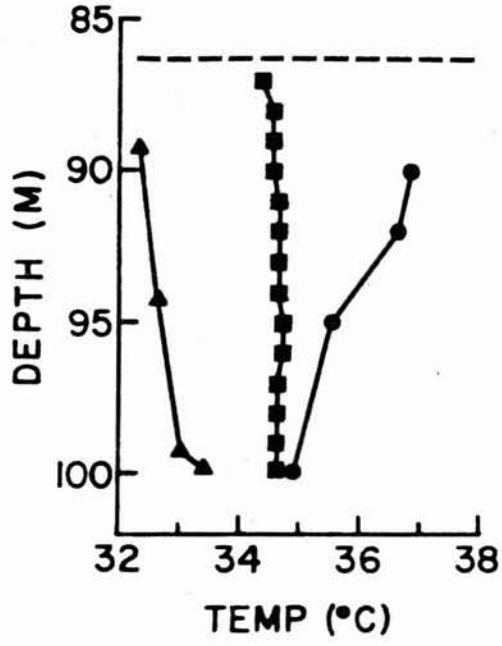

Geothermal Test Well No. 3
16 Aug. 1974
3 Sept. 1975
19 Jan. 1976
19 Nov. 1976
DEPTH (M)
0
20
40
60
80
100
120
140
160
180
200
30
40
50
60
70
80
90
TEMPERATURE (°C)



7448 - 01 and 02 (2,2 - 2, Upolu Point)



3389 - 01 (9 - 4, Keaau - Pahoa)

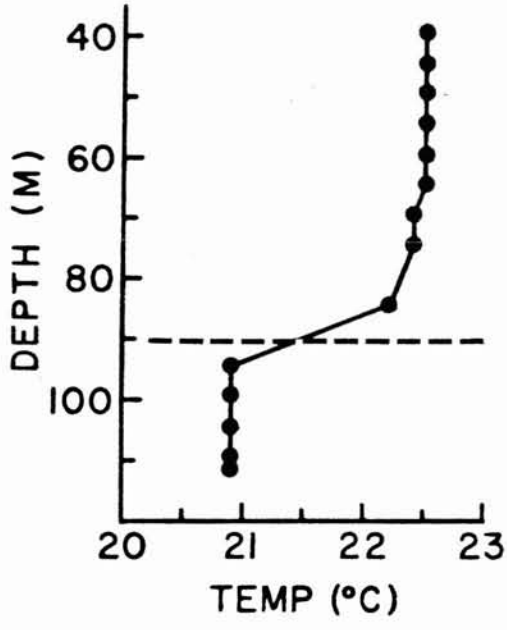


3081-01 (9-6, Kapoho)

▲ 16 Aug. 1974

● 3 Sept. 1975

■ 19 Jan. 1976



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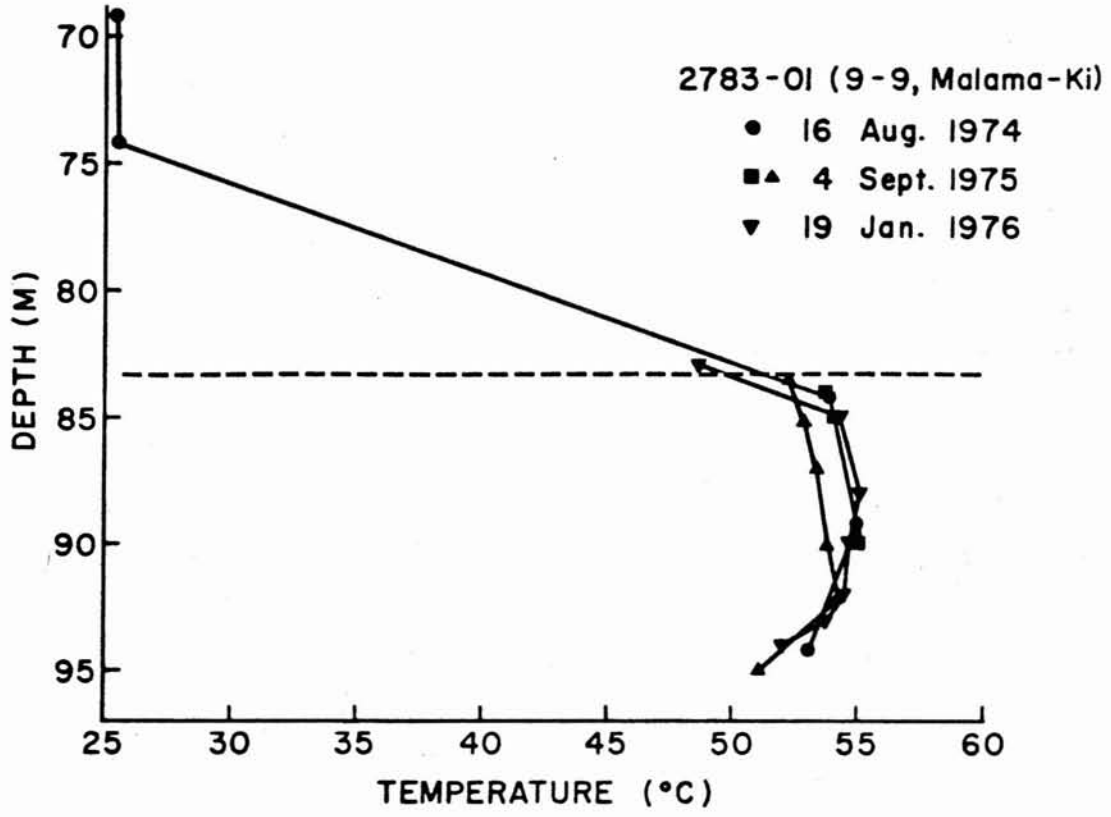
2783-01 (9-9, Malama-Ki)
16 Aug. 1974
4 Sept. 1975
19 Jan. 1976
DEPTH (M)
70
75
80
85
90
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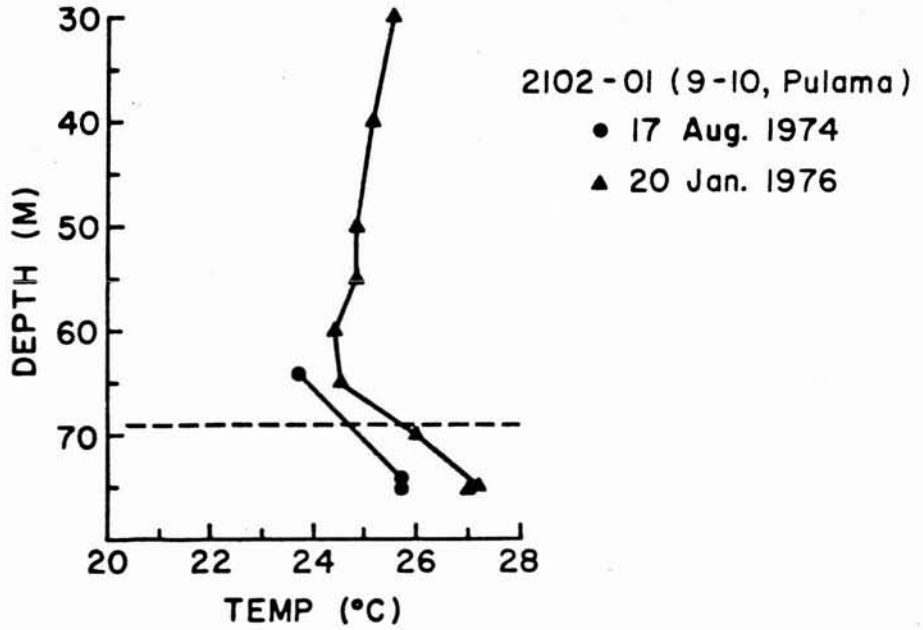
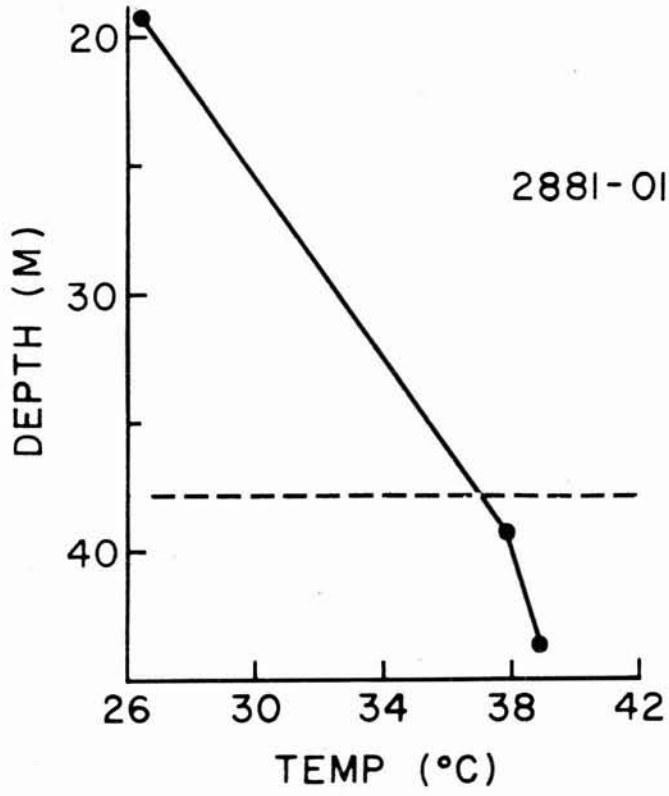
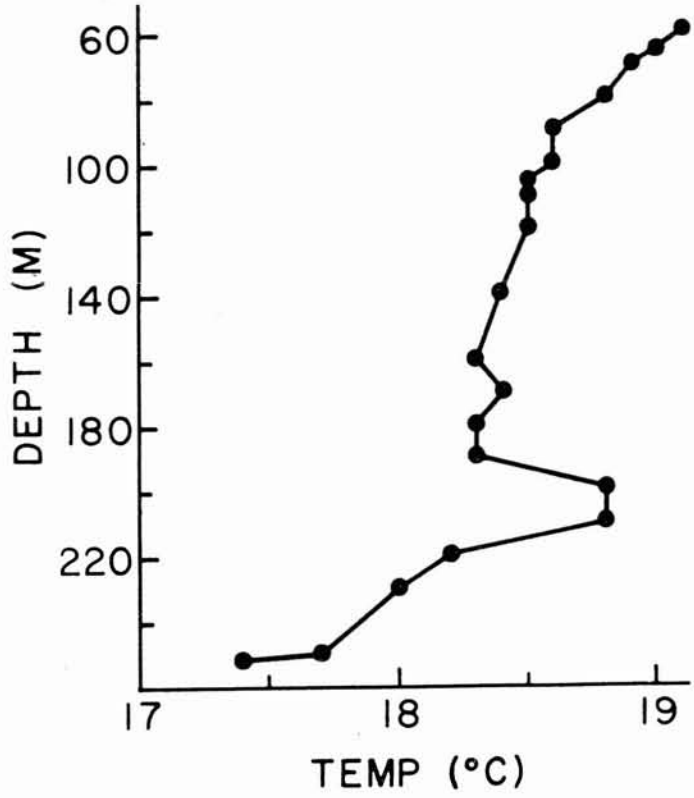
25
30
35
40
45
50
55
60
TEMPERATURE (°C)

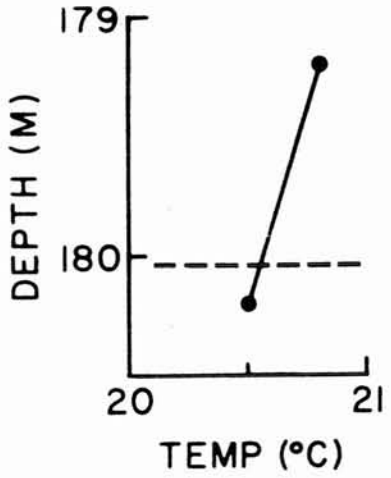

2102-01 (9-10, Pulama)
17 Aug. 1974
20 Jan. 1976
DEPTH (M)
30
40
50
60
70
20
22
24
26
28
TEMP (°C)



2881-01 (Allison, Pohoiki)



1033-01 (Ninole Valley)



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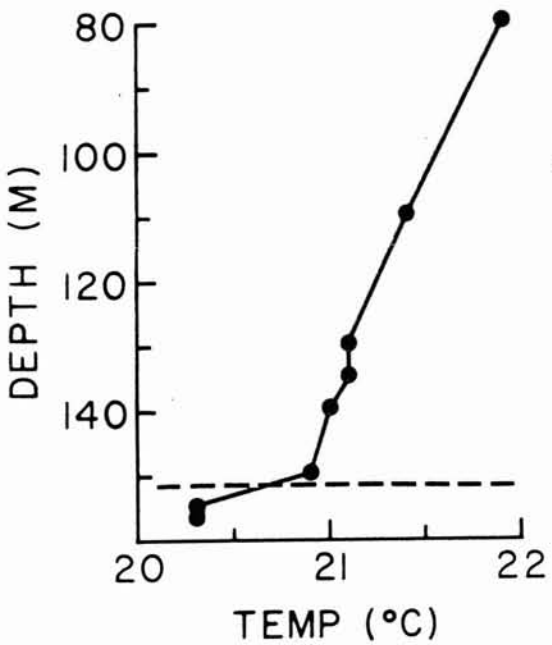

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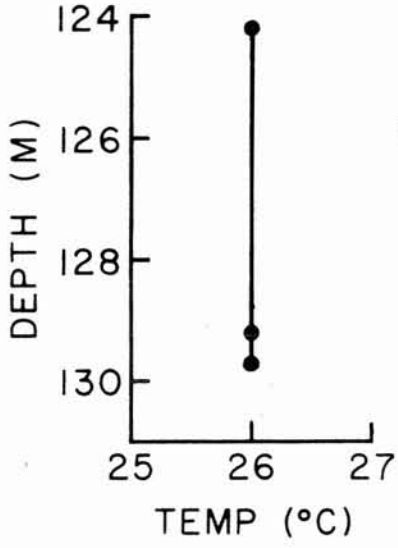

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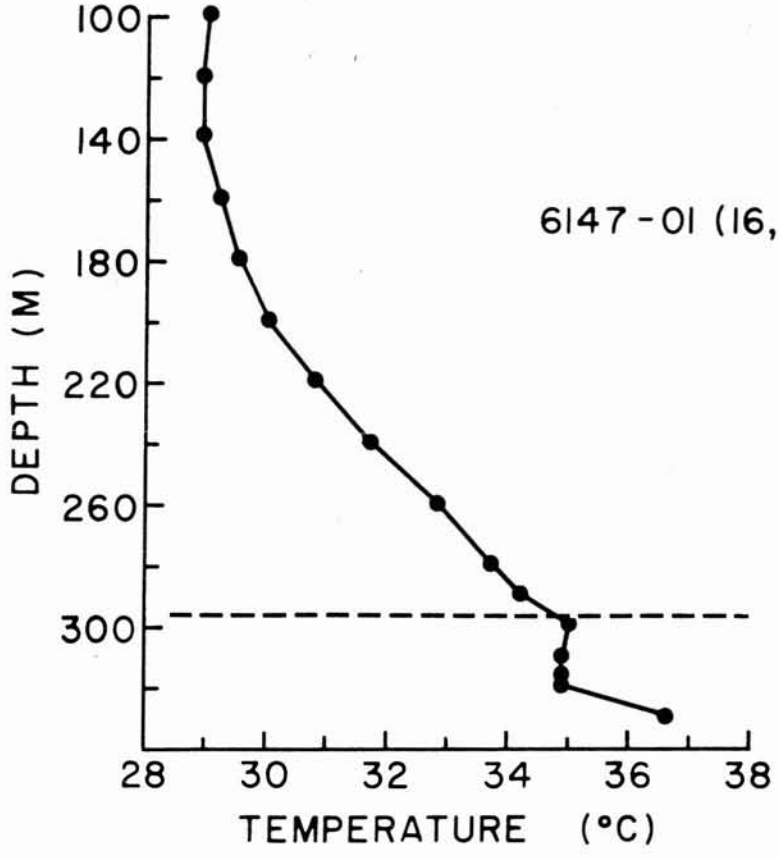
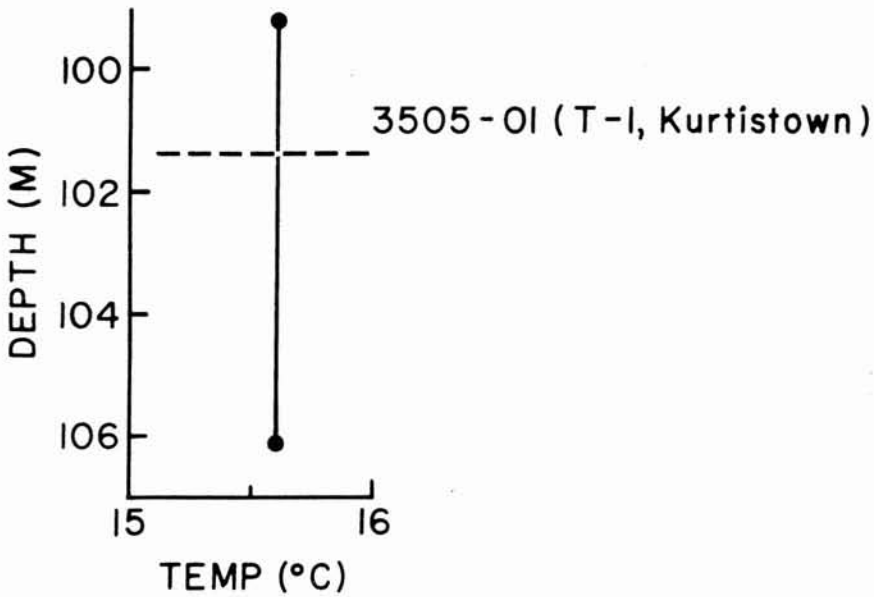
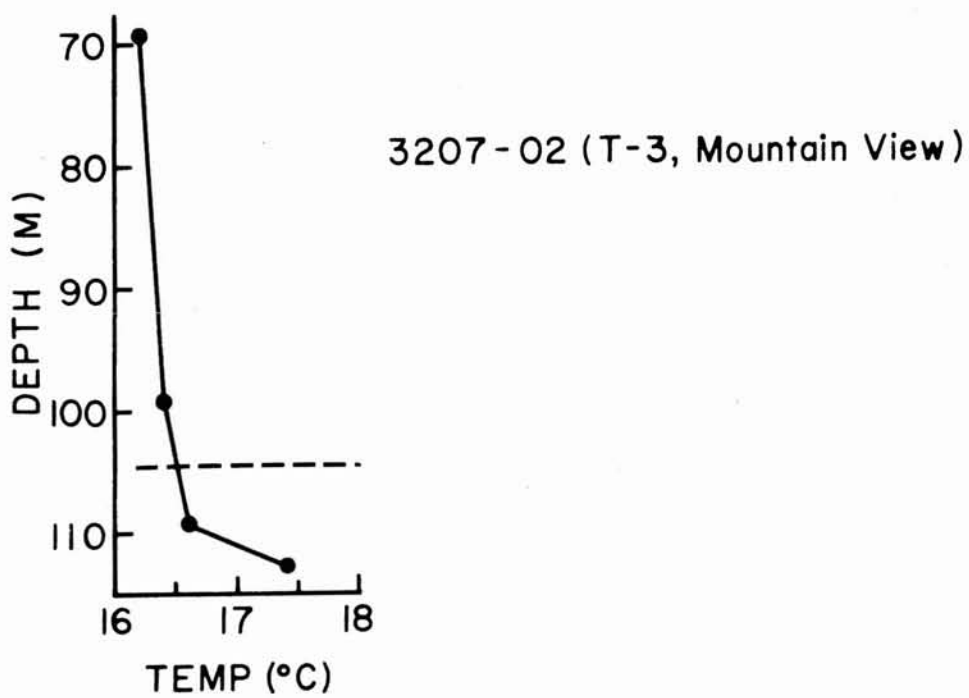


6147-01 (16, Kawaihae)


100
102
104
106
DEPTH (M)
15
16
TEMP (°C)
3505-01 (T-1, Kurtistown)


70
80
90
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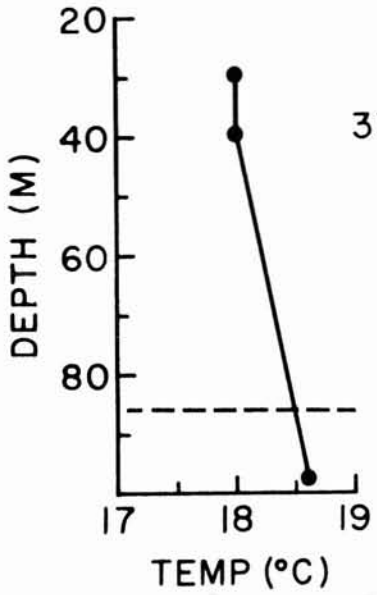
110
DEPTH (M)
16
17
18
TEMP (°C)
3207-02 (T-3, Mountain View)



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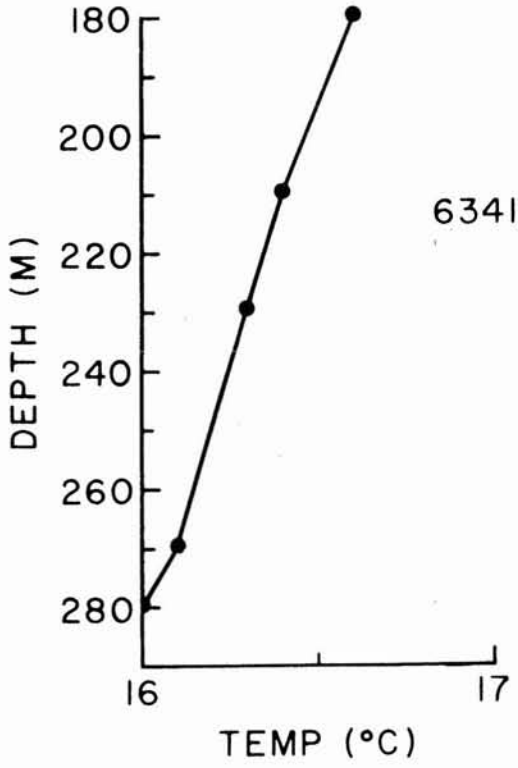

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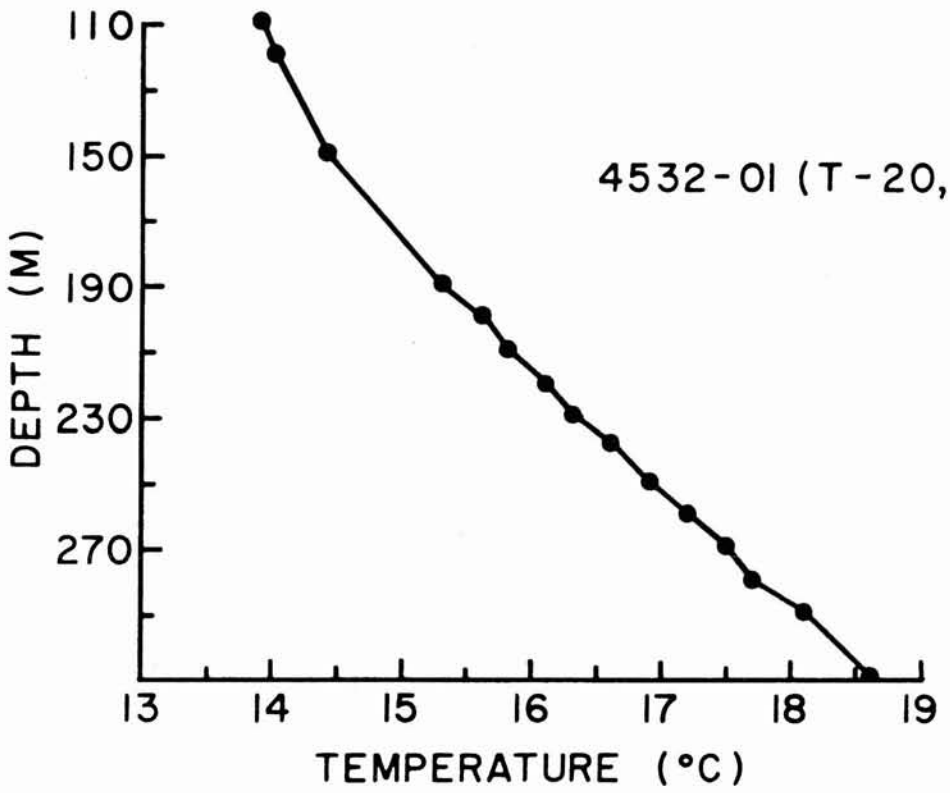

4532-01 (T-20, Pohakuloa, Hamakua)

Geothermal Test Well No. 2
Location: Puna
Date Measured: 4 Oct. 1974

Depth (m)	Temperature (°C)
0	82.5
9.2	83.0
14.2	83.0
19.2	82.9
24.2	83.0
29.2	83.0
34.2	83.0
39.2	83.0
44.2	83.2
49.2	83.3
54.2	83.3
59.2	83.4
64.2	83.4
69.2	83.5
74.2	86.5
79.2	94.3
84.2	94.3
94.2	94.8
99.2	94.8
104.2	95.7
109.2	96.6
110.3	96.7

Geothermal Test Well No. 2
Location: Puna Rift
Date Measured: 4 Sept. 1974

Depth (m)	Temperature (°C)
49.2	85.5
59.2	85.5
69.2	86.0
79.2	94.4
89.2	94.4

Geothermal Test Well No. 2
Location: Puna Rift
Date Measured: 3 Sept. 1975

Depth (m)	Temperature (°C)
0	82.7
10	82.7
20	82.7
25	82.7
30	82.7
35	82.7
40	82.7
45	82.7
50	82.7
55	82.7
60	82.7
65	82.8
70	82.8
72	83.0
74	83.5
76	86.9
78	94.5
80	94.5
82	94.5
84	94.5
86	94.6
88	94.5
90	95.0
92	95.1
94	95.2
96	95.2
98	95.2
100	95.2
102	95.1
104	95.1
106	96.5
108	97.1
110	97.1

Geothermal Test Well No. 2
Location: Puna Rift
Date Measured: 20 Jan. 1976

Depth (m)	Temperature (°C)
10	81.4
20	82.0
30	80.9
40	80.9
50	82.9
60	83.0
70	82.9
71	83.1
73	83.4
75	86.1
77	93.5
79	94.0
81	94.1
83	94.1
85	94.1
87	94.1
89	93.9
91	94.7
93	94.7
95	94.7
97	94.7
99	94.7
101	94.7
103	94.6
105	95.2
107	96.5
109	96.7
110	96.8

Geothermal Test Well No. 3
Location: Puna Rift
Date Measured: 16 Aug. 1974

Depth (m)	Temperature (°C)
79.2	30.6
89.2	30.8
99.2	31.0
109.2	31.4
114.2	31.5
119.2	36.4
129.2	39.4
139.2	40.1
149.2	48.3
164.2	75.9
169.2	92.1
174.2	91.6
179.2	87.8
184.2	71.5
189.2	66.5
194.2	61.6
199.2	56.1
204.2	52.6
209.2	48.6

Geothermal Test Well No. 3
Location: Puna
Date Measured: 3 Sept. 1975

Depth (m)	Temperature (°C)
10	28.2
50	29.1
60	29.2
70	29.5
80	30.0
90	30.3
100	30.6
110	30.8
120	37.9
125	38.6
130	38.7
135	39.3
140	39.9
145	46.7
150	48.1
155	56.5
160	68.9
165	79.7
170	92.5
175	92.1
180	87.4
185	70.5
195	61.6
205	54.9

Geothermal Test Well No. 3
Location: Puna Rift
Date Measured: 19 Jan. 1976

Depth (m)	Temperature (°C)
50	29.0
60	29.1
70	29.4
80	29.9
90	30.2
100	30.4
110	30.7
120	37.9
130	38.7
135	39.1
140	39.5
150	47.9
155	59.9
160	69.3
170	91.7
180	88.4
185	69.3
190	62.5
195	56.2
208.5	44.6

Geothermal Test Well No. 3
Location: Puna Rift
Date Measured: 19 Nov. 1976

Depth (m)	Temperature (°C)
60.1	28.6
70.1	28.9
80	29.4
90	29.7
100	29.7
110	30.2
120	37.2
130	38.1
135	38.6
140	39.0
145	45.9
150	47.7
160	69.8
170	92.8
175	92.5
180	88.1
185	74.3
200	62.2

USGS No. 7448-01 and 02
(2, 2-2)
Location: Upolu Point
Date Measured: 9 Sept. 1975

Depth (m)	Temperature (°C)
90	23.4
90.8	23.3

USGS No. 3389-01 (9-4)
Location: Keaau - Pahoa
Date Measured: 16 Aug. 1974

Depth (m)	Temperature (°C)
69.2	22.7
79.2	22.6
89.2	22.6
99.2	22.5
104.2	22.4
109.2	22.4
114.2	22.3
119.2	22.3
129.2	20.1
134.2	20.1
139.2	19.8
144.2	20.2
145.2	20.2

USGS No. 3081-01 (9-6)
Location: Kapoho (Airport)
Date Measured: 16 Aug. 1974

Depth (m)	Temperature (°C)
89.2	32.3
94.2	32.6
99.2	33.0
99.8	33.4

USGS No. 3081-01 (9-6)
Location: Kapoho (Airport)
Date Measured: 3 Sept. 1975

Depth (m)	Temperature (°C)
90	36.8
92	36.6
95	35.5
99.9	34.9

USGS No. 3081-01 (9-6)
Location: Kapoho (Airport)
Date Measured: 19 Jan. 1976

Depth (m)	Temperature (°C)
87	34.3
88	34.5
89	34.5
90	34.5
91	34.6
92	34.6
93	34.6
94	34.6
95	34.7
96	34.7
97	34.6
98	34.6
99	34.6
99.9	34.6

USGS No. 3500-01 (9-8)
Location: Waipahoehoe
Date Measured: 15 Aug. 1974

Depth (m)	Temperature (°C)
39.2	22.5
44.2	22.5
49.2	22.5
54.2	22.5
59.2	22.5
64.2	22.5
69.2	22.4
74.2	22.4
84.2	22.2
94.2	20.9
99.2	20.9
104.2	20.9
109.2	20.9
111.2	20.9

USGS No. 2783-01 (9-9)
Location: Malama-Ki
Date Measured: 4 Sept. 1975

Depth (m)**	Temperature (°C)
83.38*	52.2
85	52.8
87	53.4
90	53.8
92	54.3
94.90	51.1

*water level - measured by monitoring temperature while lowering probe.

**Depths measured from top of pipe which is 10 cm above concrete pad.

USGS No. 2783-01 (9-9)
Location: Malama-Ki
Date Measured: 16 Aug. 1974

Depth (m)	Temperature (°C)
69.2	25.4
74.2	25.5
84.2	53.8
89.2	54.9
94.2	53.0

USGS No. 2783-01 (9-9)
Location: Malama-Ki
Date Measured: 19 Jan. 1976

Depth (m)	Temperature (°C)
82.91	48.6
85	54.2
88	55.0
90	54.6
92	54.2
93	53.7
94	52.0

USGS No. 2783-01 (9-9)
Location: Malama-Ki
Date Measured: 4 Sept. 1975

Depth (m)	Temperature (°C)
84	53.6
85	54.0
90	55.0

USGS No. 2102-01 (9-10)
Location: Pulama
Date Measured: 17 Aug. 1974

Depth (m)	Temperature (°C)
64.2	23.7
74.2	25.7
75.2	25.7

USGS No. 2102-01 (9-10)
Location: Pulama
Date Measured: 20 Jan. 1976

Depth (m)	Temperature (°C)
30	25.5
40	25.1
50	24.8
55	24.8
60	24.4
65	24.5
70	26.0
75	27.2
75.3	27.0

USGS No. 2881-01 (Allison)
Location: Pohoiki
Date Measured: 17 Aug. 1974

Depth (m)	Temperature (°C)
19.2	26.4
39.2	37.8
43.7	38.91

USGS No. 0533-02 (10-1)
Location: Honuapo Mill
Date Measured: 22 Aug. 1974

Depth (m)	Temperature (°C)
34.2	18.0

USGS No. 1033-01
Location: Ka'u Sugar Co.-
Ninole Valley
Date Measured:

Depth (m)	Temperature (°C)
59.2	19.1
64.2	19.0
69.2	18.9
79.2	18.8
89.2	18.6
99.2	18.6
104.2	18.5
109.2	18.5
119.2	18.5
139.2	18.4
159.2	18.3
169.2	18.4
179.2	18.3
189.2	18.3
199.2	18.8
209.2	18.8
219.2	18.2
229.2	18.0
249.2	17.7
251.2	17.4

USGS No. 3758-01 (12)
Location: Kailua
Date Measured: 24 Aug. 1974

Depth (m)	Temperature (°C)
179.2	20.8
180.2	20.5

USGS No. 6048-01 (15)
Location: Kawaihae Well 2
Date Measured: 27 Aug. 1974

Depth (m)	Temperature (°C)
124.2	26.0
129.2	26.0
129.7	26.0

USGS No. 4858-01 (12-7)
Location: Kaupulehu
Date Measured: 26 Aug. 1974

Depth (m)	Temperature (°C)
79.2	21.9
109.2	21.4
129.2	21.1
134.2	21.1
139.2	21.0
149.2	20.9
154.2	20.3
156.2	20.3

USGS No. 6147-01 (16)
Location: Kawaihae
Date Measured: 27 Aug. 1974

Depth (m)	Temperature (°C)
99.2	29.0
119.2	28.9
139.2	28.9
159.2	29.2
179.2	29.5
199.2	30.0
219.2	30.8
239.2	31.7
259.2	32.8
279.2	33.7
289.2	34.2
299.2	35.0
309.2	34.9
314.2	34.9
319.2	34.9
329.2	36.6

USGS No. 3505-01 (T-1)
Location: Kurtistown
Date Measured: 2 Sept. 1974

Depth (m)	Temperature (°C)
99.2	15.6
106.1	15.6

USGS No. 3207-02 (T-3)
Location: Mountain View
Date Measured: 2 Sept. 1974

Depth (m)	Temperature (°C)
69.2	16.2
99.2	16.4
109.2	16.6
112.7	17.4

USGS No. 3308-01 (T-4)
Location: Mountain View
Date Measured: 2 Sept. 1974

Depth (m)	Temperature (°C)
29.2	18.0
39.2	18.0
97.2	18.6

USGS No. 6341-01 (T-19)
Location: Waiaka Gulch, Waimea
Date Measured: 28 Aug. 1974

Depth (m)	Temperature (°C)
179.2	16.6
209.2	16.4
229.2	16.3
269.2	16.1
279.2	16.0

USGS No. 4532-01 (T-20)
Location: Pohakuloa, Hamakua
Date Measured: 29 Aug. 1974

Depth (m)	Temperature (°C)
109.2	13.9
119.2	14.0
149.2	14.4
189.2	15.3
199.2	15.6
209.2	15.8
219.2	16.1
229.2	16.3
237.2	16.6
249.2	16.9
259.2	17.2
269.2	17.5
279.2	17.7
289.2	18.1
309.2	18.6