Addendum to WRRC Technical Memorandum Report No. 9
"Progress in the Development of Deep Monitoring Stations in
the Pearl Harbor Ground-Water Area, Oahu" and
to WRRC Technical Report No. 4
"Development of Deep Monitoring Stations in the Pearl
Harbor Ground Water Area on Oahu"

The paragraph beginning below the table on page 10 of Technical Memorandum Report No. 9 and beginning the last line on page 14 and ending halfway down page 15 of Technical Report No. 4 state "The water levels in the PVC casing suggested that, contrary to first expectations, there was substantially fresh water with a considerable head in the basalt 1100 below sea level at Ewa Beach. However, it was recognized that all of the water levels might have been affected by the water being contaminated with high-density drilling mud or low-density fresh water. It is also conceivable that all of the water levels might change substantially after the tubes were pumped or with time."

Subsequent longer-term measurement of water levels at the Ewa Beach location have shown that the cause of the high heads when the well was first worked upon decayed to sea level. The USGS has continued to monitor water levels in the basalt and confirmed there is no fresh water component. The water levels measured have been reported as below mean sea level at times.

As shown in Table 4 of the reports, over a 3-hour period, temperature decreased from 24.8°C to 20.0°C. These temperature levels are indicative of warmer fresher and the colder salt water following the negative ocean thermal gradient. Specific conductance E_C increased markedly from 21,800 to 33,000 micromhos, but these are field values taken with an uncalibrated bridge that was subsequently shown to have a large error due to dirty electrodes.

As the fresher water was pumped from the well bore and replaced by saline ground water, the heads decayed so the well no longer flowed after removal of the standpipe. The decay of temperature confirmed replacement by saline water of a temperature consistent with the ocean negative thermal gradient. The increase of specific conductance also confirmed replacement by salt water.

The published reports (in subsequent paragraphs on page 12 of the memorandum report and page 17 of the technical report) recognize that "part of the fresher water may, however, still be drilling water." Based on what had already been recognized in expectation of water levels of salt water in the basal aquifer, the above statement is correct in concept but not degree—that is, <u>all</u> of the head and freshness of water can be attributed to fresh water introduced in the drilling and cleanout process. The bentonite used in drilling was mixed with fresh water, as was the water used in flushing. Capping of the casing prevented the outflow of the fresh water until the cap was removed. During this interval, there was little substantial mixing of fresh water with the surrounding seawater, except along the perimeter of the bulb of fresh water due to lithologic boundaries of the lava flows and boundaries set by the drilling mud. When the standpipe was removed to allow flow and when the well was pumped for several hours at about 50 gpm or when about 10,000 gallons or 1,300 cubic feet of water had been removed from the well, the salinity returned to substantially that of seawater. The bulb of fresh water reacted accordingly with the density difference of the surrounding seawater.

Submitted by Chester Lao January 29, 2003

DEVELOPMENT OF DEEP MONITORING STATIONS IN THE PEARL HARBOR GROUND WATER AREA, OAHU

by

Doak C. Cox

and

Chester Lao

March 1967

Technical Report No. 4

Interim Report

for

HYDROLOGIC CONVERSION OF THE EWA BEACH TEST WELL

OWRR Project No. A-011-HI, Grant Agreement No. 14-01-0001-781

Principal Investigators: Doak C. Cox and Chester Lao

Project period: July 1, 1965 to June 30, 1966

The programs and activities described herein were supported in part by funds provided by the United States Department of the Interior as authorized under the Water Resources Act of 1964, Public Law 88-379.

ABSTRACT

Two deep wells, one at Puuloa and the other at Ewa Beach in the Pearl Harbor area were drilled through the thick sedimentary cap into Koolau basalt, and have been readied for multiple-zone recording of water levels and water quality. Plastic pipes were lowered into the wells to selected depths determined by core composition and electric well logs. Gravel and beach sand were used selectively to backfill the wells. Thirteen sampling tubes were installed in the Puuloa well, and seven sampling points were placed in the main well at Ewa Beach. A shallow auxilliary well was also drilled at Ewa Beach.

Evidence from preliminary development of the deep aquifer at Ewa Beach indicates the possible existence of a thin layer of fresher water floating on water of nearly seawater composition. Water levels are being monitored in this aquifer and show a tidal efficiency of approximately 15 per cent. The smaller sampling tubes are being developed at both sites.

CONTENTS

FIGURES

Figure

TABLES

INTRODUCTION

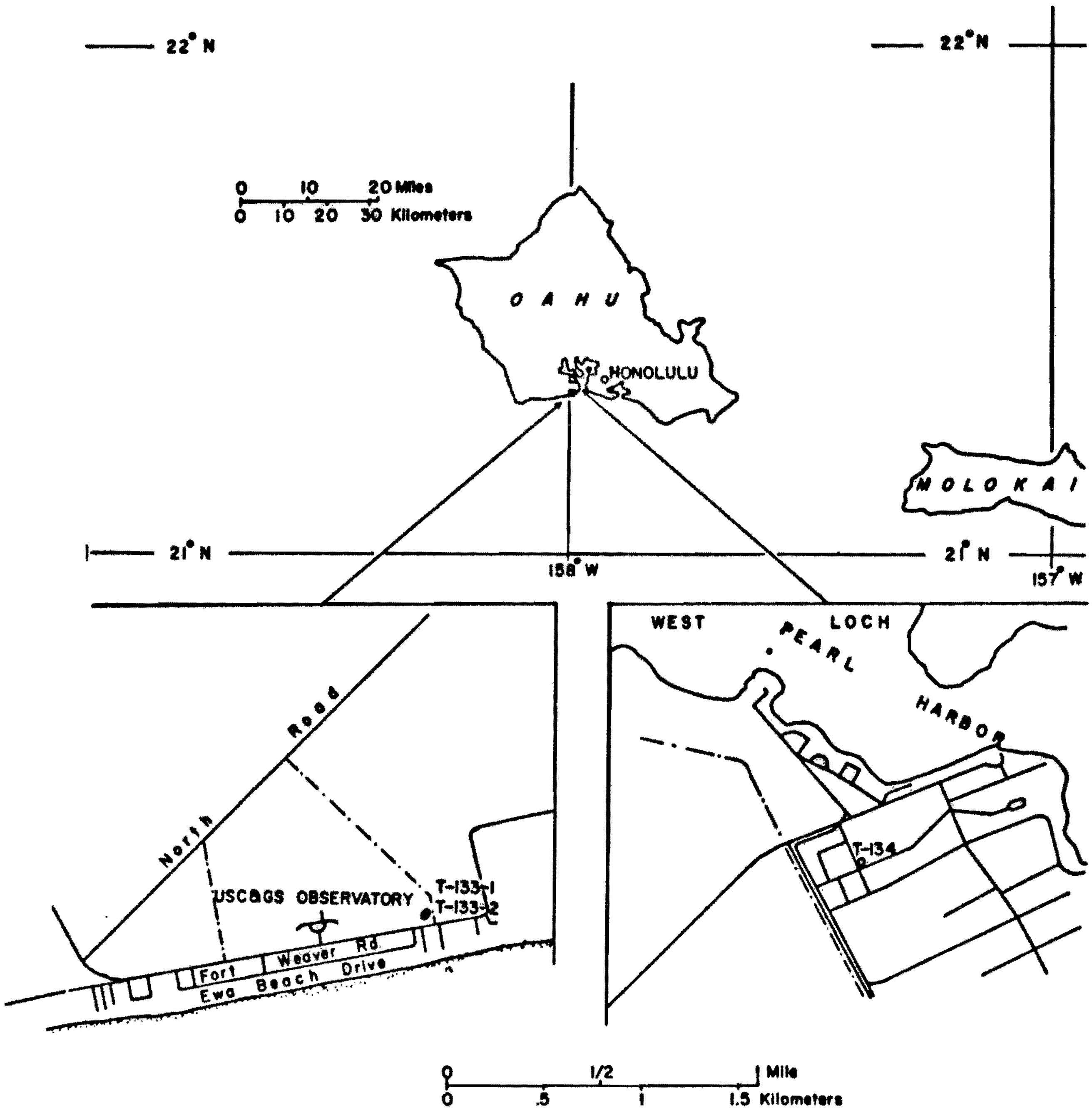
Uncertainties as to the position and behavior of the salt-fresh transition zone at the base of the important, thick Herzberg lenses of Oahu render suspect all determinations of the safe yield of these lenses involving estimates of storage change. A few deep test wells have been drilled to investigate hydrologic conditions in the lower parts of the lenses prior to 1965, but none of these wells has penetrated the lens and entered the salt water beneath. In 1965, the Hawaii Institute of Geophysics of the University of Hawaii drilled two large diameter test wells in the Ewa district for stratigraphic studies. Each of the wells passed through a considerable section of sediments of varying permeability and composition before entering the underlying Koolau basalt lava flows, which constitute the main aquifer.

The head in the Pearl Harbor aquifer in the Ewa district is approximately 18 feet. From this value and the Herzberg ratio of about 40, the depth of the transition between fresh and salt water, assuming static conditions or steady-state dynamic conditions with essentially horizontal flow, may be computed as about 720 feet below sea level. The deeper of the two test wells, located at Ewa Beach (Figure 1), entered the basalts at 1070 feet below sea level. Hence, it was expected that the part of the Koolau basalts penetrated by this well would be lower than the toe of the Pearl Harbor fresh water lens and saturated with salt water if steady state Herzberg conditions existed. It was expected, also, that all but the shallowest of the permeable layers in the sediments would be saturated with salt water, although the coral aquifer at the surface was known to contain fresh or brackish water with a low head (1 or 2 feet msl.).

The shallower of the two wells, located at Puuloa (Figure 1), penetrated the basalt aquifer at 487 feet below sea level and terminated at 544 feet below sea level. It was expected that this well tapped a part of the Herzberg lens in the basalt, although very likely a brackish part with reduced head.

The Water Resources Research Center originally planned to convert only the deeper well for hydrologic monitoring. However, when it became apparent that sealing of the shallower well would be required for water conservation, the Center proposed to pay for the additional cost of con-

FIGURE 1. LOCATION MAP OF EWA BEACH-PUULOA AREAS OF OAHU, HAWAII



version beyond that of simple sealing.

The Center's work on the two wells has been supported by its State appropriation, from Federal funds under the Water Resources Research Act of 1964 granted to the project on the "Conversion of the Ewa Beach Well for Hydrologic Monitoring," and from a grant from the Board of Water Supply of the City and County of Honolulu for Electric Well Logging. Leveling needed has been done by the U.S. Coast and Geodetic Survey (USC & GS) assisted by WRRC personnel. The continuing use of the two wells has been arranged through the courteous permission of the USC & GS on whose land the Ewa Beach well is situated, and the 14th Naval District, on whose land the Puuloa well is situated.

EWA BEACH TEST WELLS

Original Construction

The deep Ewa Beach test well, T-133-1, was drilled with a rotary rig in mid-May 1965 at Ewa Beach (Figure 1) for the Hawaii Institute of Geophysics. Starting from a surface elevation of 4 feet above mean sea level, the well penetrated a 1070-foot section of marine and continental sediments followed by 40 feet of the underlying basaltic lava flows of the Koolau Range, ending at a depth of 1103 feet below sea level. By using a special core barrel, approximately 85 per cent recovery was achieved and many excellent, continuous cores were recovered. The well was cased to a depth of 290 feet below sea level. Because of the interest expressed in the well by the Water Reosurces Research Center, the well was capped on completion, pending takeover by the Center for conversion for continuous hydrologic monitoring.

A multiple-point sampling system was installed in the well based on the expectation that: (i) the Koolau basalts penetrated would be saturated with salt water and be located below the fresh water lens, and the sediments might also be salt water saturated except near the surface, and (ii) consideration of the nature of the rocks penetrated as evaluated from available cores. One point was placed in the basalt and six others in the overlying sediments (Figure 2). Six half-inch polyethylene tubes terminating and pre-perforated at specific depths were taped to a main five-inch perforated polyvinylchloride (PVC) casing. The central casing permitted water to be sampled from the bottom of the hole and also served as a conduit for lowering a special seismometer for the USC & GS.

First Cleanout Attempt

After acquisition of the necessary materials for conversion, the well was re-opened on August 10, 1965 and flowing artesian conditions were found. The artesian head measured at this time with a piezometer was 11.3 ft. msl. Water samples of the flow and from a nearby surface pool indicated the presence of the following constituents:

FIGURE 2

EWA BEACH TEST WELL T-133-1
OAHU, HAWAII

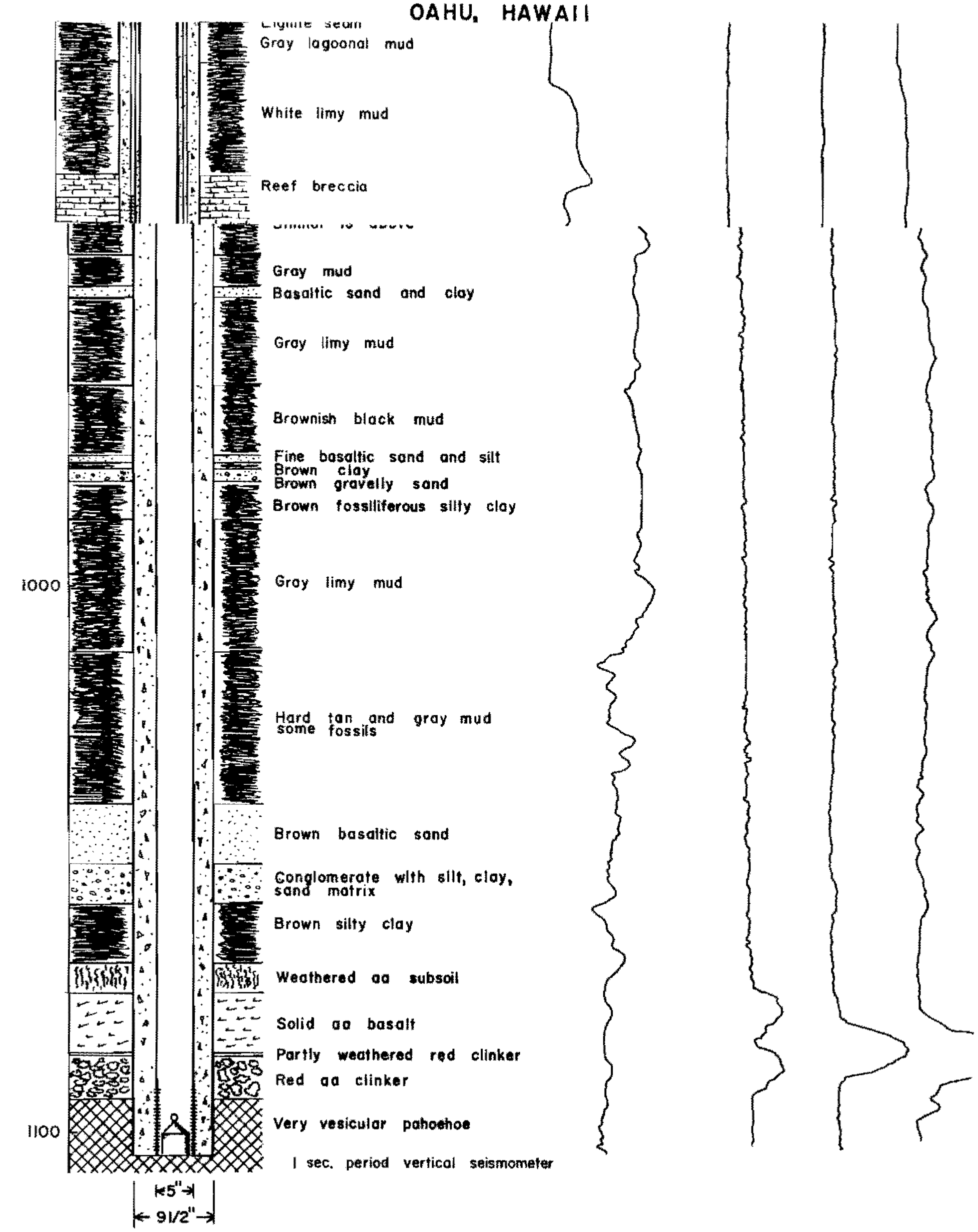


TABLE 1. INITIAL WATER SAMPLE ANALYSIS OF THE EWA BEACH WELL

	FLOW FROM WELL	NEARBY SURFACE POOL
CHLORIDE, MILLIGRAMS PER LITER	8,600.0	3,600.0
HARDNESS AS $CaCo_3$, mg/l	3,700.0	1,600.0
ALKALINITY AS $CaCo_3$, mg/l	180.0	440.0
COLOR, PLATINUM SCALE *	120.0	55.0
pH	5.9	7.6
pH AFTER AERATION	6.3	

*WATER WAS GREEN COLORED, UNFILTERABLE.

The pH values of the well water indicated a very slight acidity of the water, which might promote corrosion problems.

A standpipe was installed the following day. The head as measured by water level rise in the pipe was 9.9 feet msl. A string of 8 inch diameter tools was lowered by a cable-tool drilling rig and hit a bridge at 910 feet below msl. The driller reported 3 feet of penetration in half an hour through dark sticky clay containing some calcareous pebbles apparently sloughed from above.

Tests of artesian conditions on August 12, 1965 indicated a flow of about 5 gallons per minute with the standpipe removed. A partial traverse of the well to a depth of 625 feet made with a U. S. Geological Survey Au deep-well current meter by K. Y. Chang of the USGS and C. K. Lum of the Board of Water Supply (BWS) failed to indicate any conclusive flow component with the standpipe on or off. The meter was subsequently found to be very insensitive. A recovery test after reinstallation of the standpipe showed 67 per cent recovery occurred in the first two minutes and 75 per cent in the first 5 minutes.

A piezometer test was performed on the same day, using a half inch polyethylene pipe lowered into the well. The standpipe was left in place for a reference level. The head was measured and water samples were taken for temperature and chloride analysis at each of the five levels. Five minutes of flow were allowed for the tube to clean out before sampling and head measurement at each level. The results are tabulated below.

TABLE 2. INITIAL WATER LEVEL MEASUREMENT OF THE EWA BEACH TEST WELL

TIME	SAMPLE DEPTH (MSL)	WATER LEVEL INSIDE STANDPIPE (MSL)	WATER LEVEL INSIDE TUBE (MSL)	TEMP °C	CHLORIDE (mg/l)	pH
14.36	7	10.09	10.09	32	--	--
14.53	287	10.23	10.18	41	9000	7.3
15.05	387	10.30	10.22	33	9090	7.3
15.17	487	10.37	10.30	32	9250	7.3
15.28	587	10.44	10.77	23	8580	7.3

The drilling tools were run into the hole on the next day in an attempt to drill out the bridge. The 625-foot point at which the current meter had been stopped was passed by the tools without difficulty, but they were stopped at 898 feet below msl, and when drilling commenced, the bit became stuck. It was jarred loose and brought up covered with black clay.

On August 16, 1965, the bit was run back into the hole which had filled to 890 feet below msl. Work was suspended on this date and a blind flange with a 2-inch coupling and plug was installed the following day. The job was shut down pending the availability of a large rotary drilling rig.

Auxiliary Well Construction

On May 18, 1966 a shallow hole, T-133-2 was drilled to a depth of 260 feet near T-131-1 by the Hawaii Institute of Geophysics to attempt better core recovery in the upper horizons, poorly sampled in the first hole. To provide for hydrologic monitoring of the interval cased off in the deep hole, this shallow hole also was taken over by the WRRC and deepened to 280 feet. Electric logs were run in this well. A three-inch diameter PVC casing was perforated with four rows of 1/8 inch holes, 12 to the foot, for four feet at five-foot intervals. These lengths were cemented into 42-foot lengths and then lowered into the hole. Crushed rock, plus 3/16 in., was used to fill the annulus to the surface. A threaded coupling was cemented to the hole at the top and a plug screwed into the coupling on May 23.

The construction, lithologic log, and electric logs of T-133-2 are shown in Figure 3.

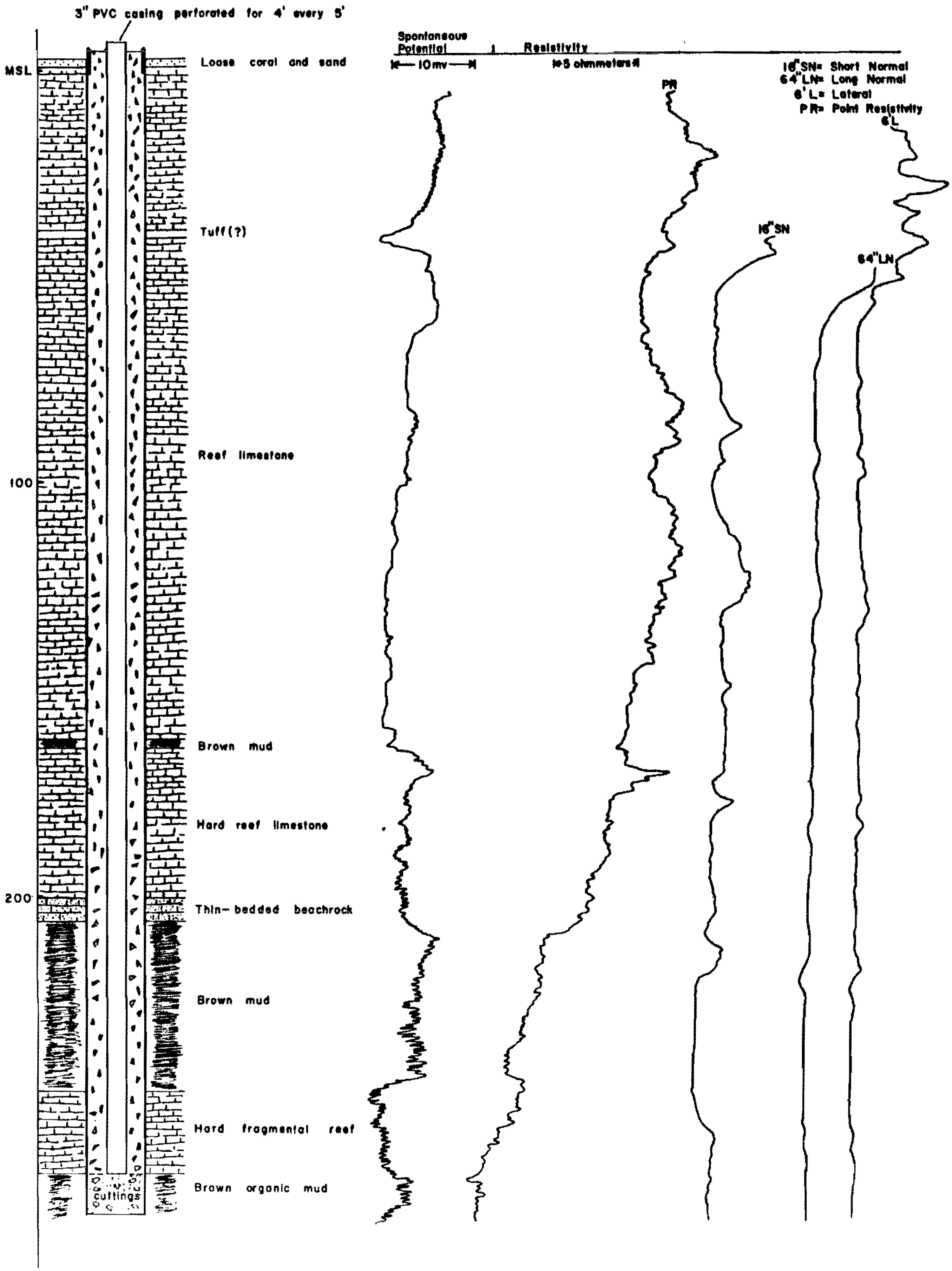
Cleanout, Logging, and Casing

On June 25, 1966, cleaning out and casing the deepest hole, T-131-1, was commenced again when a large rotary rig became available. The top and bottom of the material bridging the hole were found at 853 and 990$\pm$ feet below msl. Material brought up by the return drilling fluid consisted mostly of dark clay, fragments of carbonized wood, and bits of coral. The lava portion of the hole was reamed out from 7-1/2 inches to 9-7/8 inches and bits of lava came up in the cuttings at this stage. The hole was completed at a depth of 1,111 feet below msl.

After the cleanout process, but before the casing and sampling tubes were lowered, electric logs were made of the well (Figure 3). Although four types of surveys were accomplished, the resulting logs were not as successful as desired. After the 16" Short Normal and about half of the 64" Long Normal surveys had been run, the winch transmission failed and the sonde had to be hoisted manually. This produced erratic instead of smooth curves on the 64" Long Normal, the 6' lateralog and the Single Point surveys. The site also had a high electric noise level from either natural or induced ground currents which were evident in the electric logs.

In the meantime, the 5-inch PVC casing was glued into 63-foot lengths on the ground preparatory for hoisting by the traveling block to be lowered into the hole. The bottom 12 feet of casing was perforated with 4 rows of 1/4 inch holes, 6 to the foot. A chamfered coupling was glued on the bottom. Six half-inch O. D. polyethylene sampling pipes and a 1-inch polyethylene pipe intended to serve as a conduit for a sounding line and a tremie tube for backfilling were spooled on large wooden reels to be fed out as required. The ends of the sample pipes were sliced on the bias and securely taped to the PVC casing at points that would bring them to 310, 398, 546, 566, 594 and 770 feet respectively

FIGURE 3. EWA BEACH AUXILIARY TEST WELL, T-133-2
OAHU, HAWAII



below sea level when installed. The bottom twelve feet of each pipe was perforated with 2 rows of 1/8 inch holes, 12 to the foot.

Following the electric logging, the casing and attached sampling tubes were run into the hole. After each 63-foot section of casing was cemented to one already in the hole, 10 minutes were allowed for the special cement to set. The sampling tubes were also taped above and below each joint as the casing was lowered. For additional strength, after about 400 feet of casing had been run, the couplings were reinforced with four and then six 3/8 inch dowels.

A one-inch O. D. pipe was tied with a piece of string, threaded through holes in the PVC and taped loosely just above the chamfered coupling. This pipe was intended to be broken loose after the casing and sampling tubes were placed into position at the bottom. However, the tube was separated accidentally while being lowered at approximately the -970 foot level. With the bends that probably developed because of the loss of tension, considerable friction occurred between the tube and sounding line, jamming the line several times. Although meant to be pulled up gradually as the backfilling progressed, the tube never served the intended purpose and was actually pulled completely out of the hole before the fill reached it to provide more space for the passage of fill material.

After the sampling tubes and casing were in place, a two-inch pipe was lowered inside the casing. Water was pumped down the pipe to displace the drilling mud within the casing and annulus. The water flow from the well, which had stopped after drilling mud was introduced, returned when the drilling mud had been cleaned out sufficiently.

The tight work load of the contractor required the immediate removal of his rig to the Puuloa test well. On July 1, 1966, while the site of the Puuloa well was being prepared, a 6.3 inch standpipe fabricated of a 12-inch diameter corrugated steel culvert welded to a 1/4 inch steel plate was installed on a flange to prevent the well from flowing. The well was left in this condition until work on the other site was completed. After installation of the standpipe, the water level rose to about 8 feet above msl. Sounding inside the PVC casing with a stainless steel cable and a lead weight indicated a depth of 1,109.

About a week later when the standpipe was removed in order to repair leaky riveted joints, the water stood approximately 11 feet above msl. Since then, the normal level fluctuates over a range of a foot or so, mostly in response to tidal loading of the aquifers. On July 25, 1966, however, after two days of heavy rainfall, the head rose to 13.07 feet msl, measured by raising the flowing one-inch polyethylene tremie until flow ceased. Water samples taken from the tube, the overflowing standpipe and the nearby shallow well indicated chloride contents of 1530, 3300, and 7975 milligrams per liter, respectively. There appeared to be relatively fresh water flowing from below 970 feet. This will be discussed later.

Backfill

Backfilling the well was not a simple task owing to the small annulus left by the casing and the tubes. The principal difficulty was the inability to sound the annulus area because of obstructions, the small clearance available, and the one-inch polyethylene tube was not successful for either sounding or running in fill. A fine stainless steel cable was lowered down the tube to the bottom, but the high friction did not permit accurate sounding. Because of difficulties encountered in extracting the line from the tube, it was left there until the tube itself was withdrawn from the hole.

On July 8 when the 6' lateral sonde was lowered into the PVC casing to straighten out its cable, it was found that the depth inside the casing had decreased. The one successful sounding attempt outside the casing with the fine steel cable able to reach bottom indicated an approximate depth of 1,075 feet. Since the PVC appeared to be filling with material squeezed through the perforations from outside, it was thought that bailing the material in the casing would create a differential condition and more material could be induced to infiltrate into the casing.

A bailer was devised from a length of 2-3/4 inch O. D. pipe with a flapper valve installed at the bottom and a short length of heavy chain attached to the top. After being lowered by rope to the bottom, the bailer was hoisted and allowed to fall free several times. The material brought up by the bailer consisted of water, drilling mud, and sand-sized cuttings. Approximately 6 feet of material was bailed from the casing. Sounding the casing with a newly purchased nylon-coated sounding line indicated it was clean to the bottom. Six days later, a repeat sounding of the casing showed an accumulation of two feet of fill, which had either settled out of suspension, sloughed from the inner walls of the casing, or infiltrated through the perforations.

To add to the difficulties, a water-tight bridge developed through caving just below the steel casing of the well.

The problems were solved by lowering 3/4-inch steel pipe into the hole using a tripod and block and tackle. The bottom coupling was sharpened to form a chopping bit. Water could be passed down the pipe to jet, if necessary, through bridges. The weight of the pipe alone was sufficient to penetrate and eliminate blockages in the annulus. A total of 714 feet of pipe was lowered and several bridges were broken up before the bottom of the annulus could be consistently sounded. A significant improvement accomplished by the pipe was to straighten the PVC and allow a direct path to the bottom for the fill. As filling progressed the pipe was withdrawn gradually and dismantled.

When the filling of the annulus was begun, there was already approximately 35 feet of material around the casing. The material consisted of flocculated drilling mud, cuttings which settled out of suspension, in addition to particles of coral and basalt probably sloughed from the walls and the bridges. Twenty cubic yards of beach sand and 7 cubic yards of crushed rock were used to fill the annulus. As it was not possible to keep the sounding line in the annulus while it was being filled without danger of jamming, increments of fill were dumped in and then the accumulation was measured. The sampling zones were packed with gravel, and beach sand was used for the non-permeable sections. Some drilling mud was deposited approximately 40 feet above the bottom and also near the top of the steel casing to ensure that no flow would occur. Water stood in the steel casing until the very last shovel of fill was placed on August 23, 1966.

Before the USC & GS seismometer could be landed on bottom, fifty-three feet of fill, which had infiltrated through the perforations with the increasing load, had to be bailed from the casing. On bailing, the material was found to be composed mostly of drilling mud, fine cuttings, and some larger fragments of coral, lava, and fissile clay. The transfer of material probably coincided with a rather sudden settlement of about 70 feet of the fill in the annulus and the simultaneous ejection of water from the casing noted at the 450-foot level.

Reconciling the amount of settlement in the annulus with the amount of fill found in the casing is a matter for conjecture. Since drilling mud probably comprised a good part of the material, it could have moved easily to areas such as the pore spaces in the gravel pack or through the perforations into the casing. Part of the settlement could have been into bridged cavities. Most of the settlement undoubtedly occurred in the bottom portion of the hole.

To clean out the casing, the original bailer was modified by adding an additional length of pipe and altering the flapper valve slightly. Virtually all of the bailings were drilling mud and fine cuttings. Some gravel of the type used in the fill, bits of reef rock, small pieces of basalt and a few pieces of dark clay were also removed from the casing. When the bailing operation was completed, the selected fill had again settled 8 feet around the casing. The piston action of the hoisted bailer probably helped develop the bottom of the well as well as to induce material to flow through the perforations. The construction of the well, as completed with the several casings, sample pipes, and backfill, is shown schematically in Figure 2.

The USC & GS seismometer was lowered to the bottom within a half hour after completion of the bailing operation. A hoisting cable and an armored conductor cable were attached to the instrument and then run over sheaves into the casing. The cables were bound to the flange at the surface. A short trench was dug for the seismometer conductor cable to the cable leading from the recording house at the observatory.

On September 16, 1966, water levels were measured at the Ewa Beach wells using a battery-powered sounder borrowed from the Board of Water Supply. The electrode was lowered into the tubes until electrical contact was just established. The water levels obtained are shown in Table 3.

The water levels in the PVC casing suggested that, contrary to first

TABLE 3. WATER LEVEL MEASUREMENTS AT THE EWA BEACH TEST WELL AFTER BACKFILLING

	WATER LEVELS - T-133-1	TIME 12:45-13:30	
TUBE NUMBER	W.L. FROM FLANGE*	W.L. FROM MSL*	SAMPLE ZONE DEPTH MSL*
1	-1.4	+3.1	-310
2	-2.1	+3.4	-398
3	-18.4	+12.9	-546
4	-17.7	-12.2	-566
5	-17.4	-11.9	-594
6	-21.5	-16.0	-770
PVC CASING	+0.8	+6.5	-1104
	WATER LEVELS - T-133-2	TIME 13:45	
	W.L. FROM COLLAR*	W.L. FROM MSL*	
PVC CASING	-3.6	+1.5 (ESTIMATED)	

*ALL MEASUREMENTS ARE GIVEN IN FEET.

expectations, there was substantially fresh water with a considerable head in the basalt 1100 feet below sea level at Ewa Beach. However, it was recognized that all of the water levels might have been affected by the water becoming contaminated with high density drilling mud or low density fresh water. It is also conceivable that all of the water levels might change substantially after the tubes were pumped or with time.

Development of the Aquifers

The communication between the main casing and the six additional sample tubes and the respective aquifers appear to be relatively poor suggesting a good hydrologic separation in the well. Attempts have been made to develop the well at several aquifers. This development work has been done with the cooperation of R. Dale and I. Yamashiro of USGS.

A first attempt to develop the bedrock aquifer was made on October 26 using a swab made by wrapping and wiring pieces of a rubber inner tube to a section of the bailer. At the start of the operation, the water level stood slightly above the top of the PVC casing coupling with a small quantity of water spilling over the side. The swab was lowered over a sheave hung from a tripod on a length of rope. A wheel rim was used as a cathead for lowering and raising the swab. As a consequence of the swabbing, the fill settled an additional 5.7 feet, and the water level in the PVC casing dropped to about 8 feet below the coupling or 1.6 feet below MSL. A suction pump delivered about 5 gpm of water from the casing with a substantial but unrecorded amount of drawdown.

A second attempt was started on November 2, using dry ice and pumping. On the first day, 10 pounds of dry ice was lowered into the well brick by brick. After the dry ice was expended, the suction pump obtained about a half-hour of clear water conditions. The water then became turbid with bits of flocculated drilling mud and cuttings. A very thick suspension of drilling mud and cuttings began to pour out of the pump after an hour and continued to flow for about twenty minutes. The yield increased from about 12 to 23 gpm by the end of this period. An additional twenty-five pounds of dry ice was added six days later and pumping resumed. The output from the pump increased to 32 gpm, then to about 40 gpm, pumping clear water with a drawdown of 5 feet. The well was also surged by shutting off the pump and pumping in water from the auxiliary well. By this time, the well had been pumped approximately 18 hours in three days. The fill had settled an additional 0.3 feet to 6.0 feet below the flange.

The pumping level on November 2 was 18 feet below the collar or -12.5 feet msl, and after 5 minutes of shutting down, the water level rose to -6.5 feet msl. The next day the water level was at -2.47 feet msl in the large casing in the main well and at +2.1 feet msl in the auxiliary well. During this period, intermittent heavy rains were ponded near the wells for several weeks.

During the aquifer pumping, periodic samples were collected for temperature and conductivity analysis. The results are shown in Table 4.

The increase in salinity with pumping on November 10, the freshening between November 10 and November 17, and a similar freshening found at the upper part of the PVC casing between November and January suggest that even within the restricted depth tributary to this casing, when it is vigorously pumped, there is a significant salinity gradient. Our present interpretation is that when the well is pumped, more saline

TABLE 4. TEMPERATURE AND CONDUCTIVITY SAMPLES FROM THE EWA BEACH TEST WELL

TIME OF SAMPLE	TEMPERATURE °C	$E_c \times 10^6$ AT 25°C*
NOVEMBER 10, 1966 PUMP STARTED AT 1145		
1200	24.8	21,800
1300	20.7	26,200
1330	20.2	31,000
1400	20.2	34,900
1430	20.2	36,600
1500	20.0	34,900
(1500 TOP WATER OF AUXILIARY WELL)	29.4	1,250
1530	20.0	35,400
1600	20.0	35,870
NOVEMBER 16, 1966 PUMP STARTED AT 1000		
1005	29.4	32,800
1615	20.2	33,100
NOVEMBER 17, 1966 PUMP STARTED AT 1000		
1500	20.2	33,300
1530	20.0	33,100

* *Apply correction factor of 1.5.*

water is drawn up from below. When it is stagnant, the somewhat fresher water at the top of the basalt flows in, rises in the casing, and displaces the slightly denser brackish water. Part of the fresher water may, however, still be drilling water.

By use of appropriate fittings, the centrifugal suction pump was used in attempt to develop the well in the zones samples by some of the 1/2-inch plastic tubes. This method has not been successful probably due to plugging by viscous and dense drilling mud. Other attempts will be made with the engine manifold vacuum of a jeep, with a piston suction pump, and air lifting by compressed air. Water levels in the tubes were taken before the pump was applied and the tube primed with water. The differences caused by the development work on the basalt aquifer are noteworthy. The results are shown in Table 5.

The seismometer was hoisted from the well on October 26, 1966 in order that aquifer development could proceed. The United States Coast and Geodetic Survey discovered that high seismic noise level would allow seismometer operation at a maximum magnification of only 2000. Apparent-

TABLE 5. WATER LEVELS AT THE EWA BEACH TEST WELL
NOVEMBER 11, 1966
TIME: 14:00

TUBE NUMBER	W.L. FROM FLANGE*	W.L. FROM MSL*	SAMPLE ZONE MSL*	CHANGE FROM 9-16-66*
1	-4.9	+0.6	-310	-2.5
2	-2.1	+3.4	-398	0.0
3	-19.2	-13.7	-546	-0.8
4	-19.2	-13.7	-566	-1.5
5	-17.8	-12.4	-594	-0.4
6	-19.0	-13.7	-770	
BASALT AQUIFER	-8.0 APPROX.	-2.5 APPROX.	-1104	-8.0 APPROX.

**Measurements are in feet.*

ly bailing the hole was not sufficient to clear up all the mud and cuttings. The final stage of the aquifer development consisted of lowering a one-inch polyethylene pipe to the very bottom and pumping for a four-hour period. While the water was essentially clear, about two gallons of cuttings were pumped from the bottom. The seismometer was lowered into the well on January 26, 1967 in time to detect a moderate earthquake in the Aleutian Islands. The instrument is currently operating more satisfactorily at a magnification of 4000.

A water level recorder was installed temporarily on the well following development of the basalt aquifer which indicated a head of over two feet msl. Head records are presented as Figures 4a to 4g. A replacement recorder able to monitor over a longer period without maintenance was installed on a test basis in the Ewa deep well (T-133-1).

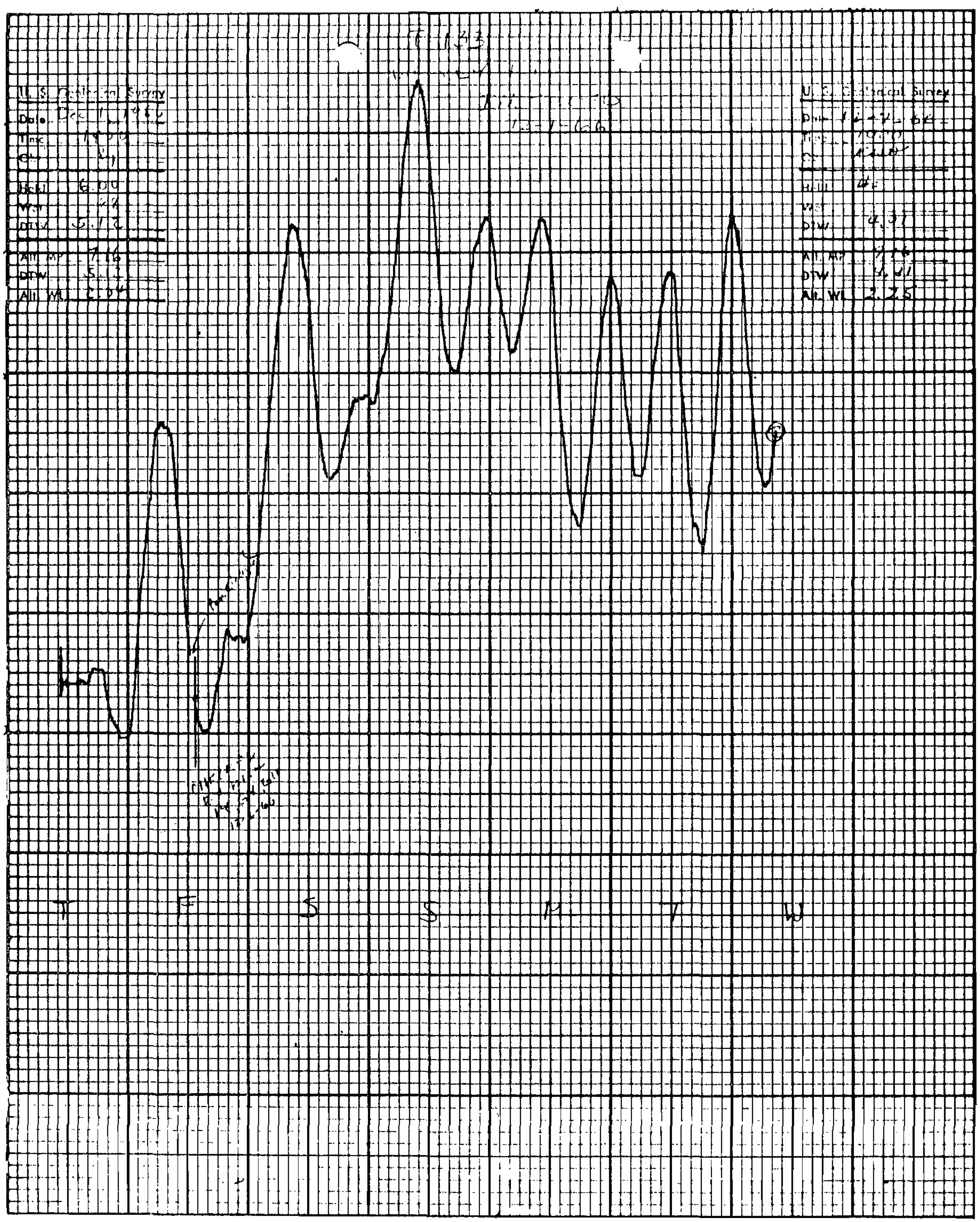


FIGURE 4a. HEAD RECORD AT EWA BEACH DEEP AQUIFER: DEC. 1-7, 1966

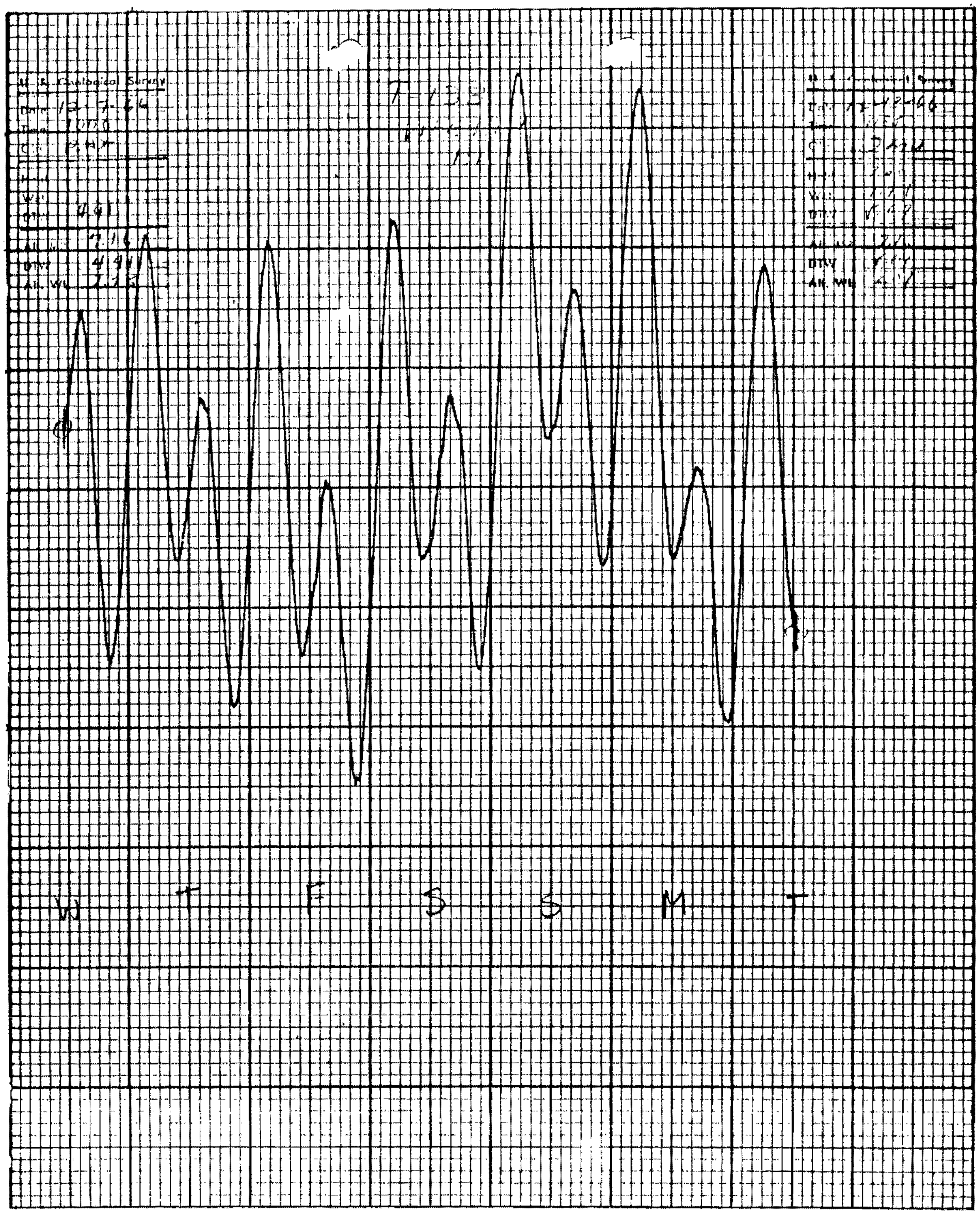


FIGURE 4b. HEAD RECORD AT EWA BEACH DEEP AQUIFER: DEC. 7-13, 1966

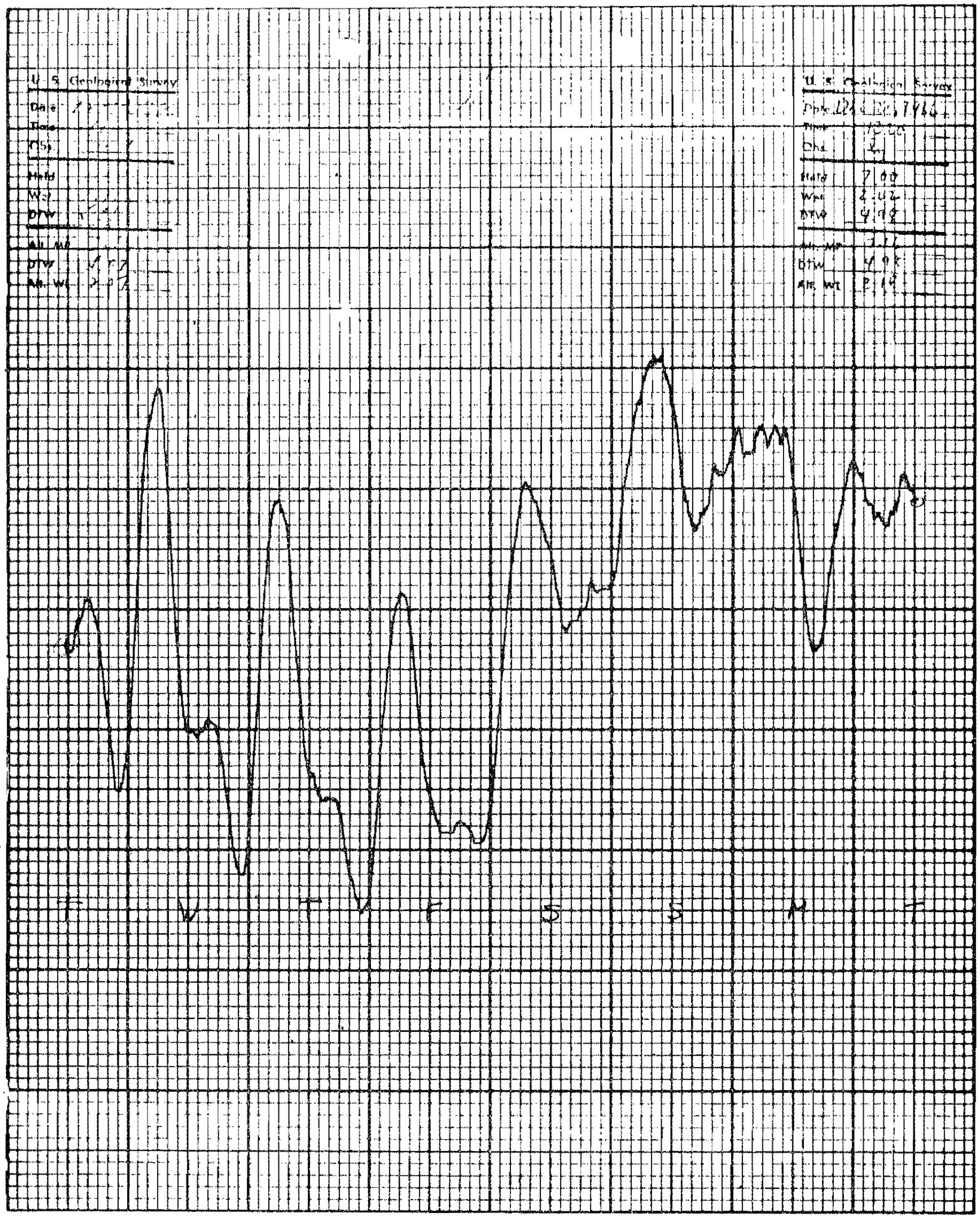


FIGURE 4c. HEAD RECORD AT EWA BEACH DEEP AQUIFER: DEC. 13-20, 1966

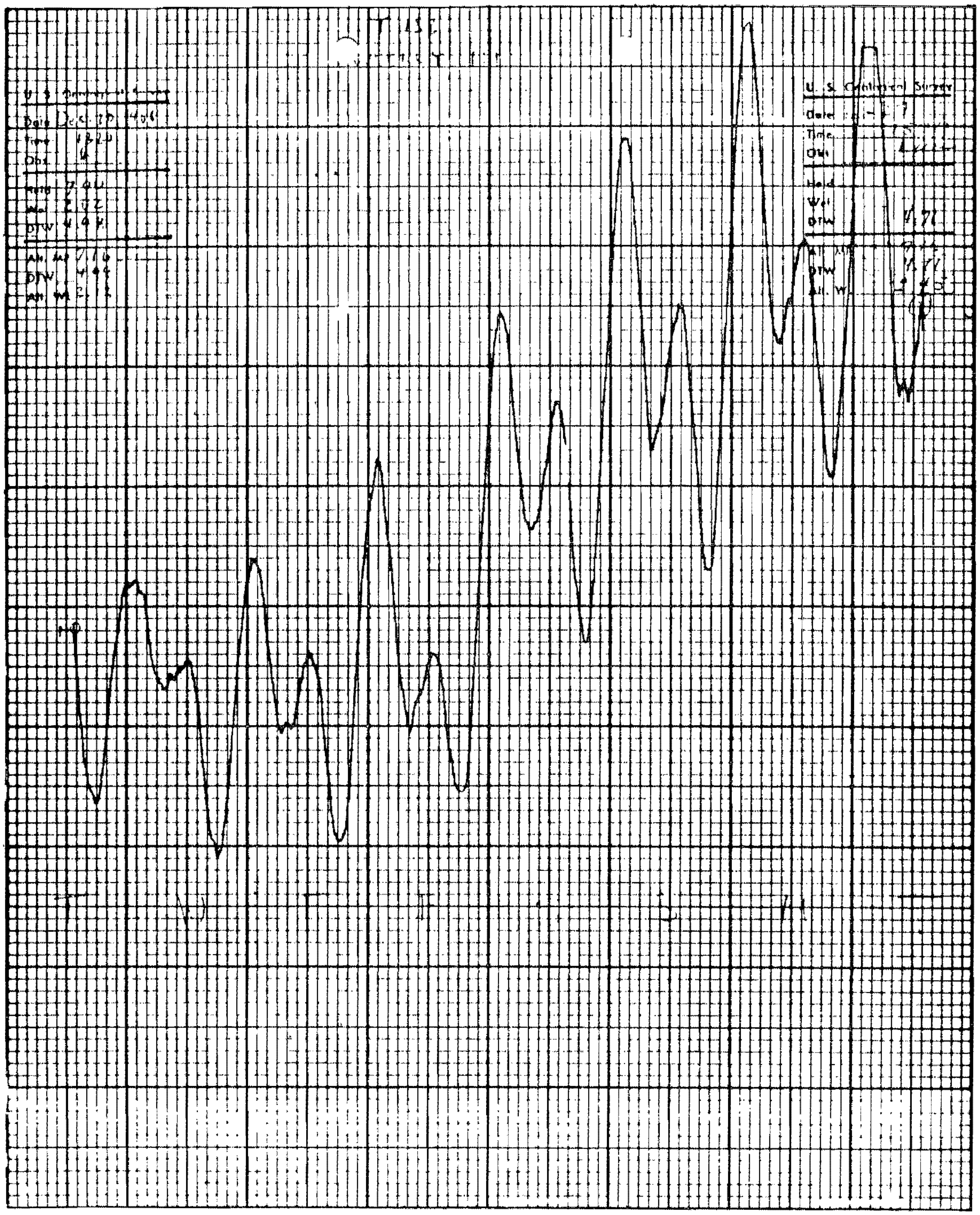


FIGURE 4d. HEAD RECORD AT EWA BEACH DEEP AQUIFER: DEC. 20-27, 1966

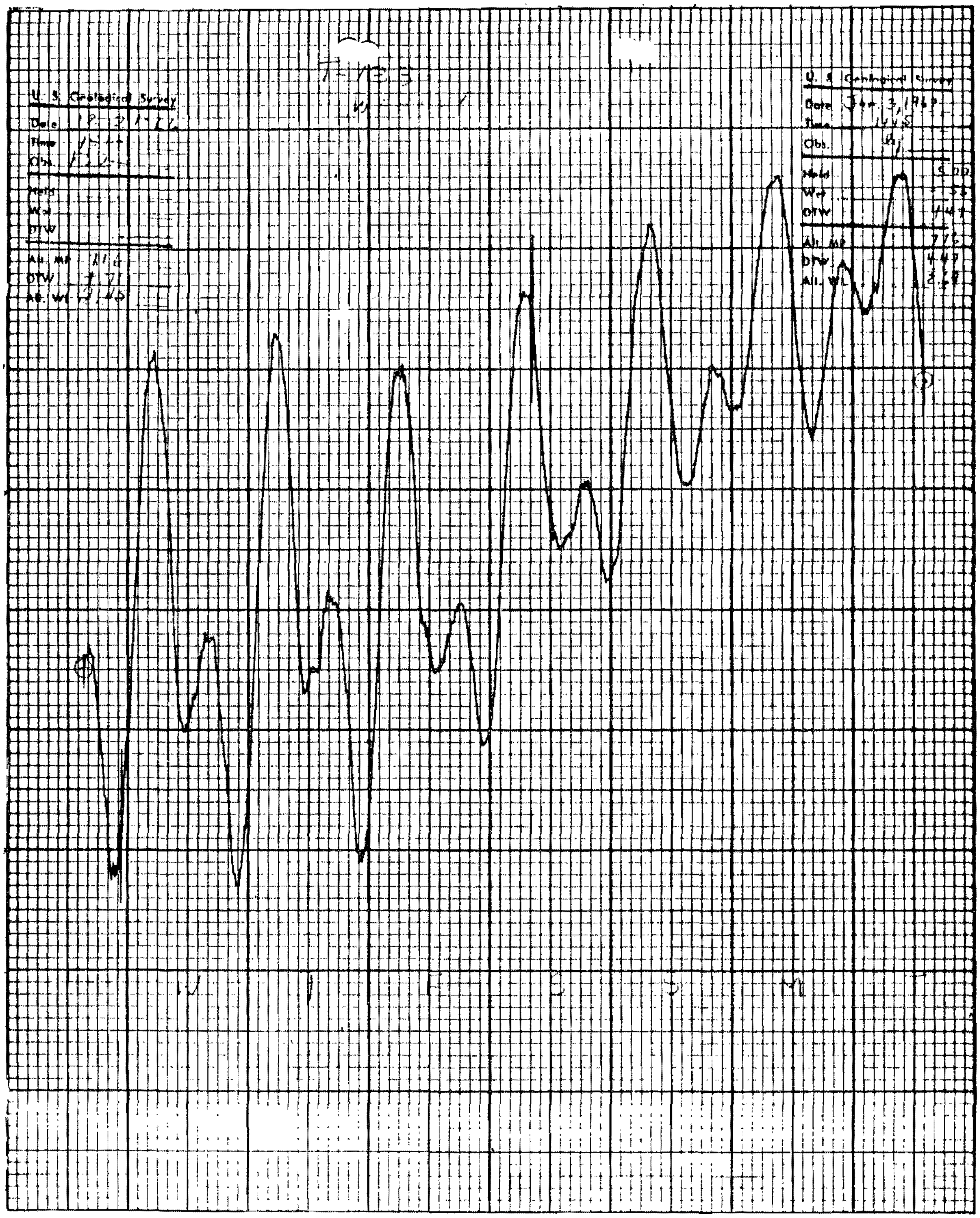


FIGURE 4e. HEAD RECORD AT EWA BEACH DEEP AQUIFER: DEC. 27, 1966-JAN. 3, 1967

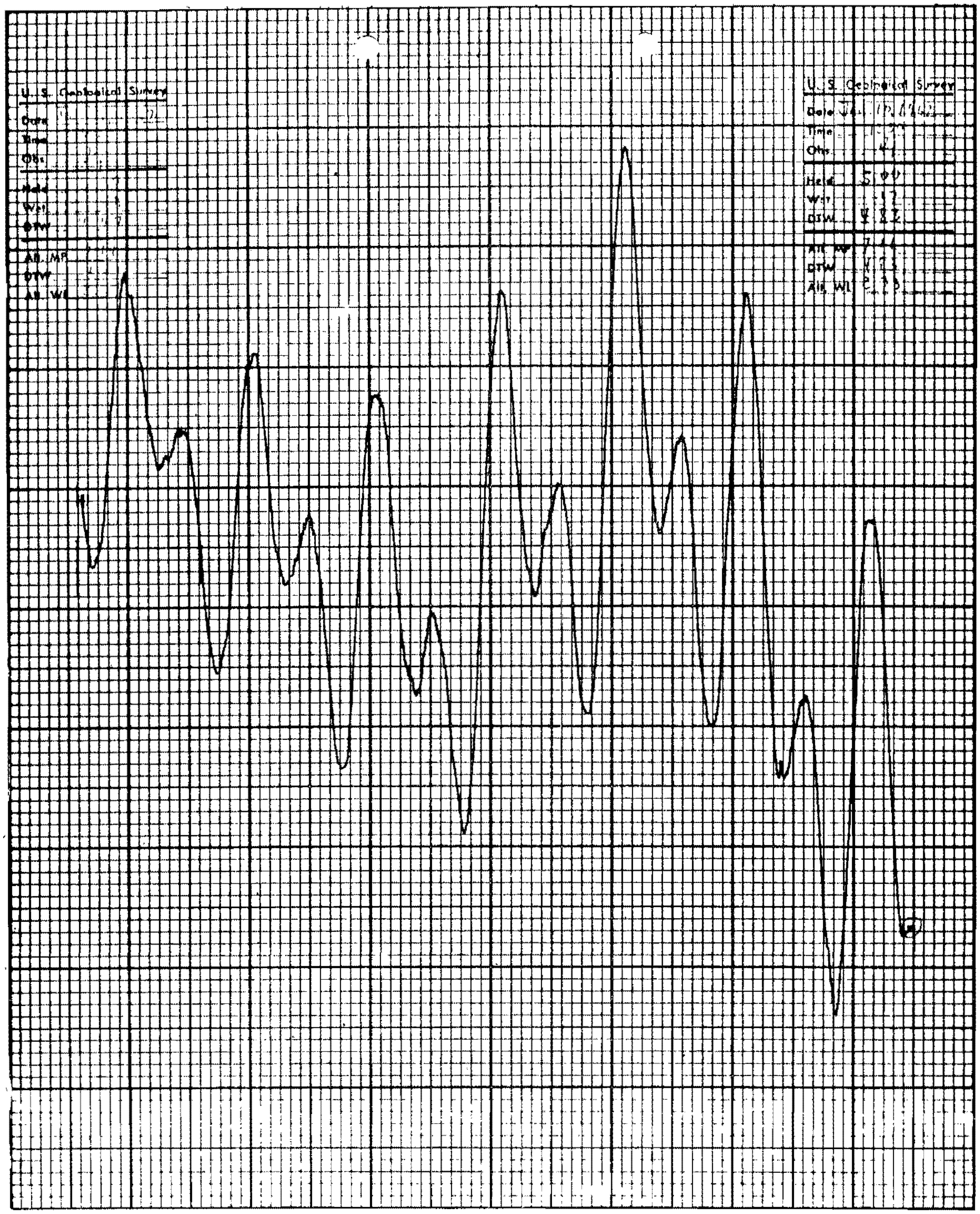


FIGURE 4f. HEAD RECORD AT EWA BEACH DEEP AQUIFER: JAN. 3-10, 1967

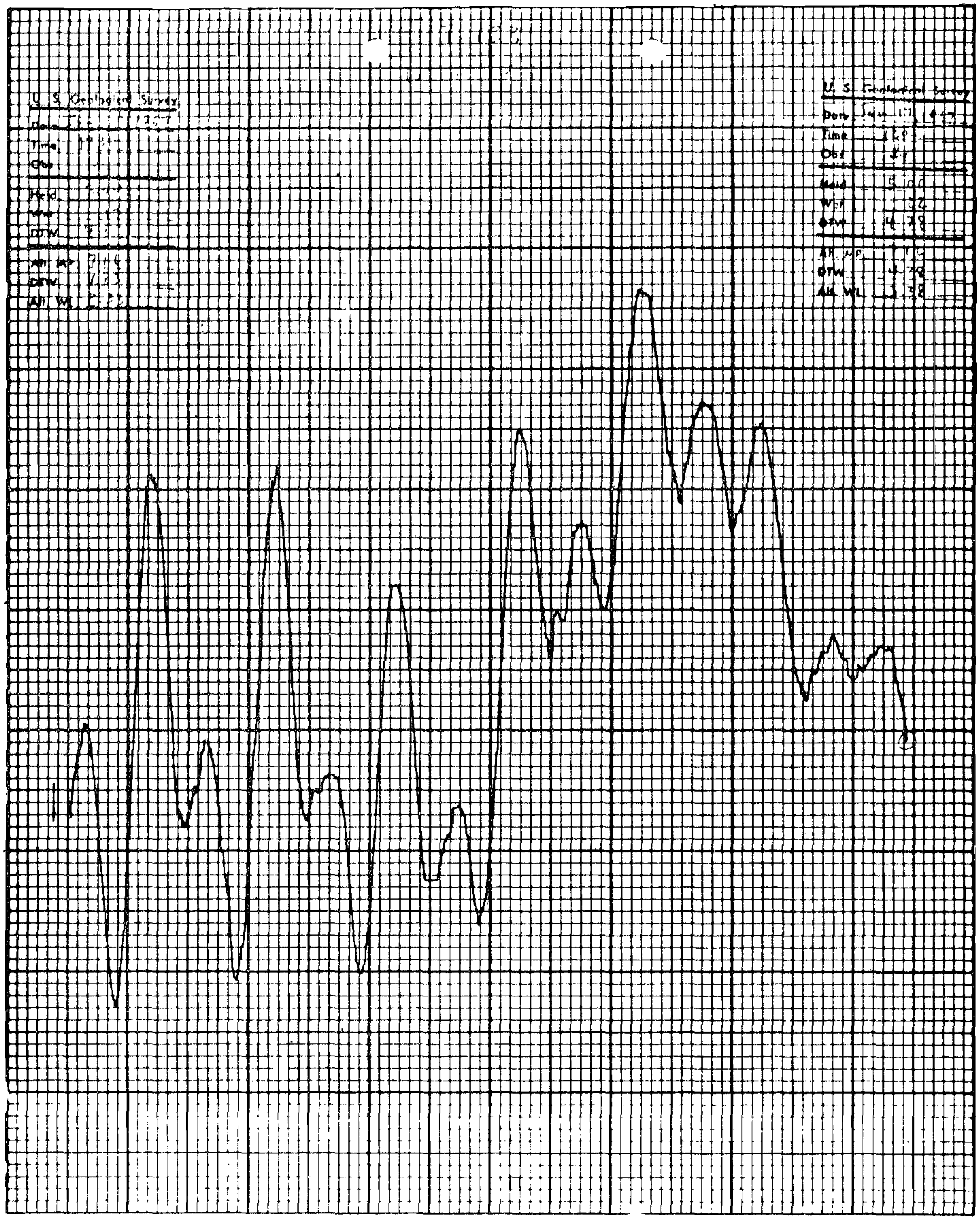


FIGURE 4q. HEAD RECORD AT EWA BEACH DEEP AQUIFER: JAN. 10-17, 1967

Present Status and Plans

At present, the communication between the basalt aquifer and the main casing seems to be adequately developed as is the isolation between the basalt aquifer and those tapped higher. The basalt aquifer yields water to the casing and expectable water level changes resulting from tidal loading and unloading of the aquifer are very well recorded (Figures 4a,b,c,d,e,f, and g). Short term fluctuations, partly seismic, and a long term trend have also been monitored. Although a detailed analysis has not yet been made, it is apparent that the ratio of tide range in well water levels and in the ocean is about 0.15. This seems reasonable considering the proximity of the ocean, about 1000 feet away.

The long term upward trend in water level seems related to the freshening, and, hence, lightening of the water column in the casing and also to the seasonal rise of head in the region. But until salinity sampling and head monitoring can be carried out simultaneously this cannot be determined with certainty. It is clear that the head is not the 18 foot± head of the really fresh water part of the lens, tapped at a higher level by wells farther inland. Nor is it even the 10 foot± head that was measured before the casing was installed. The initial high head was probably the result of a mixture of waters from several horizons and entrapped drilling water. However, the water tapped is not sea water and it appears that the head when it stabilizes will be about 2 or 3 feet above sea level.

The conditions then appear to justify fully the next step in development, which should be to provide for continuous flushing, frequently repeated or continuous sampling, continuous head measurements in the main casing, and similar measurements of the sample tubes. Considering the low ground elevation, these will probably be provided most simply by:

(1) Excavation of a pit around the well with a floor level somewhat below sea level.

(2) Connection of the main casing to a float chamber for continuous head recording.

(3) Construction of an automatically pumped sump to which the main casing can discharge slowly and continuously through the float chamber by gravity flow.

(4) Provision of means either for obtaining samples for chemical analysis integrated over a tide cycle (as has been done in a similar situation at a shallow test well on the island of Maui) or more simply for continuous monitoring of electrical conductivity.

(5) Further development of the six additional sample tubes in the main well by slow pumping.

(6) Provision of at least one and preferably two additional continous float-type head recorders and frequently repeated or a continuous sampling system to which the additional tubes may be connected.

(7) Development of the auxiliary test well by swabbing and pumping, and installation of a multiple tube sample system with packers for sampling various horizons in the zone cased off in the main well, and connection of the auxiliary well tubes to the pit at the main well or construction of a second pit at the auxiliary well.

(8) Provision of a couple of additional systems, to which any of the sample tubes in the main and the auxiliary well may be connected at will, continuous flushing and head recording, and frequently repeated or continuous sampling for conductivity measurement.

With this further development it seems probable the Ewa Beach test well will become, as originally hoped, a hydrologic monitoring station of considerable importance in the determination of the behavior of the lower parts of the Pearl Harbor Herzberg lens.

PUULOA TEST WELL

Original Construction

The Puuloa Well was drilled in June 1965 for the Hawaii Institute of Geophysics on the grounds of the United States Navy Ammunition Depot, West Loch, Pearl Harbor (Figure 1). Cores were obtained for stratigraphic studies to augment the results of the Ewa Beach cores. The hole was drilled to a depth of 544 feet from ground surface at an elevation of 21 feet. It penetrated into Koolau volcanic rock at a depth of 508 feet or 487 feet below sea level. No artesian flow was obtained from this hole. After the cores were extracted a steel plate was welded over the casing left in the ground.

Cleanout and Logging

In July 1966, the rotary rig that cleaned out the Ewa Beach well was moved to Puuloa to clear out the hole for conversion to hydrologic monitoring. A new conductor casing was landed about 6 feet below ground level and cemented. The high pressure of the drilling fluid, a mixture of bentonite clay and water, loosened the ground below and around the casing, breaking the joint. Recementing the casing caused considerable delay and was not completely successful and resulted in an unnecessary loss of much drilling fluid.

The driller found that the hole had filled back to approximately 100 feet of the surface with a soft mixture of brown soil, brown clay, and bits of white coral which probably caved in when the 90-foot casing was being pulled out. At a depth of approximately 480 feet, the hole became clear for about 20 feet, but thereafter offered resistance to the drilling bit. As the basalt portion of the hole had a diameter of 7½ inches, this portion was reamed out to 9-7/8 inches over a period of two days. For a time, the resistance of the rock and the slow progress of this work raised a question of whether a new hole was being drilled if the old hole were crooked. The finished depth of the well below ground surface is 543 feet is the old hole were crooked.

While the drillers worked on the hole, a package of thirteen one-half inch polyethylene sampling tubes of specified lengths was assembled on the ground. Each tube was plugged, perforated at the bottom portion with two rows of 1/8 inch holes, 12 holes per foot, and marked for identification. The tubes were arranged in concentric bundles around a plastic coated wire cable attached to a lead cylinder weighing approximately 35 pounds which counteracted the buoyancy of the polyethylene. The tube configuration involved a center tube attached to the bottom end of the line; six tubes extending upward from prescribed sampling depths arranged around the center tube; and an additional six tubes arranged on the first layer of tubes. Fiberglass tape was used to fabricate the bundle of tubes.

Immediately after the hole was cleaned out and flushed of cuttings and mud, the drilling tools were withdrawn and electric logging of the well commenced. Single point, 16-inch short normal, 64-inch long normal, and six to seven-foot lateral surveys were performed (Figure 5). The logs obtained were of excellent quality and indicated a permeable ten-foot zone at the 278 to 288-foot level overlooked in the original logging of the cores. A tube that was originally planned to tap a thin, poorly permeable zone was lengthened to take advantage of this better sampling zone. In general, the logs and the core samples matched very well despite a suppressed resistivity due to the saline formation water and drilling mud.

Casing and Backfilling

After completion of the electric logging, the bundle of sampling tubes was lowered into the hole using 2-inch wash rods to carry the package to bottom. Failure to reach bottom by three feet was caused by loss of contact of rods and the weight, which had a 1/4-inch steel rod projecting about 30 inches into the wash rods. The installed sampling points are at 5, 21, 40, 58, 76, 96, 147, 180, 261, 377, 397, 493, and 516 feet below msl.

As the water level in the hole was below ground level and also below the conductor casing, a section of 5-inch PVC casing about 15 feet long was lowered into the hole so the fill could be tremied into the hole. As the fill went into the hole, the displaced water rose above ground level and the tremie pipe was taken out. Thereafter, the fill was placed directly into the hole. Crushed rock exceeding 3/16-inch diameter was placed opposite sample zones. Beach sand was used for filling the remaining zones. Approximately 5 cubic yards of gravel and 18 cubic yards of sand were used to fill the hole. A continuous check of the position of the fill was accomplished with a wire sounding line kept constantly in motion. Filling was completed in 2-1/2 days.

Although as filling progressed, water and sand were forced out of the sampling tubes for varying lengths of time, all tubes ceased to flow before the last fill was emplaced. The ends of the tubes are plugged temporarily with rubber stoppers.

Unlike the Ewa Beach well, there have been only rough data collected on water quality or water levels from the Puuloa well. When the well is prepared for instrumentation, this information will be obtained in detail. While the backfill was being poured into the hole, water forced up the polyethylene tubes had a distinctly salty taste, probably exceeding 2000 milligrams per liter chloride.

Levelling

An uncertainty about the elevation of ground surface at the well prompted a request to the United States Coast and Geodetic Survey to run a level line to the Puuloa well. On September 12 and 13, 1966, personnel from WRRC assisted the USC & GS in extending the spur line to Ewa Beach into a more useful loop back to Ewa Plantation with a spur line to the Puuloa well. A bench mark was place in a concrete culvert about 100 feet from the well. The level line met the accuracy standards for second order levelling.

On September 16, 1966 water levels in the tubes were measured with an electric device borrowed from the Honolulu Board of Water Supply. The results obtained are shown in Table 6.

It is doubtful that the above water levels accurately represent the head conditions in the aquifers they are intended to tap, as there has been no test pumping of the tubes to clear them of drilling mud and water and to develop the aquifers.

FIGURE 5

PUULOA TEST WELL

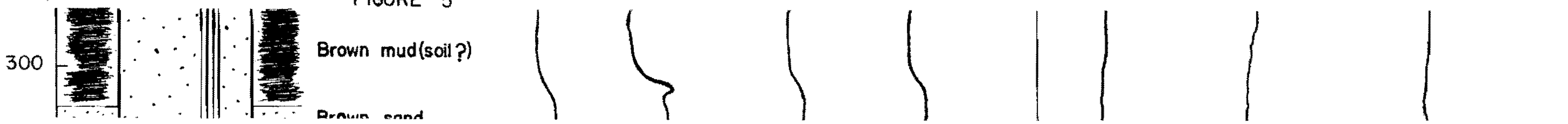


TABLE 6. WATER LEVELS AT THE PUULOA WELL
SEPTEMBER 16, 1966
TIME: 14:00 TO 14:55

TUBE NUMBER	SAMPLE ZONE BELOW MSL*	WATER LEVEL FROM TOP OF CASING*	WATER LEVEL FROM MEAN SEA LEVEL*
1	11	+0.4	+22.8
2	27	+0.3	+22.7
3	46	-1.2	+21.3
4	64	-1.1	+21.3
5	82	-0.8	+21.6
6	101	-0.5	+21.9
7	153	-17.1	+4.3
8	186	-16.1	+5.3
9	267	-14.7	+7.7
10	383	-12.7	+9.7
11	403	-12.3	+10.1
12	499	-9.2	+13.2
13	522	-7.1	+14.3

**Measurements are in feet.*

Present Status and Plans

As at the Ewa Beach Well, very little is now required to establish the Puuloa test well as a station at which head and salinity may be measured in the basaltic Pearl Harbor aquifer and also in selected points in the overlying sediments. The response of the sample tubes to the backfilling suggests that the connection between the several tubes and the respective aquifers outside the well is poor relative to the interconnections between sample points. However, it is hoped that better connections may be developed with the respective aquifers.

In contrast to the situation at Ewa Beach, it will not be expedient at Puuloa to attempt to obtain gravity flow from sample tubes by construction of a sump. Instead, suction must be used for sampling and air bubbling systems for head measurement. Incremental development will be especially desirable so that plans for the final installation may be based on results of initial experiments.

SUMMARY

The conversion of the Ewa Beach and Puuloa test wells for hydrologic monitoring was undertaken by the Water Resources Research Center as a contribution to the understanding of the hydraulic behavior of the lower parts of the thick Herzberg lenses of Oahu. Because the original drilling and the conversion for hydrologic monitoring were separately planned, the work has been hampered by caving occurring during the considerable intervals separating the times of drilling and conversion.

In spite of the difficulties (and extra costs), both of these test wells and an auxiliary well at the Ewa Beach site have now been equipped with multiple-tube casing systems intended to permit continuous sampling and head recording at various depths.

The deepest sampling point in the Ewa Beach well has been developed so that there is good communication between the casing and the aquifer. At this point water of high salinity but fresher than sea water has been sampled and a head of about two feet above sea level measured. However, both salinity and head have fluctuated during periods of measurement to indicate still present effects of the conversion procedures and the final results when conversion is completed and equilibrium restored are uncertain.

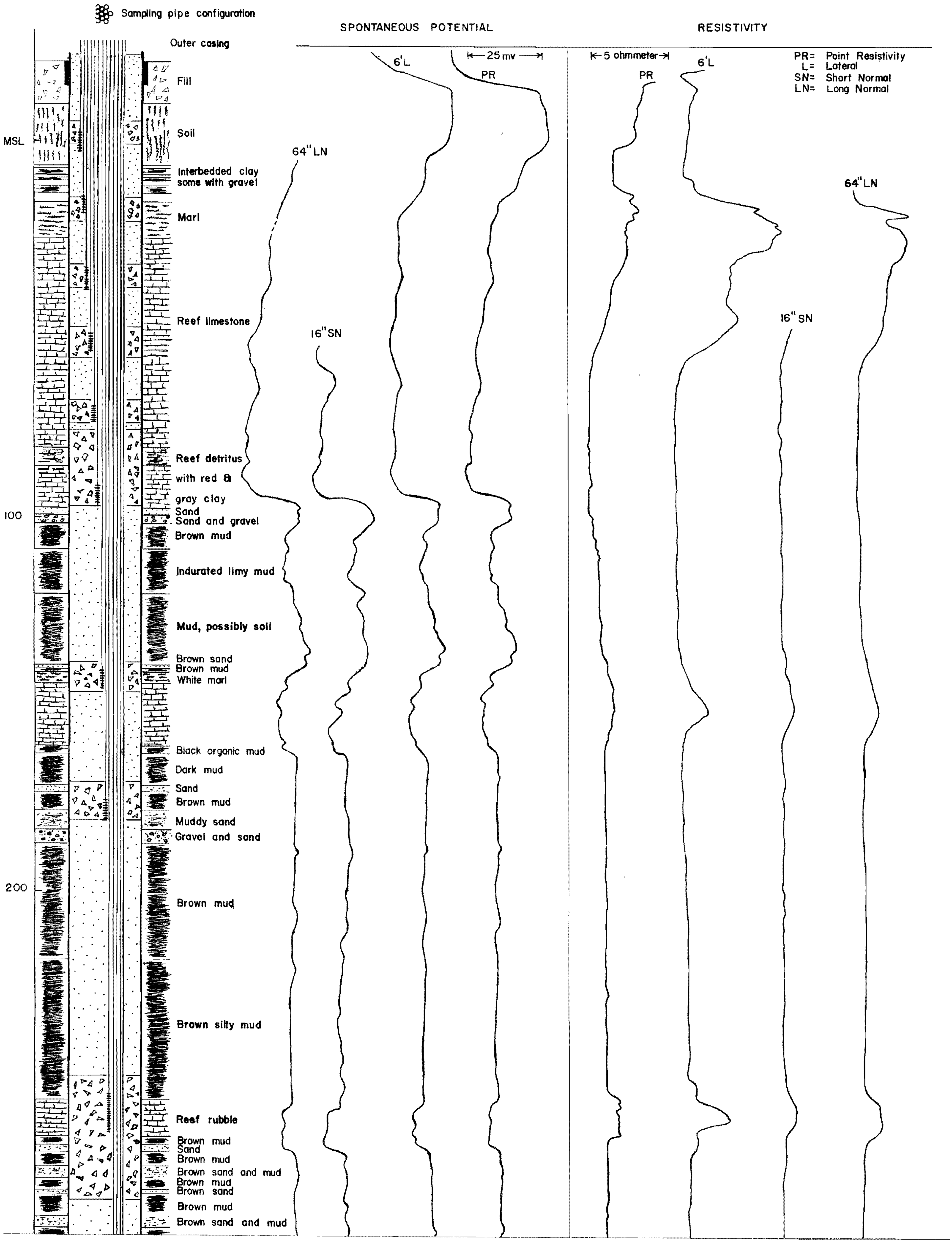
The other sampling points at both wells still need to be developed and modifications must be made to permit continuous sampling and head monitoring.

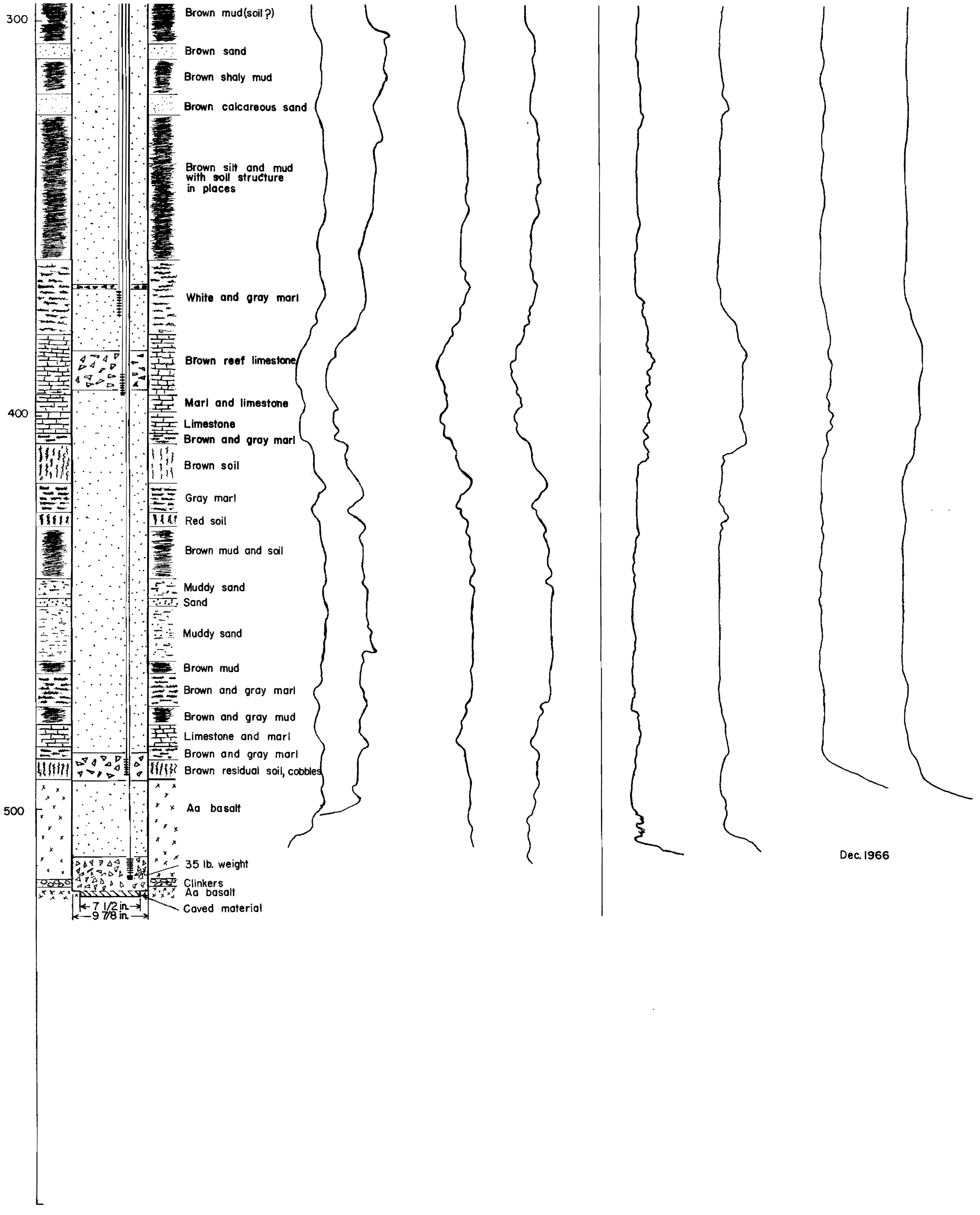
With the completion of the installations, it is probable that the Ewa Beach and Puuloa wells will be a pair of hydrologic monitoring stations of considerable importance in the determination of behavior of the lower parts of the Pearl Harbor Herzberg lens.

FIGURE 5

PUULOA TEST WELL

Oahu, Hawaii





300
400
500
Brown mud(soil ?)
Brown sand
Brown shaly mud
Brown calcareous sand
Brown silt and mud with soil structure in places
White and gray marl
Brown reef limestone
Marl and limestone
Limestone
Brown and gray marl
Brown soil
Gray marl
Red soil
Brown mud and soil
Muddy sand
Sand
Muddy sand
Brown mud
Brown and gray marl
Brown and gray mud
Limestone and marl
Brown and gray marl
Brown residual soil, cobbles
Aa basalt
35 lb. weight
Clinkers
Aa basalt
Caved material
7 1/2 in.
9 7/8 in.
Dec. 1966