Memorandum Report No. 9

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

by

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February
1967

W A T E R   R E S O U R C E S   R E S E A R C H   C E N T E R
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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, but none of these wells has penetrated the lens and entered the salt water beneath. Hence the Water Resources Research Center was greatly interested in the availability for hydrologic monitoring of two large diameter test wells that were drilled in 1965 in the Ewa District for the Hawaii Institute of Geophysics for stratigraphic studies. Each of these wells passed through a considerable section of sediments of varying permeability and then entered 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, (see Fig. 1) entered the basalts 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 (Fig. 1) penetrated the basalt aquifer at 289 feet below sea level and terminated at 544 feet below sea level. Hence, it was expected that this well tapped in the basalt a part of the Herzberg lens although very likely a brackish part with reduced head.

LOCATION MAP OF EWA BEACH—PUULOA AREAS
OAHU, HAWAII

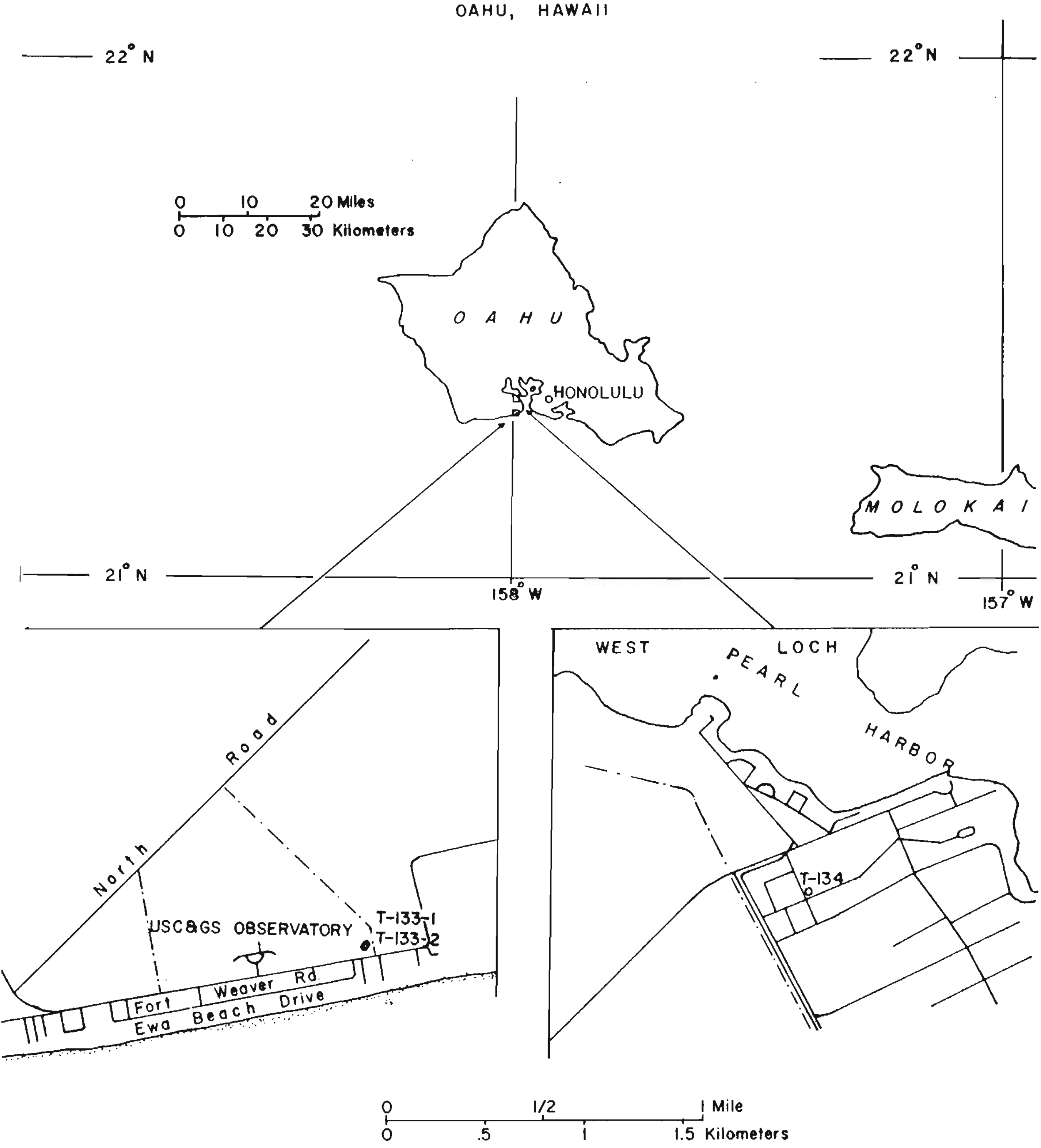


FIGURE 1

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 conversion beyond that of simple sealing.

The Center's work on the two wells has been supported in part from its State appropriation, in part 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 in part from a grant from the Honolulu Board of Water Supply for Electric Well Logging. Leveling needed has been done by the U. S. Coast and Geodetic Survey assisted by WRRC personnel. The continuing use of the two wells has been arranged through the courteous permission of the Coast and Geodetic Survey, on whose land the Ewa Beach well is situated, and the 14 Naval District, on whose land the Puuloa well is situated.

Original Construction

The deep Ewa Beach test well, T-133-1, was drilled by rotary methods in mid-May 1965 at Ewa Beach (Fig. 1). Starting from a surface elevation of 4 feet above mean sea level, the well penetrated a 1070 foot section of marine and continental sediments and flollowed by 40 feet of the underlying basalt lava flows of the Koolau Range, ending at a depth of 1103 feet below sea level. By use of a special core barrel, approximately 85 per cent core 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 Resources Research Center, the well was capped on completion, pending takeover by the WRRC 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 lower than 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 evaluated from available cores. One point was placed in the basalt and six others in the overlying sediments (Fig. 2). Six half-inch polyethylene tubes terminating and pre-perforated at specific depths were taped to a main five-inch perforated polyvinychloride (PVC) casing. The central casing permitted sampling water from the bottom of the hole and also served as a conduit for lowering a special seismometer for the United States Coast and Geodetic Survey (USC&GS).

First Cleanout Attempt

After acquisition of the necessary materials, 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:

	Flow from well	Nearby surface pool
Chloride, milligrams per liter	8,600	3,600
Hardness as $CaCo_3$, mg/l	3,700	1,600
Alkalinity as $CaCo_3$, mg/l	180	440
Color, platinum scale*	120	55
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 a half an hour through dark sticky clay containing some calcareous pebbles apparently dropped 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 USGS 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 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.

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 with black clay adhering to it.

On August 16, 1965 the bit was run back into the hole which had filled back to 890 feet below MSL. Work was suspended on this date. 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 uppermost 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. 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 first cemented into 42 feet 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 on 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 deep 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± feet below MSL. The 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 1111 feet below MSL.

After the cleanout process, but before the casing and sampling tubes were lowered, electric logs were made of the well (Fig. 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 manisfested 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 below sea level when installed. Twelve feet at the end 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 feet section of casing was cemented to one already in the hole, 10 minutes were allowed for the special cement to set. These pipes 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 in addition to cementing.

The 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 at the bottom. However, the tube was separated accidentally while being lowered at approximately the -970 feet level. With the bends that probably developed because of the loss of tension, considerable friction occurred between the tube and sounding line, jamming the sounding line several times. Although meant to be pulled up gradually as the backfilling progressed, the tube 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 atop the 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 1109.

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 has fluctuated 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

1-inch polyethylene tremie tube 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 and the small clearance available and the one-inch polyethylene tube did not prove 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 1075 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 dondition 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 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 more 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 a 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 the 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 gradually was withdrawn 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 the 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 had to be bailed from the casing. It is believed most of this was fine material which had originally settled outside the casing but had infiltrated through the perforations as a result of the increasing load of introduced fill. In confirmation, it was found, on bailing, 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 feel 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 complete, the selected fill had settled again 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 this material to flow through the perforations. The construction of the well, as completed with the several casings and backfill, is shown schematically on the log (Fig. 2).

The USC&GS seismometer was lowered to bottom within a half hour after the bailing operation. A hoisting cable and an armored conductor cable were attached to the ins-rument and then were run over sheaves into the casing. The cables were bound to the flange. A short trench was dug for the sesmometer conductor cable to the cable leading from the recording house at the observatory. The equipment used in filling the well was then removed from the site and a sign warning against unlawful trespass and destruction of property was posted.

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 following water levels were obtained:

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 feet	+ 3.1 feet	- 310 feet
#2	- 2.1	+ 3.4	- 398

Tube number	W.L. from Flange	W.L. from MSL	Sample Zone Depth MSL
#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 level - T-133-2 Time 13:45

	W.L. from Collar	W.L. from MSL
PVC casing	- 3.6 feet	+ 1.5 feet (estimated)

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 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.

A water level recorder was installed on temporarily following development of the basalt aquifer. These head records are presented as Fig. 4a-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).

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 the 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 was started obtaining 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 dumping in water from the auxiliary well from a second pump. By this time the well had been pumped a total of 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 well and at +2.1 feet MSL in the auxiliary well. During this period, intermittent heavy rains were ponded for several weeks near the wells.

During the aquifer pumping, periodic samples were collected for temperature and conductivity analysis. The results are tabulated below.

Date: November 10, 1966 Pump started at 11:45

Time of sample	Temperature °C	$E_c \times 10^6$ at 25°C	Interpolated from Chem-Physics Handbook, D at 20°C
1200	24.8	21,800	1.0096
1300	20.7	26,200	1.0116
1330	20.2	31,000	1.0137
1400	20.2	34,900	1.0160

Time of sample	Temperature °C	$E_c \times 10^6$ at 25°C	Interpolated from Chem-Physics Handbook D, at 20°C
1430	20.2	36,600	1.0169
1500	20.0	34,900	1.0157
(1500 top water of Auxiliary well)	29.4	1,250	
1530	20.0	35,400	1.0160
1600	20.0	35,870	1.0161
Date: November 16, 1966	Pump started at 10:00		
1005	29.4	32,800	1.0147
1615	20.2	33,100	1.0148
Date: November 17, 1966	Pump started at 10:00		
1500	20.0	33,300	1.0149
1530	20.0	33,100	1.0148

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 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 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 sampled 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 tabulated below.

Water levels - Ewa Beach #1 Time 14:00 11-17-66

Tube Number	W. L. from flange	W. L. from MSL	Sample Zone MSL	Change from 9-16-66
1	- 4.9 feet	+ 0.6 feet	- 310 feet	- 2.5 feet
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	-13.7	- 770	?
Basalt aquifer	- 8 approx.	- 2.5 approx.	-1104	- 8 approx.

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 the high seismic noise level would permit seismometer operation at a maximum magnification of only 2000. Apparently bailing the hole was not sufficient to clear up all the mud and cuttings. The final stage of the aquifer development consisted of lowering 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.

Present Status and Plans

As matters stand at present, the communication between the basalt aquifer and the main casing seems to be adequately developed. The isolation between the basalt aquifer and those tapped higher in the well also seems adequate. 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 (Fig. 5a,b,c,d,e,f,and g). Short term fluctuations, some of which may be 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 probably related to the freshening, and, hence, lightening of the water column in the casing and also to the seasonal rise of heat 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 even the 10 foot ± head that was measured before the casing was installed and that resulted, probably from a mixture of water 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 significance of this head again cannot be determined until the density of the water column is measured or computed from the salinity or conductivity continuously as the head is measured.

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 on the additional 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 Maui), or more simply perhaps 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 continuous flow, continuous head recording, and frequently repeated or continuous

sampling system to which any of 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 at various horizons in the zone cased off in the main well, 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 additional sample tubes in the main and the auxiliary well may be connected at will, continuous flushing, continuous head recording, and frequently repeated or continuous sampling of 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 (Fig. 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 21 feet altitude penetrating into Koolau volcanic rock, at a depth of 508 feet or 487 feet below sea level. No artesian flow was obtained from this hole. A steel plate was welded over the casing left in the ground.

Cleanout and Logging

In July 1966 the Water Resources Research Center had the rotary rig that was used to clean out the Ewa Beach Well moved to Puuloa to clear out and ready the hole for conversion to hydrologic monitoring. A new conductor casing had to be installed because the old one had been knocked askew by a bulldozer making site preparations. It had been reported that the hole was cased for 90 feet, but the information was erroneous. The 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, caused piping of loose material from below and around the casing several times in the course of the cleanout jobs. Recementing of the casing caused considerable delay and was not completely successful, resulting in the unnecessary loss of much drilling fluid.

The driller found the hole had filled back to approximately 100 feet of the surface. The fill was a soft mixture of brown soil with pieces of brown clay and bits of white coral which probably caved as a result of the 90 feet of casing being pulled. At a depth of approximately 480 feet, the hole became clear for about 20 feet, but thereafter again offered resistance to the drilling bit. As the basalt portion of the hole had a diameter of 7 1/2 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 as to whether a new hole was being drilled or if the old hole was crooked. The finished depth of the well below ground surface is 543 feet.

While the drillers worked on the hole, a package of thirteen one-half inch polyethylene sampling tubes of varying 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 was needed to counteract 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 the 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 6-7 foot lateral surveys were performed (See Fig. 4). The logs obtained were of excellent quality and indicated a permeable ten-foot zone at the 278 to 288 foot level previously 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, the fill being placed directly in 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 of the well was completed in a period of 2 1/2 days.

As filling progressed, water and sometimes 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 for cooperation from the United States Coast and Geodetic Survey to run a level line to the Puuloa well. The USC&GS had previously run a line from Ewa Plantation Sugar Mill to the Ewa Beach 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 placed in a concrete culvert about a 100 feet from the well. The level line met the accuracy standards for second order leveling.

On September 16, 1966 water levels in the tubes were measured with an electric measuring device borrowed from the Honolulu Board of Water Supply. The following results were obtained:

Water levels at Puuloa Well, Sept. 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 feet (appox)	+ 0.4 feet	+22.8 feet
#2	27	+ 0.3	+22.7

Tube Number	Sample Zone Below MSL	Water Level from Top of Casing	Water Level from Mean Sea Level
#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

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.

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 basalt Pearl Harbor aquifer and also probably 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.

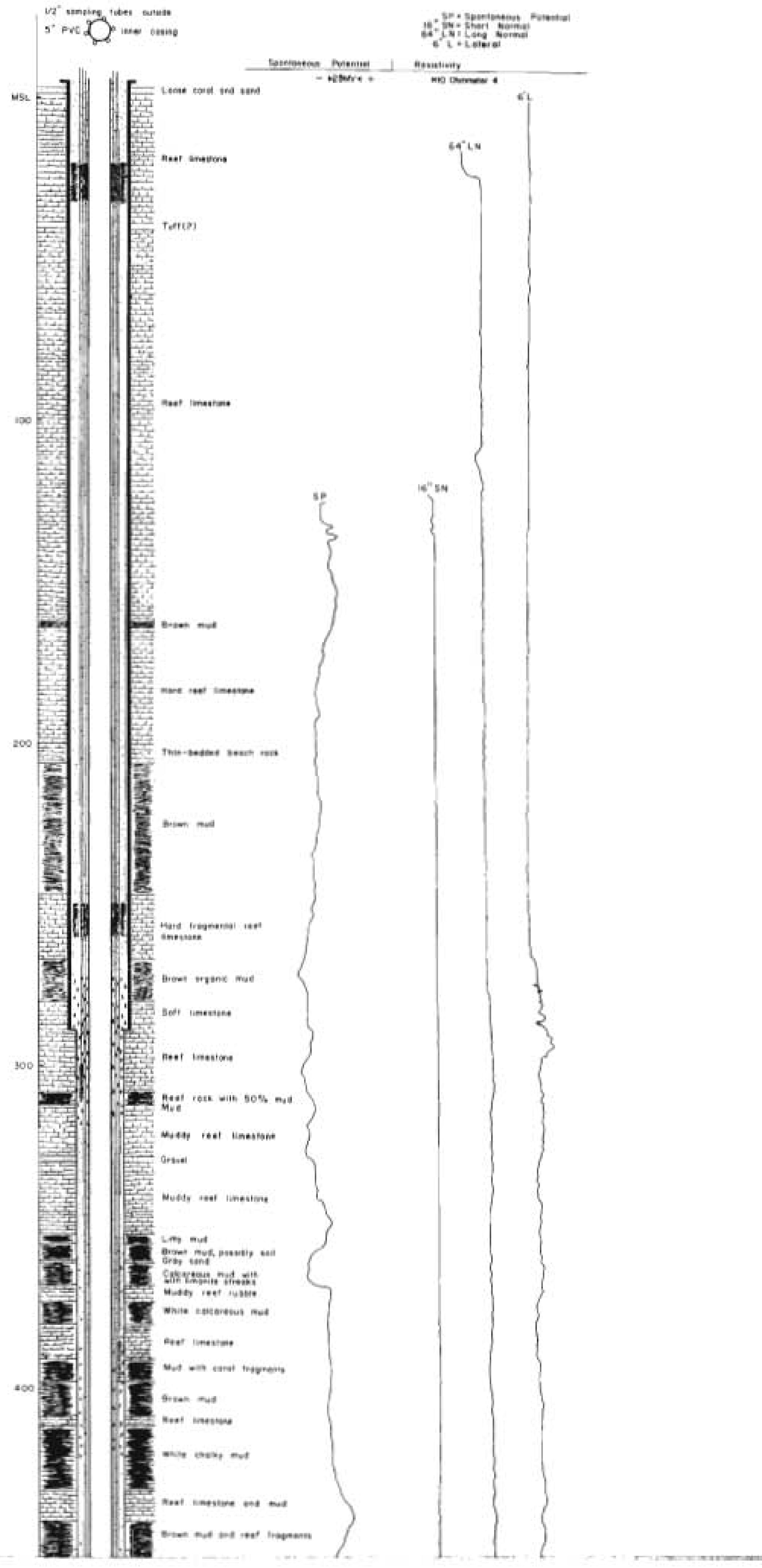
The deepest sampling point in the Ewa Beach well has been developed so that there is good communication between the casing and the aquifer. At this point water of high salinity but fresher than sea water has been sampled and a head of about two feet above sea level measured. However, both salinity and head have fluctuated during the periods of measurement in such a way as to indicate still the effects of the conversion procedures to date, and it is still not certain what the results will be when the conversion is completed and equilibrium is restored.

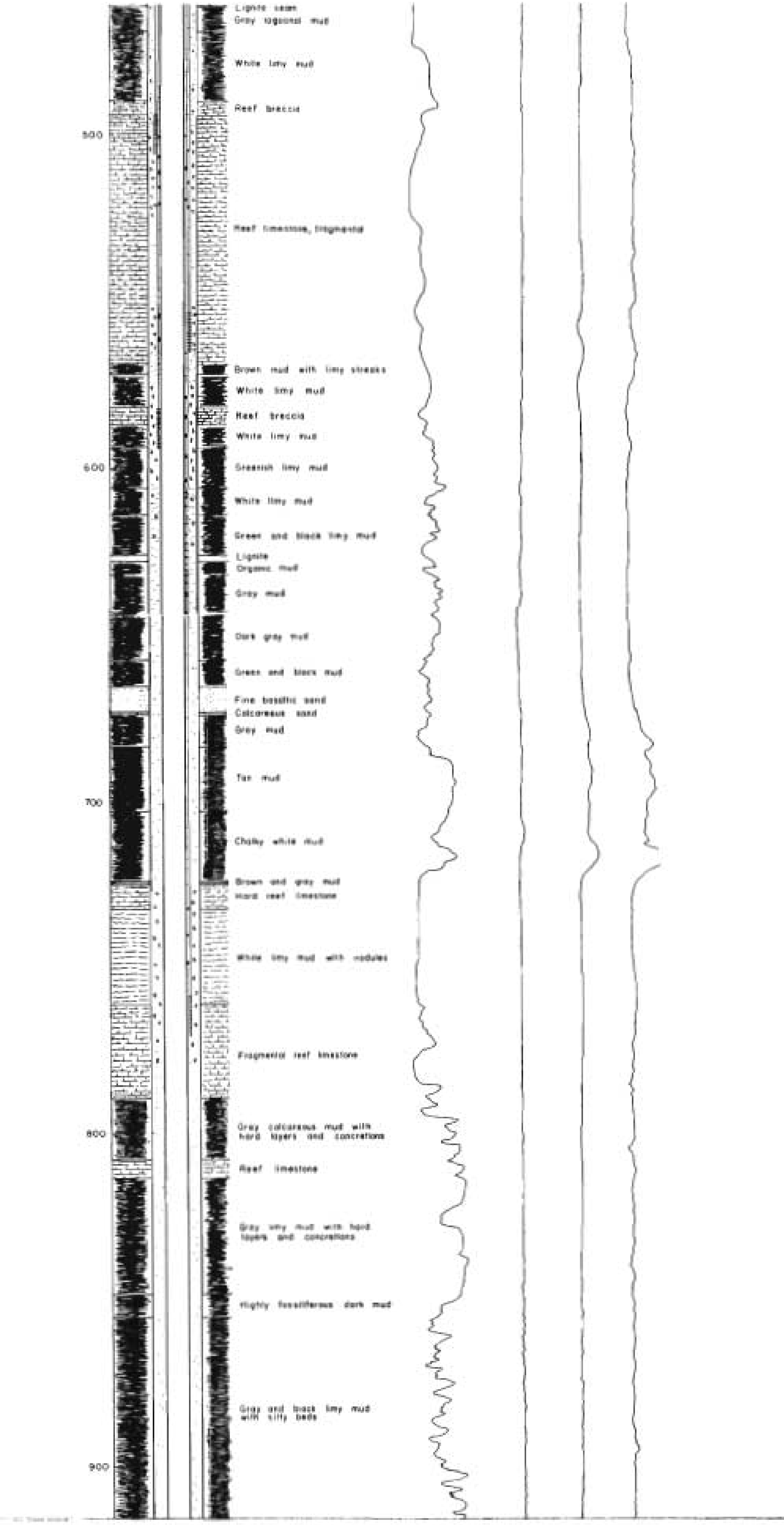
The other sampling points at both wells still need to be developed and, at each well, modifications must be made to permit continuous sampling and head monitoring.

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

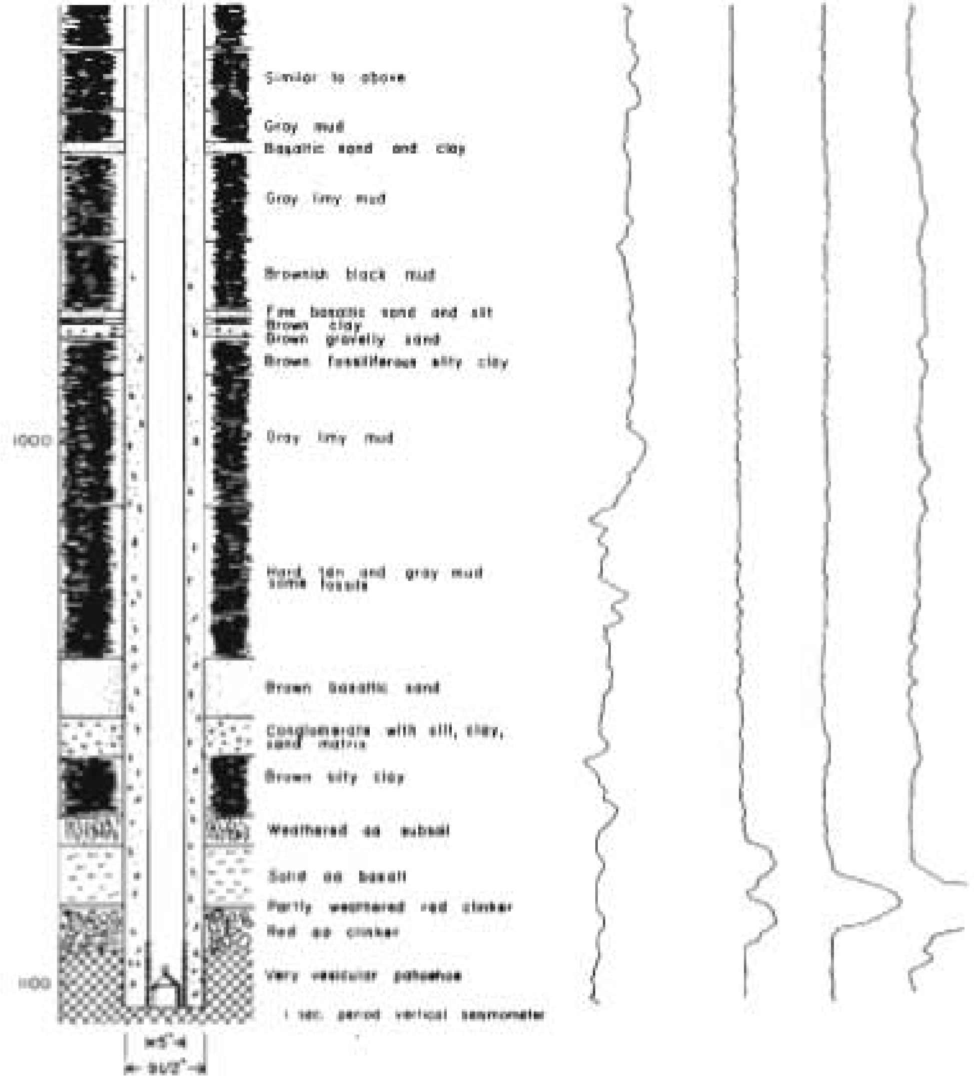
FIGURE 2

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





500
600
700
800
900
Lignite seam
Gray lagoonal mud
White limy mud
Reef breccia
Reef limestone, fragmental
Brown mud with limy streaks
White limy mud
Reef breccia
White limy mud
Greenish limy mud
White limy mud
Green and black limy mud
Lignite
Organic mud
Gray mud
Dark gray mud
Green and black mud
Fine basaltic sand
Calcareous sand
Gray mud
Tan mud
Chalky white mud
Brown and gray mud
Hard reef limestone
White limy mud with nodules
Fragmental reef limestone
Gray calcareous mud with hard layers and concretions
Reef limestone
Gray limy mud with hard layers and concretions
Highly fossiliferous dark mud
Gray and black limy mud with silty beds



Similar to above
Gray mud
Basaltic sand and clay
Gray limy mud
Brownish black mud
Fine basaltic sand and silt
Brown clay
Brown gravelly sand
Brown fossiliferous silty clay
1000
Gray limy mud
Hard tan and gray mud
some fossils
Brown basaltic sand
Conglomerate with silt, clay,
sand matrix
Brown silty clay
Weathered aa subsoil
Solid aa basalt
Partly weathered red clinker
Red aa clinker
Very vesicular pahoehoe
1100
1 sec. period vertical seismometer

EWA BEACH AUXILLIARY TEST WELL T-133-2
OAHU, HAWAII

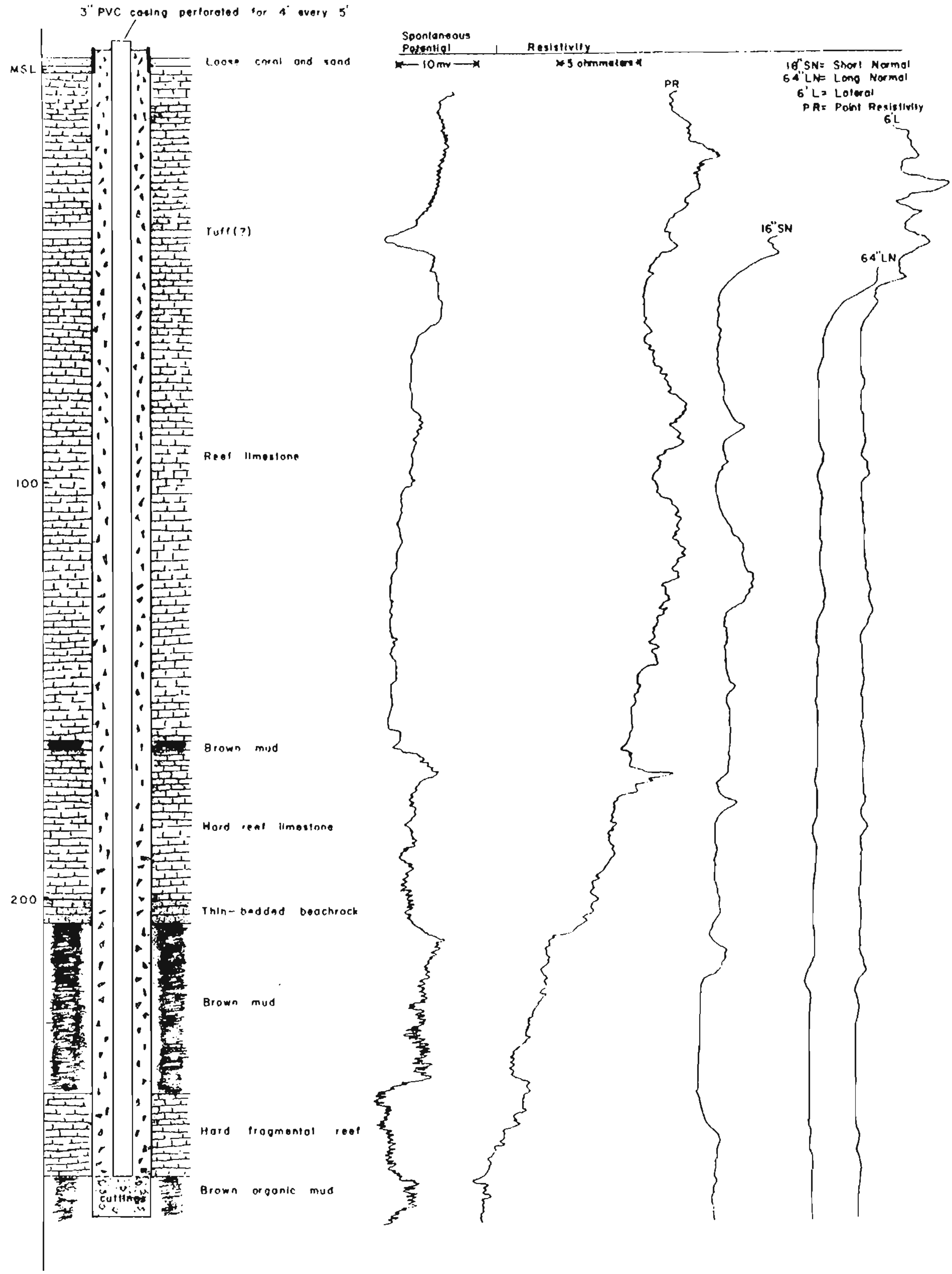


FIGURE 3

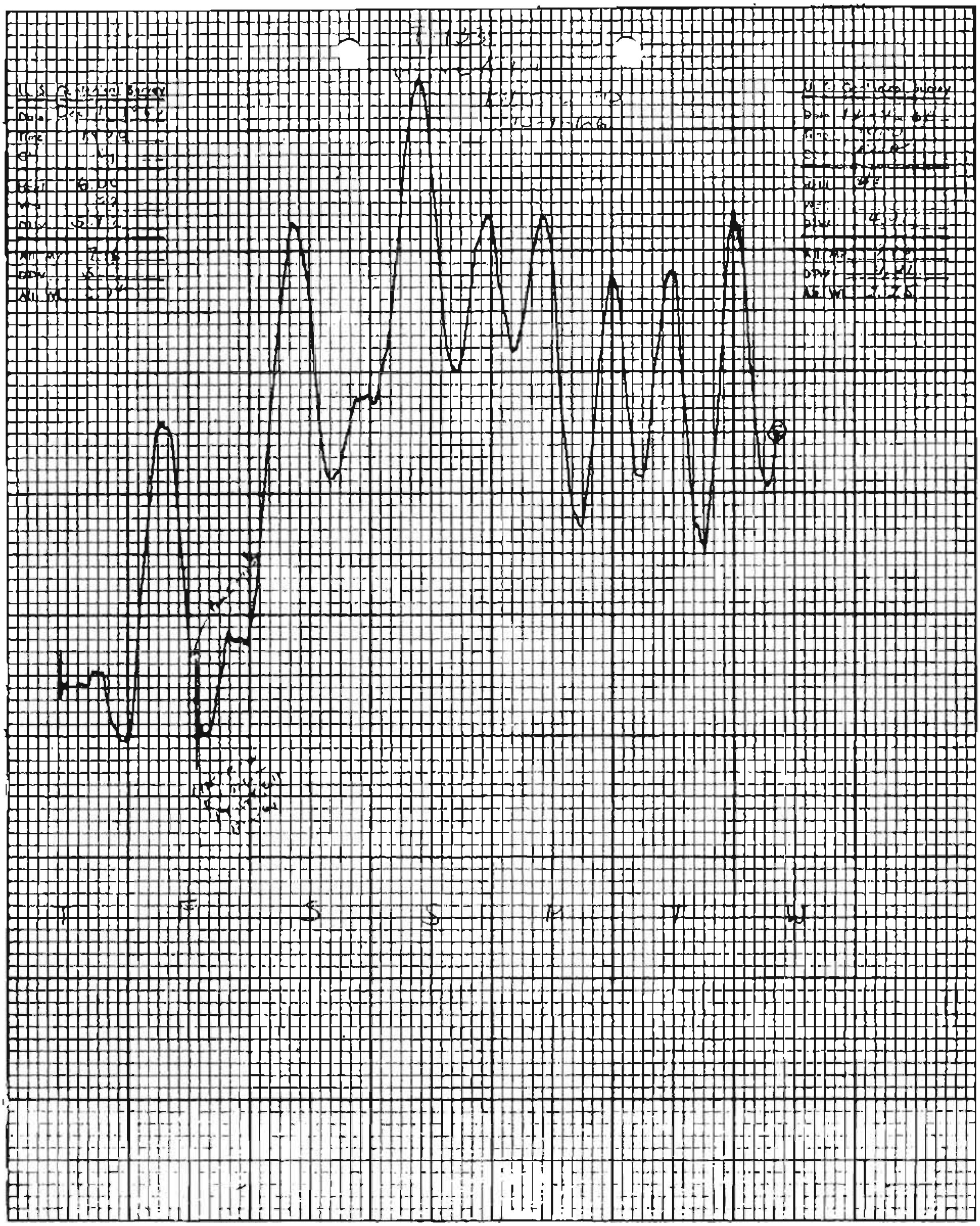


FIGURE 4A [illegible] DEC. 1-7, 1966

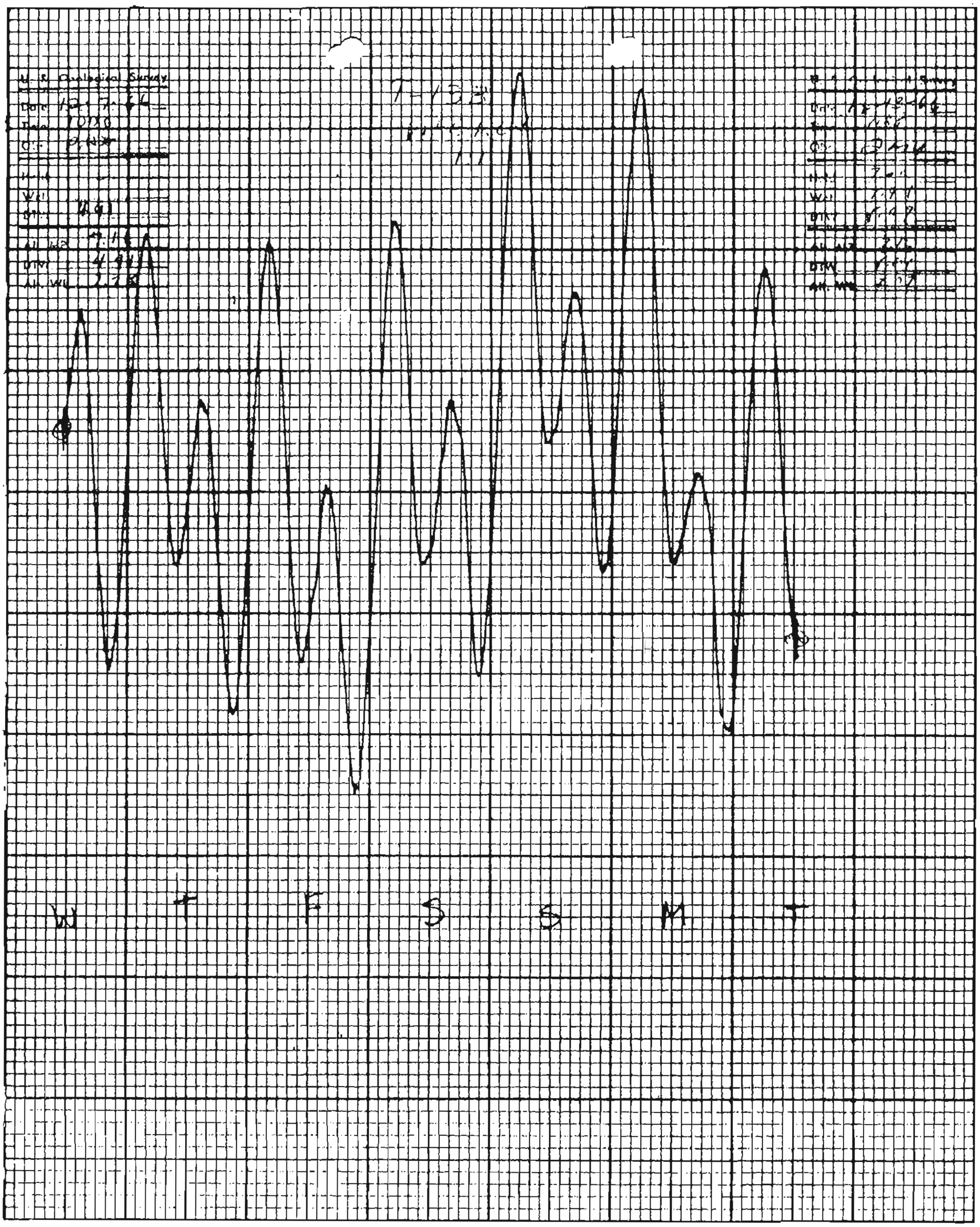


FIGURE 4B. HEAD RECORD AT EWA BEACH DEEP AQUIFER. DEC. 7-13, 1966

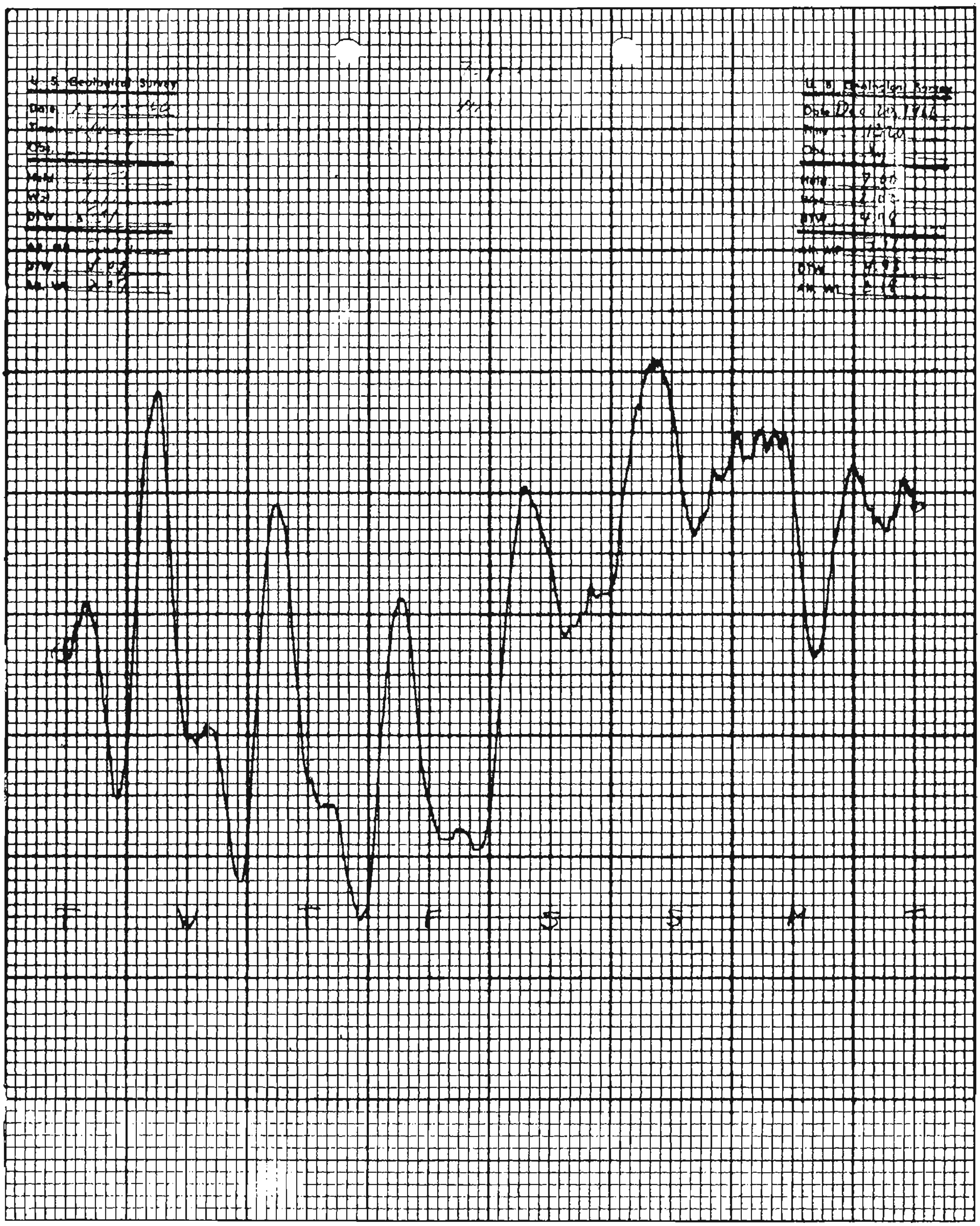


FIGURE 4e. HEAD RECORD AT EWA BEACH DEEP AQUIFER: DEC. 13-20, 1966

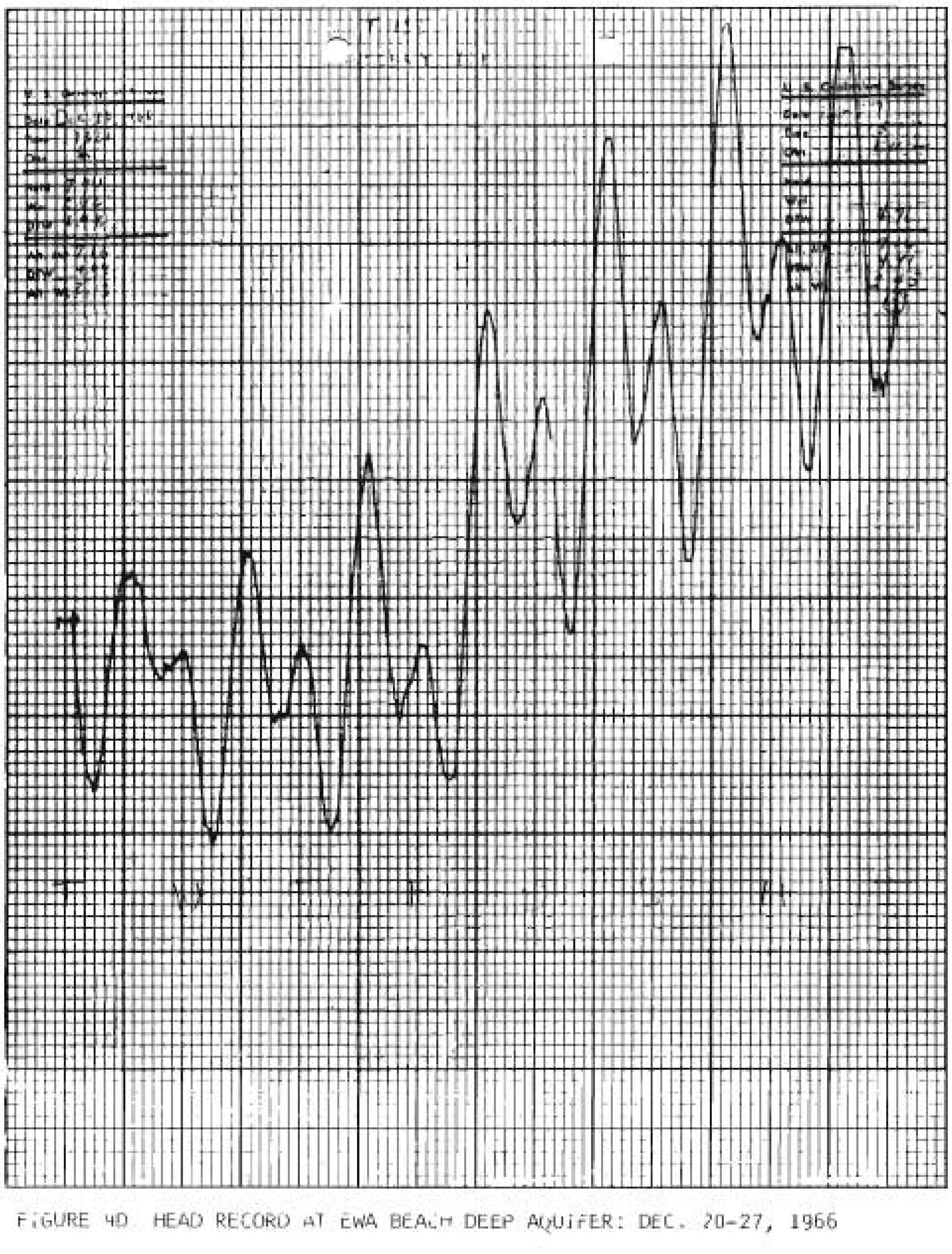


FIGURE 4D HEAD RECORD AT EWA BEACH DEEP AQUIFER: DEC. 20-27, 1966

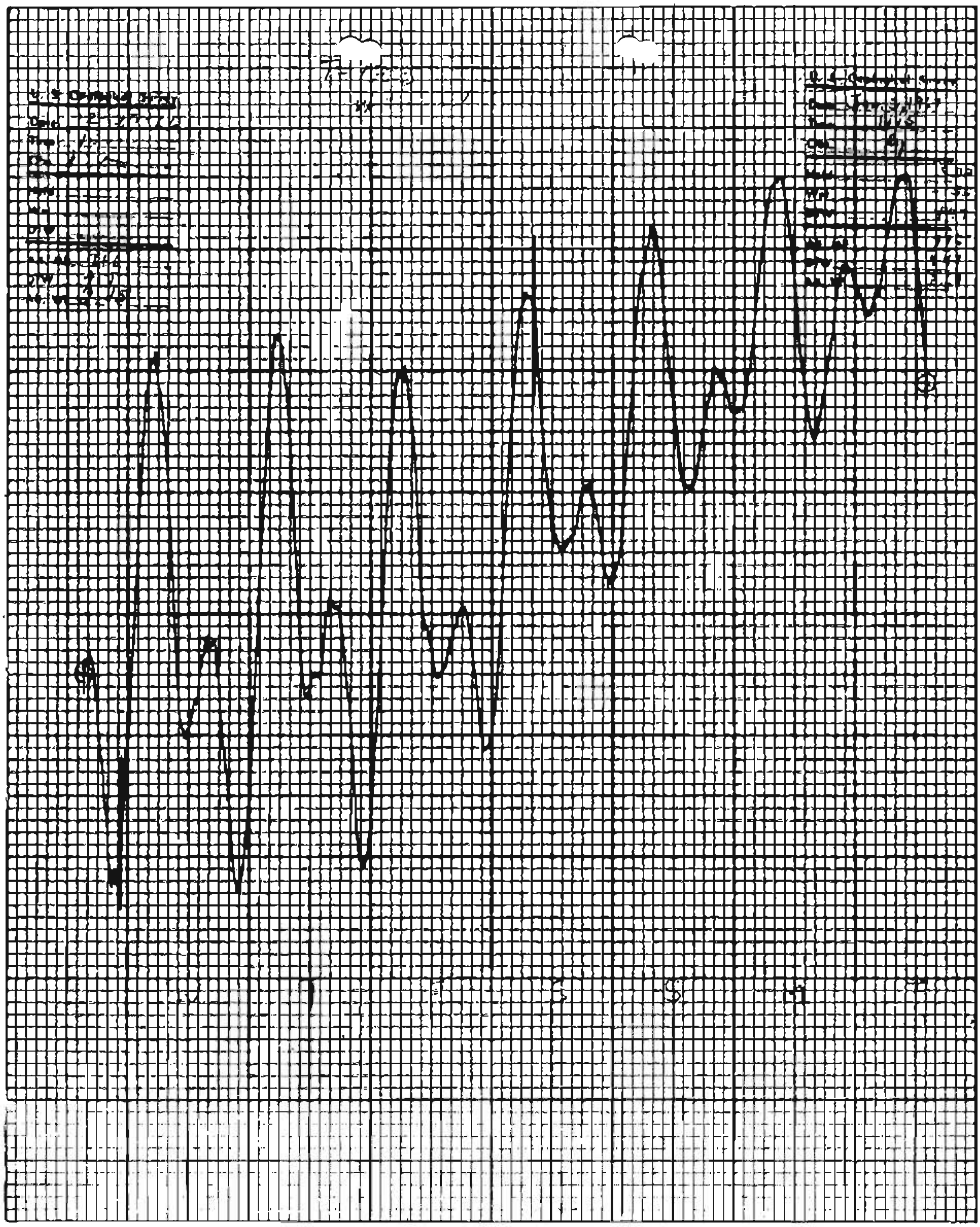


FIGURE 4E. HEAD RECORD OF LIDA BEACH DEEP AQUIFER, DEC. 27, 1966–JAN. 3, 1967

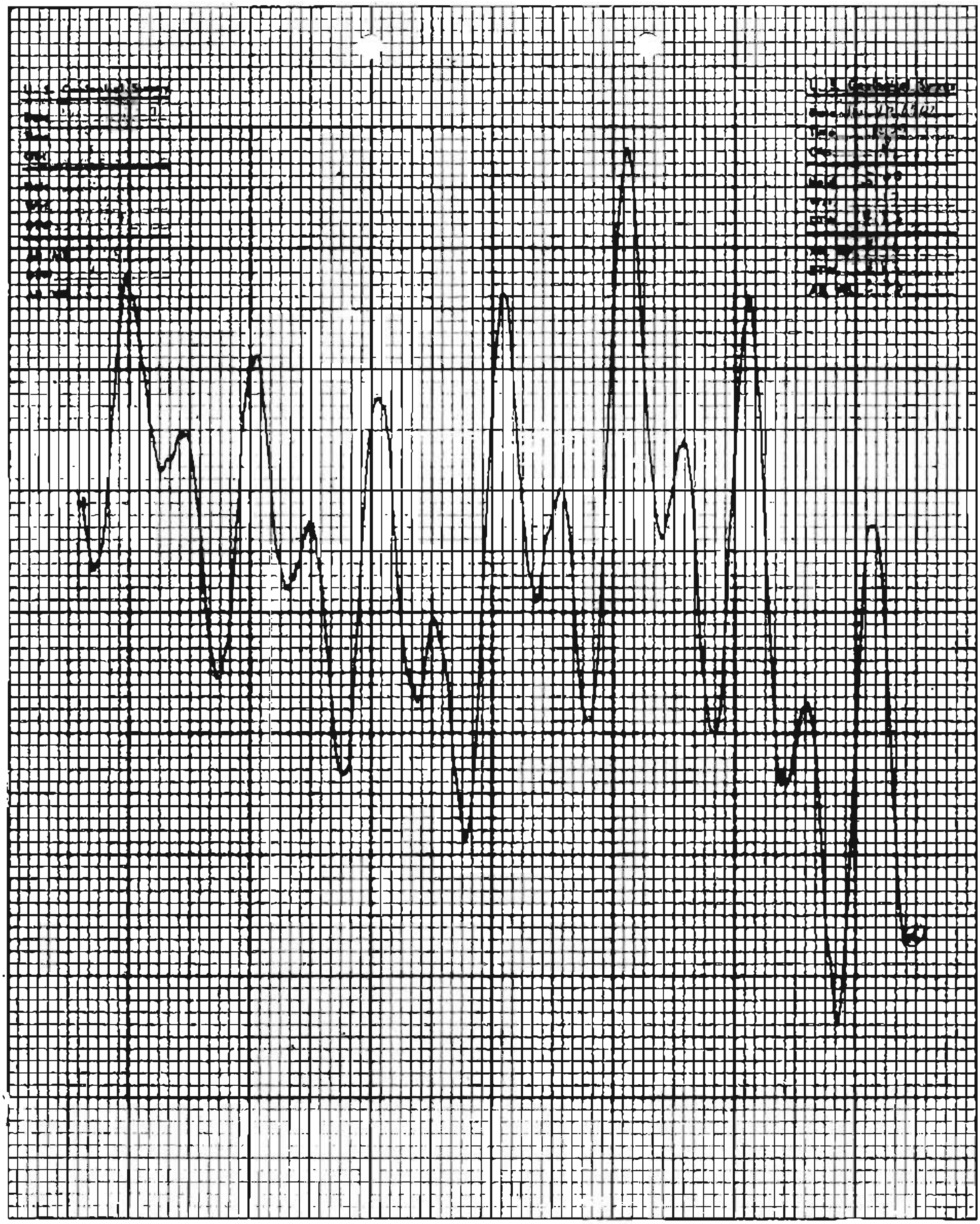


FIGURE 4F HEAD RECORD - EWA BEACH DEEP [illegible] FOR. JAN. 3-10, 1967

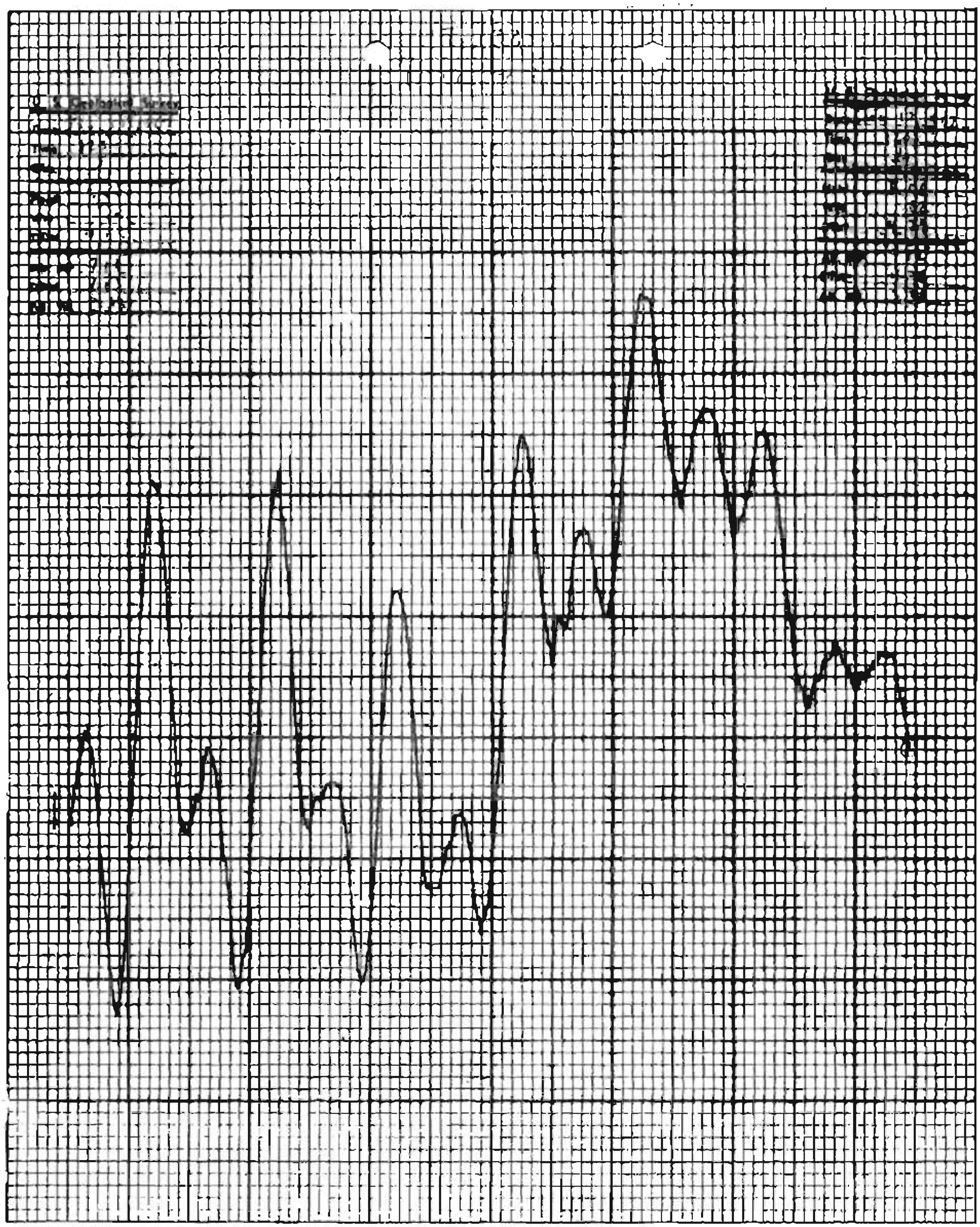


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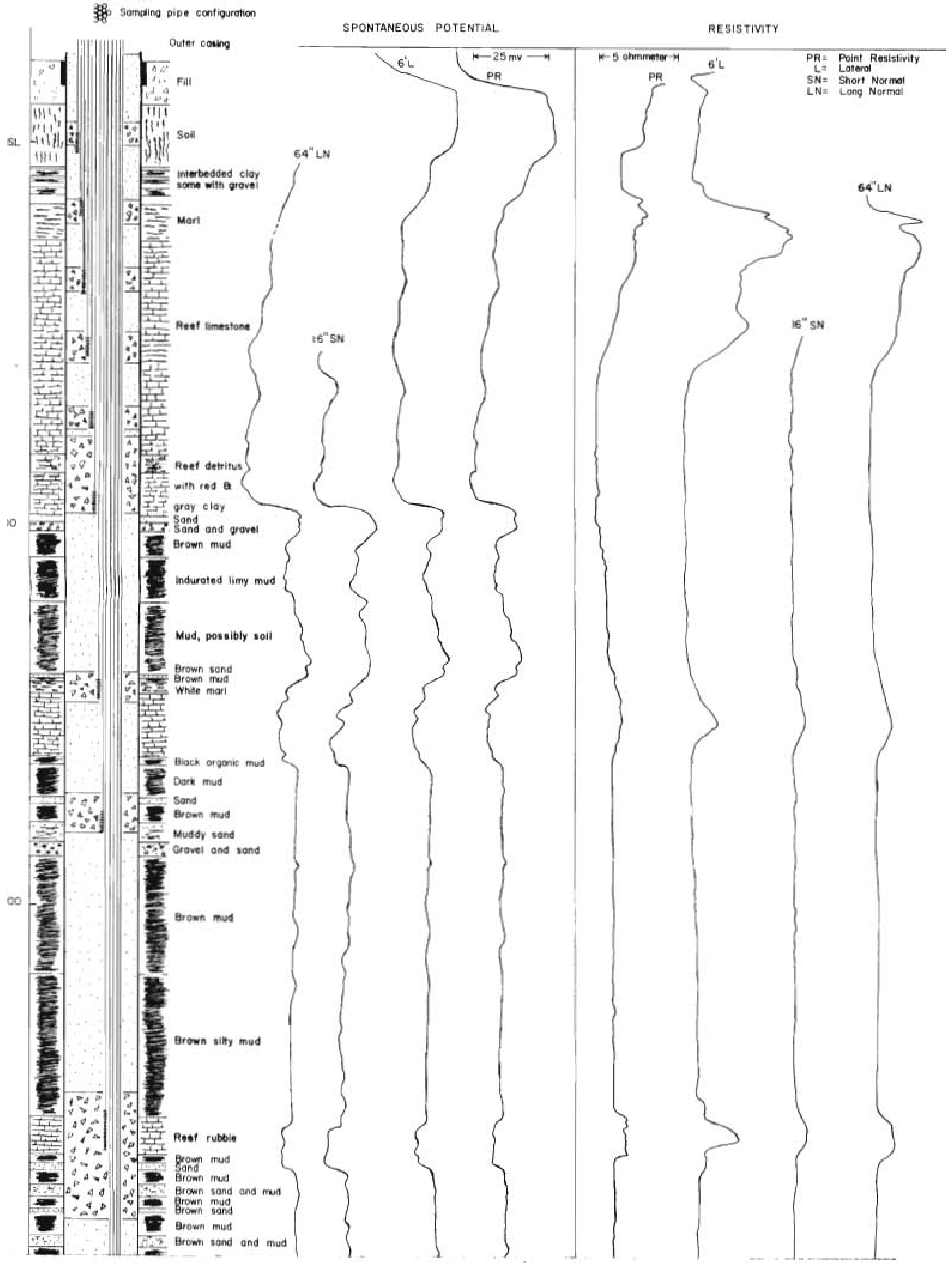
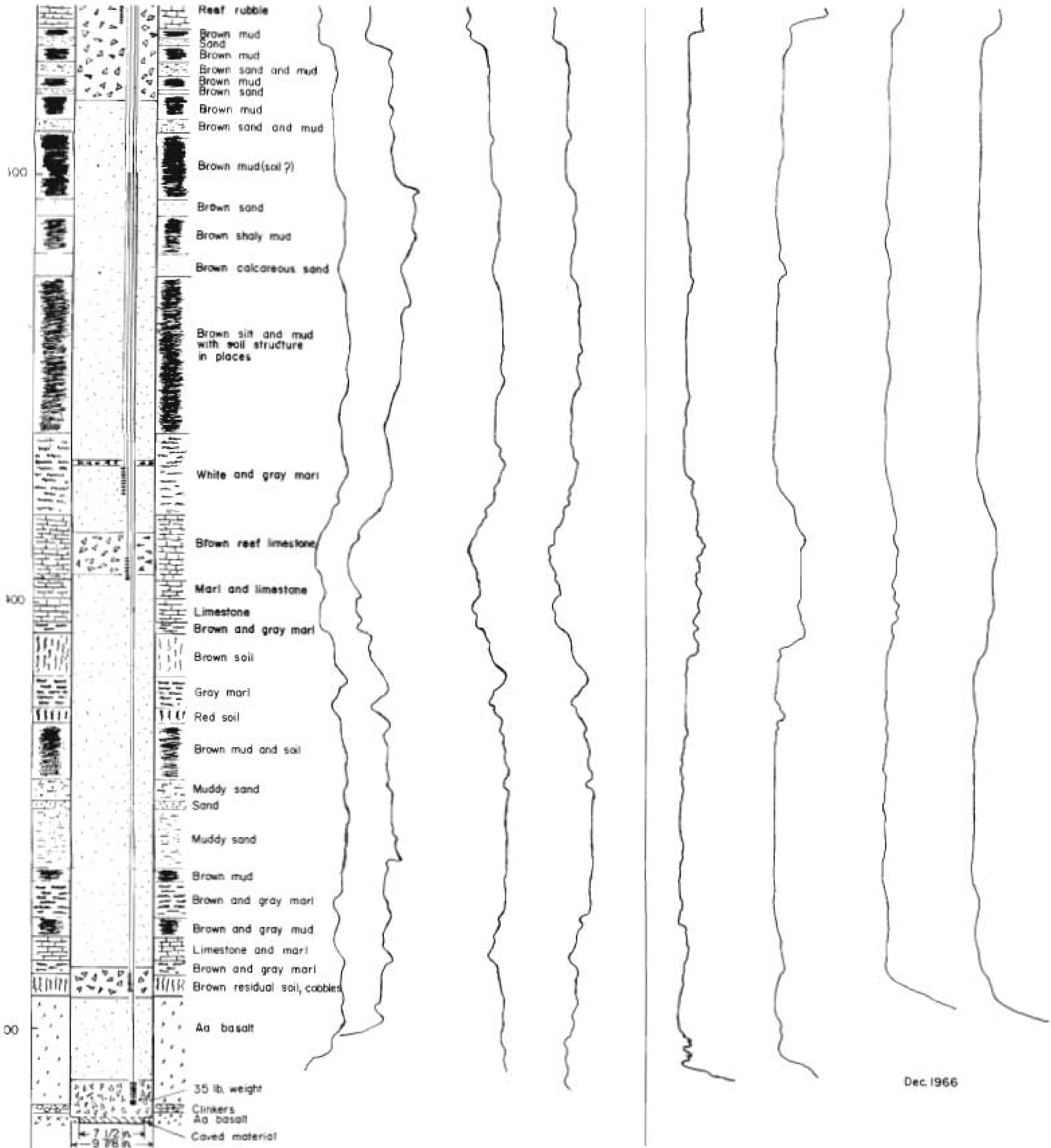
FIGURE 5

PUULOA TEST WELL

Oahu, Hawaii





Reef rubble
Brown mud
Sand
Brown mud
Brown sand and mud
Brown mud
Brown sand
Brown mud
Brown sand and mud
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
400
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