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Characterization of formations and groundwater potential of Amai and Obiaruku in Delta State using resistivity and seismic refraction measurements

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Abstract

Obiaruku and Amai are two communities with remarkable high population due to their nearness to flowing waters which is one of the bases of early settlements. Although, the two towns are only 3 kilometres apart their geological and geophysical presentations vary remarkably. While Obiaruku is flanked by the early stage of the fast flowing North - South fresh-water river Ethiope, Amai has slow flowing filthy stream which spreads out and sometimes over flows its bank.

Moreover, while Amai has numerous hand dug wells which are filled up to 2.5 metres or less depending on the season under investigation, Obiaruku has no evidence of hand dug well all the year round. The disparities in presentations are of interest. It becomes necessary to carryout a geophysical investigation of the formation strata and groundwater potential for the ever growing population of these communities. Hence a characterization of the formations and groundwater distributions were carried out using Schlumberger array of electrical resisitivity and up-hole shooting of seismic refraction surveys. Twelve Vertical Electrical Sounding (VES) stations were sounded using Self Averaging System SAS ABEM 300C tarrameter and eight refraction sounding sites were shot using Seismograph OYO MESEIS 160mx. The study shows that while Obiaruku has QA and HA curve types, which have basically four or more distinct resistive layers, Amai consists of A-type curve which has mainly three or four distinct resistive layers. The soil formation in Amai is highly conducting clay while that of Obiaruku is mainly laterite. Moreover, while Groundwater is at 45 – 50 m depth in a region of unconfined aquifer at Obiaruku, it is as low as 20 m in a zone of confined aquifer at Amai.

1.0 Introduction

Amai and Obiaruku are two major towns in Ukwuani LGA of Delta State. Although these two towns are close to each other, their geophysical presentations are remarkably different. While Obiaruku has the fast flowing river Ethiope, Amai has an almost stagnant *Okumeshi* stream which sometimes over flows its bank. Moreover, the existence of numerous hand-dug wells at Amai and the obvious absence of such in Obiaruku point to possible disparity in lithological formation. This work is therefore aimed at characterizing the underground layer formations and determining the groundwater potentials of these communities so as to provide empirical/geophysical explanation to these variations. This was done using VES soundings and seismic refraction studies to obtain geoelectric sections of the area of study. The sections were correlated with existing well records and they were found to be in agreement with available drill log records.

2.0 Geology of the Study Area

Obiaruku and Amai lie within Latitude 6.00^{o}N and Longitude 6.00^{o}E and are within the Benin formation in the Niger Delta (Figure 1). The Benin formation according to Short and Stauble (1967) is of continental fluid-tile environment consisting of sand gravels and swamp deposit. It is a continental or non-marine deposit with massive coarse-grained to medium grained sand. It is poorly to moderately sorted, gravelly and sub-angular to well-rounded grains.

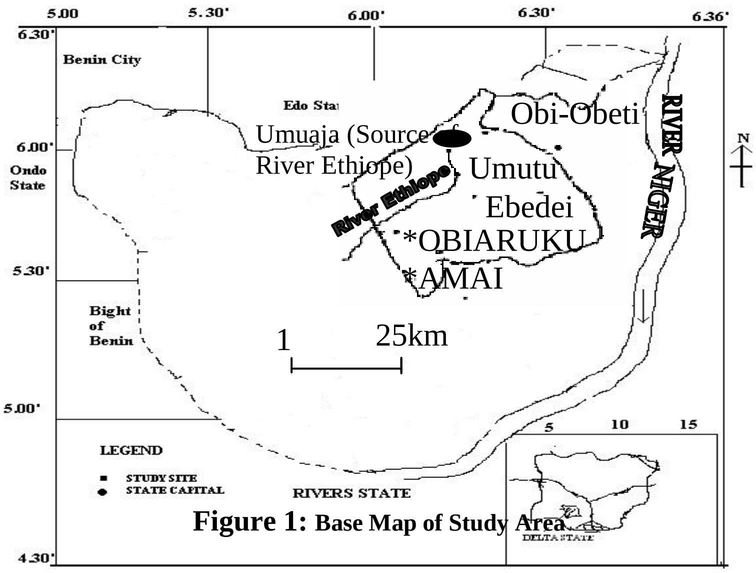

Figure 1: **Base Map of Study Area**

3.0 Materials and Methods

Two methods were used (a) The Vertical electrical sounding method and (b) the Up-hole shooting of seismic refraction

(a) The Schlumberger array developed in 1916 was applied using a 300C (self averaging system) terrameter. Twelve VES stations were sounded with a current electrode spread of 928 metres each. The Schlumberger configuration required that the current and potential pairs of electrodes have a common midpoint O, but the distance between adjacent electrodes differs (Mamah and Ekine 1989). Also, the current electrodes spacings are increased on a logarithmic scale in the course of measurements in the field (Dobrin, and King 1965) while the potential electrodes are kept at small separations relative to the current electrodes separations such that AB ≥ 5CD (Fig 2). Thus, only current electrodes need to be shifted to new positions for most readings while potentials electrodes are kept undisturbed for up to three or four readings. When the potential electrodes need move two soundings are usually shot with the same current electrodes positions. The First reading is made with the initial potential electrodes positions and next, with the new their positions (Table 1) for necessary computational adjustments. This array was the choice since it makes for greater current electrode spacing and deeper penetration (Okwueze et al, 1994).

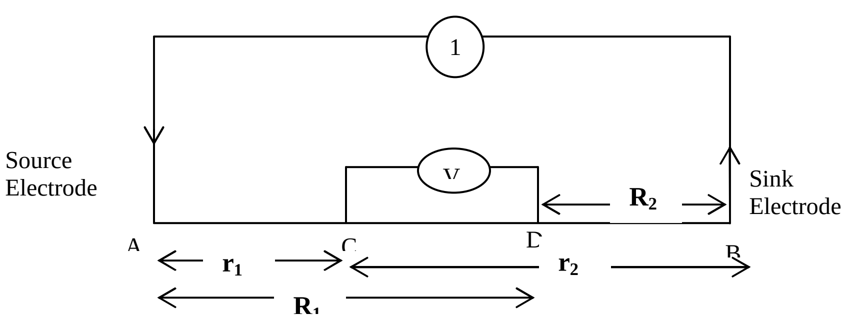

Figure 2a: General four-electrode configuration for resisitivity survey.

Thus, the potential difference ($V_c - V_D$) between the two inner electrodes (Figure 2a) measured by the voltmeter connected between C and D is given by Lowrie (1997) as

$$\nabla V = (V_c - V_D) = \frac{\rho I}{2\pi}\left\{\left(\frac{1}{r_1} - \frac{1}{r_2}\right) - \{\frac{1}{R_1} - \frac{1}{R_2}\}\right\}. \qquad (3.1)$$

Hence,

$$\rho = 2\pi \frac{\Delta V}{I}\left\{\frac{1}{(1/r_1 - 1/r_2) - \left(\frac{1}{R_1} - \frac{1}{R_2}\right)}\right\}.. \qquad (3.2a)$$

$$\Rightarrow \quad \rho = 2\pi r\left\{\frac{1}{(1/r_1 - 1/r_2) - \left(\frac{1}{R_1} - \frac{1}{R_2}\right)}\right\}. \qquad (3.2b)$$

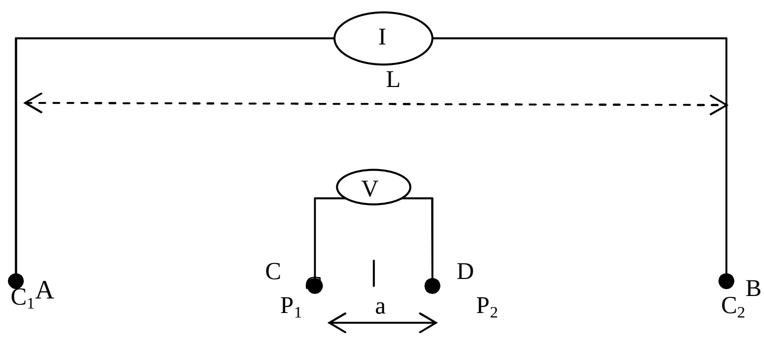

Figure 2b: Schlumberger Field Electrode Arrangement

Applying this to the Schlumberger array (Figure 2b), $C_1P_1 = P_2C_2 = (L - a)/2$. Also, $C_1P_2 = C_2P_1 = (L + a)/2$

$$\rho = 2\pi \frac{\Delta V}{I}\left\{\frac{1}{(2/L - a - 2/L + a) - \left(\frac{2}{L + a} - \frac{2}{L - a}\right)}\right\}.. \qquad (3.3)$$

$\rho = \dfrac{\pi V\left(L^2 - a^2\right)}{4Ia} = K_s R$ (Lowrie (1997)), sothat,

$$K_s = \frac{\rho 4a}{\pi\left(L^2 - a^2\right)} \qquad (3.4)$$

where *Ks* is Geometric Factor for Schlumberger array. In the study of the earth, the resistivity of the top layer is the only actual resistivity since it is measured directly while others beneath the top soil/layer are obtained as replacement from which the correct resistivity values are computed (Mbipom and Archibong, 1989). Hence it is called apparent resistivity. The geometric factors were calculated using the appropriate values of the electrode spacings from which the apparent resistivity values of each sounding was calculated and recorded against their corresponding $^{AB}/_2$ values as shown in Table 1. The resistivity values and corresponding layer thicknesses obtained from partial curve matching were then fed into the computer software and iterated with particular geo-physical software (the Resist) to obtain the final values of layer resistivities and thicknesses within limited error tolerance level of about 10% or less. When minimum percentage error was achieved, the results were printed out and used for interpretation of the subsurface formations in the study area (Figure 3).

(b) The up-hole shooting was carried out using a 24 - channel Seismograph at randomly selected sites with a view of having a good spread over the study area. A water resistant geophone was carefully cased in a tool and connecting to each of the 24 channels of the seismograph and dropped into a deep hole for a shot to be taken. A shot was taken by hammering on the plate and hence on the sensor to trigger the seismograph so that the geophone could receive the vibrations from generated waves. By this, the one-way travel time wave response from the geophone was recorded into that particular channel against the depth of geophone in the hole. A new depth was shot each time in the hole from 60m to the surface with the control shot at the surface to obtain recorded the waveforms for the different geophone depths.. A 2-metre offset was taken from the hole to the trigger (the shot point) to ensure that the waves actually travelled through the earth surface to the geophone in the deep hole (Fig 4). A measuring tape/cord was connected to the tool to position it at convenient and known depths. The recorded shot responses in the 24 channels of the seismograph were printed out for analysis.

Analyses of Data from Up-hole Survey:

The recorded first break for each shot was obtained and used for the purpose of analyses. The first break of each geophone obtained was determined from the seismograph printouts and recorded for the development of a time-distance graph, which involves plotting arrival times against geophone spacing in other to estimate the layer velocities and thicknesses. Time-distance graphs thus were plotted from the geophone distance and first arrival time Osemeikhian and Asokhia (1994). The plot clearly shows the weathering layer velocity V_w and its thickness (depth) D_w as well as those of the consolidated zones since there is an abrupt change in slope due to rapid increase in travel time as the path length in the LVL increases (Sheriff and Geldert, 1983).

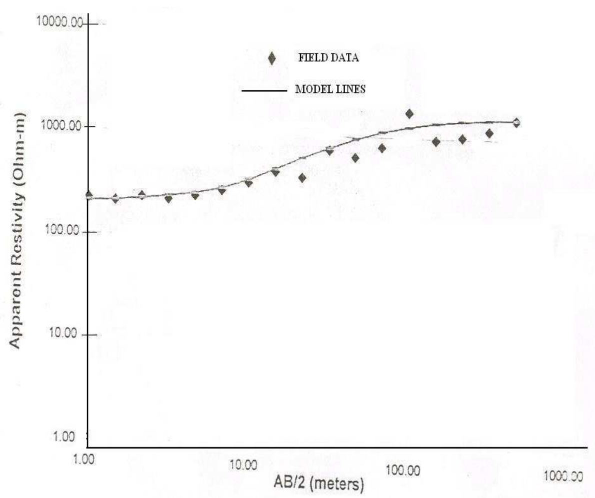

Fig 3 (b): Sample Iterated Field curve

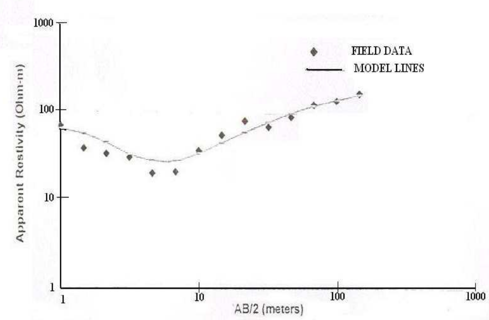

Fig 3 (a): Sample Iterated Curve for Obiaruku

The velocities of waves in the weathering layers and in the other layers were calculated from the graphs (Okwueze, 1988). The various layer thicknesses for the sites were also determined using calculation of the vertical one way travel time to a depth Z given by

$$t_r = t_r \frac{Z}{\sqrt{Z^2 + X^2}} \qquad (3.5)$$

where t_v = vertical time, t_r = recorded time and X = offset for the purpose of time correction necessitated by slant distance (Figure 4), therefore $t_r = t_r \cos\theta$ and $\theta = \tan^{-1}(^x/_z)$

$$t_r = t_r \cos(\tan^{-1}(^x/_z)) \text{ (Telford et al, 1990)} \qquad (3.6)$$

and the interval velocity, V_1 is

$$V_i = \frac{Z_m - Z_n}{t_m - t_n} \qquad (3.7)$$

where "*m*" and "*n*" are geophone points, $Z_m - Z_n$ is depth difference and $t_m - t_n$ is time difference between the geophone points.

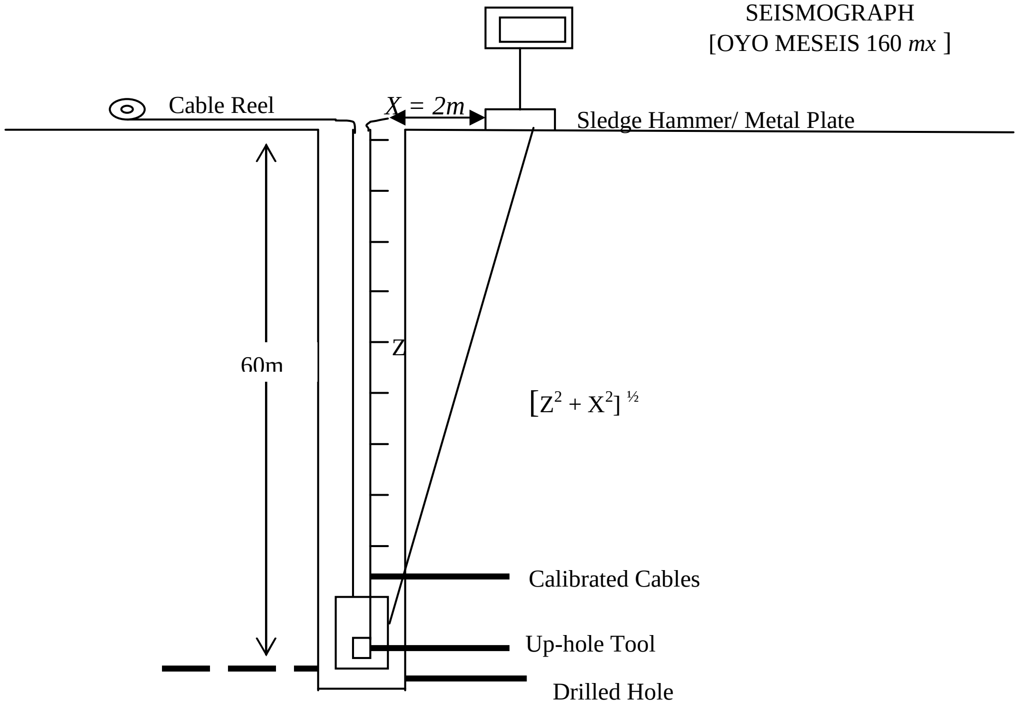

Figure 4: Up-Hole Refraction Survey Field Equipment Setup

4.0 Data Treatment

Qualitative and quantitative analyses of the field data were made

Table 1: Field data sample

MN/2 (*m*)	**AB/2 (*m*)**	**Geometric Factor (*G*)**	**Resistance at Obiaruku (*R*)(Ω)**	**Resistance at Amai (*R*) (Ω)**	**Smoothed Apparent Resistivityat Obiaruku (Ω*m*)**	**Smoothed Apparent Resistivity at Amai (Ω*m*)**
0.2	2.00	7.5	9.16	29.10	69.06	219.40
	13.8	16.7	2.33	12.57	38.82	209.54
	4.30	36.0	0.92	6.41	33.12	230.80
	6..32	78.1	0.56	2.81/3.01	30.93	219.40
0.2/1.0	9.28	168.8/32.3	0.13/0.6	1.42/7.59	20.79	239.90
	13.62	71.3	0.31	3.86	21.75	275.22
1.0/3.0	20.00	155.5/47.7	0.24/0.80	2.13	37.44	332.28
	29.40	108.4	0.52	1.28/1.77	56.60	432.20
	43.00	237	0.35	1.63	82.00	386.30
3.0/8.0	63.2	18.1/183.5	0.22/0.39	1.40	71.00	725.20
	92.8	410.2	0.23	0.56/1.34	92.66	628.30
8.0/16	136.2	898/430.0	0.14/0.24	0.87	128.00	800.00
	200.00	56.6	0.15	0.90/0.442	143.00	1754.00
16/30	294.00	96.6/1373.2	0.11/0.16	0.89/0.89	173.60	965.70
30/50	430.00	373.2/1374	0.04/0.12	0.76/0.76	160.76	1044.00
	632.00	3058	0.13	0.02/0.025	392.00	1200.00
	928.00	685	0.03	0.23	187.00	1550.00

RMS Error % = 5.50 – 6.00

Table 2: Summary of analysis from Vertical Electrical Sounding

TOWN/SITE	ρ_1 (Ωm)	ρ_2 (Ωm)	ρ_3 (Ωm)	ρ_4 (Ωm)	ρ_5 (Ωm)	h_1 (m)	h_2 (m)	h_3 (m)	h_4 (m)	h_5 (m)
OBIARUKU 1	85	270	240	550	128	1.26	0.24	1.24	42.00	∞
OBIARUKU 2	55	270	255	640	570	1.00	0.15	2.30	11.50	∞
OBIARUKU 3	120	340	360	470		1.20	0.35	4.60	∞	
OBIARUKU 4	140	707	820	540		2.30	1.80	5.40	∞	
OBIARUKU 5	80	320	1440	733		2.00	3.60	55.2	∞	
OBIARUKU 6	135	230	350	166		2.00	1.44	13.21	∞	
OBIARUKU 7	65	130	440	420	126	1.20	1.40	170	32.00	∞
OBIARUKU 8	100	43	722	133		1.20	6.00	55.00	∞	
AMAI 1	45	30	741			1.00	0.80	∞		
AMAI 2	90	450	255	960		1.30	1.20	21.00	∞	
AMAI 3	240	145	910	113		1.10	5.00	12.00	∞	
AMAI 4	220	440	960	1000		1.40	3.90	15.00	∞	

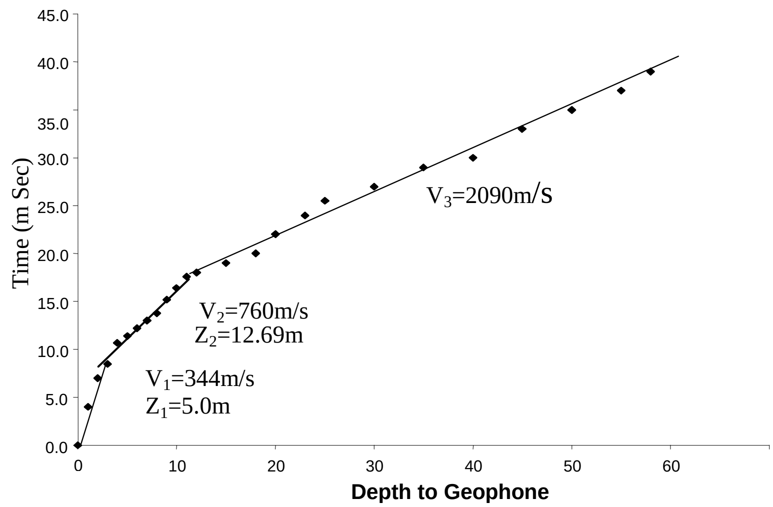

Figure 5a: Up-Hole Survey Plot for Amai

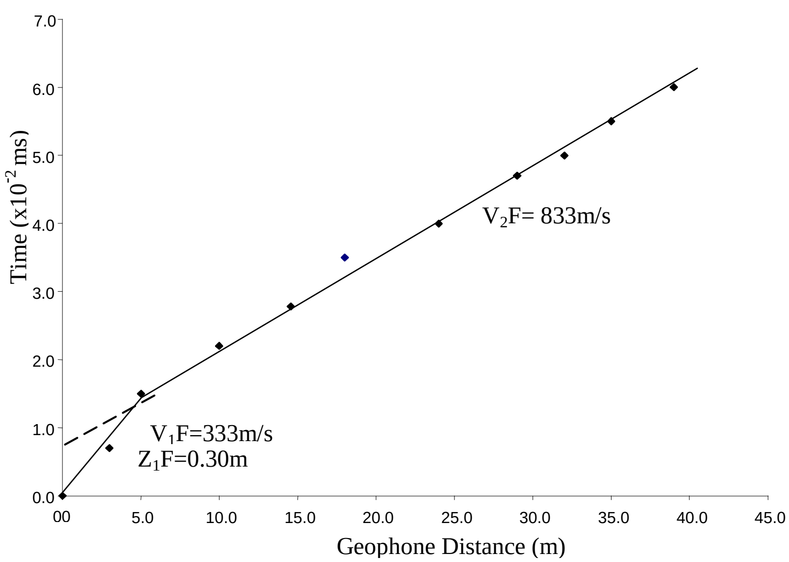

Figure: 5b: Plot of up-hole survey data for Obiaruku

5.0 Discussion and Conclusion

The analyses of the Vertical Electrical Soundings indicate that while Obiaruku has OA and HA curves which consist of four to five lithological formations, Amai has mainly A-type curve which consists of three resistive layers. Moreover, while Obairuku has sites with moderate to high resistivities which is indicative of loose to compact lateritic formations, Amai has sites with low resistivity values which are peculiar to regions high clay formations. These findings are complimented by the Up-hole plots which indicate that the generated seismic waves at about 13 metres with velocity of 2,090 m/s in Amai was in a water-bearing medium but in Obiaruku the waves did not hit a water-bearing medium even at far depth.

In conclusion, although Obiaruku and Amai are close and are of continental fluid-tile environment consisting of sand gravels and swamp deposit, their lithological presentations differ greatly.The formations with low resistivity at Amai suggest the presence of heavy clay deposits while sites with moderate to high resistivity at Obiaruku suggest the existence of non clayey formations. From the Electrical resistivity and seismic refraction studies, Amai has heavy clay deposits which can retain large quantity of water for considerable part of the year as hand dug wells but Obairuku consists basically of loose sand and laterite to far depth. Moreover, viable groundwater depth in Obiaruku is at 45 – 50 metres in a region of absence of clay (unconfined aquifer) while it is as low as 15 – 25 metres in a zone of confined aquifer at Amai. These were correlated with existing driller's log (Fig 6) and were found to be in agreement.

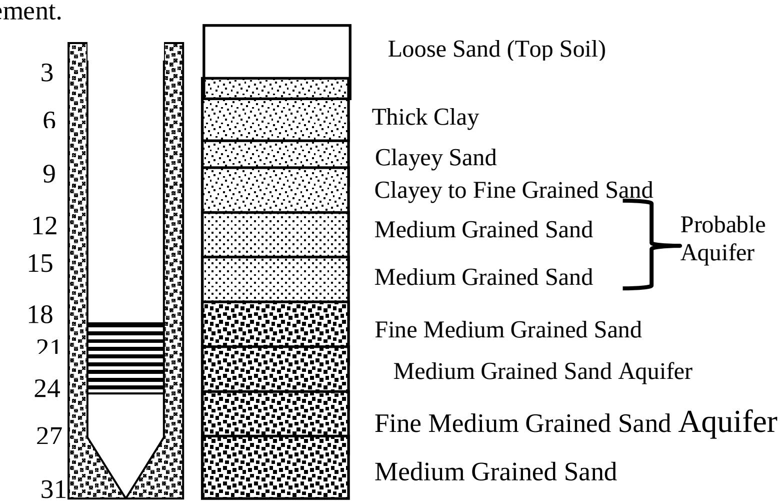

Figure 6a: Borehole Lithology for Amai

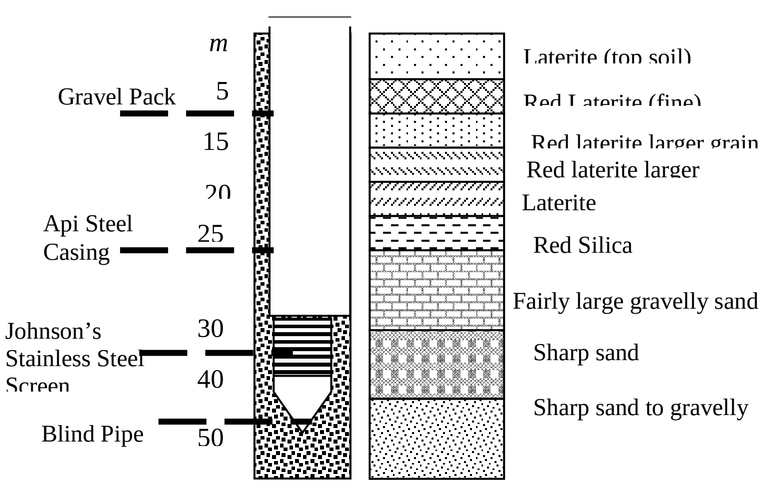

Figure 6b: Borehole Lithology for Obiaruku

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