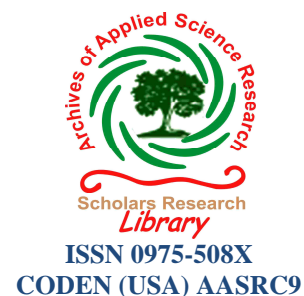




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## Salinity depths in coastal aquifers of Niger Delta, Southern Nigeria

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### ABSTRACT

*Successful management of coastal groundwater resources depends not only upon planning and regulations. It also depends on accurate assessment and prediction of the behavior of saltwater interface to both natural conditions and man's activities. Over the years, a combination of factors has resulted in changes in depth-to-saltwater (salinity depths) in the coastal aquifers of Niger Delta. In an effort to study the dynamics of salt/freshwater interface and estimate the current salinity depths in the Niger delta, down-the-hole geophysical logs (resistivity, spontaneous potential and gamma ray logs) were carried out in deep water-supply boreholes in the coastal parts of the Niger delta. The boreholes were drilled to depths ranging from 180m to 600m below ground level and completed into the Benin Formation, Pliocene-Recent in age. The logs clearly reveal the sub-surface stratigraphic successions, isolated saline-water contaminated stretches of the drilled holes and fresh water bearing layers in the area. Generally speaking, a good stretch of the drilled depth is contaminated by saline water to various depths. Water well drilling contractors can now be guided on the best section of the drilled column to place the screens to exploit fresh water from the boreholes. Proper borehole completion methods can also be adopted especially when the freshwater aquifer underlies a saltwater aquifer. Prior to this study, huge amounts of money had been wasted in drilling and completing boreholes which yielded saline water either from the onset or soon after being commissioned.*

**Key words:** salinity, groundwater, coastal aquifers, Niger Delta.

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### INTRODUCTION

The eastern Niger Delta lies between latitudes 5°22' and 7°37' North and longitudes 4°47' and 5°47' East and comprises the present day Rivers and Bayelsa states, (Fig. 1). The study area proper is the coastal fringes of the Niger Delta bordering the Bight of Benin. The area is characterized by numerous surface water bodies. Rainfall is typically high in the area. Mean annual rainfall decreases northwards and away from the coastline (Fig. 2), [1]. The land area stretching from Opobo through Bonny to Akassa constitutes the wettest part. Annual average rainfall is about 5000 mm, decreasing through the middle delta (3000 mm) to 2000 mm at the upper delta [2]. The heavy rainfall generates large volume of overland flow which empties into the Atlantic Ocean via a network of rivers, lakes and creeks.

About 70% of the population lives in the riverine areas in isolated barrier islands, beaches and other emergent land areas often separated by tidal flats, channels and swamps.

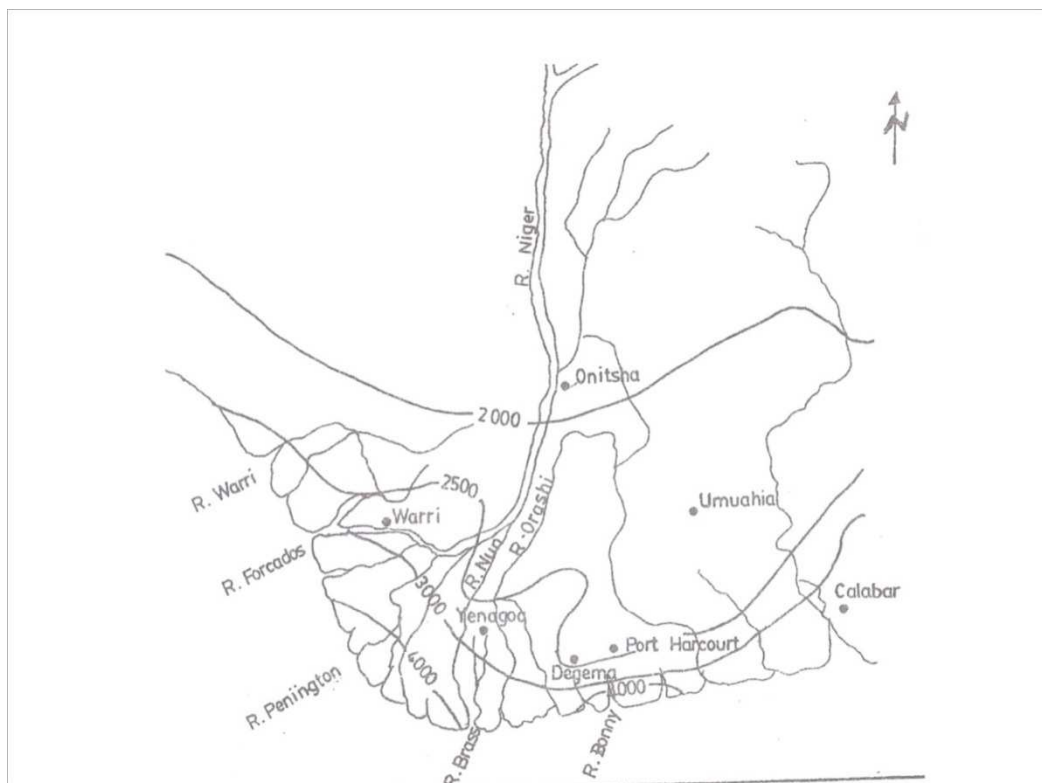
The paralic environment is typically characterized by brackish water, which is unfit for human consumption. Long history of petroleum exploration and exploitation activities further renders the water unfit for consumption due to direct discharge of oil and gas wastes into the bodies of water. Unplanned and over-exploitation of the coastal fresh water aquifers to meet cooling requirements and domestic consumption has resulted in saline water intrusion into freshwater aquifers. For most of the boreholes drilled into the formation for the purpose of extracting fresh water, a

good stretch of the drilled depth is contaminated by saline water to various depths. This study is an attempt to study the current salinity depths in the coastal aquifers of Eastern Niger Delta.

**Fig.1: Location Map of the Study Area**



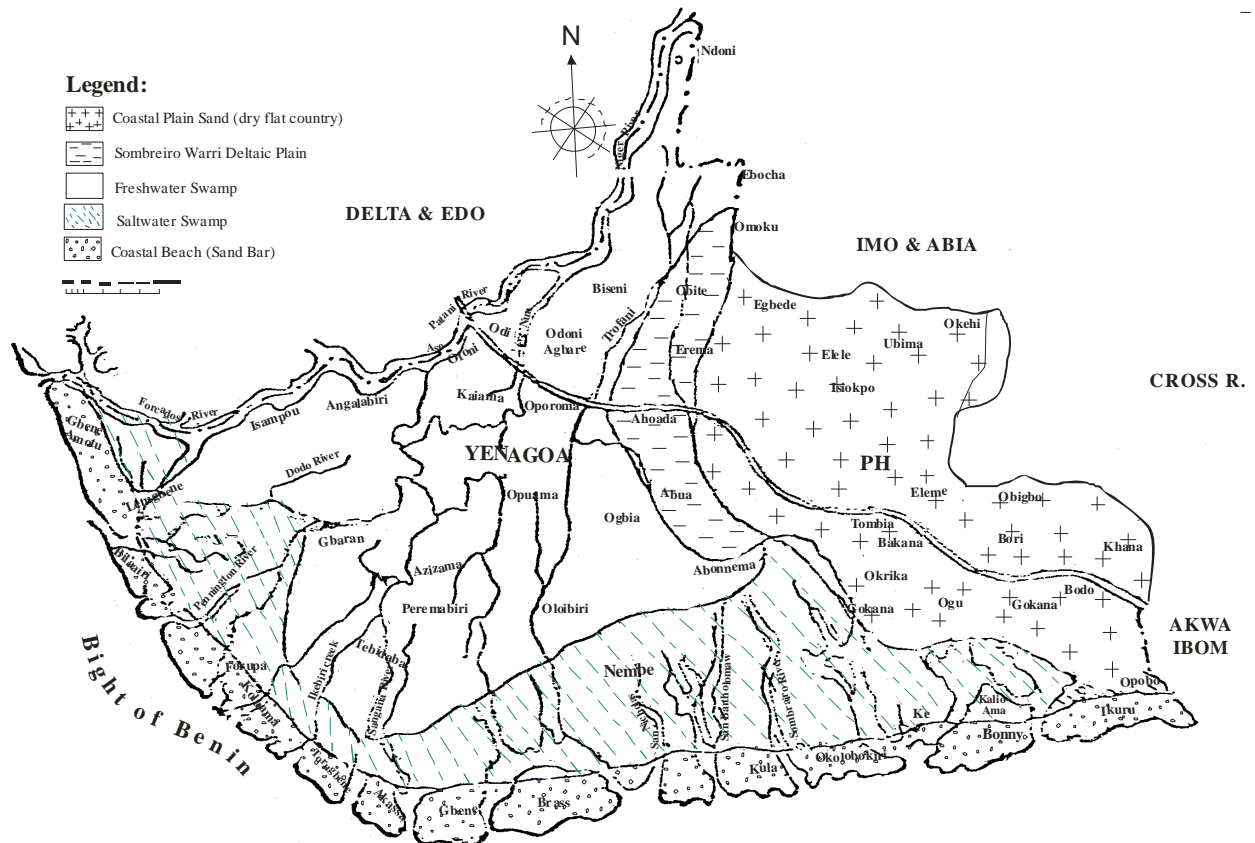
**Fig 2 Annual Rainfall Isohyet in the Niger Delta, [1].**



## Geology and Geomorphology.

The thick succession of sediments forming the present Niger Delta has been described as consisting of three lithostratigraphic units namely: Benin Formation (Miocene – Recent) at the top, the Agbada Formation (Eocene) at the middle and Akata Formation (Paleocene) at the base, [3]. The lithology of the formations reveals that only the Benin formation consisting essentially of massive highly porous, sand and gravels with a few clay intercalations can be economically exploited for groundwater supplies. These materials are believed to have been deposited in a continental fluvial to deltaic environment. Well cuttings from oil wells further show that the Niger Delta is underlain by the laterally extensive Benin formation to a great depth.

**Fig 3. Major geomorphologic units in the study area, [4].**



Quaternary deposits overlie the Benin Formation in the swampy delta areas. They consist of rapidly alternating sequence of sand and silt/clay with the clay becoming more pronounced seawards.

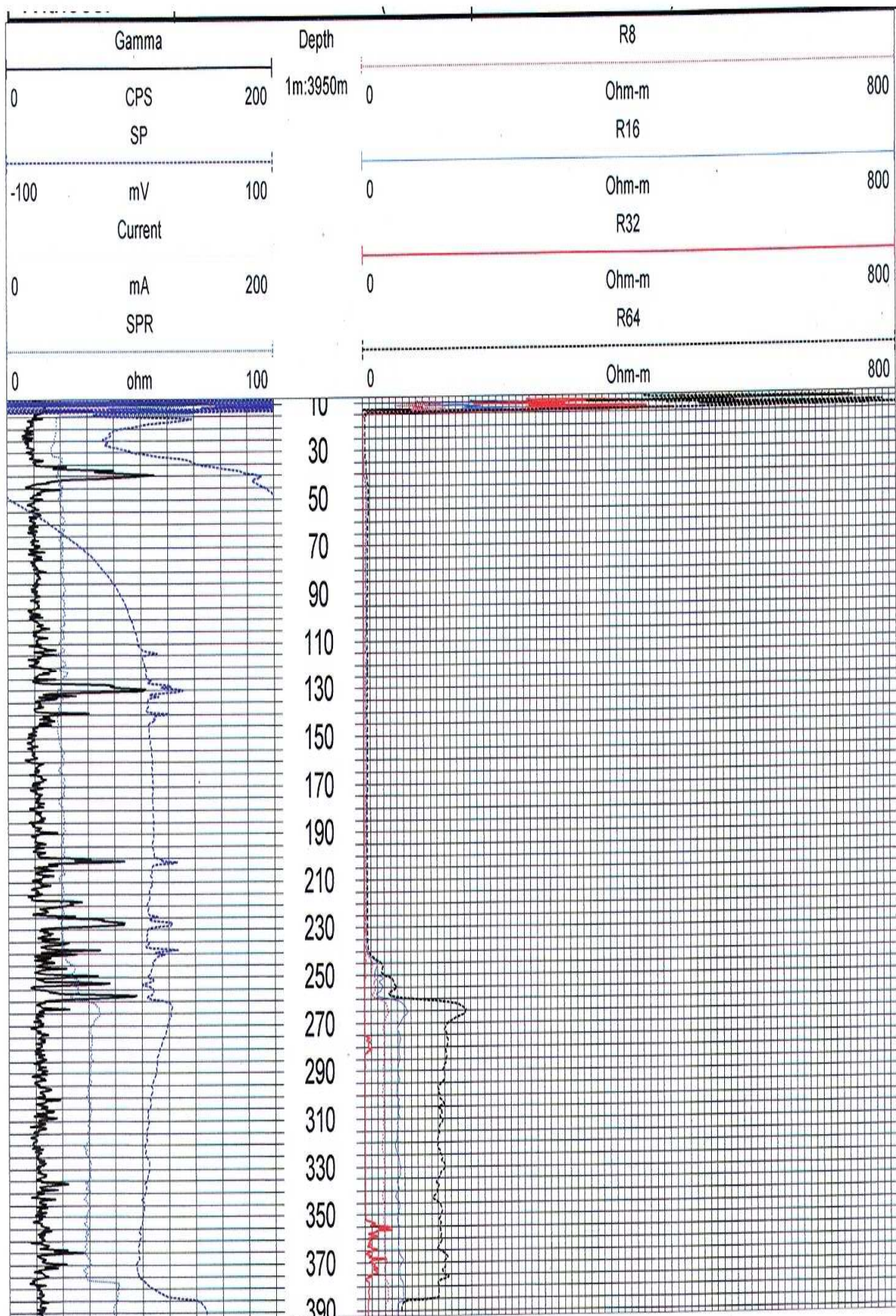
Five major geomorphologic units have been identified for the Niger Delta[4],[5].. They are the coastal plain sands (dry flatland and plain), the Sombreiro-Warri Deltaic plain (with abundant freshwater swamps), the freshwater swamps (backswamps, alluvial plain and meander belts), the saltwater or mangrove swamps and the active/abandoned coastal beaches (sand bars-beaches and bars) (Fig. 3).

The alternating sands and clay lithostratigraphy of the Benin Formation combines with the sandy quaternary deposits that form the top soil and high rainfall regime of the area to control the occurrence and distribution of groundwater in the area. This sand and clay intercalations constitutes a system of aquifers separated by aquitards. The aquifer-aquitard units reoccur several times in the sequence to form the multi-aquifer systems that characterize the Niger Delta, [6].

## MATERIALS AND METHODS

Data for the study consist mainly of lithologic and down-hole geophysical logs from recently drilled deep water supply boreholes. Study sites were selected from the geomorphic zones with high tendency for saltwater occurrence namely: the Mangrove (saltwater) swamp and the Coastal beaches and ridges. Fifteen (15) boreholes drilled to depths between 150m and 600m were studied.

Figure 4.1. Down-hole geophysical logs of a borehole in Bille



Gamma			DepthSTRATA			R8		
0	CPS	200	0	Ohm-m	1000			
	SP			R16				
-500	mV	500	0	Ohm-m	1000			
	Current			R32				
0	mA	200	0	Ohm-m	1000			
	SPR			R64				

CPS			DepthSTRATA			Ohm-m		
0	SP	130	0	R16	65			
-750	mV	750	0	Ohm-m	120			
	Current			R32				
0	mA	200	0	Ohm-m	240			
	SPR			R64				
0	ohm	50	0	Ohm-m	290			

CPS			DepthSTRATA			Ohm-m		
0	SP	130	0	R16	65			
-750	mV	750	0	Ohm-m	120			
	Current			R32				
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0	mA	200	0	Ohm-m	240			
	SPR			R64				
0	ohm	50	0	Ohm-m	290			

CPS			DepthSTR		
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Figure 4.3. Wireline logs of a deep borehole at Mobil Life camp, Bonny Island

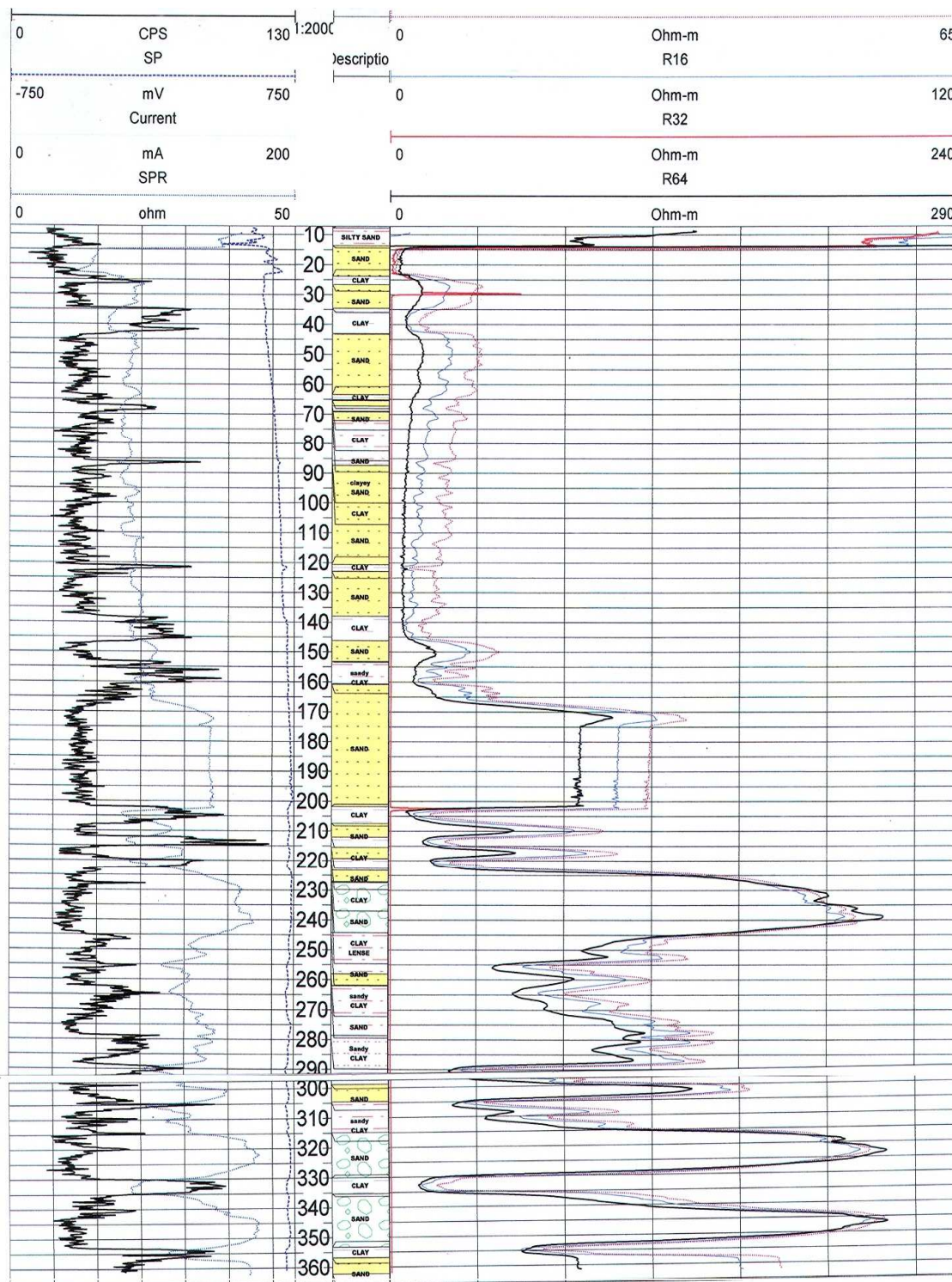


Figure 4.4 Wireline logs in a deep borehole at Bonny Water Board, Bonny Island

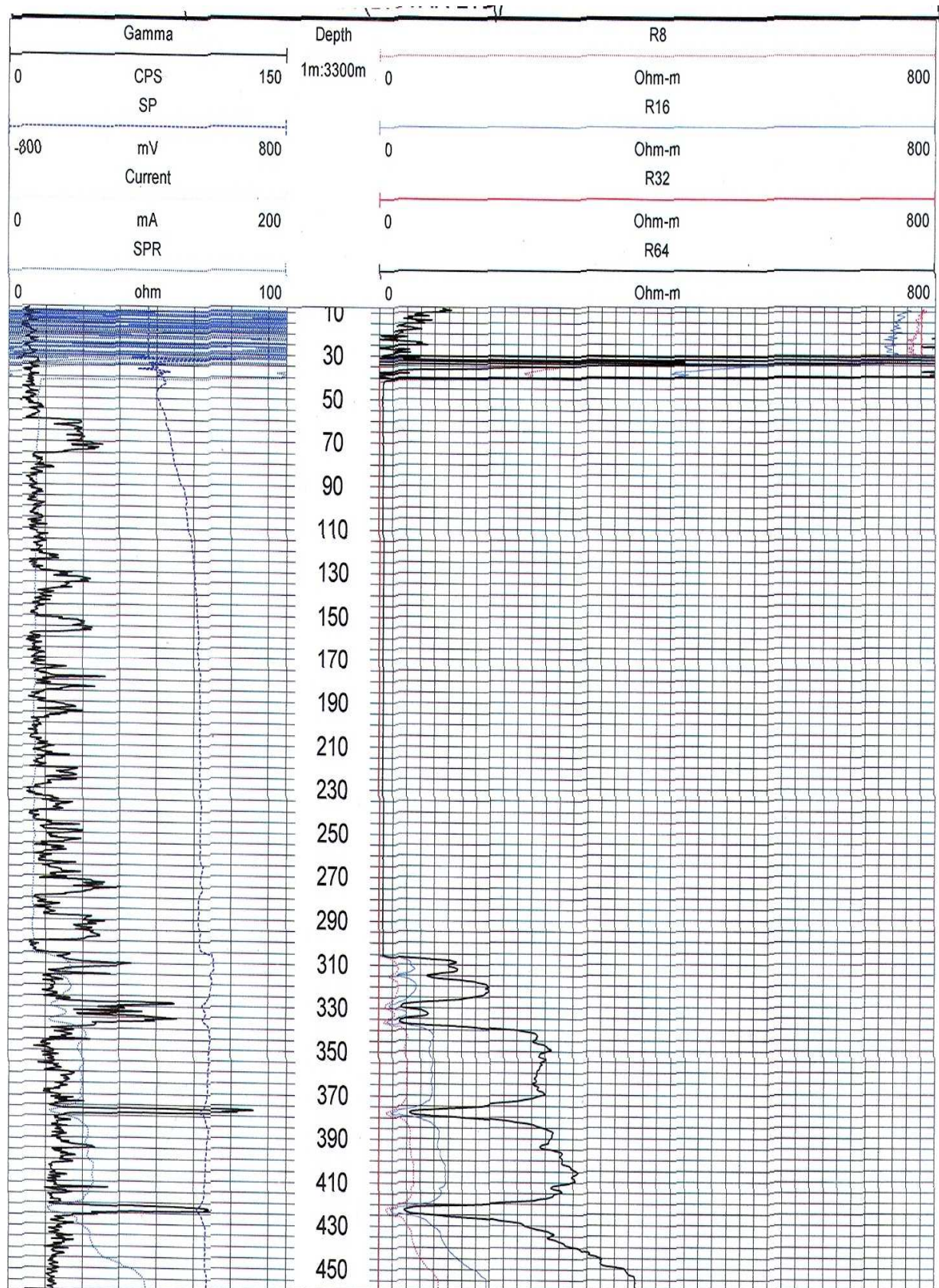


Figure 4. 5. Wireline logs in a deep water borehole at Oguede, Bonny, NLNG

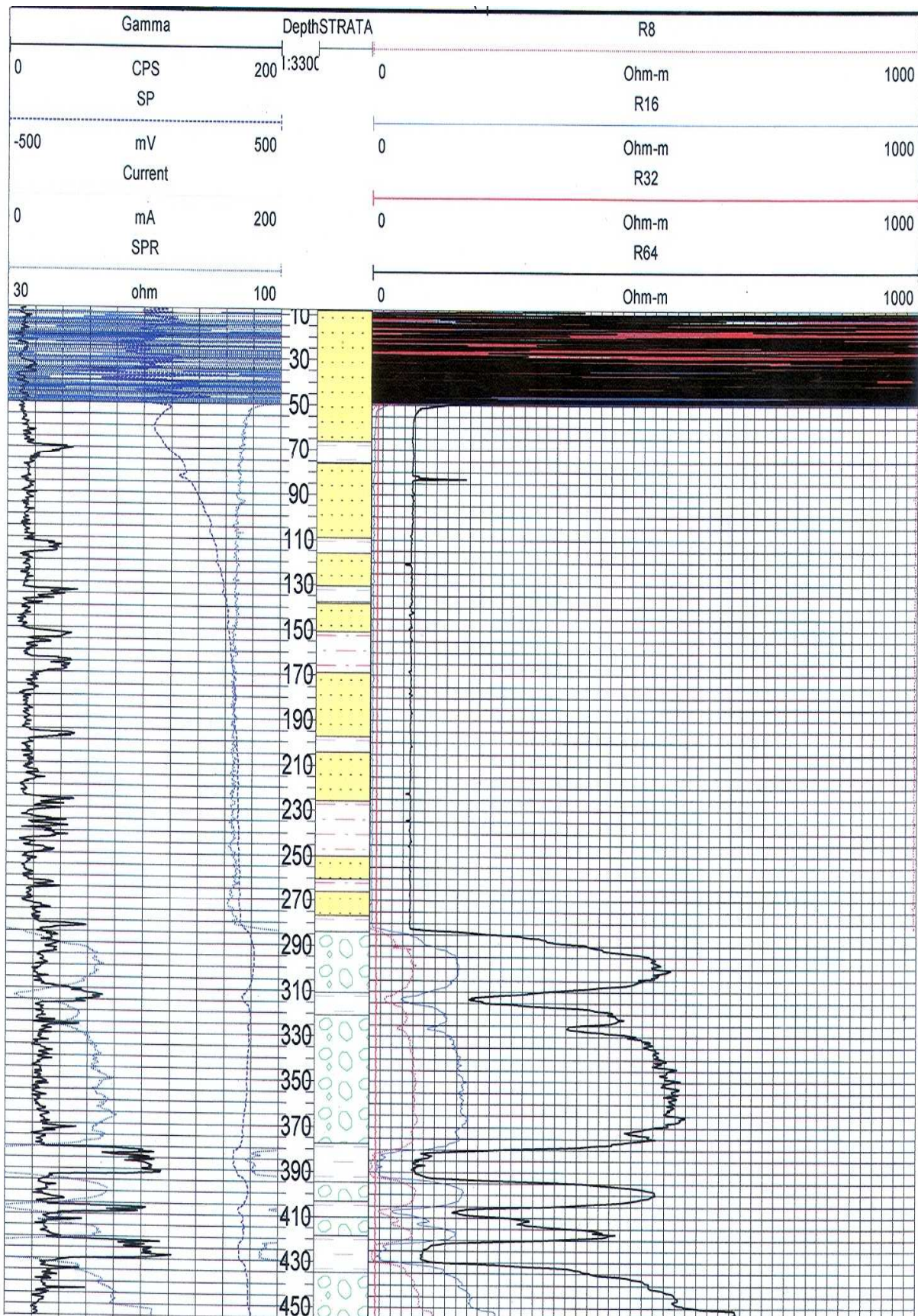


Figure 4.6 Wireline logs in a deep borehole at Finima, NLNG

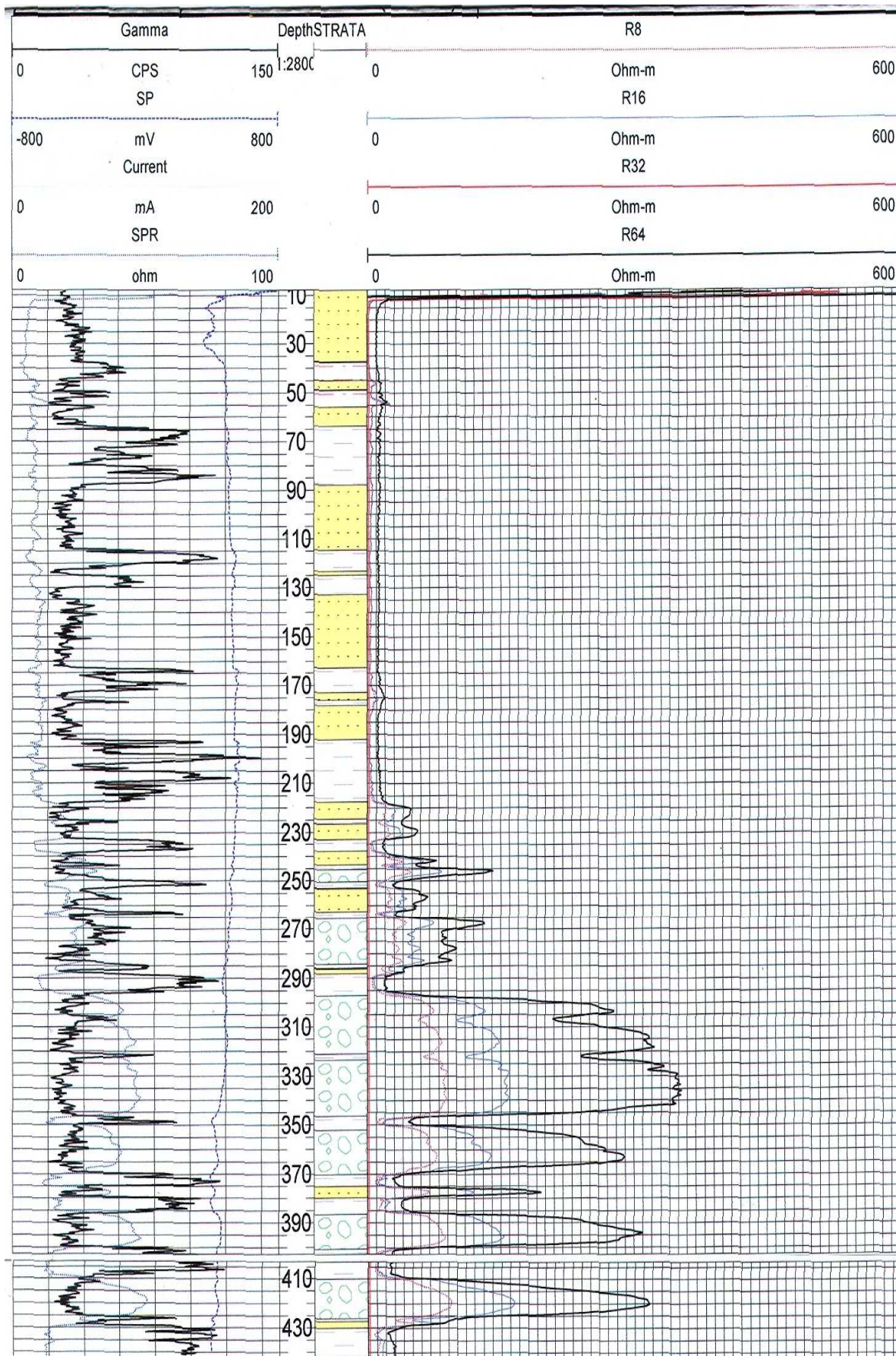
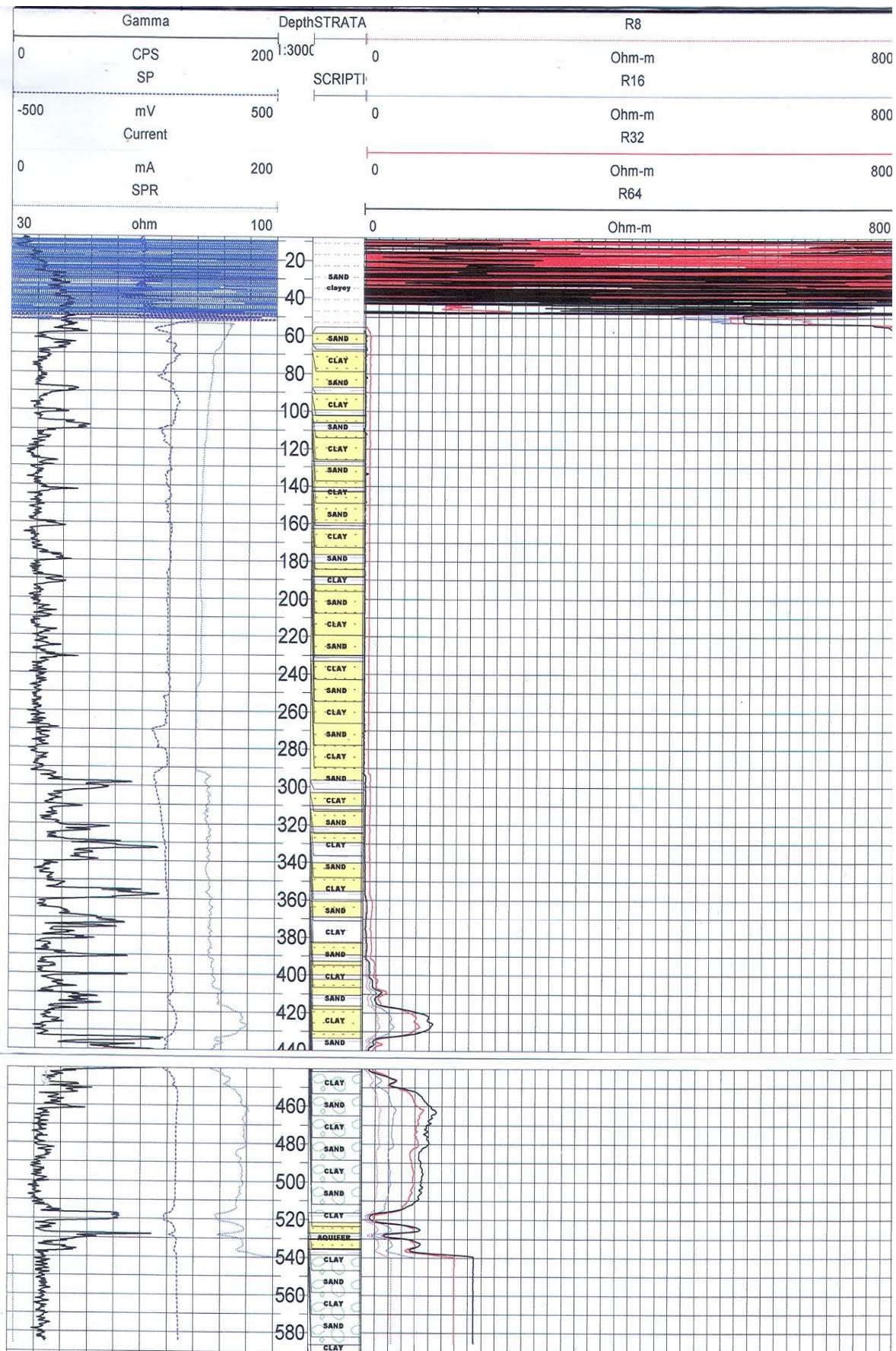


Figure 4.7 Wireline logs of a deep borehole at Ogidighen/Ughorodo.



**(a) Formation samples**

Collection of formation samples is done to determine the depths of formation contacts ie thickness of each unique stratigraphic unit and also to reflect the grain-size distribution of the aquifer materials. Sampling interval was 3m (10ft) and at any perceptible change in lithology. A total of 153 samples were studied.

**(b) Down-hole geophysical logging**

Down-hole geophysical logging was carried out using MOUNT SOPRIS INSTRUMENT, MGX II LOGGER. The following types of logs were run: Spontaneous Potential, SP, Resistivity and Gamma Ray logs.

From a careful interpretation of a suite of logs from each borehole, it was possible to separate sands from clay, freshwater-bearing sands from saltwater-bearing sands and hence determine the proper depths at which the screens should be placed for optimum productivity of the borehole. [7], [8].

**RESULTS**

The results of some of the in-hole geophysical logging from the study locations are shown in figures 4.1 – 4.7.[9]. The zero to near zero values for resistivity is indicative of saline water wedge or highly mineralized groundwater. All the logs captured the salinity zones to varying depths.

**DISCUSSION**

The salinity depths in the coastal aquifers are shown in table 1 for boreholes 250m – 600m in depth. Salinity depths range from 0? – 418m in the deepest borehole.

**Table 1. Salinity depths in Bonny Island and some coastal locations.**

S/No	Location	Borehole depth (m)	Types of log run	Saline stretch (m) from ground surface
1	Bonny Water Board	450	Gamma, Resistivity	0 - ?
2	Oguede, Bonny	452	Gamma, Resistivity	0 - 282
3	Finima	450	Gamma, Resistivity	0 - 218
4	BRT, Bonny	360	Gamma, Resistivity	0 - 215
5	Mobil Life camp, Finima1	250	Gamma, Resistivity	0 - 146
6	Mobil Life camp, Finima2	360	Gamma, Resistivity	0 - 146
7	Bille	390	Gamma, Resistivity	0 - 240
8	Ogidigbenu/ Ugborodo	600	Gamma, Resistivity	0 - 418

Exact depths at which salinity started could not be established in the boreholes because mild steel surface casings were used to prevent collapses of the saturated silty top soils during drilling. Resistivity logs do not penetrate mild steel. Similarly, the borehole at Bonny Water Board already had casing installed to 300m when the logging was done. The resistivity log could not penetrate the casing unlike the gamma log. Therefore the exact point at which the saline conditions started or ended could not be ascertained.

The coastal aquifers being an area with long history of intensive oil and gas exploration and exploitation have been subjected to long period of excessive groundwater abstraction to meet consumption demands and cooling requirements of the numerous oil and gas installations.[7], [8]. Undisturbed, coastal aquifers will naturally drain into the ocean at the coastline where they are in contact with the ocean. It would appear that the extensive groundwater abstraction has resulted in a significant decrease in seaward flow of fresh groundwater. This appears to have caused saline water to enter and penetrate inland through submarine outcrops. This phenomenon, if unchecked, will progressively displace the freshwater thereby increasing the salinity depth at so many locations. The result is that more and more portions of fresh water aquifers are lost to saline water requiring deeper and deeper boreholes to exploit fresh groundwater. The attendant costs will further worsen the potable water supply situations in the densely populated coastal areas.

**CONCLUSION**

Down-hole geophysical logging has been used to establish salinity depths at various locations in the coastal Niger Delta. Long history of unplanned and excessive groundwater withdrawal to service oil and gas activities appears to have drastically reduced the seaward flow of fresh groundwater. This, in turn, has resulted in a reversal of flow with saline water entering and displacing freshwater thereby increasing the salinity depths. Increased salinity depth means less fresh groundwater and will negatively affect the economics of potable water supply (groundwater being the only viable source) to coastal dwellers in the Niger Delta. Detailed hydrogeological studies are necessary to

evaluate the dynamics of salt/fresh water interaction in the coast. Urgent governmental intervention is needed to control this trend and effectively manage the delicate water resources of the coastal area.

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