CHARACTERIZATION OF THE AQUIFER SYSTEMS IN THE COASTAL AREAS OF NIGER DELTA USING GAMMA RAY AND ELECTRIC LOGS

BY

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A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL FEDERAL UNIVERSITY OF TECHNOLOGY, OWERRI

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY (Ph.D) IN GEOPHYSICS

JULY, 2023

CERTIFICATION

We hereby certify that this project **"Characterization of the Aquifer Systems in the Coastal Areas of Niger Delta Using Gamma Ray and Electric Logs"** was carried out by **OKORO, FELIBENS EDEHERI**, Reg. NO: **20154076818** in partial fulfillment of the requirements for the award of the degree of Doctor of Philosophy (Ph.D) in Geophysics, in the Department of Geology, Federal University of Technology, Owerri.

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DEDICATION

This research is dedicated to God Almighty who makes all things possible. What God cannot do does not exist.

ACKNOWLEDGEMENTS

I want to gratefully acknowledge the support and guidance of my principal supervisor, Prof. C. C. Z. Akaolisa, my co-supervisors, Dr. S. I. Ibeneme and Prof. C. N. Okereke for their respective criticisms and inputs that brought this work to its present status.

My profound gratitude goes to my friend and brother Prof. Alexander O. Selemo who has been a source of inspiration to me. To late Prof. C. A. Ahiarakwem, may the good Lord grant your soul eternal rest in His bosom.

I also thank profusely Prof G. I. Nwankwo, Prof. K.K. Ibe, Prof. O.C, Okeke, Prof. S.O. Onyekuru and very specially my Head of Department Dr. D. O. Ikoro. You all stretched your fatherly hands to me and accorded me the warm attention needed to pursue a Ph.D programme in this citadel of learning.

To all the staff of the Department of Geology Federal University of Technology, Owerri I say a big thank you for making this possible.

The assistance received from the Staff and Management of Govinda Services Owerri, especially Dr. Nwugha Victor and Mr. Nnosiri Obioma would not go unappreciated.

I sincerely appreciate the Management and Staff of Okoro and Company (W.A.) Limited for their support and understanding. I also acknowledge the support of the Management and Staff of Felibens Associates Nigeria Limited.

To my beloved wife Chief Barrister (Mrs.) C. U. P Okoro and my lovely children, I deeply appreciate your support and understanding.

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ABSTRACT

Gamma ray and electric logs obtained within the coastal areas of Niger Delta were utilized to characterize the aquifer systems in the area with the view to, among other things, isolate fresh water and contaminated aquifers as well as providing pragmatic results and a new lens for individuals and agencies to view the ever-increasing pursuit of groundwater development initiatives in the area. Sixty-two (62) wells and their accompanying logs as well as strata samples from these wells were studied across the five geomorphological zones of the area. The Geophysical logging operations were done using Mount Sopris Instrument, MGX II Logger. WellCAD software was used in the interpretation of the well log data. The gamma logs neatly delineated the different aquifers. The area generally is underlain by alternating sequences of sands and clay. This sequence is capped by laterized soil around the coastal plain sand areas. The area consists of a multiple aquifer system with three categories of aquifers delineated as Deep (410-600m), Medium (135-409m) and Shallow (5-134m) aquifers. Based on the amount of gamma Count Per Second (CPS), the aquifer system in the area can be classified into Very Low Gamma Count (Highly Sandy Aquifers), Low Gamma Count (Sandy Aquifers) and Medium Gamma Count (Slightly Clayey Aquifers).The very low gamma count aquifers indicating high sandy aquifer have counts ranging from 9.9 to 12.9 CPS. Considering the porosity of the aquifer media, aquifer systems of the area are classified as high (>65%), medium (36-65%), low (21-36%) and very low (<21%) porosities. Based on the distribution of aquifer resistivity values at different depths where aquifers were mapped, the entire study area was adjudged to have the following aquifer systems viz: Very Low Resistivity Aquifers with values ranging from 0 to 20 Ohm-m (Saline Water), Low Resistivity Aquifers ranging from 20 and 100 Ohm-m (High Ferrous Contamination), Medium Resistivity Aquifers with values ranging from 100 to 500 Ohm-m (Low Ferrous Contamination) and High Resistivity Aquifers with values above 600 Ohm-m (Fresh Water with no Saline or Ferrous Contamination). The saline-fresh water boundary varies from location to location within the study area. The boundary was obsvered to be shallow within Tunu flow station of Bayelsa State; NLNG Amadi Creek and Amadi Creek 2 of Rivers State; Erunailaje, Akpata Ijaw, Ayetoro and Adoloseimo areas of Ondo State. Deep saline–fresh water boundary occurs around Bonny water, Finima water Board, Bille, Idama, Kula and Asaramatoru areas of Rivers State; Jinrinwo and Abealala Ilaje area of Ondo State as Well as Ogidigben area of Delta State. The study showed that there are aquifers deeper than 80 metres within the Onne, Amadi Creek, Kidney Island and Amadi flats areas that can produce potable water free from saline water and ferrous contamination provided there is no over pumping and the hydrostatic balance is maintained. Aquifer resistivities of over 600 Ohm-m were established to be fresh water. The study also showed that salt water can be isolated in most of the areas particularly in the salt water swamps and coastal beaches areas by drilling very deep boreholes. Some of the aquifers in the coastal plain sand environments can be considered to be free from any contamination in depths exceeding 120m.The resistivity logs indicated different saline water aquifer depths for the boreholes in the area where the vertical distribution of saline water ranges from 0-80m around Onne, Amadi Creek and Kidney Island and 0-145m around Bonny, 0-218m around Finima Bonny and 0-260m in Bille. The implication is that, wells drilled from surface and terminated within these depth ranges at these locations will encounter saline water and wells drilled below these depths will not encounter saline water. It is recommended that because of the nature of the aquifers of the coastal area of Niger Delta, there is an urgent need to protect the aquifers from further contamination by enacting appropriate laws to protect the groundwater of the area and to curtail indiscriminate drilling of boreholes and over extraction of water from the few fresh water aquifers of the Niger Delta It is hoped that the results will be useful to researchers, stakeholders and government agencies involved in developing local and regional water plans.

Keywords: Aquifer, Contamination, Ferrous Aquifer, Mount Sopris, Saline Water, WellCAD

CHAPTER ONE
INTRODUCTION

1.1 Background

The United Nations Children's Fund (UNICEF) has declared that about 43% amounting to about sixty-nine (69) million Nigerians lack access to potable water and a further nineteen (19) million Nigerians have to seek water from far distances from their places of domicile. Water is an essential part of human existence. Without water very little can happen. Medical science tells us that water makes up more than two thirds of human body weight, and without water, we would die in a few days.

Potable water is an important requirement for both human existence and for every type of development programme.No Nation can survive without water.Potable water resources are becoming very scarce in most parts of the world.

A global activity in trying to provide mankind with potable water is now indispensable in order to guarantee the continued existence of the human race. There is a world-wide drive to ensure mankind has access to potable water. Governments at all levels have made great strides in trying to provide the populace with potable water and their efforts are further being complimented by individual efforts to provide water for their personal use.

Goal 6 of the United Nations Sustainable Development Goals Agenda 2030 is to ensure the availability and sustainable management of water and sanitation for all.

The Coastal areas of the Niger Delta Nigeria are crisscrossed by rivers and salt water creeks. The terrain is very peculiar because a large part of it is covered by creeks. The groundwater is seriously contaminated by the presence of saline water and ferrous iron. Many of the water boreholes drilled in the Coastal areas of the Niger Delta have failed to meet the objective of providing the people potable water. Most of the wells produce water that does not meet the WHO (2018) standard for potable water. Very little has been done in terms of detailed hydrogeophysical studies in Coastal areas of the Niger Delta to properly characterize the underground water aquifers available in the area.

Etu-Efeotor and Akpokodje (1990), noted that groundwater development in several parts of the Niger delta have been done in a random manner with little or no regards to water quality and aquifer yields. The only source of water supply for all purposes in the Niger Delta is groundwater and its demand will increase astronomically within the foreseeable future with increase in population, improved standard of living and more expansion and growth of the oil and gas industry (Oteri, 1983; Akpokodje, 2005; Nwakwoala&Ngah, 2014).

Although Etu- Efeotor and Akpokodje (1990), Etu-Efeotor and Odigi (1983) identified salt water intrusion in aquifers in the Niger Delta as a major problem, they did not identify the aquifers on a regional scale that are contaminated and the ones that are free from contamination and therefore contains potable water.

Water supply in the Coastal areas of the Niger Delta is almost getting to a crisis point as access to potable water is diminishing very fast and this may also be due to population increase as a result of oil and gas activities in the area.

The plausible approach to addressing the water supply issues in the area is to carry out detailed regional studies of the aquifers systems in a view to properly characterize the aquifers and to determine aquifers with little or no contaminations in order to improve the groundwater supply needs of the people of the area.

1.2 Statement of the Problem

Sequel to the coexistence of groundwater bodies with different water chemistry within a single aquifer unit around the coastal areas of the Niger Delta, there exists the problem of contamination of the ground waterwith salt and iron. The aquifers that produce iron water, saline water and fresh water have not been properly delineated. This has made life very difficult for the people in this area. In several coastal communities of the Niger Delta, fresh water is sourced from upland areas and transported to these communities. A sachet of pure water that sells for ten Naira in the upland can sell as high as fifty Naira in the Coastal areas of the Niger Delta, Nigeria.The cost of treatment for the surface saline water is prohibitive and not sustainable. The only sustainable option of potable water supply for the Coastal areas is to carefully explore the underground water in the area. This can only be achieved if the contaminated and uncontaminated aquifers would be properly delineated and characterized to enable proper placement of well screens.

This present study tends to carry out a comprehensive regional characterization of the aquifer systems of the Coastal areas of the Niger Delta using primary data from gamma ray and electric logs

1.3 Location of the study area

The study area falls within the Niger delta, Nigeria. It lies between Latitude 4°23'N and 6°30' N and Longitudes 4° 30'E and 8°31'E. It comprises of the Coastal areas of the Eastern and Western Niger Delta. The area was accessed by sea and land travelling through the creeks of the Niger Delta.

Figure 1.1 is the Location map of the study area. Figure 1.2 is the Topographic map of the study area showing the borehole points in the study area where data were acquired.

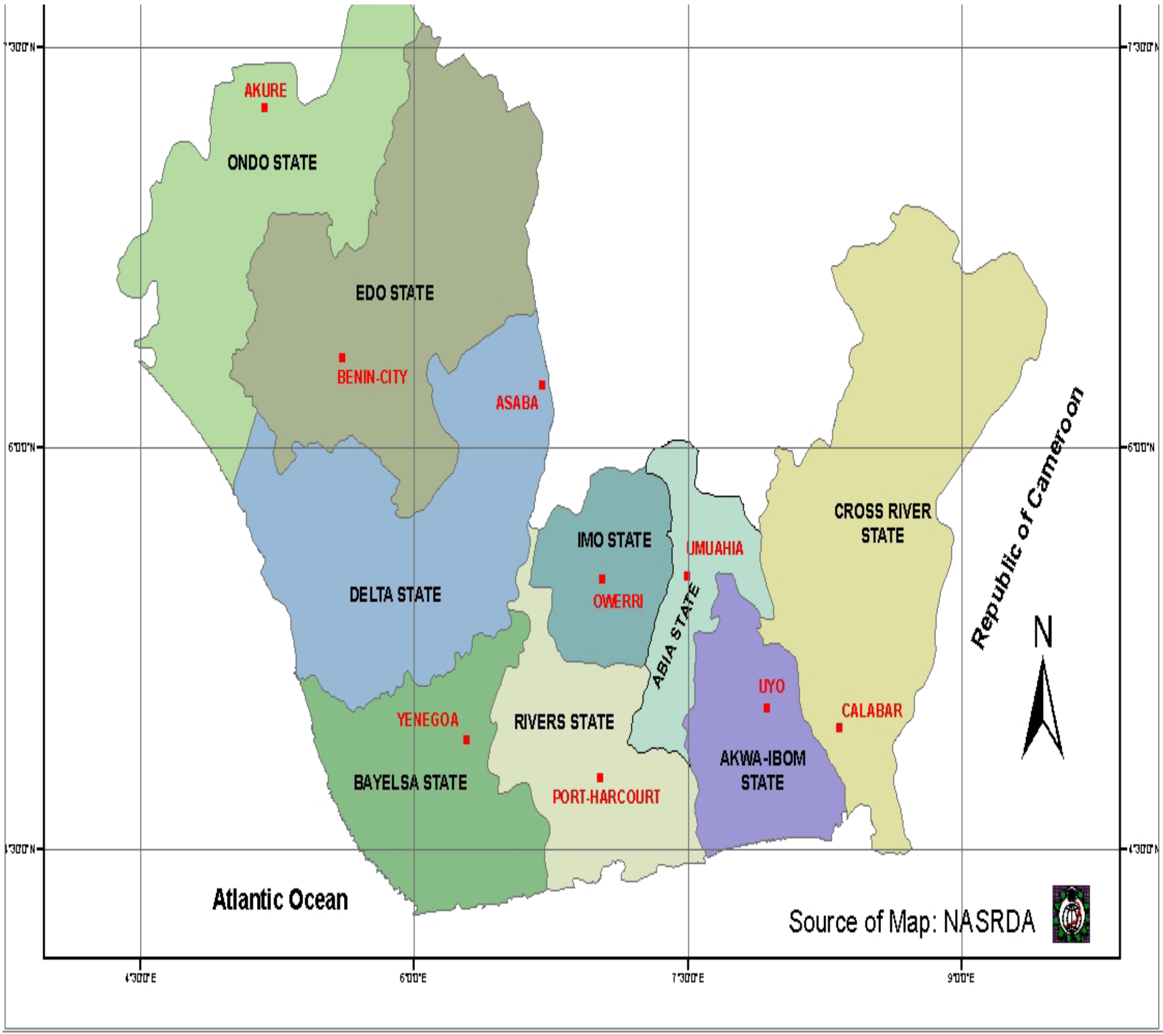

Figure 1.1: Location map of the study area

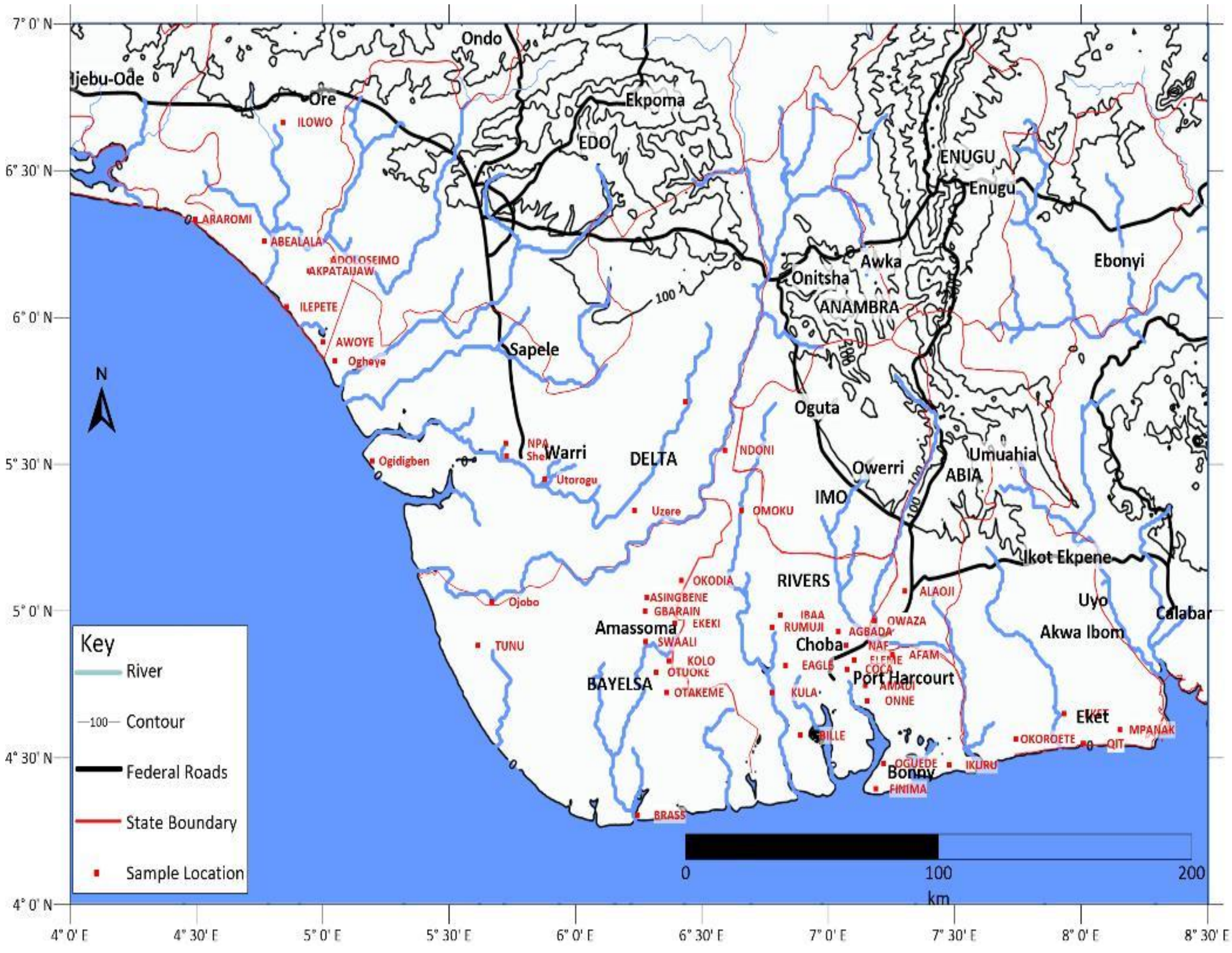

Figure 1.2: Topographic Map of the study area showing borehole points.

1.4 Justification of the Study

Oteri and Atolagbe (2003) declared that salt water intrusion into aquifers in the coastal sedimentary basins in Nigeria has occurred. Mapping of the fresh water/salt water interface(s) in most of the coastal aquifers is yet to be carried out, thereby making it difficult for many of the communities to be provided with fresh potable water. They further asserted that there is a great and urgent need for all stakeholders in Nigeria's coastal region to appreciate the phenomenon of salt water intrusion and commission the necessary studies to delineate, monitor and manage the fresh water resources of the coastal areas to the benefit of its people and the industrial community.

Nwankwoala and Ngah (2015) posited that chloride is a major quality issue especially in the groundwater of the mangrove swamps and the coastal beaches and ridges of the Niger Delta.

This research aims to fill the knowledge gap and increase the understanding of the multi aquifer systems of the Coastal areas of the Niger delta and characterize the aquifer systems with a view to finding solutions to the underground water problems of the Coastal Niger Delta.

1.5 Aim and Objectives of the Study

1.5.1 Aim

The aim of this research is to characterize the aquifer systems in the coastal areas of Niger Delta using gamma ray and electric logs.

1.5.2 Objectives

The Specific objectives are:

- To carry out and study the gamma ray and electric logs of water boreholes in the study area to identify the number of aquifers and their various depths.
- To determine the status of water contained in the aquifers,
- To study the lateral extent of each aquifer and attempt their correlation,
- To isolate fresh water aquifer and contaminated aquifers and map their distribution.
- To produce a body of data that will narrow up the knowledge gap in the multi-aquifer system of the Niger Delta that will assist in planning and execution of water projects for ground water supply development of this area of Nigeria.

1.6 Scope of the Study

The study is limited to the aquifer systems in the coastal areas of the Niger Delta. It covered the aquifer systems from near surface to deeper aquifers.

The study is on a regional scale covering most parts of the coastal areas of the Niger Delta spanning Eastern and Western parts of the Coastal Niger Delta particularly covering Abia, Akwa Ibom, Bayelsa, Delta, Imo, Ondo and Rivers States. The project involved the:

- Collection of data from drilled boreholes, such as location, depth, strata log and well diameter,
- Acquisition of Gamma ray logs data of drilled boreholes,
- Acquisition of Electrical logs data of drilled boreholes
- Collection of Strata samples from drilled boreholes
- Collection of Water samples from completed water boreholes based on the logging results were available
- Analysis and interpretation of collected data

CHAPTER TWO

GEOLOGIC SETTING OF THE AREA AND REVIEW OF RELATED LITERATURE

2.1 GEOLOGIC SETTING

2.1.1 Geomorphology of the Niger Delta.

The Niger Delta is predominantly low-lying. Most of the areas, especially the coastlines, are almost at sea level or a maximum of 6 metres above sea level (Offodile 1992).

Nedeco (1959) and Allen (1965) adopted 3 geomorphic classifications for the Niger Delta

(i) Niger flood plain (foundation zone)

(ii) Vegetated tidal flat (Mangrove zone)

(iii) Barrier Islands (Coastal zone)

Based on modes of origin, Short and Stauble (1967) described the principal geomorphologic groups in the area to include Benin Information, meander belt, fresh water and brackish swamp deposits, mangrove swamp and abandoned coastal beaches (Figure 2.1). Akpokodje (1987) included geotechnical parameters and behaviours of soils in his classification criteria and divided the region into five geomorphological zones. (Figure 2.2),

1) Active/abandoned coastal beaches and ridges mainly along the shoreline,
2) Saltwater or mangrove swamp belt
3) Freshwater swamps, back swamps, Deltaic plain, alluvium and meander belt
4) Dry deltaic plain with abandoned freshwater swamps (Sombreiro-Warri deltaic plain)
5) Dry flat land and plain. (Benin Information).

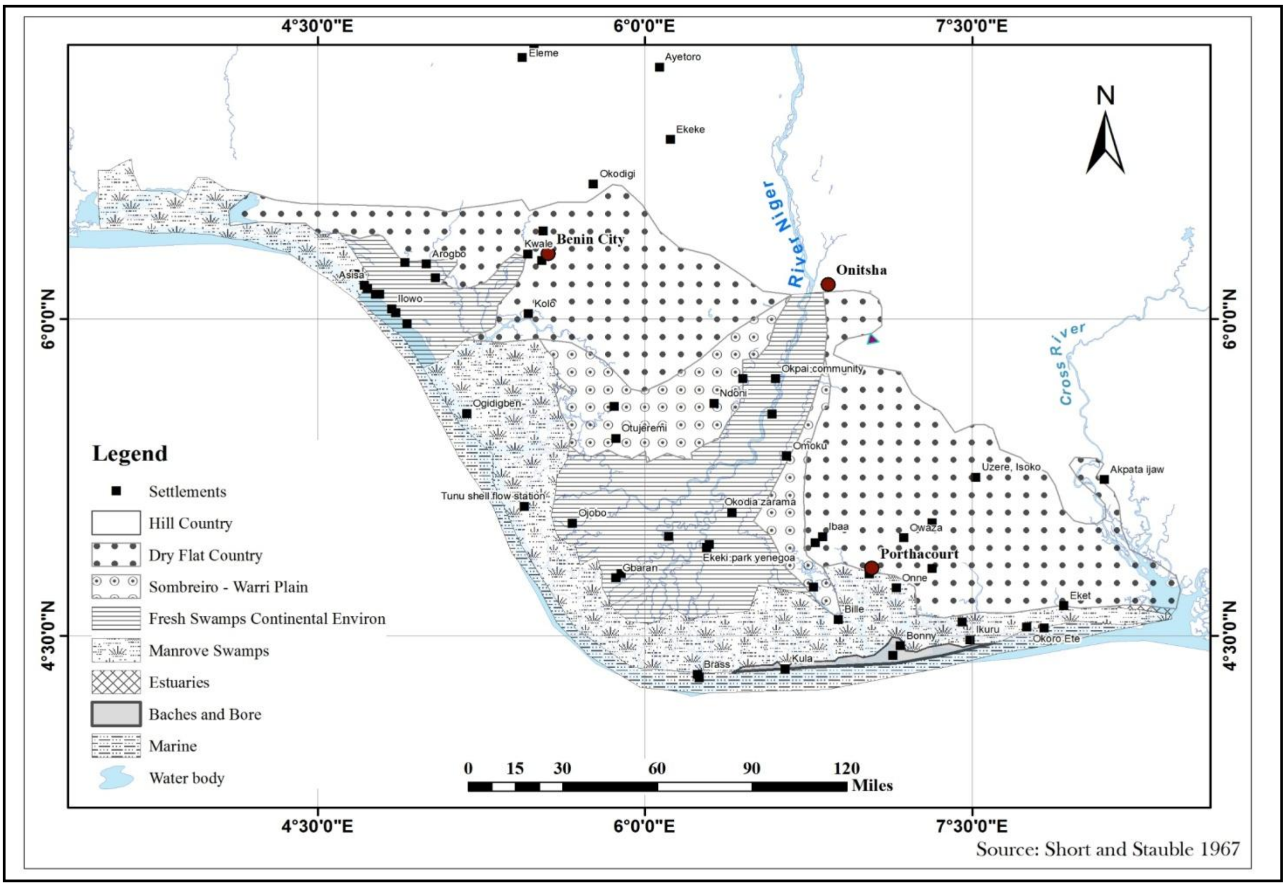

Figure 2.1: Regional Morphological features and sedimentary environments of southern Nigeria (Short and Stauble 1967)

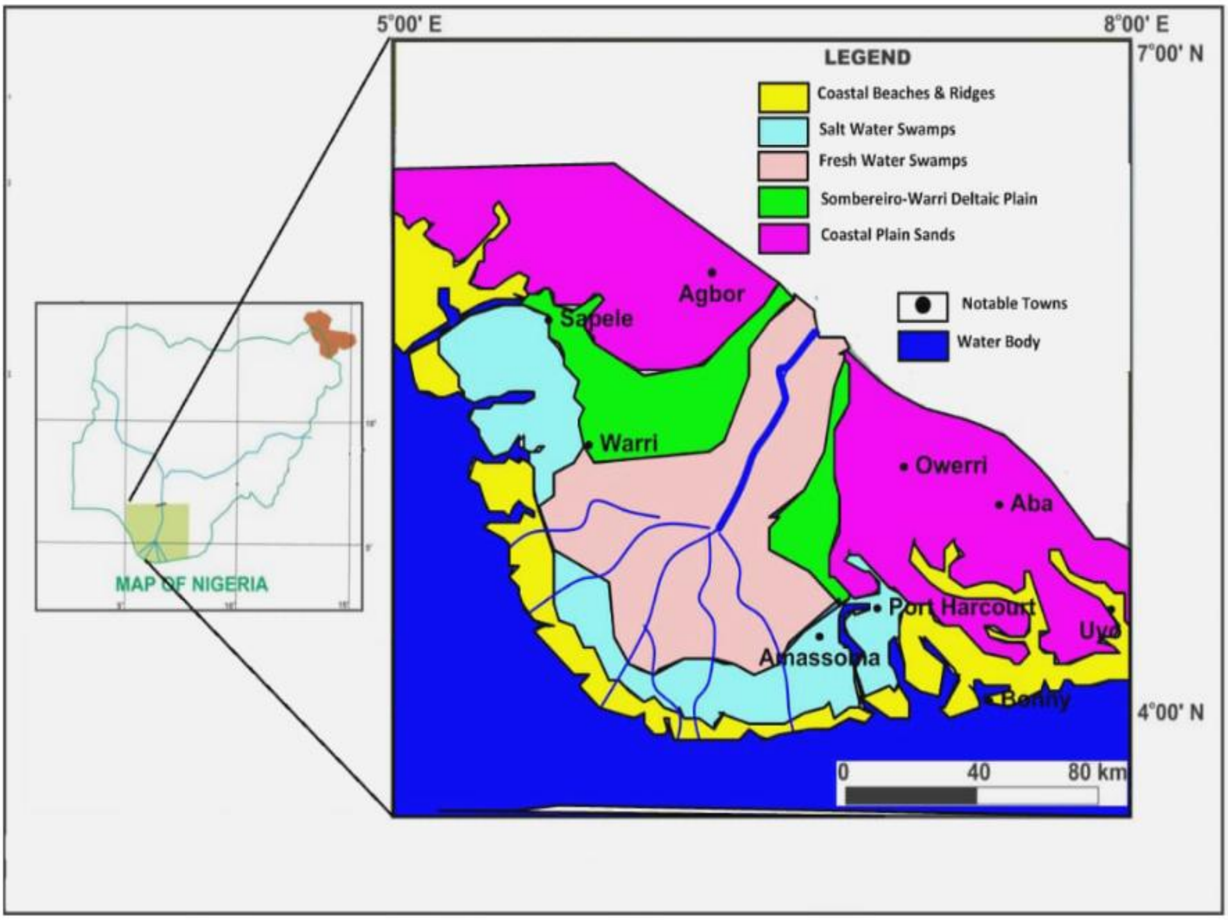

Figure 2.2: Geomorphological Zones within the Study area (Modified from Akpokodje 1987)

2.2 Ground water conditions of the study area.

The area seems to be prolific in terms of Groundwater potentials which are sustained by rains and recharge from the network of Creeks, Rivers, streams and channels in the Niger Delta.

During the rainy season, both the water tables in aquifers and the water levels in rivers and creeks rise and sometimes overflow their banks.

Rainfall is generally heavy and water table generally shallow, varying from near-surface at the Atlantic coast and coastal beaches/abandoned coastal ridges to 18m towards the apex of the Delta (Ngah 1990).

2.3 Rainfall

Two distinctive seasons, (wet and dry), dominate the region. The rainy season runs from April to October with an average annual rainfall range of about 2000mm (Bellgam, 1986). The dry season runs from November to April with an average temperature of 38°C (Bellgam, 1986). The maximum mean monthly rainfall occurs in July and September.

2.4 Humidity and Wind

Relative humidity is generally high in the Niger Delta. Minimum humidity is attained at about l300hrs while the maximum humidity occurs from 2200hrs till the next morning.

Two major types of wind are observed. During the months of November to February, a North-East or North-West wind induced by the Harmattan is dominant. Between the months of March to October are the South-East or South-West winds from the coastline carrying heavy rain.

2.5 Drainage

The study area receives the flood waters that come from River Niger and its tributaries. The area is drained by an intricately interconnected dendritic drainage system. The fresh water areas experience occasional heavy flooding during the rainy season. Figure 2.3 shows the drainage patterns of the Niger Delta.

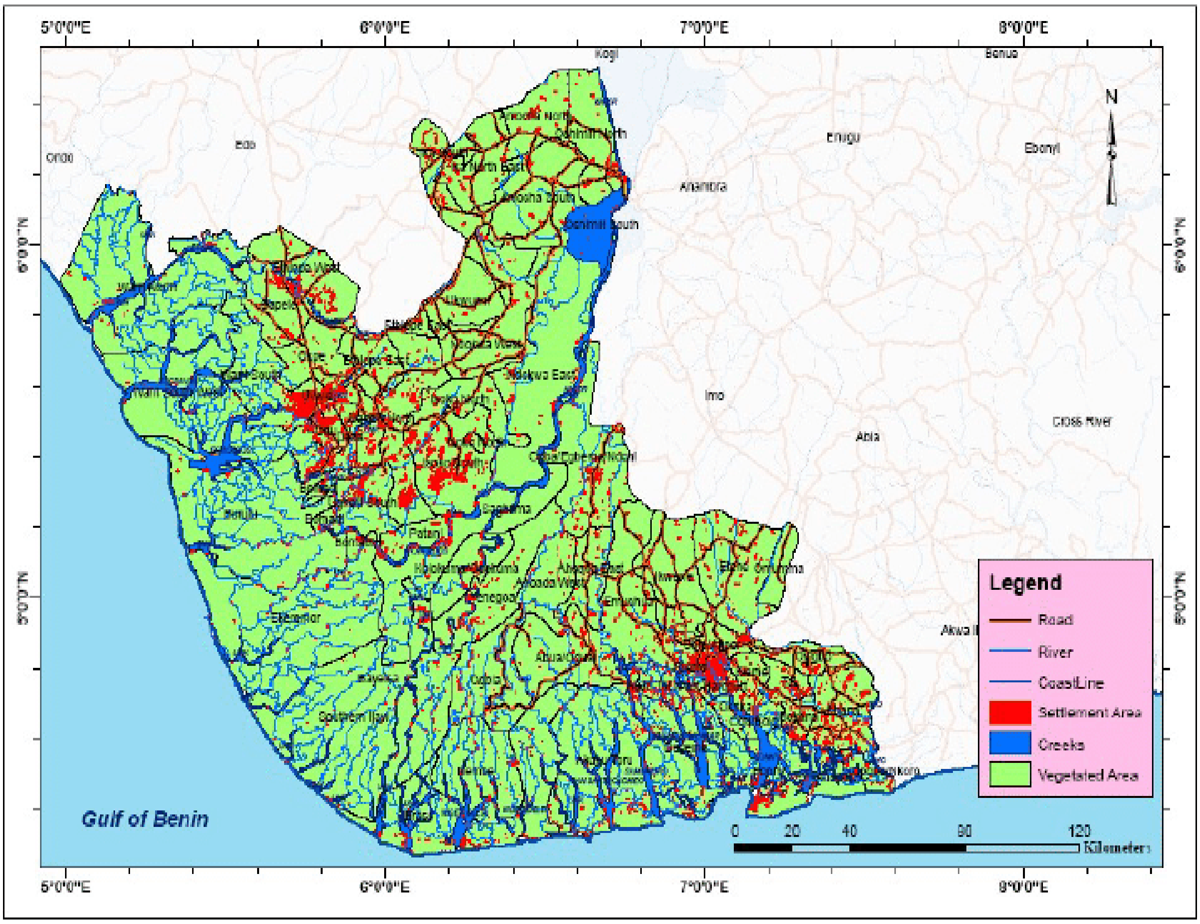

Figure 2.3: Drainage patterns of the Niger delta, modified from Amagahara*et al* 2015

2.6. Land Use/Cover

The residents of the area naturally practice fishing and farming. This is as a result of the complex environment that the people of this area leave in. Human interference has reduced the rich forests into secondary re-growth complexes. As a result, there are very few areas of natural vegetation left. The arable crops include cassava, yams, maize and cocoyam, pineapple, pepper, tomatoes, rice and leafy vegetables.

2.7 Geology of the Niger Delta

Many researchers and authors have explained the genesis and development of the Niger delta basin these include Murat (1972), Short and Stauble (1967), Hospers (1965, 1971) and Allen (1964, 1965)). They gave both the structural and the stratigraphic frameworks for the evolution of the Niger Delta basin.

2.7.1 Structural framework

Reyment (1965) opined that the Niger Delta is a Delta with tectonic origin and whose formation is associated with the movement of the South American continent away from the African continent in the Lower Turonian times. This movement left a gap about 200km wide in the crust. The gap began to fill rapidly with sediments and this marked the initiation of the Niger Delta basin.

Using the results of gravity surveys, Hospers (1965) interpreted the gravity high at the centre of the delta as representing uplifted faulted basement blocks suggesting a transitional crust beneath the present-day Niger Delta.

2.7.2 Stratigraphic framework

The Eocene to Recent regressive depositional cycle left behind a huge deltaic stratigraphic assemblage, about 8 kilometers thick at the centre of the Niger Delta, Hospers (1965, 1971), Short and Stuable (1967).

The deposition/sedimentation of the present-day Niger Delta started during the early Paleocene and it resulted from the build-up of fine grained sediments eroded and transported by the River Niger and its tributaries southward toward the Atlantic Ocean. Short and Stauble (1967) described this thick succession of sediments as consisting of three lithostratigraphic units, namely: Akata, Agbada and Benin Formations.

a) Akata Formation

The Akata Formation consists mainly of marine shales with sandy and silty intervals thought to have been laid down as turbidity and continental slope channel fills. The shales are typically under-compacted and over pressured forming diapric structures. Total thickness of the formation is not known but may not be less than 1,380m thick while the age ranges from Palaeocene to Recent. The Akata Formation represents the pro-delta megafacies of the Deltaic sequence. The Akata Formation grades upwards into the Agbada Formation.

b) Agbada Formation

The Eocene to Recent Agbada Formation is essentially a cyclic succession of poorly consolidated, porous, permeable and friable sandstones and shales representing paralic deposits of the delta front mega facies. The maximum penetrated thickness of this unit is over 9000m. The characteristic features of the sandstones here are poor sorting, calcareous matrix and occurrence of shell fragments. The top of the formation is sandy whereas the bottom is shaley because it gradually grades into the shaley Akata Formation at the base. The shales are denser at the base due to compaction process. While the sandy parts constitute the hydrocarbon reservoir the shales form the cap rock. The Agbada Formation contains numerous growth faults with the associated development of rollover anticlines and constitutes about 90% of the petroleum reservoir rocks in the Niger Delta.

c) Benin Formation

The Benin Formation overlies the Agbada Formation conformably and comprises mainly loose unconsolidated fine to very coarse sands with pebbly and lignite intervals. These deposits are predominantly continental in origin and represent delta plain megafacies. Alluvial fan, point bars, channel fill and tidal channel sands have been recognized in this unit (Amajor, 1991). The formation is recognized throughout the delta due to its few shale streaks, absence of brackish water and high percentage of sand. The coarse texture of the sediments combines with high interconnectivity and large outcrop area to make the aquifers of the Benin Formation very prolific in terms of groundwater exploration.

d) Quaternary Deposits

Quaternary deposits comprising recent deltaic sediments made up of rapidly alternating sequences of sand, silt and clay/shale interbeds which covers the Benin Formation in the swampy delta areas. Thickness of the Quarternary deposits range between 40m and 150m (Etu-Efeotor&Akpokodje, 1990).

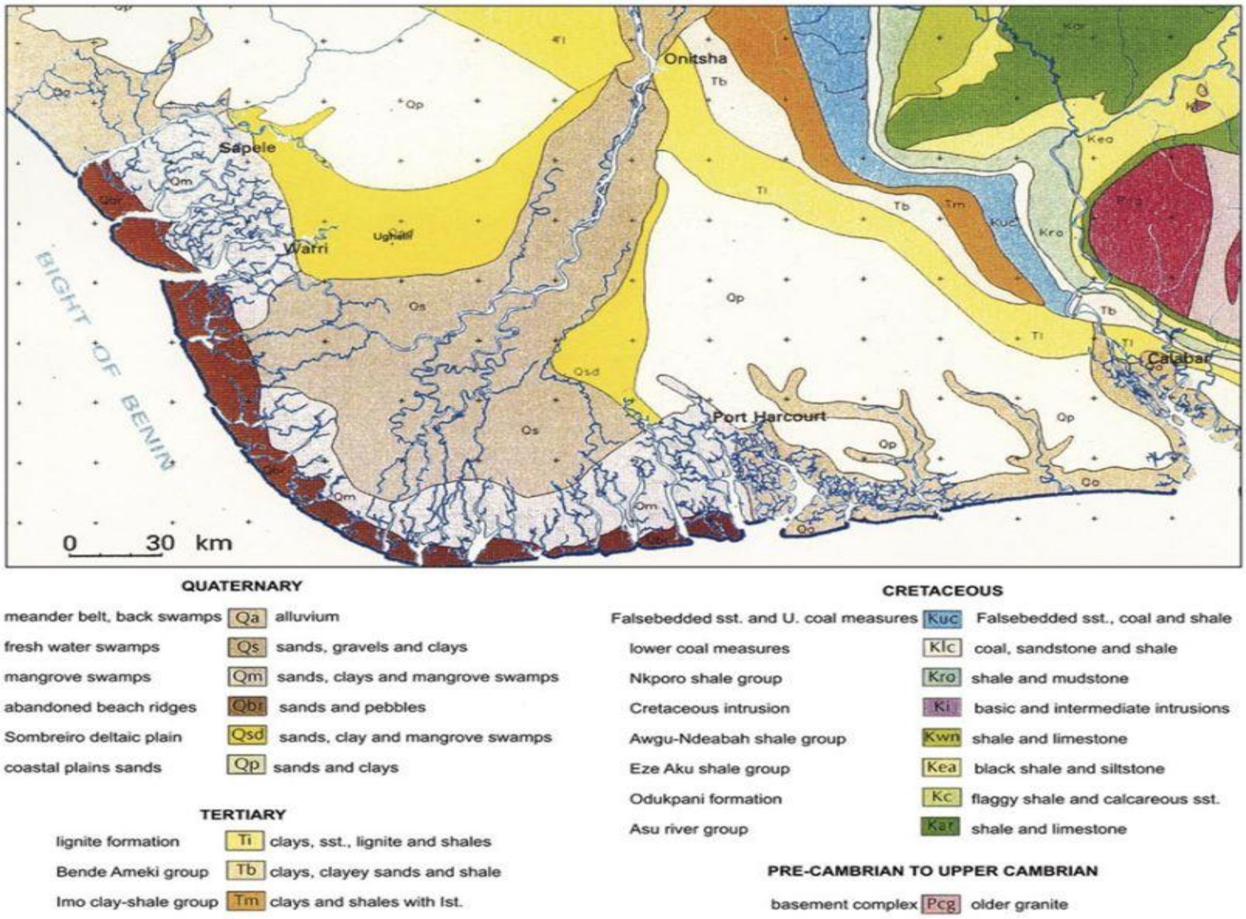

Figure 2.4: Geological Map of the Niger delta (Source: Modified from NGSA (2006)

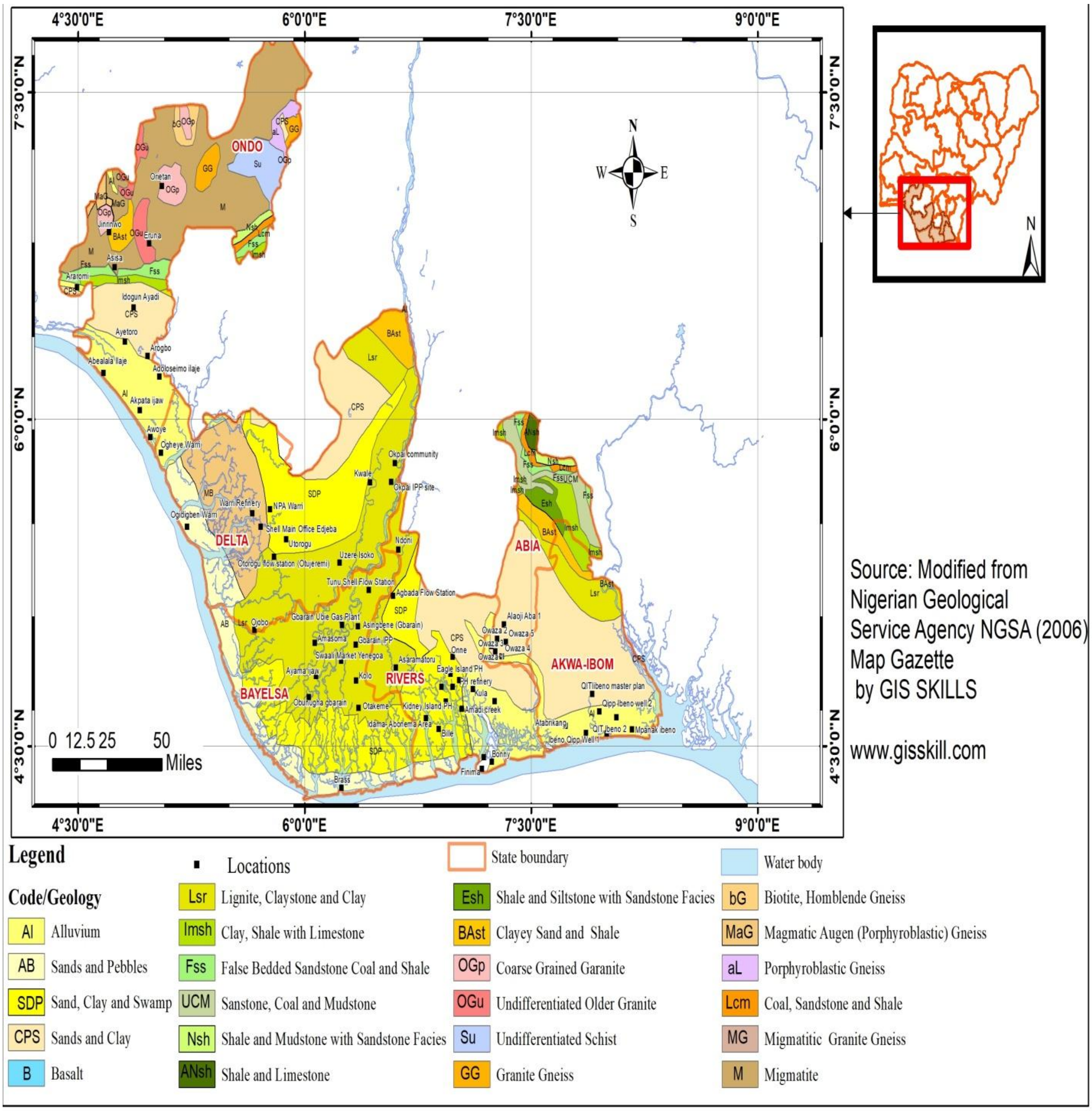

Figure 2.5: Geological Map of the Niger delta 2

2.8 Review of Previous Literature

Several authors and researches have extensively discussed geophysical prospecting methods in ground water studies. The authors including Telford*et al* (1976), Dobrin, (1960), Grant and West (1965).

Several professional societies and bodies have a section of their activities on near surface geophysics. These groups include: the Society of Exploration Geophysicists (SEG), the American Association of Petroleum Geologists (AAPG), The European Association of Exploration Geophysicists (EAEG), the Nigeria Mining and Geosciences Society (NMGS), the Nigeria Association of Hydrogeologists (NAH) and the International Association of Hydrogeologists (IAH).

Electrical methods of prospecting have proved very useful in groundwater studies as many of the geological formation properties that are critical to hydrogeology such as the porosity and permeability of rocks can be correlated with electrical conductivity signatures.

The data obtained from geophysical logging, borehole drilling records and careful analysis of the cuttings from the drilled wells can help the geophysicist and other researchers in the characterization of the aquifers within a given area. Oteze (1983) divided Nigeria into four groundwater areas based on hydrogeologic parameters; (Figure 2.6).

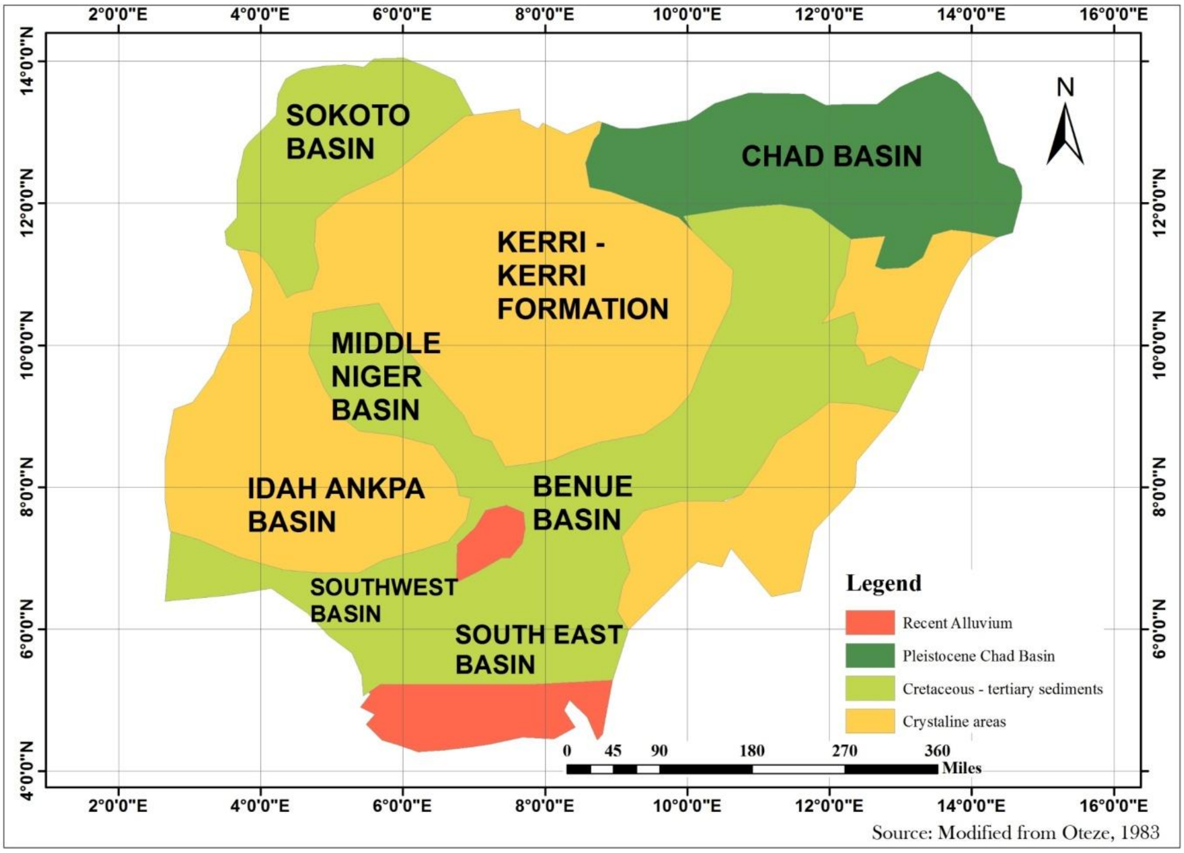

Figure 2.6: Groundwater areas of Nigeria (Oteze, 1983)

Oteze’s classification is similar to that of Egboka (1988) who used hydrogeological data to divide the country into three hydrogeologic units namely: areas with sufficient underground water and little surface flows; areas with sufficient surface flow and little underground water sources and areas with both surface and underground water sources (Table 2.1).

Geophysical logging of drilled holes provides a fundamental means of determining the properties of rock matrix, formation fluids, and the well properties. Resistivity measurements in boreholes can present useful information, not only regarding the existence of an aquifer horizon or geological information with compact characteristic (sandstones, limestones), but also regarding ground water quality.

Table 2.1: Patterns of Water Resources Availability in Nigeria (Egboka, 1988)

Zones	**Type of Water Resource Available**	**Areas affected**
1	Sufficient underground water and little surface water	Northeast, Northwest and Southern parts of the country.
2.	Good surface flows; little underground water sources	Central parts of the North, greater parts of the West and some areas in the East
3	Both surface and underground water available	Some parts in the North, East and West.

Abbey et al (2022) explored the shallow aquifer in Rumuohia community in Emohua local government area, Rivers State, Nigeria, with the goal of using seismic refraction to delineate depth to the shallow aquifer and geological structure of the terrain at five selected areas. They proposed a minimum of 7m depth to be drilled irrespective of the topography/season in the Rumuohia community to access a saturated zone for constant water supply.

Nwankwoala et al (2022) carried out Vertical Electrical Sounding (VES) in Rukpokwu, Obio/Akpor Local Government Area, Rivers State, Nigeria to investigate the effect of waste dump on groundwater quality in the study area. They opined that areas with high resistivity values are an indication of uncontaminated subsurface lithologic zones while areas with low resistivity values are an indication of contaminated subsurface lithologic zones as a result of dissolved ions and metals from waste dumps decomposing through biochemical reactions, hydrolysis, oxidation and reduction processes which subsequently leads to the formation of leachate.

Raimi and Sawyer (2022) conducted a preliminary study of groundwater quality using hierarchical classification approaches for contaminated sites in indigenous communities associated with crude oil exploration facilities in Rivers State, Nigeria. They were able to group the heavy metal occurrence in the groundwater of the area into clusters for both wet and dry seasons as 5 distinct clusters were identified for wet season and 4 clusters were identified for dry season. They encapsulated that decision-makers should take proper initiatives to get local people aware of the endangered zones before use, as drinking water is key to good health.

Umayah and Eyankware (2022) evaluated the aquifers from southeastern Nigeria from geo-electrical derived parameters. They stressed that, though the study area showed good prospects for groundwater potential, it is vulnerable to surface contamination due to anthropogenic activities as the aquifer protective capacity in the area is generally weak.

Eyankware and Ephraim (2021) carried out a comprehensive review of water quality monitoring and assessment in Delta State, Nigeria and observed that groundwater within the riverine communities is much more prone to pollution when compared to groundwater in an upland area. They suggested that geochemical processes such as rock water interaction, seawater intrusion and precipitation influence groundwater quality within the study area especially within Sombreiro-Warri Deltaic Plain Deposit.

Ogbonnaya et al (2021) assessed the physicochemical qualities of groundwater and soils around oilproducing communities in Afam, area of Porthacourt, Niger Delta Nigeria. Results from the assessment using, statistical model, geo-accumulation indices (I-geo) and water quality indices showed that pH and Cu did not correlate strongly with any of the parameters analyzed in the study area. They also observed that at 2-tailed levels of 0.02 and 0.05, no significant correlation exists between alkalinity and salinity in groundwater samples and also with any other elements.

Abam and Nwankwoala (2020) carried out a review of the Hydrogeology of Eastern Niger Delta. They observed that relatively high iron/manganese and chloride values are localized in time and space. They adduced that in the coastal areas, seawater intrusion has been identified as one of the major influences on hydrochemistry of groundwater in the shallow unconfined aquifers and recognized also that the regional groundwater flow direction in the area is from north to south.

Oghenero et al (2020) assembled resistivity and hydrogeochemical data to assess the adverse effect of anthropogenic sources on groundwater quality in Ogbe-Ijoh, a coastal area of the western Niger Delta. They observed that their geoelectrical data showed no evidence of quality degradation as reflected by high resistivity values that ranged from 29.3 to 349.9 Ωm. They opined that the groundwater condition is relatively safe for consumption; nevertheless, due to health implications they recommend that pH should be increased to the required standard before drinking.

Alaminiokuma and Warmate (2020) researched on post drilling investigation for prolific groundwater aquifer using Resistivity (Short Normal and Long Normal) and Self-Potential (SP) logs at Nigeria LNG base, Port Harcourt. In testing the two zones mapped out as zones A and B, they observed that test zone A (110-140 m), though permeable, has high membrane potential which is higher than the liquid junction potential resulting from clay intercalation thereby reducing its viability as a production zone. Zone B is found to be prolific with porosity and permeability values of 18% and 131.31 *m*D respectively at depth range of 140 to 180 m. They went further to suggest that the high TDS value observed within this prolific groundwater zone in the well may be as a result of effluent discharge by industries around the area or saline water intrusion due to its proximity to the Bonny River.

Ibrahim et al (2019) researched on the hydrostratigraphy and hydraulic characterization of shallow coastal aquifers, Niger Delta basin with the intention to develop a strategy for groundwater resource management in the area. They observed that the relatively higher hydraulic conductivity of the Benin Formation units coupled with higher static water level compared to those of the Deltaic Formation leave it with weaker climate change resilience and more vulnerable to pollution and contamination.

Ekine and Osobonye (1996) used surface geoelectric studies for the determination and characterization of aquifers in parts of Bonny and environs although the studies were for shallow aquifers between 20metres to 200 metres range and was confined to vertical electrical soundings.

Akaolisa (2006) observed that the computation of aquifer transmissivity values based on surface resistivity sounding results makes it possible to demarcate regions with good ground water potentials in an area.

Etu-Effeotor (1989) used results of surface geophysical (VES) sounding in the coastal aquifers of the Eastern Niger Delta to detect the intrusion of saltwater into the coastal aquifers while Oteze (1983), from geophysical surveys concluded that freshwater aquifers in coastal areas occur within the range of 0-200m depths.

Sarker*etal* (2021) used a combination of borehole logs, geophysical well logging, electrical conductivity of water samples and VES, electrical resistivity tomography to delineate freshwater – Saline Water in the coastal area of Bangladesh. The team identified three major aquifers with different water qualities: the upper aquifer above 100m as blackish water, 100m – 200m is slightly brackish water with low salinity and bellow 200m where the salinity has disappeared. The bellow 200m aquifer was found to be sealed off by clay layer preventing the saline water from permeating. The study emphasized the importance of combined methods in properly delineating accurate water quality types in complex coastal areas.

Ohwogbere (2017) used electrical resistivity study to appraise saltwater intrusion in shallow aquifers in Burutu area, western Niger Delta. He posited that saltwater intrusion is presumed to have significant effect on quality of groundwater and accountable for lack of access to freshwater in the coastal areas of the Niger Delta.

He used resistivity data obtained from vertical electrical sounding to ascertain the salinity of shallow aquifers, determine depth and thickness of freshwater aquifers. He concluded that aquifers saturated with saltwater are found at the depths of 10.5m, brackish water at 4m to 9m, while freshwater can be located from the depth of 19-46m.

Alaminiokuma (2017) used geoelectrical logging of two wells in Ubima community, Niger Delta, Nigeria and were tested to determine the porosity (ϕ), permeability, *k and the* total dissolved solids (TDS) in the aquifer by derivation from electrical conductivity (EC). Aquifer depths were established at 105m and 140m respectively.

Bayode (2018) used geophysical well logging to investigate salt water intrusion in parts of Lagos State Southwestern Nigeria. He particularly used gamma ray and electric logs to characterize the aquifers. He used the gamma ray index to classify the aquifers as 0-60 API as clean sand, 60 -90 API as sandy clay, 90 – 120 API as clayey sand and greater than 150 API as clay. He further classified the aquifers based on their resistivity values giving 0=60 Ohm-m as saline water, 60 – 80 Ohm-m as brackish water and 80 ->150 Ohm-m as fresh water aquifers.

Ilogbo*etal* (2019) used gamma ray and Electric logs to characterize aquifers around Ikeja area of Lagos, Southwestern Nigeria. He used resistivity values to characterize the aquifers with resistivity values varying from 190 Ohm-m to 700 Ohm-m and identifying four major aquifers between 119m to 127m.

Ngah et al (2016) used geophysical logging of water borehole in Opuama Warri North, Nigeria to establish fresh water bearing aquifers at 107 -116m. They recommended the use of geophysical logging in every water borehole project to properly characterize the aquifers.

Ngah and Allen (2006) examined the common pollutants in groundwater samples from eastern Niger delta. They identified high iron and high chloride content as the most prevalent pollutants in the groundwater. They attempted an explanation of sources of these pollutants and mapping of their local occurrence.

Datel (2009) in his paper on well logging methods in groundwater survey of complicated aquifer systems outlined the use of electric logs in aquifer characterization.

Hwang (2004) in their paper on assessment of sea water intrusion using geophysical well logging and electrical sounding in Coastal aquifers also used electric logs in aquifer characterization.

Oteri (1988) used electric log interpretation in the evaluation of saltwater intrusion in the eastern Niger Delta.

Oteri (1984) used electric logs from oil wells for deep aquifers exploration in the Niger Delta. He opined that the provision of potable water in the Niger Delta has been a major problem, despite the heavy annual rainfall of over 3000 mm. He further said that the development of groundwater resources is the only alternative to the present inadequate system, which relies on collected rainwater. Oteri posited that fresh water in the Coastal areas of the Niger Delta occurs in shallow unconfined aquifers in beach ridges and tidal point bars along creeks and/or in deep confined aquifers. He concluded that most boreholes drilled in the Niger Delta have encountered brackish water due to inadequate hydrogeological feasibility studies, stressing that a study of electric logs from oil wells is shown to be a feasible exploration tool for deep aquifers.

Offodile (1992) studied the hydrogeology of the coastal areas of the Niger Delta and described the area as consisting of a network of tidal creeks which separate small islands of less than 6m above sea level.

Most of the previous research works addressed groundwater quality issues in the Niger Delta using water analysis results from shallow aquifers. An outstanding contribution to understanding the hydrostratigraphy of the area is the study by Etu-Efeotor and Akpokodje (1990). Etu-Efeotor and Akpokodje carried out a stratigraphic synthesis of the aquifers in the Niger Delta and confirmed that the Niger Delta contains a multi – aquifers system. However, they also emphasized the knowledge-gap in the study of aquifers of the Niger Delta which is very important in the determination of accurate aquifer parameters and water quality patterns in the various lithologic units that constitute the multi- aquifer systems.

Etu-Efeotor (1981) used surface geophysical survey (VES) to investigate the hydrogeochemistry of groundwater in parts of Rivers State and delineated areas with water high in chloride contents around Port Harcourt, Buguma, Abonnema and Bille. He concluded that some of the aquifers produce water with high chloride content.

Jimohetal (2018) used geophysical logs obtained from ten wells to characterize the coastal aquifers around Apapa, Lagos Nigeria. The geophysical logs ran included the Gamma Ray, Self Potential (SP) and electrical resistivity logs (N16’’ and LN64’’). The work identified the intercalations of clay, sand and clayey sand formations. The work concluded that shallow aquifers of freshwater overlie salt water aquifers and the deeper confined fresh water aquifers are recommended for ground water exploitation. The depth range for the deeper aquifers is 150m to 160m and bellow.

Amajor (1991) presented a regional lithostratigraphic and hydraulic interpretation of the upper 0 to 300m of the Benin Formation from where groundwater is abstracted in Port Harcourt. Amajor identified a North-South regional groundwater flow pattern except in the North East (Imo catchment area) and concluded that groundwater quality generally compares with WHO(2018) standards for drinking water supply except for high iron and chloride which is localized. He also discussed the depositional environments of the various lithologic units and further identified four aquifer systems within the 0 - 300m depth bracket in the Benin Information.

Ngah and Youdeowei (2013) recommended detailed hydrogeological studies to evaluate the dynamics of salt/fresh water interaction in the coastal area of the Niger Delta.

According to Nwakwaola and Ngah (2014), geology has been observed to be responsible for the complex groundwater distribution, extractability and quality in the Niger Delta. They further declared that the present knowledge of the true geological condition prevailing within the groundwater domain of the Niger Delta is limited.

Most of the previous research works on underground water problems of the Niger Delta addressed groundwater quality issues in the Niger Delta on a local basis and not on a regional scale. It is imperative to determine and characterize the multi- aquifer systems of the Coastal areas Niger Delta on a regional scale.

All the studies above succeeded in identifying major groundwater pollutants in the area to be iron and chloride but did not identify the particular aquifers within the drilled column that contains these parameters in objectionable concentration.

2.9 Principles of Electric Logging

Open-hole geophysical logging implies the recording of one or more physical variables in the subsurface to provide information on lithology, straitigraphy and physiochemical properties of the fluid filling the pores of the perforated formations.

There are different types of borehole logs for example; Spontaneous Potential, SP, Resistivity, Single Point Resistance, Gamma Ray, Caliper logs etc.

During logging, the probe is lowered into the open hole and one or more electrodes are suspended on a conductor cable as it goes into a borehole filled with drilling fluid. An electric current is forced to flow from these electrodes to other electrodes that may be in the borehole or placed in the ground near the top of the well. Variations in resistivity are caused primarily by differences in the character of the subsurface strata and in the mineral content of the water contained in these formations.

No one single log can adequately provide unequivocal information on lithology, formation boundary, fluid chemistry etc. A beautiful feature of Mount Sopris Instrument MGX II LOGGER is its ability to run several logs which can provide more accurate qualitative and quantitative information. The instrument runs seven logs in one pass of the hole. They are Self potential SP, Single Point resistivity, SPR, Gamma Ray, Resistivity (N8, N16, N32, and N64). These variables are recorded continuously as a function of depth of the probe when it is moving upward or downward in the mud-filled hole

The SP logs measure the natural electrical potential of the lithology in millivolts. Spontaneous potentials are naturally occurring electrical potentials that result from chemical and physical changes at the contacts between different types of subsurface geologic beds.

Gamma ray log utilizes the difference between the quantities of gamma rays emitted by the minerals that make up different lithological units. For instance, the minerals in shale and clay emit more gamma rays than the minerals in gravels and sands. This difference in the quantity or amount of emitted gamma rays is employed in gamma ray logs to differentiate between sand, shale and clay. Gamma logs measure total gamma radiation that is naturally released from the formation. Gamma ray logs can be run in cased or uncased wells.

Electric log seek to measure and record two quantities. The first is the variations in the borehole of electrical resistivity of permeable beds whenever such beds are in contact.

The second quantity, which the electric log seeks to measure, is the electrical resistivity of the formation penetrated by the borehole.

Conductivity in sedimentary rocks is distinguished from conductivity in metal and certain metallic ores by the fact that in sedimentary rocks the conduction is due to the movement of ions, whereas in metals it is due to the movement of electrons. In one case the conduction may be electrolytic, in another electronic.

The ions, which conduct the current in sedimentary rocks results from the dissociation of salts. Such dissociation occurs when salts are dissolved in water. It is the movement of these charged ions under the influence of an electrical potential, which enables a solution of salt to conduct electricity. Since each ion is able to carry only a definite quantity of electric charge, it follows that the more ions that are available in solution to carry charge and faster the ions travel, the greater will be a charge that can be carried. Since the movement of charge constitutes an electrical current, it follows also that a solution containing a large number of ions will conduct a large current, every other thing being equal, than a solution containing a smaller number of ions. Accordingly, the solution with the large number of ions will have the higher number of conductivity and therefore, the lower the resistivity.

The main object of quantitative log interpretations is to determine the nature and percentages of the fluids, which fill the pore spaces of the rock. Second object of interpretation is to find correlation between the trace patterns of logs from different wells thereby permitting the continuity and the relative position of sub-surface formations to be assessed. Another object, which perhaps may be considered as part of the general problem of correlation, is to determine which beds are permeable and thus possibly productive, and which are shaley that they can be eliminated from the search for potential aquifers and reservoirs.

A careful interpretation of the different logs is used to determine the proper depths at which the screens should be placed for optimum productivity of the borehole.

A limiting factor of electric logging however is that it can only be run in boreholes that do not have casing (except for gamma ray) and are filled with drilling fluid.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Data Acquisition

The author relied solely on primary data acquired in the study area. He acquired gamma ray and electric logs data for this study during the course of his involvement in water wells drilling operations for water supply in different parts of the coastal areas of the Niger Delta. The data collection covered most parts of the Niger Delta: the Eastern, Western and Southern parts of the Coastal Areas. The data include lithologic logs, gamma ray, electric logs, and some results of water quality analysis where available.

To ensure representativeness of the coastal areas of the Niger Delta, study sites were chosen from each of the five major geomorphologic units. Boreholes were located in different areas of each geomorphologic unit.

The study was carried out in five geomorphic zones of the Niger Delta namely: Benin Formation, saltwater swamps and coastal beaches and ridges. Study sites for each geomorphologic unit are as follows, (Table3.1).

Data were collected from sixty-three boreholes drilled in different parts of the coastal areas of the Niger Delta. Areas where data were collected included the list below.

3.1.1 Data Acquisition Coverage

DELTA STATE

1. Kwale
2. Ogheye Warri
3. Ogidigben
4. Ojobo
5. Utorogu
6. Shell Main Office Edjeba
7. Uzere, Isoko
8. Warri Refinery
9. NPA Warri

10 .Okpai IPP site

11 . Otorogu flow station (Otujeremi)

12 . Okpai community

BAYELSA STATE

1. BRASS
2. OTAKEME
3. ASINGBENE (GBARAIN)
4. GBARAIN UBIE GAS PLANT
5. TUNU SHELL FLOW STATION
6. SWAALI MARKET YENEGOA
7. AMASOMA
8. AYAMA IJAW
9. OBUNUGHA GBARAIN
10 KOLO
11 GBARAIN IPP

AKWA IBOM STATE

1. ATABRIKANG
2. MPANAK IBENO
3. IBENO QIPP WELL 1
4. QIT IBENO 2
5. QIT IBENO WELL 3
6. QIT IBENO MASTER PLAN
7. QIPP IBENO WELL 2

ABIA STATE

1. OWAZA 1
2. OWAZA 2
3. OWAZA 3
4. OWAZA 4
5. OWAZA 5

ONDO STATE

1. ABEALALA ILAJE
2. ADOLOSEIMO ILAJE
3. AYETORO
4. AKPATA IJAW

5. ARAROMI
6. AROGBO
7. ASISA
8. AWOYE
9. ERUNA
10. IDOGUN AYADI
11. JINRINWO
12. ORIETAN

RIVERS STATE

1. ASARAMATORU
2. BILLE
3. NAF BASE PORT HARCOURT
4. NDONI
5. ONNE
6. PH REFINERY
7. AMADI CREEK
8. BONNY
9. EAGLE ISLAND PH
10. KIDNEY ISLAND PH
11. KULA
12. AGBADA FLOW STATION
13. FINIMA
14. OGUEDE BONNY.
15. IDAMA- ABONEMA AREA
16. NLNG AMADI CREEK PORT HARCOURT
17. BUA NPA YARD PORT HARCOURT

Table 3.1: Study sites and their geomorphic zones

Geomorphic Zone	Location of Study Sites
Benin Information (CPS) (21 sites)	Onne Kidney Island Amadi Creek BH-1 Amadi Creek (NLNG) Eagle Island NAF Base PH BUA Yard NPA PH Port Harcourt Refinery Agbada Flow station Owaza BH-1 Owaza BH-2 Owaza BH-3 Owaza BH-4 Owaza BH-5 Atabrikang MpanakIbeno QIT Ibeno BH-1 QIT Ibeno BH-2 QIT Ibeno BH-3 QIPP Ibeno BH-1 QIPP Ibeno BH-2
Sombreiro-Warri Deltaic plain(SWD) (4 sites)	Ndoni Warri Refinery

	Shell Main Office Edjeba NPA Warri
Fresh Water Swamps (FWS) (19 sites)	Kwale Otorogu Flow station Utorogu Gas Plant Ojobo Uzere Okpai IPP Okpai Community Otakeme Community Asingbene GbarainUbie Gas plant Amasoma ObunaghaGbarain Swali Market Garain IPP Ayama Ijaw KoloOgbia Arogbo Ijaw Awoye Ondo Orietan Ondo
Salt Water Swamps (SWS) (13 sites)	Bille Asaramatoru Idama Kula

	Tunu flow station Ogheye Abealala Adoloseimo Ayetoro Akpata Ijaw Eruna IdogunAyadi Jiririnwo
Coastal Beaches/Ridges (5 sites)	Bonny Finima Oguede Brass Ogidigben

3.1.2 Collection of Hydrogeological and Well Data

Data under this heading relate to location of borehole, total depth of borehole, interval of drilled section where the screens were placed, thickness of the aquifer and confining beds.

3.1.3 WaterWell Drilling Operation

The drilling method employed in drilling all the water boreholes is the direct rotary drilling method with a suitable Rotary drilling rig capable of drilling to borehole total depths. The drilling rig bore holes through a rotary process using water and adequate and relevant drilling chemical properly mixed using a mud Engineer. Several of the drilling locations were in the coastal areas and movement of equipment to site involved marine transportation using Badges and Tug boats to ferry the drilling rigs and other associated equipment and tools to site.

3.1.4 Instrumentation and Description of WaterWell Drilling Operation

The drilling method employed is the direct rotary drilling method with a suitable drilling rig. The drilling operations involved:

- drilling of the hole
- bringing out the cuttings from depths drilled to the surface for collection and labeling.
- maintaining an open hole by mitigating against collapse
- Installation of casings and screens
- placing the gravel pack
- cement grouting and
- Development of the well to ensure sand-free operation and maximum yield.

Drilling is usually achieved by the drilling rig mechanical systems rotating a bit and cuttings are removed by continuous circulation of the drilling mud as the bit penetrates the formation. As the drilling mud is pumped from the mud tank through the drill string and out of the bit, the cuttings are returned to the surface where they are collected as samples.

The most common drilling fluid in use for water wells drilling is the bentonite. It is swelling clay consisting of mainly montmorillonite which is a mineral with strong water-absorbing, gel-forming characteristics.

According to Selemo and Ibeneme (2020), the functions of the drilling mud in direct rotary drilling include:

- It buoys up and lifts loose well cuttings to the surface during drilling and prevents the cuttings from sliding back to the bottom of the hole during stoppages.
- It supports and stabilizes the borehole wall to prevent caving. This is achieved because the drilling mud exerts pressure against the wall. The hole is compelled to remain open as long as the hydrostatic pressure of the mud exceeds the formation pressure and any confining pressure in the aquifer.
- It seals the borehole wall and reduces fluid loss. As drilling progresses, a film of small particles builds up on the wall of the borehole which is normally referred to as Mud Cake. Mud cakes form when the pressure of the

drilling fluid forces small volumes of water into the formation leaving fine, suspended materials on the borehole wall. Mud cake protects the wall from being eroded by the upward flowing stream of drilling fluid.

- It cools and cleans the bit
- It allows cuttings to drop out in the settlement tank
- It lubricates the bit, bearings, mud pump and drill pipes

3.2 Collection of Formation Samples

Sample collection was done at 3m intervals and at any perceptible change in lithology. At any sampling depth, drilling is momentarily stopped and circulation allowed for a few minutes to allow the fresh cuttings travel from the bottom of the well to the surface. The samples are then collected using a pail or plastic bucket, bagged and properly labeled.

Fig. 3.1 Typical drilling and logging operations.

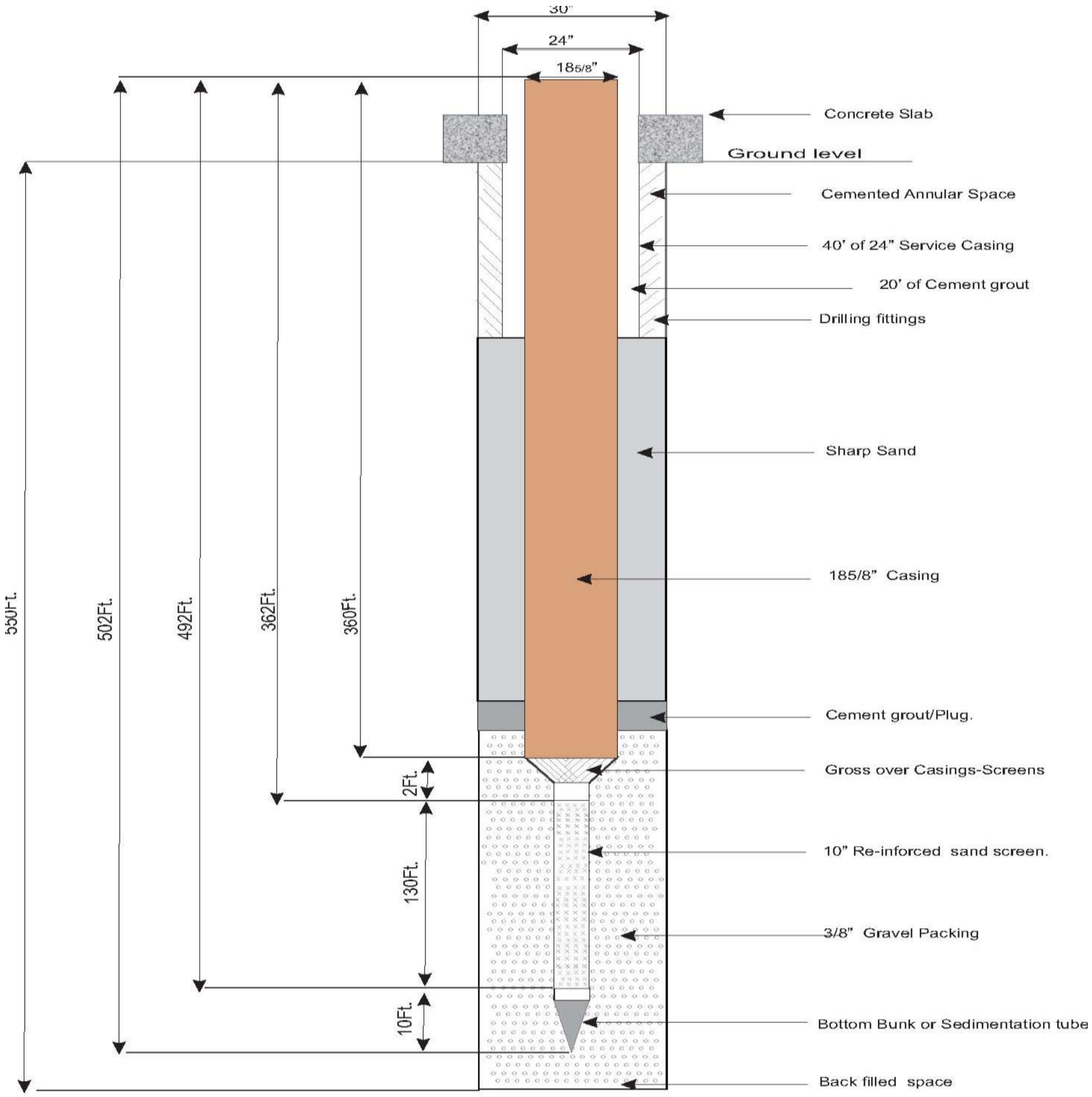

Figure 3.2: Typical Borehole Design

3.3 Open-Hole Geophysical Logging

Open-hole logging is used as a guide in determining the thickness of formations, zones of highest porosity, and water quality. In most of the study sites, borehole drilling was followed up with open-hole geophysical logging running the gamma ray and electric logs in one pass of the hole.

3.3.1. Instrumentation for Gamma Ray and Electric Logs

The Geophysical logging operations were done using the MOUNT SOPRIS INSTRUMENT, MGX II LOGGER. This is an ultra-modern fully automated geophysical logging instrument. The instrument consists of four principal components:

i. An electronic unit that feeds the electric current to a down-the-hole electrode and measures the resistivity of the entire circuit.
ii. A cable reel with conductor cable. The probe is lowered into and lifted out of the hole by the fully automated forward and backward drive cable drum reel. The instrument has a depth encoder that automatically displays depth being logged. The cable drum holds a wireline cable of 1000m lenth.
iii. A sonde or probe from which current passes to the drilling fluid and formation surrounding the borehole. The electrical probe consists of a cylindrical tool, 38 - 45mm in diameter. One or more electrodes in the form of short metal rings are mounted on the tool. Each electrode is connected to one of the wires of the conductor cable on which the tool is suspended
iv. A recorder for automatically plotting values of resistivity against depth as a continuous curve.

The Mount Sopris Instrument MGX II LOGGER has the ability to run a suite of logs in one pass of the hole which can provide more accurate qualitative and quantitative information. All the logs used in this study were run in suites consisting Spontaneous potential, SP, Resistivity (N8, N16, N32 and N64) and Gamma Ray logs. All these variables are recorded continuously as a function of depth of the probe when it is moving upward or downward in the borehole.

The SP logs measure the- natural electrical potential of the lithology in millivolts. Spontaneous potentials are naturally occurring electrical potentials that result from chemical and physical changes at the contacts between different types of subsurface geologic materials.

Gamma ray log utilizes the difference between the quantities of gamma rays emitted by the minerals that make up different lithological units. This difference in gamma rays is employed in gamma ray logs to differentiate between sand, shale and clay. Gamma logs measure total gamma radiation that is naturally released from the formation. No radioactive materials are introduced into the well.

3.3.2 Available Data

Sixty-two (62) open-hole logs from various parts of the study area were collected. The locations where the logs were collected and their geomorphological areas are presented in chapter four.

3.3.3 Work Methodology for the Logging

The work methodology for running the geophysical log includes the following work sequence:

PRE-MOBILIZATION ACTIVITIES

1. Prepare health, Safety, Environment and Security documentation
2. Acquire all insurance documentation including workmen compensation
3. Carry out a pre-mobilization audit on all equipment.
4. Medical certification for all workers to be engaged for this project

MOBILIZATION

1. Assemble all materials needed at take off base.
2. Loading and handling of all materials
3. Mobilize all materials at once to avoid delays.

SITE PREPARATION

1. Ascertain that the drilling contractor has drilled to the recommended depth.
2. Ascertain that all drilling rods have been pulled out of the hole and hole is free and empty.
3. Prepare a suitable platform and set up logging equipment tripod near the borehole mouth
4. Set up logging equipment and all accessories.
5. Set up inverter and power supply source.
6. Test all cable leads to ensure proper power supply.
7. Connect to laptop computer
8. Properly demarcate the logging site to avoid unauthorized access.

9. Provide shade for logging equipment and personnel as protection against rain/sun.

RUNNING THE DOWN-HOLE LOGS

1. Take an appropriate datum on the well head or ground level.
2. Install probe on tripod
3. On computer
4. Zero depth and set logging datum
5. Prepare logging header
6. Initialize appropriate tool for the job
7. Set tool reading range
8. Power tool
9. Activate recording facility
10. Save work in the appropriate file
11. On printer for automatic online printing of graphs.
12. Carry out down-hole geophysical logging in open mud-filled borehole using ultramodern digital down-hole geophysical equipment capable of running seven parameters in one pass in real time colour.

SITE RESTORATION/DEMOBILIZATION

1. Restore environment to as-met condition and demobilize equipment, materials and personnel.

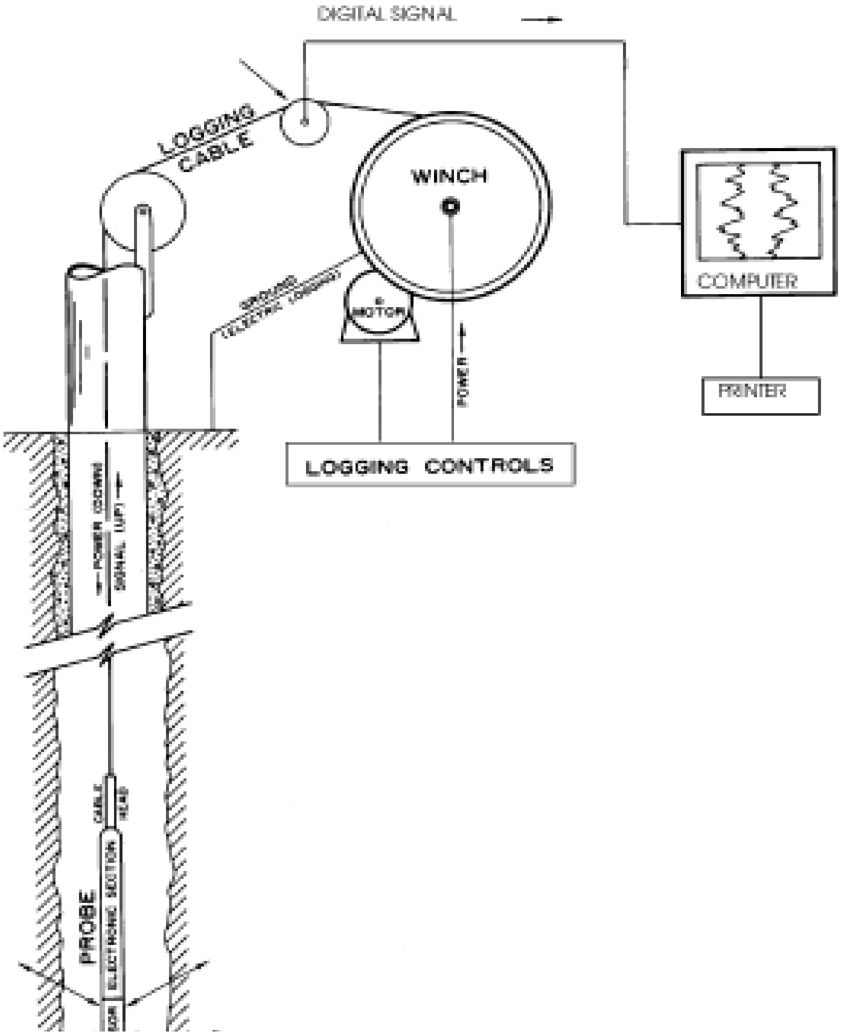

Figure 3.3: Block Diagram of Geophysical Well-Logging Equipment (from Keys and MacCary 1971)

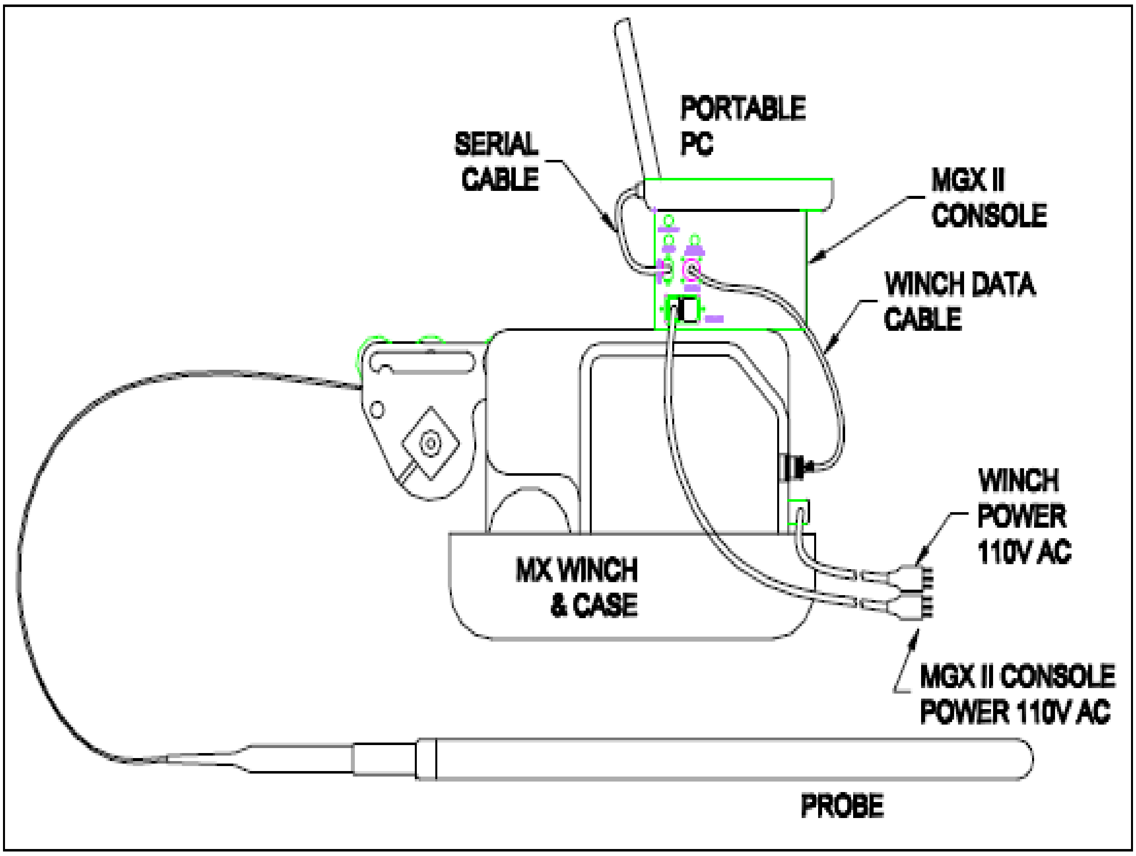

Figure 3.4: Mount Sopris MGX 11 Logger (Source: Mount Sopris Operation Manual, 2005)

Figure 3.5: Mount Sopris MGX 11 Logging Equipment

Figure 3.6: Running the Open Hole Geophysical Logging.

3.4 Well Log Interpretation Software

The interpretation software used to analyze the logs is the WellCAD software. WellCAD is a powerful and interactive PC based well data management tool, developed by Advanced Logic Technology (ALT) sà. ALT is committed to the design and production of specialist, open software, for the geosciences industry. The company is innovative and progressive in its outlook and is staffed by geoscientists with direct and relevant experience of the petroleum, minerals, geotechnical and hydrogeological industries.

From conception, WellCAD has been designed with the end user in mind, and thus reflects the state of the art in terms of powerful graphics functionality and processing capabilities.

WellCAD has been specifically designed to meet the needs of not only the professional log analyst, but also to meet the needs of the petroleum geologist, sedimentologist, geotechnical engineer, mining geologist or hydrogeologist, in fact anyone who wishes to manage, manipulate or process borehole data and who wishes to produce a professional report quality document.

3.6 Collection and Analysis of Water Samples

Three samples of groundwater were collected from boreholes for laboratory analysis to ascertain the quality of water from the aquifers.

The depth of the screen was taken to represent the depth in the drilled section from which the water was abstracted. To ensure integrity of samples and those representative samples collected, the following measures were taken:

- Before a sample was taken, stagnant water was removed by pumping the well for about 30 minutes
- Water samples were taken directly from the sampling tap at the well head.
- The sampling bottles were properly sterilized before collecting the sample.
- The sample was properly labeled indicating location, date, sample number, time collected, depth of screen and borehole depth.
- To minimize sample deterioration, samples were properly preserved in refrigerators prior to analysis.

3.6.1 Laboratory Analysis of Water Samples

Analysis of water samples was carried out in different laboratories. The Rivers State Water Board, Port Harcourt, SPDC and other certified laboratories complying as much as possible with standard laboratory practice and environmental standards according to the Nigeria Standard for water Quality (NSDWQ 2007) and WHO (2018) standard.

Table 3.2: WHO recommended standards for drinking water quality, WHO (2018).

Parameter	Limit of general acceptability (mg/l)	Allowable limit (mg/l)
Total solids	500	1500
Colour	5	50
pH	7-8	6.5-9.2
Turbidity	3	25
Chloride	200	600
Iron	0.3	1
Manganese	0.1	0.5
Copper	1.0	1.5
Zinc	5	15
Calcium	75	200
Magnesium	50	150
Mg as Sodium sulphate	500	1000
Nitrate as NO_2	45	-
Phenols	0.001	0.002
Synthetic detergents	0.5	1
Carbon chloroform (ABS)	0.2	0.5

3.7 Available data

Sixty-two Open-hole logs from various parts of the study area were collected. The study covered most coastal areas of the Niger Delta stretching several kilometers in land and the swamps (a very difficult terrain indeed). The data collected included Gamma Ray logs, Electric Logs, lithologic samples and water samples.

CHAPTER FOUR
RESULTS, INTERPRETATION AND DISCUSSION

4.1 Results and Interpretation

The data acquired using the techniques outlined in Chapter three are presented, analyzed and discussed in this chapter.

4.1.1 Well Data

The wells studied were drilled from surface to between 100m and 600m crossing the aquifer systems of the study area. Most of the wells were cased with steel casings to API standard with stainless steel screens of various lengths depending on the aquifer thickness.

4.1.1 Strata Samples (Strata Logs).

Strata samples were collected at 3m intervals from the drilled wells and were compared with the results of the gamma log to give an accurate subsurface soil stratification of the study area.

The drill cuttings revealed that the subsurface in most areas is capped by clay cover. The layer of clay is underlain by sands and clay sequence. The sand bodies are coarse grained, occasionally very coarse, gravelly and occasionally pebbly.

In most cases, the layers of sand are confined by thin layers of clay or sometimes very thick layers of clay. The clay beds are grayish brown, sandy to silty and sometimes organic.

4.1.2 Description of the Lithologic Units

The lithologic units were obtained from an integrated interpretation of the gamma ray logs and the samples collected from the wells during drilling. The lithologic boundaries were properly delineated by the gamma logs.

4.1.2.1 Lateritic Soil Cover

The Laterite soil cover exists in some parts of the study area. Areas around Owaza, NAF base, Shell base have lateritic cover while there is no laterite cover in Onne (FOT), Kidney Island, Amadi Creek, Bonny, Finima, Oguede and Bille. The predominant soil covers is silty sand which gives way to a black to brownish black clay.

4.1.2.2 Clay Beds

The claybeds are grey to brown in colour with thicknesses varying from 1 to 30 meters in some parts of the study area.

4.1.2.3 Peat and Lignite

These are dark brown to brownish black organic matter with variable thicknesses. These organic deposits are interpreted as marshes developed on fluvial flood plains and swampy areas.

4.1.2.4 Conglomerates

The conglomerate beds were observed within the study area. Amajor (1991) described the pebbles as mostly quartz, chert and laterite clasts and are usually coated with iron stains.

4.1.2.5 Sand

Thickness of the sand is very high in the study area. The sand bodies are generally loose, friable and poorly consolidated. They are fine – medium grained to gravelly and pebbles. Sand colour varies from reddish brown to brownish and occasionally light grey to whitish. The sand sequentially arranged with conglomerates at the bottom followed by coarse to very coarse sand, medium sand, fine to very fine sand and clay on top.

4.2 Aquifer Systems

The saturated sand bodies form the aquifers in the study area. The aquifer systems were established by an integrated interpretation of the lithologic logs, gamma logs and resistivity logs.

The deep boreholes have revealed the existence of more aquifer systems in the study area.

4.2.1 Static Water Level

Static water level varies in the study area. In the most of the wells the static water level is less than 5 metres. The static water level in the wells was measured in some completed wells using an automated water level meter. Table 4.3 shows the static water level for the wells in the study area.

Table 4.1 Distribution of boreholes studied **in** the geomorphic zones.

S/No	**Geomorphic Zone**	**Number of Boreholes**
1	Benin Formation	21
2	Fresh water swamp	19
3	Saltwater/mangrove swamp	13
4	Sombreiro Warri Deltaic plain	4
5	Coastal beaches and ridges	5
TOTAL		**62**

Table 4.2 Static water levels in the study area.

S/No.	LOCATION	STATIC WATER LEVEL S.W.L (m)
1.	Onne	3.3
2.	Bille	Artesian
3.	Bonny	3.0
4.	Finima	1.3
5.	Finima	1.0
6.	Bonny water Board	1.2
7.	Bonny Oguede	Artesian
8.	Amadi Creek	Artesian
9.	Kidney Island	2.0

4.3 Aquifers in the Benin Informations

Several boreholes were drilled and gamma ray and electric logs carried out in the Benin Informations depositional environment of the Niger Delta Southern Nigeria. The wells covered several areas in the Benin Informations. The different locations are discussed below.

4.3.1 Onne Borehole

The electric log of the 210m deep borehole at Onne (figure 4.1), shows the presence of four aquifers between 0 - 210m. The aquifers were properly isolated from the interpretation of the gamma logs and strata logs. The gamma log has a scale of 0-140

CPS. The areas with low gamma counts tending towards zero are sand formations while the areas with medium to high gamma counts tending towards 140 CPS indicate clay/shale. The first aquifer occurs between 0 -90m, however this aquifer is divided into two parts viz: from 20m to 70m fresh water with a peak resistivity of 627.0 Ohm-m at 40metres and from 70m to 90m salt water with resistivity of less than 15 Ohm-m. The salt water zones are with low resistivity of less than 15 ohm-m and are also indicated with low gamma counts implying a sandy formation. While clay/shale areas with low resistivity are indicated on the gamma log with high gamma counts. This helps to differentiate clay/shale zones from saline water as both have low resistivity. The fresh water is floating on top of the saline water as a result of density difference and hydrostatic balance. If a heavy pump is installed in this aquifer, it will alter the balance and the two water bodies will mix.

The second aquifer is sealed off from the upper saline water aquifer with a thick layer of clay. This aquifer is 100m-114m with a peak resistivity of 366.41 Ohm-m at 108m. A third aquifer is 120m to 131m with a peak resistivity of 499.23 Ohm-m at 125m and a fourth aquifer from 151m to 205m with a peak resistivity of 623.0 Ohm-m at 182m. Figure 4.2 is a down-hole geophysical log of the well at Onne. The aquifers with low resistivity values less than 500 Ohm-m indicated ferrous iron contamination. The fourth aquifer with a peak resistivity of 623 Ohm-m was recommended for screening. The potable water column has a resistivity of 623 Ohm-m while the contaminated water has a resistivity of 15 Ohm-m.

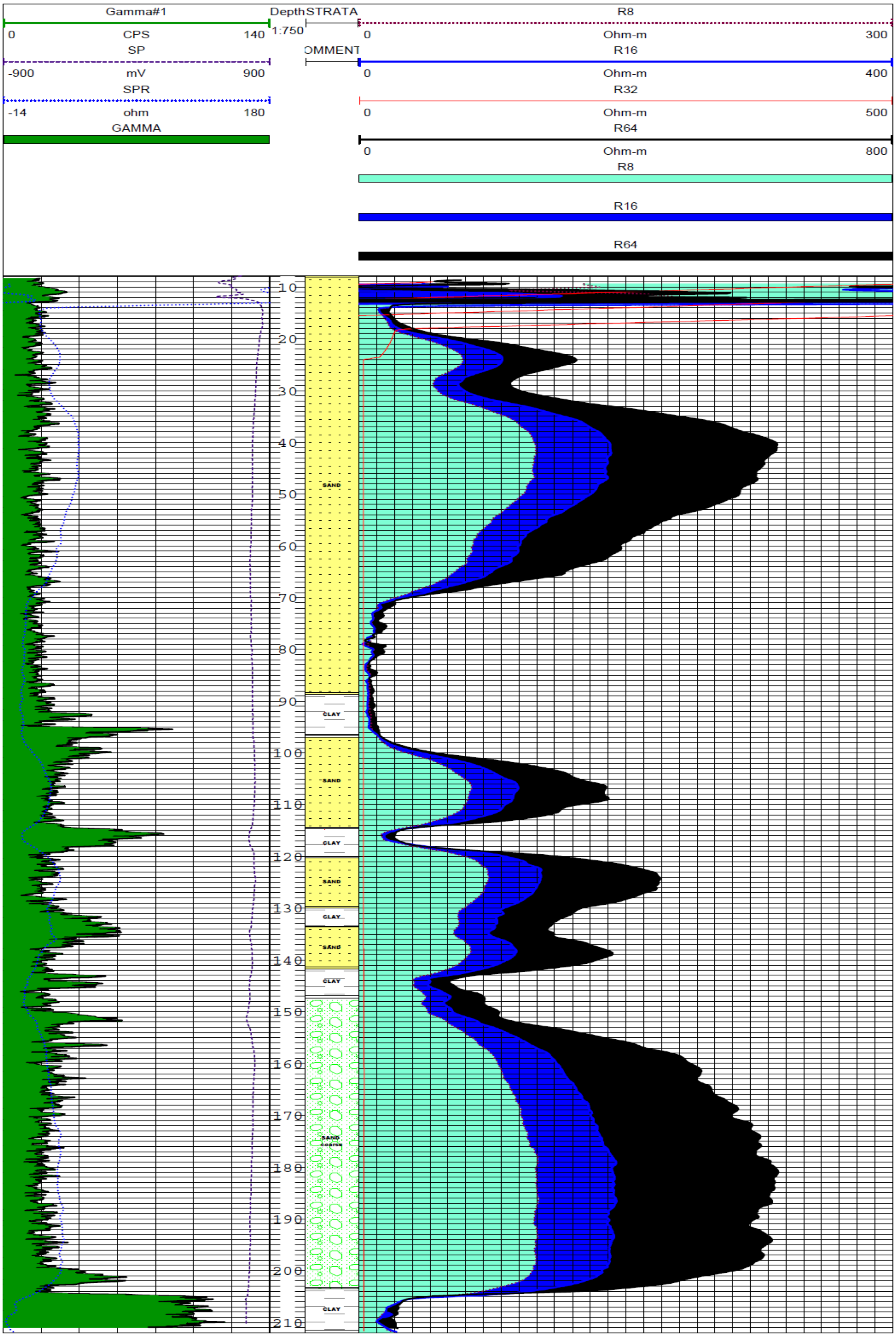

Figure 4.1: Onne FOT Borehole Log

4.3.2 Kidney Island Borehole

A borehole of 150m was drilled at Kidney Island Abonema Warf area of Port Harcourt (figure 4.2) and both the lithologic log, the gamma ray log and the electric logs of the borehole revealed two aquifers, 5m-85metres with floating fresh water between 20m and 40m on top saline water a similar feature that was observed in the Onne borehole. Between 20-40metres the peak resistivity of 373Ohm-m was obtained at 27metres. The resistivity of the saline water between 40metres to 85 metres was about 13.5Ohm-m. This upper saline water aquifer was sealed from the lower aquifer with a layer of clay. The resistivity of the aquifer between 100-130metres was at its peak at 115metres with a resistivity of 889.0 Ohm-m. Figure 4.2 is the down-hole log of the borehole at Kidney Island.

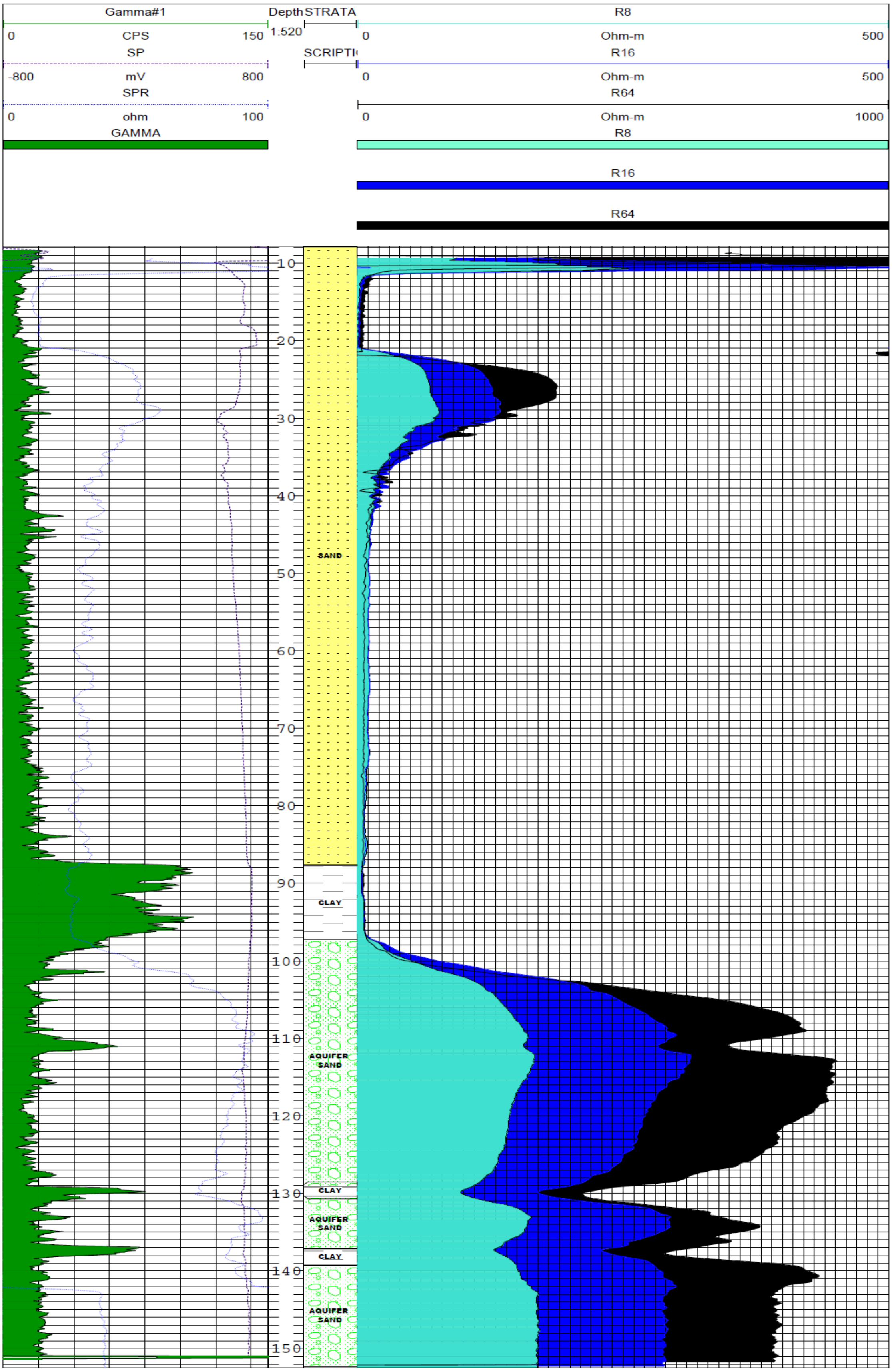

Figure 4.2: Kidney Island Geophysical Log

4.3.3 Amadi Creek Borehole 1- Van Oord Yard

A borehole of 210m was drilled at Van Oord yard, Amadi Creek Eastern Bypass Port Harcourt Nigeria. Two major aquifers were encountered. From 0m-80metres was marked with sandy formation with very low resistivity values of less than 10 Ohm-m indicative of salt water intrusion. The first major aquifer runs from 90m to 150m with an average resistivity of 610 Ohm-m. The second aquifer is from 153m to 200m with an average resistivity of 660 Ohm-m. Figure 4.3 is the down-hole log of the borehole at Amadi Creek Port Harcourt borehole.

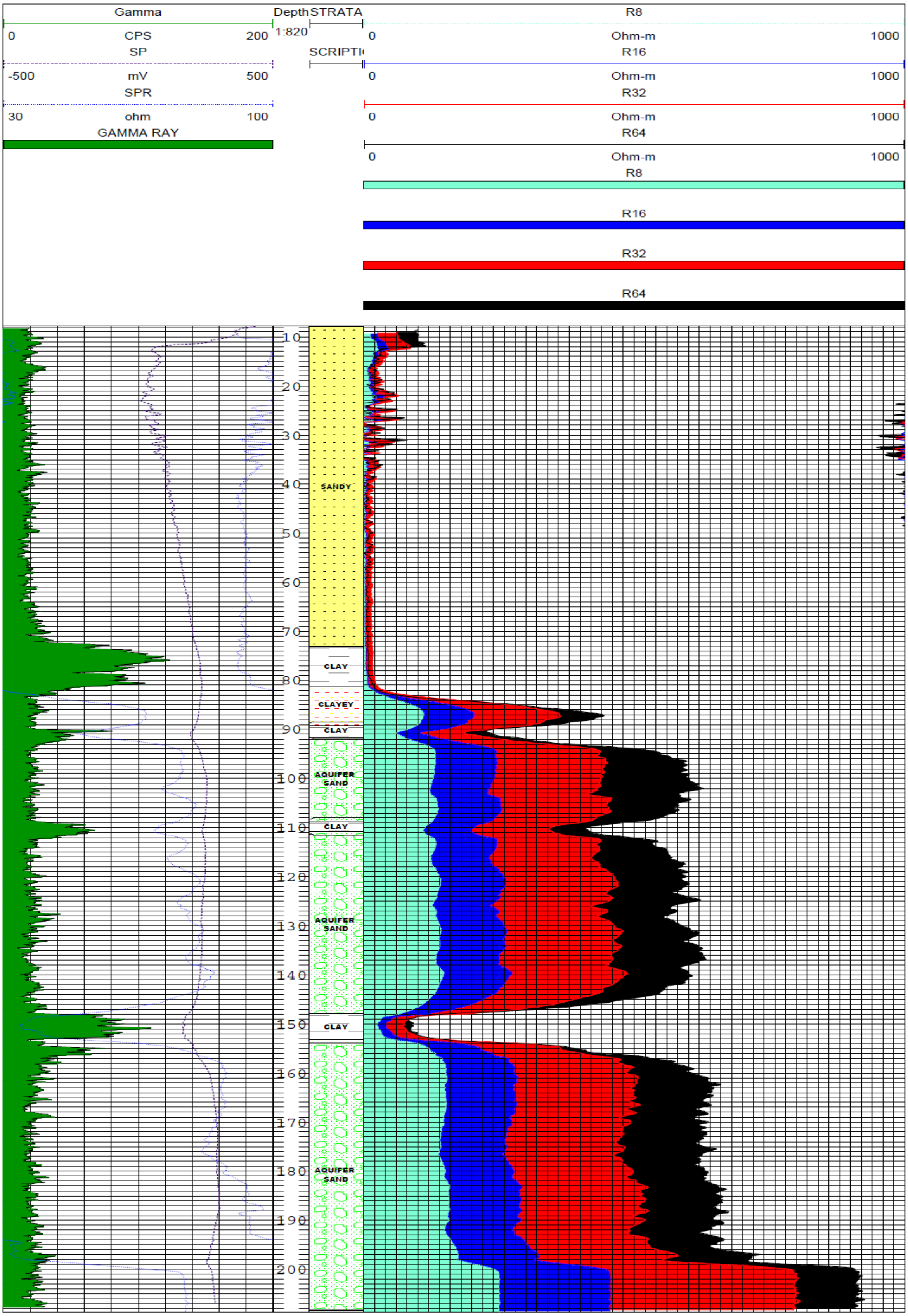

Figure 4.3: Amadi Creek Borehole (Van Oord Yard)

4.3.4 NLNG Amadi Creek Borehole

A borehole of 360m was drilled at NLNG Amadi Creek, Eastern By pass Port Harcourt. The down-hole geophysical logs of the borehole revealed eight major aquifers. From 10m-90metres was marked with sandy formation with very low resistivity indicative of salt water intrusion. The thickness of this aquifer was 80m and the average resistivity for this formation was less than 12.84 Ohm-m. This upper salt water aquifer was sealed off from the aquifer below with a layer of clay between 90 to 100 metres. The second aquifer runs from 100m to 112m with an average resistivity of 465.25 Ohm-m and a thickness of 12m. The third aquifer is from 120m to 148m with a thickness of 28m and an average resistivity of 458 Ohm-m. The fourth aquifer is from 153m to 187m with a thickness of 34m and a peak resistivity of 439 Ohm-m. The fifth aquifer is from 192m to 249m with a thickness of 57m and a peak resistivity of 463.5 Ohm-m. The sixth aquifer is from 228m to 246m with a thickness of 18m and a peak resistivity of 512 Ohm-m. The seventh aquifer is from 250m to 312m with a thickness of 62m and a peak resistivity of 453 Ohm-m. The eighth aquifer is from 321m to 354m with a thickness of 33m and a peak resistivity of 401.93 Ohm-m. Figure 4.4 is the open-hole log of the borehole at NLNG Amadi Creek, Port Harcourt.

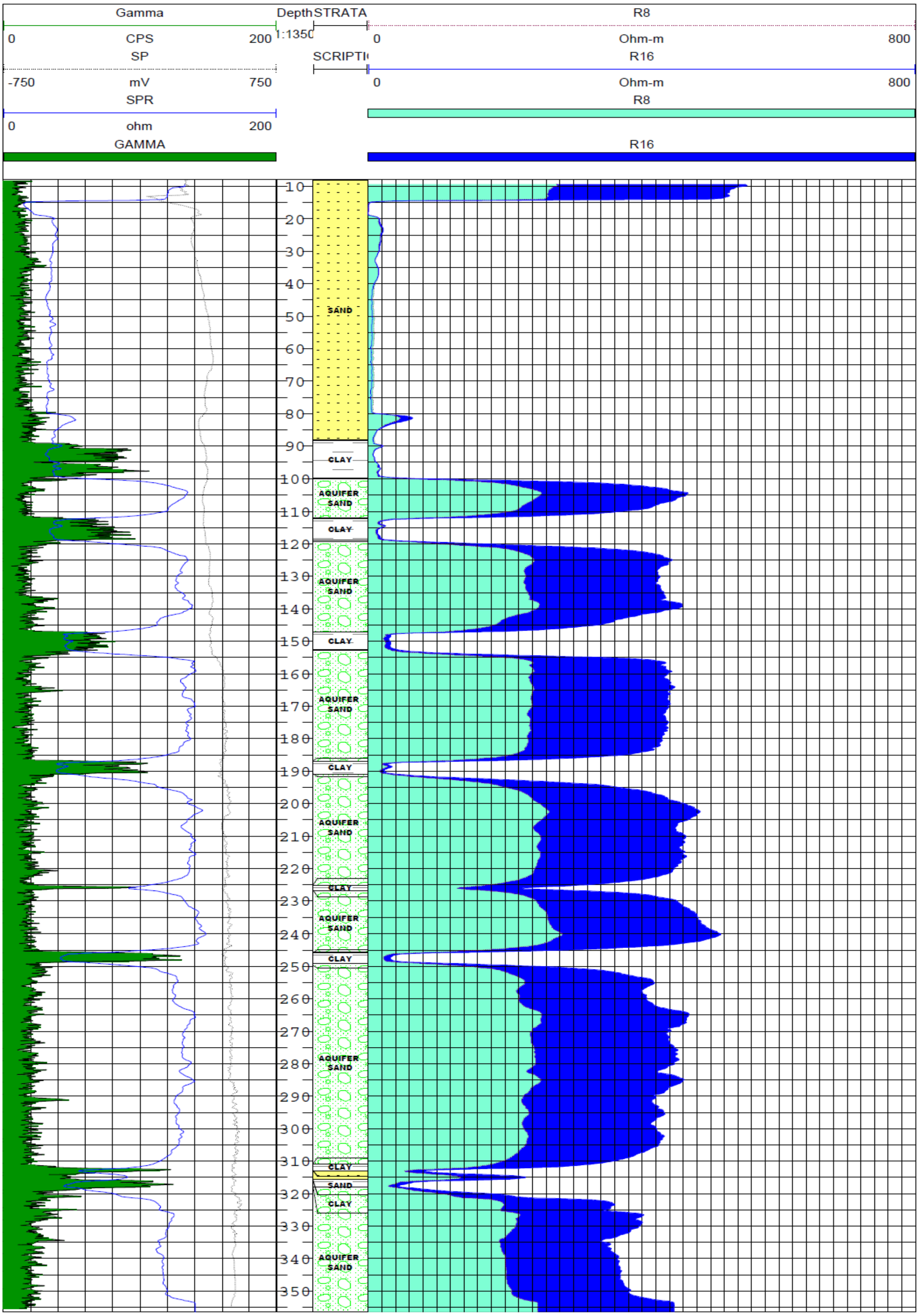

Figure 4.4: NLNG Amadi Creek Borehole

4.3.5 Eagle Island Port Harcourt Area

A borehole of 179m was drilled at Eagle Island Port Harcourt area. The geophysical logs of the borehole revealed three aquifers. The first aquifer was from 10m-90metres with a thickness of 80m and a peak resistivity of 300.67 Ohm-m. The second aquifer was from 107m to 123m with a thickness of 16m and a peak resistivity of 385.8 Ohm-m. The third aquifer stretched from 129m to 179 metres with an average resistivity of 441.63 Ohm-m and a thickness of 50m. There was no salt water observed in this well. Figure 4.5 shows the geophysical logs of the Eagle Island borehole.

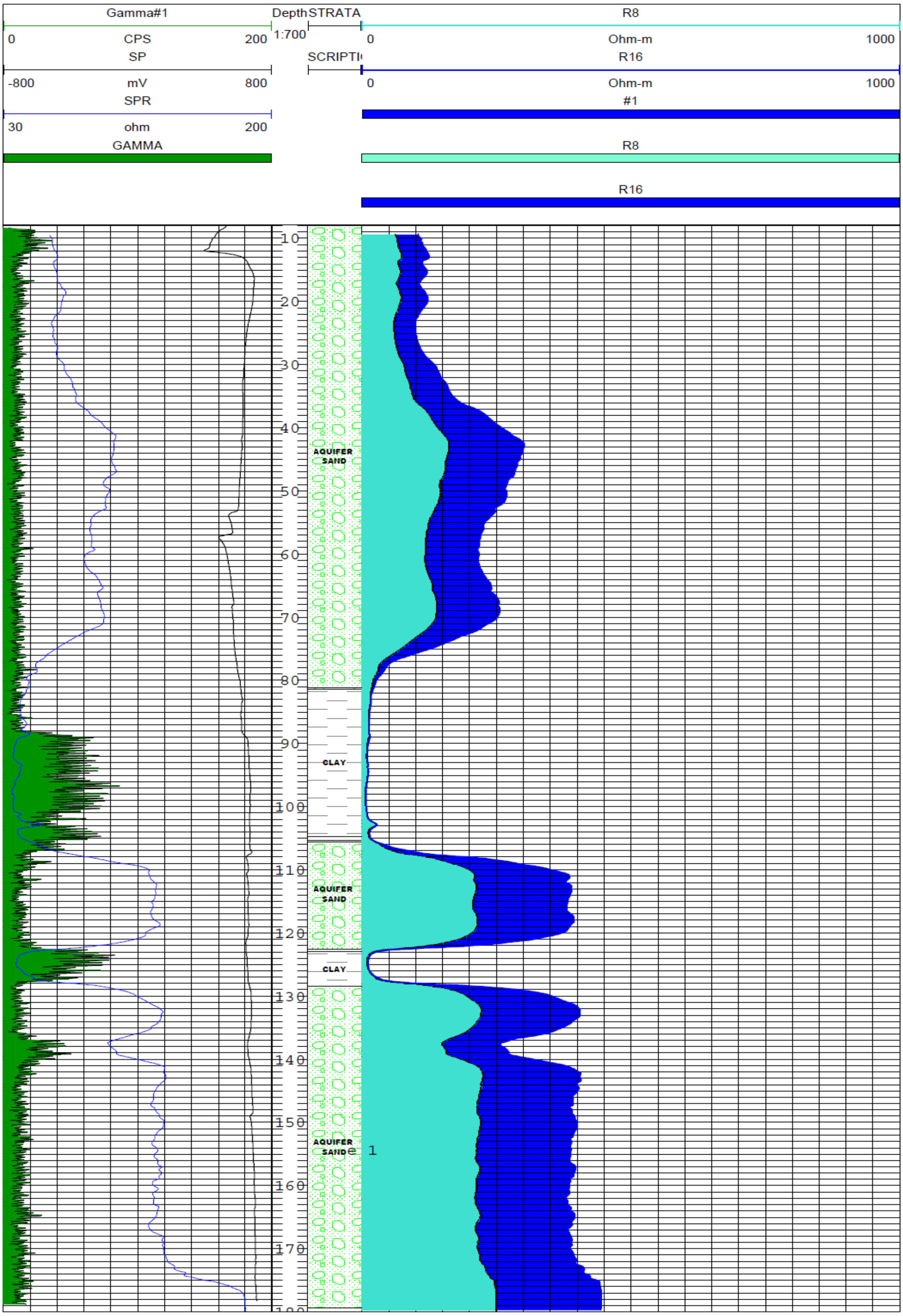

Figure 4.5: Eagle Island Port Harcourt Borehole Log

4.3.6 NAF Base Port Harcourt

The down-hole geophysical logging of the borehole at NAF Base Estate Port Harcourt was analyzed. The logs isolated four aquifers. The first aquifer is from 10m to 85m with a thickness of 75m and peak resistivity of 1499.8 Ohm-m. The second aquifer was from 90m to 138m with a thickness of 48m and peak resistivity of 901.4 Ohm-m. The third aquifer was from 141m to 165m with a thickness of 24m and a peak resistivity of 867.6 Ohm-m. The fourth aquifer was from 180m to 200m with a thickness of 20m and a peak resistivity of 947 Ohm-m. The open-hole geophysical log for NAF Base Port Harcourt is shown in Figure 4.6.

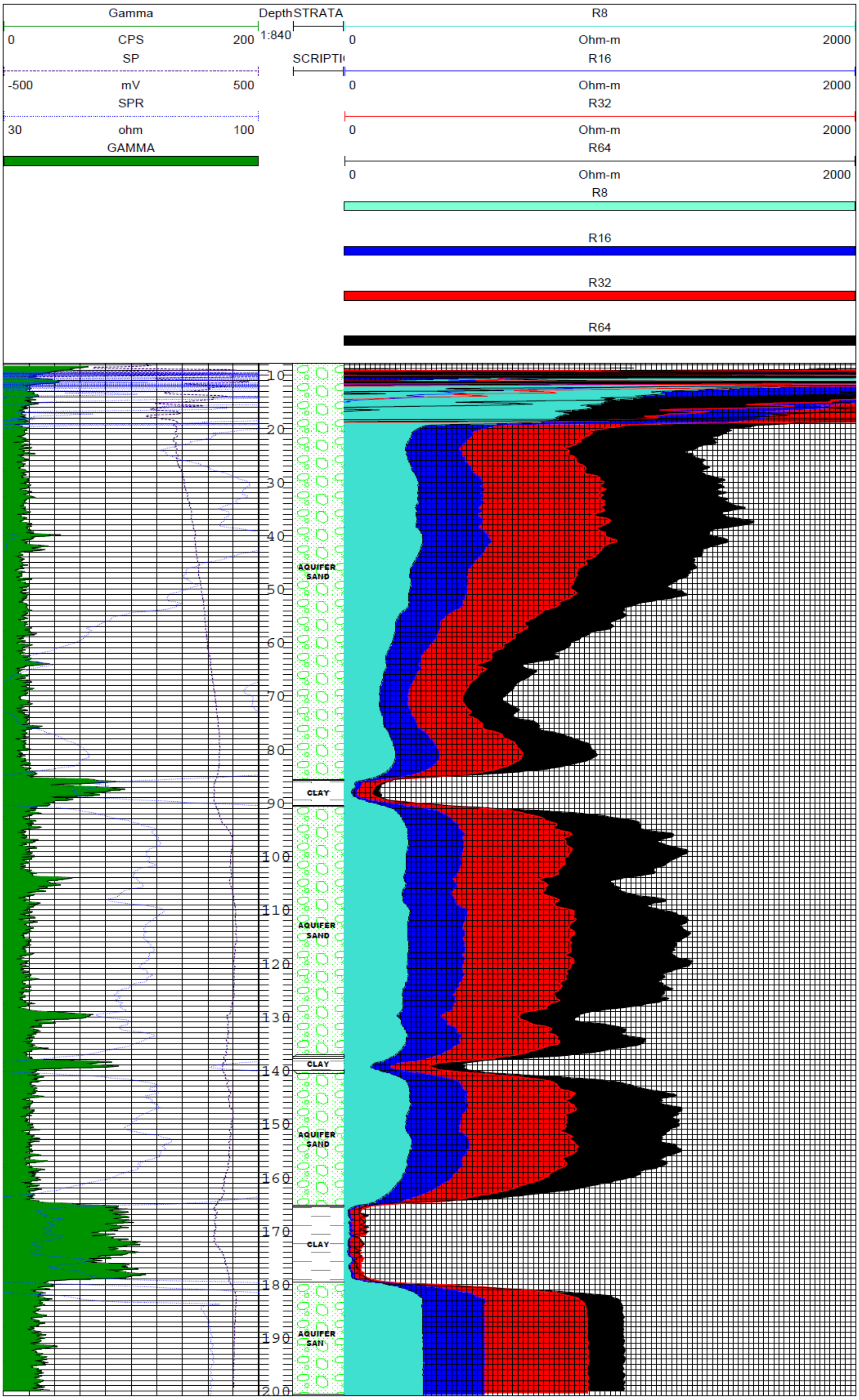

Figure 4.6: NAF Base Port Harcourt Borehole log.

4.3.7 BUA Yard NPA Port Harcourt

A borehole of 225m was drilled at the BUA Yard NPA Port Harcourt. The Open-hole geophysical logging of the borehole isolated five aquifers. The first aquifer is from 14m to 58m with a thickness of 44m and peak resistivity of 186 Ohm-m. The second aquifer was from 114m to 140m with a thickness of 26m and peak resistivity of 267.2 Ohm-m. The third aquifer was from 150m to 172m with a thickness of 22m and a peak resistivity of 252 Ohm-m. The fourth aquifer was from 175m to 200m with a thickness of 25m and a peak resistivity of 242 Ohm-m. The fifth aquifer stretched from 203m to 227m where the log touched the bottom of the well. The fifth aquifer has a thickness of 24m and a peak resistivity of 244 Ohm-m.

The open-hole geophysical log for BUA Yard NPA Port Harcourt is shown in Figure 4.7.

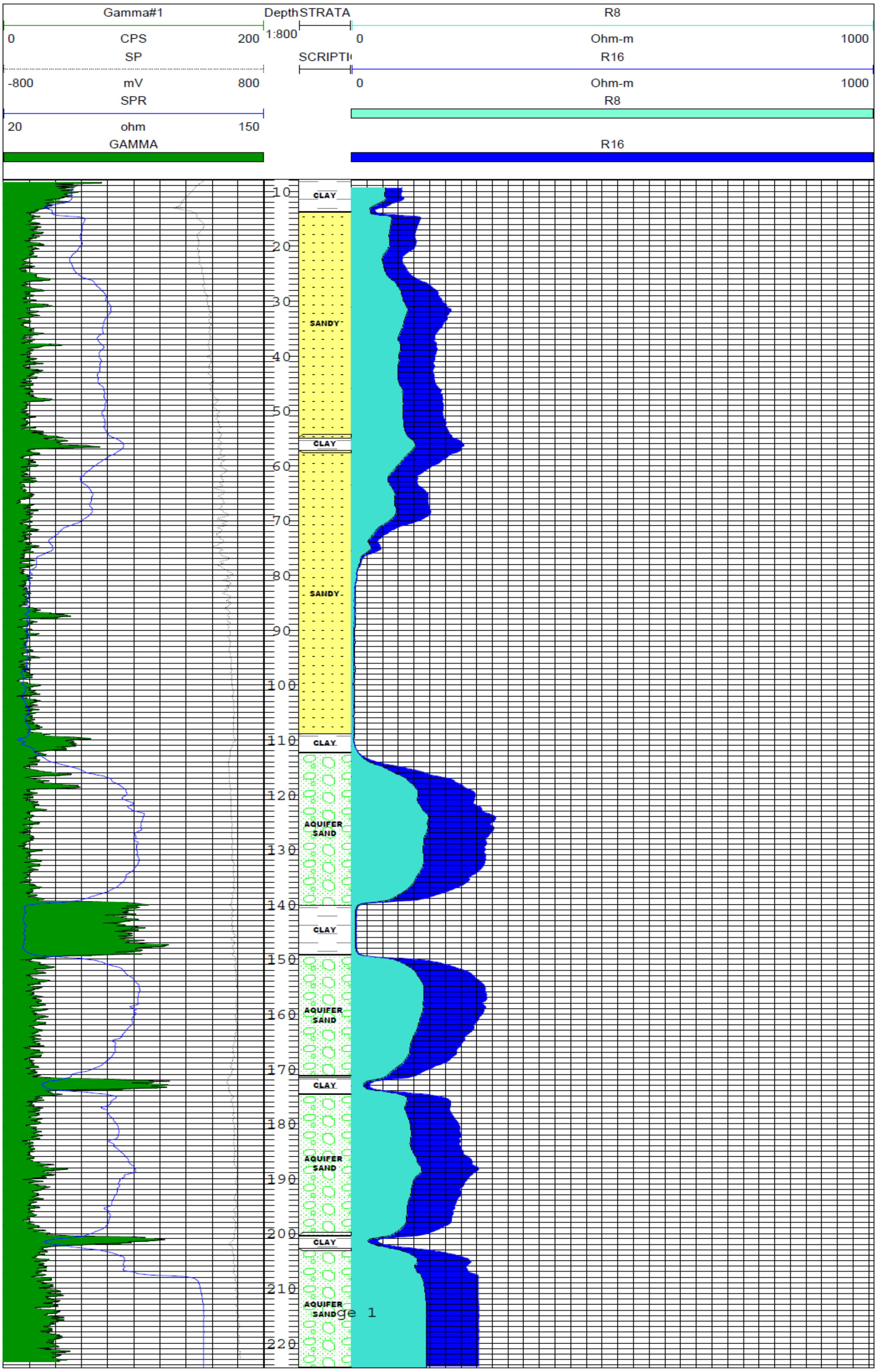

Figure 4.7: BUA Yard NPA Port Harcourt Borehole log.

4.3.8 Port Harcourt Refinery Eleme

A borehole of 214m was drilled at the Port Harcourt Refinery, Eleme, Port Harcourt. The Open-hole geophysical logging of the borehole isolated five aquifers. The first aquifer is from 10m to 41m with a thickness of 31m and peak resistivity of 322.3 Ohm-m. The second aquifer was from 48m to 102m with a thickness of 54m and peak resistivity of 352 Ohm-m. The third aquifer was from 112m to 130m with a thickness of 18m and a peak resistivity of 335 Ohm-m. The fourth aquifer was from 133m to 168m with a thickness of 35m and a peak resistivity of 343.6 Ohm-m. The fifth aquifer stretched from 170m to 195m where the log touched the bottom of the well. The fifth aquifer has a thickness of 25m and a peak resistivity of 405.2 Ohm-m.

The open-hole gamma ray and electric logs for the Port Harcourt Refinery, Port Harcourt is shown in Figure 4.8.

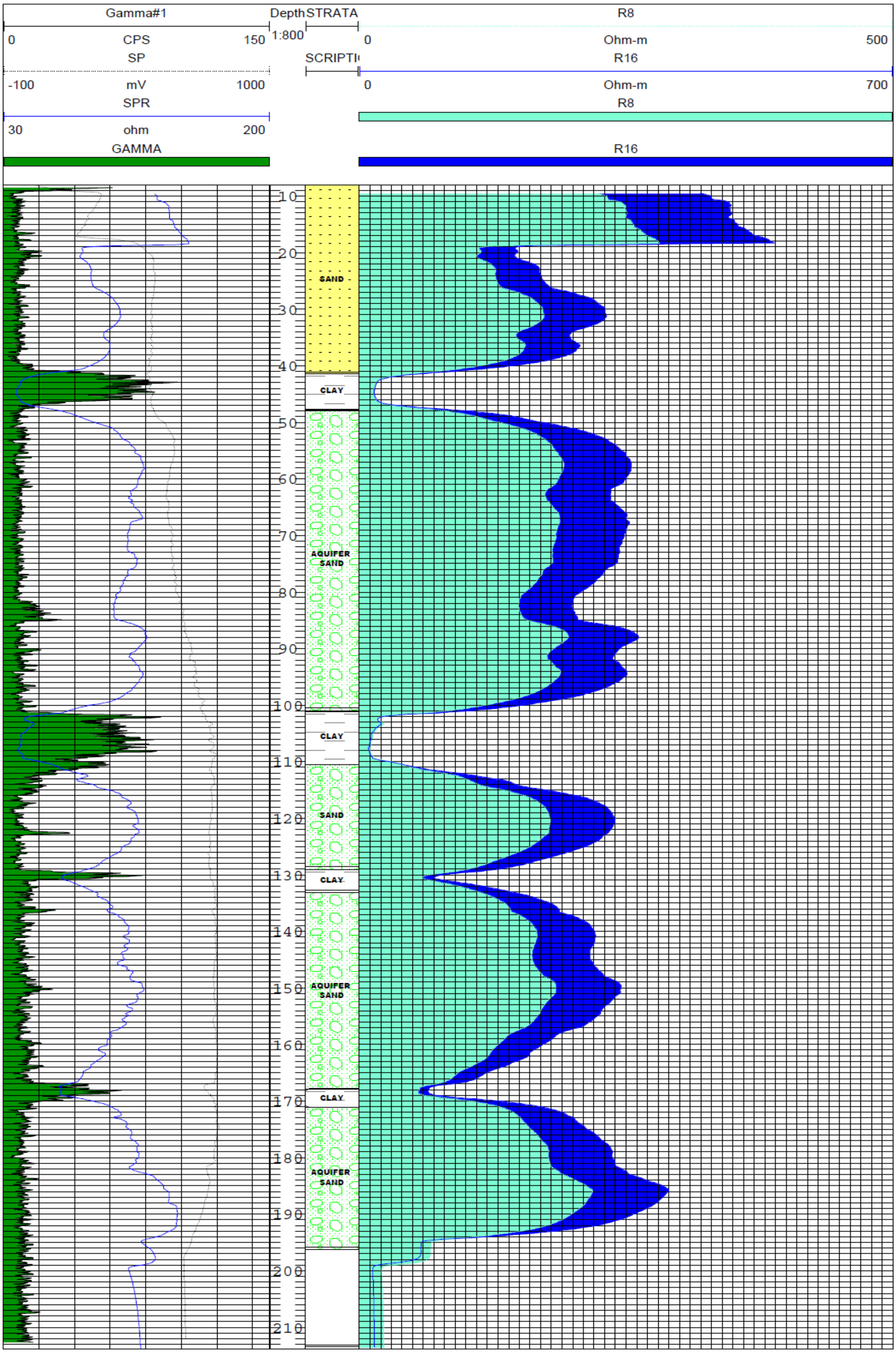

Figure 4.8: Port Harcourt Refinery Borehole log.

4.3.9 Agbada Flow Station

A borehole of 120m was drilled at the Agbada Flow Station, Port Harcourt area. The Open-hole geophysical logging of the borehole isolated two aquifers. The first aquifer is from 10m to 83m with a thickness of 73m and peak resistivity of 1306.7 Ohm-m. The second aquifer was from 90m to 120m with a thickness of 30m and peak resistivity of 1518.6 Ohm-m.The aquifers were well isolated and the resistivity values were very good for potable water.

The open-hole geophysical log for the Agbada flow station, is shown in Figure 4.9.

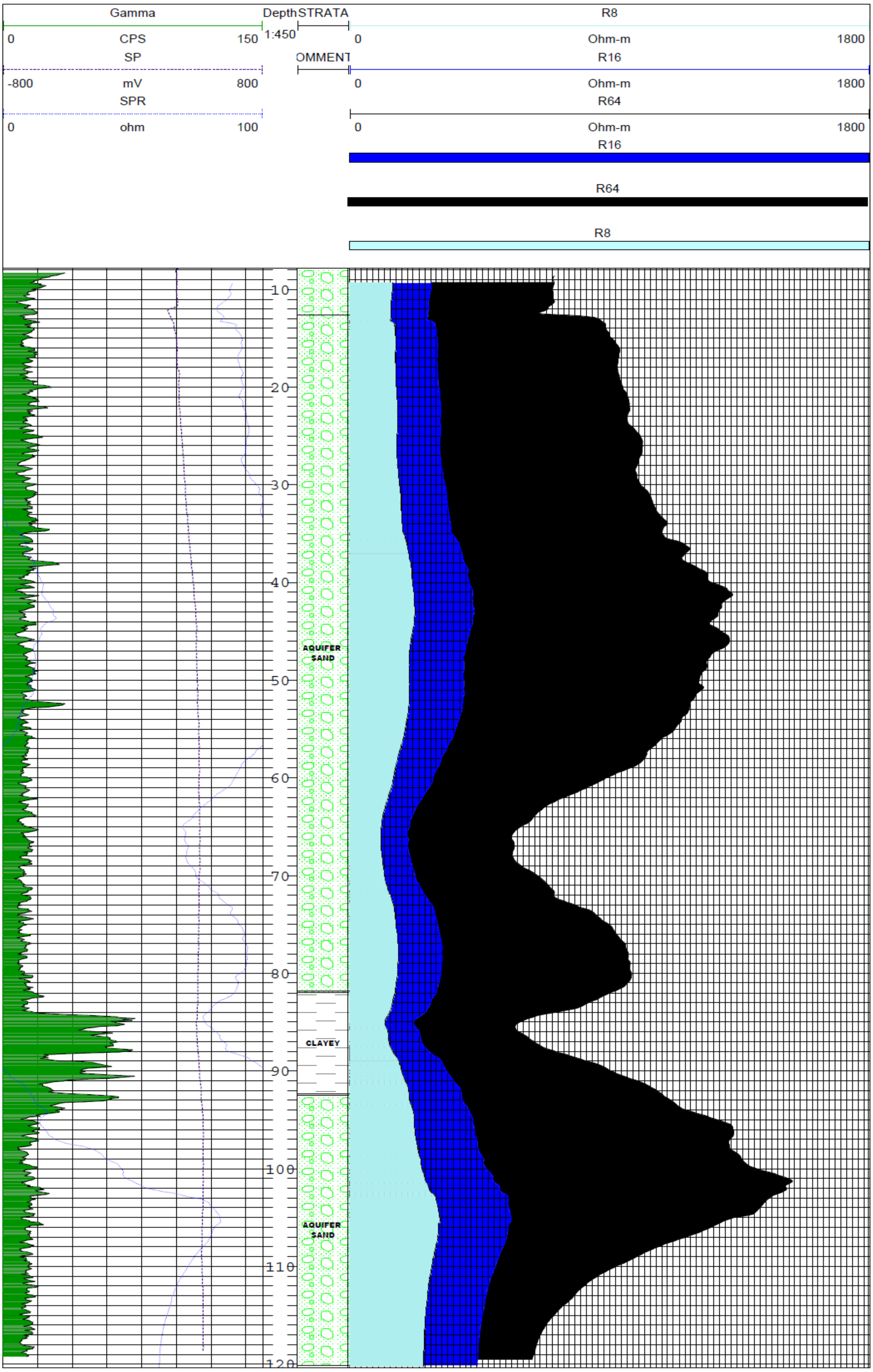

Figure 4.9 Agbada Flow Station Borehole log.

4.3.10 Owaza Gas processing Station Borehole 1

A borehole of 120m was drilled at the Owaza gas processing station, Owaza Asa area of Abia state . The Open-hole geophysical logging of the borehole isolated three aquifers. The first aquifer is from 15m to 33m with a thickness of 18m and peak resistivity of 496 Ohm-m. The second aquifer was from 44m to 103m with a thickness of 59m and peak resistivity of 620 Ohm-m. The third aquifer was from 107m to 120m with a thickness of 13m and a peak resistivity of 616 Ohm-m. The aquifers were well isolated the logs.

The open-hole geophysical log for the Owaza Gas Processing Station borehole 1, is shown in Figure 4.10.

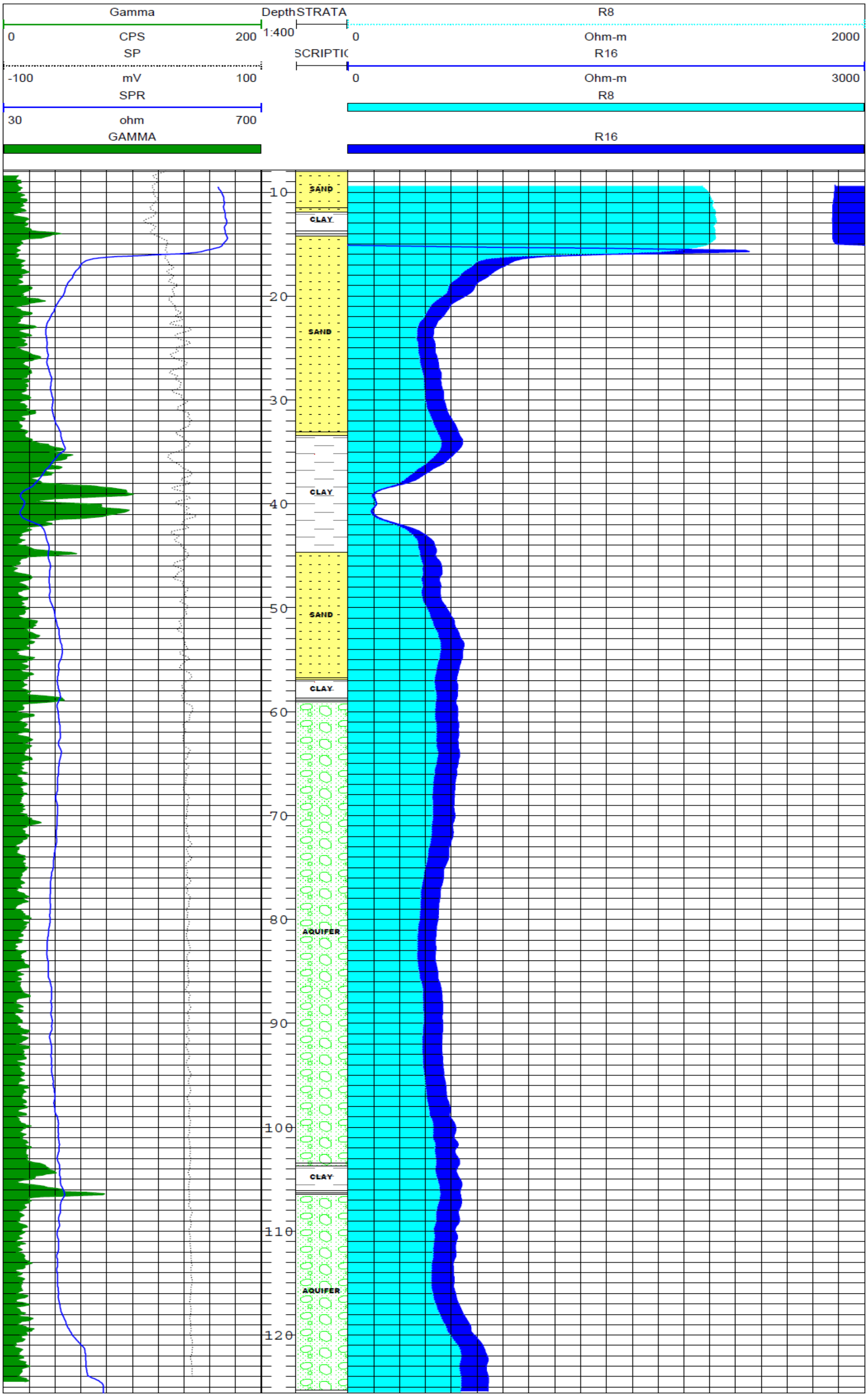

Figure 4.10: Owaza Gas Processing Station Borehole 1

4.3.11 Owaza Gas processing Station Borehole 2

A second borehole of 120m was drilled at the Owaza gas processing station, Owaza Asa area of Abia state . The Open-hole geophysical logging of the borehole isolated five aquifers. The first aquifer is from 10m to 29m with a thickness of 19m and peak resistivity of 270 Ohm-m. The second aquifer was from 32m to 38m with a thickness of 6m and peak resistivity of 314 Ohm-m. The third aquifer was from 46m to 59m with a thickness of 13m and a peak resistivity of 313 Ohm-m. The fourth aquifer was from 61m to 104m with a thickness of 43m and peak resistivity of 310 Ohm-m. The fifth aquifer is from 107m to 120m with a thickness of 13m and a peak resistivity of 324 Ohm-m .The aquifers were well isolated the logs.

The open-hole geophysical log for the Owaza Gas Processing Station borehole 2, is shown in Figure 4.11.

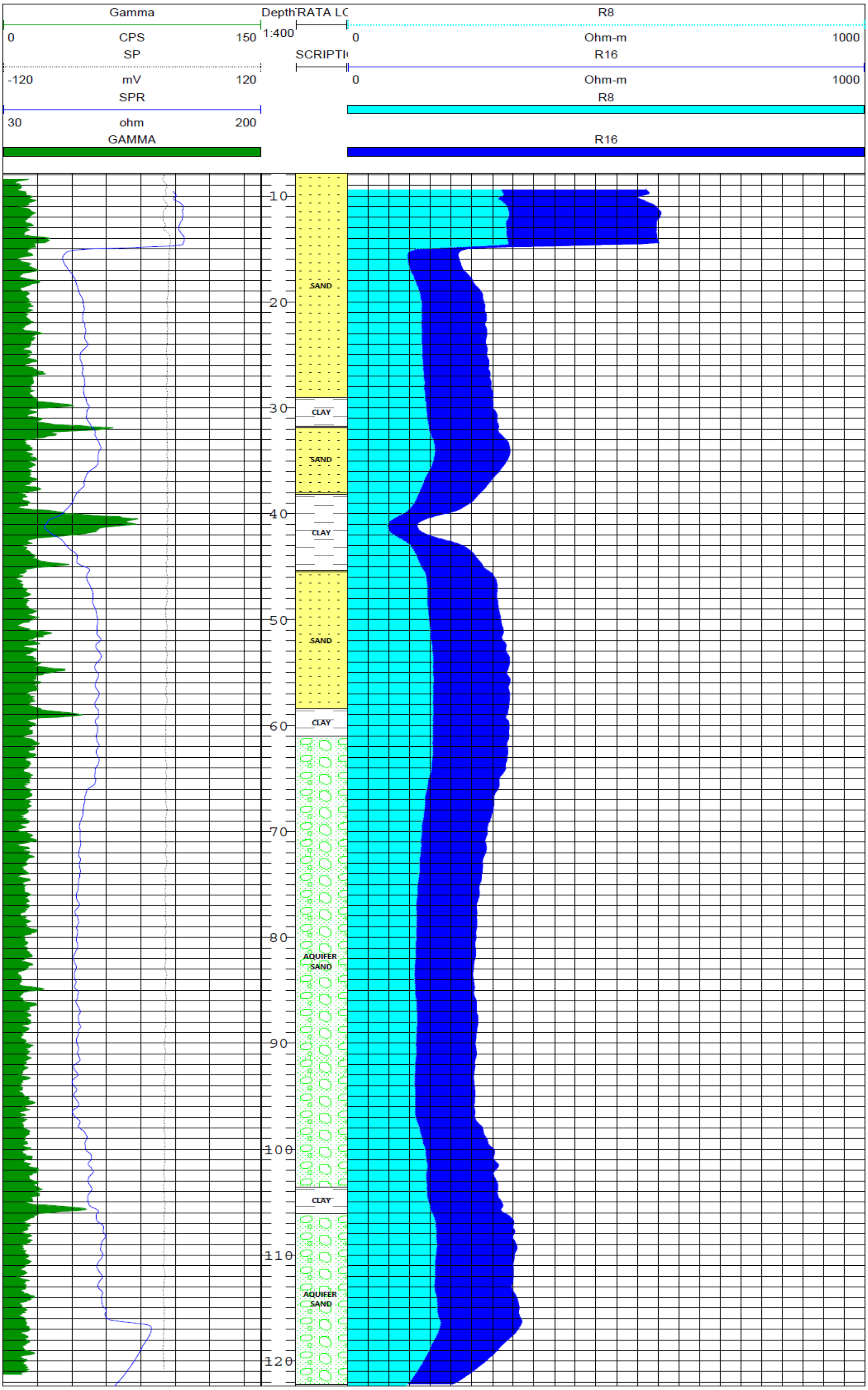

Figure 4.11: Owaza Gas Processing Station Borehole 2

4.3.12 Owaza Gas processing Station Borehole 3

A third borehole of 120m was drilled at the Owaza gas processing station, Owaza Asa area of Abia state. The Open-hole geophysical logging of the borehole isolated five aquifers. The first aquifer is from 10m to 29m with a thickness of 19m and peak resistivity of 612 Ohm-m. The second aquifer was from 31m to 39m with a thickness of 8m and peak resistivity of 722 Ohm-m. The third aquifer was from 46m to 80m with a thickness of 34m and a peak resistivity of 732 Ohm-m. The fourth aquifer was from 85m to 99m with a thickness of 14m and peak resistivity of 694 Ohm-m. The fifth aquifer is from 102m to 120m with a thickness of 18m and a peak resistivity of 747 Ohm-m .The aquifers were well isolated the logs.

The open-hole geophysical log for the Owaza Gas Processing Station borehole 3, is shown in Figure 4.12.

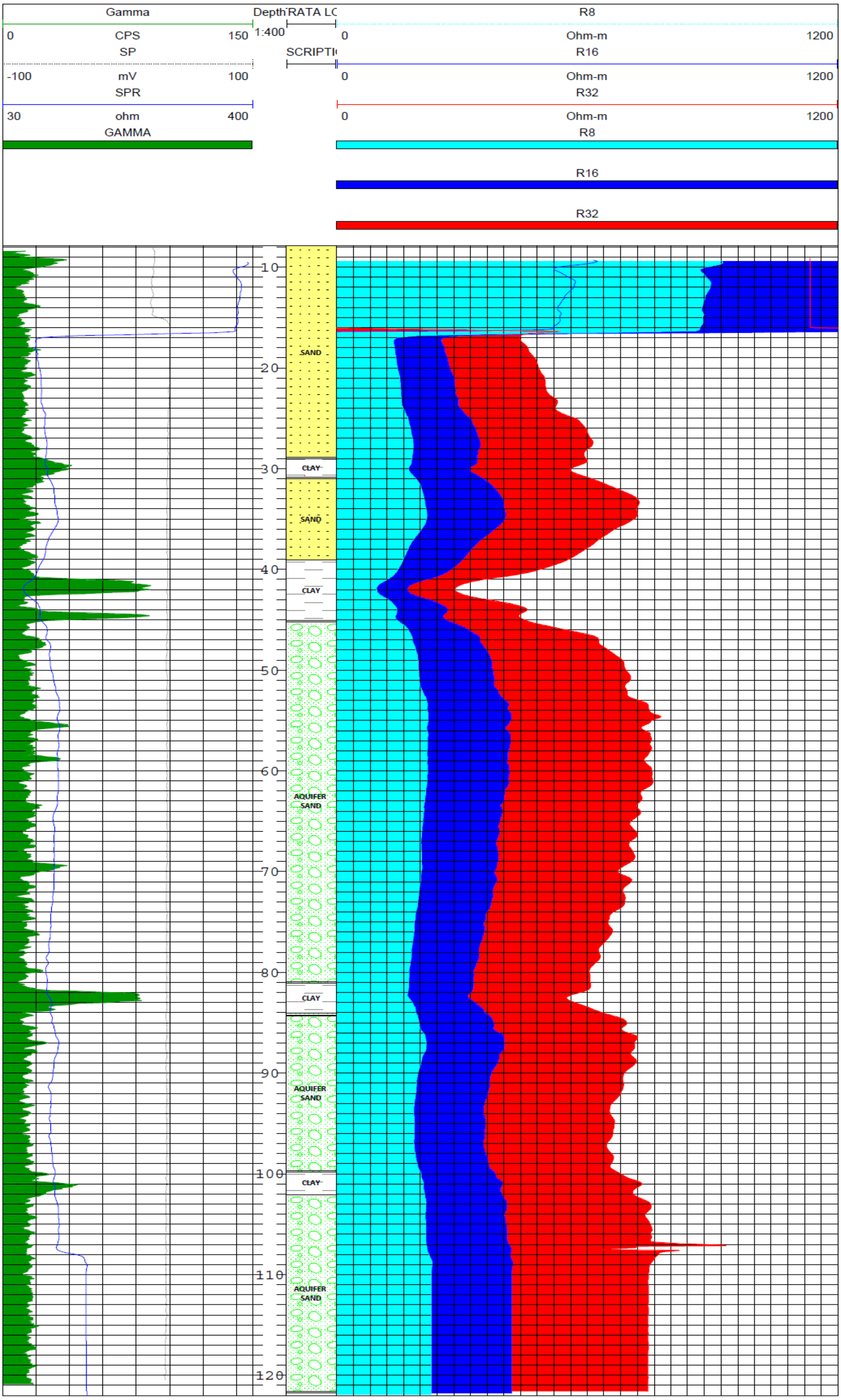

Figure 4.12: Owaza Gas Processing Station Borehole 3

4.3.13 Owaza Gas processing Station Borehole 4

A fourth borehole of 120m was drilled at the Owaza gas processing station, Owaza Asa area of Abia state. The Open-hole geophysical logging of the borehole isolated five aquifers. The first aquifer is from 10m to 29m with a thickness of 19m and peak resistivity of 269 Ohm-m. The second aquifer was from 32m to 38m with a thickness of 6m and peak resistivity of 314 Ohm-m. The third aquifer was from 45m to 58m with a thickness of 13m and a peak resistivity of 299 Ohm-m. The fourth aquifer was from 61m to 103m with a thickness of 42m and peak resistivity of 297 Ohm-m. The fifth aquifer is from 106m to 120m with a thickness of 14m and a peak resistivity of 330 Ohm-m .The aquifers were well isolated the logs.

The open-hole geophysical log for the Owaza Gas Processing Station borehole 4, is shown in Figure 4.13.

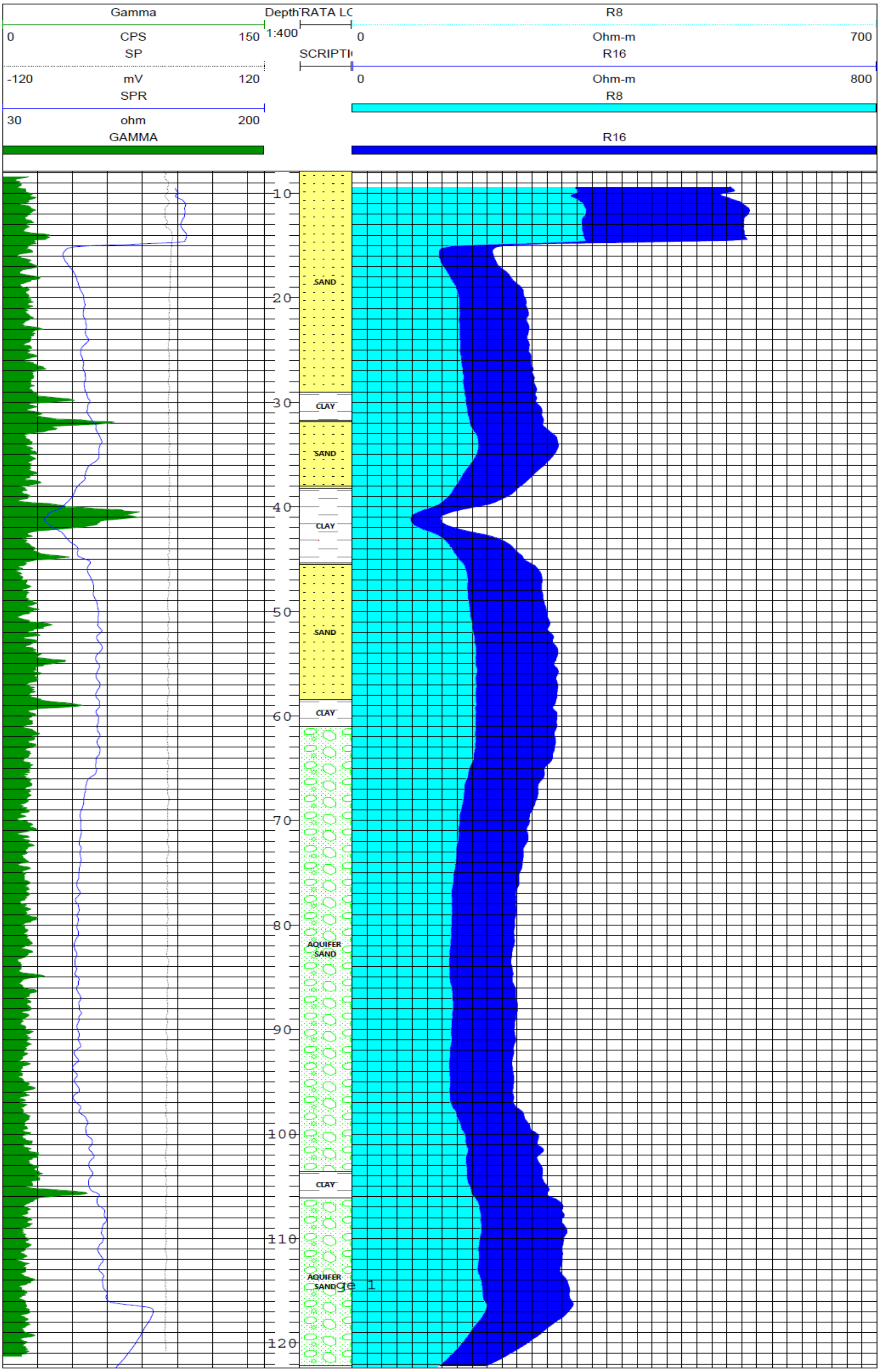

Figure 4.13: Owaza Gas Processing Station Borehole 4

4.3.14 Owaza Gas processing Station Borehole 5

A fifth borehole of 150m was drilled at the Owaza gas processing station, Owaza Asa area of Abia state. The Open-hole geophysical logging of the borehole isolated only one continuous aquifer. The aquifer stretched from 14m to 150m with a thickness of 136m and an average resistivity of 1300 Ohm-m. There were no clay layers in this well.

The open-hole geophysical log for the Owaza Gas Processing Station borehole 5 is shown in Figure 4.14.

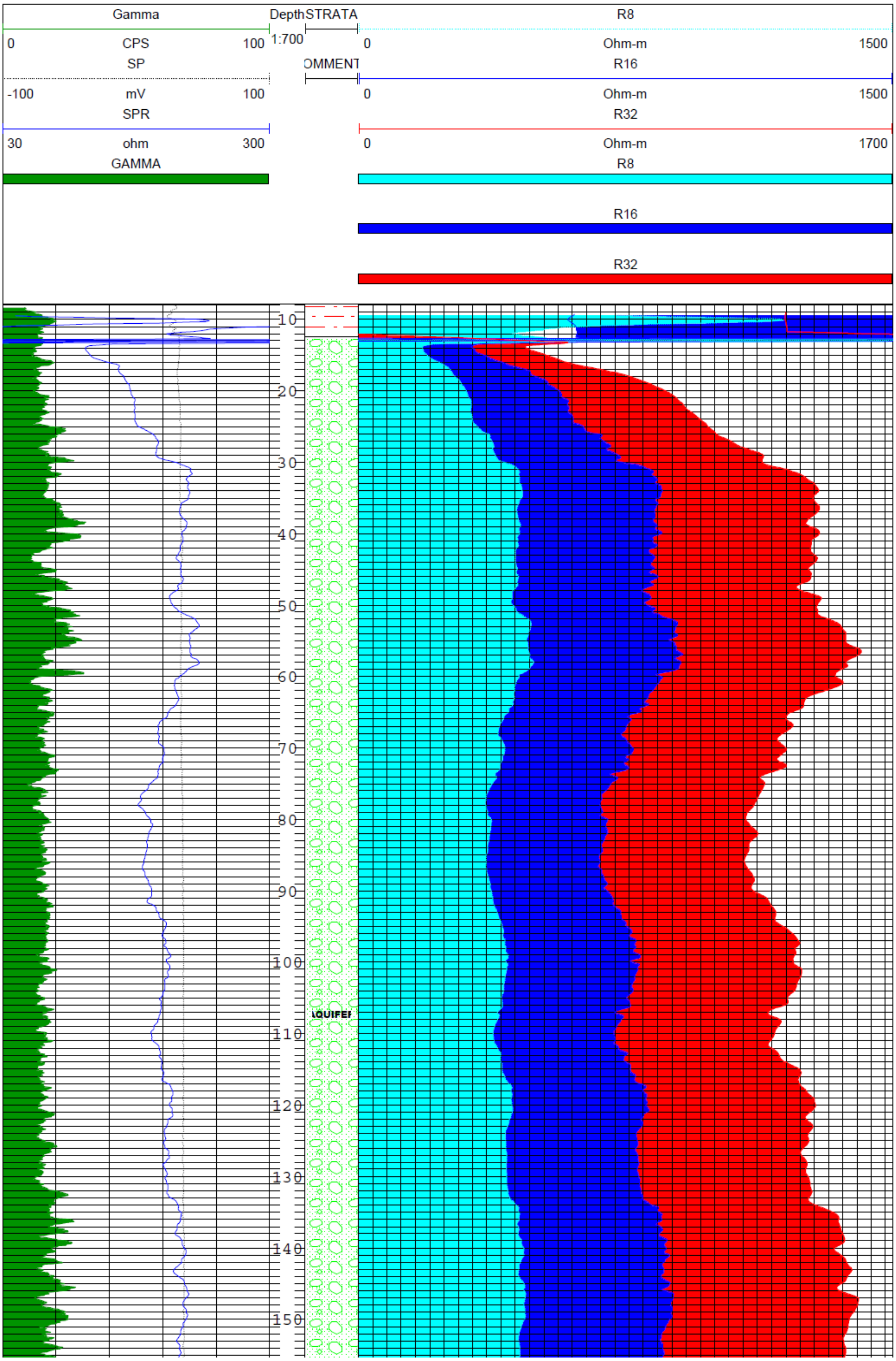

Figure 4.14: Owaza Gas Processing Station Borehole 5

4.3.15 Borehole at Atabrikang Community

A 100m borehole was drilled at Atabrikang in the Eastern Obolo area of Akwa Ibom state, Niger Delta. The Open-hole geophysical logging of the borehole isolated three aquifers. The first aquifer was from 23m to 60m with a thickness of 37m and an average resistivity of 1126 Ohm-m. The second aquifer was from 64m to 71m with a thickness of 7m and an average resistivity of 1522 Ohm-m. The third aquifer was from 75m to 84m with a thickness of 9m and an average resistivity of 1390 Ohm-m.

The open-hole geophysical log for the Atabrikang community borehole is shown in Figure 4.15.

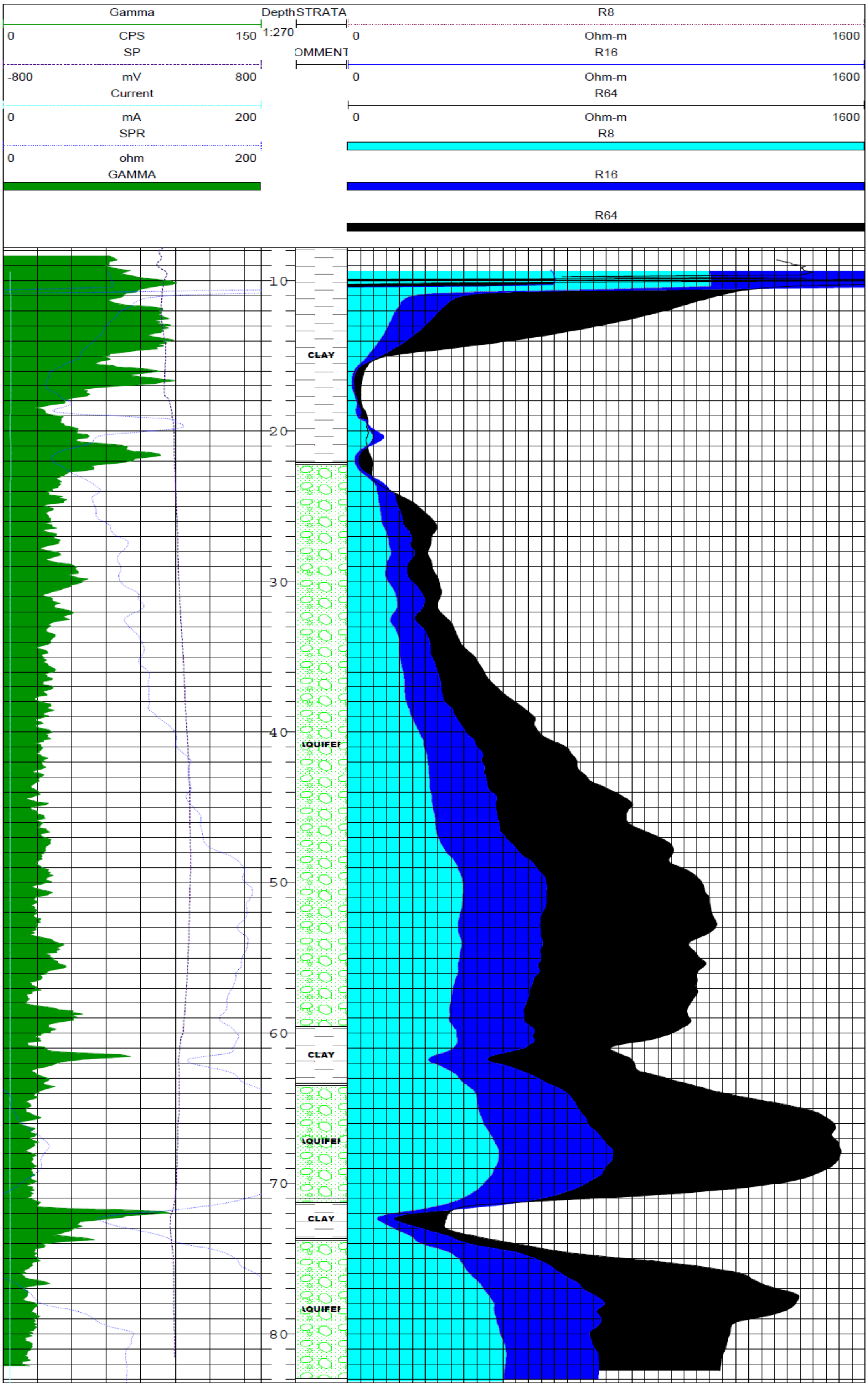

Figure 4.15: Atabrikang Community Borehole

4.3.16 Borehole at Mpanak Community Ibeno

A 250m borehole was drilled at the Mpanak Community Ibeno area of Akwa Ibom state, Niger Delta. The Open-hole geophysical logging of the borehole isolated seven aquifers. The first aquifer was from 9m to 14m with a thickness of 5m and an average resistivity of 230 Ohm-m. The second aquifer was from 18m to 64m with a thickness of 46m and an average resistivity of 296 Ohm-m. The third aquifer was from 75m to 81m with a thickness of 6m and an average resistivity of 238 Ohm-m. The fourth aquifer was from 86m to 108m with a thickness of 22m and an average resistivity of 252 Ohm-m. The fifth aquifer was from 145m to 151 with a thickness of 6m and an average resistivity of 188 Ohm-m. The sixth aquifer was from 156m to 177m with a thickness of 21m and an average resistivity of 152 Ohm-m. The seventh aquifer was from 185m to 220m with a thickness of 35m and an average resistivity of 310 Ohm-m. The aquifers were properly separated with layers of clay.

The open-hole geophysical log for the Mpanak community borehole is shown in Figure 4.16.

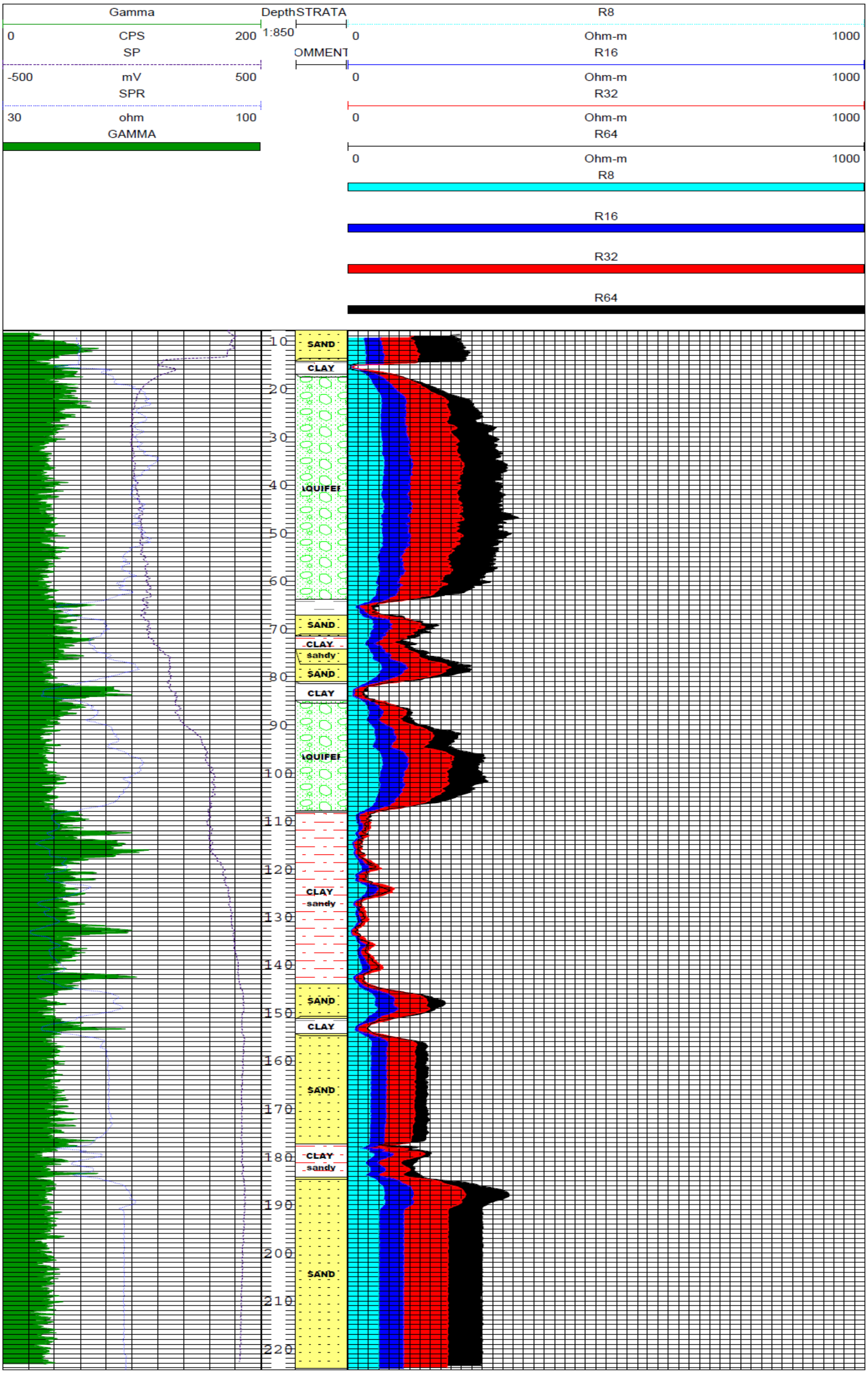

Figure 4.16: Mpanak community Borehole

4.3.17 QIT IBENO Borehole 1

A 150m borehole was drilled at the QIT Ibeno area of Akwa Ibom state, Niger Delta. The Open-hole geophysical logging of the borehole isolated three aquifers. The first aquifer was from 16m to 64m with a thickness of 48m and an average resistivity of 520 Ohm-m. The second aquifer was from 74m to 79m with a thickness of 5m and an average resistivity of 317 Ohm-m. The third aquifer was from 88m to 102m with a thickness of 14m and an average resistivity of 374 Ohm-m.

The aquifers were properly separated with layers of clay.

The open-hole geophysical log for the QIT Ibeno borehole 1 is shown in Figure 4.17.

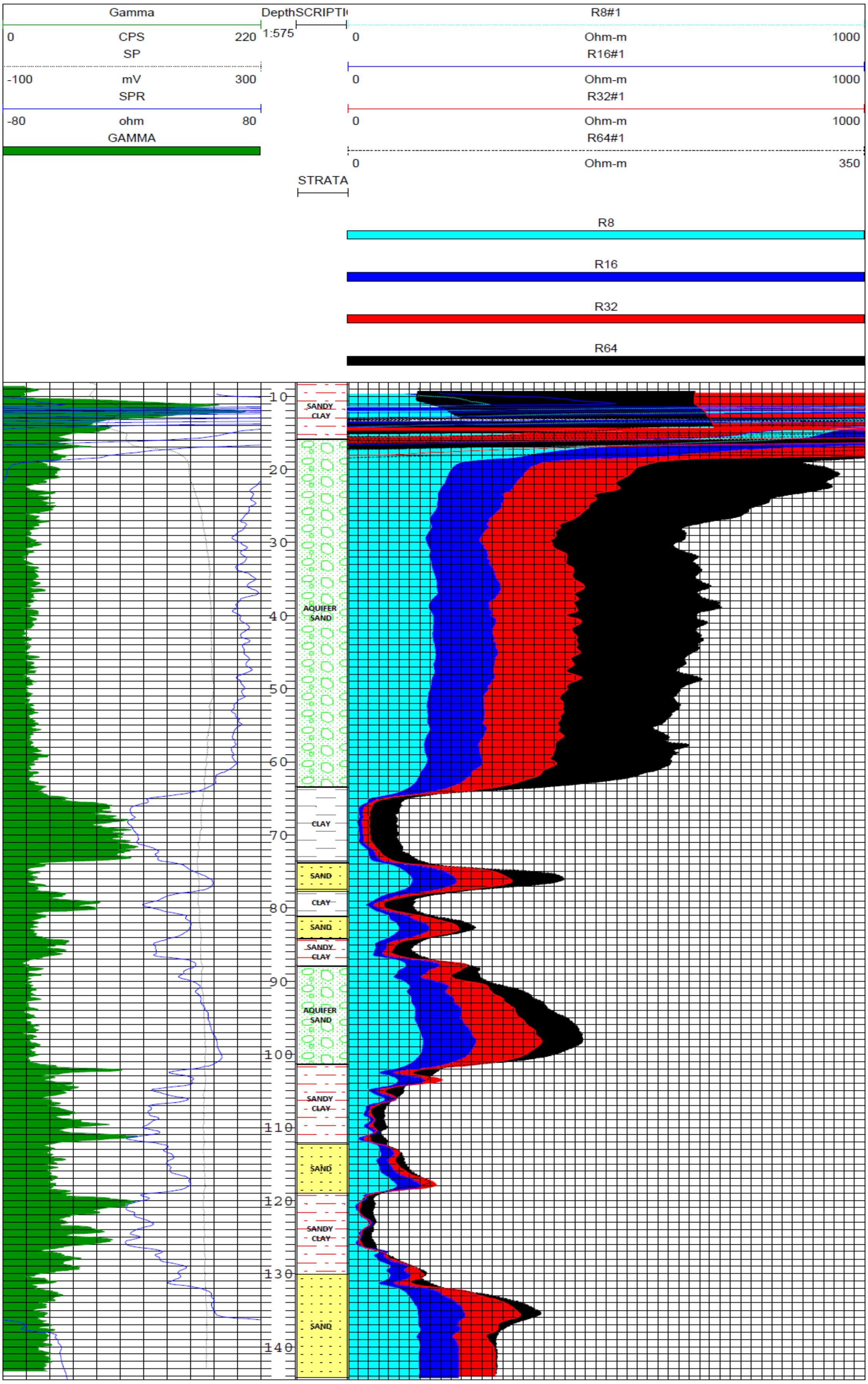

Figure 4.17: QIT Ibeno Borehole 1

4.3.18 QIT IBENO Borehole 2

A second borehole of 190m was drilled at the QIT Ibeno area of Akwa Ibom state, Niger Delta. The Open-hole geophysical logging of the borehole isolated four aquifers. The first aquifer was from 26m to 86m with a thickness of 60m and an average resistivity of 467 Ohm-m. The second aquifer was from 107m to 114m with a thickness of 7m and an average resistivity of 142 Ohm-m. The third aquifer was from 128m to 148m with a thickness of 20m and an average resistivity of 229 Ohm-m. The fourth aquifer was from 166m to 172m with a thickness of 6m and average resistivity of 239 Ohm-m

The aquifers were properly separated with layers of clay.

The open-hole geophysical log for the QIT Ibeno borehole 2 is shown in Figure 4.18.

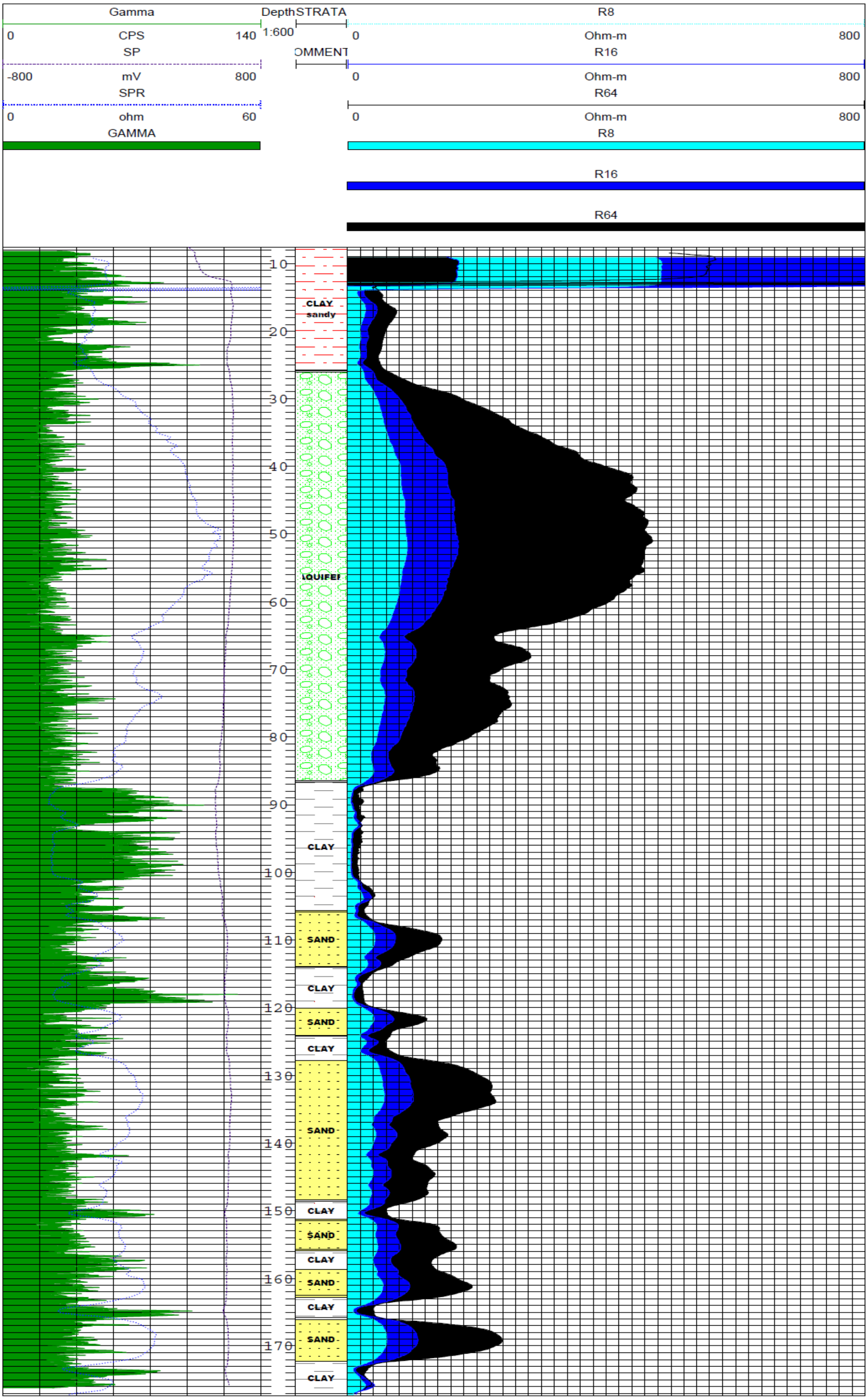

Figure 4.18: QIT Ibeno Borehole 2

4.3.19 QIT IBENO Borehole 3

A third borehole of 190m was drilled at the QIT Ibeno area of Akwa Ibom state, Niger Delta. The Open-hole geophysical logging of the borehole isolated five aquifers. The first aquifer was from 26m to 60m with a thickness of 34m and an average resistivity of 317 Ohm-m. The second aquifer was from 69m to 85m with a thickness of 16m and an average resistivity of 244 Ohm-m. The third aquifer was from 116m to 124m with a thickness of 8m and an average resistivity of 137 Ohm-m. The fourth aquifer was from 130m to 147m with a thickness of 17m and average resistivity of 160 Ohm-m. The fifth aquifer was from 165m to 171m with a thickness of 6m and an average resistivity of 192 Ohm-m

The aquifers were properly separated with layers of clay.

The open-hole geophysical log for the QIT Ibeno borehole 3 is shown in Figure 4.19.

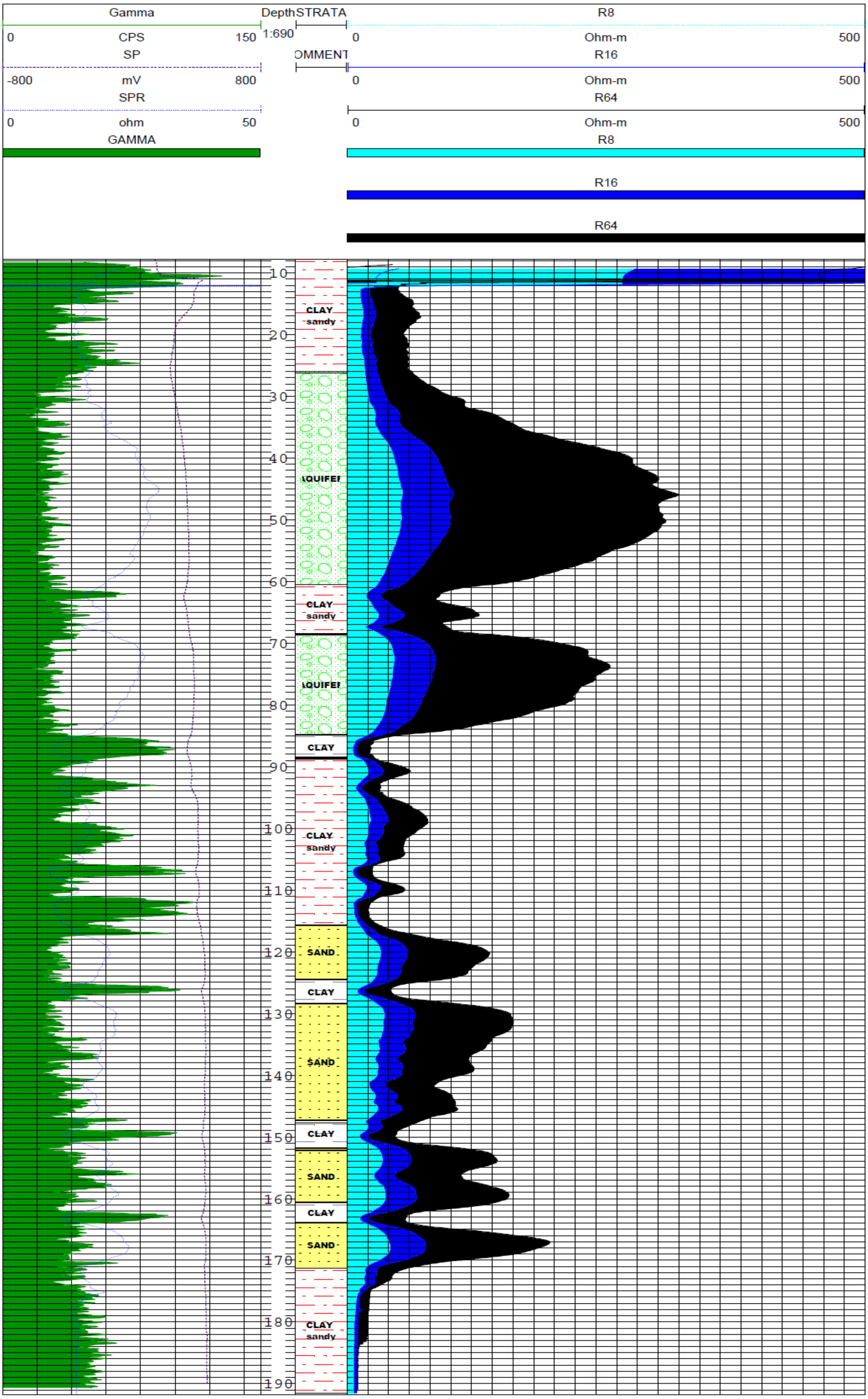

Figure 4.19: QIT Ibeno Borehole 3

4.3.20 QIPP IBENO Borehole 1

A borehole of 250m was drilled at the QIPP site, Ibeno area of Akwa Ibom state, Niger Delta. The Open-hole geophysical logging of the borehole isolated six aquifers. The first aquifer was from 25m to 62m with a thickness of 37m and an average resistivity of 434 Ohm-m. The second aquifer was from 68m to 80m with a thickness of 12m and an average resistivity of 248 Ohm-m. The third aquifer was from 110m to 116m with a thickness of 6m and an average resistivity of 94 Ohm-m. The fourth aquifer was from 129m to 139m with a thickness of 10m and average resistivity of 115 Ohm-m. The fifth aquifer was from 146m to 170m with a thickness of 24m and an average resistivity of 210 Ohm-m. The sixth aquifer is from 184m to 250m with a thickness of 66m and an average resistivity of 570 Ohm-m

The aquifers were properly separated with layers of clay.

The open-hole geophysical log for the QIPP Ibeno borehole 1 is shown in Figure 4.20.

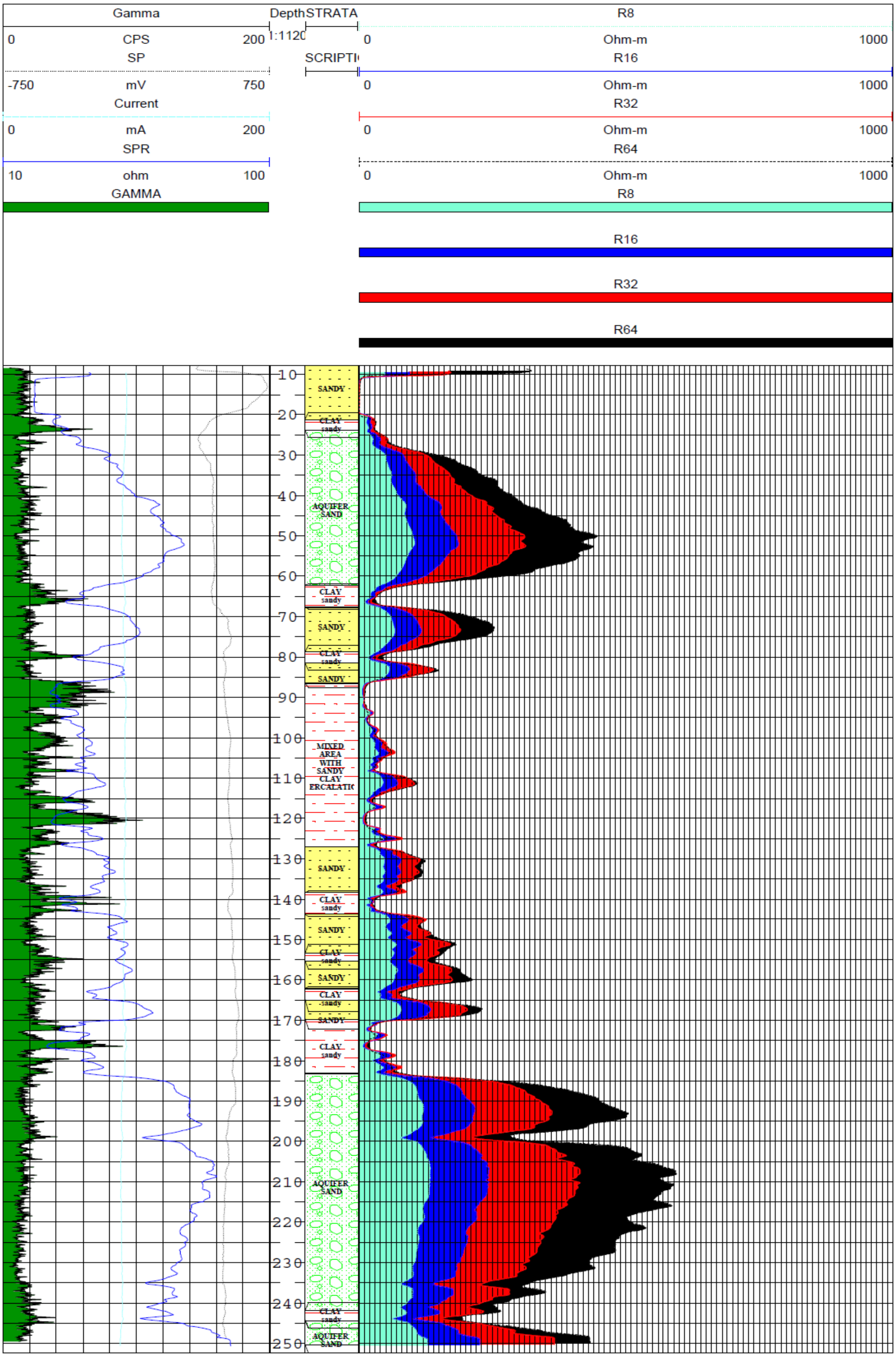

Figure 4.20: QIPP Ibeno Borehole 1

4.3.21 QIPP IBENO Borehole 2

A second borehole of 250m was drilled at the QIPP site, Ibeno area of Akwa Ibom state, Niger Delta. The Open-hole geophysical logging of the borehole isolated six aquifers. The first aquifer was from 23m to 61m with a thickness of 38m and an average resistivity of 166 Ohm-m. The second aquifer was from 66m to 79m with a thickness of 13m and an average resistivity of 109 Ohm-m. The third aquifer was from 111m to 116m with a thickness of 5m and an average resistivity of 106 Ohm-m. The fourth aquifer was from 132m to 140m with a thickness of 8m and average resistivity of 147 Ohm-m. The fifth aquifer was from 151m to 170m with a thickness of 19m and an average resistivity of 167 Ohm-m. The sixth aquifer is from 181m to 250m with a thickness of 69m and an average resistivity of 338 Ohm-m

The aquifers were properly separated with layers of clay.

The open-hole geophysical log for the QIPP Ibeno borehole 2 is shown in Figure 4.21.

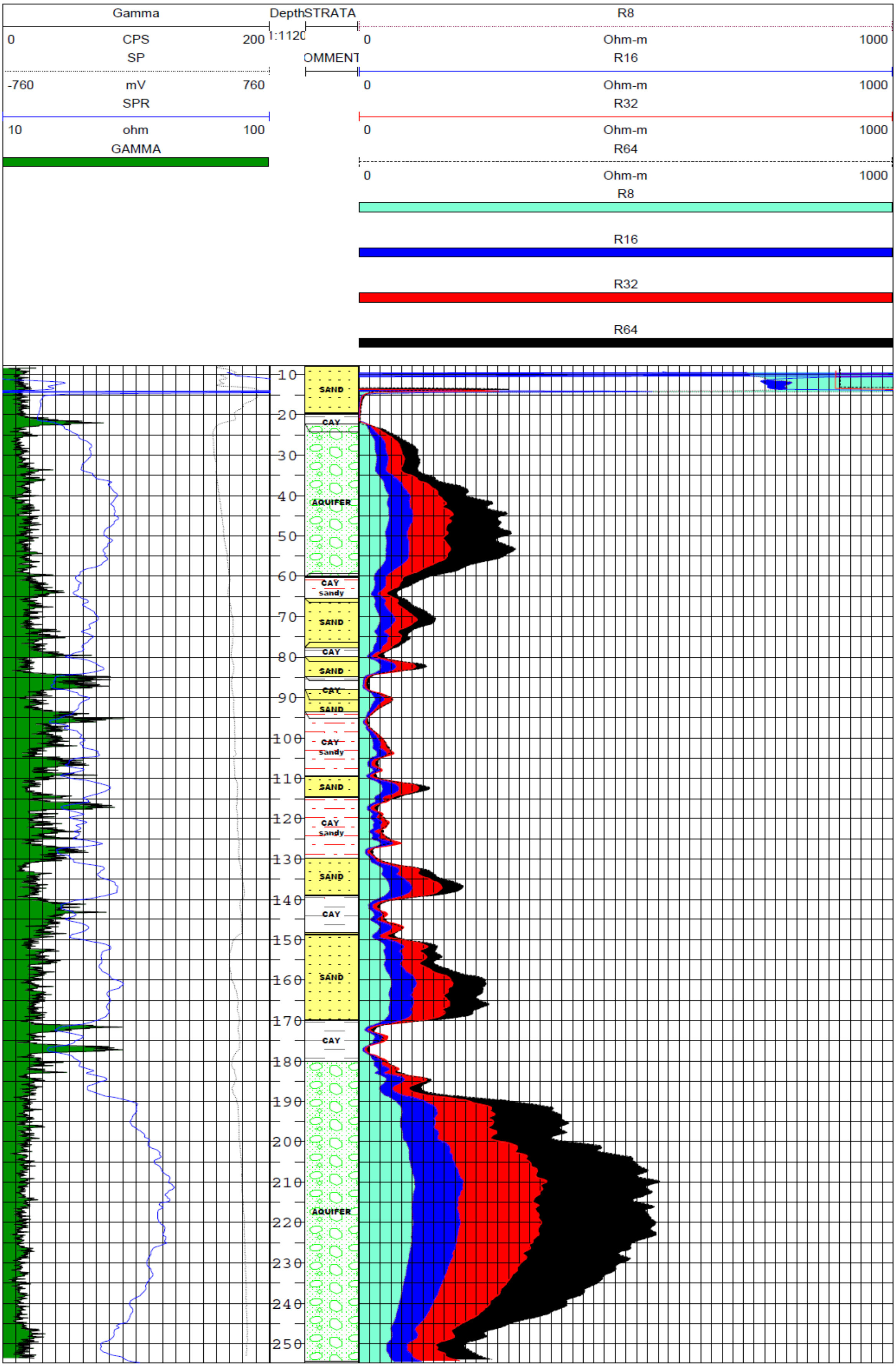

Figure 4.21: QIPP Ibeno Borehole 2

4.4 Aquifers in the Sombreiro –Warri - Deltaic Plain

Several boreholes were drilled and gamma ray and electric logs carried out in the Sombreiro – Warri- Deltaic pain depositional environment of the Niger Delta Southern Nigeria. The wells covered several areas in this depositional environment.. The different locations are discussed below.

4.4.1 Borehole at Ndoni Rivers

A borehole of 310m was drilled at Ndoni Rivers state and this well encountered only one continuous stretch of aquifer from 10m to 310m. The average resistivity for this area is 331 Ohm-m.

The open-hole geophysical log for the Ndoni borehole is shown in Figure 4.22.

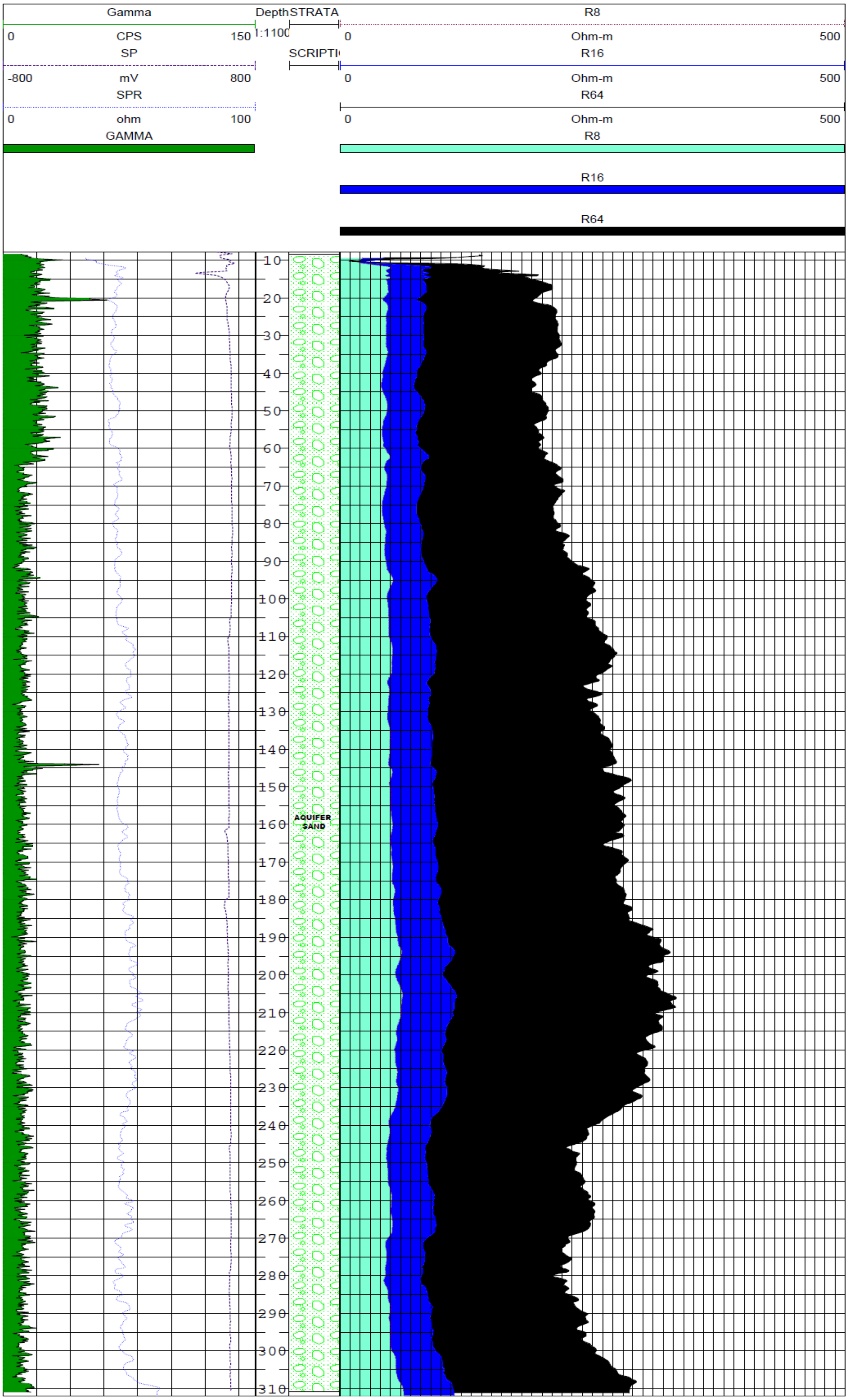

Figure 4.22: Ndoni Borehole log

4.4.2 Borehole at Warri Refinery

A borehole of 110m was drilled at Warri Refinery Delta state in the Sombreiro – Warri – Deltaic plain sands and this well encountered three aquifers. The first aquifer was from 10m to 20m with a thickness of 10m and an average resistivity of 220 Ohm-m. The second aquifer was from 31m to 50m with a thickness of 19m and an average resistivity of 354 Ohm-m. The third aquifer is from 54m to 110m with a thickness of 56m and an average resistivity of 748 Ohm-m. The aquifers were separated by layers of clay.

The open-hole geophysical log for the Warri Refinery borehole is shown in Figure 4.23.

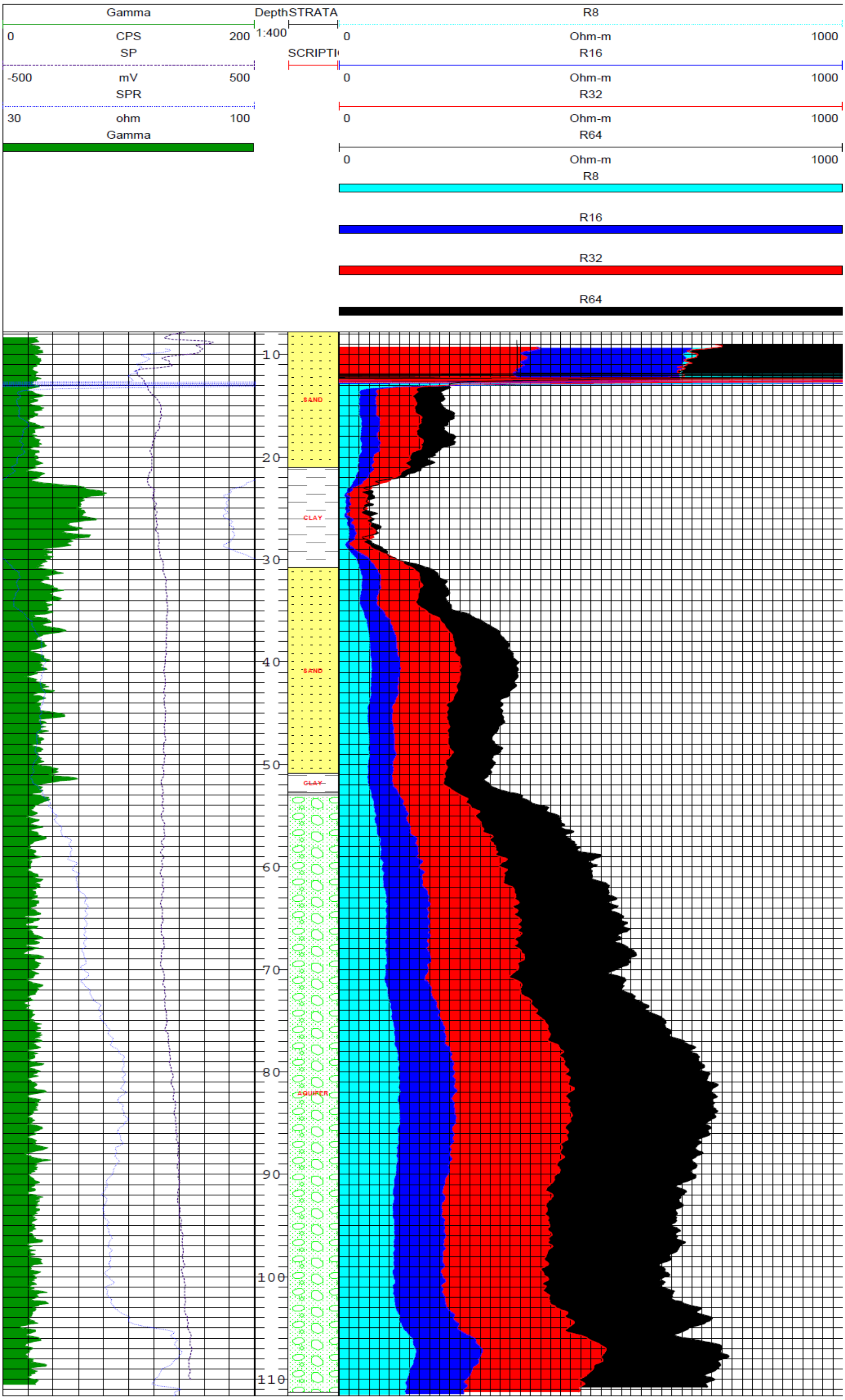

Figure 4.23: Warri Refinery Borehole log

4.4.3 Borehole at Shell Main Office Edjeba Warri

A borehole of 100m was drilled at Shell main office, Edjeba Warri, Delta State in the Sombreiro – Warri – Deltaic plain sands. The gamma ray and electric logs of this well isolated two aquifer zones. The first aquifer was from 29m to 42m with a thickness of 13m and an average resistivity of 359 Ohm-m. The second aquifer was from 70m to 97m with a thickness of 27m and an average resistivity of 735 Ohm-m.

The aquifers were separated by layers of clay.

The open-hole geophysical log for the Shell main office Edjeba borehole is shown in Figure 4.24.

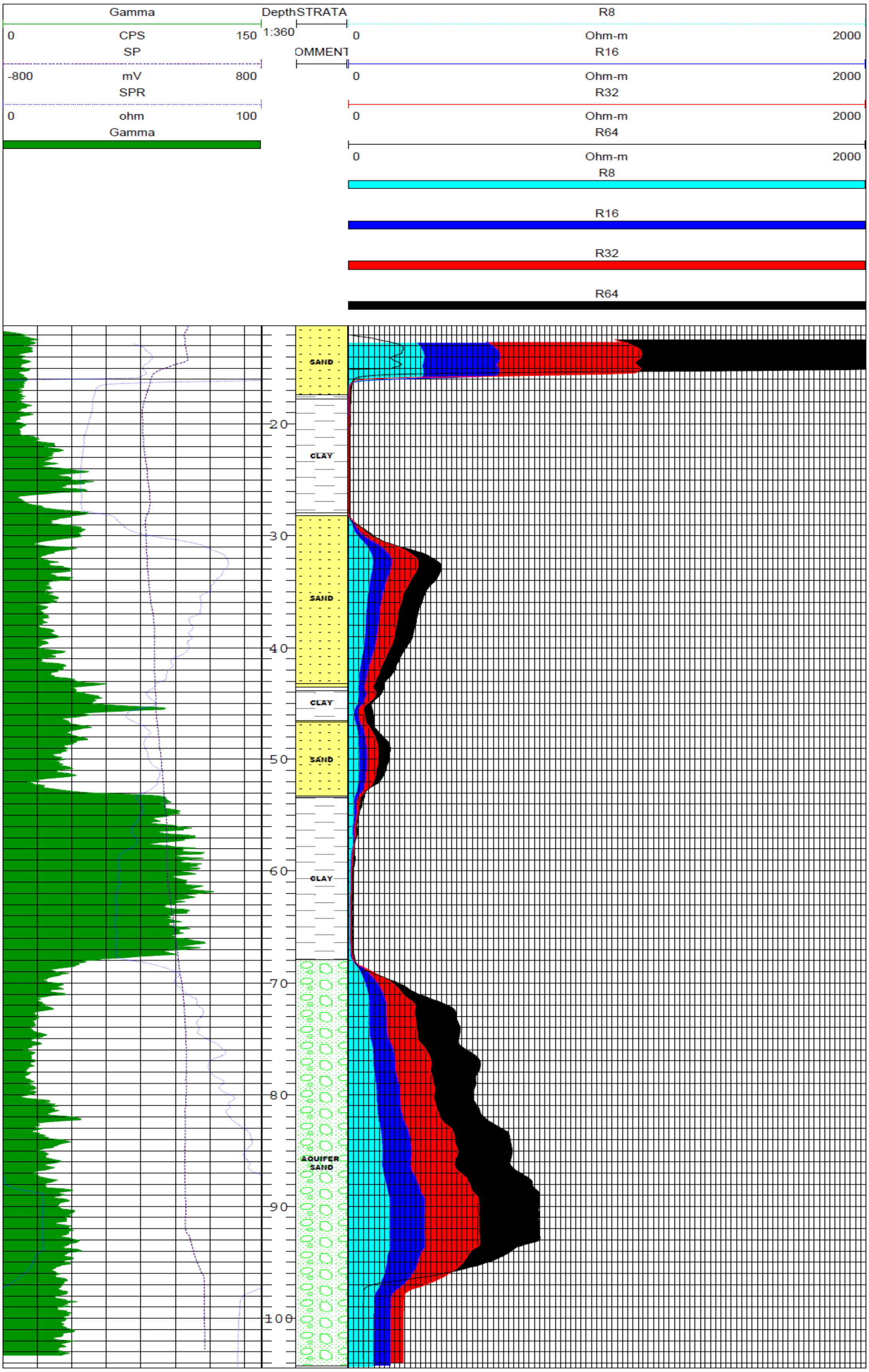

Figure 4.24: Shell Main office Edjeba, Warri Borehole log

4.4.4 Borehole at NPA Warri

A borehole of 220m was drilled at Nigeria Ports Authority (NPA) premises Warri, Delta State in the Sombreiro – Warri – Deltaic plain sands. The gamma ray and electric logs of this well isolated four aquifer zones. The first aquifer was from 16m to 39m with a thickness of 23m and an average resistivity of 212 Ohm-m. The second aquifer was from 45m to 61m with a thickness of 16m and an average resistivity of 56 Ohm-m. A third aquifer was from 70m to 86m with a thickness of 16m and an average resistivity of 48 Ohm-m. The fourth aquifer was from 130m to 220m with a thickness of 90m and average resistivity of 38 Ohm-m

The aquifers were separated by layers of clay.

The open-hole geophysical log for the NPA Warri borehole is shown in Figure 4.25.

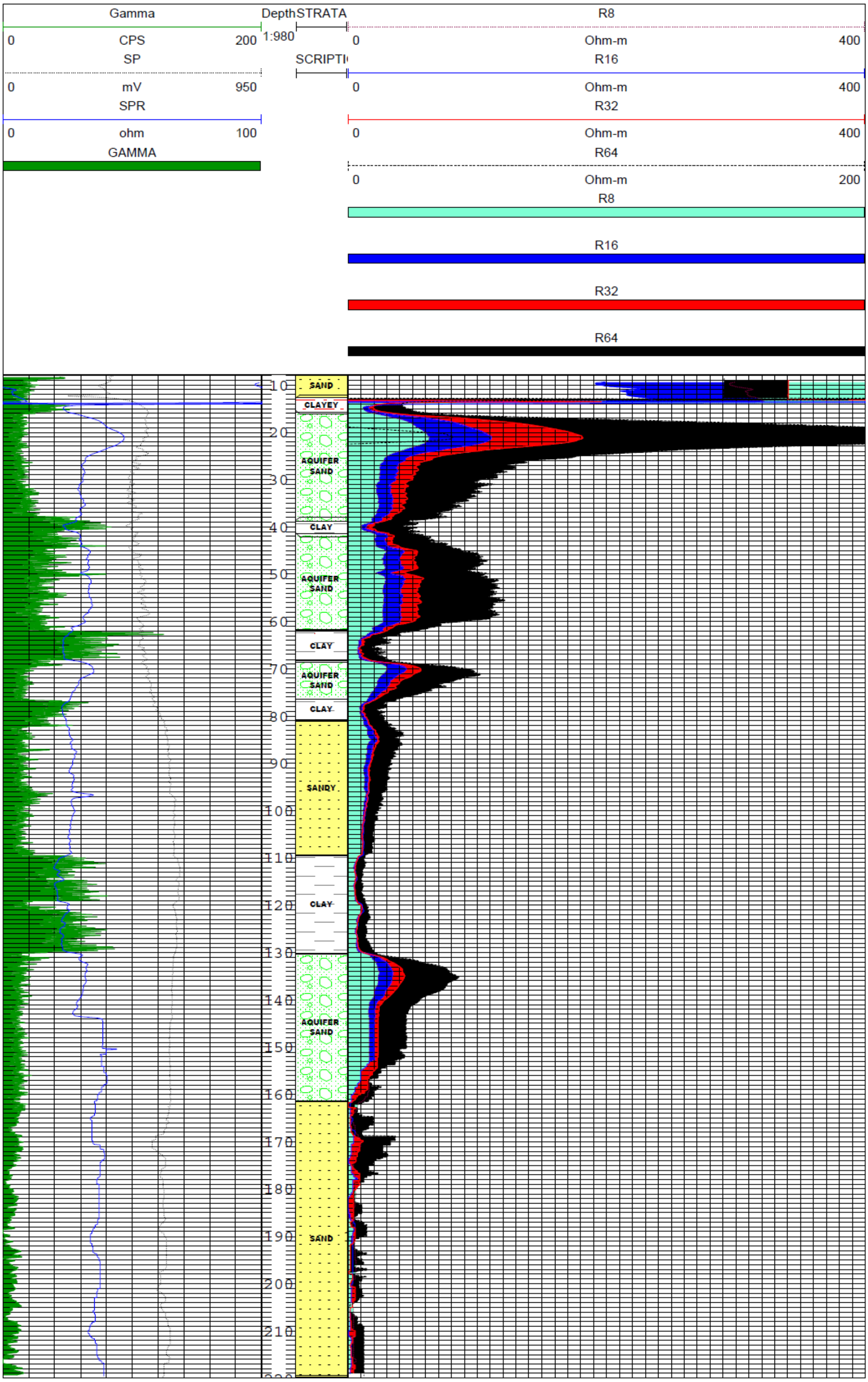

Figure 4.25: NPA Warri Borehole log

4.5 Aquifers in the Fresh water swamps

Several boreholes were drilled and gamma ray and electric logs carried out in the Fresh Water Swamps depositional environment of the Niger Delta Southern Nigeria. The wells covered several areas in this depositional environment. The logs from the different locations are discussed below.

4.5.1 Borehole at Kwale

A borehole of 100m was drilled at Kwale for Agip, Delta State in the fresh water swamps of the Coastal areas of Niger Delta. The gamma ray and electric logs of this well isolated two aquifer zones. The first aquifer was from 10m to 46m with a thickness of 36m and an average resistivity of 317 Ohm-m. The second aquifer was from 54m to 100m with a thickness of 46m and an average resistivity of 210 Ohm-m.

The aquifers were separated by layers of clay.

The open-hole geophysical log for the Kwale borehole is shown in Figure 4.26.

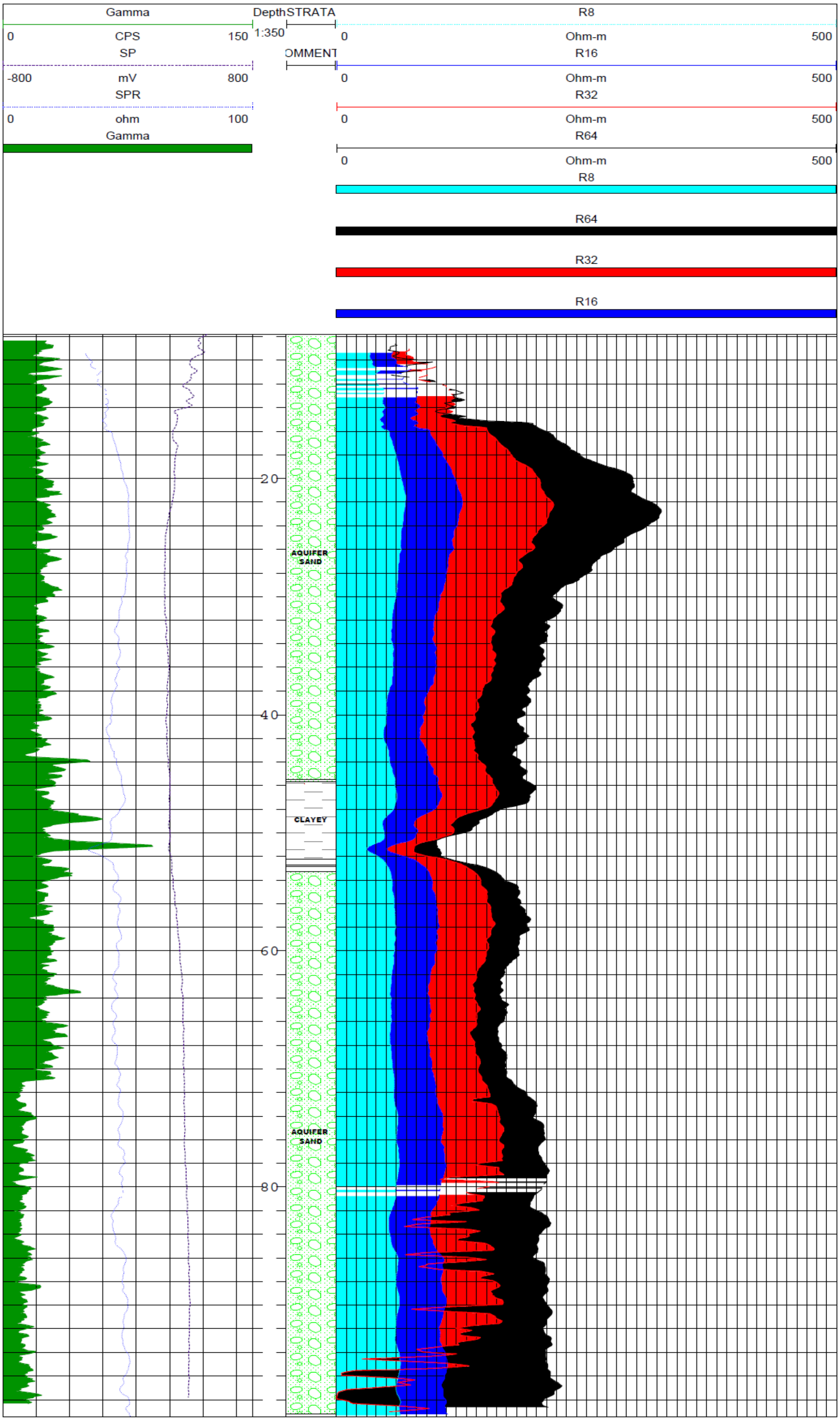

Figure 4.26: Kwale Borehole log

4.5.2 Borehole at Otorogu flow station

A borehole of 100m was drilled at the Otorogu flow station, Delta State in the fresh water swamps of the Coastal areas of Niger Delta. The gamma ray and electric logs of this well isolated three aquifer zones. The first aquifer was from 10m to 21m with a thickness of 11m and an average resistivity of 639 Ohm-m. The second aquifer was from 25m to 44m with a thickness of 19m and an average resistivity of 1000 Ohm-m. The third aquifer was from 50m to 92m with a thickness of 42m and an average resistivity of 900 Ohm-m

The aquifers were separated by layers of clay.

The open-hole geophysical log for the Otorogu flow station borehole is shown in Figure 4.27.

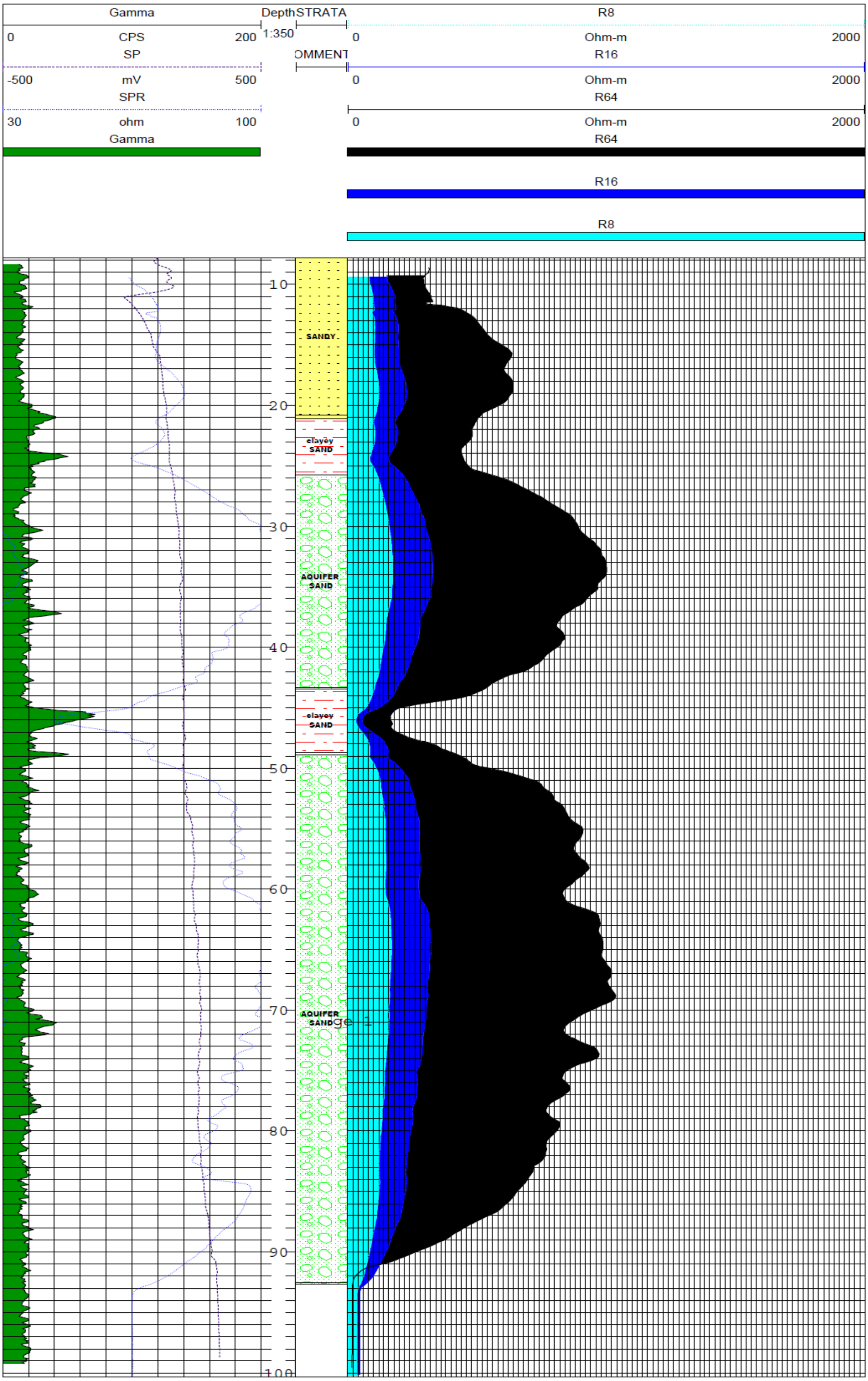

Figure 4.27: Otorogu Flow station Borehole log

4.5.3 Borehole at Utorogu Gas plant

A borehole of 95m was drilled at the Utorogu gas plant, Delta State in the fresh water swamps of the Coastal areas of Niger Delta. The gamma ray and electric logs of this well isolated one major aquifer zone.The aquifer stretched from 50m to 94m with a thickness of 44m and an average resistivity of 1250 Ohm-m.The aquifer was sealed by an upper clay layer.

The open-hole geophysical log for the Utorogu Gas plant borehole is shown in Figure 4.28.

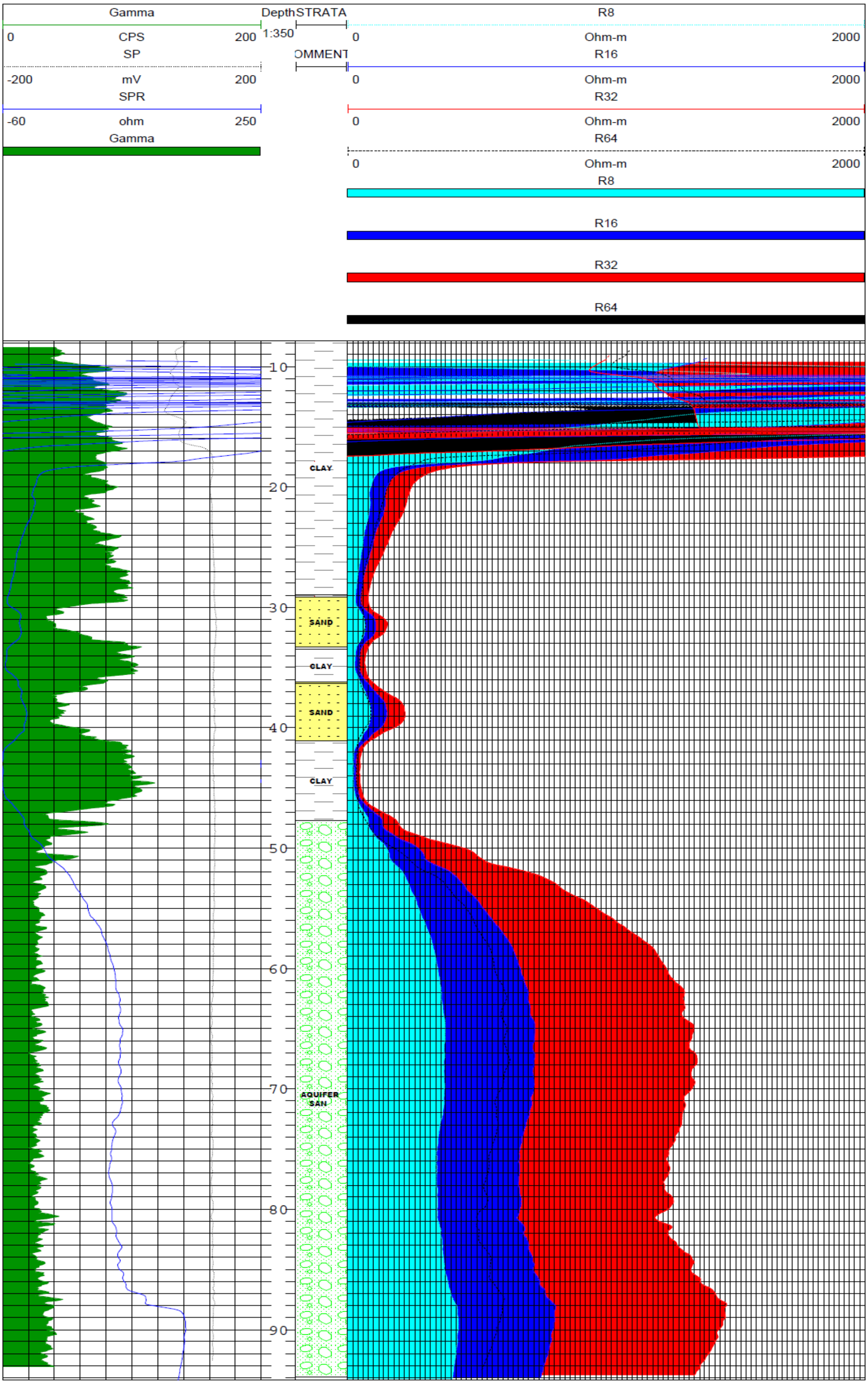

Figure 4.28: Utorogu Gas plant Borehole log

4.5.4 Borehole at Ojobo

A borehole of 90m was drilled at Ojobo, Delta State in the fresh water swamps of the Coastal areas of Niger Delta. The gamma ray and electric logs of this well isolated two major aquifer zones. The first aquifer stretched from 14m to 24m with a thickness of 10m and an average resistivity of 32 Ohm-m. The second aquifer was from 44m to 88m with a thickness of 44m and an average resistivity of 27 Ohm-m.

The aquifers were separated by clay layer.

The open-hole geophysical log for the Ojobo borehole is shown in Figure 4.29.

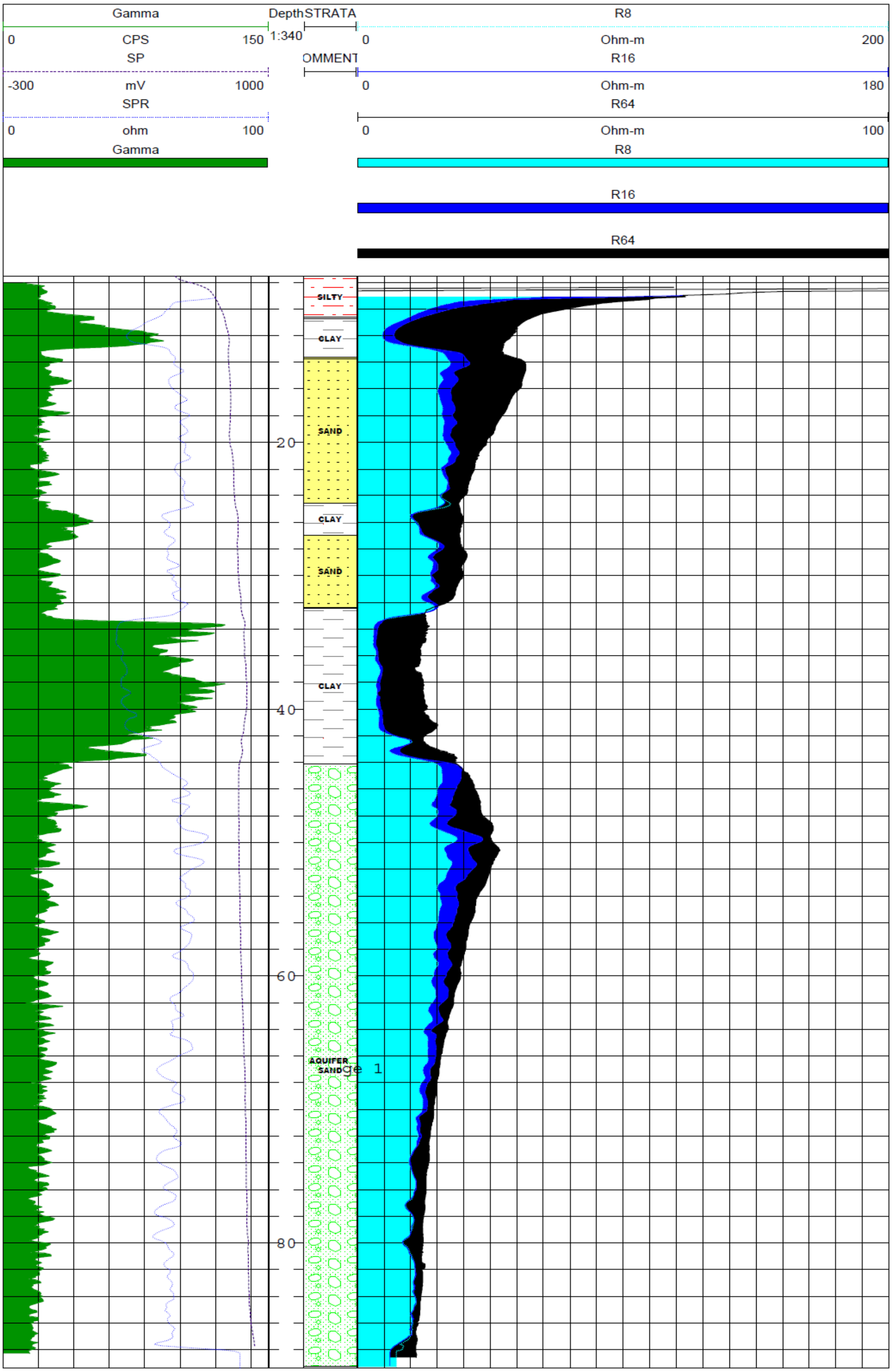

Figure 4.29: Ojobo Borehole log

4.5.5 Borehole at Uzere

A borehole of 230m was drilled at Uzere, Delta State in the fresh water swamps of the Coastal areas of Niger Delta. The gamma ray and electric logs of this well isolated three major aquifer zones. The aquifer zones were differentiated by their resistivity values. The first aquifer stretched from 31m to 130m with a thickness of 99m and an average resistivity of 800 Ohm-m. The second aquifer was from 135m to 200m with a thickness of 65m and an average resistivity of 680 Ohm-m. The third aquifer was from 201m to 230m with a thickness of 29m and an average resistivity of 750 Ohm-m

The open-hole geophysical log for the Uzere borehole is shown in Figure 4.30.

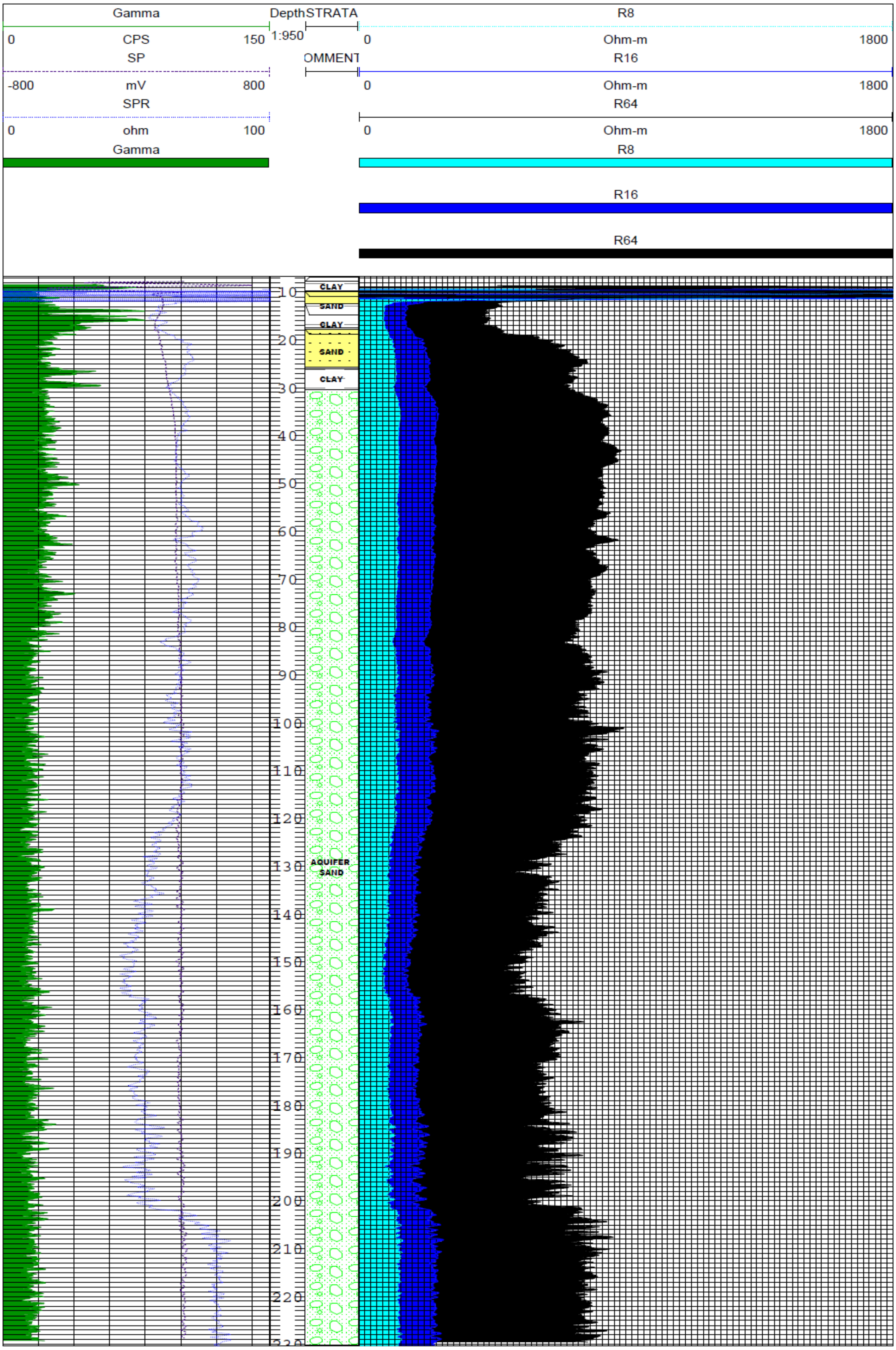

Figure 4.30: Uzere Borehole log

4.5.6 Borehole at Okpai IPP Site

A borehole of 253m was drilled at Okpai IPP site, Delta State in the fresh water swamps of the Coastal areas of Niger Delta. The gamma ray and electric logs of this well isolated six aquifer zones. The aquifer zones were differentiated by their gamma counts and resistivity values. The first aquifer stretched from 9m to 16m with a thickness of 7m and an average resistivity of 1775 Ohm-m. The second aquifer was from 23m to 183m with a thickness of 160m and an average resistivity of 761 Ohm-m. The third aquifer was from 186m to 189m with a thickness of 3m and an average resistivity of 293 Ohm-m. The fourth aquifer is from 192m to 200m with a thickness of 8m and an average resistivity of 387 Ohm-m. The fifth aquifer is from 204m to 224m with a thickness of 20m and an average resistivity of 536 Ohm-m. The sixth aquifer is from 227m to 253m with a thickness of 26m and an average resistivity of 490 Ohm-m. The aquifers were separated by clay layers.

The open-hole geophysical log for the Okpai IPP site borehole is shown in Figure 4.31.

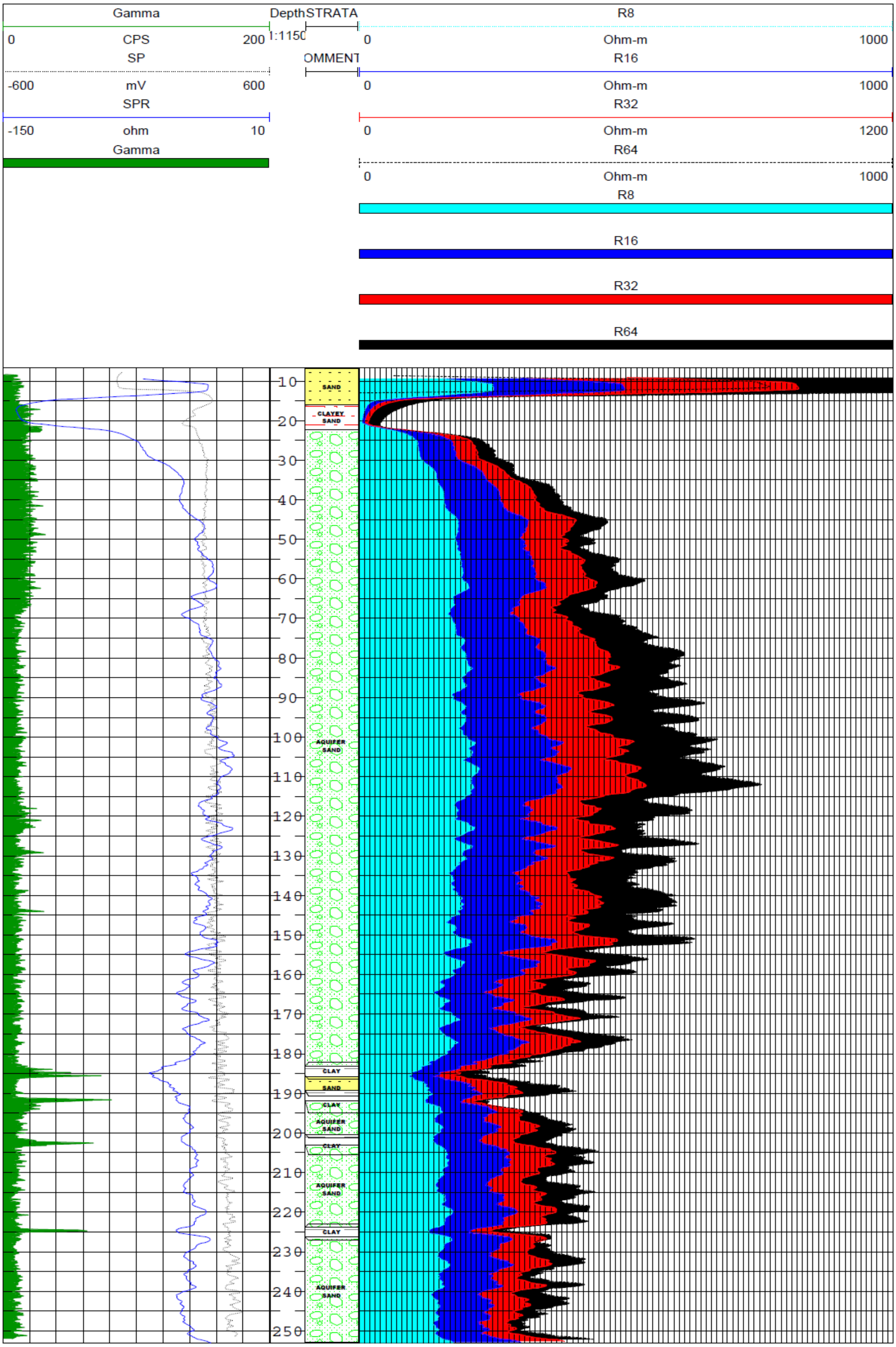

Figure 4.31: Okpai IPP site Borehole log

4.5.7 Borehole at Okpai Community Site

A borehole of 252m was drilled at Okpai Community site, Delta State in the fresh water swamps of the Coastal areas of Niger Delta. The gamma ray and electric logs of this well isolated five aquifer zones. The aquifer zones were differentiated by their gamma counts and resistivity values. The first aquifer stretched from 9m to 60m with a thickness of 51m and an average resistivity of 1882 Ohm-m. The second aquifer was from 61m to 107m with a thickness of 46m and an average resistivity of 682 Ohm-m. The third aquifer was from 114m to 152m with a thickness of 38m and an average resistivity of 484 Ohm-m. The fourth aquifer is from 160m to 216m with a thickness of 56m and an average resistivity of 500 Ohm-m. The fifth aquifer is from 222m to 252m with a thickness of 30m and an average resistivity of 375 Ohm-m.

The aquifers were separated by clay layers.

The open-hole geophysical log for the Okpai Community site borehole is shown in Figure 4.32.

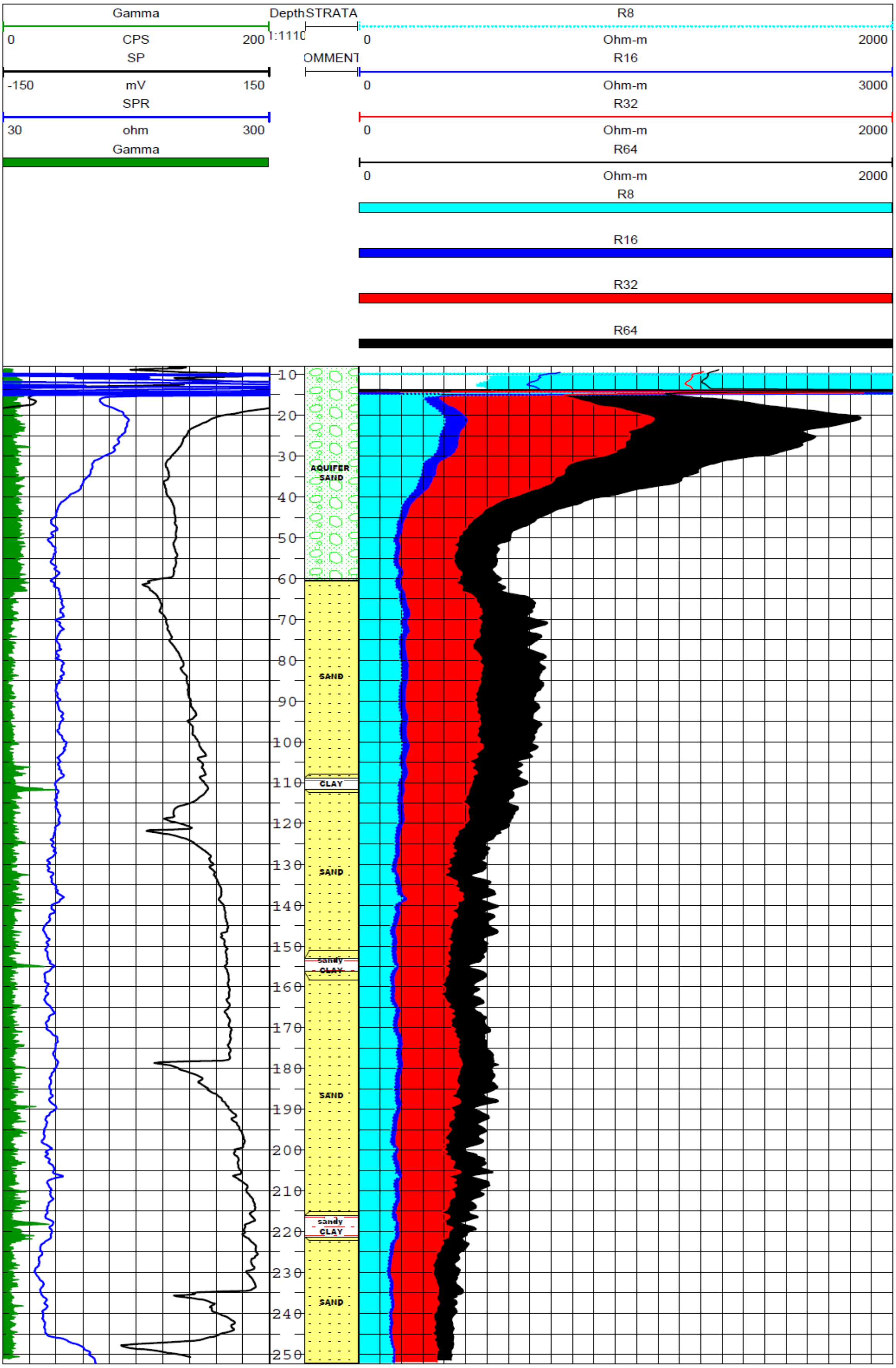

Figure 4.32: Okpai Community site Borehole log

4.5.8 Borehole at Otakeme Community Site

A borehole of 300m was drilled at Otakeme Community in the Ogbia area of Bayelsa State in the fresh water swamps of the Coastal areas of Niger Delta. The gamma ray and electric logs of this well isolated eight aquifer zones. The aquifer zones were differentiated by their gamma counts and resistivity values. The first aquifer stretched from 9m to 13m with a thickness of 4m and an average resistivity of 532 Ohm-m. The second aquifer was from 16m to 22m with a thickness of 6m and an average resistivity of 92 Ohm-m. The third aquifer was from 26m to 67m with a thickness of 41m and an average resistivity of 205 Ohm-m. The fourth aquifer is from 74m to 102m with a thickness of 28m and an average resistivity of 302 Ohm-m. The fifth aquifer is from 107m to 136m with a thickness of 29m and an average resistivity of 636 Ohm-m. The sixth aquifer is from 141m to 176m with a thickness of 35m and an average resistivity of 791 Ohm-m. The seventh aquifer is from 181m to 236m with a thickness of 55m and an average resistivity of 809 Ohm-m. The eighth aquifer is from 246m to 296m with a thickness of 50m and an average resistivity of 839 Ohm-m.

The open-hole geophysical log for the Otakeme Community site borehole is shown in Figure 4.33.

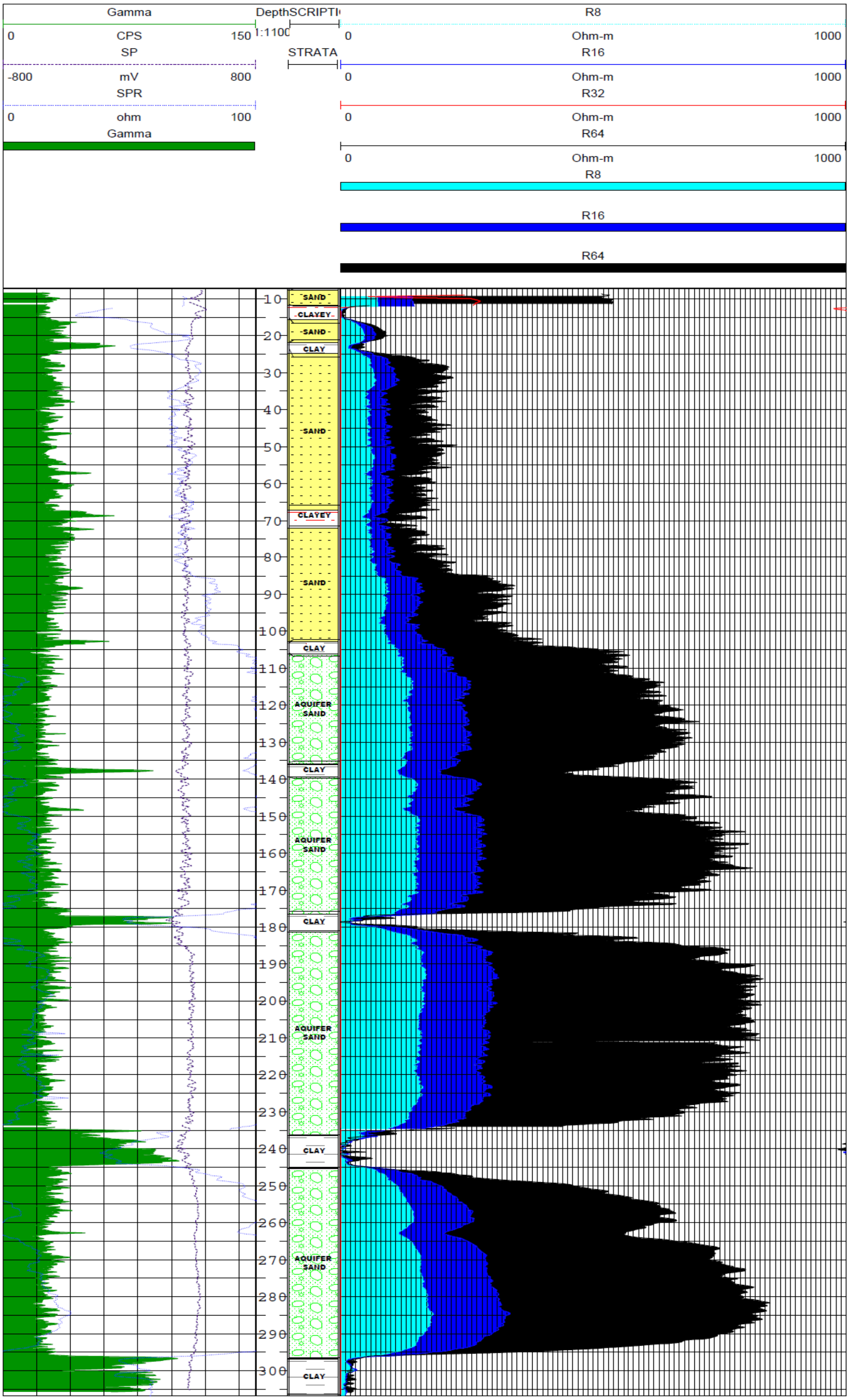

Figure 4.33: Otakeme Community site Borehole log

4.5.9 Borehole at Asingbene Community Site

A borehole of 100m was drilled at Asingbene Community in the Gbarain area of Bayelsa State in the fresh water swamps of the Coastal areas of Niger Delta. The gamma ray and electric logs of this well isolated four aquifer zones. The aquifer zones were differentiated by their gamma counts and resistivity values.   The first aquifer stretched from 11m to 46m with a thickness of 35m and an average resistivity of 610 Ohm-m. The second aquifer was from 55m to 69m with a thickness of 14m and an average resistivity of 256 Ohm-m. The third aquifer was from 75m to 82m with a thickness of 7m and an average resistivity of 175 Ohm-m. The fourth aquifer is from 84m to 96m with a thickness of 12m and an average resistivity of 177 Ohm-m.

The open-hole geophysical log for the AsingbeneGbarain Community site borehole is shown in Figure 4.34.

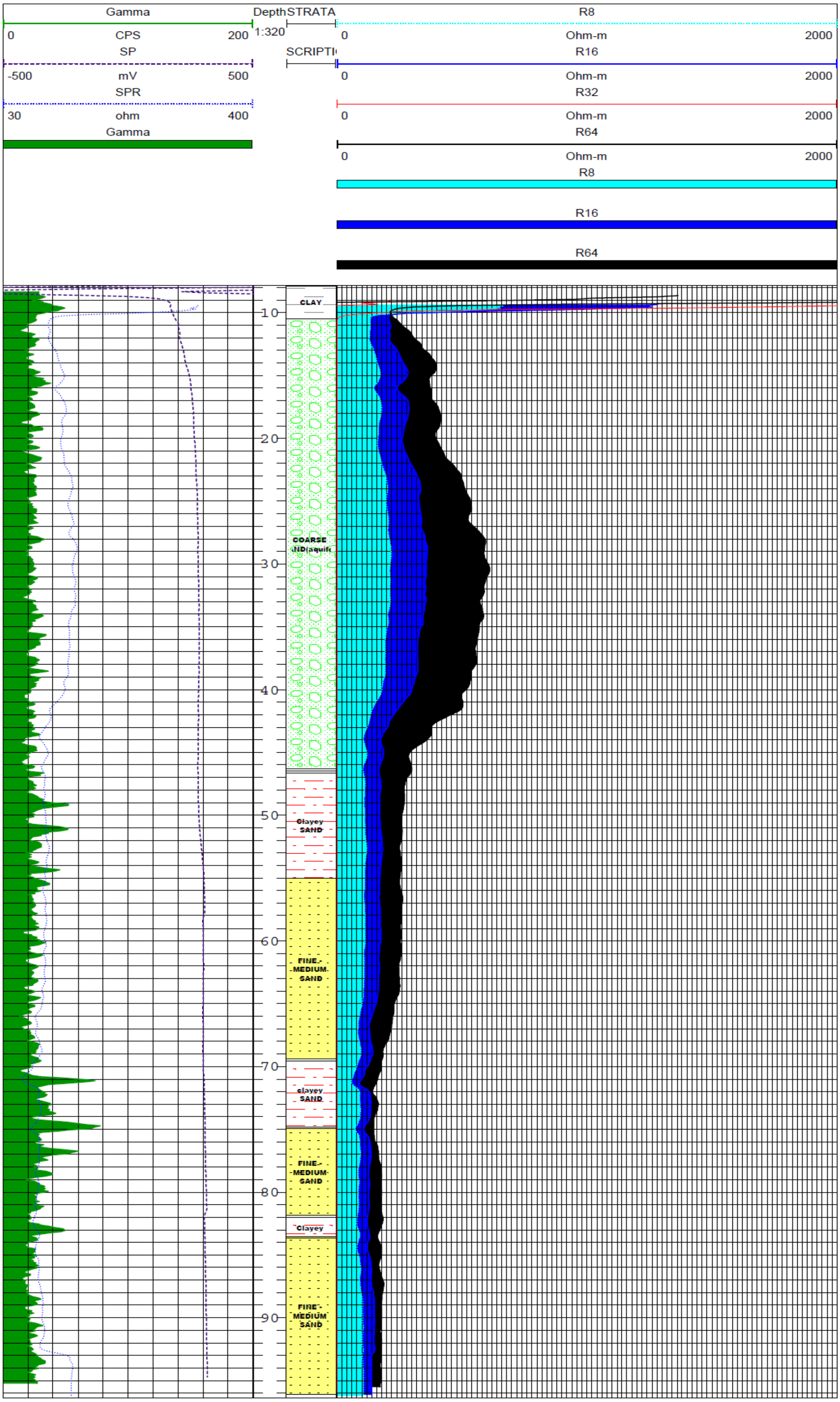

Figure 4.34: AsingbeneGbarain Community site Borehole log

4.5.10 Borehole at GbarainUbie gas plant Site

A borehole of 520m was drilled at GbarainUbie Gas plant in the Gbarain area of Bayelsa State in the fresh water swamps of the Coastal areas of Niger Delta. The gamma ray and electric logs of this well isolated four aquifer zones. The aquifer zones were differentiated by their gamma counts and resistivity values. The first aquifer stretched from 10m to 120m with a thickness of 110m and an average resistivity of 312 Ohm-m. The second aquifer was from 132m to 170m with a thickness of 38m and an average resistivity of 331 Ohm-m. The third aquifer was from 181m to 300m with a thickness of 119m and an average resistivity of 212 Ohm-m. The fourth aquifer is from 332m to 520m with a thickness of 188m and an average resistivity of 435 Ohm-m.

The open-hole geophysical log for the GbarainUbie Gas plant borehole is shown in Figure 4.35.

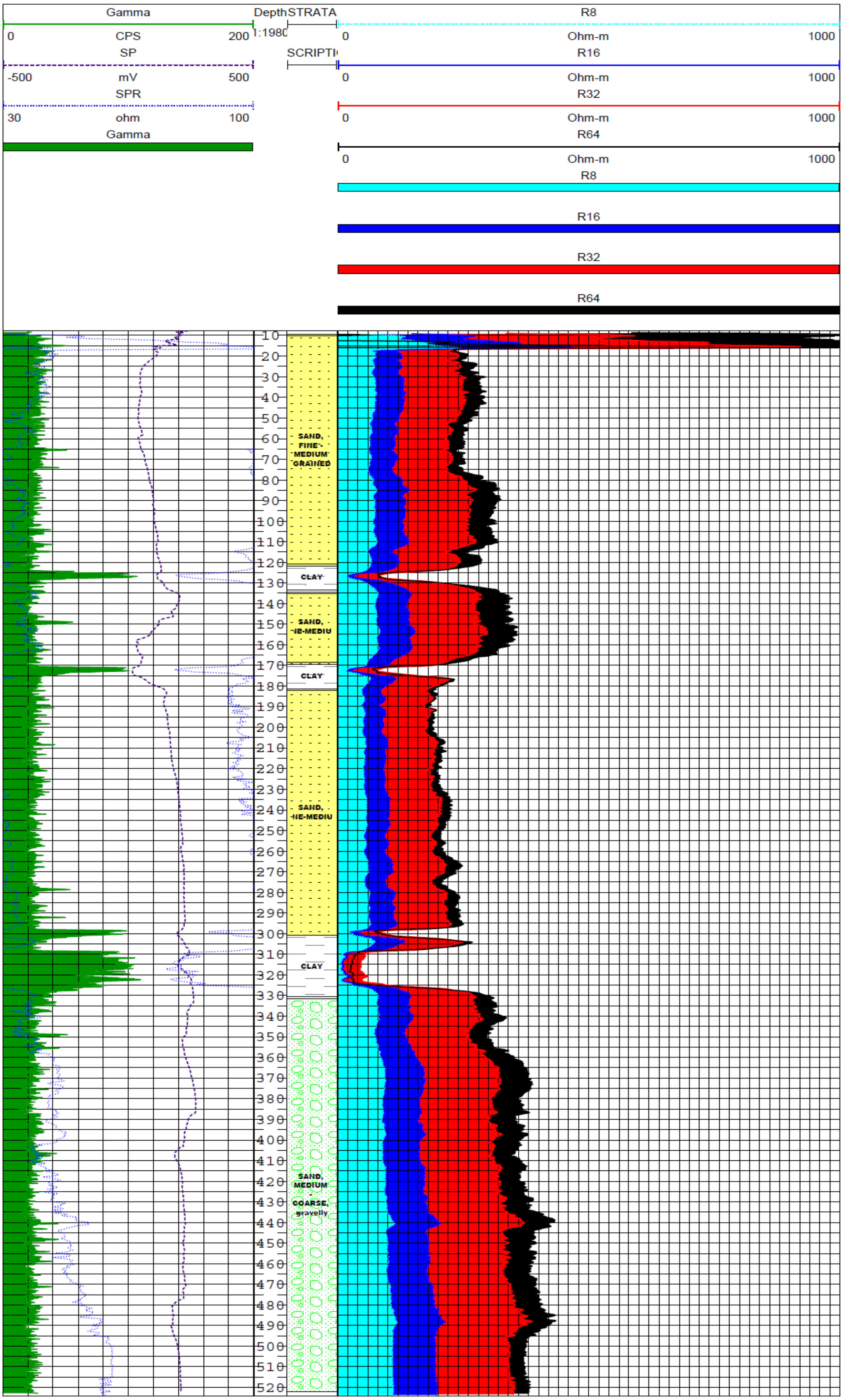

Figure 4.35: GbarainUbie Gas plant site Borehole log

4.5.11 Borehole at Amasoma Site

A borehole of 150m was drilled at Amasoma area of Bayelsa State in the fresh water swamps of the Coastal areas of Niger Delta. The gamma ray and electric logs of this well isolated two aquifer zones. The aquifer zones were differentiated by their gamma counts and resistivity values. The first aquifer stretched from 20m to 104m with a thickness of 84m and an average resistivity of 248 Ohm-m. The second aquifer was from 108m to 142m with a thickness of 34m and an average resistivity of 220 Ohm-m.

The open-hole geophysical log for the Amasoma borehole is shown in Figure 4.36.

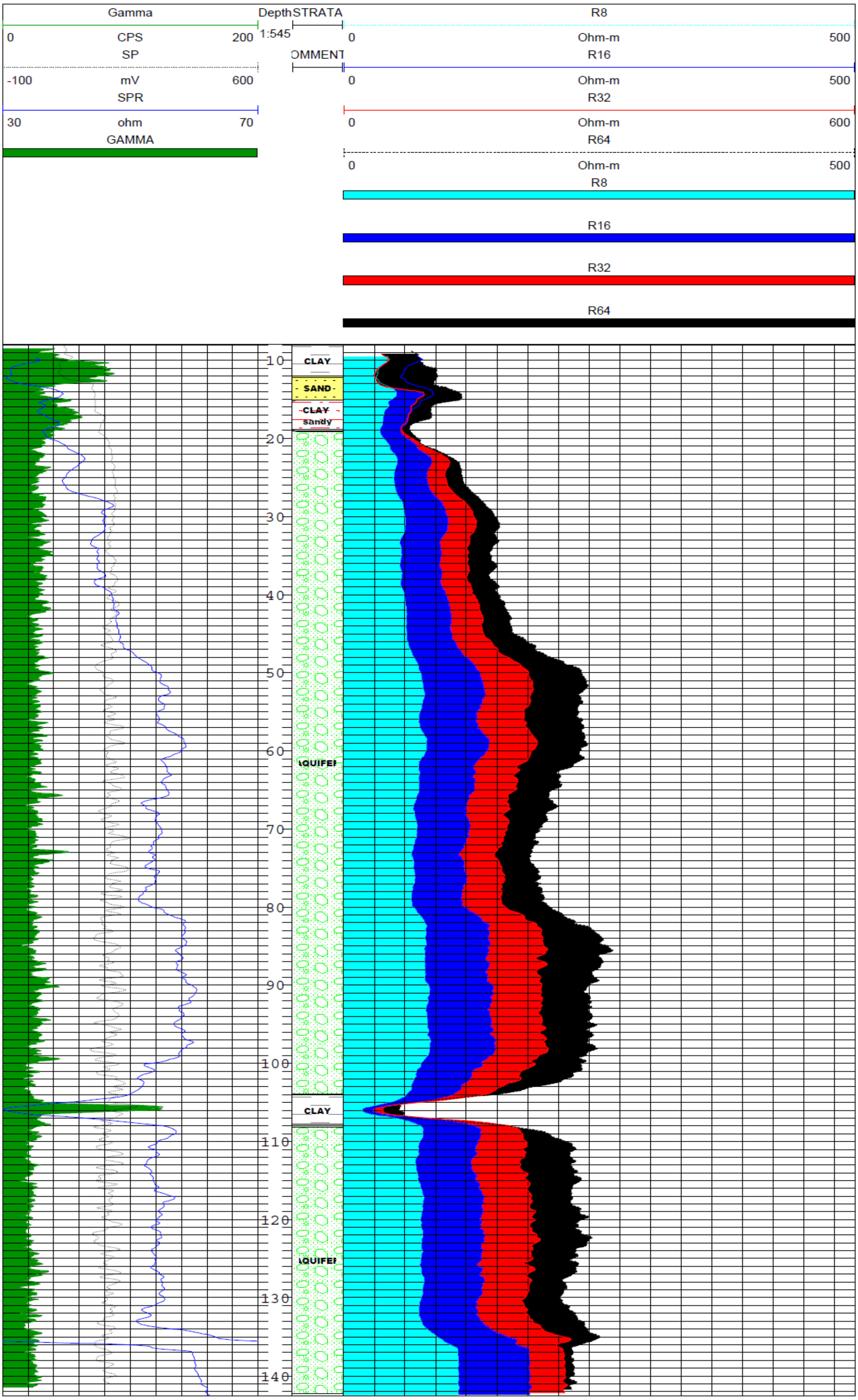

Figure 4.36: Amasoma Borehole log

4.5.12 Borehole at ObunaghaGbarain Site

A borehole of 180m was drilled at ObunaghaGbarain area of Bayelsa State in the fresh water swamps of the Coastal areas of Niger Delta. The gamma ray and electric logs of this well isolated two aquifer zones. The aquifer zones were differentiated by their gamma counts and resistivity values. The first aquifer stretched from 12m to 54m with a thickness of 42m and an average resistivity of 221 Ohm-m. The second aquifer was from 82m to 165m with a thickness of 83m and an average resistivity of 267 Ohm-m.

The open-hole geophysical log for the ObunaghaGbarain borehole is shown in Figure 4.37.

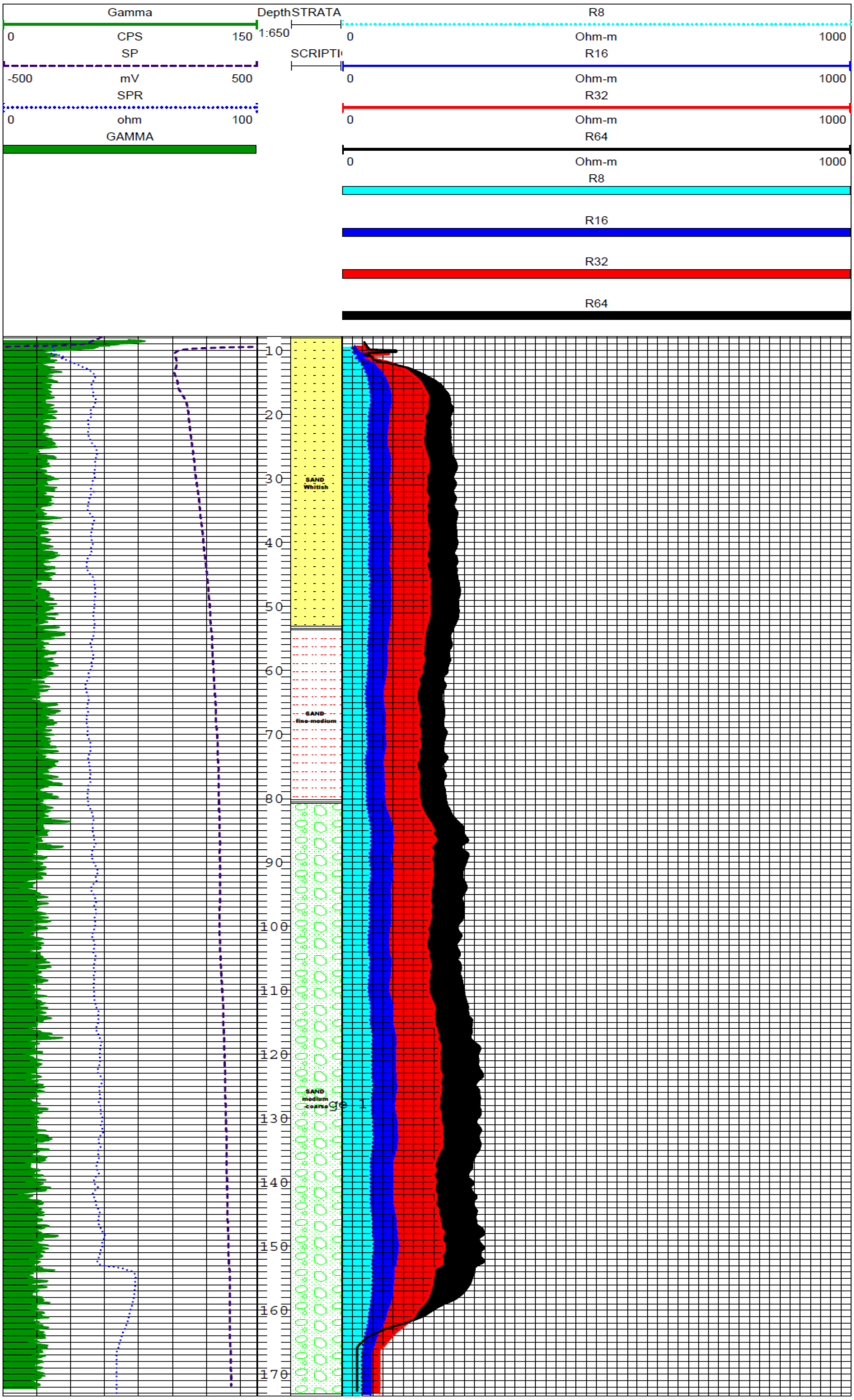

Figure 4.37: ObunaghaGbarain Borehole log

4.5.13 Borehole at Swali market Yenegoa Site

A borehole of 150m was drilled at Swali market area, Yenegoa , Bayelsa State in the fresh water swamps of the Coastal areas of Niger Delta. The gamma ray and electric logs of this well isolated two aquifer zones. The aquifer zones were differentiated by their gamma counts and resistivity values. The first aquifer stretched from 11m to 76m with a thickness of 65m and an average resistivity of 178 Ohm-m. The second aquifer was from 85m to 150m with a thickness of 65m and an average resistivity of 266 Ohm-m.

The open-hole geophysical log for the Swali Market borehole is shown in Figure 4.38.

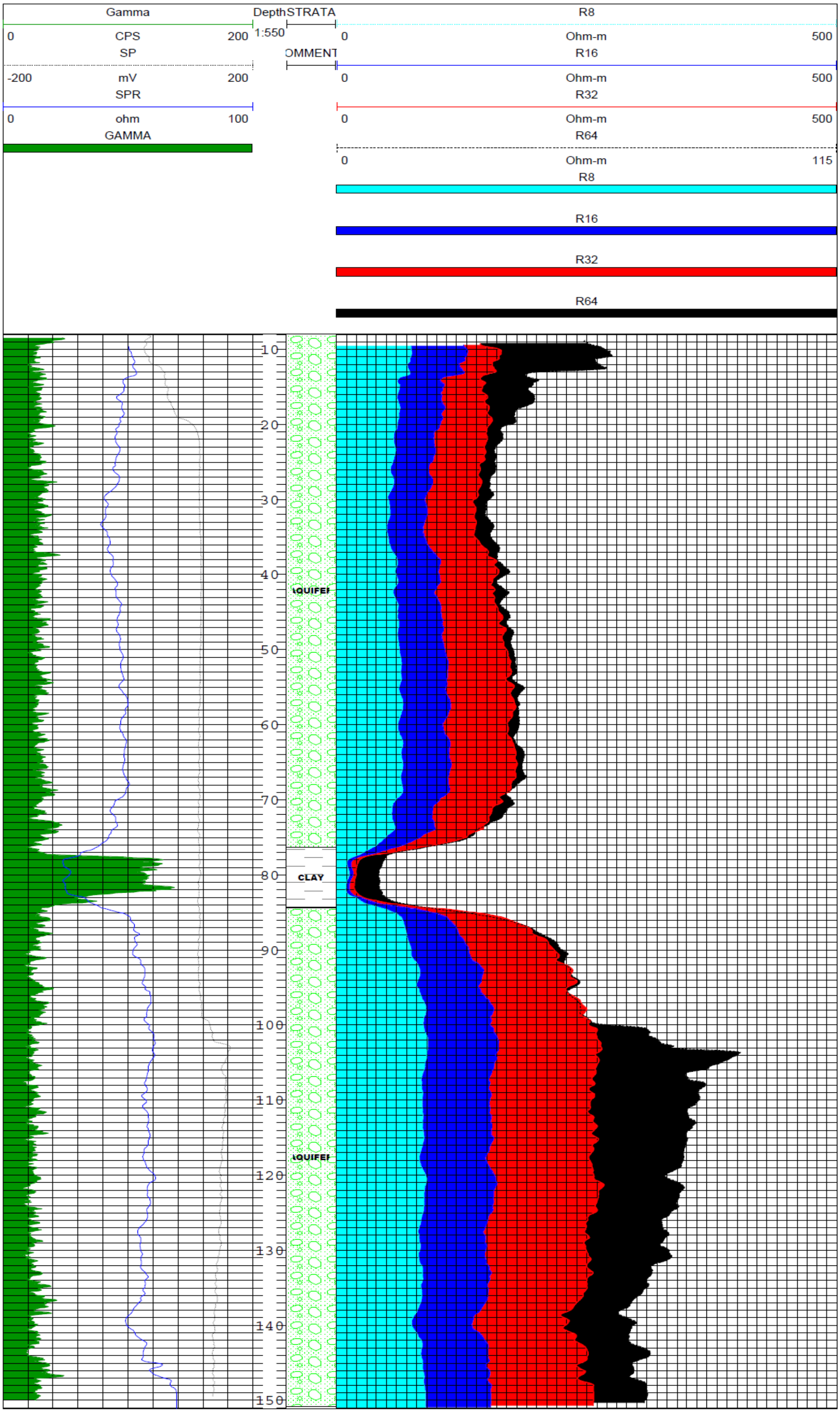

Figure 4.38: Swali market Borehole log

4.5.14 Borehole at Gbarain IPP Site

A borehole of 250m was drilled at Gbarain IPP site , Bayelsa State in the fresh water swamps of the Coastal areas of Niger Delta. The gamma ray and electric logs of this well isolated three aquifer zones. The aquifer zones were differentiated by their gamma counts and resistivity values. The first aquifer stretched from 10m to 65m with a thickness of 55m and an average resistivity of 340 Ohm-m. The second aquifer was from 77m to 163m with a thickness of 86m and an average resistivity of 347 Ohm-m. The third aquifer was from 171m to 253m with a thickness of 82m and an average resistivity of 353 Ohm-m.

The open-hole geophysical log for the Gbarain IPP site borehole is shown in Figure 4.39.

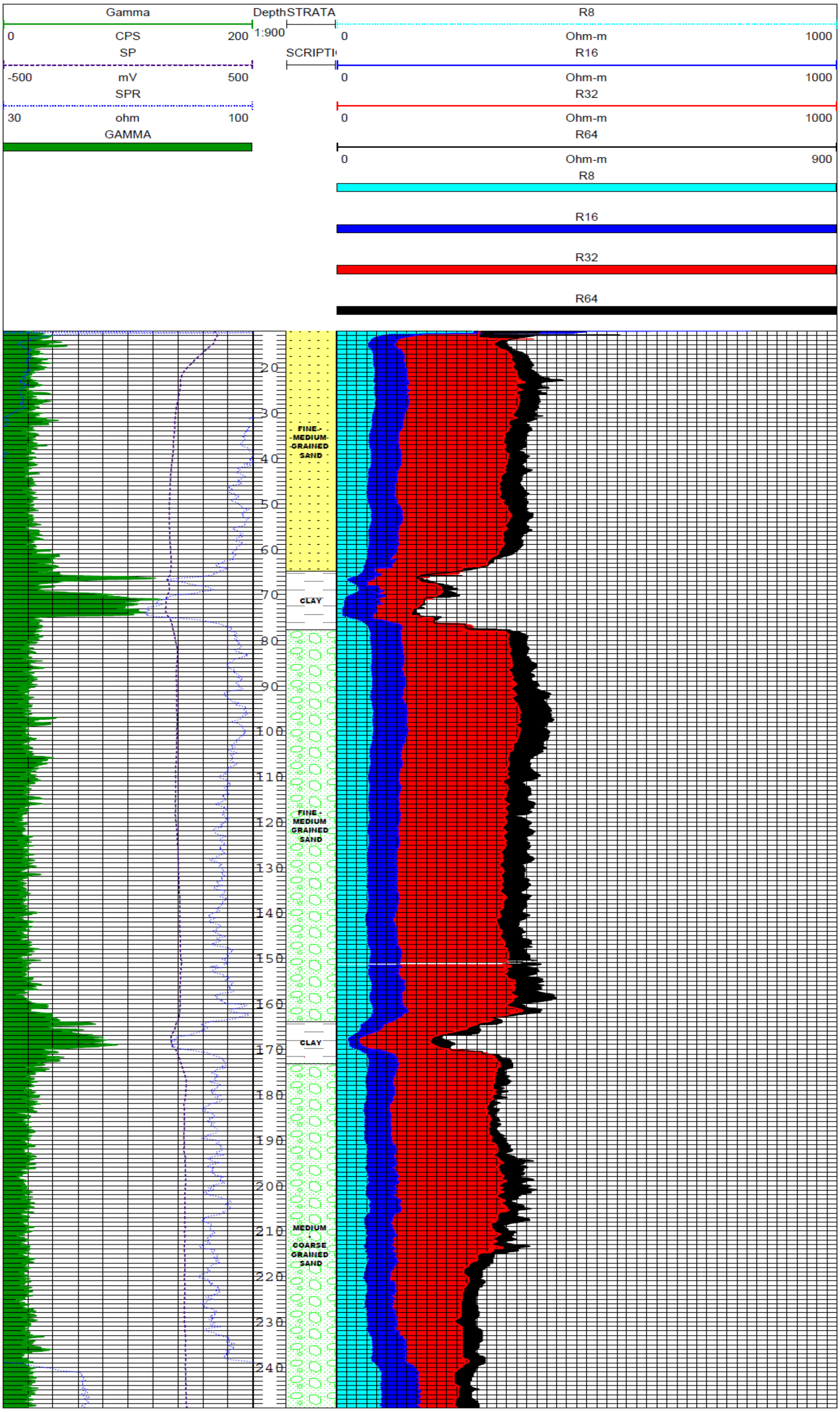

Figure 4.39: Gbarain IPP site Borehole log

4.5.15 Borehole at Ayama Ijaw Site

A borehole of 150m was drilled at Ayama Ijaw , Bayelsa State in the fresh water swamps of the Coastal areas of Niger Delta. The gamma ray and electric logs of this well isolated three aquifer zones. The aquifer zones were differentiated by their gamma counts and resistivity values. The first aquifer stretched from 10m to 50m with a thickness of 40m and an average resistivity of 330 Ohm-m. The second aquifer was from 60m to 89m with a thickness of 29m and an average resistivity of 169 Ohm-m. The third aquifer was from 93m to 152m with a thickness of 59m and an average resistivity of 182 Ohm-m.

The open-hole geophysical log for the Ayama Ijaw site borehole is shown in Figure 4.40.

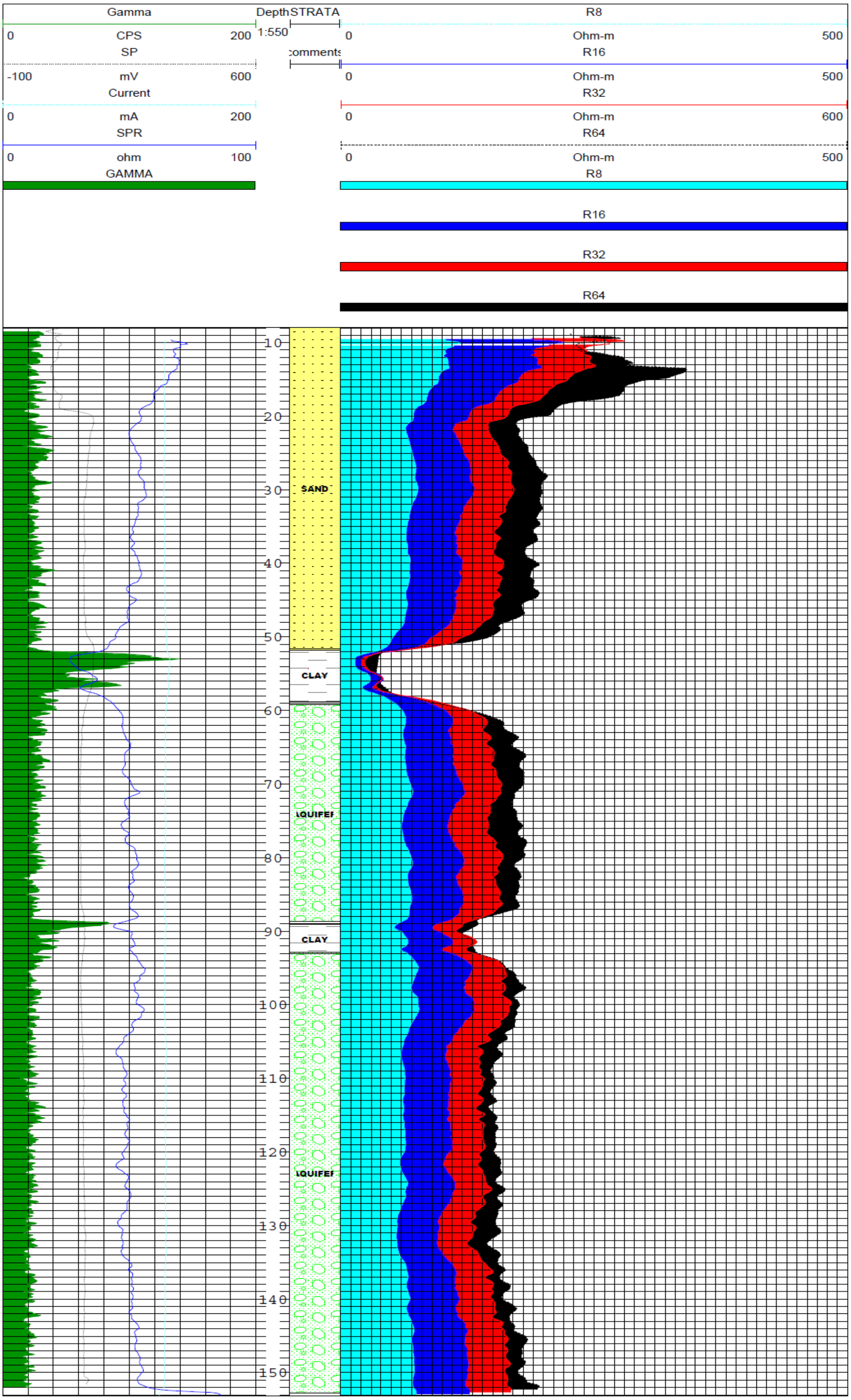

Figure 4.40: Ayama Ijaw site Borehole log

4.5.16 Borehole at KoloOgbia

A borehole of 100m was drilled at Kolo, Ogbia area of Bayelsa State in the fresh water swamps of the Coastal areas of Niger Delta. The gamma ray and electric logs of this well isolated seven aquifer zones. The aquifer zones were differentiated by their gamma counts and resistivity values. The first aquifer stretched from 11m to 25m with a thickness of 14m and an average resistivity of 840 Ohm-m. The second aquifer was from 29m to 34m with a thickness of 5m and an average resistivity of 817 Ohm-m. The third aquifer was from 39m to 43m with a thickness of 4m and an average resistivity of 828 Ohm-m. The fourth aquifer was from 47m to 49m with a thickness of 2m and an average resistivity of 1065 Ohm-m. The fifth aquifer was from 50m to 56m with a thickness of 6m and an average resistivity of 886 Ohm-m. The sixth aquifer was from 58m to 83m with a thickness of 25m and an average resistivity of 889 Ohm-m. The seventh aquifer was from 91m to 98m with a thickness of 7m and an average resistivity of 908 Ohm-m.

The open-hole geophysical log for the KoloOgbia area site borehole is shown in Figure 4.41.

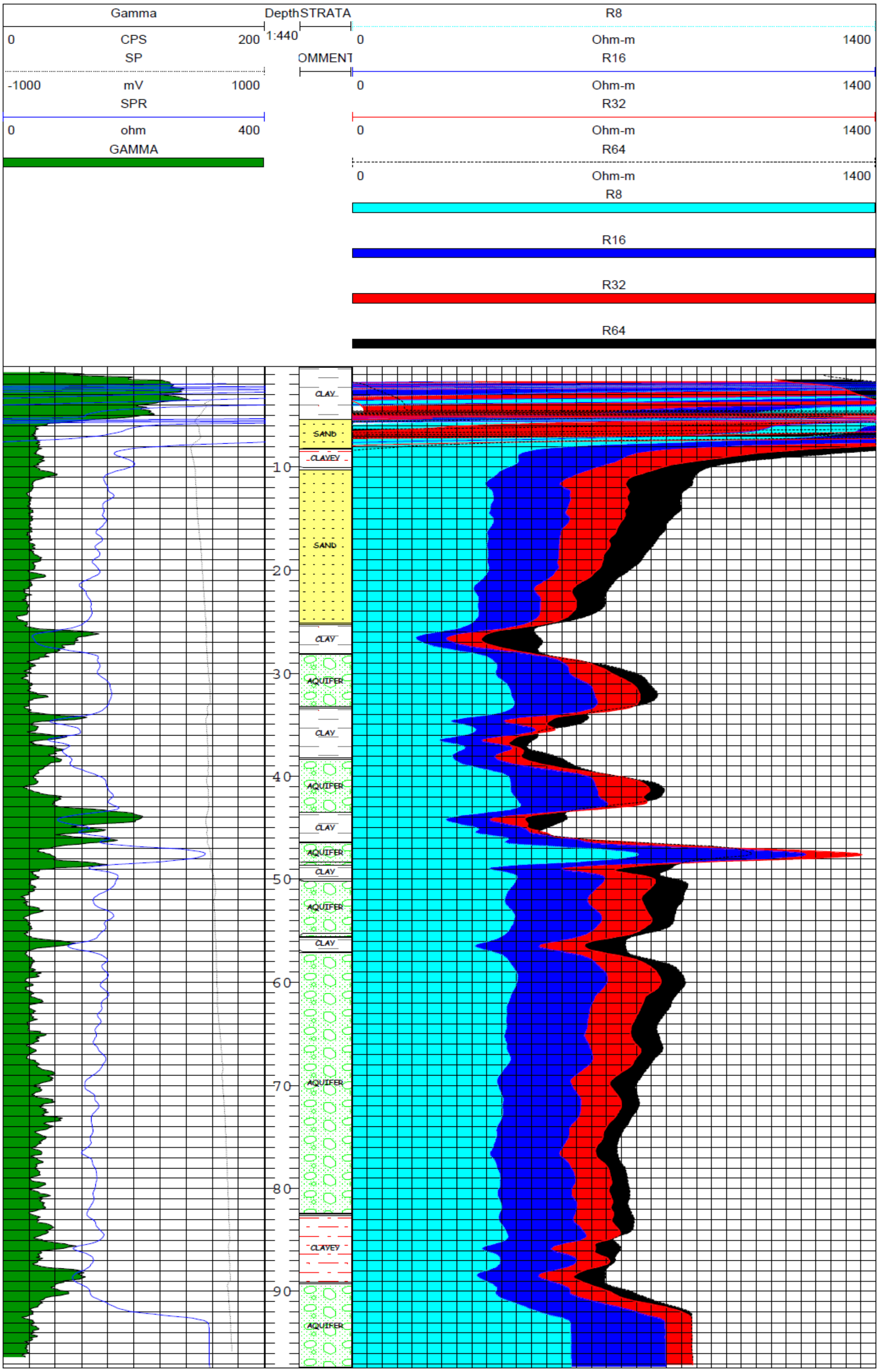

Figure 4.41: KoloOgbia site Borehole log

4.5.17 Borehole at Arogbo

A borehole of 380m was drilled at Arogbo Ondo State in the fresh water swamps of the Coastal areas of Niger Delta. The gamma ray and electric logs of this well isolated eight aquifer zones. The aquifer zones were differentiated by their gamma counts and resistivity values and clay layers seperators.. The first aquifer stretched from 28m to 45m with a thickness of 17m and an average resistivity of 201 Ohm-m. The second aquifer was from 59m to 86m with a thickness of 27m and an average resistivity of 409 Ohm-m. The third aquifer was from 92m to 105m with a thickness of 13m and an average resistivity of 329 Ohm-m. The fourth aquifer was from 110m to 115m with a thickness of 5m and an average resistivity of 244 Ohm-m. The fifth aquifer was from 145m to 153m with a thickness of 8m and an average resistivity of 200 Ohm-m. The sixth aquifer was from 171m to 178m with a thickness of 7m and an average resistivity of 196 Ohm-m. The seventh aquifer was from 190m to 202m with a thickness of 12m and an average resistivity of 230 Ohm-m.

The open-hole geophysical log for the Arogbo Ondo area site borehole is shown in Figure 4.42.

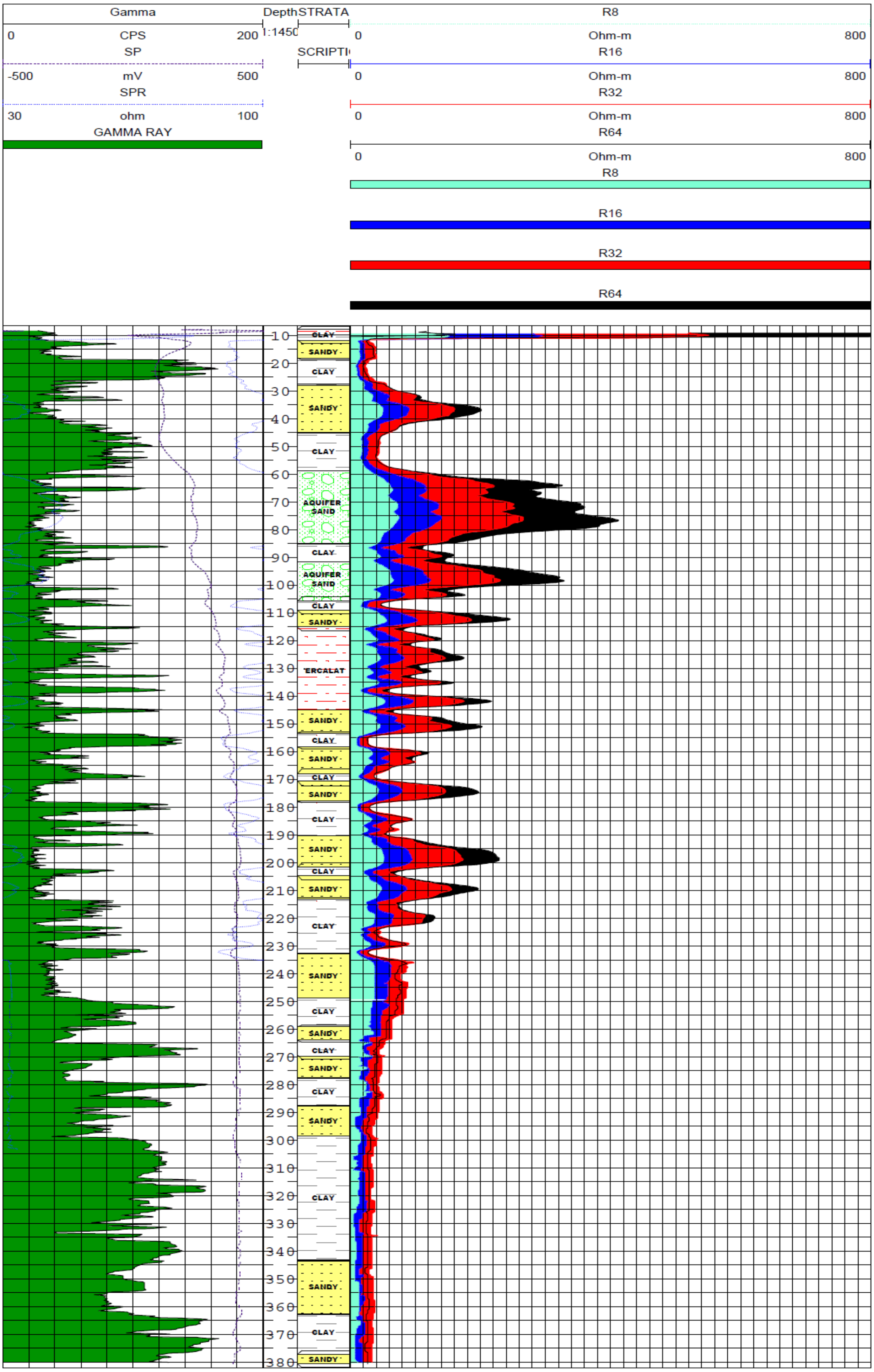

Figure 4.42: Arogbo Ondo state Borehole log

4.5.18 Borehole at Awoye Ondo

A borehole of 300m was drilled at Awoye Ondo State in the fresh water swamps of the Coastal areas of Niger Delta. The gamma ray and electric logs of this well isolated four aquifer zones. The aquifer zones were differentiated by their gamma counts and resistivity values and clay layers separators. The first aquifer stretched from 132m to 148m with a thickness of 16m and an average resistivity of 50.14 Ohm-m. The second aquifer was from 152m to 165m with a thickness of 13m and an average resistivity of 44 Ohm-m. The third aquifer was from 168m to 183m with a thickness of 15m and an average resistivity of 42.2 Ohm-m. The fourth aquifer was from 228m to 250m with a thickness of 22m and an average resistivity of 39 Ohm-m.

The open-hole geophysical log for the Awoye Ondo area site borehole is shown in Figure 4.43.

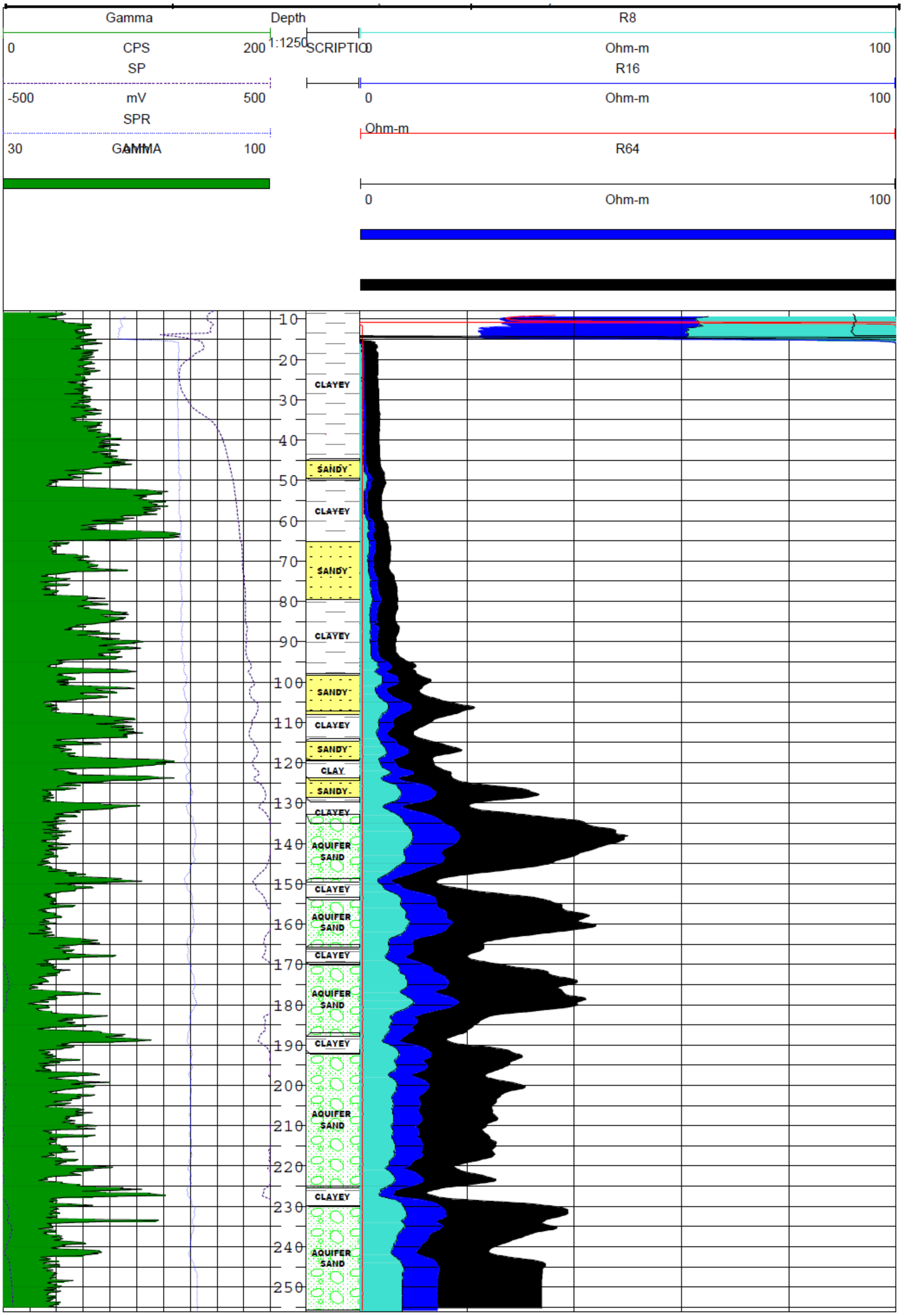

Figure 4.43: Awoye Ondo state Borehole log

4.5.19 Borehole at Orietan Ondo

A borehole of 200m was drilled at Orietan Ondo State in the fresh water swamps of the Coastal areas of Niger Delta. The gamma ray and electric logs of this well isolated three aquifer zones. The aquifer zones were differentiated by their gamma counts and resistivity values and clay layers separators. The first aquifer stretched from 96m to 125m with a thickness of 29m and an average resistivity of 32 Ohm-m. The second aquifer was from 140m to 158m with a thickness of 18m and an average resistivity of 42 Ohm-m. The third aquifer was from 160m to 170m with a thickness of 10m and an average resistivity of 42.2 Ohm-m.

The open-hole geophysical log for the Orietan Ondo area site borehole is shown in Figure 4.44.

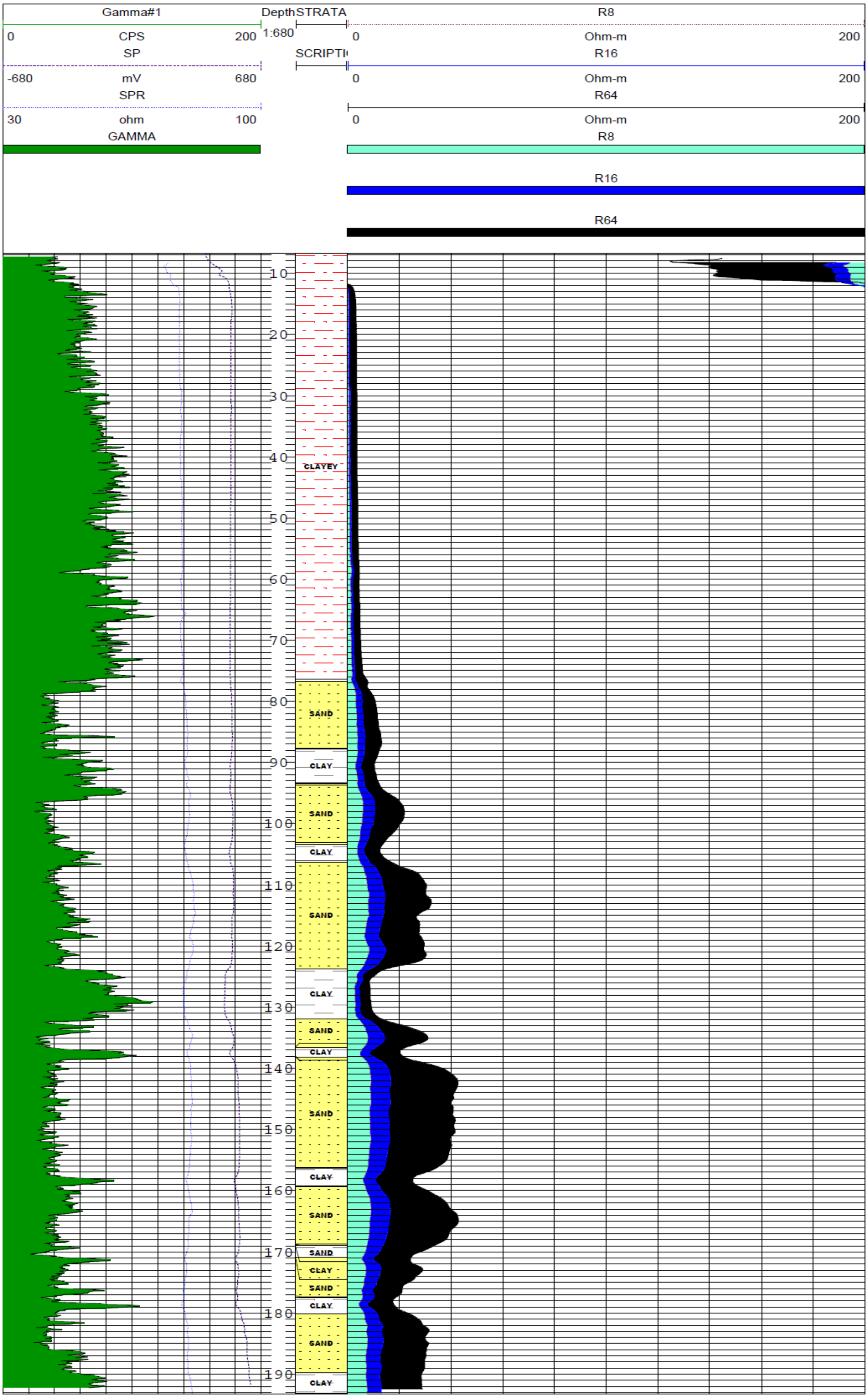

Figure 4.44: Orietan Ondo state Borehole log

4.6 Aquifers In Saltwater Swamps

The down-hole geophysical logging of boreholes in the salt water swamps depositional environment of the coastal areas of the Niger Delta are presented below. Several boreholes in the salt water environment were drilled and gamma and electric logs carried out on them. The resistivity logs indicated the vertical extent of salt water intrusion in the area.

4.6.1 Bille Rivers State Borehole log.

From the gamma log it was deduced that the area is underlain by 6 saturated sand bodies. However the resistivity log shows that the groundwater in the sand bodies occurring between 0 and 260m is saline with resistivity values bellow 10 Ohm-m. Below the clay at 260m all the aquifer contain fresh water, fresh in the sense that it is not saline but contains ferrous ions with a resistivity of between 100-152 Ohm-m.

The gamma and electric logs of the Bille borehole is shown is fig.4.45.

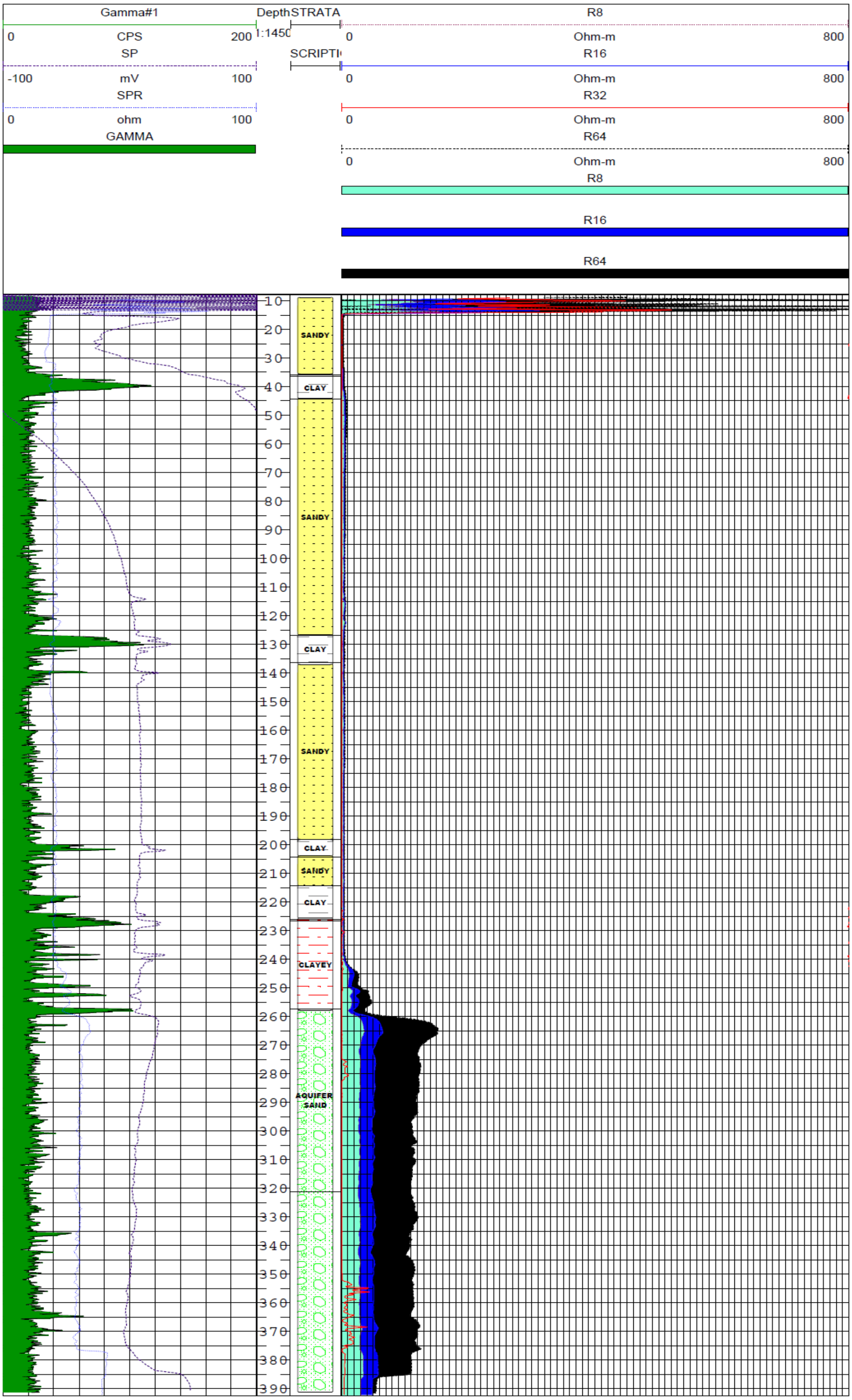

Figure 4.45: Bille Rivers State Borehole log

4.6.2 Asaramatoru Rivers State Borehole log.

A borehole of 270m was drilled at Asaramatoru Rivers State in the salt water swamps of the coastal areas of the Niger Delta . The gamma and electric logs for this well deduced that the area is underlain by seven aquifer zones. However the resistivity log showed salt water contamination in the upper aquifers. The first aquifer is from 60m to 114m with a thickness of 54m and an average resistivity of 1.03 Ohm-m. The second aquifer is from 116m to 137m with a thickness of 21m and an average resistivity of 7.46 Ohm-m. The third aquifer is from 148m to 156m with a thickness of 8m and an average resistivity of 61.43 Ohm-m. The fourth aquifer is from 161m to 186m with a thickness of 25m and an average resistivity of 116 Ohm-m. The fifth aquifer is from 205m to 215m with a thickness of 10m and an average resistivity of 85 Ohm-m. The sixth aquifer is from 218m to 226m with a thickness of 8m and an average resistivity of 125 Ohm-m. The seventh aquifer is from 242m to 270m with athickness of 28m and an average resistivity of 187.3 Ohm-m.

The gamma and electric logs of the Asaramatoru borehole is shown is fig.4.46.

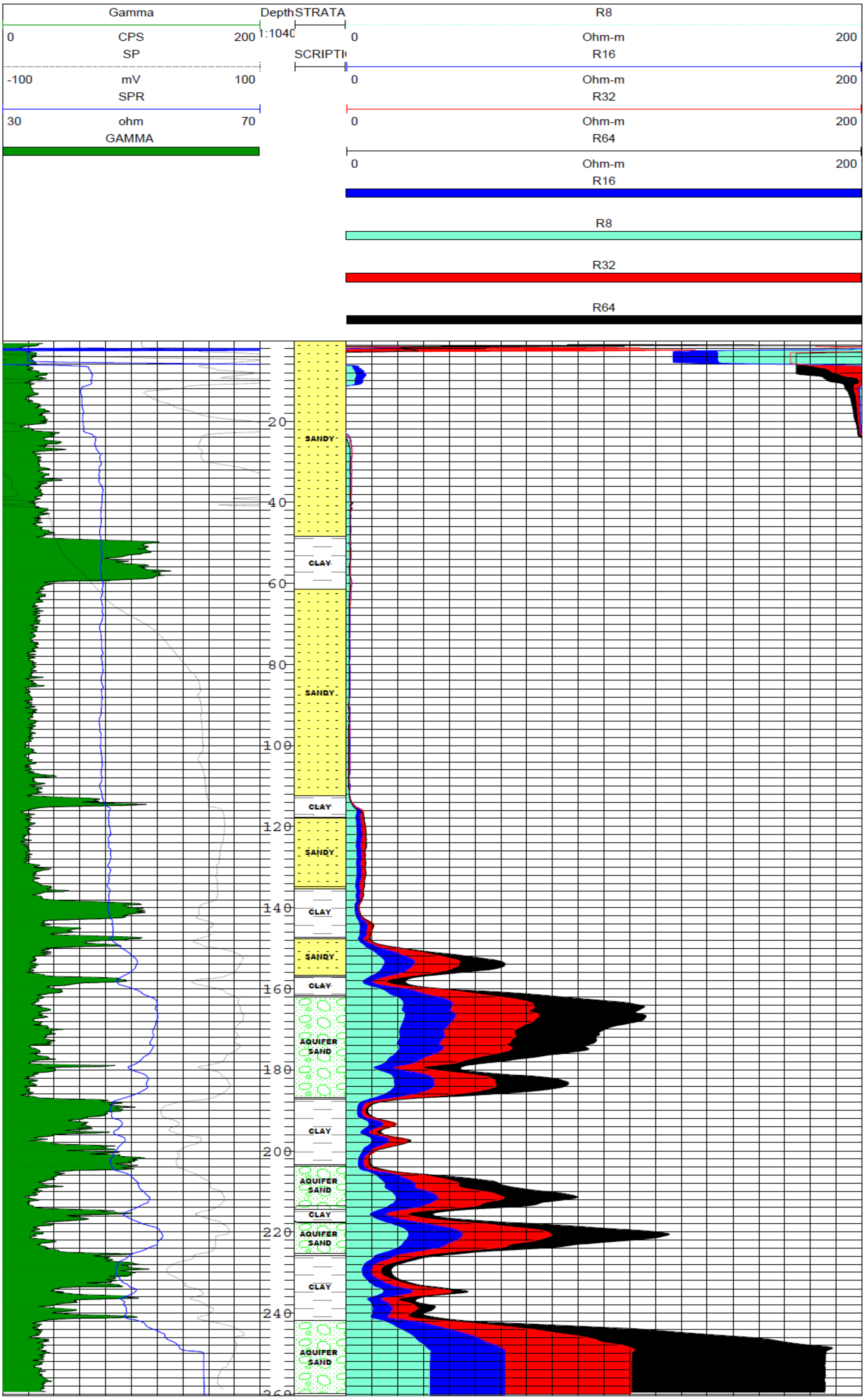

Figure 4.46: Asaramatoru Rivers State Borehole log

4.6.3 Idama Rivers State Borehole log.

A borehole of 570m was drilled at Idama Rivers State in the salt water swamps of the coastal areas of the Niger Delta. The gamma and electric logs for this well deduced that the area is underlain by five aquifer zones. However the resistivity log showed salt water contamination in the upper aquifers. The first aquifer is from 40m to 135m with a thickness of 95m and an average resistivity of 0.27 Ohm-m. The second aquifer is from 145m to 300m with a thickness of 155m and an average resistivity of 34.8 Ohm-m. The third aquifer is from 310m to 350m with a thickness of 40m and an average resistivity of 7.0 Ohm-m. The fourth aquifer is from 360m to 400m with a thickness of 40m and an average resistivity of 10.4 Ohm-m. The fifth aquifer is from 415m to 570m with a thickness of 155m and an average resistivity of 4.3 Ohm-m.

The gamma and electric logs of the Idama borehole is shown is figure 4.47.

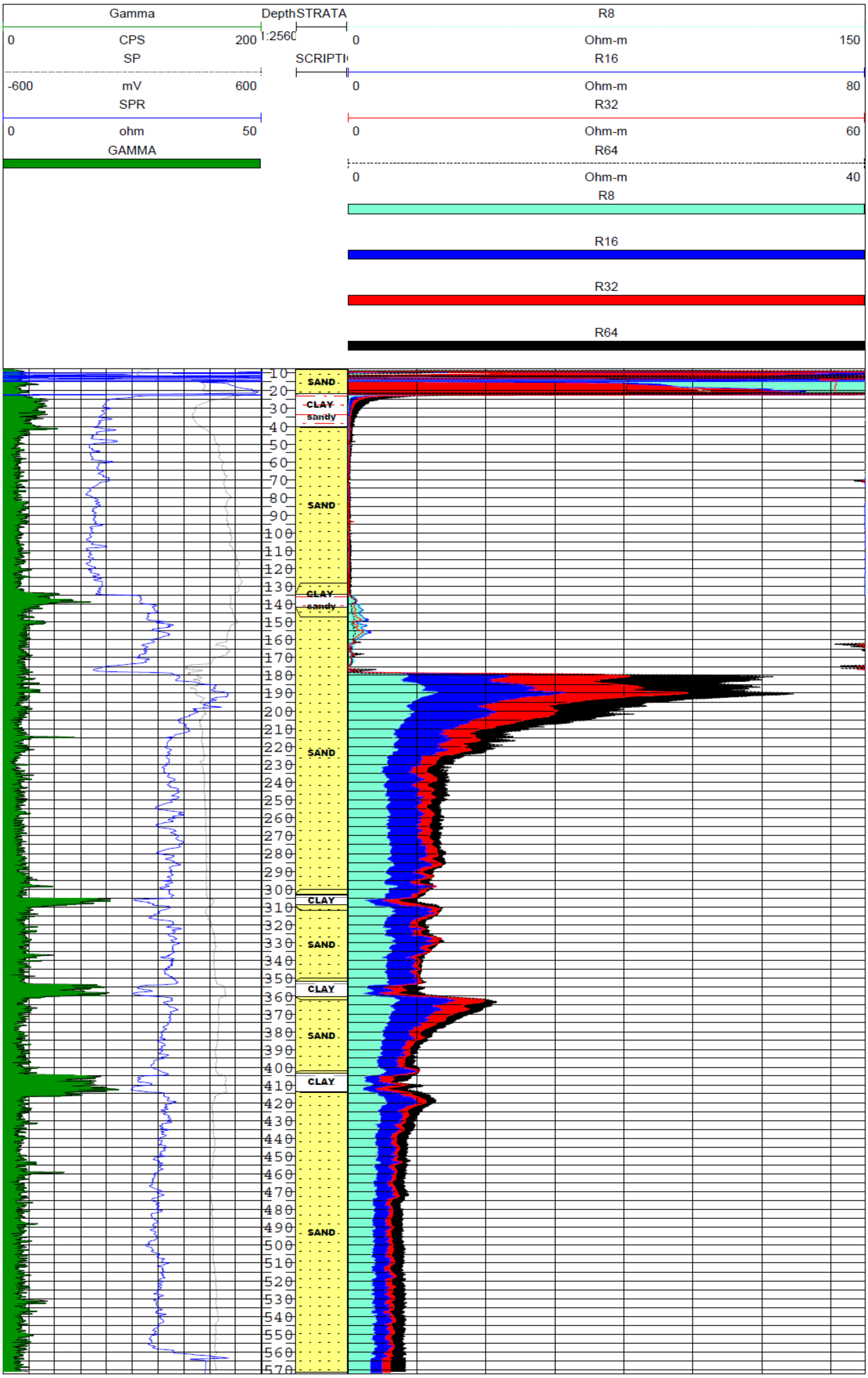

Figure 4.47: Idama Rivers State Borehole log

4.6.4 Kula Rivers State Borehole log.

A borehole of 480m was drilled at Kula Rivers State in the salt water swamps of the coastal areas of the Niger Delta. The gamma and electric logs for this well deduced that the area is underlain by six aquifer zones. However the resistivity log showed salt water contamination in the upper aquifers. The first aquifer is from 10m to 35m with a thickness of 25m and an average resistivity of 0.21 Ohm-m. The second aquifer is from 42m to 71m with a thickness of 29m and an average resistivity of 0.07 Ohm-m. The third aquifer is from 74m to 118m with a thickness of 44m and an average resistivity of 40 Ohm-m. The fourth aquifer is from 132m to 230m with a thickness of 98m and an average resistivity of 220 Ohm-m. The fifth aquifer is from 315m to 334m with a thickness of 19m and an average resistivity of 198 Ohm-m. The sixth aquifer is from 338m to 465m with a thickness of 127m and an average resistivity of 230 Ohm-m.

The gamma and electric logs of the Kula borehole is shown is figure 4.48.

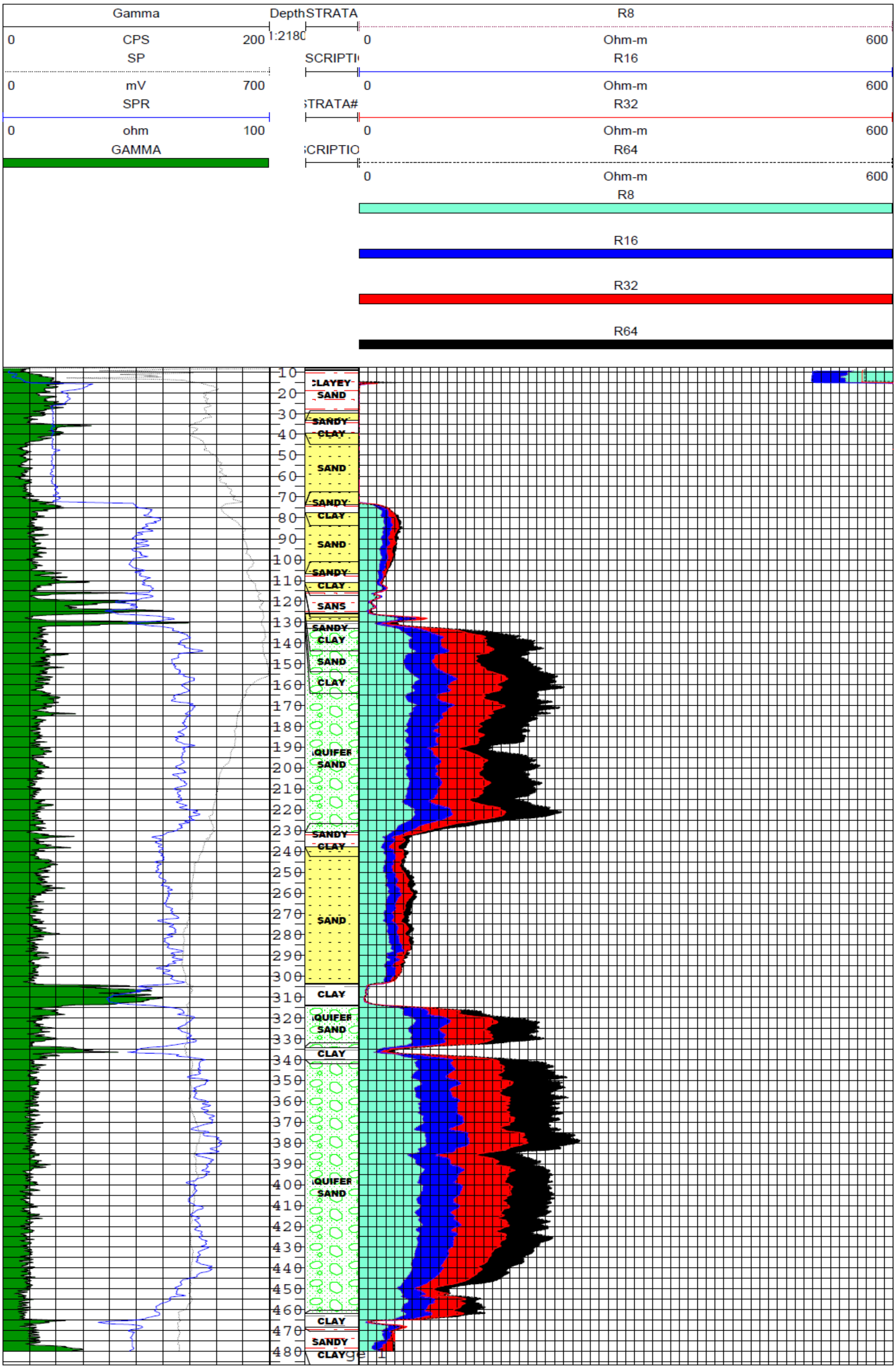

Figure 4.48: Kula Rivers State Borehole log

4.6.5 Tunu Flow Station Borehole log.

A borehole of 270m was drilled at Tunu Bayelsa State in the salt water swamps of the coastal areas of the Niger Delta. The gamma and electric logs for this well delineated six aquifer zones. However the resistivity log showed salt water contamination in the upper aquifers. The first aquifer is from 10m to 30m with a thickness of 20m and an average resistivity of 2.0 Ohm-m. The second aquifer is from 35m to 90m with a thickness of 55m and an average resistivity of 15 Ohm-m. The third aquifer is from 98m to 102m with a thickness of 4m and an average resistivity of 15.1 Ohm-m. The fourth aquifer is from 111m to 150m with a thickness of 39m and an average resistivity of 13 Ohm-m. The fifth aquifer is from 157m to 177m with a thickness of 20m and an average resistivity of 48 Ohm-m. The sixth aquifer is from 191m to 268m with a thickness of 77m and an average resistivity of 48 Ohm-m.

The gamma and electric logs of the Kula borehole is shown is figure 4.49.

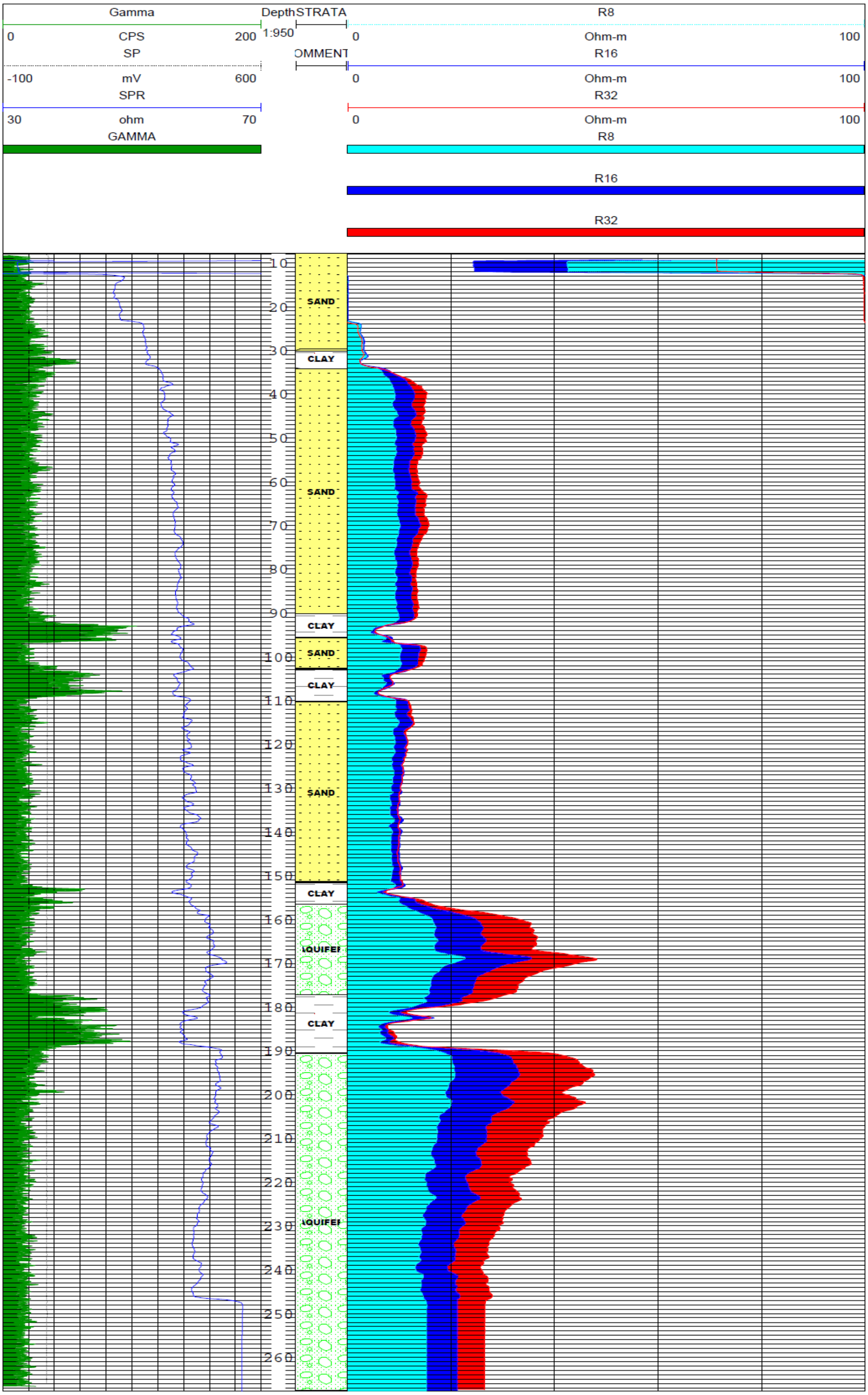

Figure 4.49: Tunu Bayelsa State Borehole log

4.6.6 Ogheye Delta State Borehole log.

A borehole of 120m was drilled at Ogheye Delta State in the salt water swamps of the coastal areas of the Niger Delta. The gamma and electric logs for this well delineated one fresh water aquifer. The area from 0m to 75m indicated very low resistivity zone. The resistivity of the clayey salt water zone was between 3 Ohm-m to 12Ohm-m. The fresh water aquifer was from 75m to 110m with a thickness of 35m. The resistivity of the fresh water aquifer was 67 Ohm-m

The gamma and electric logs of the Ogheye Delta State borehole is shown is figure 4.50.

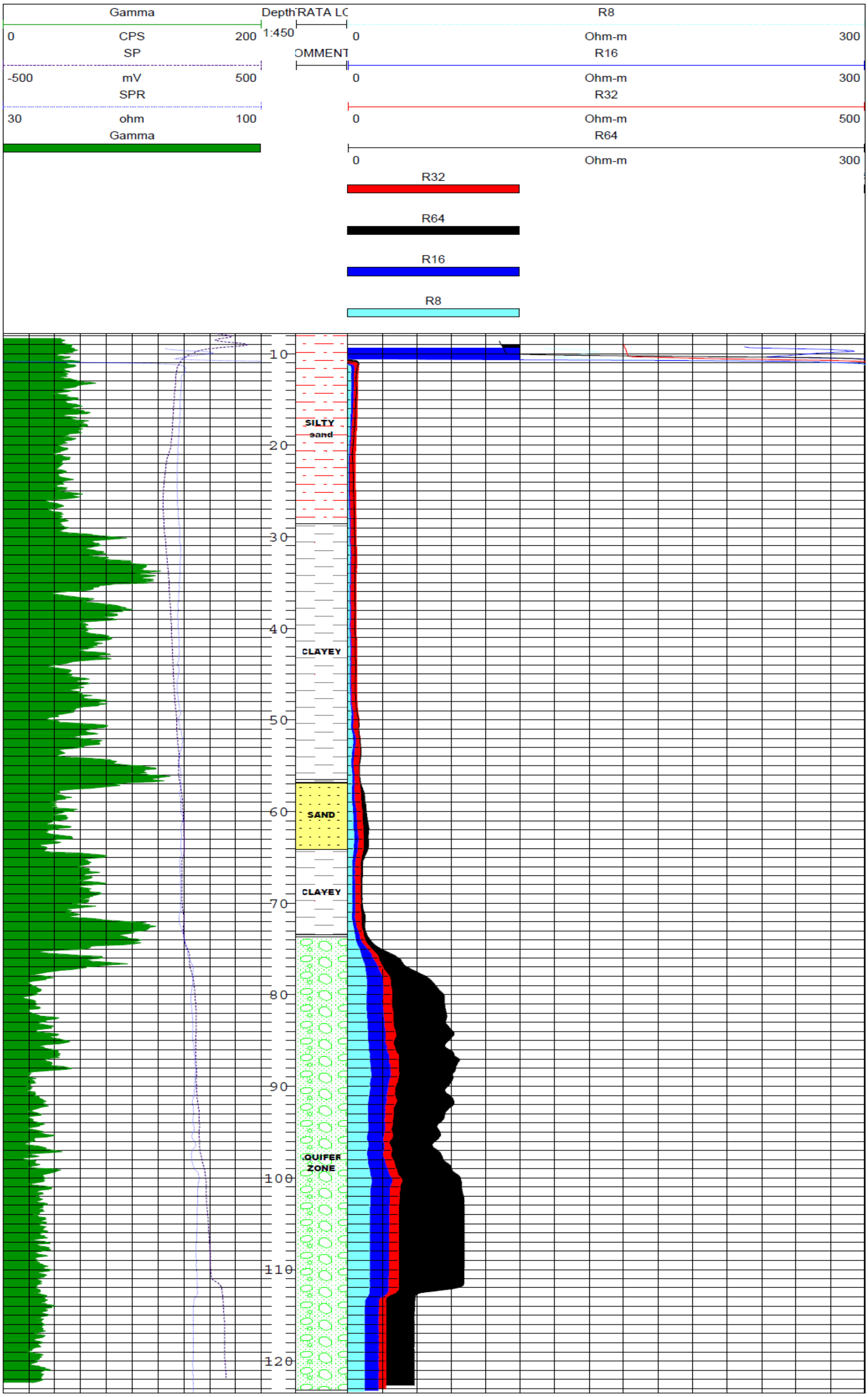

Figure 4.50: Ogheye Delta State Borehole log

4.6.7 Abealala Ondo State Borehole log.

A borehole of 400m was drilled at Abealala Ondo State in the salt water swamps of the coastal areas of the Niger Delta. The gamma and electric logs for this well delineated nine aquifer zones. The first aquifer is from 27m to 55m with a thickness of 28m and an average resistivity of 5.0 Ohm-m. The second aquifer is from 63m to 84m with a thickness of 21m and an average resistivity of 4.2 Ohm-m. The third aquifer is from 104m to 116m with a thickness of 12m and an average resistivity of 3.7 Ohm-m. The fourth aquifer is from 130m to 228m with a thickness of 98m and an average resistivity of 5.0 Ohm-m. The fifth aquifer is from 232m to 256m with a thickness of 24m and an average resistivity of 3.9 Ohm-m. The sixth aquifer is from 261m to 298m with a thickness of 37m and an average resistivity of 3.7 Ohm-m. The seventh aquifer is from 301m to 318m with a thickness of 17m and an average resistivity of 3.8 Ohm-m. The eight aquifer is from 346m to 353m with a thickness of 7m and an average resistivity of 24 Ohm-m. The tenth aquifer is from 369m to 400m with a thickness of 31m and an average resistivity of 85.5 Ohm-m.

The gamma and electric logs of the Abealala Ondo State borehole is shown is fig.4.51.

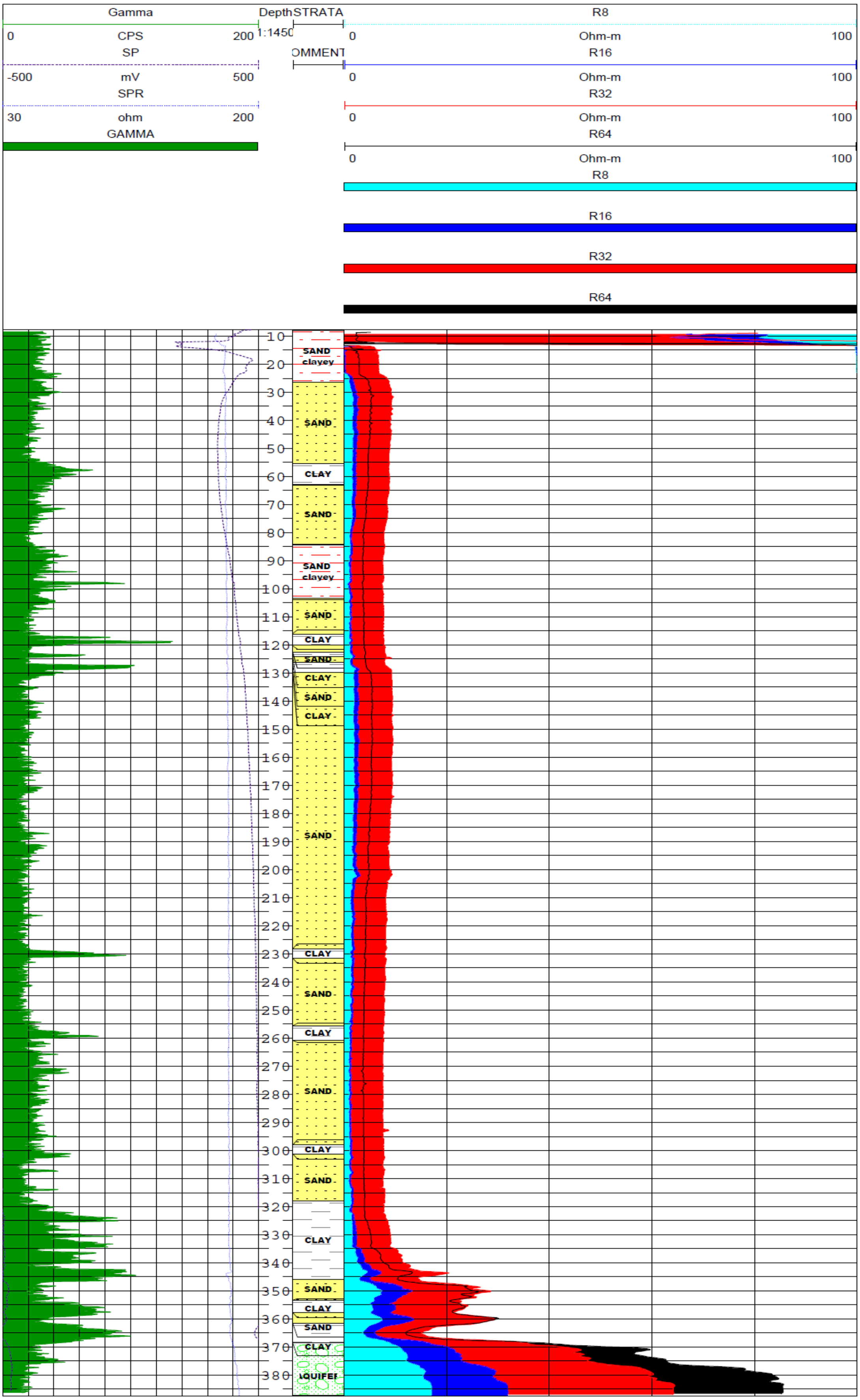

Figure 4.51: Abealala Ondo State Borehole log

4.6.8 Adoloseimo Ondo State Borehole log.

A borehole of 160m was drilled at Adoloseimo Ondo State in the salt water swamps of the coastal areas of the Niger Delta. The gamma and electric logs for this well delineated seven aquifer zones. The first aquifer is from 40m to 44m with a thickness of 4m and an average resistivity of 8.0 Ohm-m. The second aquifer is from 52m to 71m with a thickness of 19m and an average resistivity of 18.8 Ohm-m. The third aquifer is from 80m to 88m with a thickness of 8m and an average resistivity of 83.2 Ohm-m. The fourth aquifer is from 96m to 111m with a thickness of 15m and an average resistivity of 229.3 Ohm-m. The fifth aquifer is from 115m to 123m with a thickness of 8m and an average resistivity of 123 Ohm-m. The sixth aquifer is from 126m to 136m with a thickness of 10m and an average resistivity of 117 Ohm-m. The seventh aquifer is from 140m to 160m with a thickness of 20m and an average resistivity of 224 Ohm-m.

The gamma and electric logs of the Adoloseimo Ondo State borehole is shown is figure 4.52.

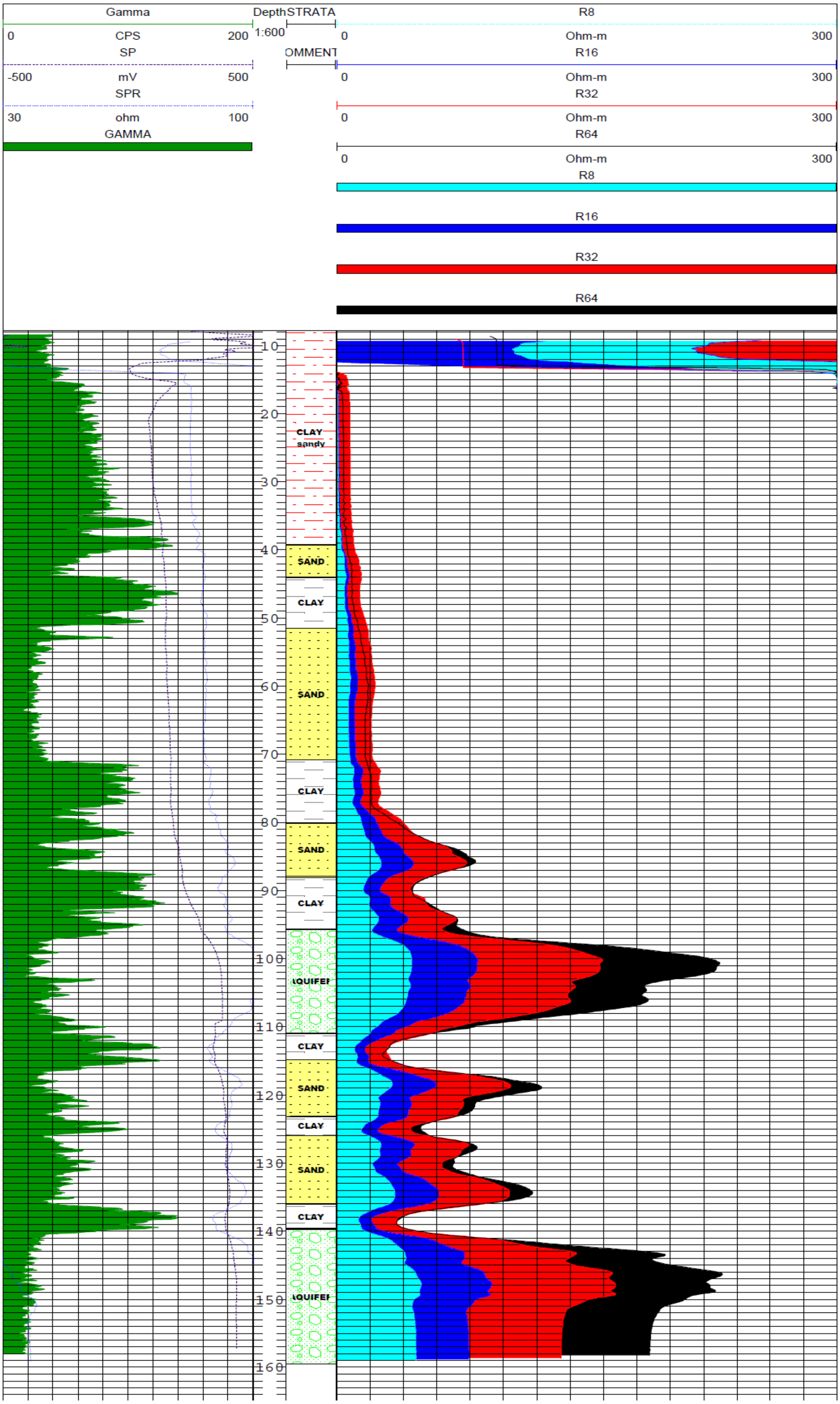

Figure 4.52: Adoloseimo Ondo State Borehole log

4.6.9 Ayetoro Ondo State Borehole log.

A borehole of 200m was drilled at Ayetoro Ondo State in the salt water swamps of the coastal areas of the Niger Delta. The gamma and electric logs for this well delineated six aquifer zones. The first aquifer is from 40m to 60m with a thickness of 20m and an average resistivity of 8.0 Ohm-m. The second aquifer is from 64m to 76m with a thickness of 12m and an average resistivity of 14 Ohm-m. The third aquifer is from 90m to 100m with a thickness of 10m and an average resistivity of 11 Ohm-m. The fourth aquifer is from 101m to 120m with a thickness of 19m and an average resistivity of 7 Ohm-m. The fifth aquifer is from 140m to 154m with a thickness of 14m and an average resistivity of 15 Ohm-m. The sixth aquifer is from 160m to 200m with a thickness of 40m and an average resistivity of 21 Ohm-m.

The gamma and electric logs of the Ayetoro Ondo State borehole is shown is fig.4.53.

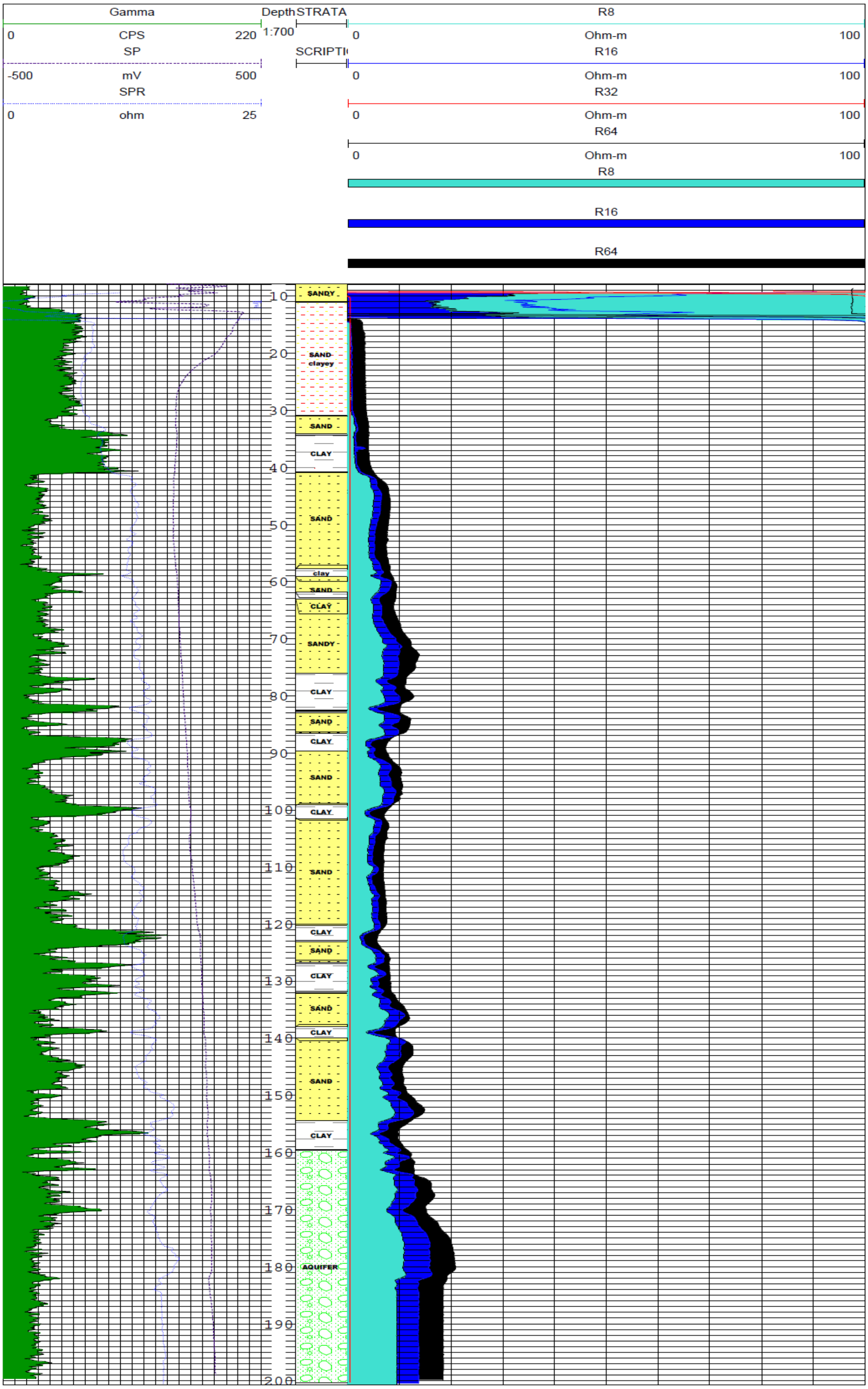

Figure 4.53: Ayetoro Ondo State Borehole log

4.6.10 Akpata Ijaw Ondo State Borehole log.

A borehole of 180m was drilled at Akpata Ijaw Ondo State in the salt water swamps of the coastal areas of the Niger Delta. The gamma and electric logs for this well delineated five aquifer zones. The first aquifer is from 50m to 58m with a thickness of 8m and an average resistivity of 7.7 Ohm-m. The second aquifer is from 63m to 72m with a thickness of 9m and an average resistivity of 17 Ohm-m. The third aquifer is from 80m to 90m with a thickness of 10m and an average resistivity of 37 Ohm-m. The fourth aquifer is from 95m to 114m with a thickness of 19m and an average resistivity of 100.8 Ohm-m. The fifth aquifer is from 121m to 136m with a thickness of 15m and an average resistivity of 91.8 Ohm-m.

The gamma and electric logs of the Akpata Ijaw Ondo State borehole is shown is figure 4.54.

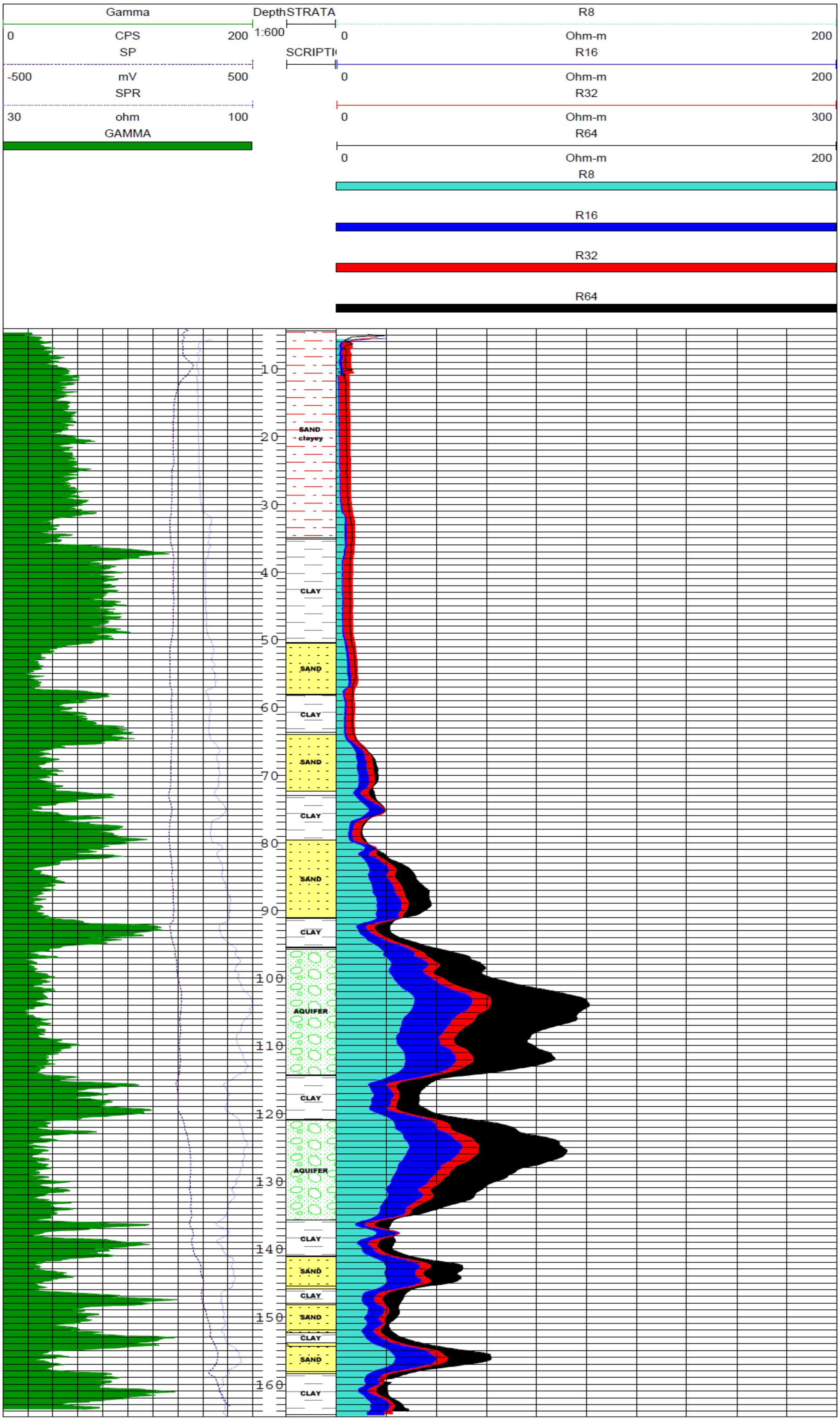

Figure 4.54: Akpata Ijaw Ondo State Borehole log

4.6.11 Eruna Ondo State Borehole log.

A borehole of 400m was drilled at Eruna Ondo State in the salt water swamps of the coastal areas of the Niger Delta. The gamma and electric logs for this well delineated seven aquifer zones. The first aquifer is from 67m to 83m with a thickness of 16m and an average resistivity of 11.3 Ohm-m. The second aquifer is from 163m to 175m with a thickness of 12m and an average resistivity of 19.4 Ohm-m. The third aquifer is from 179m to 187m with a thickness of 8m and an average resistivity of 19.6 Ohm-m. The fourth aquifer is from 189m to 195m with a thickness of 6m and an average resistivity of 18.5 Ohm-m. The fifth aquifer is from 196m to 228m with a thickness of 32m and an average resistivity of 21.9Ohm-m. The sixth aquifer is from 235m to 320m with a thickness of 85m and an average resistivity of 16.7 Ohm-m. The seventh aquifer is from 340m to 400m with a thickness of 60m and an average resistivity of 8.1 Ohm-m.

The gamma and electric logs of the Eruna Ondo State borehole is shown is figure 4.55.

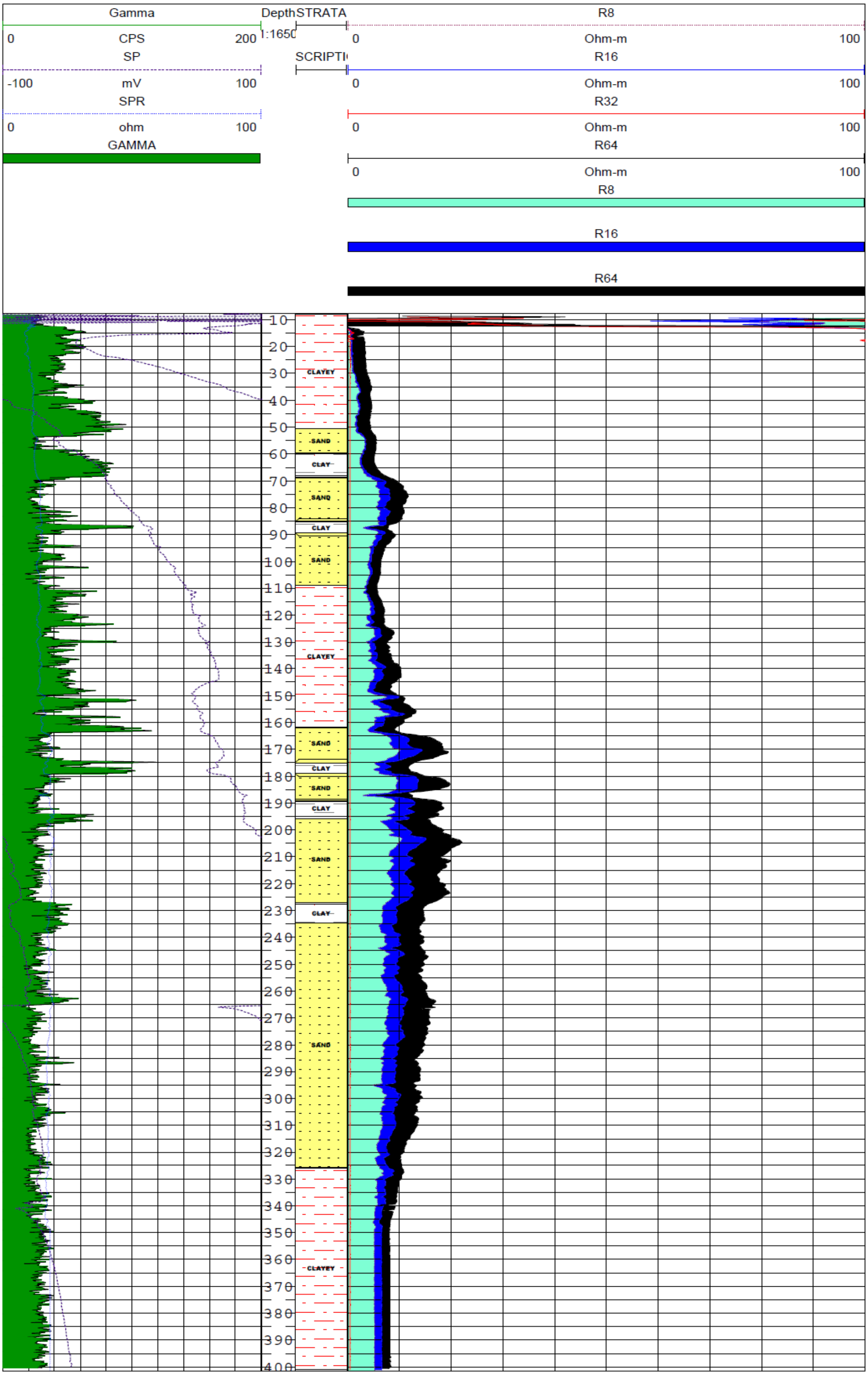

Figure 4.55: Eruna Ondo State Borehole log

4.6.12 IdogunAyadi Ondo State Borehole log.

A borehole of 400m was drilled at IdogunAyadi Ondo State in the salt water swamps of the coastal areas of the Niger Delta. The gamma and electric logs for this well delineated eight aquifer zones. The first aquifer is from 32m to 46m with a thickness of 14m and an average resistivity of 8.7 Ohm-m. The second aquifer is from 48m to 62m with a thickness of 14m and an average resistivity of 10.2 Ohm-m. The third aquifer is from 80m to 98m with a thickness of 18m and an average resistivity of 11.2 Ohm-m. The fourth aquifer is from 106m to 126m with a thickness of 20m and an average resistivity of 9.7 Ohm-m. The fifth aquifer is from 184m to 210m with a thickness of 26m and an average resistivity of 6.7 Ohm-m. The sixth aquifer is from 212m to 232m with a thickness of 20m and an average resistivity of 7.06 Ohm-m. The seventh aquifer is from 237m to 320m with a thickness of 83m and an average resistivity of 12.2 Ohm-m. The eighth aquifer is from 325m to 400m with a thickness of 75m and an average resistivity of 4.4 Ohm-m.

The gamma and electric logs of the IdogunAyadi Ondo State borehole is shown is fig.4.56.

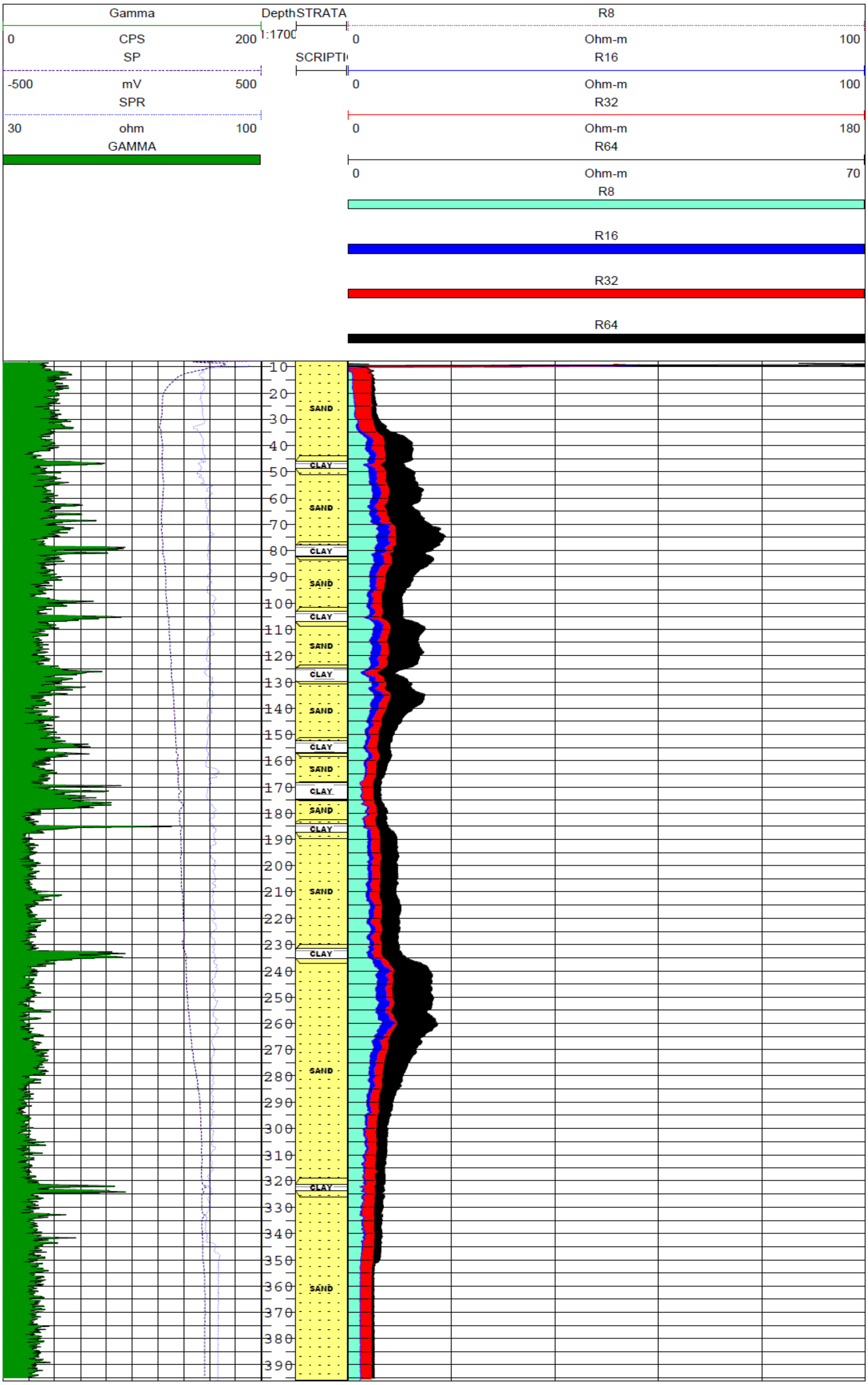

Figure 4.56: IdogunAyadi Ondo State Borehole log

4.6.13 Jiririnwo Ondo State Borehole log.

A borehole of 230m was drilled at Jiririnwo Ondo State in the salt water swamps of the coastal areas of the Niger Delta. The gamma and electric logs for this well delineated six aquifer zones. The first aquifer is from 51m to 59m with a thickness of 8m and an average resistivity of 5.5 Ohm-m. The second aquifer is from 70m to 77m with a thickness of 7m and an average resistivity of 5.4 Ohm-m. The third aquifer is from 83m to 100m with a thickness of 17m and an average resistivity of 5.1 Ohm-m. The fourth aquifer is from 115m to 126m with a thickness of 11m and an average resistivity of 19.0 Ohm-m. The fifth aquifer is from 130m to 144m with a thickness of 14m and an average resistivity of 49.2 Ohm-m. The sixth aquifer is from 170m to 183m with a thickness of 13m and an average resistivity of 53.3 Ohm-m.

The gamma and electric logs of the Jiririnwo Ondo State borehole is shown is fig.4.57.

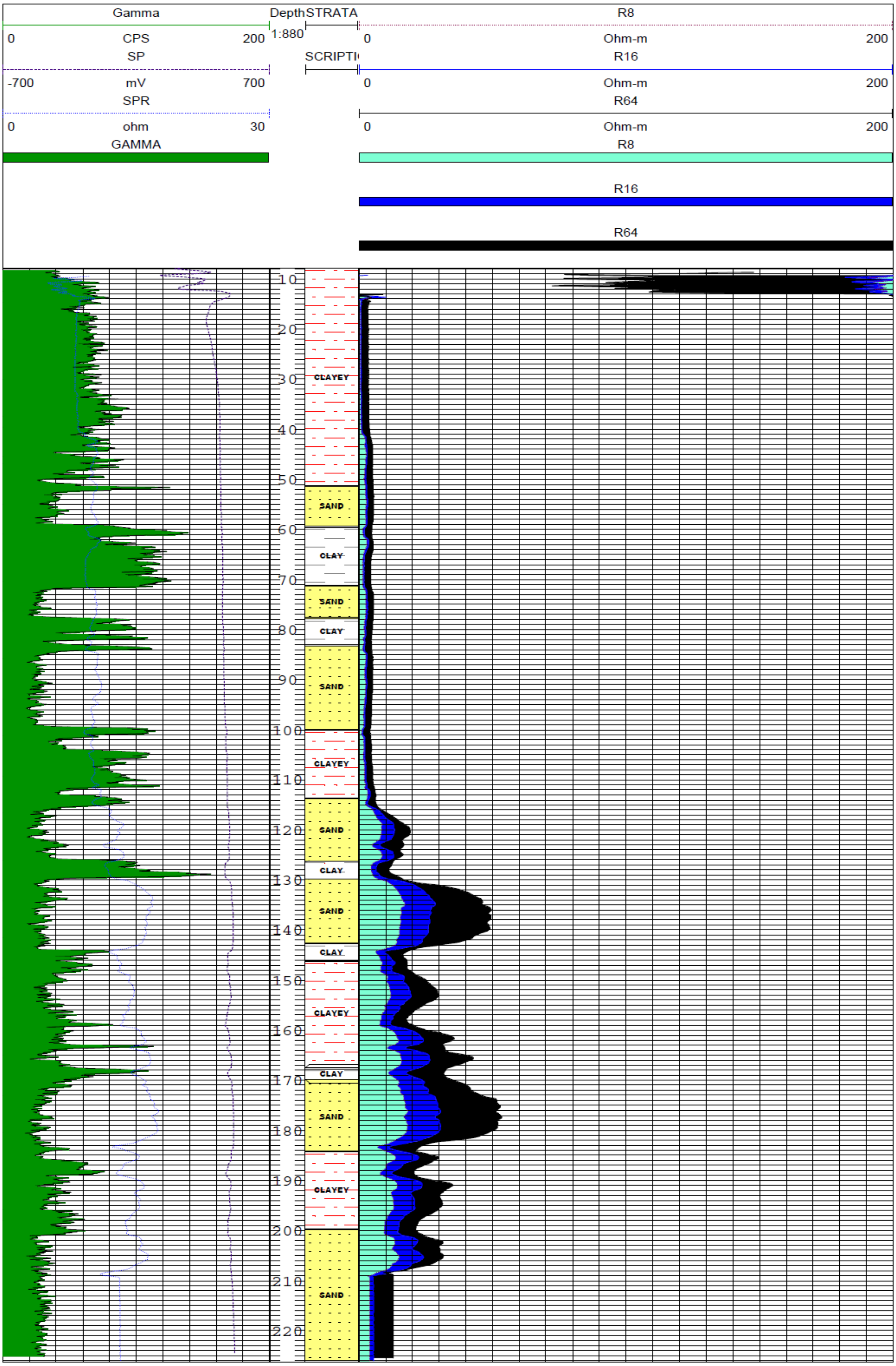

Figure 4.57: Jiririnwo Ondo State Borehole log

4.7 Aquifers in the Coastal Beaches/Ridges.

The coastal beaches and abandoned ridges have the deepest boreholes in the coastal areas of the Niger delta. The shallow aquifers in this depositional environment are heavily contaminated by saline water intrusion. The option is to drill deep boreholes that will probably cross the contaminated aquifers and get to fresh water aquifers. .Even the fresh water aquifers most times contain water that has ferrous iron in solution that gets oxidized to ferric iron on exposure to atmospheric oxygen and the water thereafter turns brownish..

Several boreholes were drilled and logged using gamma ray and electric logs in the geomorphologic zone.

4.7.1 Borehole at Oguede Bonny.

This well was drilled to a depth of 452m at Oguede, Bonny. The geophysical logs appear as Figure 4.58. The well was already cased with steel casings and cemented up to 280m. The resistivity logs were only effective below 280m where the steel casings stopped.

The logs reveal a significant difference between the nature of subsurface sequence at in the Bonny area. The gamma log revealed that the area is underlain by 5 saturated sand bodies up to the depth of 452m. The fresh water aquifers started from 280m to 310m with a resistivity of 554 Ohm-m. A layer of 10m of clay separated this aquifer from the next one from 320m to 380m with a resistivity of 554 Ohm-m. Another 12m of clay separated the next aquifer from 392m to 406m with a resistivity of 526 Ohm-m. The third aquifer was from 410m to 420m with a resistivity of 446 Ohm-m. The lower aquifer was from 430m to 450m with resistivity of 560 Ohm-m. The ferrous iron contamination in this well is very minimal with resistivity values approaching the threshold of 600 Ohm-m.

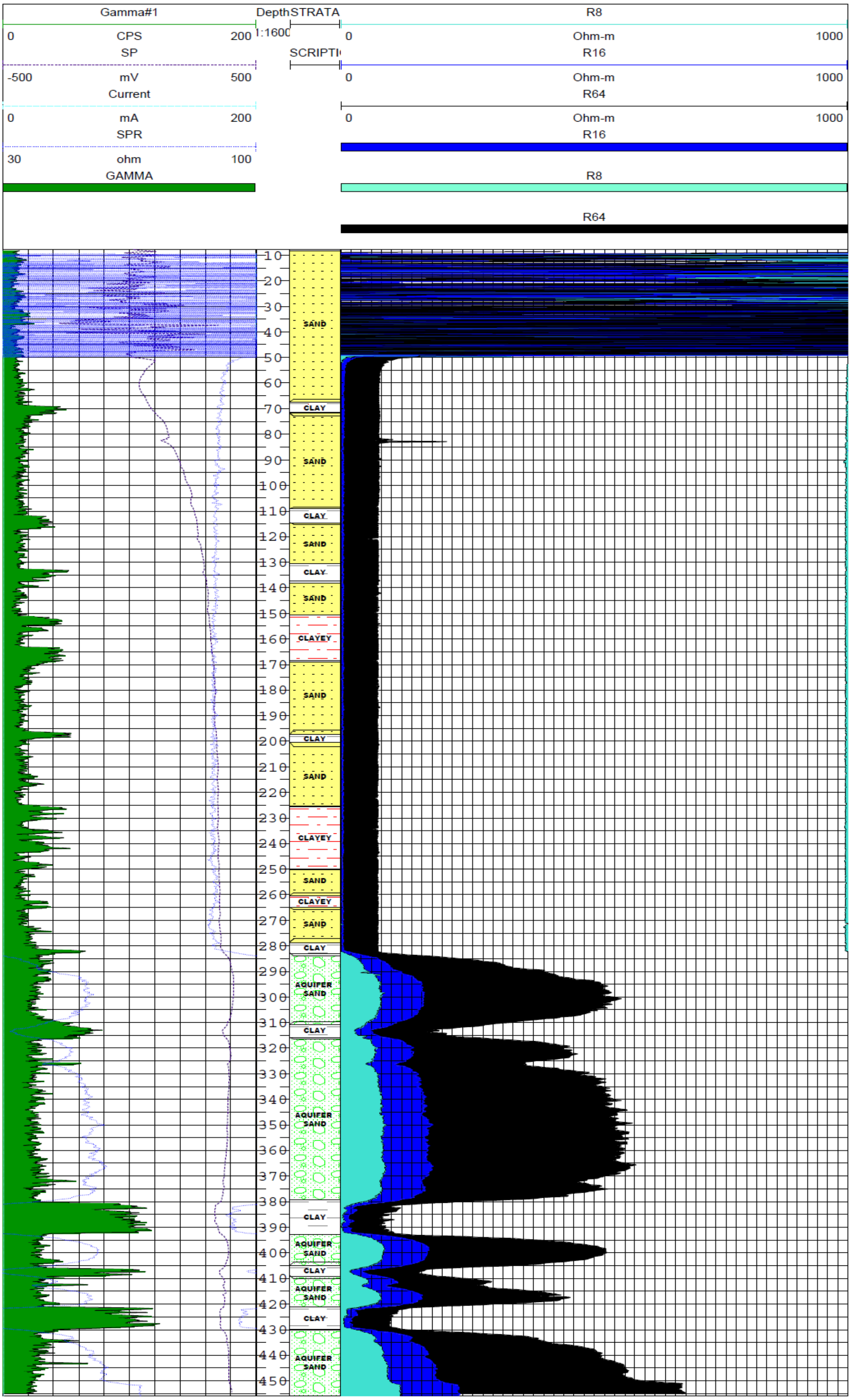

Figure 4.58: Oguede, Bonny Borehole Log

4.7.2 450m Deep Borehole at Finima Water Board

This well was drilled to a depth of 450m. The lithological successions were inferred from the gamma ray and electric logs shown in Figure 4.59.

The area is underlain by 9 saturated sand bodies upto the depth of 450m. The gamma log properly delineated the sand bodies. Six of the aquifers occur within the first 300m. From the resistivity logs, the aquifers are saturated with saline water from 0 - 220m. The fresh water aquifers are: 220m to 233m with resistivity of 50 Ohm-m, 239m to 250m with resistivity of 139 Ohm-m, 253m to 261m with resistivity of 64 Ohm-m, 261m to 285m with resistivity of 96 Ohm-m, 296m to 346m with a resistivity of 350 Ohm-m, 350m to 370m with resistivity of 288 Ohm-m, 375m to 380m with resistivity of 196 Ohm-m, 385m to 400m with a resistivity of 312 Ohm-m, and from 410m to 430m with a resistivity of 317 Ohm-m. The aquifers are properly separated by clay layers.

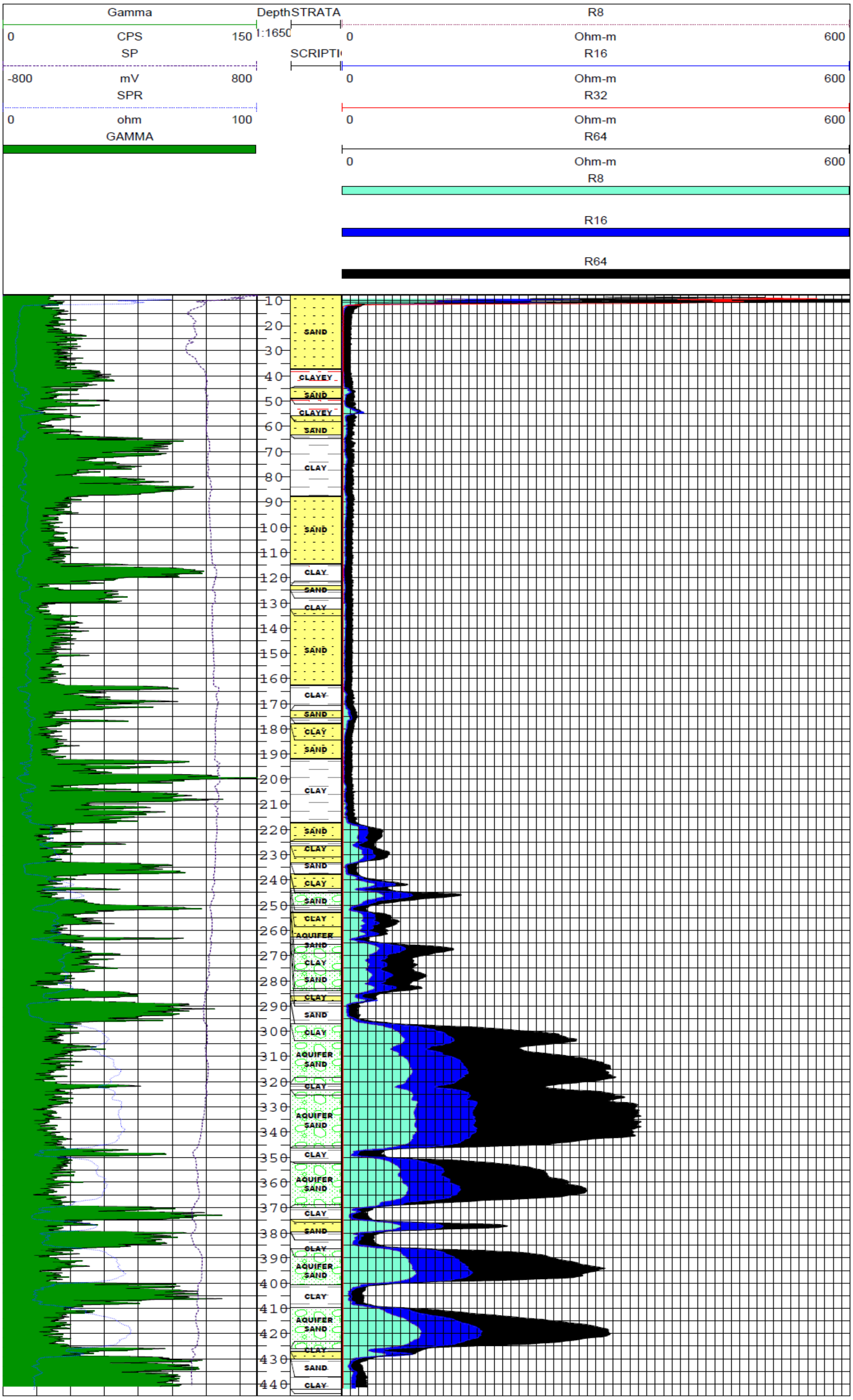

Figure 4.59: Finima Borehole Log

4.7.3 Deep Water Borehole at Bonny River Terminal Shell Facility

A 600m deep borehole was drilled for SHELL at BONNY BRT Nigeria. The borehole is one of the deepest known water boreholes in the Niger Delta. The gamma log reveals the following strata succession; Figure 4.60 is the log of the well. Table 4.4 is aquifer and resistivity values extracted from the log. From the table, the area is underlain by about 18 saturated sand bodies up to the depth of 601m logged. Eight of the aquifers occur within the first 300m while the rest are bellow 300m. Some of the aquifers are very thick stretching for over 20m and some others stretching for over 50m. From the resistivity logs, the aquifers are saturated with saline water from 0 – 140m. The resistivity values of the saline water environment between 0-140m are less than 10 Ohm-m. The salt water aquifer boundary for this area is 140m. The resistivity values of the aquifers from 140-601m ranged from 25 Ohm-m to 246 Ohm-m. The aquifers occurring between 140m and 600m contain water freshwater but contaminated by ferrous Iron..

Table 4.3: Aquifer and resistivity values for the 600m deep borehole at SHELL, BITP, Bonny

'Depth interval (m)	Resistivity values(Ohm-m)	Thickness of bed (m)
0 - 54	‹ 5	54
54 -120	‹ 10	66
122 -134	‹ 10	12
140- 150	25	10
154 -172	28	18
182 -212	160	30
214 -218	43	4
220-230	132	10
253-264	59	11
266-276	128	10
277-282	62	5
292-322	235	30
324-332	143	8
336-386	160	50
388-396	159	8
398-412	170	14
430-464	170	34
478-494	178	16
500-522	218	22
528-574	246	46
580-588	214	8

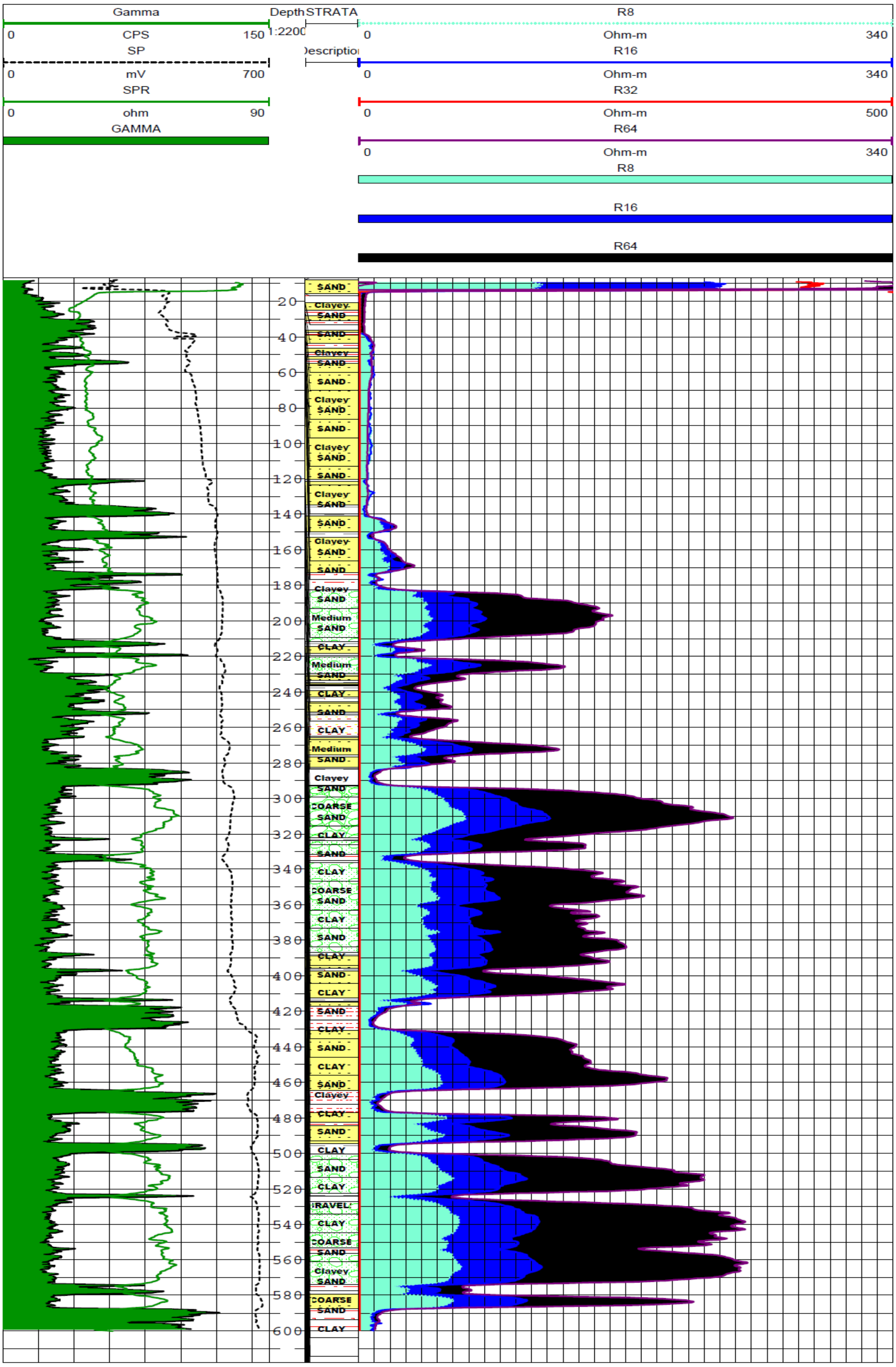

Figure 4.60: Bonny Shell Terminal Deep Borehole Log

4.7.4 Deep Water Borehole at Brass

A deep borehole of 310m was drilled for Brass NLNG in the Coastal ridges depositional environment of the Niger Delta Nigeria. From the gamma and electric logs carried out on this well, twelve aquifers were identified. The first aquifer is from 9.5m to 15m with a thickness of 5.5m and peak resistivity of 146 Ohm-m. The second aquifer is from 24m to 30m with a thickness of 6m and peak resistivity of 15.8 Ohm-m. The third aquifer is from 35m to 48m with a thickness of 13m and peak resistivity of 18.1 Ohm-m. The fourth aquifer is from 102m to 112m with a thickness of 10m and peak resistivity of 53 Ohm-m. The fifth aquifer is from 136m to 148m with a thickness of 12m and peak resistivity of 90 Ohm-m. The sixth aquifer is from 153m to 167m with a thickness of 14m and peak resistivity of 67 Ohm-m. The seventh aquifer is from 172m to 177m with a thickness of 5m and peak resistivity of 76.3 Ohm-m. The eighth aquifer is from 193m to 196m with a thickness of 3m and peak resistivity of 65 Ohm-m. The ninth aquifer is from 200m to 205m with a thickness of 5m and peak resistivity of 50 Ohm-m. The tenth aquifer is from 214m to 219m with a thickness of 5m and peak resistivity of 124 Ohm-m. The eleventh aquifer is from 222m to 240m with a thickness of 18m and peak resistivity of 154 Ohm-m. The twelfth aquifer is from 243m to 306m with a thickness of 63m and peak resistivity of 152 Ohm-m. Figure 4.61 is the log of the well.

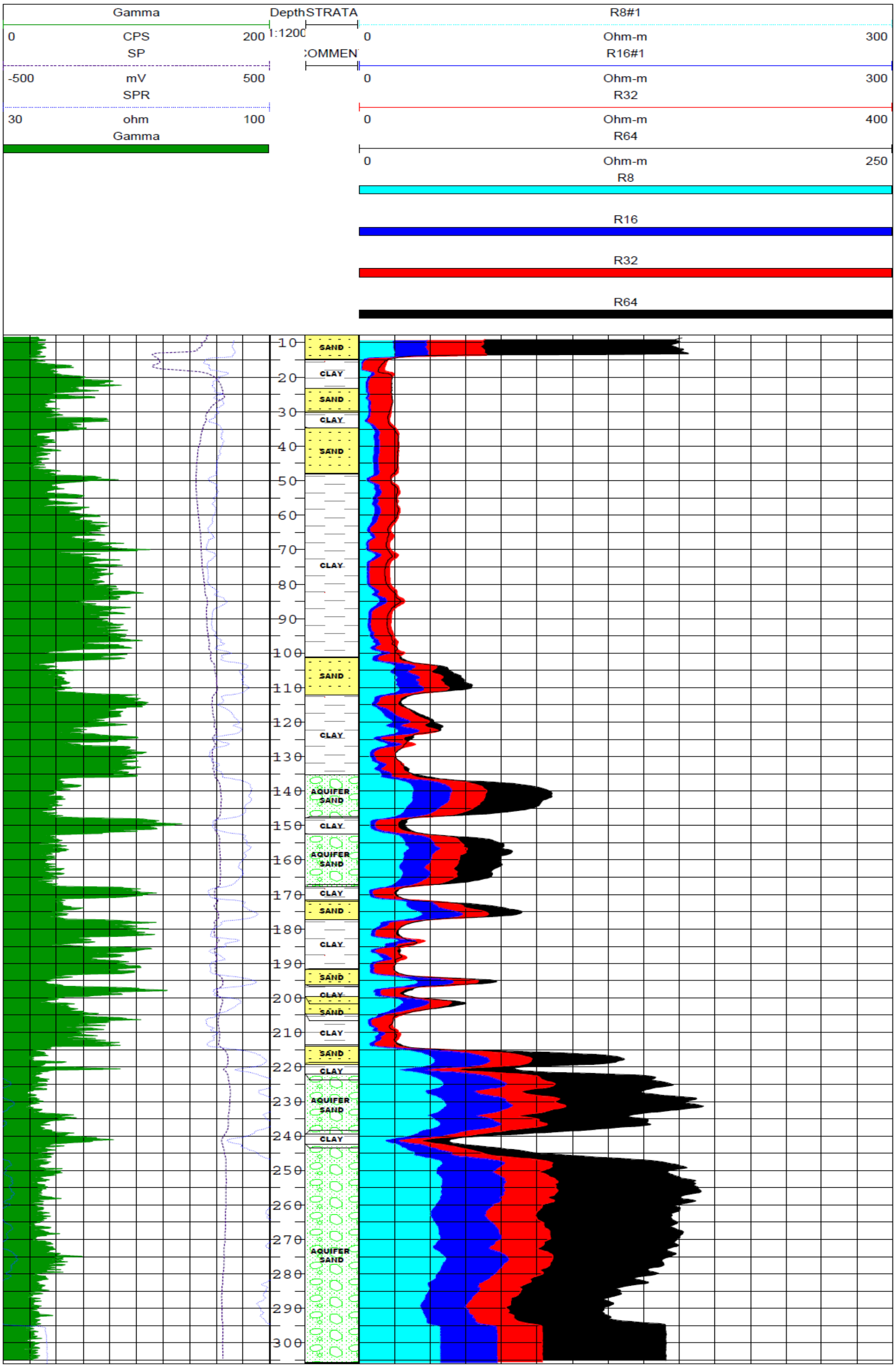

Figure 4.61: Brass NLNG Deep Borehole Log

4.7.5 Deep Water Borehole at Ogidigben

A deep borehole of 580m was drilled for the Ogidigben community, Escavos in the Coastal ridges depositional environment of the Niger Delta Nigeria. From the gamma and electric logs carried out on this well, the upper zones from 60m to 290m indicated sandy environment with clay intercalates. The resistivity of this zone was very low indicative of saline water intrusion. From 415m to 434m was the first major aquifer with thickness of 19m and a peak resistivity of 108 Ohm-m. From 450m to 516m was the second major aquifer with thickness of 66m and a peak resistivity of 108 Ohm-m. From 537m to 580m was the third major aquifer with thickness of 43m and a peak resistivity of 171 Ohm-m.

Figure 4.62 is the log of the Ogidigben well.

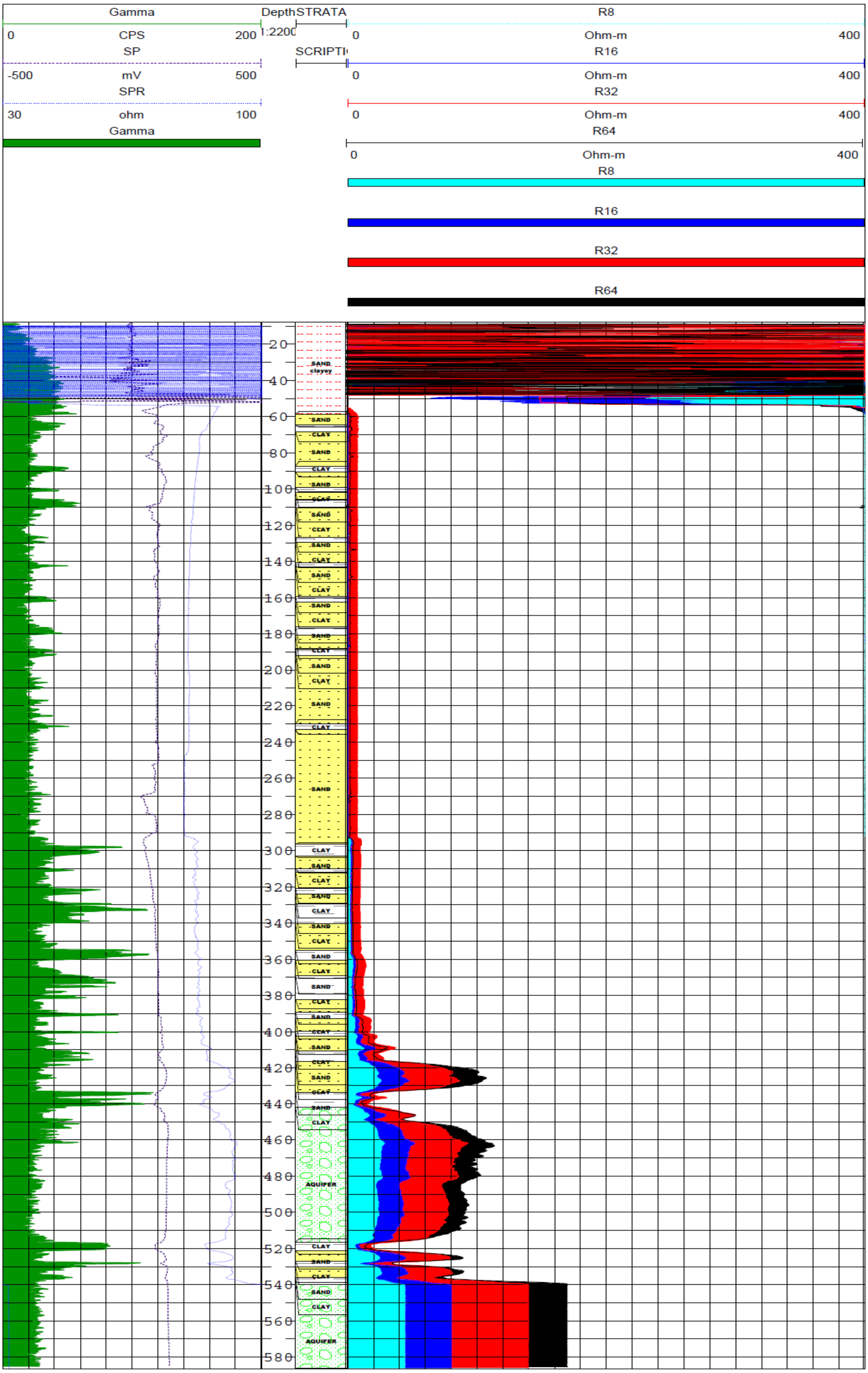

Figure 4.62 Ogidigben Deep Borehole Log

4.8 Borehole Depths

The 2D plot of borehole depth is shown in figure 4.63. The Total Drill Depth (TDD) of Boreholes within the study area ranges from 80 to 600m. The deepest boreholes were encountered around Ogigiben area of Delta State, Bille area, Bonny Terminal and Finima Water Board areas of Rivers State.

Depths to the different aquifer units mapped were plotted on a 2-D map. Three categories of aquifers were delineated as Deep, Medium and Shallow aquifers. Each of the aquifers was considered separately and depths to their tops and bottom were also plotted. The plot of the depth to the top of the deep aquifers within the study area is shown in figure 4.64. Here it was observed that the deepest aquifer within the study area was delineated around the western part of the area with depth exceeding 410m. Similarly, the same location recorded the highest depth to the bottom of the aquifer mapped in the area as the base of the aquifer was observed to occur far beneath 580m (figure 4.65) An average deep aquifer thickness of more than 150 (figure 4.66) was recorded in the study area.

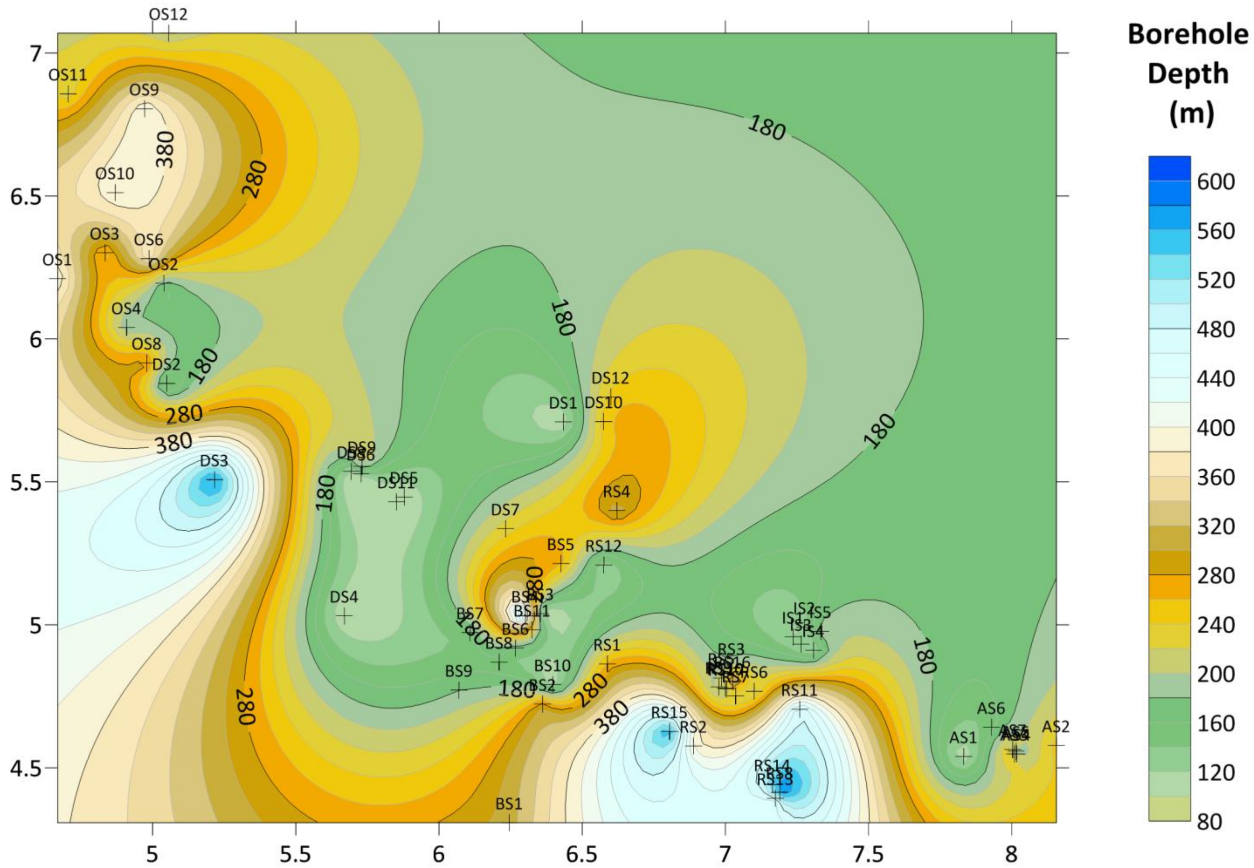

Figure 4.63: Plot of Borehole Depths in the Area

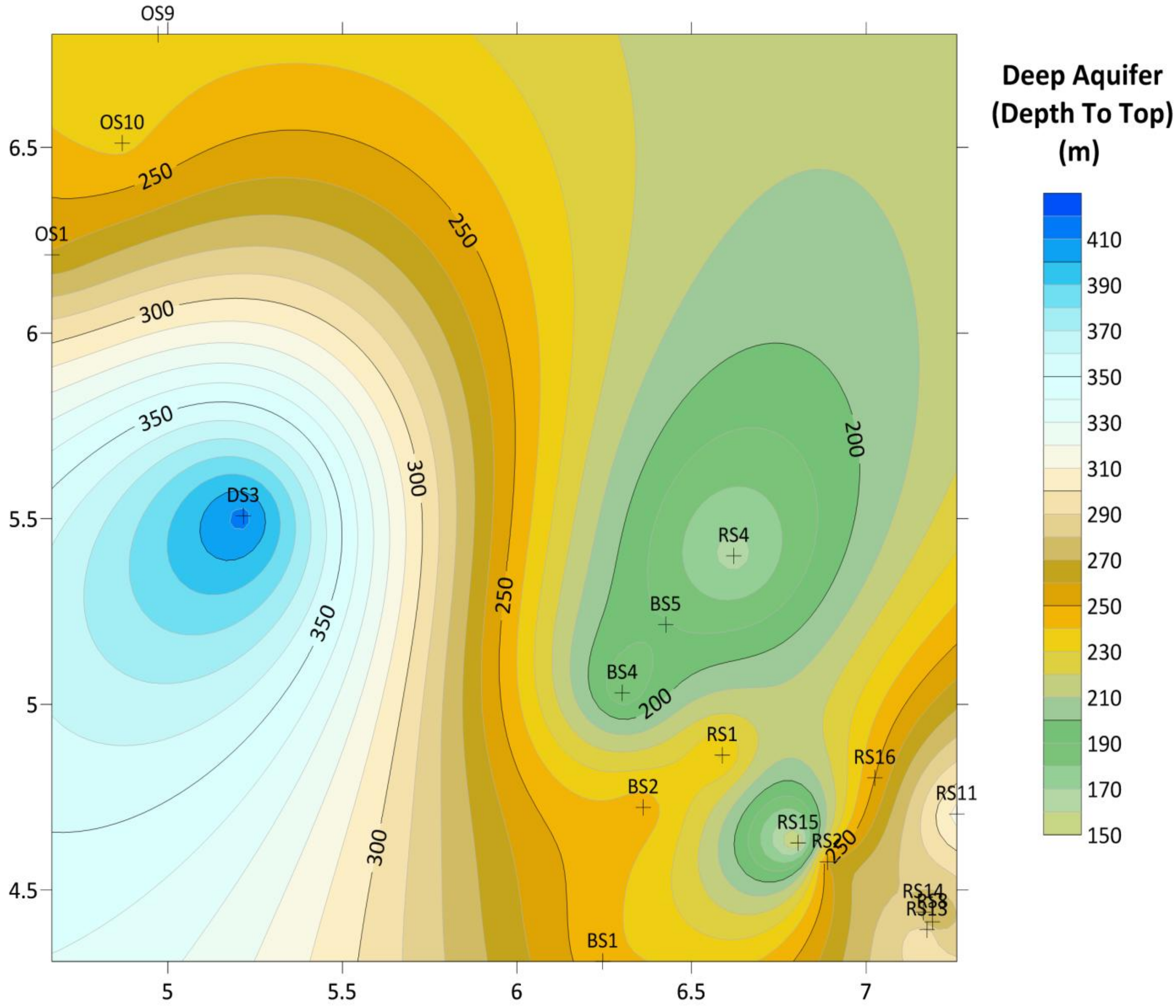

Figure 4.64: Depth to Top of Deep Aquifers

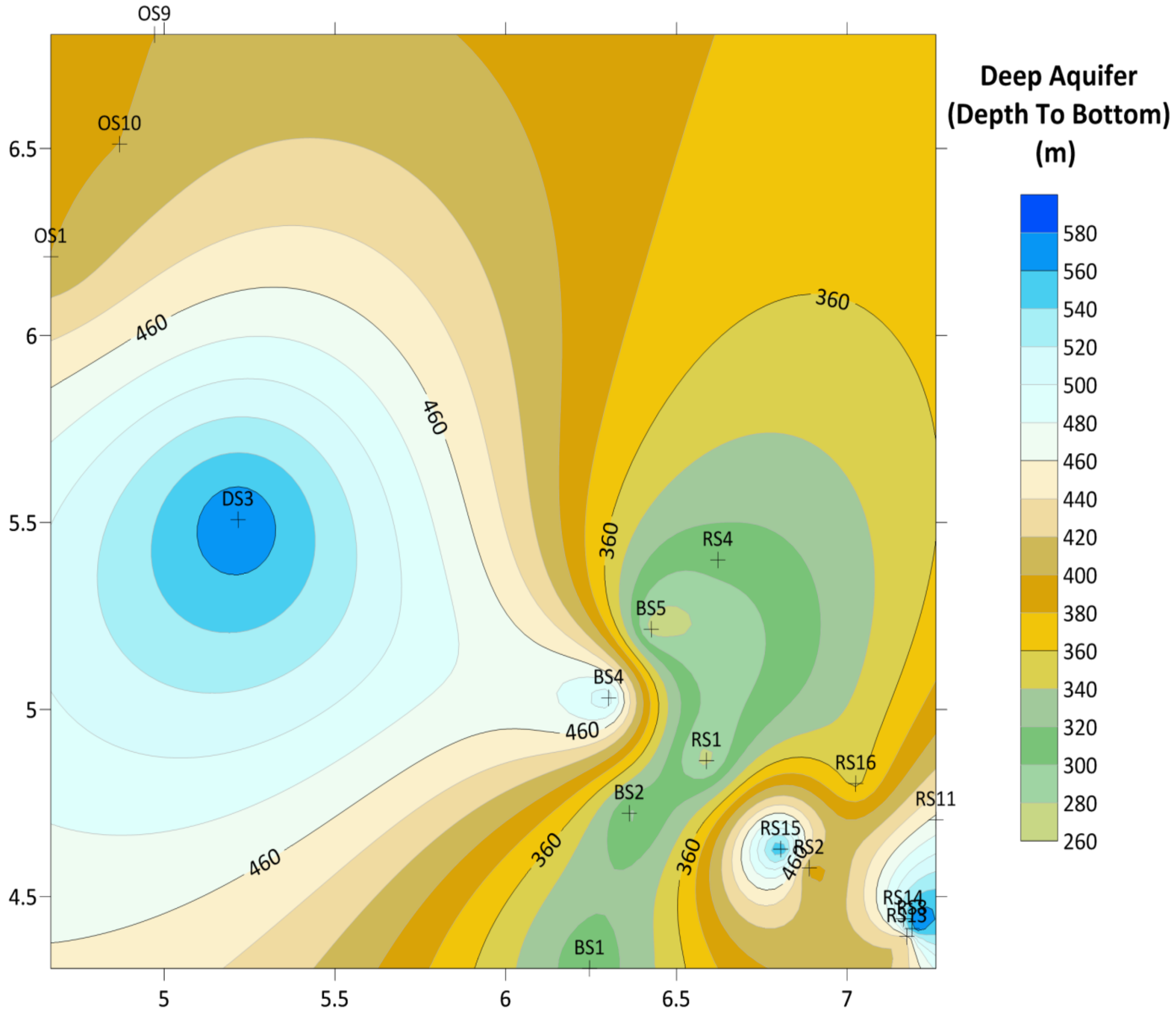

Figure 4.65: Depth to Bottom of Deep Aquifers

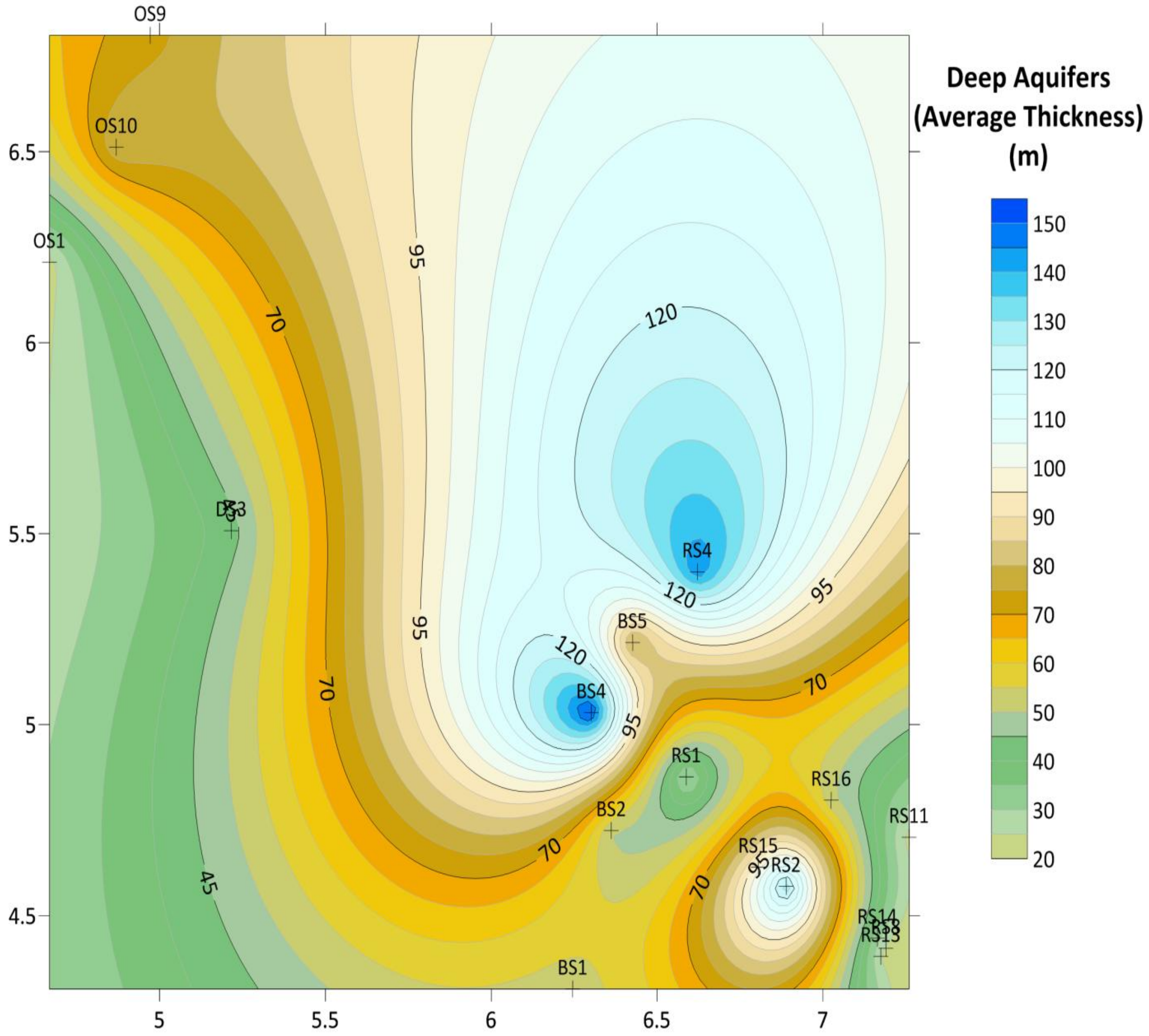

Figure 4.66: Average Thickness of Deep Aquifers

The plot of the depth to the top of the medium aquifers in the area is shown in figure 4.67. The highest depth to the top of the medium aquifers occurred within the Northwestern part of the study area with values greater than 165m corresponding to locations within ErunaIlaje area of Ondo State. The depth to bottom of medium aquifer in the area ranges from 135 to above 260m with the deepest located within Okpai area of Delta State and QIT Ibono location of AkwaIbom State (figure 4.68). The average medium aquifer thickness in the study area ranges from 1m to more than 190m with Owaza area of Abia State recording the thickest medium aquifer in the study area (figure 4.69).

Figure 4.70 shows the plot of the depth to the top of the shallow aquifer units encountered in the study area with range between 5 to 100m. The shallowest top of 5 to 10m was observed as pockets of closures within the central and southern fringes of the study area. These areas corresponded to Kwlae area of Delta State; Oguede Bonny, Ndoni Rivers and Agbada Flow station areas of Rivers State, Otakeme and brass areas of Bayelsa State, as well as Owaza well 4 location in Abia State (figure 4.70). The depth to bottom of shallow aquifer in the area ranges from 25 to over 125m within the northern fringe of the area corresponding to the zone occupied by the Benin Informations (Benin Formation) showing the deepest shallow aquifers greater than 125m (figure 4.71). Pockets of very shallow aquifer were seen disseminated around Okapi IPP area of Delta state, within Bille and Eagle Island locations of Rivers State. The average thickness of the shallow aquifers in the area ranges from 5 to over 105m within Okpai IPP location showing the thickest (figure 4.72).

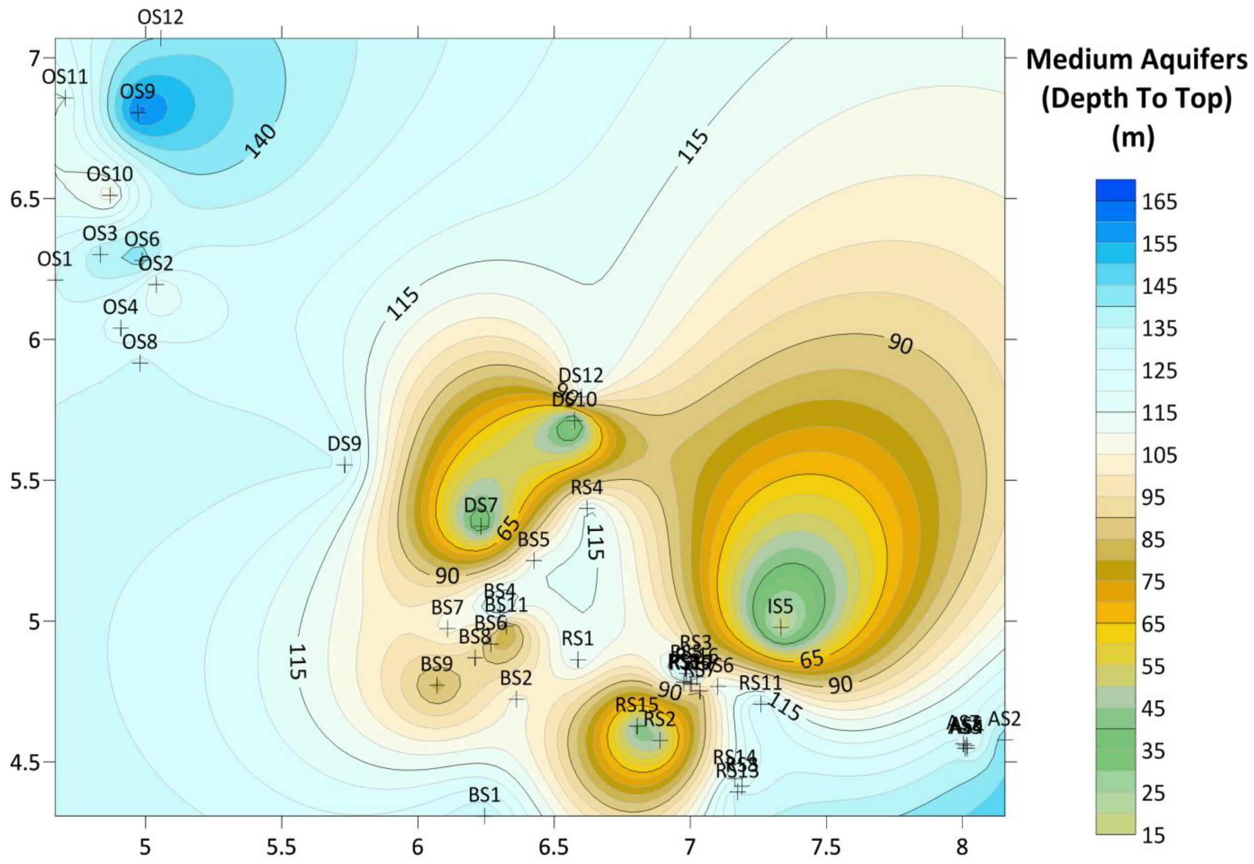

Figure 4.67: Depth to Top of Medium Aquifers

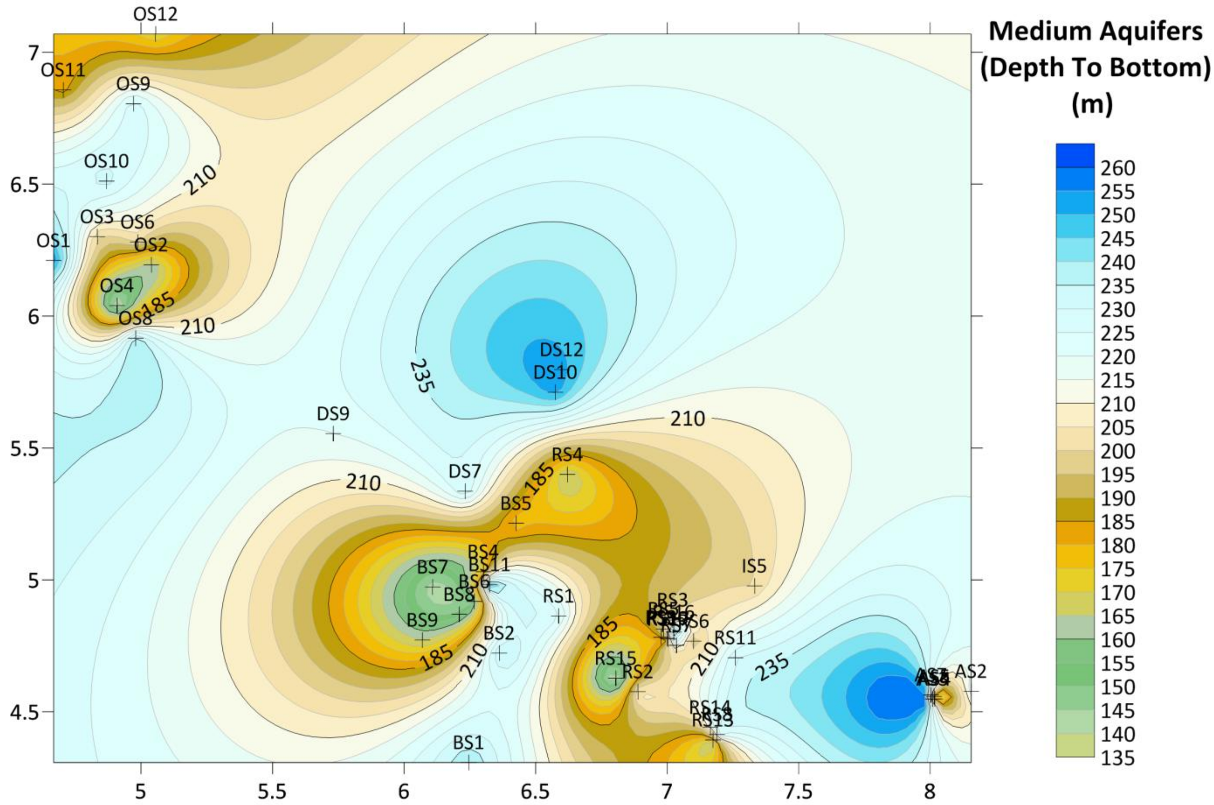

Figure 4.68: Depth to Bottom of Medium Aquifers

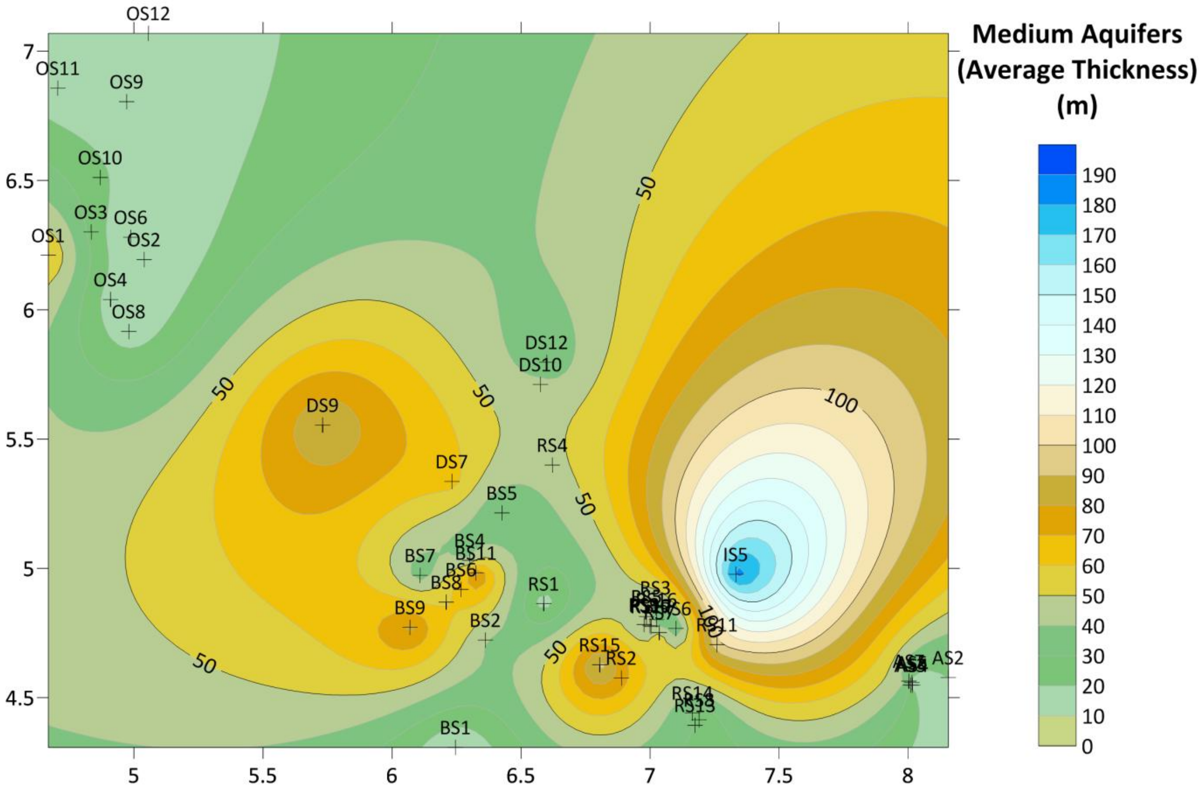

Figure 4.69: Average Thickness of Medium Aquifers

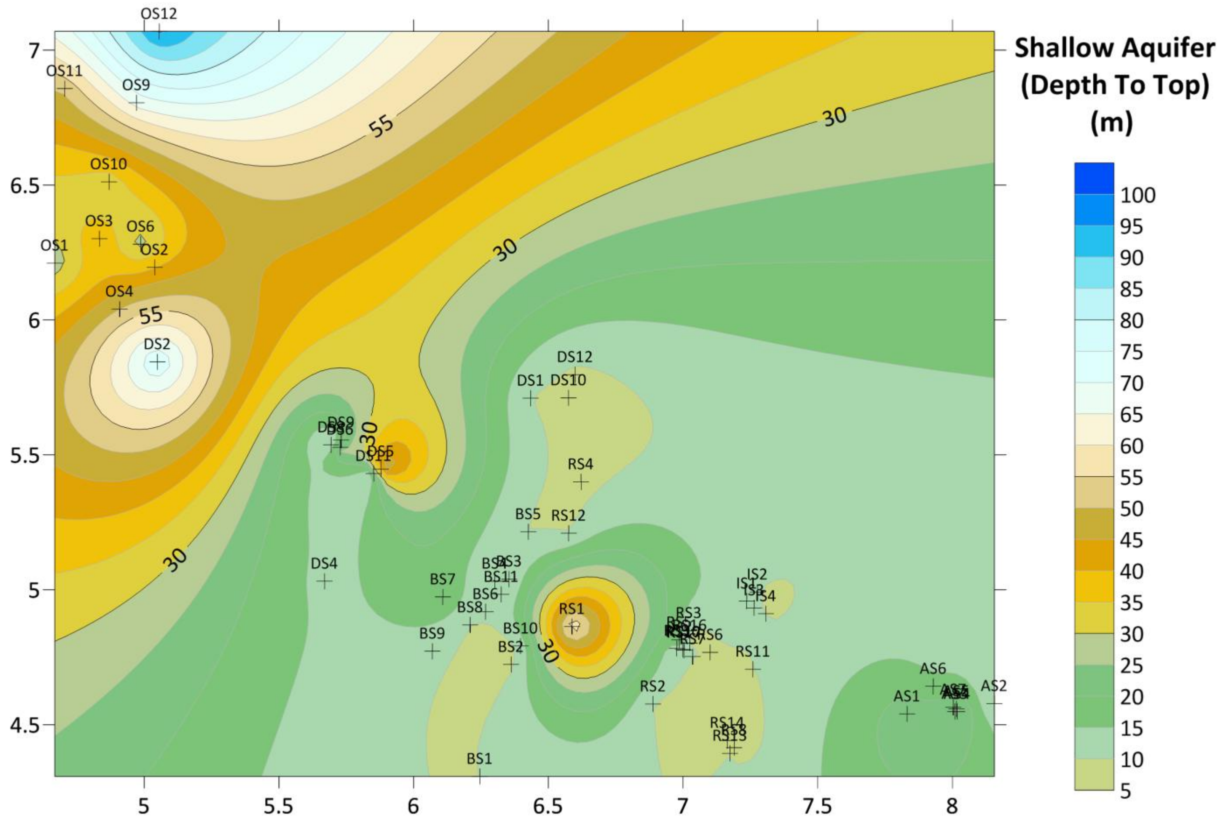

Figure 4.70: Depth to Top of Shallow Aquifers

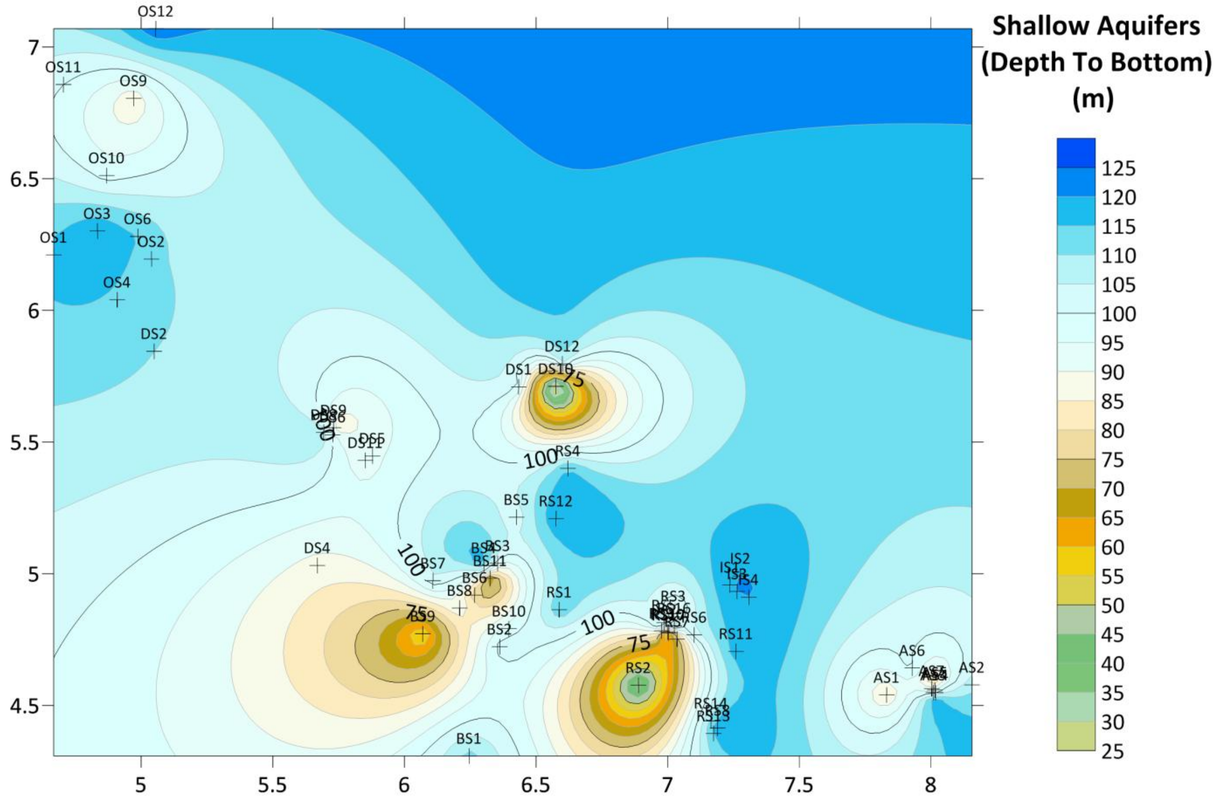

Figure 4.71: Depth to Bottom of Shallow Aquifers

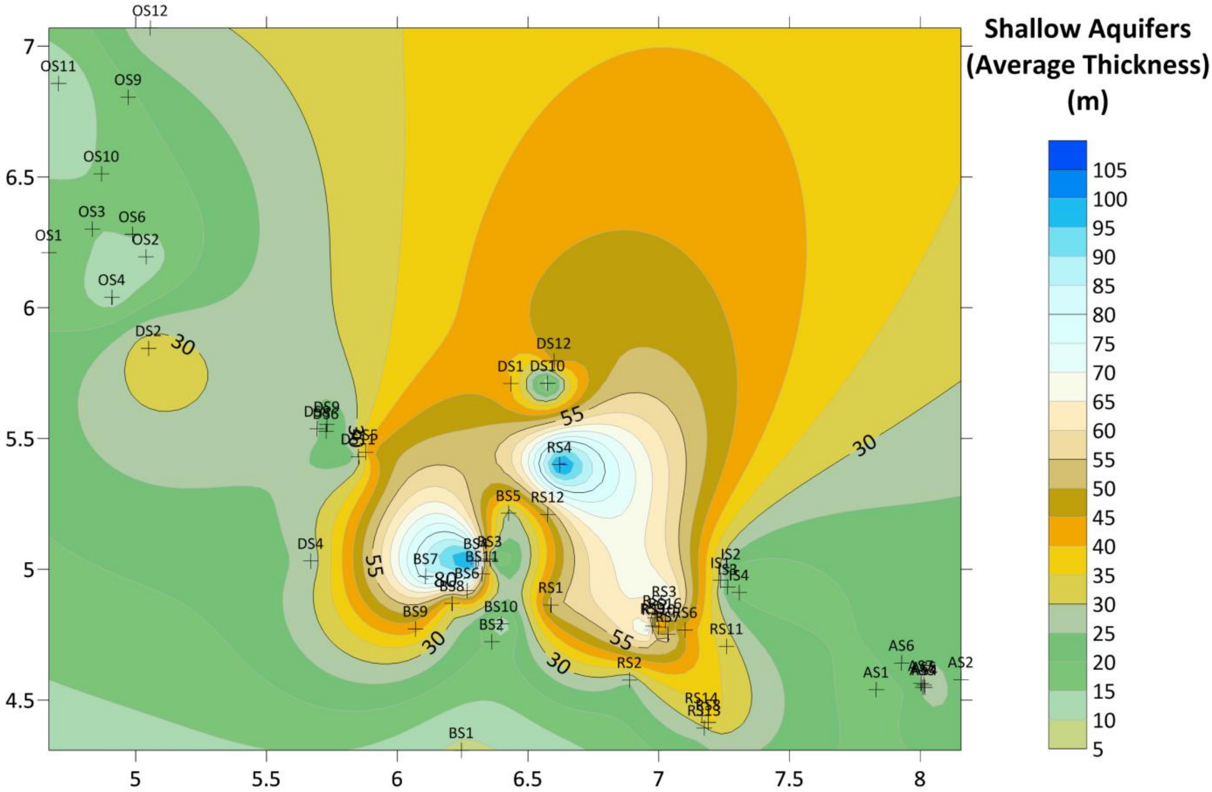

Figure 4.72: Average Thickness of Shallow Aquifers

4.9 Resistivity Profile of the Aquifers in the Study Area

To establish the subsurface resistivity profile of the aquifers of the area as inferred from the open-hole geophysical logging, the resistivity values of various lithologic units as recorded by the logging system were obtained. Table 4.5 shows the location of the wells and the resistivity values of the aquifers as obtained from the open-hole resistivity log. The log from where the values were obtained is the N64 resistivity log which obtains data 64" from the well bore beyond the mud cake zone.

Table 4.5: Resistivity values for the aquifers in the study area

Lat	Long	Location	Aquifer Depth (M)	Resistivity Values (Ohm-m)	Remarks
4.6913492	7.1543762	Onne Federal Ocean Terminal	20.0 40.0 70.0 100.0 108.0 113.6 120.0 124.6 131.0 181.9 204.0	244.0 626.9 243.2 106.5 366.4 166.0 308.9 449.2 322.3 623.0 329.5	Screened Aquifer
4.7757354	7.00464309	SHELL Kidney Island, Abonema Warf PHC	26.6 85.0 114.0	373.6 13.5 889.0	Screened
4.79276835	7.02102912	Amadi Creek (Eastern By Pass) BH 1	70.0 140.0 180.0	10.0 610.0 660.0	screened
4.78722501	7.02067583	Amadi Creek (PRODECO Yard) BH2	60.0 150.0 180.0	10.0 848.0 950.0	screened

Table 4.5 (Contd): Resistivity values for the aquifers in the study

4.79419562	7.00867706	Amadi Flats Ogbunabali PH	35.0 70.0 120.0 140.0	930.0 800.0 1000.0 1000.0	 Screened
4.5759	6.8869	Bille	0-240 240-260 260-390	8.0 20.0 150.0	 Screened
4.410430	7.164351	MOBIL Bonny River Terminal Finima	0-215 230-250 300-320 330-340 345-360	15.0 192.0 331.6 252.1 357.6	 Screened
4.405556	7.169550	MOBILE Life Camp Finima	0-145 146-153 167-201 223-245 300-305 315-330 336-354	15.0 24.0 100.0 252.0 151.0 253.0 252.0	 Screened Screened
4.434562	7.164850	Bonny Water Board	300-327 337-377 380-421 425-450	159.0 241.0 278.0 322.0	 Screened
4.437062	7.172264	Bonny National Grammer School	30-48 75-110 134-150	22.0 15.0 263.0	 Screened
4.434843	7.1999445	Oguede Bonny	280-310 320-380 392-406 410-420 430-450	554.0 554.0 526.0 446.0 560.0	 Screened
4.397411	7.155778	Finima Water Board	220-233 239-250	50.0 139.0	

Table 4.5 (Contd): Resistivity values for the aquifers in the study

			253-261	64.0	
			261-285	96.0	
			296-346	350.0	
			350-370	288.0	
			375-380	196.0	
			385-400	312.0	
			410-430	317.0	Screened
4.343601	7.14845	SHELL Bonny River Terminal, Bonny	0-54	5.0	
			54-120	10.0	
			122-134	10.0	
			140-150	25.0	
			154-172	28.0	
			182-212	160.0	
			214-218	43.0	
			220-230	132.0	
			253-264	59.0	
			266-276	128.0	
			277-282	62.0	
			292-322	235.0	
			324-332	143.0	
			336-386	160.0	
			388-396	159.0	
			398-412	170.0	
			478-494	178.0	
			500-522	218.0	
			528-574	246.0	Screened
			580-588	214.0	

Table 4.5 was studied in conjunction with the logs and it shows that it is easier to get water free from salt water and iron water contamination around the Port Harcourt axis than the Bonny, Finima and Bille areas were the wells are much deeper to be free from salt water and lower ferrous contamination.

The resistivity values of the aquifers are higher within the Onne, Amadi Creek, AmadiFlats and Kidney Island area which are within the Port Harcourt area. There is general decrease in aquifer resistivity as we move from the Port Harcourt area towards the Bonny area.

The resistivity values around the Onne, Amadi Creek, Kidney Island and the Amadi flats are above 600 Ohms and the water produced from these aquifers is potable and therefore free from saline water and ferrous contaminations. The water from the Aquifers around Finima, Shell Bonny, Bonny water board, and Oguede had resistivity values below 600 ohms. Water produced from the aquifers contained ferrous iron contamination in treatable quantities but had no salt content.

Based on the distribution of aquifer resistivity values at different depths where aquifers were mapped out, the entire study area was adjudged to have the following aquifer systems viz: Very Low Resistivity Aquifers (Saline Water), Low Resistivity Aquifers (High Ferrous Contamination), Medium Resistivity Aquifers (Low Ferrous Contamination) and High Resistivity Aquifers (Fresh Water with no Saline or Ferrous Contamination).

From the shallow aquifer resistivity plot (figure 4.73), the northeastern part of the study area was seen to contain fresh water without the presence of saline water and ferrous contamination. This water type also occurs in pockets within Otorogu gas plant of Delta state; around Otakeme and Kolo areas of Bayelsa State as well as QITIbeno Land 3 locations of Akwa Ibom State. Very reduce ferrous contamination, decreased ferrous contamination as well as high ferrous contamination aquifers were seen aligned in a linear form from the Northeastern part to the Southern part of the study area. Saline water aquifers were quite predominant within the Southern fringe of the study area (figure 4.73). Similar trend was observed in the medium aquifers plot (figure 4.74). The only observed difference is that at this depth the occurrence of fresh water tends to extend to Uzere area of Delta State and Otakeme area of Bayelsa State (figure 4.74). From the resistivity plot of the deep aquifers, fresh water aquifers units and those with very low to decreased ferrous contamination were encountered within the Southern part of the study area (figure 4.75). Thus within the coastal area of Niger Delta, effect of ferrous contamination may not be completely eliminated through the drilling of deep wells.

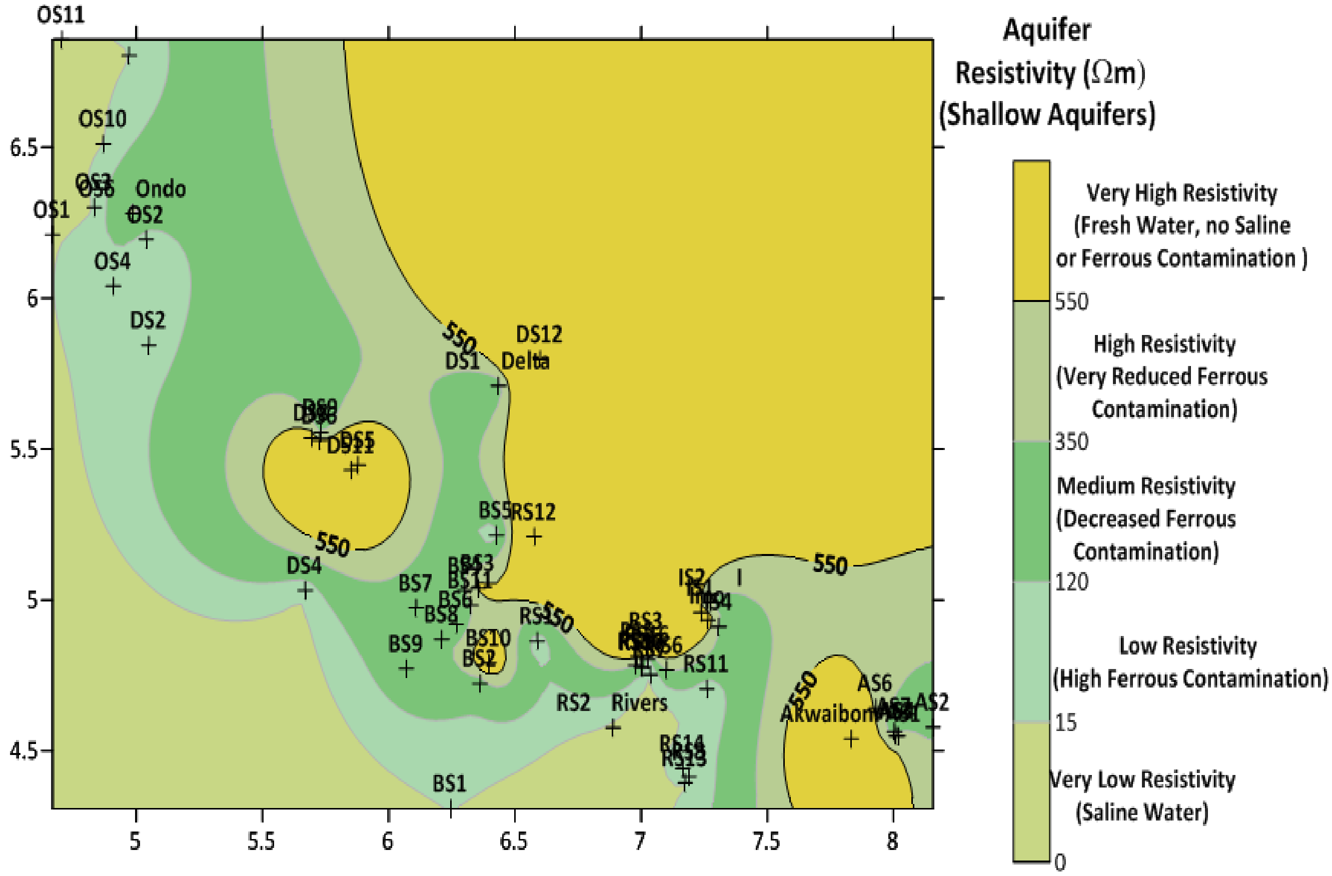

Figure 4.73: Resistivity Plot for Shallow Aquifers

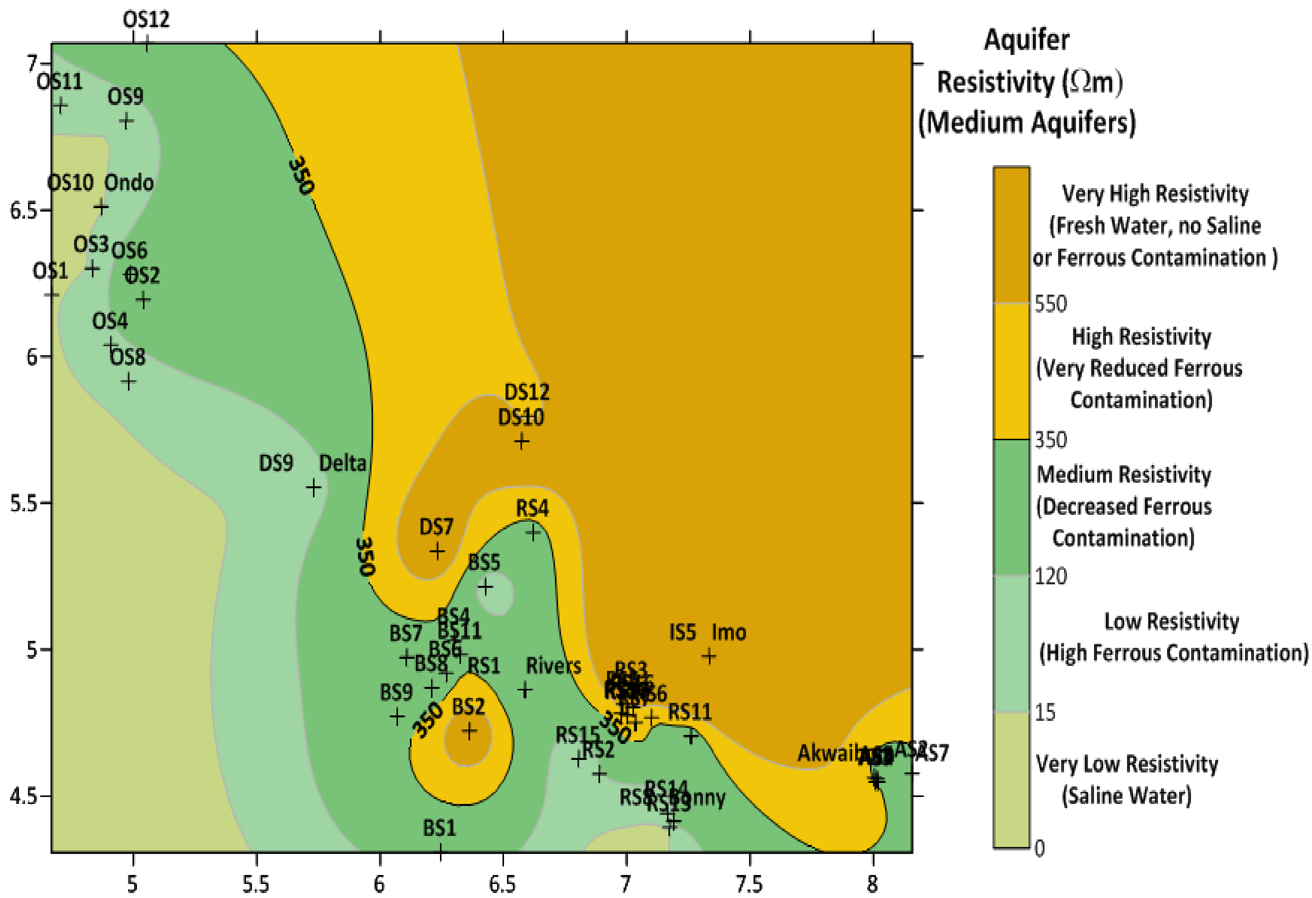

Figure 4.74: Resistivity Plot for Medium Aquifers

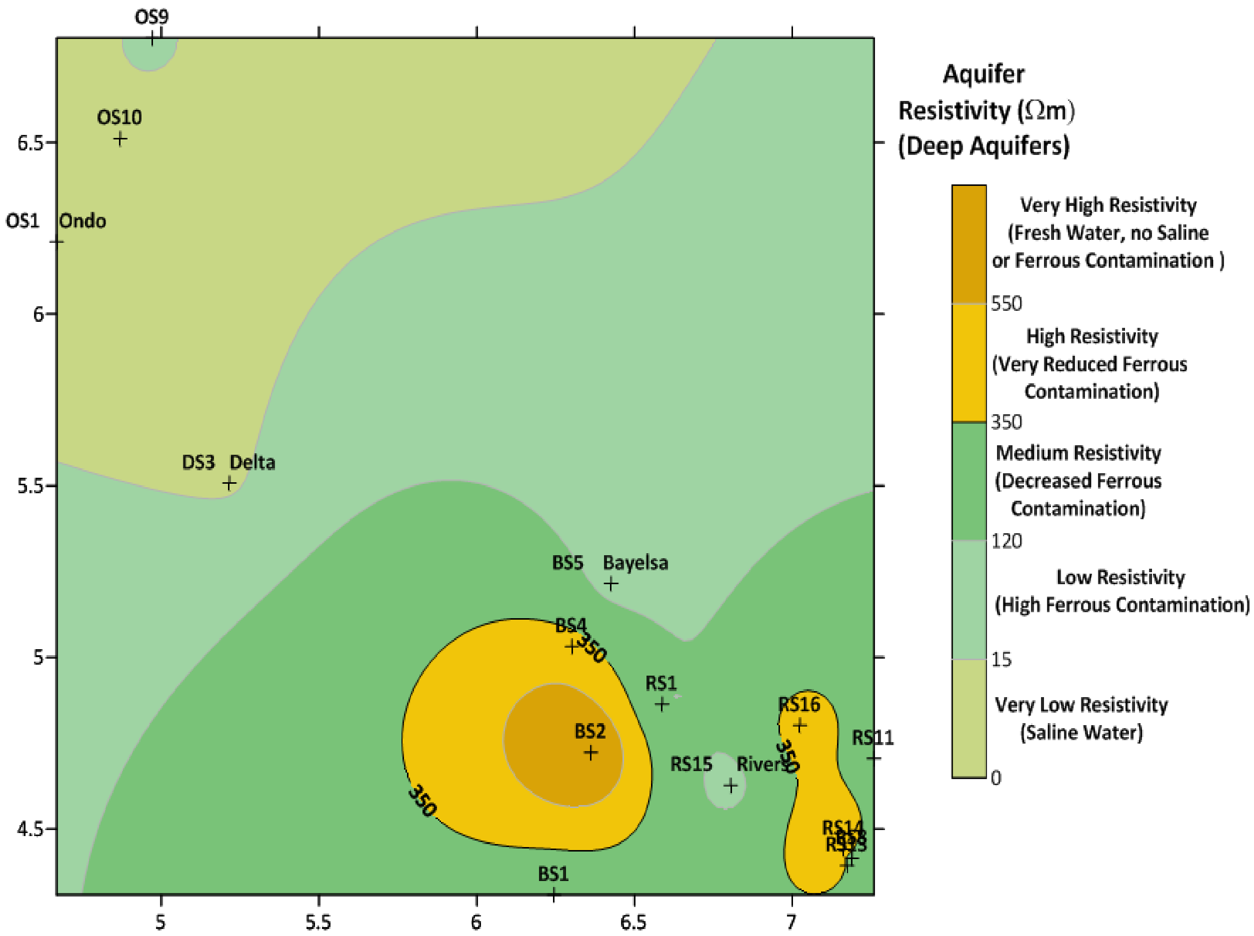

Figure 4.75: Resistivity Plot for Deep Aquifers

4.10 Gamma Count

Based on the amount of gamma Count Per Second (CPS), the aquifer system in the area can be classified into Very Low Gamma Count (Highly Sandy Aquifers), Low Gamma Count (Sandy Aquifers) and Medium Gamma Count (Slightly Clayey Aquifers).

The very low gamma count aquifers indicating high sandy aquifer have counts ranging fron 9.9 to over 12.9 CPS. Bonny waters aquifer has the least gamma count (figure 4.76).

The low gamma count aquifers signifies sandy aquifers and have count ranging from 15 to over 27CPS. The Southwestern part of the study area has a relatively high gamma count than the surrounding areas within this category of sandy aquifers. A rising plume or relatively high value within the low gamma account domain was encountered within the southwestern part of study areas. It eventually caps up around Ojobo area of Delta State. There exists a near-linear trend along Northwest – Southwest direction of gamma counts ranging from 17.5 to 22.5CPS showing well deposited and probably proper structurally aligned sandy units that serve as good aquifer system within those localities (figure 4.77).

The medium gamma count areas indicate zones dominated by slightly claying Aquifers with counts ranging from 20 to 45CPS (figure 4.78). This type of aquifer unit has its relatively high value of greater than 40CPS occurring mainly around OrientanIlaje, AwoyeIlaje and Odoloseino areas of Ondo State. Its relatively low value occurs around the Southern and Northeastern parts of the study areas.

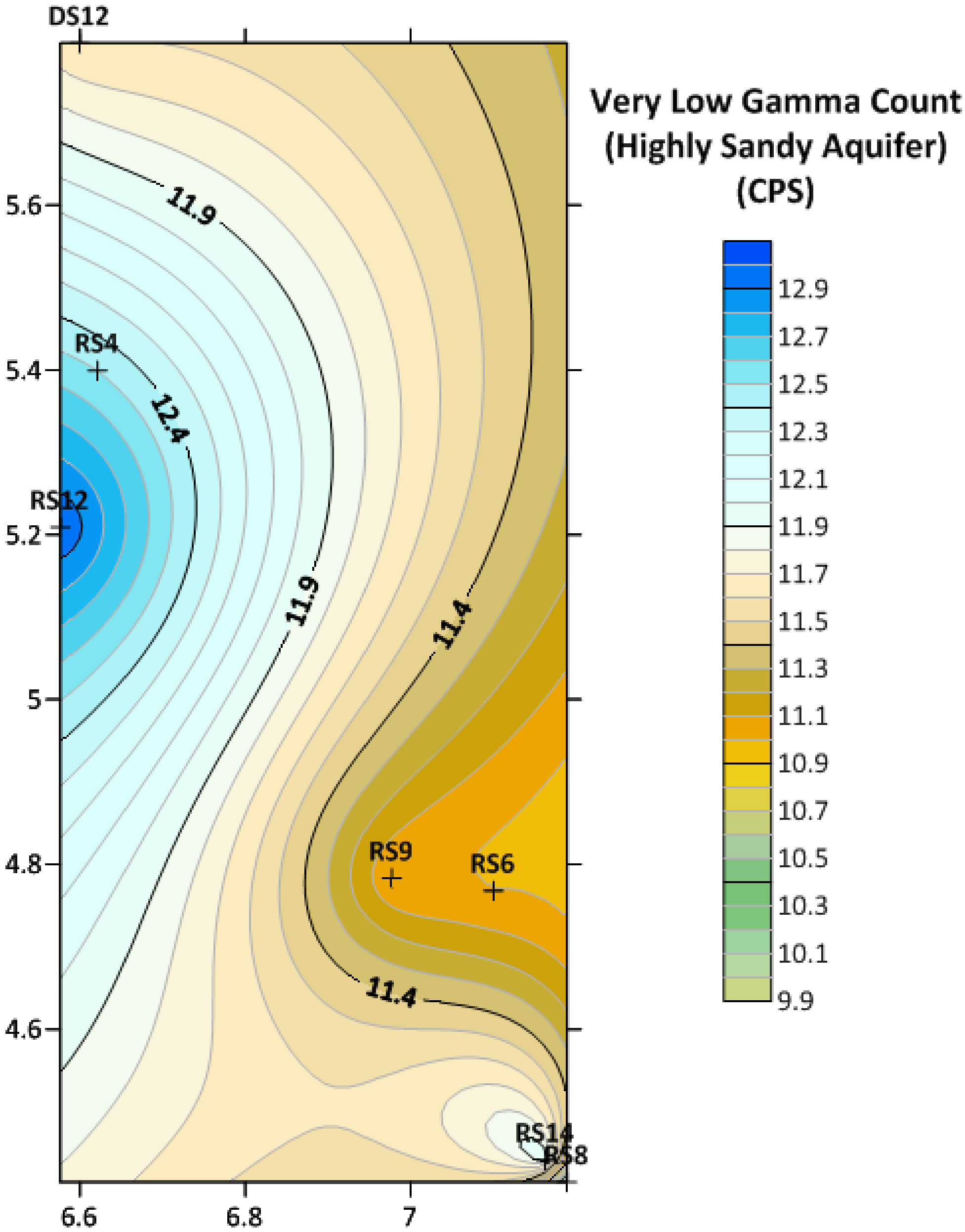

Figure 4.76: Very Low Gamma Count Plot of the Study Area

Table 4.6a: Aquifer Low Gamma Counts

LONG	LAT	BORE HOLE ID	LOCATION	AQUIFER GAMMA COUNT (CPS)	AVERAGE AQUIFER GAMMA COUNT (CPS)
7.1898	4.4142	RS8	Bonny Water	10	10
7.1643	4.4409	RS14	Oguede, bonny	12	12
7.1643	4.4409	RS14	Oguede, bonny	12	
6.576	5.2093	RS12	AGBADA FLOW STATION	13	13
6.6211	5.3998	RS4	NDONI RIVERS	13	12.5
6.6211	5.3998	RS4	NDONI RIVERS	12	
6.9773	4.7829	RS9	EAGLE ISLAND	10	11
6.9773	4.7829	RS9	EAGLE ISLAND	12	
7.1007	4.7676	RS6	PH REFINERY	11	11
6.5997	5.797	DS12	OKPAI COMMUNITY	12	11.6
6.5997	5.797	DS12	OKPAI COMMUNITY	11	
6.5997	5.797	DS12	OKPAI COMMUNITY	11	
6.5997	5.797	DS12	OKPAI COMMUNITY	11	
6.5997	5.797	DS12	OKPAI COMMUNITY	13	

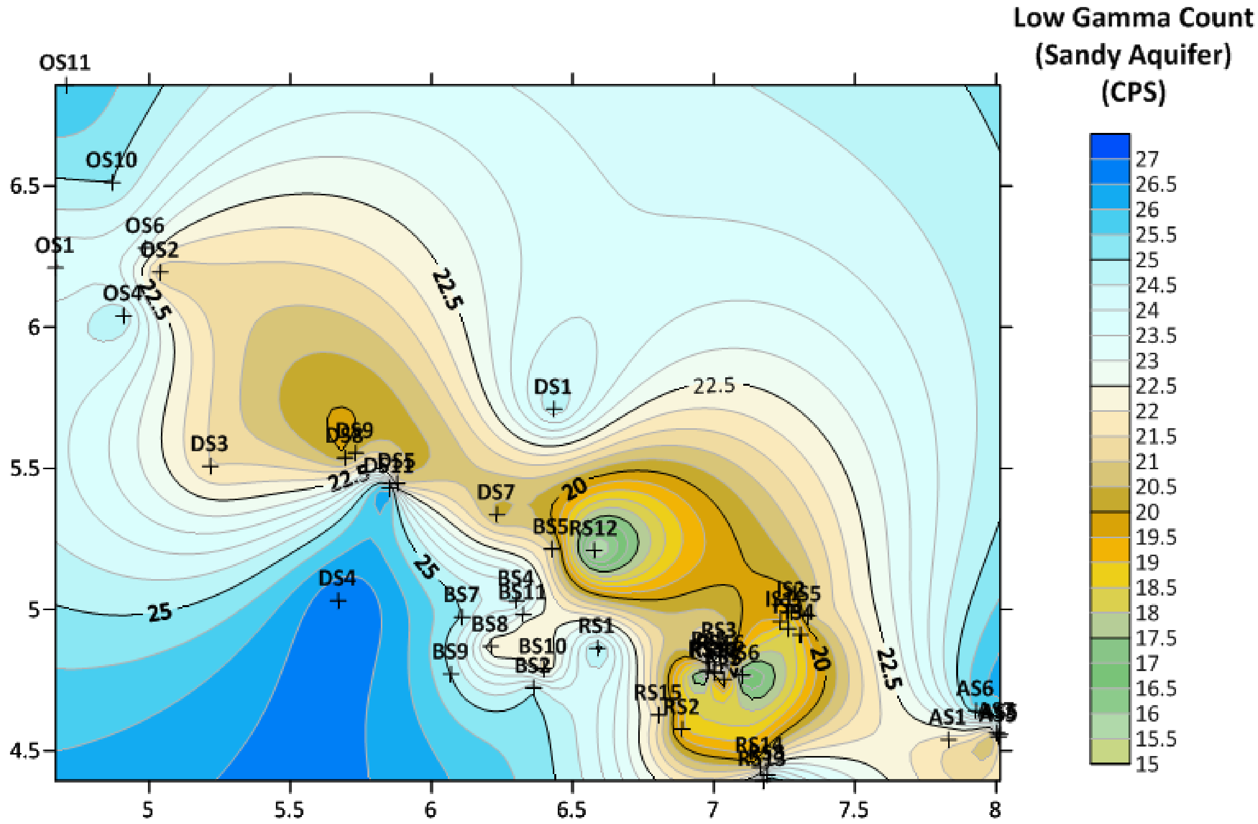

Figure 4.77: Low Gamma Count Plot of the Study Area

Table 4.6b: Average Aquifer Medium Gamma Counts

LONG	LAT	BORE HOLE ID	LOCATION	AQUIFER GAMMA COUNT (CPS)	AVERAGE AQUIFER GAMMA COUNT (CPS)
7.1898	4.4142	RS8	Bonny Water	25	25.29
7.1898	4.4142	RS8	Bonny Water	25	
7.1898	4.4142	RS8	Bonny Water	25	
7.1898	4.4142	RS8	Bonny Water	26	
7.1898	4.4142	RS8	Bonny Water	25	
7.1898	4.4142	RS8	Bonny Water	25	
7.1898	4.4142	RS8	Bonny Water	26	
7.1643	4.4409	RS14	Oguede, bonny	15	20.20
7.1643	4.4409	RS14	Oguede, bonny	18	
7.1643	4.4409	RS14	Oguede, bonny	17	
7.1643	4.4409	RS14	Oguede, bonny	20	
7.1643	4.4409	RS14	Oguede, bonny	15	
7.1643	4.4409	RS14	Oguede, bonny	15	
7.1643	4.4409	RS14	Oguede, bonny	25	
7.1643	4.4409	RS14	Oguede, bonny	22	
7.1643	4.4409	RS14	Oguede, bonny	25	
7.1643	4.4409	RS14	Oguede, bonny	30	
7.1744	4.3933	RS13	Finima water board	25	25.00
7.0216	4.848	RS3	NAF BASE PH	20	21.75
7.0216	4.848	RS3	NAF BASE PH	25	
7.0216	4.848	RS3	NAF BASE PH	20	
7.0216	4.848	RS3	NAF BASE PH	22	
6.576	5.2093	RS12	AGBADA FLOW STATION	15	15.00
7.0045	4.7755	RS17	BUA NPA PHC	18	20.75
7.0045	4.7755	RS17	BUA NPA PHC	20	
7.0045	4.7755	RS17	BUA NPA PHC	20	
7.0045	4.7755	RS17	BUA NPA PHC	25	

Table 4.6b (Contd): Average Aquifer Medium Gamma Counts

6.8888	4.5763	RS2	BILLE	20	19.00
6.8888	4.5763	RS2	BILLE	19	
6.8888	4.5763	RS2	BILLE	15	
6.8888	4.5763	RS2	BILLE	22	
6.8051	4.6269	RS15	IDAMA RIVERS	15	21.67
6.8051	4.6269	RS15	IDAMA RIVERS	20	
6.8051	4.6269	RS15	IDAMA RIVERS	23	
6.8051	4.6269	RS15	IDAMA RIVERS	22	
6.8051	4.6269	RS15	IDAMA RIVERS	20	
7.2597	4.7049	RS11	KULA RIVERS	22	
7.2597	4.7049	RS11	KULA RIVERS	25	
7.2597	4.7049	RS11	KULA RIVERS	28	
7.2597	4.7049	RS11	KULA RIVERS	20	
7.0001	4.7788	RS10	KIDNEY ISLAND	21	22.00
7.0001	4.7788	RS10	KIDNEY ISLAND	23	
6.9773	4.7829	RS9	EAGLE ISLAND	15	15.00
7.025	4.802	RS16	NLNG AMADI CREEK	21	22.25
7.025	4.802	RS16	NLNG AMADI CREEK	22	
7.025	4.802	RS16	NLNG AMADI CREEK	25	
7.025	4.802	RS16	NLNG AMADI CREEK	20	
7.025	4.802	RS16	NLNG AMADI CREEK	21	
7.025	4.802	RS16	NLNG AMADI CREEK	23	
7.025	4.802	RS16	NLNG AMADI CREEK	25	
7.025	4.802	RS16	NLNG AMADI CREEK	21	
7.0357	4.7518	RS7	AMADI CREEK 2	21	21.33

Table 4.6b (Contd): Average Aquifer Medium Gamma Counts					
7.0357	4.7518	RS7	AMADI CREEK 2	23	
7.0357	4.7518	RS7	AMADI CREEK 2	20	
6.9866	4.8138	RS5	ONNE PORT	21	23.67
6.9866	4.8138	RS5	ONNE PORT	24	
6.9866	4.8138	RS5	ONNE PORT	26	
7.1007	4.7676	RS6	PH REFINERY	15	16.00
7.1007	4.7676	RS6	PH REFINERY	19	
7.1007	4.7676	RS6	PH REFINERY	20	
7.1007	4.7676	RS6	PH REFINERY	10	
6.588	4.8632	RS1	ASARAMATORU	22	25.33
6.588	4.8632	RS1	ASARAMATORU	25	
6.588	4.8632	RS1	ASARAMATORU	24	
6.588	4.8632	RS1	ASARAMATORU	28	
6.588	4.8632	RS1	ASARAMATORU	25	
6.588	4.8632	RS1	ASARAMATORU	28	
4.7053	6.8572	OS11	JINRINWO ONDO	26	26.00
4.7053	6.8572	OS11	JINRINWO ONDO	27	
4.7053	6.8572	OS11	JINRINWO ONDO	25	
4.8694	6.5116	OS10	IDOGUN AYADI ILAJE ONDO	23	25.00
4.8694	6.5116	OS10	IDOGUN AYADI ILAJE ONDO	27	
4.8694	6.5116	OS10	IDOGUN AYADI ILAJE ONDO	25	
4.9875	6.2806	OS6	AROGBO IJAW ONDO	25	23.20
4.9875	6.2806	OS6	AROGBO IJAW ONDO	25	
4.9875	6.2806	OS6	AROGBO IJAW ONDO	22	
4.9875	6.2806	OS6	AROGBO IJAW ONDO	21	
4.9875	6.2806	OS6	AROGBO IJAW	23	

Table 4.6b (Contd): Average Aquifer Medium Gamma Counts

			ONDO		
4.9092	6.0399	OS4	AKPATA IJAW ONDO	25	25.00
5.0392	6.1946	OS2	ADOLOSEIMO ONDO	27	21.00
5.0392	6.1946	OS2	ADOLOSEIMO ONDO	15	
4.668	6.2106	OS1	ABEALALA ILAJE	25	23.43
4.668	6.2106	OS1	ABEALALA ILAJE	23	
4.668	6.2106	OS1	ABEALALA ILAJE	20	
4.668	6.2106	OS1	ABEALALA ILAJE	21	
4.668	6.2106	OS1	ABEALALA ILAJE	22	
4.668	6.2106	OS1	ABEALALA ILAJE	28	
4.668	6.2106	OS1	ABEALALA ILAJE	25	
7.3078	4.9108	IS4	OWAZA WELL 4	19	19.00
7.3078	4.9108	IS4	OWAZA WELL 4	15	
7.3078	4.9108	IS4	OWAZA WELL 4	20	
7.3078	4.9108	IS4	OWAZA WELL 4	18	
7.3078	4.9108	IS4	OWAZA WELL 4	14	
7.2643	4.9326	IS3	OWAZA WELL 3	17	18.00
7.2643	4.9326	IS3	OWAZA WELL 3	19	
7.2643	4.9326	IS3	OWAZA WELL 3	20	
7.2643	4.9326	IS3	OWAZA WELL 3	16	
7.2643	4.9326	IS3	OWAZA WELL 3	18	
7.2764	4.9913	IS2	OWAZA WELL 2	19	18.60
7.2764	4.9913	IS2	OWAZA WELL 2	18	

Table 4.6b (Contd): Average Aquifer Medium Gamma Counts					
7.2764	4.9913	IS2	OWAZA WELL 2	20	
7.2764	4.9913	IS2	OWAZA WELL 2	19	
7.2764	4.9913	IS2	OWAZA WELL 2	17	
7.2368	4.9577	IS1	OWAZA WELL 1	20	19.67
7.2368	4.9577	IS1	OWAZA WELL 1	20	
7.2368	4.9577	IS1	OWAZA WELL 1	19	
7.3326	4.9771	IS5	OWAZA WELL 5	21	21.00
8.0093	4.5488	AS3	IBENO QIPP 1	21	21.00
8.0093	4.5488	AS3	IBENO QIPP 1	22	
8.0093	4.5488	AS3	IBENO QIPP 1	20	
8.0093	4.5488	AS3	IBENO QIPP 1	21	
8.0031	4.5639	AS7	IBENO QIPP 2	28	21.50
8.0031	4.5639	AS7	IBENO QIPP 2	15	
8.0148	4.5584	AS5	QIT IBENO 3	25	26.00
8.0148	4.5584	AS5	QIT IBENO 3	27	
7.9291	4.6417	AS6	QIT IBENO 1	25	25.67
7.9291	4.6417	AS6	QIT IBENO 1	27	
7.9291	4.6417	AS6	QIT IBENO 1	25	
7.832	4.5395	AS1	ATABRIKAN AKWA IBOM	25	21.67
7.832	4.5395	AS1	ATABRIKAN AKWA IBOM	20	
7.832	4.5395	AS1	ATABRIKAN AKWA IBOM	20	
6.3971	4.7911	BS10	KOLO BAYELSA	20	21.75
6.3971	4.7911	BS10	KOLO BAYELSA	21	
6.3971	4.7911	BS10	KOLO BAYELSA	25	
6.3971	4.7911	BS10	KOLO BAYELSA	21	
6.2099	4.8696	BS8	AYAMA IJAW	22	22.00
6.3253	4.9824	BS11	GBARAIN IPP	25	22.67
6.3253	4.9824	BS11	GBARAIN IPP	22	
6.3253	4.9824	BS11	GBARAIN IPP	21	
6.0699	4.7719	BS9	OBUNAGHA	25	25.00

Table 4.6b (Contd): Average Aquifer Medium Gamma Counts					
			GBARAIN		
6.109	4.9731	BS7	AMASOMA	25	25.00
6.4261	5.2147	BS5	TUNU FLOW STATION	25	21.25
6.4261	5.2147	BS5	TUNU FLOW STATION	20	
6.4261	5.2147	BS5	TUNU FLOW STATION	20	
6.4261	5.2147	BS5	TUNU FLOW STATION	20	
6.3016	5.0311	BS4	GBARAIN UBIE	25	25.00
6.3618	4.7226	BS2	OTAKEME	25	25.00
6.575	5.7112	DS10	OKPAI IPP	18	
6.575	5.7112	DS10	OKPAI IPP	19	
6.575	5.7112	DS10	OKPAI IPP	15	
6.575	5.7112	DS10	OKPAI IPP	17	
6.575	5.7112	DS10	OKPAI IPP	15	
6.575	5.7112	DS10	OKPAI IPP	16	
5.7311	5.5543	DS9	NPA WARRI	17	20.50
5.7311	5.5543	DS9	NPA WARRI	28	
5.7311	5.5543	DS9	NPA WARRI	18	
5.7311	5.5543	DS9	NPA WARRI	19	
6.2323	5.3362	DS7	UZERE	21	20.33
6.2323	5.3362	DS7	UZERE	20	
6.2323	5.3362	DS7	UZERE	20	
5.6692	5.0313	DS4	OJOBO	27	27.00
5.8788	5.4469	DS5	OTOROGU GASS PLANT	20	20.67
5.8788	5.4469	DS5	OTOROGU GASS PLANT	21	
5.8788	5.4469	DS5	OTOROGU GASS PLANT	21	
5.694	5.5369	DS8	WARRI	20	20.00

Table 4.6b (Contd): Average Aquifer Medium Gamma Counts

			REFINERY		
5.8516	5.4304	DS11	OTOROGU FLOW STATION	27	27.00
6.4344	5.7098	DS1	KWALE	25	25.00
5.2162 5.2162	5.5075 5.5075	DS3 DS3	OGIDIGBEN OGIDIGBEN	22 21	21.50

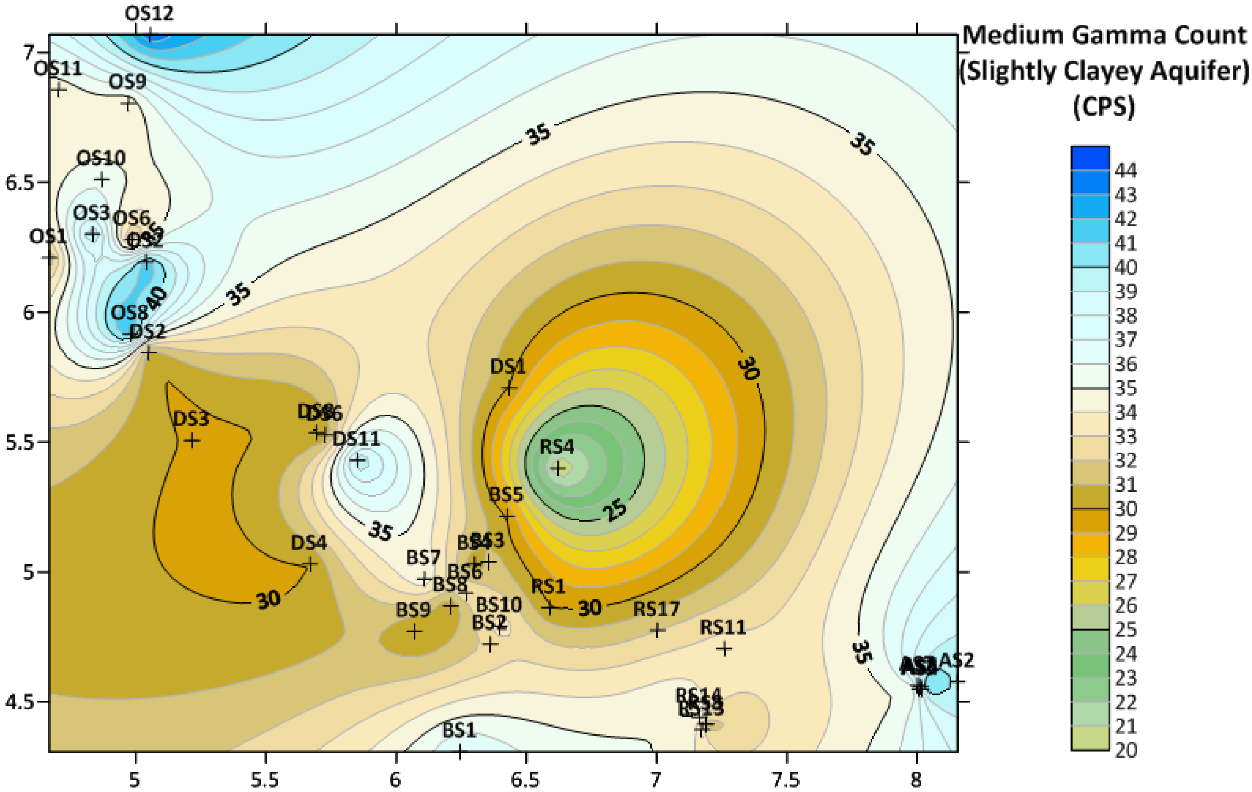

Figure 4.78: Medium Gamma Count Plot of the Study Area

Table 4.6c: Average Low Aquifer Gamma Counts

LONG	LAT	BOREHOLE ID	LOCATION	AQUIFER GAMMA COUNT (CPS)	AVERAGE AQUIFER GAMMA COUNT (CPS)
7.1898	4.4142	RS8	Bonny Water	30	31.00
7.1898	4.4142	RS8	Bonny Water	32	
7.1898	4.4142	RS8	Bonny Water	35	
7.1898	4.4142	RS8	Bonny Water	30	
7.1898	4.4142	RS8	Bonny Water	30	
7.1898	4.4142	RS8	Bonny Water	30	
7.1898	4.4142	RS8	Bonny Water	30	
7.1898	4.4142	RS8	Bonny Water	32	
7.1898	4.4142	RS8	Bonny Water	30	
7.1643	4.4409	RS14	Oguede, bonny	35	35.00
7.1744	4.3933	RS13	Finima water board	35	33.50
7.1744	4.3933	RS13	Finima water board	33	
7.1744	4.3933	RS13	Finima water board	36	
7.1744	4.3933	RS13	Finima water board	30	
7.1744	4.3933	RS13	Finima water board	35	
7.1744	4.3933	RS13	Finima water board	32	
7.0045	4.7755	RS17	BUA NPA PHC	32	32.00
6.6211	5.3998	RS4	NDONI RIVERS	20	20.00
7.2597	4.7049	RS11	KULA RIVERS	35	33.50
7.2597	4.7049	RS11	KULA RIVERS	32	
6.588	4.8632	RS1	ASARAMATO	30	30.00

Table 4.6c (Contd): Average Low Aquifer Gamma Counts					
			RU		
5.0563	7.0692	OS12	ORIETAN ILAJE ONDO	47	44.00
5.0563	7.0692	OS12	ORIETAN ILAJE ONDO	45	
5.0563	7.0692	OS12	ORIETAN ILAJE ONDO	40	
4.7053	6.8572	OS11	JINRINWO ONDO	40	34.33
4.7053	6.8572	OS11	JINRINWO ONDO	32	
4.7053	6.8572	OS11	JINRINWO ONDO	31	
4.8694	6.5116	OS10	IDOGUN AYADI ILAJE ONDO	40	35.80
4.8694	6.5116	OS10	IDOGUN AYADI ILAJE ONDO	42	
4.8694	6.5116	OS10	IDOGUN AYADI ILAJE ONDO	37	
4.8694	6.5116	OS10	IDOGUN AYADI ILAJE ONDO	30	
4.8694	6.5116	OS10	IDOGUN AYADI ILAJE ONDO	30	
4.9717	6.8048	OS9	ERUNA ILAJE ONDO	35	34.14
4.9717	6.8048	OS9	ERUNA ILAJE ONDO	32	
4.9717	6.8048	OS9	ERUNA ILAJE	37	

Table 4.6c (Contd): Average Low Aquifer Gamma Counts

			ONDO		
4.9717	6.8048	OS9	ERUNA ILAJE ONDO	30	
4.9717	6.8048	OS9	ERUNA ILAJE ONDO	30	
4.9717	6.8048	OS9	ERUNA ILAJE ONDO	35	
4.9717	6.8048	OS9	ERUNA ILAJE ONDO	40	
4.98	5.916	OS8	AWOYE ILAJE ONDO	40	42.25
4.98	5.916	OS8	AWOYE ILAJE ONDO	42	
4.98	5.916	OS8	AWOYE ILAJE ONDO	43	
4.98	5.916	OS8	AWOYE ILAJE ONDO	44	
4.9875	6.2806	OS6	AROGBO IJAW ONDO	30	31.00
4.9875	6.2806	OS6	AROGBO IJAW ONDO	30	
4.9092	6.0399	OS4	AKPATA IJAW ONDO	30	
4.9092	6.0399	OS4	AKPATA IJAW ONDO	34	
4.9092	6.0399	OS4	AKPATA IJAW ONDO	32	
4.9092	6.0399	OS4	AKPATA IJAW ONDO	30	
4.8339	6.3011	OS3	AYETORO ONDO	31	40.33
4.8339	6.3011	OS3	AYETORO ONDO	40	

Table 4.6c (Contd): Average Low Aquifer Gamma Counts

4.8339	6.3011	OS3	AYETORO ONDO	40	
4.8339	6.3011	OS3	AYETORO ONDO	45	
4.8339	6.3011	OS3	AYETORO ONDO	45	
4.8339	6.3011	OS3	AYETORO ONDO	41	
5.0392	6.1946	OS2	ADOLOSEIMO ONDO	40	41.75
5.0392	6.1946	OS2	ADOLOSEIMO ONDO	40	
5.0392	6.1946	OS2	ADOLOSEIMO ONDO	42	
5.0392	6.1946	OS2	ADOLOSEIMO ONDO	45	
4.668	6.2106	OS1	ABEALALA ILAJE	32	31.00
4.668	6.2106	OS1	ABEALALA ILAJE	30	
8.0093	4.5488	AS3	IBENO QIPP 1	40	35.00
8.0093	4.5488	AS3	IBENO QIPP 1	30	
8.0031	4.5639	AS7	IBENO QIPP 2	42	37.67
8.0031	4.5639	AS7	IBENO QIPP 2	30	
8.0031	4.5639	AS7	IBENO QIPP 2	41	
8.0148	4.5584	AS5	QIT IBENO 3	35	40.00
8.0148	4.5584	AS5	QIT IBENO 3	40	
8.0148	4.5584	AS5	QIT IBENO 3	45	
8.0175	4.5485	AS4	QIT IBENO 2	37	40.25
8.0175	4.5485	AS4	QIT IBENO 2	41	
8.0175	4.5485	AS4	QIT IBENO 2	41	
8.0175	4.5485	AS4	QIT IBENO 2	42	
8.1557	4.5778	AS2	MPANAK	40	39.67

Table 4.6c (Contd): Average Low Aquifer Gamma Counts

			AKWA IBOM		
8.1557	4.5778	AS2	MPANAK AKWA IBOM	42	
8.1557	4.5778	AS2	MPANAK AKWA IBOM	35	
8.1557	4.5778	AS2	MPANAK AKWA IBOM	40	
8.1557	4.5778	AS2	MPANAK AKWA IBOM	41	
8.1557	4.5778	AS2	MPANAK AKWA IBOM	40	
6.3971	4.7911	BS10	KOLO BAYELSA	35	33.67
6.3971	4.7911	BS10	KOLO BAYELSA	35	
6.3971	4.7911	BS10	KOLO BAYELSA	31	
6.2099	4.8696	BS8	AYAMA IJAW	30	30.00
6.2099	4.8696	BS8	AYAMA IJAW	30	
6.2673	4.9186	BS6	SWALI MARKET	36	33.00
6.2673	4.9186	BS6	SWALI MARKET	30	
6.0699	4.7719	BS9	OBUNAGHA GBARAIN	30	30.00
6.109	4.9731	BS7	AMASOMA	35	35.00
6.4261	5.2147	BS5	TUNU FLOW STATION	30	30.00
6.4261	5.2147	BS5	TUNU FLOW STATION	30	
6.3016	5.0311	BS4	GBARAIN UBIE	30	30.00
6.3016	5.0311	BS4	GBARAIN	30	

Table 4.6c (Contd): Average Low Aquifer Gamma Counts					
6.3016	5.0311	BS4	UBIE GBARAIN UBIE	30	
6.3545	5.0393	BS3	ASIGBENE	30	31.50
6.3545	5.0393	BS3	ASIGBENE	30	
6.3545	5.0393	BS3	ASIGBENE	36	
6.3545	5.0393	BS3	ASIGBENE	30	
6.3618	4.7226	BS2	OTAKEME	30	32.14
6.3618	4.7226	BS2	OTAKEME	30	
6.3618	4.7226	BS2	OTAKEME	37	
6.3618	4.7226	BS2	OTAKEME	38	
6.3618	4.7226	BS2	OTAKEME	30	
6.3618	4.7226	BS2	OTAKEME	30	
6.3618	4.7226	BS2	OTAKEME	30	
6.2456	4.3078	BS1	BRASS	35	37.17
6.2456	4.3078	BS1	BRASS	40	
6.2456	4.3078	BS1	BRASS	35	
6.2456	4.3078	BS1	BRASS	40	
6.2456	4.3078	BS1	BRASS	40	
6.2456	4.3078	BS1	BRASS	34	
6.2456	4.3078	BS1	BRASS	40	
6.2456	4.3078	BS1	BRASS	40	
6.2456	4.3078	BS1	BRASS	40	
6.2456	4.3078	BS1	BRASS	37	
6.2456	4.3078	BS1	BRASS	35	
6.2456	4.3078	BS1	BRASS	30	
5.6692	5.0313	DS4	OJOBO	30	30.00
5.694	5.5369	DS8	WARRI REFINERY	30	30.00
5.694	5.5369	DS8	WARRI REFINERY	30	
5.7274	5.5278	DS6	SPDC MAIN OFFICE	30	30.00

Table 4.6c (Contd): Average Low Aquifer Gamma Counts					
5.7274	5.5278	DS6	WARRI SPDC MAIN OFFICE WARRI	30	
5.8516	5.4304	DS11	OTOROGU FLOW STATION	40	40.00
5.8516	5.4304	DS11	OTOROGU FLOW STATION	42	
6.4344	5.7098	DS1	KWALE	30	30.00
5.2162	5.5075	DS3	OGIDIGBEN	30	30.00
5.2162	5.5075	DS3	OGIDIGBEN	30	
5.0495	5.8444	DS2	OGHEYE	30	30.00

4.11 Porosity of Aquifer Material

The average aquifer porosity plot is as shown in figure 4.79. Four classes of porosities were delineated which include: high, medium, low and very low porosities.

Majority of the research areas is dominated by High porosity, aquifer materials greater than 65%. The Southern fringe of the study area contains aquifers occurring in low porosity to medium with porosity values ranging from 21 to 36%. Medium porosity aquifers are seen within the Northwestern part of the study area with porosity value ranging from 36 to 65% (figure 4.79).

Table 4.7: Aquifer Porosity

LONG	LAT	BORE HOLE ID	LOCATION	AQUIFER ESTIMATED POROSITY (%)	AVERAGE AQUIFER POROSITY (%)
7.1898	4.4142	RS8	Bonny Water	70 80 70 60 58 68 70 70 70 70 60 65 70 75 80 70 80	69.76
7.1643	4.4409	RS14	Oguede, bonny	65 70 90 70 85 65 65 60 70 70 70	71.54

Table 4.7 (Contd): Aquifer Porosity

				70 80	
7.1744	4.3933	RS13	Finima water board	45 60 60 70 65 60 65	60.71
7.0216	4.848	RS3	NAF BASE PH	75 75 90 85	81.25
6.576	5.2093	RS12	AGBADA FLOW STATION	75 90	82.50
7.0045	4.7755	RS17	BUA NPA PHC	75 80 80 70 65	74.00
6.6211	5.3998	RS4	NDONI RIVERS	70 72 75	72.33
6.8888	4.5763	RS2	BILLE	65 70 70 65	67.50

Table 4.7 (Contd): Aquifer Porosity

6.8051	4.6269	RS15	IDAMA RIVERS	85 80 75 70 90	80.00
7.2597	4.7049	RS11	KULA RIVERS	45 60 70 70 65 75	64.17
7.0001	4.7788	RS10	KIDNEY ISLAND	70 70	70.00
6.9773	4.7829	RS9	EAGLE ISLAND	95 85 85	88.33
7.025	4.802	RS16	NLNG AMADI CREEK	60 65 50 90 80 80 65 80	71.25
7.0357	4.7518	RS7	AMADI CREEK 2	90 72	84.00

Table 4.7 (Contd): Aquifer Porosity					
				90	
6.9866	4.8138	RS5	ONNE PORT	90 85 80	85.00
7.1007	4.7676	RS6	PH REFINERY	85 80 70 72 95	80.40
6.588	4.8632	RS1	ASARAMAT ORU	70 60 65 60 60 60 70	63.57
5.0563	7.0692	OS12	ORIETAN ILAJE ONDO	45 65 50	53.33
4.7053	6.8572	OS11	JINRINWO ONDO	55 60 65 65 68 60	62.17
4.8694	6.5116	OS10	IDOGUN AYADI ILAJE ONDO	45 45	61.00

Table 4.7 (Contd): Aquifer Porosity					
				50 55 75 70 78 70	
4.9717	6.8048	OS9	ERUNA ILAJE ONDO	65 70 60 70 75 60 50	64.29
4.98	5.916	OS8	AWOYE ILAJE ONDO	80 70 70 60	70.00
4.9875	6.2806	OS6	AROGBO IJAW ONDO	75 78 80 85 78 80 85	80.14
4.9092	6.0399	OS4	AKPATA IJAW ONDO	80 70 70 78 75	74.60

Table 4.7 (Contd): Aquifer Porosity					
4.8339	6.3011	OS3	AYETORO ONDO	65 50 60 45 45 75	56.67
5.0392	6.1946	OS2	ADOLOSEI MO ONDO	40 70 45 60 50 55 85	57.86
4.668	6.2106	OS1	ABEALALA ILAJE	60 55 60 60 70 45 50 60 70	58.89
7.3078	4.9108	IS4	OWAZA WELL 4	60 65 55 70 75	65.00
7.2643	4.9326	IS3	OWAZA WELL 3	70	69.00

Table 4.7 (Contd): Aquifer Porosity

				70 60 70 75	
7.2764	4.9913	IS2	OWAZA WELL 2	60 70 60 65 70	65.00
7.2368	4.9577	IS1	OWAZA WELL 1	65 70 70	68.33
7.3326	4.9771	IS5	OWAZA WELL 5	70	70.00
8.0093	4.5488	AS3	IBENO QIPP 1	70 65 55 65 65 75	65.83
8.0031	4.5639	AS7	IBENO QIPP 2	70 60 60 65 75	66.00
8.0148	4.5584	AS5	QIT IBENO 3	60 60 50 55	57.00

Table 4.7 (Contd): Aquifer Porosity

				60	
7.9291	4.6417	AS6	QIT IBENO 1	75 65 75	71.67
8.0175	4.5485	AS4	QIT IBENO 2	70 50 50 65	58.75
8.1557	4.5778	AS2	MPANAK AKWA IBOM	45 60 50 65 65 60 65	58.57
7.832	4.5395	AS1	ATABRIKAN AKWA IBOM	60 75 75	70.00
6.3971	4.7911	BS10	KOLO BAYELSA	80 80 70 60 70 55 70	69.29
6.2099	4.8696	BS8	AYAMA IJAW	60 65	65.00

Table 4.7 (Contd): Aquifer Porosity

				70	
6.3253	4.9824	BS11	GBARAIN IPP	60 65 70	65.00
6.2673	4.9186	BS6	SWALI MARKET	60 60	60.00
6.0699	4.7719	BS9	OBUNAGHA GBARAIN	60 60	60.00
6.109	4.9731	BS7	AMASOMA	65 68	66.50
6.4261	5.2147	BS5	TUNU FLOW STATION	45 60 68 60 70 70	62.17
6.3016	5.0311	BS4	GBARAIN UBIE	65 62 60 70	64.25
6.3545	5.0393	BS3	ASIGBENE	68 80 80 82	77.50
6.3618	4.7226	BS2	OTAKEME	65 60 55 70	66.88

Table 4.7 (Contd): Aquifer Porosity					
				75 70 70 70	
6.2456	4.3078	BS1	BRASS	65 60 65 60 65 66 60 62 60 63 60 68	62.83
6.5997	5.797	DS12	OKPAI COMMUNITY	90 80 70 65 90	79.00
6.575	5.7112	DS10	OKPAI IPP	70 65 80 80 80 90	77.50
5.7311	5.5543	DS9	NPA WARRI	95 70 65 60	72.50

Table 4.7 (Contd): Aquifer Porosity					
6.2323	5.3362	DS7	UZERE	75 62 80	72.33
5.6692	5.0313	DS4	OJOBO	70 60	65.00
5.8788	5.4469	DS5	OTOROGU GASS PLANT	75	65.00
5.694	5.5369	DS8	WARRI REFINERY	80 80 70	76.67
5.7274	5.5278	DS6	SPDC MAIN OFFICE WARRI	90 90	90.00
5.8516	5.4304	DS11	OTOROGU FLOW STATION	95 97 94	95.33
6.4344	5.7098	DS1	KWALE	70 70	70.00
5.2162	5.5075	DS3	OGIDIGBEN	90 90 90	90.00
5.0495	5.8444	DS2	OGHEYE	75	75.00

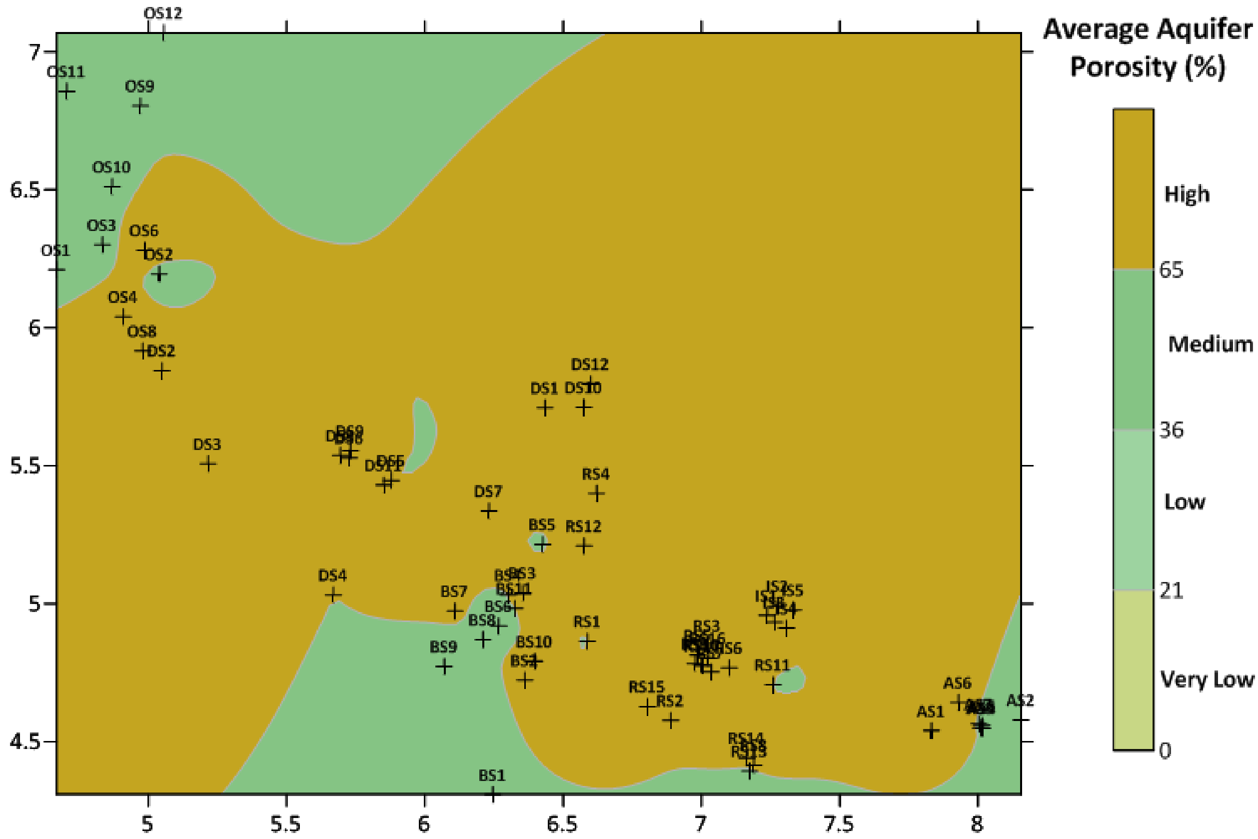

Figure 4.79: Average Aquifer Porosity Plot of the Area.

4.12 Saline Water Aquifers Boundary Based on Down-Hole Gamma Ray and Electric Log Results for the Study Area

The groundwater quality in the study area showed variation with local geology, and the depositional environment. The gamma ray and electric logs data gave reasonable indications of the underground salt water aquifer boundary of this area. The result of the down-hole logging conducted in about sixty-two boreholes in the area indicated the aquifers that contain saline water and those that contain fresh water. Saline water was encountered in aquifers in the salt water swamps, Coastal ridges and beaches depositional environment and some parts of the Benin Informations. The average salt water aquifer boundary is about 145m in Bonny area, 240m in the Finima area to 318m in some areas like Abealala in Ondo State. The average resistivity value of the saline water aquifer zones is less than 15 Ohm-m. Table 4.8 is the underground salt water aquifer level for the study area as deduced from the electric and gamma ray logs from wells in the study area.

Table 4.8: Underground Salt water aquifer boundary for the study area.

S/No	Long	Lat	Location	Borehole ID	Borehole depth (m)	Types of log run	Saline water Aquifer level (m) bsl
1.	7.1898	4.4142	Bonny Water board	RS8	450	Gamma, SP, SPR, Resistivity	145
2	7.1643	4.4409	Oguede, Bonny	RS14	452	Gamma, SP, SPR, Resistivity	143
3	7.1744	4.3944	Finima water board	RS13	450	Gamma, SP, SPR, Resistivity	218
4	6.8888	4.5763	Bille	RS2	390	Gamma, SP, SPR, Resistivity	240
5.	7.1485	4.3436	Bonny Shell	RS8	600	Gamma, SP, SPR, Resistivity	140
6	7.1544	4.6913	Onne FOT	RS18	210	Gamma, SP, SPR, Resistivity	16 and 70-97
7	7,0210	4.7928	Amadi Creek Borehole 1	RS17	210	Gamma, SP, SPR, Resistivity	80
8	7.0207	4.7872	Amadi Creek Borehole 2	RS7	210	Gamma, SP, SPR, Resistivity	16 and 20-80

4.12.1 Fresh Water/Saline Water Delineation

The study clearly shows the salt water aquifer boundary within Bonny and Finima area. The salt water aquifer boundary is undulating with an average of 145m in Bonny and some parts of Finima and 218m in Finima water board.

The fresh water/ saline water aquifer delineation for the Bille and Finima areas is over 200 metres depth. While the fresh water/ saline water aquifer delineation for the Onne, Amadi creeks, Amadi flats area is less than 100metres.

The fresh water /saline water aquifer delineation for the Bille, Kidney Island and Amadi creeks area shows the saline water aquifer boundary to be over 200 metres in Bille and less than 100 metres in Kidney Island and Amadi creeks areas.

These fresh water/saline water aquifer boundaries implies that below these depths, there is no more saline water aquifers up the depth of investigation within the study area. The water below the saline water aquifer line is fresh. The fresh water aquifers are confined by thick clay layers and have no interference from other aquifers.

The plot of the saline – fresh water boundary is as clearly displayed on figure 4.80. From the figure, it can be observed that the boundary between saline and fresh water varies from location to location within the study area. The boundary was observed to be shallow within Tunu flow station of Bayelsa State; NLNG Amadi Creek and Amadi Crack 2 of Rivers State; ErunaIlaje, Akpata Ijaw, Ayetoro and Adoloseimo areas of Ondo State. Deep saline –fresh water boundary occurs around Bonny water, Fanima water Beard, Bille, Idama, Kula and Asaramatoru areas of Rivers State; Jinrinwo and AbealalaIlaje area of Ondo State as Well as Ogidigben area of Delta State. The Depth to Saline-Fresh water boundary is shown in Table 4.9.

Table 4.9: Depth to Saline-Fresh Water Boundary

LONG	LAT	BOREHOLE ID	Location	DEPTH TO SALINE – FRESH WATER BOUNDARY (m)
7.1898	4.4142	RS8	Bonny Water	135
7.1744	4.3933	RS13	Finima water board	163

6.8888	4.5763	RS2	BILLE	208
6.8051	4.6269	RS15	IDAMA RIVERS	135
7.2597	4.7049	RS11	KULA RIVERS	105
7.025	4.802	RS16	NLNG AMADI CREEK	90
7.0357	4.7518	RS7	AMADI CREEK 2	70
6.588	4.8632	RS1	ASARAMATORU	137
4.7053	6.8572	OS11	JINRINWO ONDO	100
4.9717	6.8048	OS9	ERUNA ILAJE ONDO	86
4.9092	6.0399	OS4	AKPATA IJAW ONDO	58
4.8339	6.3011	OS3	AYETORO ONDO	60
5.0392	6.1946	OS2	ADOLOSEIMO ONDO	44
4.668	6.2106	OS1	ABEALALA ILAJE	318
6.4261	5.2147	BS5	TUNU FLOW STATION	30
5.2162	5.5075	DS3	OGIDIGBEN	300

4.13 Lithologic Cross Section

The correlation of the Lithologic cross section along the Northwest-Southeast direction is shown in figure 4.81. The different geologic units encountered are clay, clayey sand, sand, sandy clay as well as saturated sand. The saturated sand horizons were observed to form the fresh water aquifer systems of the area while the clayey sand and sandy clay units harbour the ferrous and saline aquifer systems in the area.

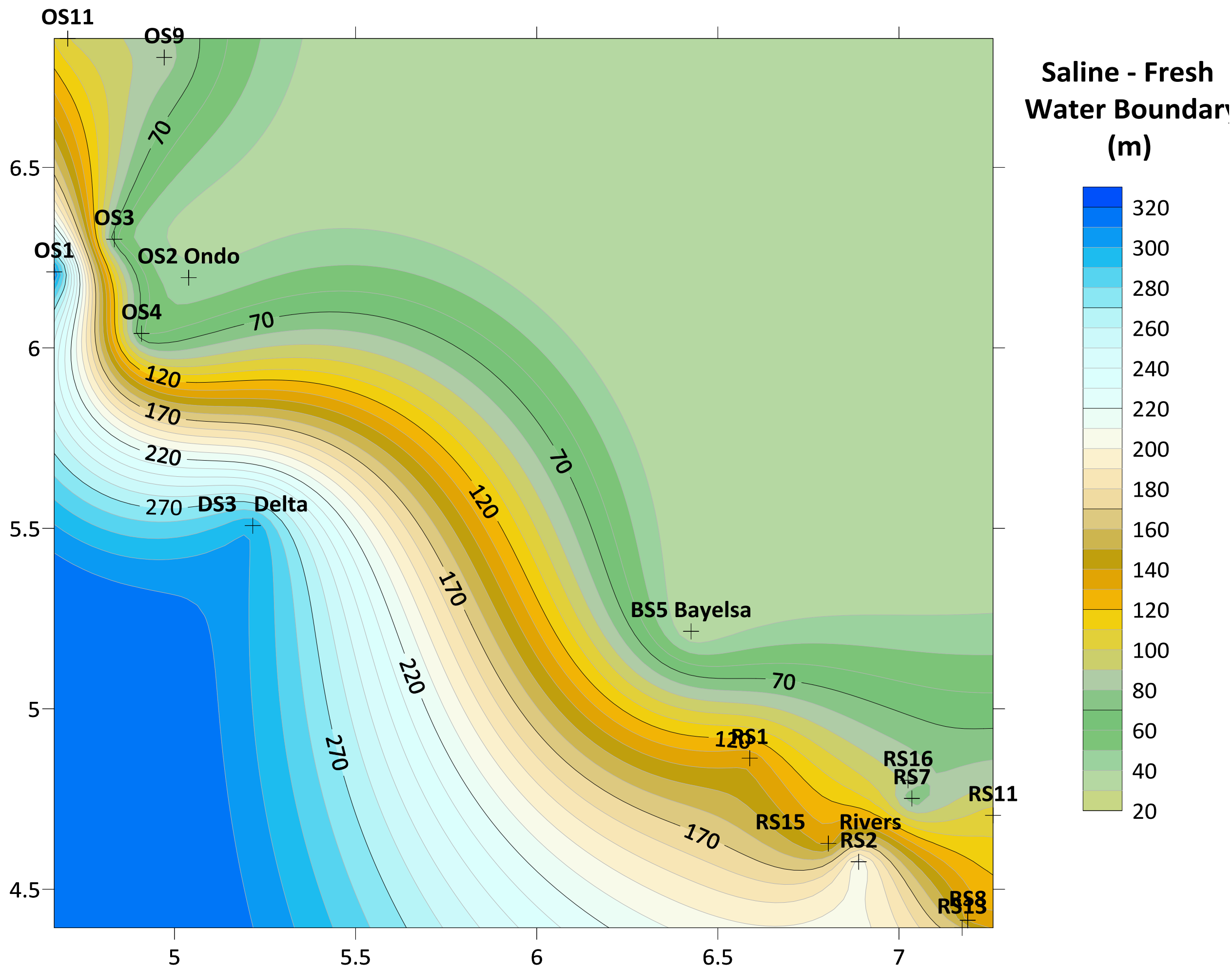

Figure 4.80: Saline-Fresh Water Boundary Plot of the Area

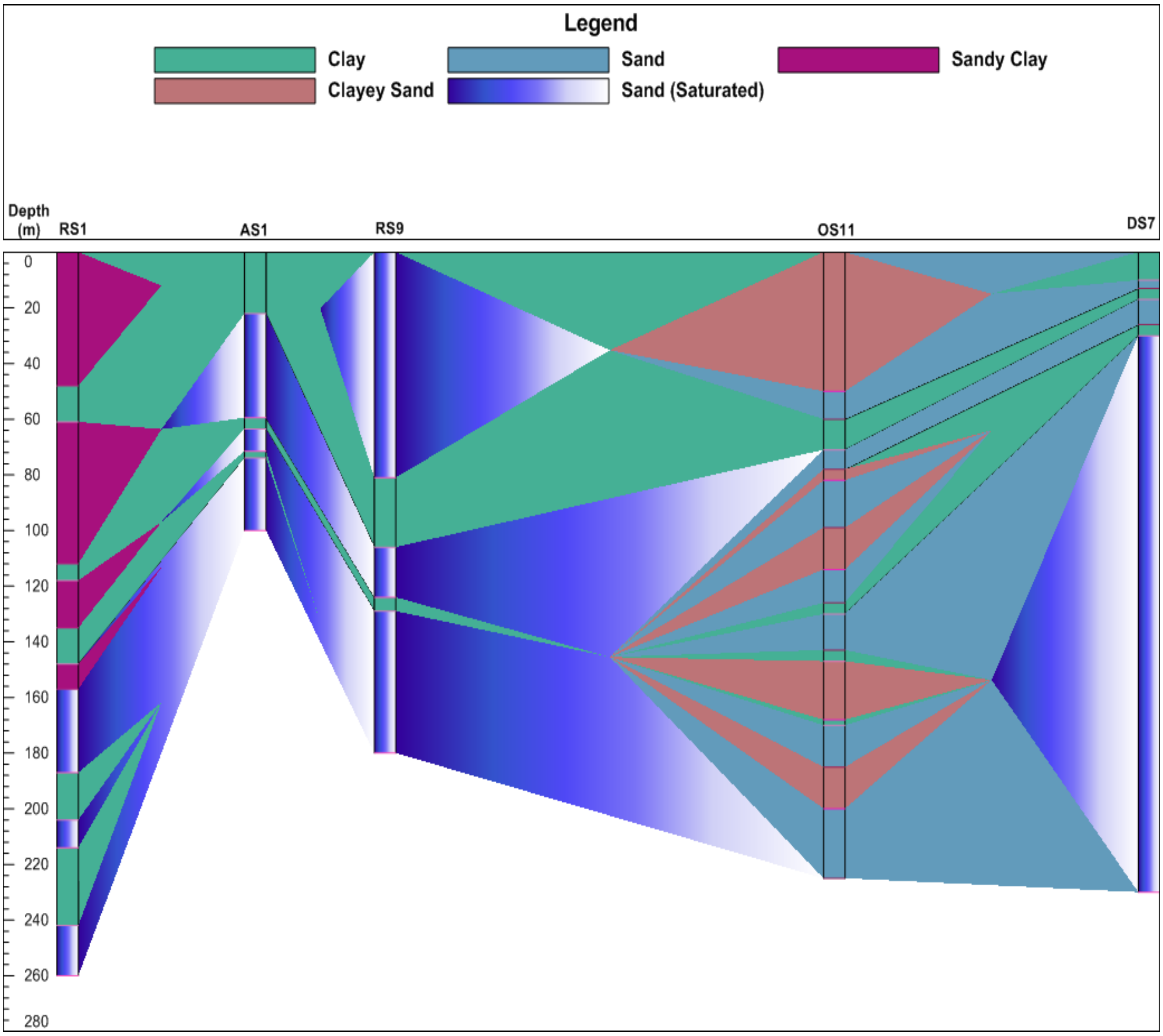

Figure 4.81: Lithologic Cross Section along NW-SE Direction

4.14 Water Analysis Results

Water samples from some of the drilled wells were analyzed at the Rivers State water board laboratory. Since the screens are inserted at recommended aquifers, it can be assumed that the water quality represents the water at the total completion depth of the well and hence the aquifer from which water is pumped. The water analysis examines the physiochemical and bacteriological purity of the water. The results are compared to WHO (2018) Standard for potable water. The results of analysis of groundwater samples from water wells in the study area indicate that some quality issues really exist in the groundwater which accounts for the varying resistivity values observed in the logs.

4.15 Produced Water Quality

Appendix I shows the water analysis result for the Onne water Borehole. The results clearly shows the water to be free from saline water and ferrous iron with iron content at 0.001Mg/L which compares favourably with the WHO (2018) limit of 0.3Mg/L. The resistivity value of this aquifer is over 600 Ohm-m.

Appendix II shows the water analysis of the Borehole in Bonny River Terminal. The water has no saline but an iron content of 1.2mg/L which does not meet the WHO (2018) limit for potable water. The resistivity value of this aquifer is 246 Ohm-m.

Appendix III is the water analysis result for the Amadi Creek borehole. The water has no salt or ferrous iron with iron content of 0.001mg/L. The water meets WHO (2018) standard for potable water. This aquifer has resistivity over 600 Ohm-m.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

This study was initiated to improve on the existing knowledge on the hydro-geophysical data base of the study area and give insight into the groundwater quality of the area at depths up to 600metres.

The gamma ray and electric log results and strata logs, water quality analysis results were reviewed. Results of gamma ray and electric geophysical logs from 62 locations were studied. The gamma logs neatly delineated the different aquifers. The area generally is underlain by alternating sequences of sands and clay. This sequence is capped by laterized soil around the Benin Information areas. The area consists of a multiple aquifer system with aquifer depths ranging from 80-600 metres. The aquifers are properly separated with layers of clay. The study showed that there are aquifers deeper than 80 metres within the Onne, Amadi Creek, Kidney Island and Amadi flats areas that can produce potable water free from saline water and ferrous iron contamination provided there is no over pumping and the hydrostatic balance is maintained. Aquifer resistivities of over 600 Ohm-m were established to be fresh water.

The study also showed that salt water can be isolated in most of the areas particularly in the salt water swamps and coastal beaches by drilling very deep boreholes. However, the fresh water still has to be treated to meet WHO (2018) standard for potable water. Most of the aquifers still contain some level of ferrous iron contamination even in the very deep boreholes. Some of the aquifers in the Benin Information environments can be considered to be free from any contamination in depths exceeding 120m.

The resistivity logs indicated different saline water aquifer depths for the boreholes in the area where the vertical distribution of saline water ranges from 0-80m around Onne, Amadi Creek and Kidney Island and 0 - 145m around Bonny , 0 - 218m around the Mobil BRT in Finima Bonny and 0-260m in Bille. The implication is that, wells drilled from surface to the above depths will encounter saline water and wells drilled bellow these depths will not encounter saline water. There is no more saline water aquifers bellow the above threshold depths up to the depth of 600m investigated.

The major contaminant is iron as the geophysical logging completely isolated the saline water and other contaminated aquifers zones. Areas with very low resistivity values of less than 20 ohm-m which the gamma log indicated to be sand were classified as saline water zones. Iron is a major chemical issue in groundwater of the area.

The study clearly established that for the produced water from the study area to be potable, the resistivity of the producing aquifer must be over 600 Ohm-m and for the water to be free from salt, the resistivity should be above 100 Ohm-m. Aquifer resistivities between 100 and 500 Ohm-m contain varying degrees of iron water concentration.

5.2 Conclusion

The study has revealed that the area consists of multiple aquifer system with more occurring between 300 and 600 metres. The depth to potable water around Port Harcourt Onne areas is shallower than in Bonny, Finima and Bille areas. The Study also showed that there is no salt water aquifer bellow 150metres in Bonny.

To obtain potable water supply within the study area, the resistivity value of the aquifer should be above 600 Ohm-m. This is the threshold resistivity value for potable as established by the study. The study also showed that the resistivity of the aquifers varied with the pollutant content. While areas with high chloride content gave very low resistivity values between 0 to 20 Ohm-m, areas with high iron presence gave resistivity values varying from 20 to 100 Ohm-m. The areas with less iron content gave resistivity values between 200 to 500 Ohm-m. This study has been able to give a new insight of hydro geophysical properties of aquifers in Bonny/Finima area, Bille, Onne FOT and some parts of Port Harcourt. It is hoped that the results will be useful to researchers, Government agencies involved in developing local and regional water plans, and other stakeholders.

5.3 Recommendations

Having carried out this research to this level, I hereby recommended that because of the nature of the aquifers of the coastal area of Niger Delta, there is an urgent need to protect the aquifers from further contamination by enacting appropriate laws to protect the groundwater of the area and to curtail indiscriminate drilling of boreholes and over extraction of water from the few fresh water aquifers of the Niger Delta.

For critical water need areas where fresh water is not readily available and for over contaminated areas where the cost of water treatment may be unsustainable, government and institutions can consider piping water from the Benin Information aquifers where there is less contamination to the critical water need areas.

5.4 Contribution to Knowledge

This research has contributed immediately to the body of scholarly knowledge by presenting to the fore the following:

1. It is possible that salt and Iron contaminated water to occur in association with fresh water without clay demarcation. Tapping only the fresh water effectively depends on proper placement of the screen and adequate choice of the capacity of the submersible pump, to be installed without disturbing the hydrostatic balance
2. In the coastal beaches and ridges areas of Niger Delta, it is more difficult to exploit for groundwater as deep wells are needed to escape from salt water intrusion and high concentration of Iron.
3. There is a gradual increase in the depth of water wells across the depositional environments of the Niger Delta as one traverses from the shore towards the swamps.
4. It is possible to isolate individual aquifers in a given well and identify which particular aquifer(s) contain(s) the major known groundwater pollutants of Chloride and Iron in objectionable concentration within the drilled column.
5. It is possible to run out of fresh water in the Niger Delta through over extraction of the only available ones.

REFERENCES

Abam T. K. S. and Nwankwoala H. O. (2020): Hydrogeology of Eastern Niger Delta: A Review. Journal of Water Resource and Protection, Vol. 12, pp. 741-777 https://www.scirp.org/journal/jwarp

Abbey M. E., Tamunoberetonari I. and Horsfall O. I. (2022): Sustainability of Shallow Aquifer in Rumuohia Community, Emohua L.GA, Rivers State, Nigeria. Asian Journal of Applied Science and Technology (AJAST) Volume 6, Issue 1, Pages 50-60.

Adeoti L., Alile O. M.andUchegbulam O. (2010)**:** Geophysical investigation of saline water intrusion into freshwater aquifers: A case study of Oniru, Lagos StateScientific Research and Essays, 5 (3), 248-259.

Akaolisa C. C. (2006): Aquifer Transmissivity and Basement Structure Determination using Resistivity sounding, Jos, Plateau State.Nigeria Environmental Monitoring and assessment, 27-34.

Akpokodje E. G (1987): TheEngineering geological characteristics and classification of the major superficial soils of the Niger Delta. Engineering Geology. 23,193-211.

Alaminiokuma G.I. Warmate T. andEmudianughe J.E. (2017) Geoelectrical logging for well screening in prolific aquifers in Ubima, Ikwerre LocalGovernment Area, River State, Nigeria. Academic Journal, 11(6), 324-330.

Alaminiokuma G. I. and Warmate T. (2020): Post drilling investigation for prolific groundwater aquifer using geoelectric logging at Nigeria LNG base, Port Harcourt. International Journal of Water Resources and Environmental Engineering, Vol. 12(1), pp. 1-9DOI: 10.5897/IJWREE2019.0911

Allen J.R.L. (1965): Late Quaternary Niger Delta and adjacent areas:sedimentary environments and lithofacies. Bull. Am. Ass. Petrol.Geol. 49, 547-600.

Allen J.R.L. (1964): Coastal Geomorphology of Eastern Nigeria: Beach Ridge Barrier Islands and Vegetated Tidal Flats. GeologieenMijnbouw, 44, 1-21.

Amangahara G. T. and Obenade M. (2015): Flood Vulnerability Assessment of Niger Delta StatesRelative to 2012 Flood Disaster in Nigeria American Journal of Environmental Protection, 2015, Vol. 3, No. 3, 76-83

AmajorL. C. (1991): Aquifers in the Benin Formation (Miocene-Recent) Eastern Niger Delta, Nigeria: Lithostraigraphy, Hydraulics and Water Quality, Environ. Geol. Water Sci., 17, (2) 85 - 101.

Bayode S. (2018): Application of Well logging in investigation of salt water intrusion in parts of Lagos State, South western Nigeria. Journal of Environmenment and Earth Science. ISSN2224-3216(paper) ISSN 2225-0948 (online) Vol.8, No.5, 2018.

Bellgam W. I. (1986): Delta and Coastal Erosion. National Workshop on Ecological Disaster, Soil Erosion. Owerri FMST, Lagos.

BRGM (1979): Bureau de RecherchesGeologiques et Minieres, Hydrogeological Investigations in the Sedimentary Basin Areas XVIII and XIX (Coastal Plains and Niger Delta).

Datel J.V, Kobr M.andProchazka M. (2009): Well logging methods in groundwater surveys of complicated aquifer systems-Bohemian cretaceous Basin. Environ Geology, 57:1021-1034.

Dobrin M.B. (1960): Introduction to Geophysical prospecting; Mc-Graw Hill Book Co. Pp 569,571,591.

Egboka B. C. E. (1988): Hydrogeological Provinces *of* Nigeria. In water Quality Bull. 13, No.4,pp. 117 - 125.

Ekine, A. S.and Osobonye O. (1996): Surface Geo-electric sounding for the determination of Aquifer characteristics in parts of Bonny Local Government Area of River State. Nigeria Journal of Physics, 85, 93 – 97.

Etu-Efeotor, J.O. (1981): Preliminary hydrogeochemical investigationsof sub-surface waters in parts of the Niger Delta. J. Mining & Geol. 18(1), 103-107.

Etu-Efeotor J. O. andAkpokodje E.G, (1990): Aquifer Systems *of* the Niger Delta. Nig. 1. Min. Geol., 26(*2),* 278 - 284.

Etu-Effeotor J. O.,Alabo E. H.and Michalski, A. (1989): Geophysical investigationfor groundwater in parts of the Eastern Niger Delta. Journal of Mining & Geology, 25(1), 51 - 54.

Etu-Efeotor J.O. and Odigi M. I. (1983): Water Supply Problems in the Eastern Niger Delta. Journal of Mining Geology 20(1 &m2): 183 – 193.

Eyankware M. O. and Ephraim B. E. (2021): A Comprehensive Review of Water Quality Monitoring and Assessment in Delta State, Southern Part of NigeriaJournal of Environmental & Earth Sciences. Vol. 03, Issue 01, pp. 16-28

Ezeigbo H. (1990): Facilities for Credible Hydrogeologic Studies in Nigeria. Jour ofWater. Resources (NAH), Vol. 2, No. I, October 1990. pp. 40 - 42.

Grant F.S. and West, G.F. (1965): Interpretation theory in Applied Geophysics, New York, Mc-Grall Hill.

Hospers J. (1965): Gravity Field and structure of the Niger Delta, Nigeria. Geol. Soc. America Bull., 76, 407 - 422.

Hospers J. (1971): The Geology of the Niger Delta area. In: The Geology of the East Atlantic Continent Margins of Africa. Great Britain Inst. Geol. Sci. rept. 70(16), 121-142.

Hwang S., Shin J., Park I. and Lee S. (2004): Assessment of seawater intrusion using geophysical well logging and electrical soundings in a coastal aquifer, Youngkwang-gun, Korea- Exploration Geophysics (2004) 35, 99-104 Butsuri-lansa (Vol. 57, No. 1) Mulli'lamsa (Vol. 7, No. 1)

Ibrahim H., Robert M. K., Christopher J. W. and Jamiu A. A. (2019): Hydrostratigraphy and Hydraulic Characterization of Shallow Coastal Aquifers, Niger Delta Basin: A Strategy for Groundwater Resource Management.Geosciences,Vol., 9, Issue 470, 16p;doi:10.3390/geosciences9110470

Ilugbo S.O., Edunjobi H.O., Alabi T.O., Ogabi A.F., Olomo K.O., Ojo O.A. and Adeleke K.A. (2019): Evaluation of ground water level using combined Electrical resistivity log with gamma (Elgg) around Ikeja, Lagos, South West Nigeria. Asian Journal of Geological Resources-2(3): 1-13, 2019 Article No; AJOGER.51709.

Jimoh R.A., Bankole O.M., Ahmed K., ChristopherO.A., Adeniji M.A., Ebodaghe J., Sedara S.O., Obende P.W., AlebuO., Ezima E.A. (2018): Using Geophysical Logs in Hydrogeological studies and borehole design: case study of Apapa Coastal area, Lagos, Nigeria. Applied Water Science (2018) 8.191

MacDonald A.M.and Davies J. (2000): A brief review of groundwater for rural water supply in sub-Saharan Africa BGS Technical Report WC,00,33

Mount Sopris-Operations Manual- Mt. Sopris Instrument Co., Inc. and Advanced Logic Technology s.à. All©Copyright 1998 - 2013 rights reserved.

NGSA (2006): Nigeria Geological Survey Agency. Geological Map of Nigeria. NGSA, Abuja

NSDWQ (2007):Nigerian Standard for drinking water QualityGuidelines, 2ed; Nigerian Industrial standard, pp14-21.

Nedeco (1959) (Netherlands Engineering Consultants), Report on Niger Delta Development, 57.

Ngah S. A. and Allen R. O., (2006): High bi-valent Iron Contaminants in groundwaters of the Niger Delta: their genesis and distribution. African journal of Environ. Pollut. Health, 5(1), 35 - 47.

Ngah S. A. (1990): Groundwater Resource Development in the Niger Delta: Problems and Prospects. Proceedings of 8th International IAEG Congress, Balkema, Rotterdam, 1379 - 1386.

Ngah S.A. and Nwankwoala H.O. (2016): Geophysical Logging of a Borehole for Supply of Potable Groundwater at Opuama Community, Warri North L.G.A., Delta State, Nigeria. N Y Sci J 2016;9(10):83-88]. ISSN 1554-0200 (print); ISSN 2375-723X (online). http://www.sciencepub.net/newyork. 14. doi:10.7537/marsnys091016.14

Ngah S.A. andYoudeowei P.O. (2013). Salinity depths in coastal aquifers of Niger Delta, Southern Nigeria. Archives of Applied Science Research, 5, 222-233.

Nwankwuoala H.O. andNgah S.A. (2015): Journal of Geosciences and Geomatics, 2015, Vol. 3,No. 5, 128-132 Available online at http://pubs.sciepub.com/jgg/3/5/3 © Science and Education Publishing DOI:10.12691/jgg-3-5-3

Nwankwoala H.O.andNgah, S.A. (2014) Groundwater resources of the Niger Delta: Quality implications and management considerations. Int.Journal of water resources and Enviromental, 6(5),155-163

Nwakwoala H. O., Osayande A. D. and Mba J. C. (2022): Geophysical investigation of the effects of waste dump on groundwater quality in Rukpokwu, Port Harcourt Metropolis. World Journal of Advanced Research and Reviews, 2022, 13 (01), 583–589

Offodile M. E. (1992): An Approach to Groundwater Study and Management in Nigeria. Mecon Services Ltd., Jos, Nigeria. 247 pp.

Ogbonnaya I., Moses N., Bernadette U. U. and Oyem E. U. (2021): Assessment of the physicochemical qualities of groundwater and soils around oil‑ producing communities in Afam, area of Porthacourt, Niger Delta Nigeria. Applied Water Science, Vol. 11, Issue 74, 13p.

Oghenero O. A., Ruth I. E., Kizito E. A. and Merrious O. O. (2020): Geophysical investigation of resistivity and groundwater quality in Ogbe‑ Ijoh coastal area of the western Niger Delta of Nigeria. Applied Water Science (2020) 10:70 https://doi.org/10.1007/s13201-020-1144-0

Ohwoghere A. O.,Chinyem I.F., Essi O.E. (2017) Saltwater Intrusion Appraisal of Shallow Aquifer in Burutu Area of the Western Niger Delta with 2D Electrical Resistivity Tomography.J. Appl. Sci. Environ. Manage, 21 (2) 372-377

Okoro F.E. Selemo A.O.andNwugha V. (2015): Using Electric logs to characterize aquifers in Bonny Island, Bille and parts of Port Harcourt, South Eastern Nigeria-paper presented at the 27th Annual Conference of the Nigeria Association of Hydrogeologists.

Onwuemesi A. G., and OlaniyanI. O. (1996): Hydrogeophysical Investigation of parts of Anambra State, Nigeria. Water Resources (NAH),(1-2), 56 - 61.

Oteri A. U. (1983): Electric Log Interpretation for the Evaluation of Salt Water Intrusion in the Eastern Niger Delta. Hydrological Sciences, 33,1,2,1988.

Oteri A.U. (1984): Electric Logs for Groundwater Exploration in the Niger Delta. Challenges in African Hydrology and Water Resources (Proceedings of the Harare Symposium, July, 1984), IAHS Publication No.144

Oteri A.U. andAtolagbe F. P. (2003): The second international conference on saltwater Intrusion and Coastal Monitoring, Modelling, and Managenent, Merida, Yucatan, Mexico, 2003.

Oteze G. E. (1983): Groundwater Levels and Ground Movements. In: Tropical Soils of Nigeria in Engineering Practice. (S.A. ala, ed) A. A. Balkema, 172 - 195.

Raimi M.O. and Sawyerr H.O. (2022): Preliminary Study of Groundwater Quality Using Hierarchical Classification Approaches for Contaminated Sites in Indigenous Communities Associated with Crude Oil Exploration Facilities in Rivers State, Nigeria. Open Journal of Yangtze Gas and Oil, Vol. 7, pp. 124-148. https://doi.org/10.4236/ojogas.2022.72008

Reyment R. A. (1965): Aspects of the Geology of Nigeria, Ibadan Univ. Press, Ibadan 145pp.

Sarker M.M.R., Van Camp M., Hermans T., Hossain D., Islam M., Uddin M.Z., Ahmed N., Bhuiyan M.A.Q., Karim M.M. and Walraevens K. (2021): Geophysical Delineation of Freshwater – Saline Water Interfaces in Coastal Area of South West Bangladesh. Water, 13, 2527.

Selemo A. O. I. and Ibeneme S. I. (2020): Basic Principles of Geophysical Logging: Open Hole Wire line Logs. XGraffixPublishers, 202pp.

Short K. C. andStauble A. J., (1967): Outline of the Geology of the Niger Delta. Bull. AAPG., 51, 761 -779.

Telford G.M., Geldart L.P., Sheriff R.F. and Keys D.A. (1976): Applied Geophysics, Cambridge University Press, 632-700.

Umayah S. O. and Eyankware M. O. (2022): Aquifer evaluation in southern parts of Nigeria from geo-electrical derived parameters. World News of Natural Sciences, Vol. 42, pp. 28-43www.worldnewsnaturalsciences.com

WHO (1984): Water Quality Surveys (a guide for the collection and interpretation of water quality data_IRD- WHO working Group) 352pp.

WHO (2018): Water Quality Surveys (a guide for the collection and interpretation of water quality Data- WHO working Group) 352.

APPENDIX I

RIVERS STATE WATER BOARD
QUALITY CONTROL/OPERATION DEPARTMENT

SOURCE OF SAMPLE: BOREHOLE | **REF: FEDERAL OCEAN TERMINAL ONNE**

LABORATORY NO: RSWB/LAB/10

DATE SAMPLE WAS TAKEN: 20-9-2010 | **DATE ANALYZED: 20-9-2010**

RESULT OF ANALYSIS

PARAMETERS	*RESULTS*	*W.H.O. STANDARD*
APPEARANCE	Clear/Particles	Clear
COLOUR IN HAZEN UNITS	5 hazen unit	5 Hazen units
TURBIDITY	Nil	5 N.T.U.
ODOUR IN T.O.N	Nil	Unobjectionable
HYDROGEN SUPHIDE	Nil	NIL
TASTE	Tasteless	Unobjectionable
CONDUCTIVITY (US cm)	10 us cm	1000 US Cm
ACIDITY (C.C.) OF 0.5% Na_2CO_3	36.0mg/l	
ON 100ML SAMPLE PH VALUE (TEMP)	5.9	6.5-8.5
CHLORIDES AS Cl	4.1mg/l	250mg/l
CHLORIDES AS Nacl	5.7 mg/l	
TOTAL ALKALINITY AS $CaCO_3$	10.0 mg/l	
TOTAL HARDNESS AS $CaCO_3$	12.0 mg/l	50mg/l
CALCIUMS HARDNESS	8.0 mg/l	
MAGNESIUM HARDNESS AS $MgCO_3$	4.0 mg/l	
TOTAL IRON AS Fe	0.001mg/l	0.3 mg/l
MANAGANESE AS Mn		0.10mg/l
FLUORIDES AS F		1.5mg/l
SULPHATES AS SO_4	0.07mg/l	400mg/l
CARBONATES AS CO_3	Nil	
BI-CARBONATES AS HCO_3	10.0 mg/l	
HYDROXIDES AS OH	Nil	
ASBESTOS		
SILICA AS SIO_2	0.02 mg/l	
SALINE & FREE AMMONIA		0.05mg/l
ALBUMINIOD AMMONIA AS AN	Nil	
NITRATES AS N		10mg/l
NITRATES AS N		1.010mg/l
TOTAL DISSOLVED SOLID (DRIED AT 180^0C FOR 1 HOUR)	0.1 mg/l	1000mg/l
TOTAL SUSPENDED SOLIDS	0.05 mg/l	25mg/l
SODIUM AS Na		200mg/l
DISSOLVED FREE CARBONDIOXIDES AS CO_2	30.0 mg/l	
PHENOL		0.001
ARSENIC		0.05
LANGELIER IDEX		

GENERAL REMARK

Sample is slightly acidic.

It is within tolerable limits.

M. C. NWOFOR (MRS)
ASSISTANT DIRECTOR (QUALITY CONTROL)

APPENDIX II

RIVERS STATE WATER BOARD
QUALITY CONTROL/OPERATION DEPARTMENT

SOURCE OF SAMPLE: BOREHOLE **REF: UTILITY WATER WELL 1**
LOCATION: BONNY (P-3302B)

LABORATORY NO: RSWB/LAB/07
DATE SAMPLE WAS TAKEN: 2-2-07 **DATE ANALYZED: 2-2-07**

RESULT OF ANALYSIS

PARAMETERS	*RESULTS*	*W.H.O. STANDARD*
APPEARANCE	Turbid	Clear
COLOUR IN HAZEN UNITS	15 hazen units	5 Hazen units
TURBIDITY	20 N.T.U	5 N.T.U.
ODOUR IN T.O.N	Nil	Unobjectionable
HYDROGEN SUPHIDE	Nil	NIL
TASTE	Slight Taste	Unobjectionable
CONDUCTIVITY (US cm)	25 US cm	1000 US Cm
ACIDITY (C.C.) OF 0.5% Na_2CO_3	18.0mg/l	
ON 100ML SAMPLE PH VALUE (TEMP)	6.2	6.5-8.5
CHLORIDES AS Cl	9.4mg/l	250mg/l
CHLORIDES AS Nacl	13 mg/l	
TOTAL ALKALINITY AS $CaCO_3$	30.0 mg/l	
TOTAL HARDNESS AS $CaCO_3$	15.0 mg/l	50mg/l
CALCIUMS HARDNESS	10.0 mg/l	
MAGNESIUM HARDNESS AS $MgCO_3$	5.0 mg/l	
TOTAL IRON AS Fe	1.2mg/l	0.3 mg/l
MANAGANESE AS Mn		0.10mg/l
FLUORIDES AS F		1.5mg/l
SULPHATES AS SO_4	0.04mg/l	400mg/l
CARBONATES AS CO_3	Nil	
BI-CARBONATES AS HCO_3	30.0 mg/l	
HYDROXIDES AS OH	Nil	
ASBESTOS		
SILICA AS SIO_2	0.02 mg/l	
SALINE & FREE AMMONIA	0.03mg/l	0.05mg/l
ALBUMINIOD AMMONIA AS AN		
NITRATES AS N	Nil	10mg/l
NITRATES AS N		1.010mg/l
TOTAL DISSOLVED SOLID (DRIED AT 180^0 C FOR 1 HOUR)	0.9 mg/l	1000mg/l
TOTAL SUSPENDED SOLIDS	12.0 mg/l	25mg/l
SODIUM AS Na		200mg/l
DISSOLVED FREE CARBONDIOXIDES AS CO_2	20.0 mg/l	
PHENOL		0.001
ARSENIC		0.05
LANGELIER IDEX		

GENERAL REMARK

Sample has high iron content above "WHO" standard.

Treatment is recommended before use.

M. C. NWOFOR (MRS)
CHIEF TECHNOLOGIST

RIVERS STATE WATER BOARD QUALITY CONTROL DEPT.

APPENDIX III

RIVERS STATE WATER BOARD
QUALITY CONTROL/OPERATION DEPARTMENT

SOURCE OF SAMPLE: BOREHOLE **REF: EASTERN BY PASS AMADI CREEK**

LABORATORY NO: RSWB/LAB/06

DATE SAMPLE WAS TAKEN: 17-08-06 **DATE ANALYZED: 17-08-06**

RESULT OF ANALYSIS

PARAMETERS	*RESULTS*	*W.H.O. STANDARD*
APPEARANCE	Clear	Clear
COLOUR IN HAZEN UNITS	5 hazen unit	5 Hazen units
TURBIDITY	Nil	5 N.T.U.
ODOUR IN T.O.N	Nil	Unobjectionable
HYDROGEN SUPHIDE	Nil	NIL
TASTE	Acceptable	Unobjectionable
CONDUCTIVITY (US cm)	10 us cm	1000 US Cm
ACIDITY (C.C.) OF 0.5% Na_2CO_3	39.2mg/l	
ON 100ML SAMPLE PH VALUE (TEMP)	5.8	6.5-8.5
CHLORIDES AS Cl	13.0mg/l	250mg/l
CHLORIDES AS Nacl	15.9 mg/l	
TOTAL ALKALINITY AS $CaCO_3$	10.0 mg/l	
TOTAL HARDNESS AS $CaCO_3$	13.0 mg/l	50mg/l
CALCIUMS HARDNESS	14.0 mg/l	
MAGNESIUM HARDNESS AS $MgCO_3$	9.0 mg/l	
TOTAL IRON AS Fe	0.001mg/l	0.3 mg/l
MANAGANESE AS Mn		0.10mg/l
FLUORIDES AS F		1.5mg/l
SULPHATES AS SO_4	0.04mg/l	400mg/l
CARBONATES AS CO_3	Nil	
BI-CARBONATES AS HCO_3	10.0 mg/l	
HYDROXIDES AS OH	Nil	
ASBESTOS		
SILICA AS SIO_2	0.02 mg/l	
SALINE & FREE AMMONIA	0.01mg/l	0.05mg/l
ALBUMINIOD AMMONIA AS AN		
NITRATES AS N	Nil	10mg/l
NITRATES AS N		1.010mg/l
TOTAL DISSOLVED SOLID (DRIED AT 180^0 C FOR 1 HOUR)	0.2mg/l	1000mg/l
TOTAL SUSPENDED SOLIDS	0.1 mg/l	25mg/l
SODIUM AS Na		200mg/l
DISSOLVED FREE CARBONDIOXIDES AS CO_2	30.0 mg/l	
PHENOL		0.001
ARSENIC		0.05
LANGELIER IDEX		

GENERAL REMARK

Sample is acidic.

It is within tolerable limits.

SIGN ....
DATE ....

M. C. NWOFOR (MRS)
CHIEF TECHNOLOGIST

RIVERS STATE WATER BOARD QUALITY CONTROL DEPT.