IMAGING THE EARTH'S SUBSURFACE

An Inaugural Lecture delivered at the University of Ibadan

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By

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UNIVERSITY OF IBADAN

The Vice-Chancellor, Deputy Vice-Chancellor (Administration), Deputy Vice-Chancellor (Academic), Registrar, Librarian, Provost, College of Medicine, Dean of Science, Dean of the Postgraduate School, Deans of other Faculties and of Students, Members of Senate, Heads of Departments, My lords, Spiritual, Temporal and Geological, Esteemed Colleagues, Distinguished Ladies and Gentlemen.

Introduction

I thank the Almighty God for giving me the opportunity to present this year's Professorial Inaugural Lecture (PIL) on behalf of the Faculty of Science. The Dean of Science, my brother and esteemed colleague, Professor Kayode O. Adebowale, has been most supportive in this regard. The tradition of inaugural lectures in this university is as old as the institution itself. Available record shows that Paul Christopherson, a Professor of English, delivered the first lecture titled 'Bilingualism' on the Foundation Day, 17 November, 1948. The lecture, this evening, is coming a little over 10 years after I attained the professorial rank; I probably have no reason to complain. This is because many eminent scholar-researchers who have been professors for upward of 20 years have not yet had this opportunity, no thanks to the policy of one PIL per faculty per session in the University of Ibadan. I am aware that there are about 20 professors in the Faculty of Science waiting for the chance to deliver their Inaugurals. There are probably similar situations in other very big faculties. If the original intention of an inaugural was for each and every professor to use this platform to address the public on his/her area of specialization soon after attaining the full professorial rank, it is obvious we need to devise another procedure to give all our professors this benefit. Soyibo (1996) made a similar plea about 14 years ago. Up till now, however, not much seems to have changed. But, of course, this is Ibadan, reputed as one of the most conservative universities in the world! The only consolation can be found in the Yoruba adage that says 'there is no time a man sews a garment that he would not have an opportunity to wear it'.

Geology was established as a unit in the Department of Geography of this university in 1959. It subsequently became a full-fledged department in 1962, thus becoming the first of such departments in any Nigerian University. It is gratifying to note that the first Inaugural Lecture from our Department was delivered barely a year later by our First Head of Department, Prof R.A. Reyment, who studied virtually all the sedimentary basins of Nigeria and produced the first coherent synthesis of their biostratigraphy. The second inaugural came from our highly revered Professor M.O. Oyawoye, a petrologist, in 1970. Subsequent inaugurals from the Department were presented by Professor E.A. Fayose, a biostratigrapher, in 1979; Professor T.A. Badejoko a geochemist in 1995, and Professor A.A. Elueze, an economic geologist, in 2002. Today's lecture is the sixth from our stable (see table 1).

From the modest beginning, some 50 years ago, the Department of Geology at Ibadan has grown in leaps and bounds. We are delighted to report that as of today, we can boast of 19 academic members of staff, with a satisfactory staff mix. It is also gratifying to note that the members of staff are in various areas of specialization in basic and applied geology.

Table 1: Inaugural Lectures from the Department of Geology, University of Ibadan, 1962-2010

S/No.	Presenter	Area of Specialization	Topic	Year
6.	Prof. A. I. Olayinka	Applied Geophysics	*Imaging the Earth's Subsurface*	2010
5.	Prof. A. A. Elueze	Economic Geology	*Compositional Character: Veritable Tool in the Appraisal of Geomaterials*	2002
4.	Prof. T. A. Badejoko	Geochemistry	*Geochemistry: The Heartbeat of Mineral Resources*	1995
3.	Prof. E. A. Fayose	Biostratigraphy	*Man and Minerals*	1979
2.	Prof. M. O. Oyawoye	Petrology	*Politics and Economics of Mineral Resources in Developing Countries*	1970
1.	Prof. R. A. Reyment	Biostratigraphy	*The Future of Geology in Nigeria*	1963

Geology as a Discipline

Geology is a branch of science involving the study of the Earth, the materials of which it is made, the structure of those materials and the processes acting upon them. It includes the study of organisms that have inhabited our planet. An important part of geology is the study of how Earth's materials, structures, processes and organisms have changed over time. Many processes, such as landslides, earthquakes, floods and volcanic eruptions can be hazardous to people. Geologists work to understand these processes well enough to avoid building important structures where they might be damaged. If geologists could prepare maps of areas that have been flooded in the past, they can prepare maps of areas that might be flooded in the future. These maps can be used to guide the development of communities and determine where flood protection or flood insurance is needed.

We use Earth materials everyday. We use oil that is produced from wells, metals that are produced from mines, and water that has been drawn from streams or from underground. Geologists conduct studies that locate rocks that contain important metals, plan the mines that produce them and the methods used to remove the metals from the rocks. They do similar work to locate and produce oil, natural gas and groundwater. Today, we are concerned about climate change. Many geologists are working to learn about the past climates of the Earth and how they have changed across time. This information is valuable to understand how our current climate is changing and what the results might be.

Some Basic Geological Concepts

Internal Structure of the Earth

The Earth is spherical in shape with a radius of about 6,378 km (fig. 1). The internal structure of the earth can be subdivided into three main regions; namely, the *crust*, the *mantle* and the *core*. The crust is very thin, averaging 20 km. The thinnest parts are under the oceans (Oceanic Crust) that go to a depth of roughly 10 km. The thickest parts are the continents (Continental Crust) which extend down to 35 km on average. The continental crust in the Himalayas is some 75 km deep. The interface between the crust and the mantle is called the *Moho discontinuity*. The mantle is the layer beneath the crust which extends about half-way to the centre. It is made of solid rock and behaves like an extremely viscous liquid. The convection of heat from the centre of the Earth is what ultimately drives the movement of the tectonic plates and causes mountains to rise. The interface between the mantle and the core is called the *Gutenberg discontinuity*. The *outer core* is the layer beneath the mantle. It is made of liquid iron and nickel. Complex convection currents give rise to a dynamo effect, which is responsible for the Earth's magnetic field. The *inner core* is the bit in the middle, and it is made of solid iron and nickel. Temperatures in the core are thought to be in the region of 5000-6000 °C and it is solid due to the massive pressure.

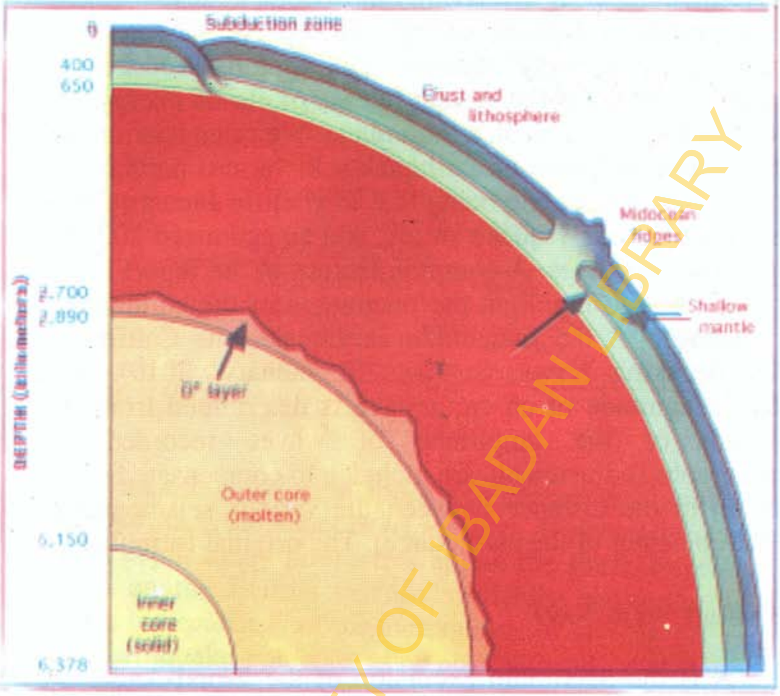


Fig 1. Internal structure of the Earth

Source: (*http://www.moorlandschool.co.uk/earth/earths_structure.htm*; retrieved 18 December, 2009).

Crust is created at the *mid-ocean ridges* and is destroyed at the *subduction zones*. The processes are driven by the convection currents created by the heat produced by natural radioactive processes deep within the Earth.

The crust and uppermost mantle down to a depth of about 70 to 100 km under deep ocean basins and 100 to 150 km under continents is rigid, forming a hard outer shell called the *lithosphere*. Beneath the lithosphere lies the *asthenosphere*, a layer in which seismic velocities often decrease, suggesting lower rigidity. It is about 150 km thick. This weaker layer is thought to be partially molten. The asthenosphere plays an important role in plate tectonics because it makes possible the relative motions of the overlying lithospheric plates.

The brittle condition of the lithosphere causes it to fracture when strongly stressed. The rupture produces an *earthquake*, which is the violent release of elastic energy due to sudden displacement on a fault plane. We often hear or see, on television, incidents of earthquakes in various parts of the world, a most recent one being that in Haiti in January 2010, where a magnitude-7 quake struck, and an estimated 200,000 people lost their lives. A common feature of the report in the mass media is to highlight the magnitude of the earthquake. For instance, 'A 6.5 magnitude earthquake hits California' (CNN Breaking News, Sunday, 10 January, 2010). The Richter magnitude of an earthquake is determined from the logarithm of the amplitude of waves recorded by seismographs (adjustments are included to compensate for the variation in the distance between the various seismographs and the epicenter of the earthquake). The original formula is:

$$M_L = \log_{10} A - \log_{10} A_o(\delta)$$

where A is the maximum excursion of the Wood-Anderson seismograph; the empirical function A_0 depends only on the epicentral distance of the station, δ. In practice, readings from all observing stations are averaged after adjustment with station-specific corrections to obtain the M_L value.

Because of the logarithmic basis of the scale, each whole number increase in magnitude represents a tenfold increase in measured amplitude; in terms of energy, each whole number increase corresponds to an increase of about 31.6 times the amount of energy released. Events with magnitudes of about 4.6 or greater are strong enough to be recorded by any of the seismographs in the world, given that the seismograph's sensors are not located in an earthquake's shadow. An earthquake magnitude scale is shown in table 2.

Table 2. Earthquake Magnitude Scale

Magnitude (M_L)	Earthquake effects	Estimated number per year
8.0 or greater	Great earthquake. It can totally destroy communities near the epicenter.	One every 5 to 10 years
7.0 to 7.9	Major earthquake. It can cause serious damage.	20
6.1 to 6.9	May cause a lot of damage in very densely populated areas.	100
5.5 to 6.0	Slight damage to buildings and other structures.	500
2.5 to 5.4	Often felt but only causes minor damage.	30,000
2.5 or less	Usually not felt but can be recorded by seismograph.	900,000

Source: (*http://www.geo.mtu.edu/UPSeis/magnitude.html* retrieved 14 January 2010).

An earthquake often appears to happen at a point which is referred to as the *focus* or *hypocenter*. It generally occurs at a focal depth many kilometers below the Earth's surface. The point on the Earth's surface vertically above the focus is called the *epicenter* of the earthquake.

Earthquake epicenters are not uniformly distributed over the Earth's surface, but occur predominantly along narrow zones of interpolate seismic activity. Three of such zones can be identified (fig. 2). First, the circum-Pacific zone, in which 75 to 80% of the annual release of seismic energy takes place, forms a girdle that encompasses the mountain ranges on the west coast of the Americas and the island arc along the east coast of Asia and Australia. Second, the Mediterranean-transasiatic zone, responsible for about 15 to 20% of the annual seismic energy release, begins at the Azores triple junction in the Atlantic Ocean and extends along the Azores-Gibraltar ridge. After passing through North Africa, it makes a loop through the Italian peninsula, the Alps and the Dinarides; it then runs through Turkey, Iran, the Himalayan mountain chain and the island arcs of the southeast Asia which terminates at the circum-Pacific zone. Third, the system of oceanic ridges and rises accounts for 3 to 7% of the annually released seismic energy. In addition to their seismicity, each of these zones is also characterized by active volcanism.

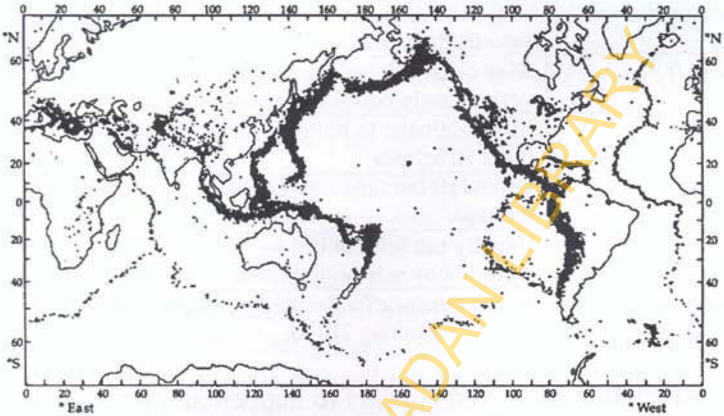


Fig. 2: The geographical distribution of epicentres for 30,000 earthquakes for the years 1961-1967 (After Barazangi and Dorman, 1969).

The remainder of the earth is considered *aseismic*. However, *no region of the Earth can be regarded as completely earthquake-free*. About 1% of the global seismicity is due to intraplate earthquakes, which occur remote from the major seismic zones.

Earthquakes can also be classified according to their focal depths. Earthquakes with shallow focal depths less than 70 km occur in all seismically active zones; only shallow earthquakes occur on the oceanic ridge systems. The largest proportion (about 85%) of the annual release of seismic energy is liberated in shallow-focus earthquakes. The remainder is set free by earthquakes with *intermediate* focal depths of 70 to 300 km (about 12%) and by earthquakes with *deep* focal depths greater than 300 km (about 3%).

Geologic Time Scale

The geologic time scale (fig. 3) is a chronologic scheme (or idealized model) relating stratigraphy to the time that is used by geologists, paleontologists and other earth scientists to describe the timing and relationships between events that have occurred during the history of the Earth. The table of geologic time spans presented here agrees with the dates and nomenclature proposed by the International Commission on Stratigraphy, and it uses the standard colour codes of the United States Geological Survey.

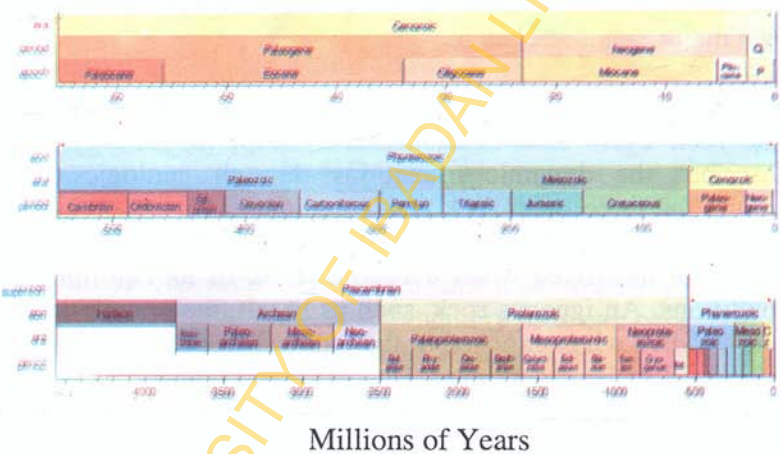


Fig 3. Geologic time scale (*http://en.wikipedia.org/wiki/Geologic_time_scale*; retrieved 18 December, 2009).

This clock representation shows some of the major units of geological time and definitive events of Earth history. The Hadean eon represents the time before fossil record of life on Earth; its upper boundary is now regarded as 4.0 Ga. Other subdivisions reflect the evolution of life; the Archean and Proterozoic are both eons, while the Palaeozoic, Mesozoic and Cenozoic are eras of the Phanerozoic eon. The two million year Quaternary period, the time of recognizable humans, is too small to be visible at this scale.

Evidence from radiometric dating indicates that the Earth is about 4.570 billion years old. The geological or *deep time* of Earth's past has been organised into various units according to events which took place in each period. Different spans of time on the time scale are usually delimited by major geological or paleontological events such as mass extinctions. For example, the boundary between the Cretaceous period and the Paleogene period is defined by the Cretaceous–Tertiary extinction event, which marked the demise of the dinosaurs and of many marine species. Older periods which predate the reliable fossil record are defined by absolute age. Each era on the scale is separated from the next by a major event or change.

The Rock Cycle

The rock cycle is a fundamental concept in geology that describes the dynamic transitions through geologic time among the three main rock types: sedimentary, metamorphic and igneous. As illustrated in fig. 4, each type of rock is altered or destroyed when it is forced out of its equilibrium conditions. An igneous rock, such as basalt, may break down and dissolve when exposed to the atmosphere, or melt as it is subducted under a continent. Due to the driving forces of the rock cycle, plate tectonics and the water cycle, rocks do not remain in equilibrium and are forced to change as they encounter new environments. The rock cycle is an illustration that explains how the three rock types are related to each other and how processes change from one type to another over time.

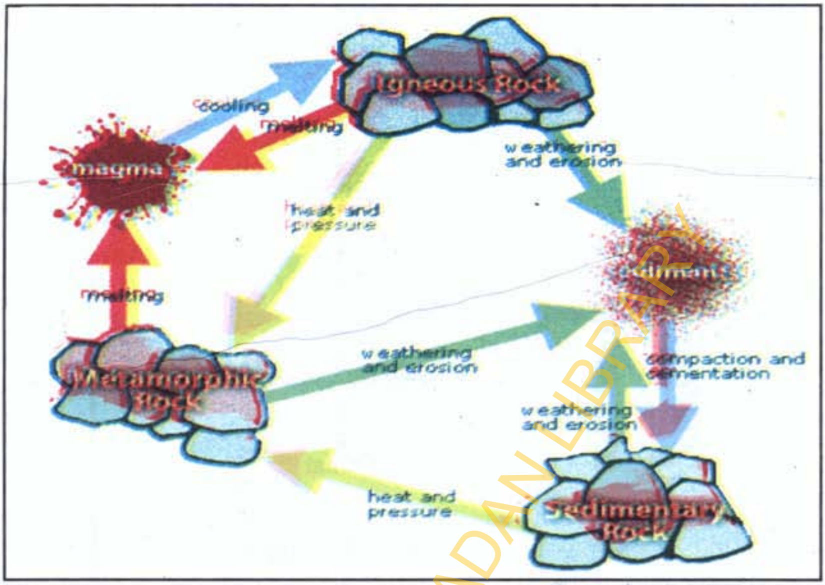


Fig 4. The Rock Cycle.
Source: (*http://www.cotf.edu/ete/modules/msese/earthsysflr/rock.html*; retrieved 26 December, 2009).

An igneous rock can change into a sedimentary rock or into a metamorphic rock. A sedimentary rock can change into metamorphic rock or into igneous rock, while a metamorphic rock can change into igneous or sedimentary rock. An example of metamorphic change from mud into shale (a sedimentary rock), into slate, phyllite, schist and gneiss (metamorphic rocks) is shown in fig 5.

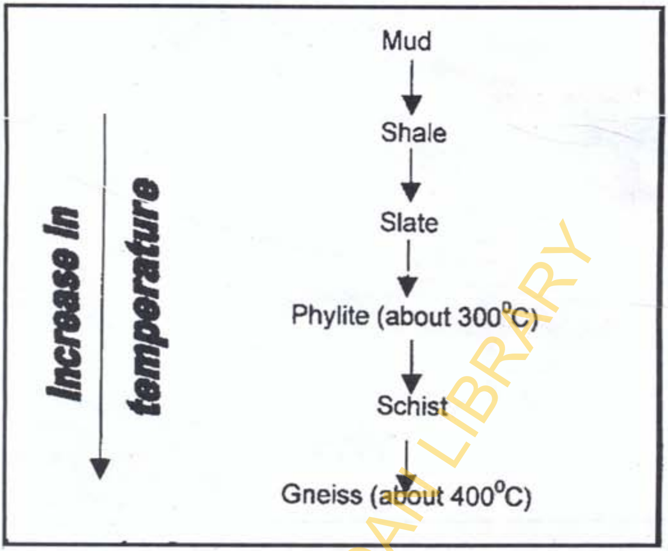


Fig. 5. An example of metamorphic change

Igneous rocks form when magma cools and makes crystals. Magma is a hot liquid made of melted minerals. The minerals can form crystals when they cool. An igneous rock can form underground, where the magma cools slowly, or, it can form above ground, where the magma cools quickly. When magma pours out on the Earth's surface, it is called lava.

On the Earth's surface, wind and water can break rock into pieces. They can also carry rock pieces to another place. Usually, the rock pieces, called sediments, drop from the wind or water to make a layer. The layer can be buried under other layers of sediments. After a long time, the sediments can be cemented together to make sedimentary rock. In this way, an igneous rock can become a sedimentary rock.

All rocks can be heated. But where does the heat come from? Inside the Earth, there is heat from pressure (push your hands together very hard and feel the heat). There is heat from friction (rub your hands together and feel the heat). There is also heat from radioactive decay (the process that gives us nuclear power plants that make electricity). The heat are stored as freshwater in lakes. Not all runoff flows into rivers, much of it soaks into the ground as infiltration. Some water infiltrates deep into the ground and replenishes aquifers, which store freshwater for long periods of time. Some infiltration stays close to the land surface and can seep back into surface-water bodies (and the ocean) as groundwater discharges. Some groundwater finds openings in the land surface and comes out as freshwater springs. Over time, the water returns to the ocean, where our water cycle started.

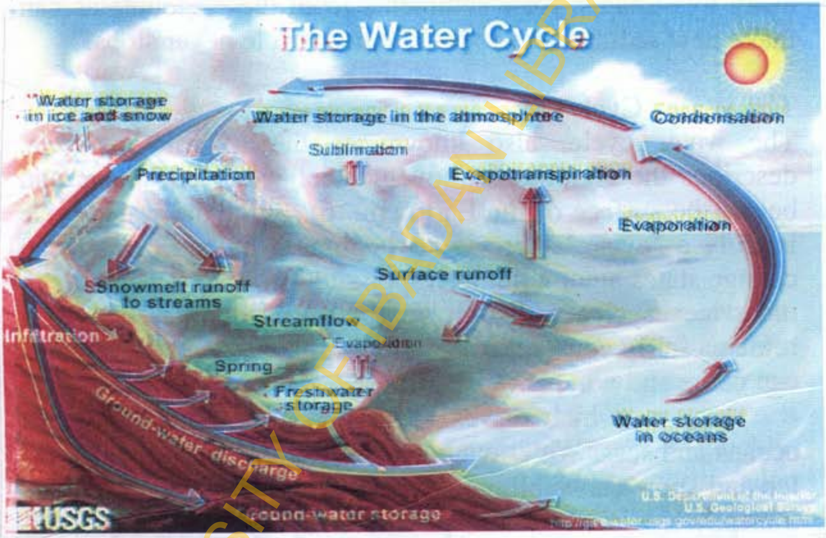


Fig. 6. The Water Cycle
Source: (*http://en.wikipedia.org/wiki/File:Water_cycle.png*; retrieved 27 December, 2009).

The *residence time* of a reservoir within the hydrologic cycle is the average time a water molecule will spend in the reservoir (table 3). It is a measure of the average age of the water in such a reservoir.

Groundwater can spend over 10,000 years beneath Earth's surface before leaving. Particularly old groundwater is called fossil water. Water stored in the soil remains there very briefly, because it is spread thinly across the Earth, and it is readily lost by evaporation, transpiration, stream flow or groundwater recharge. After evaporating, the residence time in the atmosphere is about 9 days before condensing and falling to the Earth as precipitation.

Table 3: Average Reservoir Residence Time

Reservoir		Average residence time
Oceans		3,200 years
Glaciers		20 to 100 years
Seasonal snow cover		2 to 6 months
Soil moisture		1 to 2 months
Groundwater	shallow	100 to 200 years
	deep	10,000 years
Lakes		50 to 100 years
Rivers		2 to 6 months
Atmosphere		9 days

Source: (PhysicalGeography.net. *CHAPTER 8: Introduction to the Hydrosphere* Retrieved on 24 October, 2006

Overview of Geology of Nigeria

The surface area of Nigeria is about 923, 768 km^2 and about 50% of this is underlain directly by various suites of crystalline rocks (igneous and metamorphic rocks) while the remainder is underlain by sedimentary rocks (fig. 7). The crystalline rocks are further divided into three main groups namely:

- The Basement Complex of Precambrian age (over 570 Ma),
- The Younger Granites of carboniferous to cretaceous (300-140 Ma), and
- The Tertiary to Recent Volcanics (65 Ma – 0.01 Ma)
- The sedimentary rocks are found in sedimentary basins which include the Eastern Dahomey (or Benin) Basin, the Niger Delta, the Anambra Basin, the Benue Trough, the Bornu Basin, the Middle Niger Basin and the Sokoto Basin.

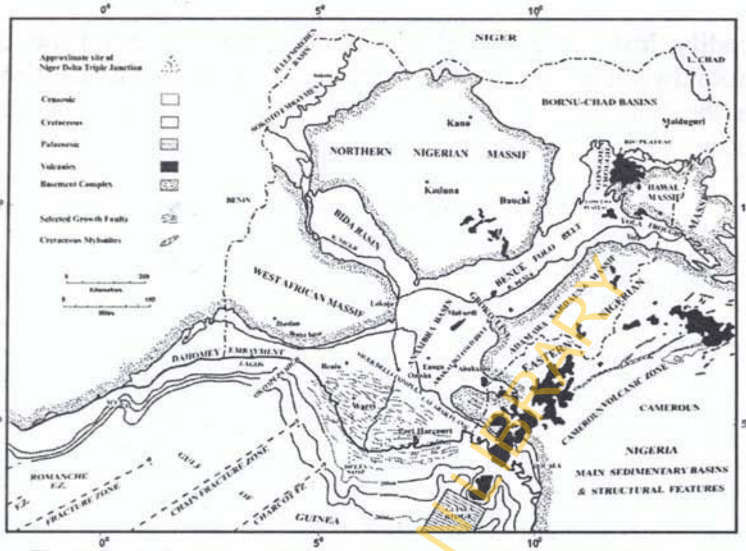


Fig. 7. Geological Map of Nigeria (Adapted from Whiteman, 1982).

Rocks are resources that bring a lot of revenues for the technological take-off of a nation (Ekwueme, 2006). They are the sources of mineral wealth, and with a sound knowledge of their structures indications of possible areas of mineral occurrences can be reasonably predicted based on geological principles. Some of the products include dimension stone, slate, roadstone, aggregate, bricks, tiles, cement, glass, plaster, plasterboard, insulating materials and bitumen.

One of the major tools used in studying geological problems is by applying the principles of physics. An overview of geophysics is given in the following section.

Definition of Geophysics

Geophysics has been defined variously as:

(i) The study of the earth by the quantitative physical method, especially by seismic reflection and refract-tion, gravity, magnetic, electrical, electromagnetic and radioactivity methods.

(ii) The application of physical principles to the study of the earth. This includes the branches of

(a) seismology (earthquakes and elastic waves);
(b) geo-thermometry (heating of the earth, heat flow, volcanology, and hot springs);
(c) hydrology (ground and surface water, sometimes including glaciology);
(d) physical oceanography;
(e) meteorology;
(f) gravity and geodesy (the earth's gravitational field and the size and form of the earth);
(g) atmospheric electricity and terrestrial magnetism (including ionosphere, Van Allen belts, telluric currents, etc.);
(h) tectonophysics (geological processes in the earth); and
(i) exploration and engineering geophysics.

Geochronology (the dating of earth history) and geo-cosmogony (the origin of the earth) are sometimes added to the foregoing list.

Geophysics often refers to solid-earth geophysics only, thus excluding (c), (d), (e), and portions of other subjects from the above list.

In this discourse, exploration geophysics is the use of methods such as seismic, gravity, magnetic, electrical and electromagnetic (table 4) in the search for oil, gas, minerals, groundwater, etc., with the objective of economic exploitation.

Some geophysicists spend most of their time outdoors studying various features of the Earth, and others spend most of their time indoors using computers for modelling and calculations. Some geophysicists use these methods to find oil, iron, copper and many other minerals. Some evaluate earth properties for environmental hazards and evaluate areas for dams or construction sites, and for other structures such as buildings, tunnels and bridges. Research geophysicists study the internal structure and evolution of the earth, earthquakes, the ocean and other physical features using these methods.

Table 4. Geophysical Methods, the Properties Involved and the Parameters Measured

Method	Nature	Property involved	Value measured
Gravity	P	Density	Spatial variations in natural gravity field
Magnetic	P	Magnetic susceptibility	Spatial variations in natural magnetic field
Radioactive	P	Abundance of radio nucleides	Gamma radiation
Heat flow	P	Thermal conductivity	Heat flow
Electrical	A	Electrical conductivity	Apparent resistivity
Telluric current	P	Electrical conductivity	Relative apparent resistivity
Spontaneous polarization	P	Oxidation potential, ion concentrations	Natural electrochemical potentials
Induced polarization	A	Electronic conductivity	Polarization voltages
Electromagnetic	A	Electrical conductivity and/or magnetic permeability	Alternating electrical/magnetic field phase and intensity relationships
Seismic	P	Ground unrest	Ambient seismic noise
	A	Seismic travel time, velocity, acoustic impedance	Seismic travel times of different waves, wave amplitudes, reflection patterns
Remote sensing	P	Natural radiation	Radiation intensity
	A	Reflectivity (albedo)	Reflected radiation
Borehole	P	Natural radiation	Natural voltages, natural gamma radiation
	A	Electrical conductivity, seismic velocity, nuclear reactions	Apparent resistivity, travel times and amplitudes, induced, back-scattered radiation

Note: P, passive method involving measurement of natural effects; A, active method involving an artificial disturbance.
Source: Sheriff, 1989

My Odyssey in the Geological Sciences

For some inexplicable reasons, as a secondary school student at the famous and prestigious Ilesha Grammar School, all I wanted to become in life in terms of a career choice was a geologist. Up till now, I cannot fathom exactly what motivated this choice, safe for, perhaps, the fact that I was very good in Geography, and I probably thought the next possible nice-sounding course to choose was Geology. Incidentally, a credit level pass in Geography at the Ordinarily Level/West African School Certificate examination was not a requirement for reading geology at the University of Ibadan when people of my generation were seeking admission by concessional entrance into Ibadan. Invariably, I got admitted into the University of Ibadan through the Preliminary Science class (now 100 Level) to read Geology during the 1977/78 session. One tough course I offered in my second year in the University was "PHY 102: Classical Physics 1" (now PHY 201). Somehow, the course lecturer, Dr S.C. Garde, informed me that my performance was outstanding, and that I led the class. He added that if I were a Physics major student, I would have been awarded one of the scholarships on offer by an international oil company. I felt most humbled with such encomium showered on me, and this, I believe, in retrospect, was the beginning of my romance with Geophysics.

In our final year in 1980/81, we were given the opportunity to choose an area of specialization that we were interested in for the purpose of the "Project in Geology". I picked Applied Geophysics and was assigned to Dr Ofiafate Ofrey as my Supervisor. My project partner was my very good friend, the highly cerebral Dr George Ifechukwude Unomah, now a leading explorationist with Mobil Producing Nigeria Unlimited. We worked on a micro-gravity survey of the Physics Experimental Station at the University of Ibadan.

A few years later when I joined the University of Ibadan as a lecturer in my old department, some of my old secondary school mates teased me that it was a *fait accompli*, in so far as I had satisfied my childhood curiosity.

I was admitted to read Geophysics (Pure and Applied) for my MSc degree at the Imperial College of Science and Technology, London, in 1983. The Geophysics Section of the Geology Department at Imperial College was then reputed to be the largest of its kind in Western Europe, with an unusually large number of postgraduate students. It was such an exciting experience studying in a postgraduate class of 23 students drawn from 11 different nationalities. On completion of the programme, I proceeded to the University of Birmingham. It was a great and rewarding experience working under some of the giants in our discipline. My thesis supervisor and mentor was Dr R.D. Barker, who invented the Offset-Wenner array (Barker 1979, 1981). His own PhD supervisor, Prof D.H. Griffiths, who co-authored with Dr R.F. King the world-acclaimed geophysics textbook, *Applied Geophysics for Engineers and Geologists*, was still very much around in the Department, albeit as an Emeritus Professor, when I arrived in Birmingham. As it later turned out, Professor Griffiths served as the Internal Examiner for my PhD thesis.

In the following section, which is the longest in this lecture, an attempt is made to give a synopsis of my research endeavours.

Areas of Specialization and My Modest Contributions to Scholarship

My research interest is in Exploration Geophysics. The principal methods that my collaborators and I have employed till date comprise direct current surface geoelectrics, electromagnetics, seismics and borehole geophysics.

The various research topics can be summarized in the following groups:

Group I : Microprocessor-Controlled Resistivity Traversing and its geophysical applications.

Group II : Regional Ground-water Resource Evaluation.

Group III : 1-D Inversion of Resistivity Sounding Data.

- Quantitative assessment of geoelectrical suppression
- Errors in depth determination from resistivity soundings

- Constraining the inversion of resistivity sounding data
- Accuracy of partial curve-matching
- Use of longitudinal resistivity
- Fuzzy logic modelling

Group IV : 2-D Resistivity Imaging

- Use of longitudinal conductances
- Non-uniqueness and equivalence in 2-D imaging and modelling
- Choice of the best model in 2-D geoelectrical imaging
- Use of Block Inversion in the 2-D Interpretation of Apparent Resistivity Data and Comparison with Smooth Inversion.
- Smooth and sharp-boundary inversion of 2-D pseudosection data in the presence of a decrease in resistivity with depth

Group V : Groundwater Occurrence in Ibadan Metropolis

- Groundwater occurrence
- Aspects of quality

Group VI : Environmental Geophysics

- Geoelectric Imaging at an abandoned dump site
- Environmental Assessment of a Sewage Disposal System.
- Corrosion potential along a pipeline route in the Niger Delta
- Two-Dimensional Geoelectric Response of a Hydrocarbon-Impacted Sand formation

- Geophysical investigation of suspected springs

Group VII : Engineering Geophysics
Group VIII : Integrated Geophysical Investigation at a Geological Transition Zone
Group IX : Archaeological investigation
Group X : Geoelectric imaging of a valley bottom soil in relation to its agricultural significance
Group XI : 3-D Geoelectric Imaging
Group XII : Petroleum Geophysics

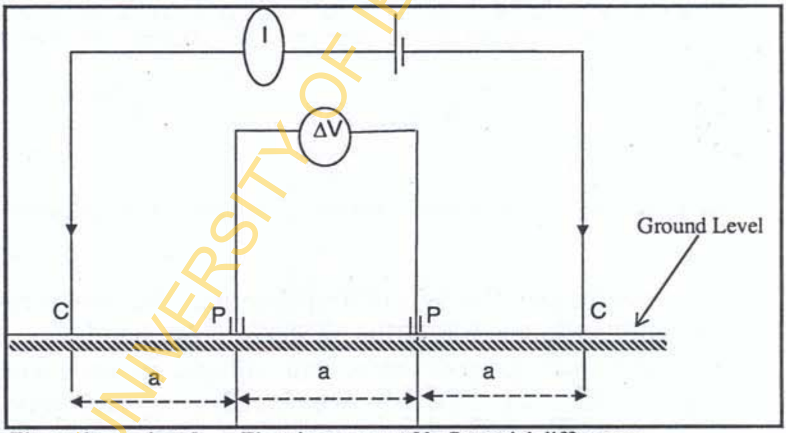
- Stratigraphy and hydrocarbon potential of the Opuama Channel Complex, western Niger Delta.
- Use of kriging for estimation of 2-D permeability distribution in a hydrocarbon reservoir.
- Seismic impedance character of the weathering layer in Eastern Niger Delta.
- Generation of rock property for seismic modelling.

Group XIII: Research Methodologies

Group I: Microprocessor-Controlled Resistivity Traversing (MRT)

The conventional approach to electrical resistivity surveying entails injecting electrical current into the ground through a pair of electrodes and measuring the potential difference developed as a result, using another pair of electrodes (fig. 8). My PhD thesis involved the development of simple procedures for the interpretation of resistivity survey data collected, using the Microprocessor-Controlled Resistivity Traversing (MRT) System and an evaluation of the use of the technique in hydrogeological investigations in tropical basement areas of Africa and, in particular, southwestern Nigeria (Olayinka, 1988). The MRT technique is a multi-electrode resistivity array in which a small microprocessor is used to switch through the electrodes at different Wenner spacings and positions. This greatly simplifies the field operations, both in terms of the survey time and the manpower requirements. The layout of the MRT system is given in fig. 9, and the sequence of measurement of a pseudosection is presented in fig.10 (Griffiths *et al*., 1990).

One of the methods of deriving an initial interpretation involves averaging vertical sets of data to provide a summed profile from which dimensionless characteristics are subsequently measured. Another method is based on the estimation of the total longitudinal conductances of the weathered mantle from the vertical sets of data, and it is used with interactive computer graphics. The final step in the MRT interpretation consists of iterative two-dimensional computer modelling. Olayinka (1988) established that the accuracy of the Dey and Morrison's (1979) finite difference algorithm used for this purpose is affected by the resistivity contrast. Correction factors were subsequently determined.



a = Electrode spacing; I = Electric current; ΔV= Potential difference;
P = Potential electrode; C = Current electrode.

Fig. 8: Typical field layout (Wenner) in electrical resistivity method.

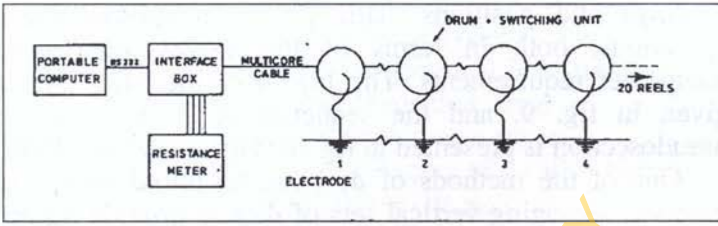


Fig. 9: The Microprocessor-controlled Resistivity Traversing (MRT) System (after Griffiths *et al.*, 1990).

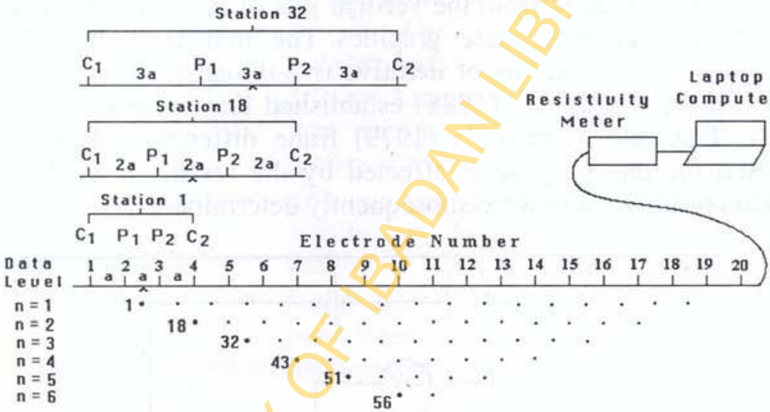


Fig. 10: Sequence of measurements to build up a pseudosection (after Griffiths *et al.*, 1990).

Olayinka and Barker (1990a) described the versatility of the MRT system for siting water-supply boreholes with examples from several towns and villages in southwestern Nigeria (fig. 11). Deeply weathered sites and probable fracture zones, for which there are often no surface indications, and which can be missed altogether with conventional sounding techniques, were delineated. A study of the MRT results suggests a strong relationship between low-resistivity anomalies on the contoured MRT sections and productive boreholes. The MRT pseudosections allow a visual appreciation of the structure of the subsurface not readily obtained with other geophysical techniques. The results suggest that the success of borehole drilling in Basement Complex areas is related to the identification of a sufficient thickness of regolith, a low clay content, and a high degree of saturation within the weathered zone, coupled with underlying fractured bedrock. In all of the productive boreholes, the depth to bedrock exceeds 15 m. A correlation of the surface-measured geoelectrical data with pumping test results suggests that for a weathered basement aquifer in this area to be water-yielding, its resistivity should lie within the range of 40 to 150 Ω-m. The most productive boreholes appear to penetrate regolith with a resistivity between 60 and 90 Ω-m.

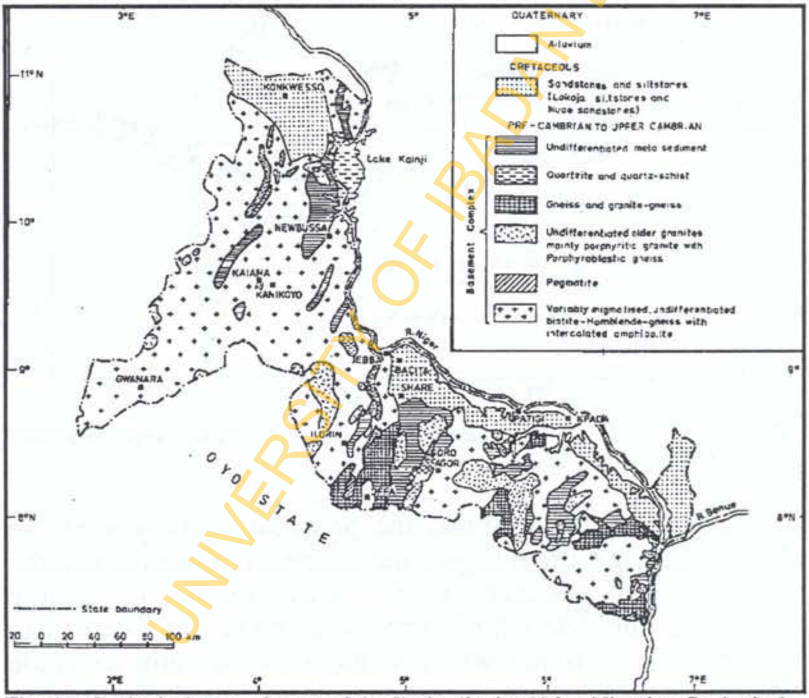


Fig. 11: Geological map of parts of the Ilorin district (After Nigerian Geological Survey Agency).

Some of the towns and villages where the MRT technique was used as part of a borehole siting programme are shown in fig. 12.

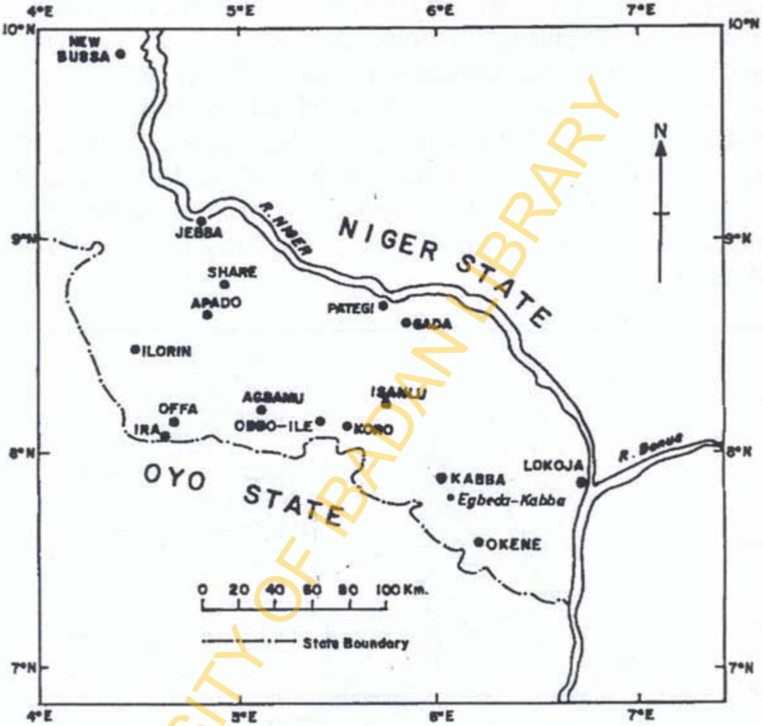


Fig. 12: Location map of some of the towns and villages where the MRT technique was tested.

Our work demonstrated the potential usefulness of the MRT imaging system to provide information from which the distribution of subsurface resistivity in cross-section along a profile can be determined. The initial successes recorded in our pioneering studies served as the basis for multi-electrode resistivity arrays, a technique that is now used routinely in several parts of the world for hydrogeological, geotechnical and archaeological purposes.

Group II: Groundwater Resource Evaluation

Groundwater is an important component of the earth's environment. The occurrence of groundwater in areas underlain by crystalline Basement Complex rocks is structurally-controlled, and it is, therefore, amenable to investigation by geophysical techniques to furnish information on the geometry and hydrogeological characteristics of the aquifers. The object of such surveys include determination of depth to the hard, competent bedrock; indications of depth to water, extent of saturation and porosity of the regolith; location of steeply-dipping structures, such as faults and dykes; and mapping variations in overburden composition and bedrock lithology. A typical weathering profile developed upon crystalline Basement Complex rocks and variations in the hydraulic properties is shown in fig. 13. The electrical resistivity method is recognized as the most widely adopted approach on account of its cost effectiveness and ease of operation (Olayinka, 1998b). In particular, combined sounding/profiling surveys offer distinct advantages over the conventional methods in areas of complex geology. Efforts have been made towards developing simple methods to aid the interpretation of the apparent resistivity data.

The emphasis of the research in this category has been how to improve on the content of information obtained from the use of geophysical surveying techniques (electrical soundings, multi-electrode resistivity profiling and electromagnetics) in routine surveys. Field evaluation has been conducted in several parts of the Basement Complex terrain of Nigeria. Practical strategies to aid the improvement of the success rates of borehole drilling have been developed accordingly.

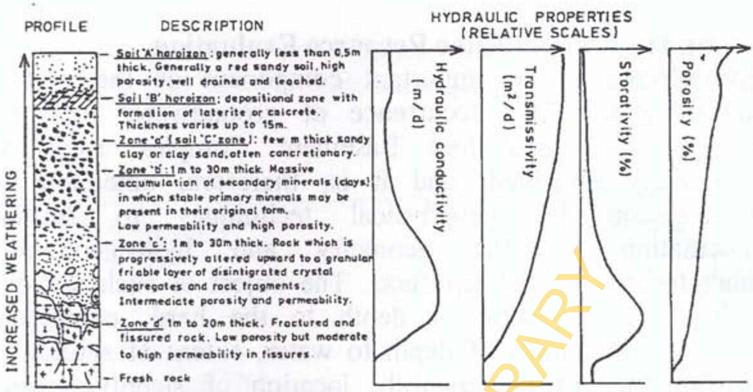


Fig. 13: Typical weathering profile developed upon crystalline basement rocks and variations in the hydraulic properties (adapted from Acworth, 1987; Chilton and Smith-Carington, 1984; Buckley and Zeil, 1984).

A vertical section through the weathered profile developed above crystalline basement rocks in low-latitude regions comprises, from top to bottom, the soil layer, the saprolite (product of the *in situ* chemical weathering of the bedrock), the saprock (fractured bedrock) and the fresh bedrock (fig. 14). It is worth noting that the resistivity of the saprolite can be as low as 10 Ω-m, especially when the regolith is rich in clay. The geoelectrical succession over a tropically-weathered regolith based on southwestern Nigerian conditions, is shown in table 5.

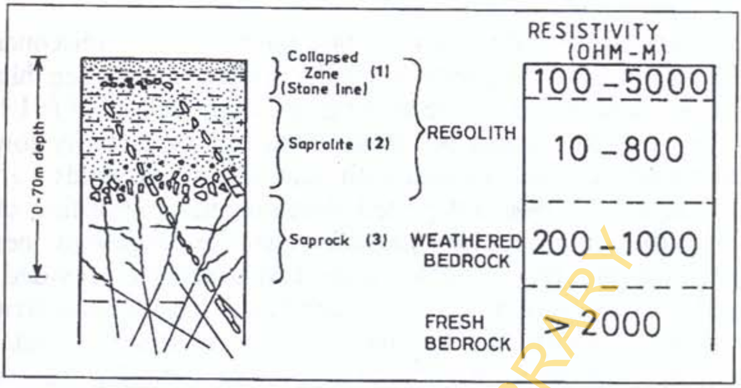


Fig. 14: Schematic weathered profile above crystalline basement rocks and the typical range of resistivity for each weathering grade

Table 5. Geoelectrical Succession over a Tropically-weathered Regolith based on Southwestern Nigerian Conditions

Layer	Thickness (m)	Resistivity (Ω-m)	Hydrogeological significance
1	<5	<200 (wet)	The residual soil.
		Up to 5000 (dry)	Often forms lateritic cappings. Could be associated with deep weathering.
2	5-35	10-800	The saprolite zone. Often has a high clay content; good aquifers when permeable.
3	0-20	200-1000	The fractured basement sequence. Has low effective relative thickness, which makes its detection difficult fro surface geoelectrics. Often a transitional zone. Good aquifer when not too highly resistive
4		∞	The semi-infinite bedrock. Poor aquifer unless when fractured.

Olayinka (1990b) employed ground electromagnetic profiling, using a Geonics EM-34-3 instrument, to identify areas of high conductivity in parts of the Precambrian crystalline Basement Complex of southwestern Nigeria. The surveys, conducted as part of a rural water supply programme, indicate that the apparent conductivities are generally lower than about 60 mmho m^{-1}. Subsequent borehole drilling suggests a good correlation between high EM34 anomalies, deep weathering and high well yield (>1 l s^{-1}). On the other hand, boreholes sited on conductivity lows penetrated a thinner regolith with relatively lower yields.

Olayinka (1990c) integrated electromagnetic profiling and resistivity soundings in ground-water investigations near Egbeda-Kabba (fig. 15). While the EM technique provided a rapid reconnaissance tool in identifying high conductivity anomalies thought to be due to deep weathering and/or bedrock fissuring, a quantitative interpretation of the sounding data indicated that the resistivity of the weathered zone varies over a wide range, from about 10 to 200 Ω -m, and that the overburden is generally less than 40 m thick (fig. 16).

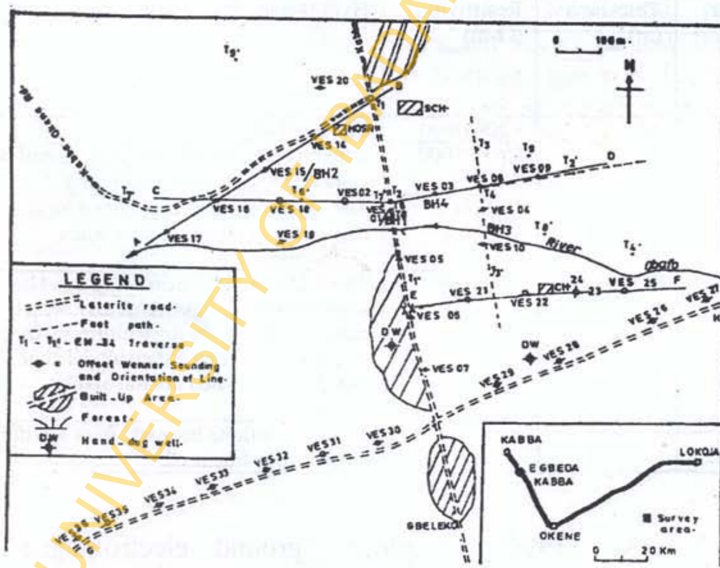


Fig. 15: Orientation of geophysical traverses at the Egbeda-Kabba survey area (Inset: location of Egbeda-Kabba in relation to neighbouring towns).

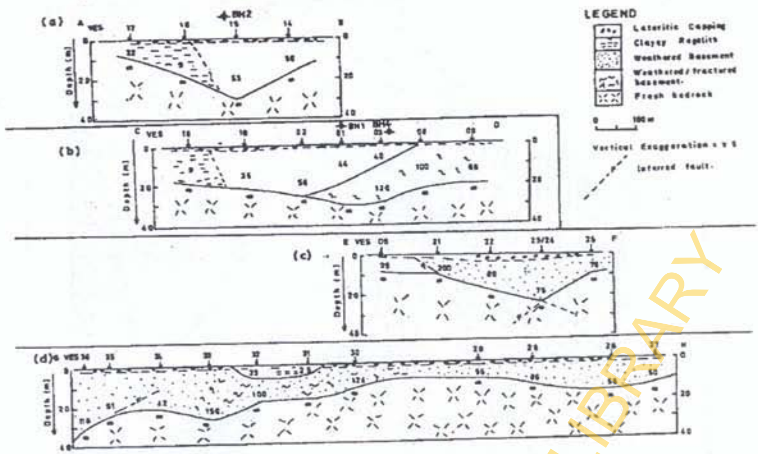


Fig. 16: Interpreted geological sequences along selected profiles at Egbeda-Kabba.

A similar approach was adopted for groundwater exploration in Igbeti, southwestern Nigeria (Olayinka *et al*., 2004). The bedrock geology comprises a suite of metasediments, gneisses and intrusive granites (fig. 17). The three main targets for groundwater in the locality consist of the weathered zone, the fractured zone and vertical dykes. The fractured gneiss sequence was inferred from the VES data as relatively low model resistivity at less than 1500 Ω -m for the geoelectric basement. The vertical dykes were inferred from the large separation between the horizontal and vertical dipoles on the EM conductivity profiles, coupled with negative readings on the vertical dipole curves. The boreholes drilled, based on results of the geophysical surveys, penetrated a sequence of topsoil/laterite, moderately weathered granite, fractured gneisses and fresh bedrock (fig. 18).

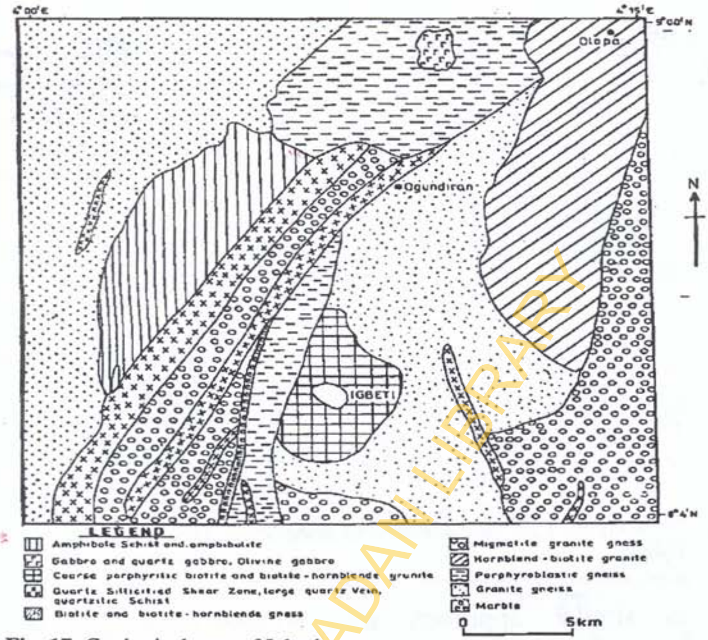


Fig. 17: Geological map of Igbeti area.

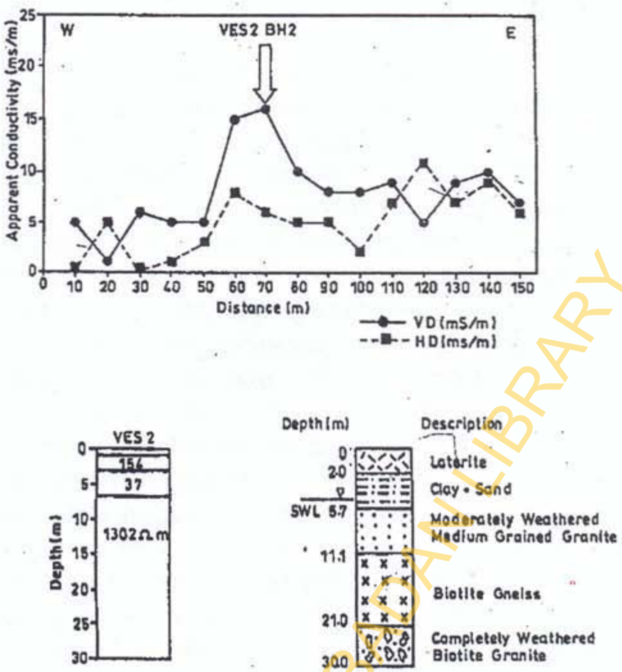


Fig. 18: Geophysical survey at the Igbeti palace ground. Upper diagram: the EM profile; left bottom: geoelectric data interpretation; right bottom: borehole lithologic description (After Olayinka *et. al.*, 2004).

An attempt was made to assess the effectiveness of surface geophysical methods notably electrical resistivity, electromagnetic, seismic refraction, magnetic, gravity and induced polarization for ground-water exploration in crystalline basement areas (Olayinka, 1992). The critical factors in the choice of a particular method include the local geological setting, the initial and maintenance costs of the equipment, the speed of surveying, the manpower required as field crew, the degree of sophistication entailed in data processing to enable a geologically meaningful interpretation, and anomaly resolution. These explain the preference for electrical resistivity (both vertical sounding and horizontal profiling) from several case histories from Nigeria and the rest of Africa.

Olayinka and Olorunfemi (1992) and Olayinka (1995b) appraised some EM34 ground conductivity profiling, electrical resistivity sounding and 2-D resistivity data from parts of southwestern Nigeria to ascertain why some geophysically-sited boreholes in crystalline Basement Complex terrains are productive, while some are not. The results indicate that, first, poor drilling results can often be attributed to shallow weathering. Second, a very thick slightly weathered and/or fractured basement, which is often typified by a relatively high resistivity, may be undersaturated and, consequently, dry. Third, a high resitivity, which is much greater than 1000 Ω-m for the geoelectrical basement may be indicative of a lack of productive bedrock fissures. Fourth, in the qualitative assessment of pseudosection data, relatively low resistivity zones may not necessarily be owing to deep weathering and/or bedrock fractures if the magnitude of the apparent resistivities are very high. The dominant geophysical inference in each case of an unsuccessful well may comprise more than one of these factors.

The apparent conductivity at Ogaminana BH4 site was very high at 48 mS/m (fig. 19). It may be noted that the peak anomaly was not recommended for borehole drilling because the VES at that location indicated a very shallow overburden, a low-resistivity clay-rich overburden and a high-resistivity fresh bedrock. BH 4 was productive. On the other hand, the apparent conductivity at Gada BH 1 was much lower at 7.6 mS/m, and this zone coincided with a low resistivity anomaly on the 2-D pseudosection data. The borehole drilled at this location was dry.

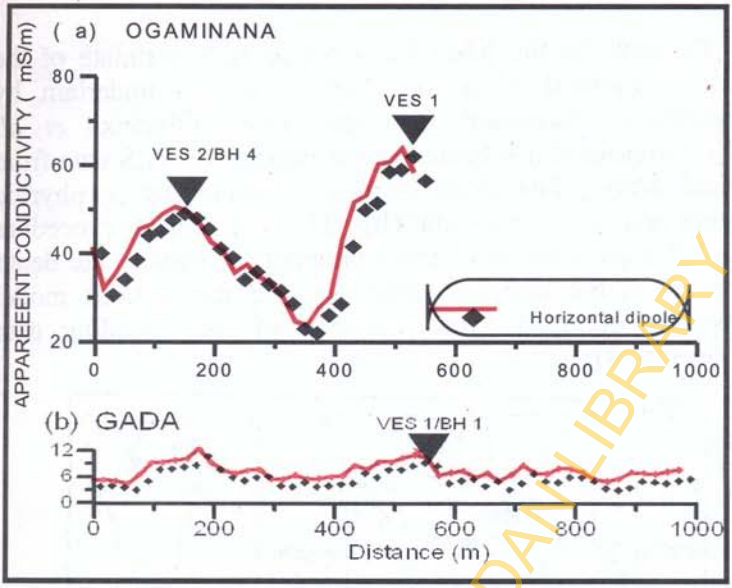


Fig. 19: EM34 traverses at (a) Ogaminana, near Okene; (b) Gada, near Patigi.

An examination of the pseudosection data has shown that the apparent resistivities along the Gada MRT line are much higher than those for other sites in the same zone for any given electrode spacing (fig. 20).

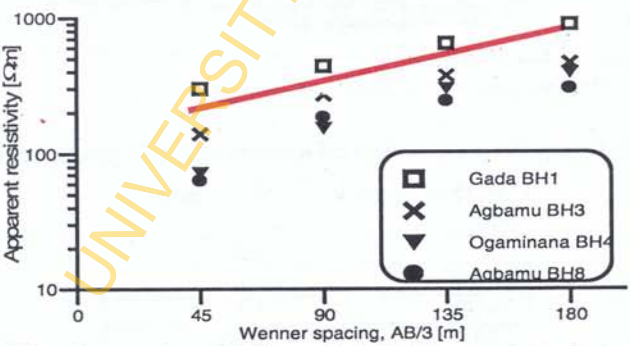


Fig. 20: Plot of apparent resistivities against the Wenner electrode spacings at some borehole positions in crystalline basement areas of southwestern Nigeria. Note that values above the solid line are from a dry hole (Gada BH 1) while those below are for productive wells (After Olayinka, 1995b).

To serve as the basis for a preliminary estimate of the aquifer potential in a low latitude terrain underlain by Precambrian Basement Complex rocks, Olayinka *et al.* (1997) presented a scheme for the ranking of VES data from around Shaki. The study area is underlain by porphyritic granite and potassic syenite (fig. 21). The ranking procedure entailed consideration of three parameters, namely the depth to bedrock, the saprolite resistivity and the bedrock model resistivity obtained from inversion of the sounding data (tables 6 to 8).

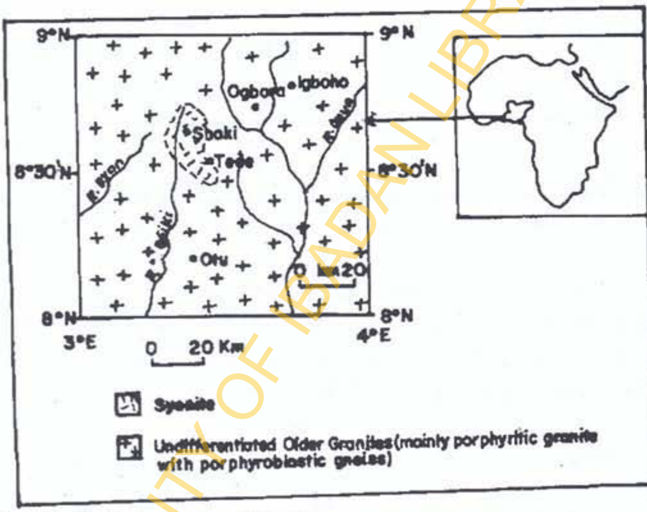


Fig. 21: Geological map of Shaki area.

Table 6. Aquifer Potential as a Function of the Depth to Bedrock

Depth to bedrock (m)	Weighting
<10	2.5
10-20	5.0
20-30	7.5
>30	10.0

Source: **Olayinka *et al.* 1997**

Table 7. Aquifer Potential as a Function of Saprolite Resistivity

Saprolite resistivity (Ω-m)	Aquifer characteristics	Weighting
<20	Clayey; limited aquifer potential	7.5
20-100	Optimum weathering and groundwater potential	10.0
100-150	Medium aquifer conditions and potential	7.5
150-300	Limited weathering and poor potential	5.0
>300	Negligible potential	2.5

Source: **Modified after Wright, 1992**

Table 8. Aquifer Potential as a Function of the Fractured Bedrock Resistivity

Saprock resistivity (Ω-m)	**Aquifer characteristics**	**Weighting**
<750	High fracture permeability as a result of weathering; high aquifer potential.	10.0
750-1500	Reduced influence of weathering; medium aquifer potential.	7.5
1500-3000	Fairly low effect of weathering; low aquifer potential.	5.0
>3000	Little or no weathering of the bedrock; negligible aquifer potential.	2.5

Source: **Olayinka *et al.* 1997**

The geometric mean of the weighting from the three geoelectrical parameters varies between 3 and 9, with the modal class being 5 to 6. Weighted means less than 5 indicate low aquifer potential which can only support hand pumps. Weighted means between 5 and 7 represent medium aquifer potential and can support surface pumps. The weighted means higher than 7 are indicative of areas with high aquifer potential and can support submersible pumps.

Okurumeh and Olayinka (1998) employed radial VES in the Okeho area to determine electrical anisotropy and map the trend of concealed structures (fig. 22). The results indicate that the concealed bedrock is anisotropic with the causative structural features comprising joints, foliations and faults. Dual structural trends were observed at some of the radial VES locations, and they were interpreted as the intersection of structural elements at depth (figs. 23 and 24). The coefficient of anisotropy varies from 1.02 to 1.54, with a mean of 1.21. The bedrock model resistivity shows an inverse relationship with the coefficient of anisotropy, and localities with low bedrock model resistivity may indicate a fractured zone which could favour groundwater storage. This is also true of sites with dual structural trends as the interconnected structures should aid groundwater movement. This study has shown that radial VES could complement surface geologic mapping and remotely sensed data in structural analysis of concealed basement structures.

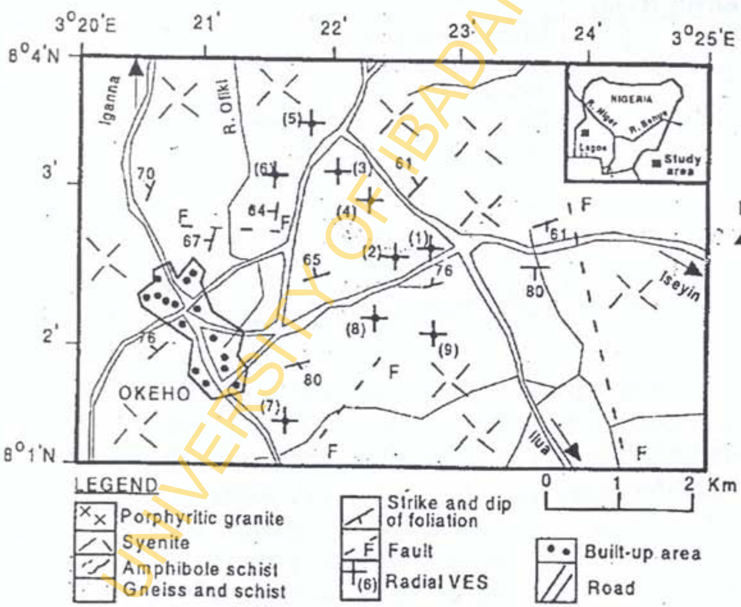


Fig. 22: Geological map of Okeho area showing the position of radial soundings (after Okurumeh and Olayinka, 1998).

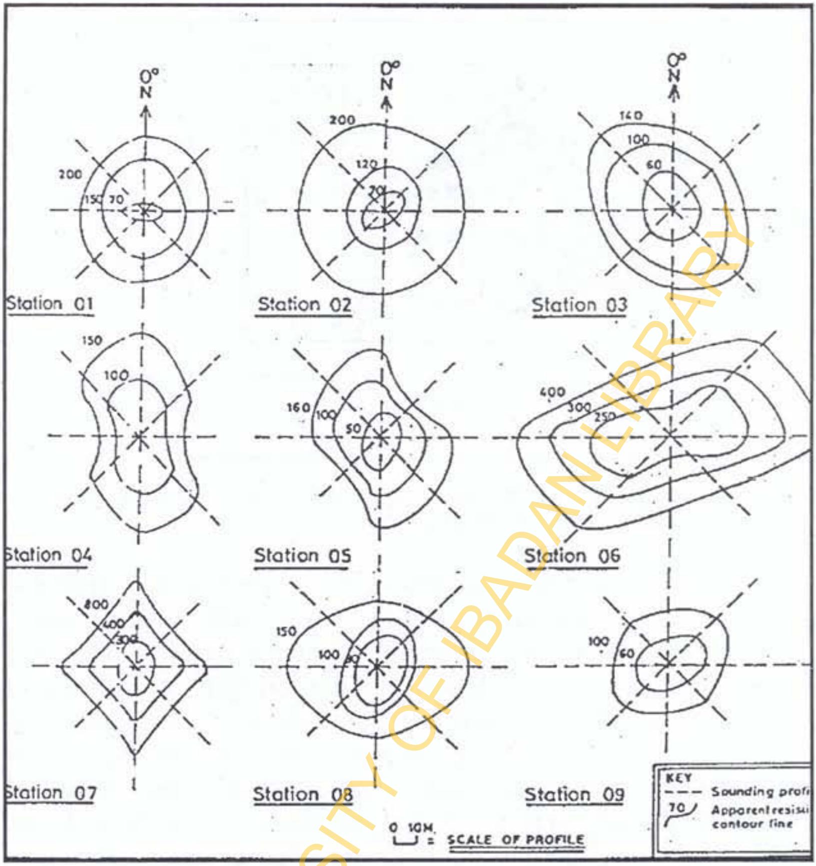


Fig. 23: Apparent resistivity polar diagrams for the respective radial VES stations at Okeho (After Okurumeh and Olayinka, 1998).

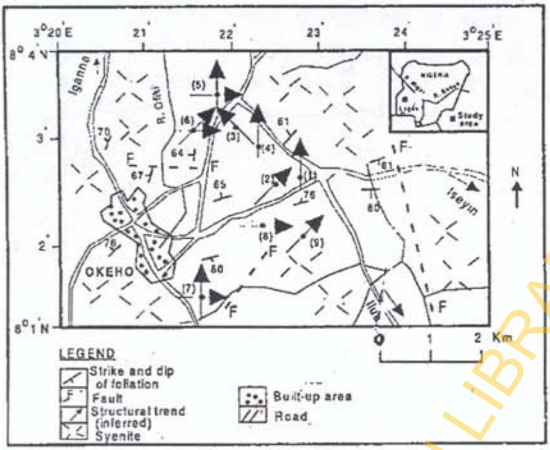


Fig. 24: Superposition of the inferred structural trends on the solid geology at Okeho (After Okurumeh and Olayinka, 1998).

Due to poor planning, most urban centres and metropolis in Nigeria do not have adequate and reliable public water supply schemes for domestic use. In an attempt to ameliorate this, an alternative is sought in the drilling of boreholes. However, the decision to drill a borehole is not made until the completion of building construction with most facilities, such as underground cables, pipes, septic tanks, and concrete surfaces, already in place. It then becomes very difficult to be able to conduct geophysical survey without extensive noise interference. Ironically, the lack of space often restricts the usefulness of surface geophysical techniques. It is recommended here that private housing developers, including individuals, should conduct surface geophysical surveys to decide on the best location for borehole sites on their property before the commencement of actual construction of other structures.

Due to the irregular nature of the bedrock topography and the unpredictability of the nature of regolith materials, Olayinka (1998b) proposed that the separation between adjacent sounding centres should not exceed 100 m. This would permit an adequate sampling of the subsurface.

Group III: 1-D Inversion of Resistivity Sounding Data

It is only through model studies, involving synthetic data in which the true solutions are known, that a realistic meaningful assessment of resistivity inversion schemes can be conducted. Consequent upon this, the investigations that we have carried out have relied greatly on synthetic data. The limitations of each scheme were evaluated in defining the geometry and true resistivity. The applicability of the inversion schemes was tested with real data from southwestern Nigeria.

Quantitative Assessment of Geoelectrical Suppression

It was, hitherto, assumed that geoelectrical suppression should not constitute a major limitation in resistivity interpretation since the effect of the intermediate layer was expected to be incorporated into the adjacent layers. Using computer models, it has been shown that this may not always be the case, and consequently, if the possibility of suppression is overlooked, it could constitute a major source of mistie between inversion results and the true subsurface condition. The factors influencing geoelectrical suppression of the penultimate layer in a four-layer HA-type curve ($\rho_1<\rho_2>\rho_3<\rho_4$), previously intuitively established, were quantitatively documented by Olayinka and Oladipo (1994) using test statistics between theoretical Wenner H-type ($\rho_1>\rho_2<\rho_3$) and HA-type sounding data. The results indicate that the most dominant influence on suppression is the reflection coefficient between layers 2 and 3 ($K_{2,3}$), followed closely by $K_{3,4}$. The study has shown that, contrary to what was hitherto assumed, the penultimate layer could still be detectable when its relative thickness is less than 1.0. This is often the case when $K_{2,3}$ is very small and/or $K_{3,4}$ is very large.

Errors in Depth Determination from Resistivity Soundings

Olayinka (1997) investigated the magnitude of errors in the determination of depth to bedrock from Wenner and Schlumberger resistivity sounding curves, caused by the non-identification of a suppressed layer. The principal objective is to evaluate how the layer thicknesses and resistivities affect the accuracy of depth estimates. In the computations, the intermediate layer in a 3-layer model, in which the resistivity increases with depth, is removed, and the 2-layer sounding curve that is electrically equivalent to the 3-layer curve is generated. It has been shown that there is a possibility for large depth underestimation when the resistivity contrast between layers 1 and 2 is very large. This is manifested in a steeply rising terminal branch on the sounding curve. There is a slight decrease in the depth underestimation as the resistivity contrast between layers 2 and 3 increases.

Conversely, if the intermediate layer is fairly thick and the resistivity contrasts are not too large, the best-fit 2-layer curve shows large deviations from the 3-layer curve. In such cases, the intermediate layer can be identified, resulting in reliable depth estimates (fig. 25).

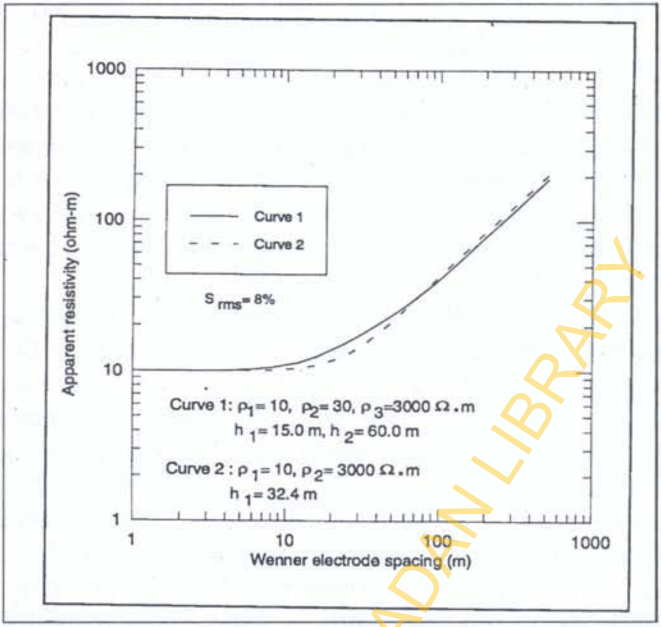


Fig. 25: Illustration showing the difficulty in computing a 2-layer curve that fits a 3-layer curve as a way of detecting the intermediate layer (Wenner array). Note that Curve 1 and Curve 2 are not in phase.

Constraining the Inversion of Resistivity Sounding Data

Olayinka and Mbachi (1992) described an approach for the interpretation of resistivity soundings in which a single resistivity value is assigned to each geo-electrical layer in all the soundings from the same locality. Since the ground water can reasonably be expected to be chemically homogeneous within a study area, assigning a constant value to each geo-electrical layer implies that only the layer thickness would be permitted to vary from one sounding point to another. An essential condition to be fulfilled in applying this technique is for the ground water in any part of the aquifer not to be saline. This pre-requisite is often met in crystalline Basement Complex areas of Nigeria. The accuracy of this approach to interpretation would depend on how representative the layer resistivities are. Field examples were presented to demonstrate the usefulness of the technique.

Olayinka (1998a) examined the implications of constraining the inversion of direct current resistivity sounding data by fixing the bedrock resistivity. This involved an evaluation of how the layer parameters from such a procedure compares with what would have been otherwise obtained if each data set was interpreted without prescribing the bedrock resistivity.

The Wenner sounding curve calculated for a two-layer model in which the resistivity of the upper layer is 50 Ω-m, that of the bedrock 5000 Ω-m and the depth to the interface 20 m is presented as curve 1 in fig. 26. The bedrock resistivity was then changed, and a sounding curve that best fitted this curve was generated. For models in which the bedrock resistivity is less than the reference value of 5000 Ω-m, the depth to interface in the equivalent model is slightly less than 20 m. Conversely, where the bedrock resistivity is higher than 5000 Ω-m, the depth in the equivalent model is also higher.

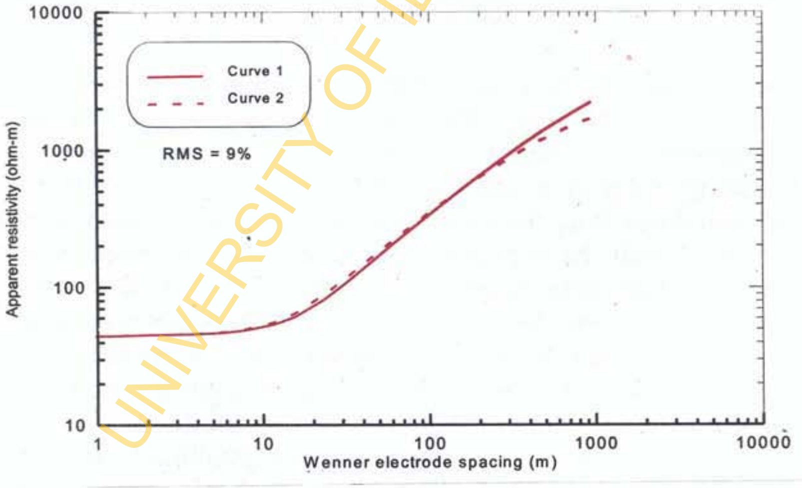


Fig. 26: Synthetic Wenner VES data to illustrate the effect of changing the model bedrock resistivity.

However, if the ratio of the prescribed bedrock resistivity to the reference bedrock resistivity is much less than, or much greater than 1.0, it becomes difficult to generate an equivalent model that fits curve 1 to within 1 or 2%. In such cases, the two curves are not in-phase, with the RMS error being very high. An example is shown in curve 2, in fig. 26, for a model in which the bedrock resistivity is 2500 Ω-m. The best-fit two-layer model in this case is one in which the depth to the interface is 17.9 m. The fit between curves 1 and 2 is very poor, with the RMS error being high at 9%. It may be noted that the ascending branch of the curves can be divided into two parts. In the initial segment, for electrode spacing between 9 and 200 m, there is an overestimation of the apparent resistivities in curve 2, while for larger spacings the reverse is the case.

The only way to improve the quality of the fit between curves 1 and 2 was found to be the introduction of a basal unit of higher resistivity into the model of curve 2, thus converting it into a 3-layer case. The new layer would be expected to reduce the apparent resistivities in curve 2 over the section where they were previously overestimated, while at the same time increasing them where they were underestimated. Similar results were recorded for the Schlumberger array.

A field example from Ogboro near Shaki, southwestern Nigeria, is presented. The initial interpretation is shown in the geoelectric section in fig. 27a, with the bedrock resitivity ranging between 1000 and 9000 Ω-m. The depth to bedrock is fairly shallow towards both ends of the survey line, while the maximum development of weathering is about 27 m at the position of VES 7. Each sounding data was re-interpreted four times with new bedrock model resistivities of 1000, 3000, 6000 and 9000 Ω-m, respectively. It was very difficult to model VES 1 and 2 accurately when a very high bedrock resistivity was prescribed. The only feasible way to retain a high bedrock resistivity was to introduce an additional layer of intermediate resistivity between layers 2 and 3 at these sounding positions. This helped in reducing the RMS error significantly. A good fit was then attained with a model in which there is a 48-m thick layer having a resistivity of 628 and 650 Ω-m, respectively, in VES 1 and 2 (fig. 27b).

A major advantage of fixing the bedrock resistivity is that it affords a way of standardizing the interpretation by reducing the number of variables to be considered. In most field situations, this would lead to a better resolution of the subsurface geology as suggested by previous workers (Seara and Granda, 1987; Sandberg, 1993).

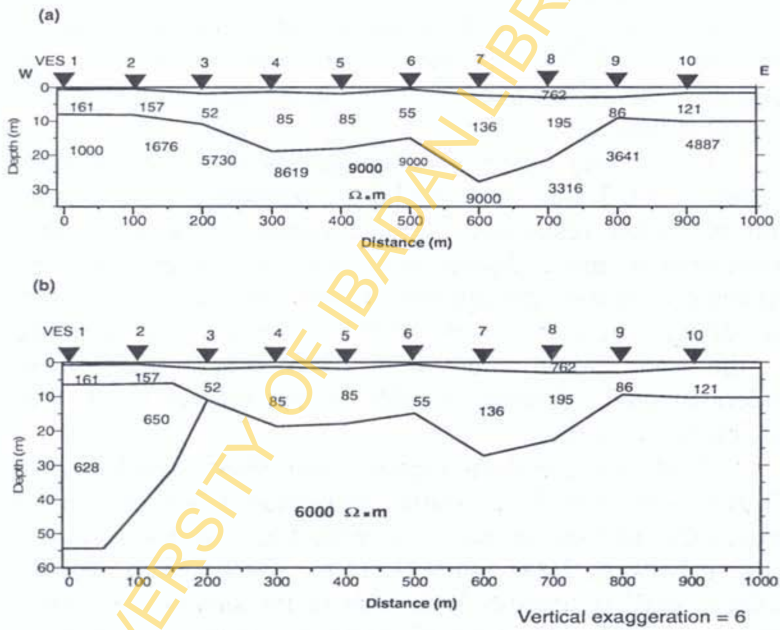


Fig. 27: Two interpretation schemes for sounding data from Ogboro, Shaki area. (a) independent interpretation of each VES curve. (b) re-interpretation of the VES data with a single bedrock model resistivity of 6000 Ω-m.

A steeply rising terminal branch on a sounding curve is conventionally thought to always represent fresh bedrock with negligible water content. Olayinka (1996) investigated this assertion based on theoretical and field data. The results have shown that the bedrock model resistivity obtained from sounding interpretation could be non-unique. Firstly, the terminal branch of the curve might still have a slope approaching +1 even for relatively low bedrock resistivity, provided the resistivity contrast at the bedrock interface is very high. This may account for instances where bedrock fissures/fractures containing groundwater have been encountered during borehole drilling while fresh bedrock would ordinarily be expected from the sounding results. Secondly, alternative interpretations of the same curve could give widely contrasting bedrock model resistivities.

Olayinka (1999) described aspects of limitations of 1-D inversion of VES data caused by lateral variations in resistivity. A more direct way to determine the bedrock resistivity is by laboratory measurements (Olayinka and Sogbetun, 2003)

Accuracy of Partial Curve-matching

There are now commercially-available computer packages for the interpretation of resistivity sounding curves. In some of these algorithms, however, the interpreter is required to prescribe the initial/starting model as the input to the computer. To ensure a considerable reduction in the number of iterations necessary before attaining a good fit to the field data, it is essential that such a starting model is a fair approximation to the subsurface geology. Olayinka (1994) investigated the accuracy of partial curve matching of resistivity sounding curves involving two-layer master curves and auxiliary charts, by comparing the results obtained, using the technique with the computer-assisted interpretation of sounding data at borehole locations. As a test case, field examples from a crystalline Basement Complex area of southwestern Nigeria, in which Offset Wenner soundings were conducted as part of hydro-geological investigations have been examined. The results have shown that a careful application of curve matching often yields a good model, which is a reasonable approximation of the subsurface geology. The major difference between the approximate and accurate interpretation is due to the influence of electrical equivalence, and this is exhibited by the equality of the longitudinal conductance of the weathered zone.

Use of Longitudinal Resistivity

Olayinka *et al.* (2000) described two simple and rapid graphical procedures for the determination of the longitudinal resistivity of all the beds above a highly resistive crystalline basement as the basis for a preliminary depth determination of Schlumberger VES curves. Several theoretical model data indicate that the error in interpretation generally lies within ±10%. Application to real data acquired from the area round Igbo-Ora, southwestern Nigeria, which is underlain by gneisses and granites shows agreement with the results obtained from computer interpretation. These were also corroborated by subsurface geological information from sounding data conducted near borehole sites in the study area.

Fuzzy Logic Modelling

Adabanija *et al.* (2008) developed a Linguistic Fuzzy Logic System (LFLS)-based expert system for the assessment of aquifers for the location of productive water-supply boreholes in a crystalline Basement Complex area. The model design employed a Multiple Input/Single Output (MISO) approach with geo-electrical parameters and topographic features as input variables and control crisp value as the output. The application of the method to field data from a Basement Complex terrain in Vizianagaram District, south India, shows that potential groundwater zones that have control output in the range, 0.3295 to 0.3484, have a yield greater than 6000 litres per hour. The range, 0.3174 to 0.3226, gives a yield less than 4000 litres per hour. On the other hand, validation of the control crisp value, using data from Oban massif, a Basement Complex in southeastern Nigeria, indicates a yield less than 3000 litres per hour for control output values in the range 0.2938 to 0.3065. This validation corroborates the ability of control output values to predict a yield, thus vindicating the applicability of linguistic fuzzy logic system in siting productive water boreholes in a basement complex area.

Group IV: 2-D Resistivity Imaging

The initial research we conducted in the interpretation of 2-D resistivity data was concerned with the development of simple techniques to aid in the interpretation of pseudosection data. Further work on 2-D geo-electrical imaging was geared towards the development of practical techniques to aid the quantitative interpretation of 2-D apparent resistivity pseudosection data. A comparison has been made between smooth inversion and block, that is, sharp boundary inversion. The limitations of each scheme were evaluated in defining the geometry and true resistivity. In particular, I devised a novel technique for determining an initial (starting) model in block inversion. This permits an estimate of the range of equivalent 2-D models which fit the same data set, and it has been applied in interpreting field data.

Use of longitudinal conductances

In a two-layer model, where the shallower layer is much more conductive than the deeper layer, and for very large current electrode separations, the flow of current in the upper layer will, for all practical purposes, be parallel to the horizontal strata. The important parameter that defines the resistivity data in this case is the longitudinal conductance S. A value of S can often be determined with a good precision from surface measurements of resistivity. This was the basis of a simple and rapid method we devised to provide the field geophysicist with a reasonably accurate model on which basis a firm decision regarding borehole siting can be made (Olayinka and Barker, 1990b). Such a model can also be used as the starting model for the final stage of the MRT interpretation carried out later. A theoretical example is given in fig. 28 and application to field data in fig. 29.

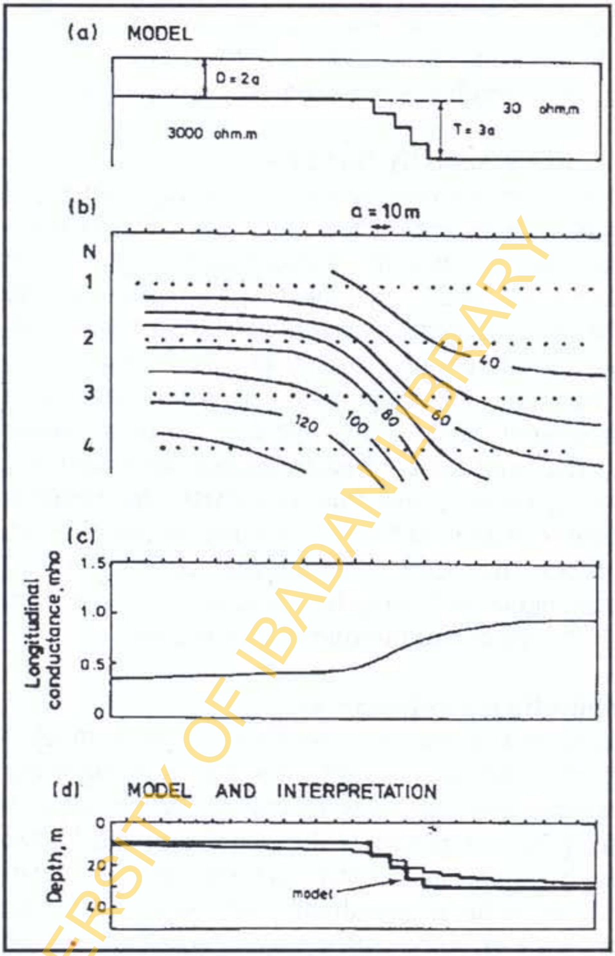


Fig. 28: Theoretical Wenner pseudosection over simple fault. (a) model of 3 fault. (b) computed Wenner pseudosection with a 10 m electrode spacing. (longitudinal conductance profile. (d) interpretation compared with origi model. Steps on the model represent elements of the finite difference netwo (After Olayinka and Barker, 1990b).

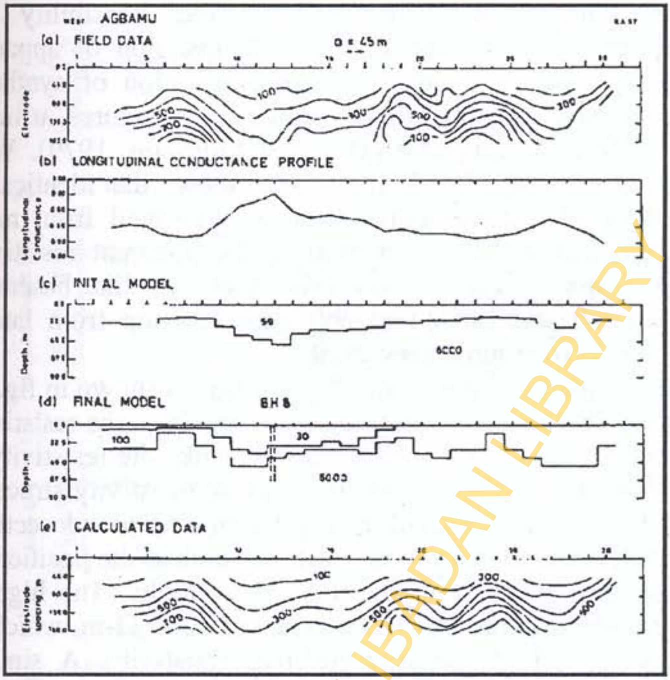


Fig. 29: MRT survey, Agbamu, southwestern Nigeria. (a) measured pseudosection (b) longitudinal conductance profile (c) initial model (d) final model (e) computed pseudosection. The values inside the plots are resistivities in Ω-m. (After Olayinka and Barker, 1990b).

Olayinka (1991b) described how averaging vertical sets of Wenner pseudosection data, 'beneath' a sampling station to produce a summed profile, can aid in deriving a fast interpretation. We have also shown that the lateral variation index could be useful in inferring the probable positions of shallow and vertical (or near-vertical) contacts (Griffiths *et al.*, 1990).

Non-uniqueness and Equivalence in 2-D Imaging and Modelling

It is widely appreciated that the interpretation of geophysical data is hardly unique with more than one geologic model fitting the same set of field observations. Olayinka (1991a) and Olayinka (2000) investigated the possibility for geoelectrical equivalence in the 2-D inversion of apparent resistivity data. This involved the calculation of synthetic pseudosection data for simple geological structures, using a finite difference approach (Dey and Morrison, 1979). With the aid of statistical F-test, it has been shown that identical or near-identical pseudosections can be generated from more than one 2-D model. In particular, the apparent resistivity pseudosection measured over 2-D structures, like basement fault, trough and horst resemble those arising from lateral variations in overburden resistivity.

An example for the dipole dipole array is shown in fig. 30 for a model with two vertical contacts in which the resistivity at the centre is 50 Ω-m, while, at the flanks the resistivity is much higher at 200 Ω-m. There is a low resistivity structure flanked by highs at shallow depths of the pseudosection. However, at depth, there is a resistivity high at the position of the low resistivity structure, flanked by highs. The highest apparent resistivities are of the order of 1000 Ω-m, which is about one-third of the true bedrock resistivity. A similar pseudosection (fig. 30) was calculated for a basement trough structure in which the depth to the bottom of the trough is 27 m, while at the upthrown block the depth to the interface is 4.6 m. The F-ratio between the two pseudosections is 1.054, which is not statistically significant at the 95% confidence interval.

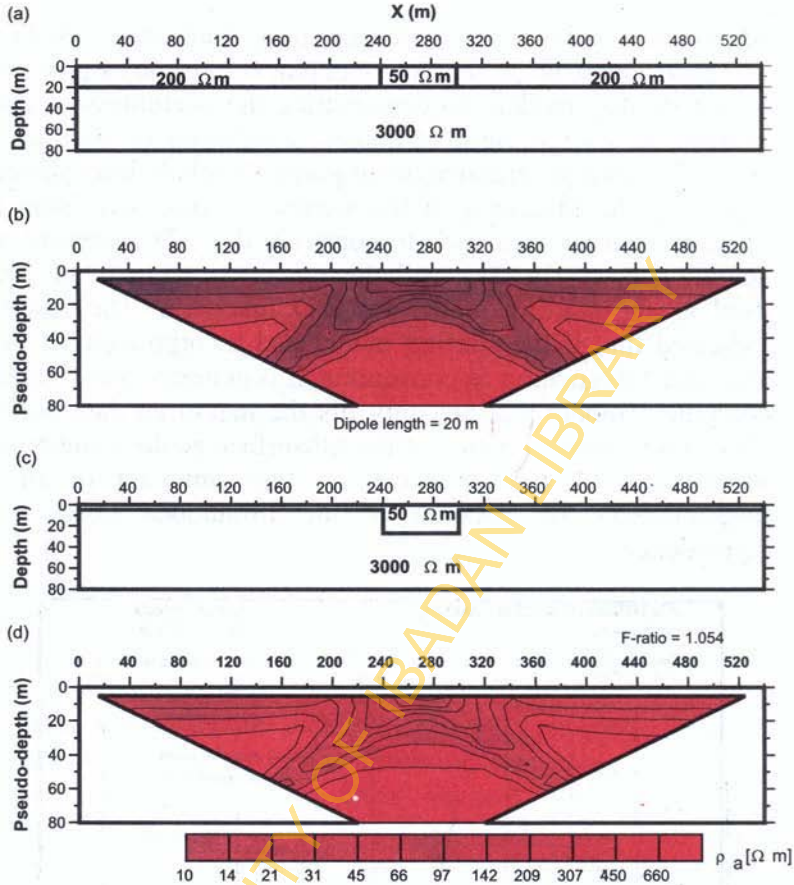


Fig. 30: Illustration of 2-D equivalence (a) 2-D model with lateral variation in overburden resistivity; (b) dipole dipole apparent resistivity pseudosection data calculated from the model in (a); (c) 2-D model representing a trough structure; (d) dipole dipole apparent resistivity pseudosection data calculated from the model in (c).

Olayinka and Weller (1997) presented a methodology for the inversion of 2-D geoelectrical data for solving hydrogeological problems in crystalline basement areas. The initial step entails compiling an earth model, using all available geological, borehole and geophysical information. This model served as the input to an algorithm based on the

Simultaneous Iterative Reconstruction Technique (SIRT). The algorithm tries to find a model that is as close as possible to the starting model. To demonstrate the usefulness of this procedure, several field examples, conducted as part of a borehole siting programme, were given. Borehole information regarding the thickness of the weathered zone overlying a gneissic bedrock was used to constrain the 1-D inversion of sounding data (fig. 31), and the model thus compiled was used as the starting model for 2-D inversion. The results indicated that if the starting model had incorporated all the available information as constraints, it is generally possible to compute a model that not only fits the measured data but is also a good approximation of the subsurface geology, more so when many 2-D models can fit the same set of field measurements on account of the limitations posed by equivalence.

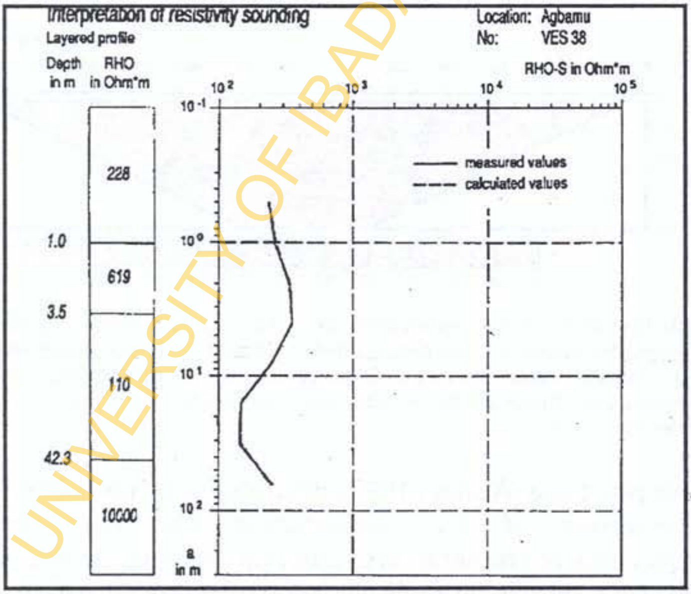


Fig. 31: 1-D interpretation of a VES curve from Agbamu used as starting model for inversion of the 2-D data. (After Olayinka and Weller, 1997).

Choice of the Best Model in 2-D Geoelectrical Imaging

The conventional approach in the inversion of vertical electrical sounding data is to accept the model which gives the minimum data rms misfit between the field and calculated data in the forward model. The model rms misfit was never considered in this approach. However, Simms and Morgan (1992) showed that the data rms misfit and the model rms misfit are not always simultaneously minimized in the 1-D inversion of vertical electrical sounding data. While the data rms misfit is a measure of the fit between the field data and the calculated data, the model rms misfit is a measure of the fit between the inverted model parameters and the known synthetic model.

Olayinka and Yaramanci (2000a) investigated the reliability of inversion of apparent resistivity pseudosection data in order to accurately determine the true resistivity distribution over 2-D structures, using a common inversion scheme based on a smoothness-constrained non-linear least-squares optimization, for the Wenner array (Loke and Barker, 1996). This involved calculation of synthetic apparent resistivity pseudosection data, which were then inverted, and the model estimated from the inversion was compared with the original 2-D model. Over vertical structures, the resistivity models obtained from inversion are usually much sharper than the measured data. However, the inverted resistivities can be smaller than the lowest or greater than the highest true model resistivity. The data rms misfit always converges towards a limiting value representing the amount of noise in the data.

However, the substantial reduction generally recorded in the data misfit is not always accompanied by any noticeable reduction in the model misfit. The response of the model rms misfit can be grouped into three classes (fig. 32). Firstly, as would be expected theoretically, the model rms misfit could decrease in response to a decrease in the data rms misfit for successive iterations. The diagonal line with a negative slope would then be applicable. This simultaneous minimization of the data rms misfit and the model rms misfit would yield an optimum model at a high iteration number as the outcome of the inversion procedure, and it is referred to as the 'ideal' behavior. Both the data rms misfit and the model rms misfit are very low in the optimum model. This situation arises at very low resistivity contrasts.

Secondly, there are instances in which the model rms misfit remains, for all practical purposes, invariant. The plot of the M_{rms} against the iteration number is represented by a horizontal line, and it is referred to as 'non-unique' behavior. None of the inverted models for the respective iteration numbers represents the true solution uniquely. The inverted model at any iteration step can be considered as good as that at any other iteration, since each and all of them have roughly the same model rms misfit in spite of large differences in the data rms misfit.

Thirdly, there could be an increase in the model rms misfit for successive iterations. As the data rms misfit is being minimized for successive iterations, the model rms misfit is being maximized. This is represented by the diagonal line with a positive slope on the diagram. This is referred to as 'anti-ideal' behavior, and is often encountered at very large resistivity contrasts. This pattern would inadvertently lead to the attainment of the most sub-optimal model since the supposedly 'worst' model for which the D_{rms} is a maximum is, in fact, the 'best' model by virtue of having the lowest M_{rms}. This would have grave implications when working with field data in which it is generally impossible to calculate the model rms misfit, and the best model is often taken as that for which the data rms misfit is the least.

There are several modifications of these three basic patterns. In particular, there are instances where the model rms misfit begins by converging as the number of iteration increases only to start diverging at a high iteration number.

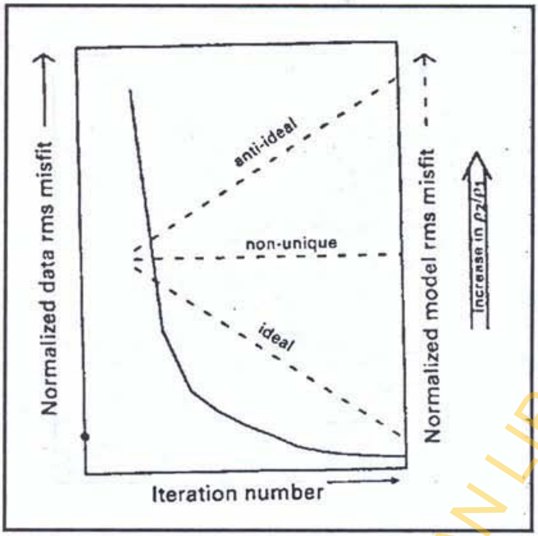


Fig. 32: Variation in the data rms misfit (solid curve) and the model rms misfit (discontinuous curve) during the 2-D inversion of apparent resistivity data. The misfits are normalized with respect to the value at the first iteration. (After Olayinka and Yaramanci, 2000a).

A case history to demonstrate the application of this approach was described from a waste dump site in Ibadan (Olayinka and Yaramanci, 1999). The solid geology comprises quartzite and quartz-schist that have been extensively weathered and fractured (fig. 33). Inversion of the Wenner pseudosection data indicates that the model bedrock resistivities at about the second iteration are geologically realistic. The thickness of the waste dump varies from about 2 to 17 m, while its resistivity is low and lies between 4 to 8 Ω-m. The low resistivity is due to the presence of leachate emanating from the site, and this has also polluted the surface and ground waters in the immediate vicinity. It is concluded that geoelectric imaging, with appropriate geologic constraints, provided a realistic subsurface image for the noisy environment of the waste dump (fig. 34).

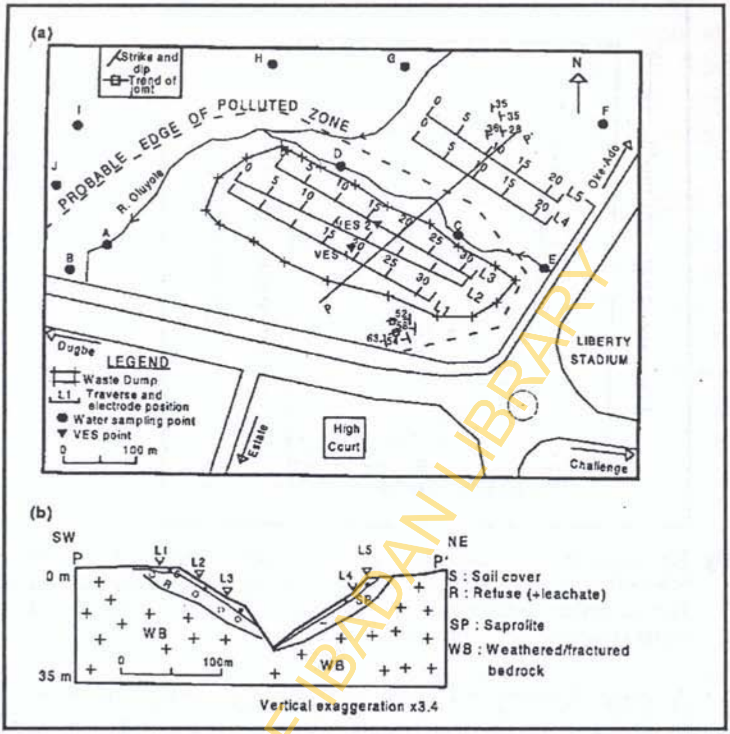


Fig. 33: Enlarged map of the Ibadan Ring Road Refuse Dump Site (now inactive), showing (a) orientation of geoelectrical traverses and position of water sampling points. The edge of the polluted zone has been inferred from the geoelectrical imaging results, supplemented with hydrochemical data; (b) A SW-NE vertical cross-section across the study area. The positions of the resistivity traverse lines are indicated (after Olayinka and Yaramanci, 1999).

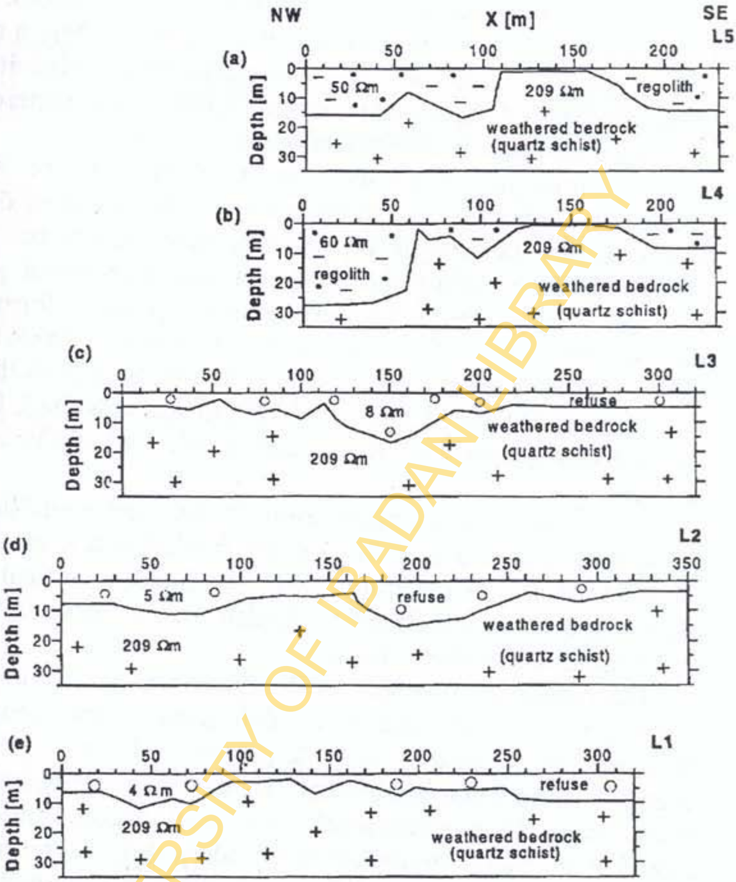


Fig. 34: Integrated interpretation and geologic model of the resistivity images at the Ibadan Ring Road Waste Dump Site (After Olayinka and Yaramanci, 1999).

Use of Block Inversion in the 2-D Interpretation of Apparent Resistivity Data and Comparison with Smooth Inversion

Studies conducted on smooth inversion of apparent resistivity pseudosection data have shown that such schemes can only provide an approximate guide of the true geometry of the subsurface. While this information is generally adequate for most hydrogeological and environmental investigations, it is often unsatisfactory in petrophysical evaluation where a more representative value of the true formation resistivity is generally desired. The largest model misfit is encountered in the zone immediately above and below a contact.

The foregoing suggests that a block-type (or sharp boundary) inversion, in which polygons are used to define layers and/or bodies of equal resistivity, might be more suitable in determining the geometry and true resistivity of subsurface structures, especially as any *a priori* information can be introduced (Olayinka and Yaramanci, 2000b). An example of a smooth 2-D inversion algorithm is RES2DINV by Loke and Barker (1996), while the program RESIX IP2DI by Interpex (1996) is representative of a block inversion scheme.

The study involved calculation, by forward modelling, of the synthetic data over 2-D geologic models and inversion of the data. The 2-D structures modelled include vertical fault, graben and horst, which are of significance in areas underlain by crystalline basement rocks.

The results indicate that the images obtained from smooth inversion are very useful in determining the geometry. However, they can only provide guides to the true resistivity because of the smearing effects. However, in the presence of sharp, rather than gradational, resistivity discontinuities, the model from block inversion more adequately represents the true subsurface geology, in terms of both the geometry and the formation resistivity. We devised a simple technique, based on a plane layer earth model, for deriving the initial model (Olayinka and Yaramanci, 2000b) (fig. 35).

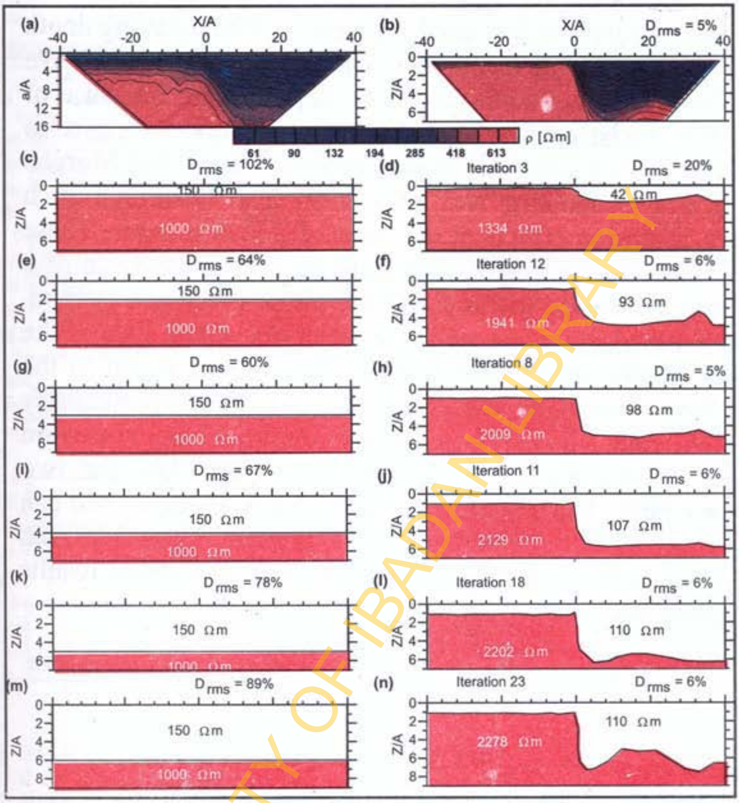


Fig. 35: (a) Synthetic pseudosection data calculated for a vertical fault structure, buried by a single overburden unit, with 5% Gaussian noise added. (b) resistivity image obtained from the smooth inversion algorithm. From (c) to (n), the left hand panel is the starting model used as input for block inversion while the right-hand panel is the inverted model (After Olayinka and Yaramanci, 2000b).

Field examples from a crystalline Basement Complex area of Nigeria were used to demonstrate the versatility of the two resistivity inversion schemes (fig. 36). The test data have shown that the block inversion method gives very good results if the actual subsurface consists of two homogeneous regions with a sharp interface and if the starting depth of the two-layer model is reasonably accurate. If the subsurface is more complicated with several regions, or if the starting depth is too shallow or too deep, the results can be unstable. We have shown that, in such cases, the depth of the interface of the lower resistive layer in the inverted model begins to undulate, as if a type of ringing occurs. Beard and Morgan (1991) and Oldenburg and Li (1999) also described such unusual inversion effects at the edge of 2-D structures. These weaknesses can be easily overcome by a combined use of a cell-based inversion method and the block inversion method. The cell-based inversion will at least give a rough idea of the bedrock depth, which will prevent the starting depth in the block inversion to be too shallow or too deep, particularly with field data. The cell-based inversion model can also warn the user if the subsurface is more complex than the two regions model. The different inversion methods described can be viewed as complementary tools that an interpreter can employ to obtain the most consistent and reasonable results for a given data set.

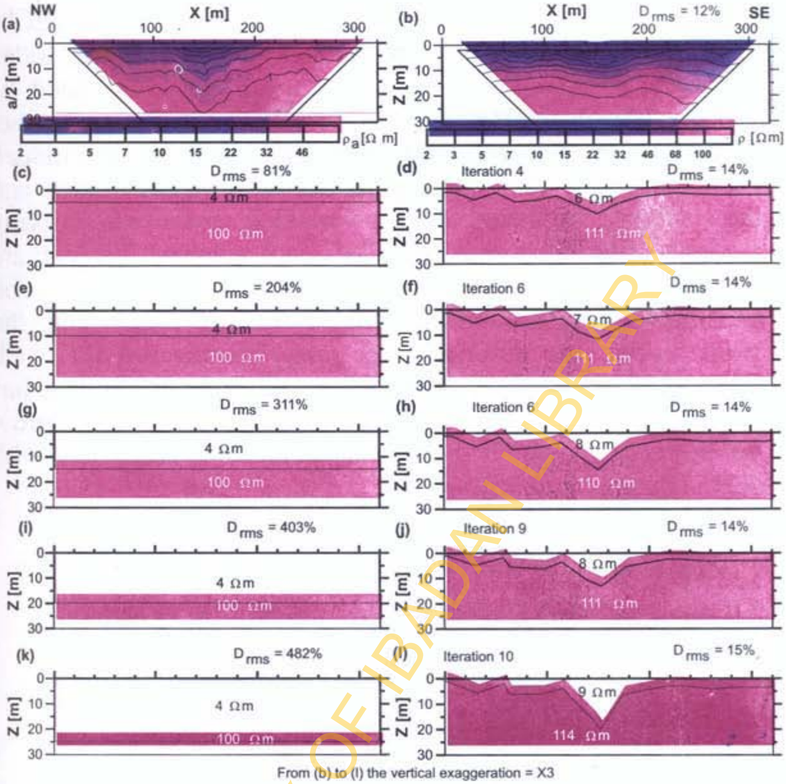


Fig. 36: Interpretation of Wenner pseudosection data (line 3) from the Ibadan Ring Road Waste Dump. (a) Measured data. (b) model from smooth inversion. From (c) to (l), the left-hand panel is the initial model for block inversion while the right-hand panel is the respective inverted model (After Olayinka and Yaramanci, 2000b).

Smooth and sharp-boundary inversion of 2-D pseudo-section data in the presence of a decrease in resistivity with depth

Situations often arise in environmental, engineering and hydrogeological investigations in which there is a decrease in resistivity with depth. Olayinka and Yaramanci (2002) examined the performance of smooth and sharp-boundary inversion schemes in such cases by considering synthetic data over 2-D geologic models such as vertical fault, graben and horst. It was demonstrated that the starting model could be based on a plane layer earth model, which has the added advantage that only the depth to the interface(s) need be varied as the inversion result is for all practical purposes not dependent on the resistivity contrast in the starting model. Fortunately, the data rms misfit between the calculated and the synthetic 'observed' data is very diagnostic in identifying a reasonable interpretation. The bad inverted models are invariably attained after a very few iterations and accompanied by a high data misfit. On the other hand, the good models are attained after many iterations with much lower data misfit. With this interpretation procedure, it has been shown that the range of 2-D equivalence is very narrow for the case in which there is a decrease in resistivity with depth (figs. 37 and 38).

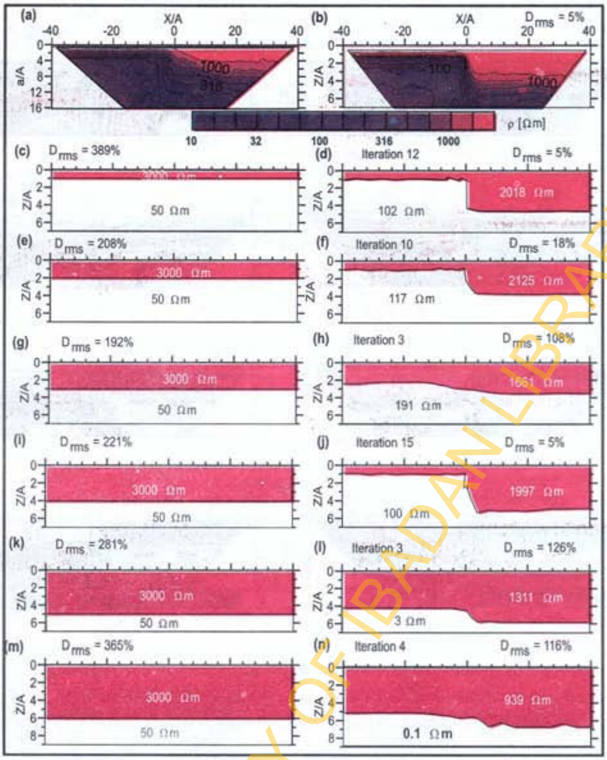


Fig. 37: Interpretation of data over a vertical fault model. (a) Synthetic apparent resistivity pseudosection data containing 5% Gaussian noise; (b) Model obtained from smooth inversion; From (c) to (n), the left-hand panels are the initial models for sharp-boundary algorithm, while the right-hand panels are the corresponding inverted models. A is the minimum Wenner spacing (After Olayinka and Yaramanci (2002).

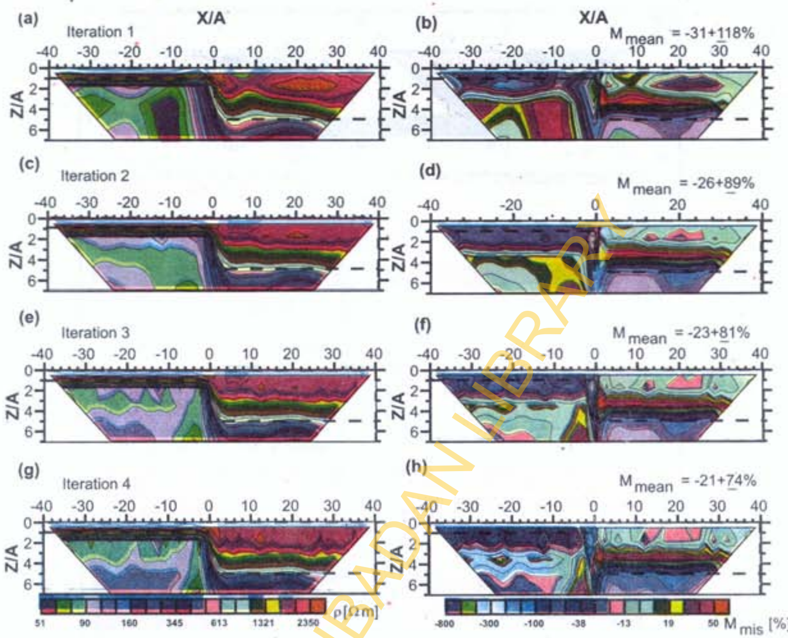


Fig. 38: Inverted model (the left-hand panels) at various iteration steps in the smooth inversion of the data in fig. 35 and the corresponding model misfit (the right-hand panels). (After Olayinka and Yaramanci, 2002).

A field example is given from Nauen, northern Germany, where partly-saturated sand of high resistivity in the vadose zone (4000 Ω-m) is underlain in succession by less resistive saturated sand (150 Ω-m), which in turn is underlain by glacial till (100 Ω-m). The smooth and sharp-boundary inversion results are in agreement with the geo-radar and surface magnetic nuclear resonance (SNMR) and borehole information (figs. 39 to 42).

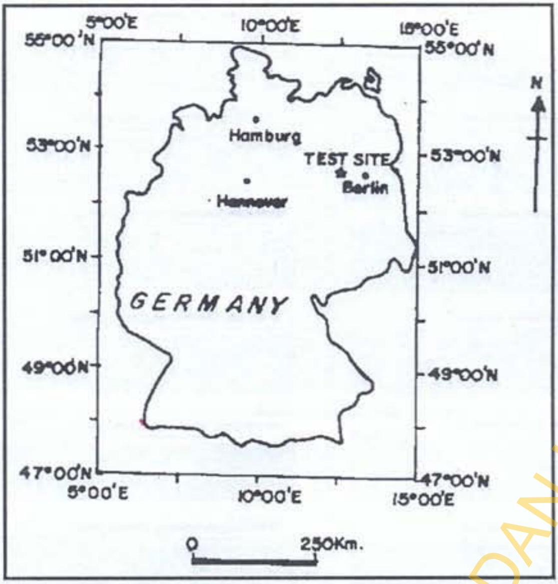


Fig. 39: Sketch map showing the location of study area in northern Germany.

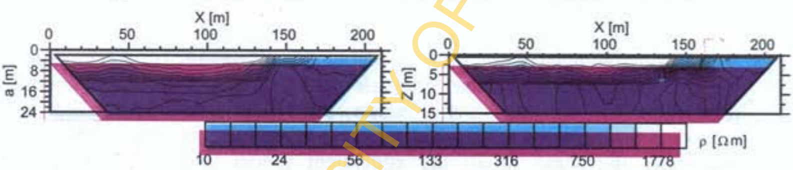


Fig. 40: (a) Measured pseudosection data at Nauen test site, northern Germany; (b) Smooth inversion resistivity model (After Olayinka and Yaramanci, 2002).

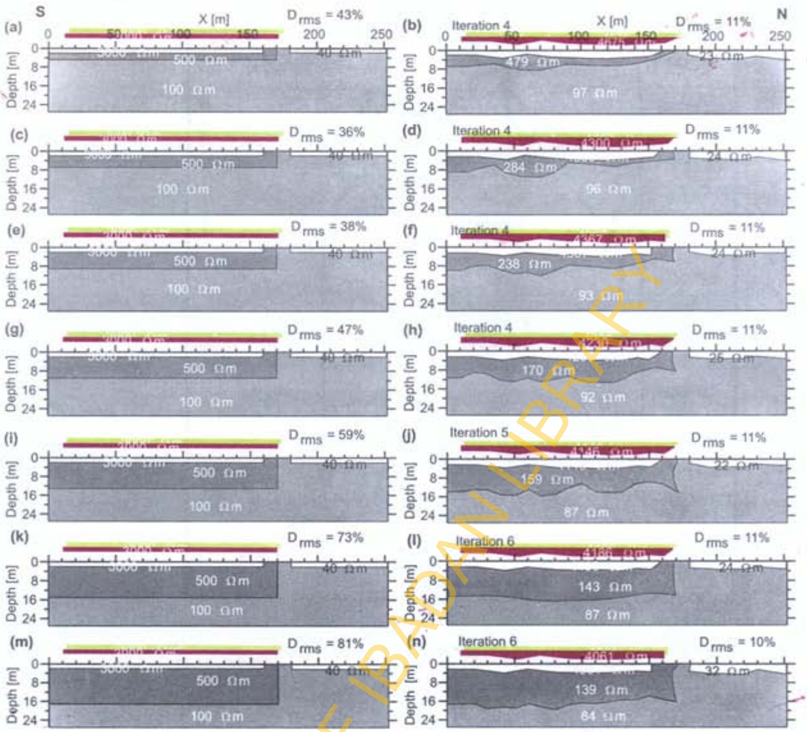


Fig. 41: Model obtained from the sharp-boundary inversion of the measured pseudosection data at Nauen. The left-hand panels are the initial models prescribed by the interpreter while the right-hand panels are the corresponding inverted 2-D models. Note that the data rms misfit stays practically the same in all the equivalent model interpretations. (After Olayinka and Yaramanci, 2002).

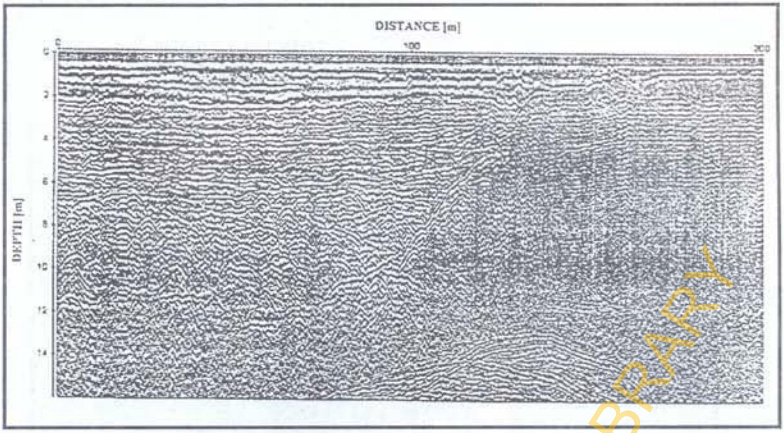


Fig. 42: Geo-radar section from the same traverse as the electrical image line from Nauen (After Olayinka and Yaramanci, 2002).

Group V: Groundwater Occurrence in Ibadan Metropolis

Groundwater Availability

The provision of water for domestic and other uses in both rural and urban centers is one of the most intractable problems in Nigeria today. In recent times, the inadequacy of the pipe-borne water supply system in the country, generally, and Ibadan metropolis, in particular, coupled with the need to improve the supply and quality of potable water in these areas, has led to the increase in the construction and drilling of boreholes. Ibadan, located in the southwestern part of Nigeria, is the largest pre-colonial city in Nigeria and sub-Saharan Africa, with a total area of about 540 km^2 and an estimated population of about 3.5 million in 2007. Nearly all houses in the medium and low density residential areas of Ibadan now have either large-diameter dug wells or boreholes.

Ibadan metropolis is underlain by quartzites of the metasedimentary series and the migmatites complex comprising banded gneisses, augen gneisses and migmatites with minor intrusions of pegmatites, quartz, aplite, diorites and amphibolites (fig. 43). The low porosity and negligible permeability of these crystalline basement rocks do not completely rule out the possibility of the presence of localized and productive aquifers from the saprolite and the saprock, if proper exploratory work is carried out.

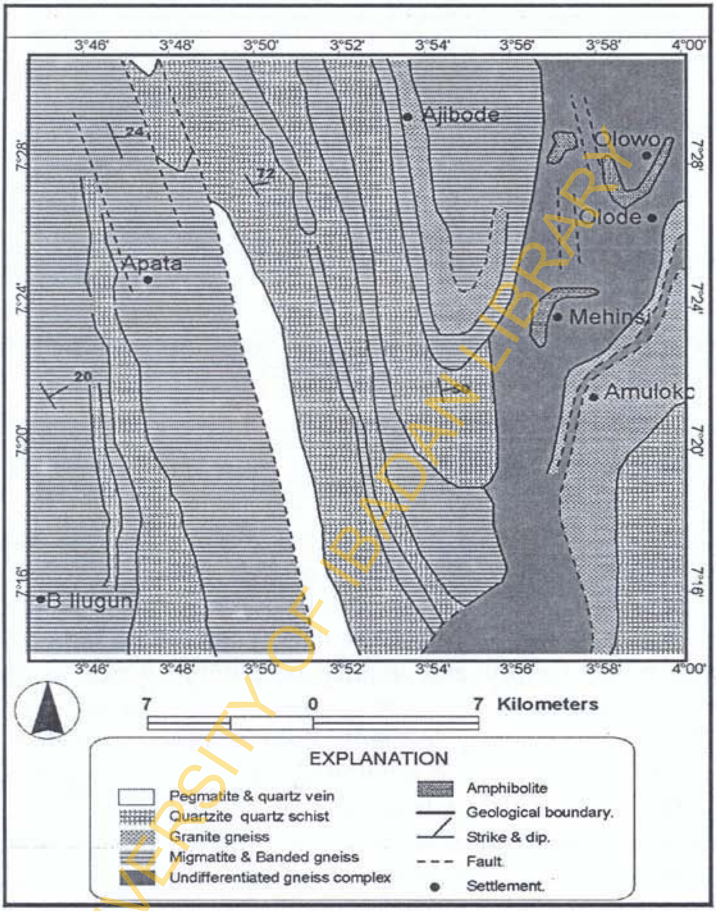


Fig. 43: Geological Map of Ibadan and environs (After Okunlola *et al*., 2009).

In an ongoing research, we have conducted about 516 Schlumberger VES in various parts of Ibadan metropolis to characterize the aquifer properties and groundwater potential. The survey locations cover the different rock types (fig. 44) (Oladunjoye and Olayinka, 2010). The data obtained were processed, using a 1-D algorithm to generate geo-electric parameters (table 9).

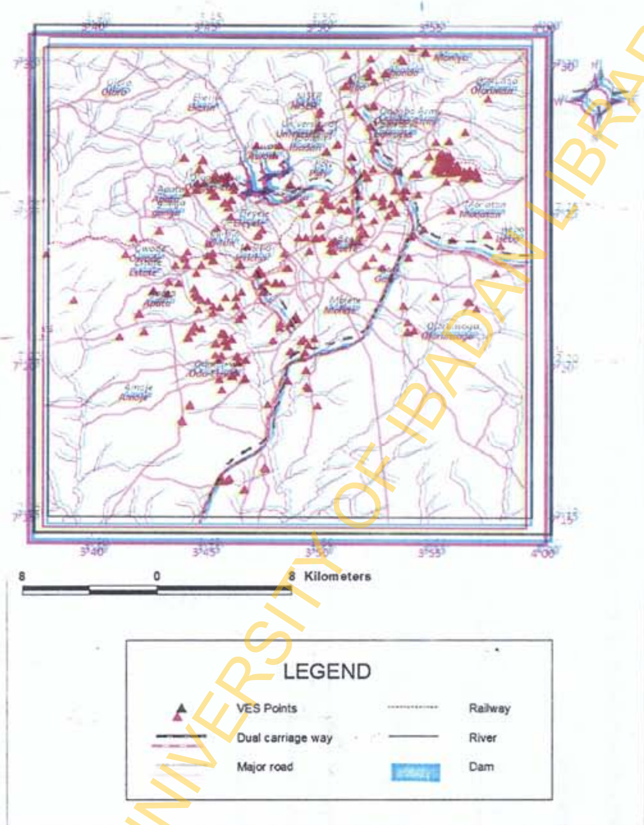
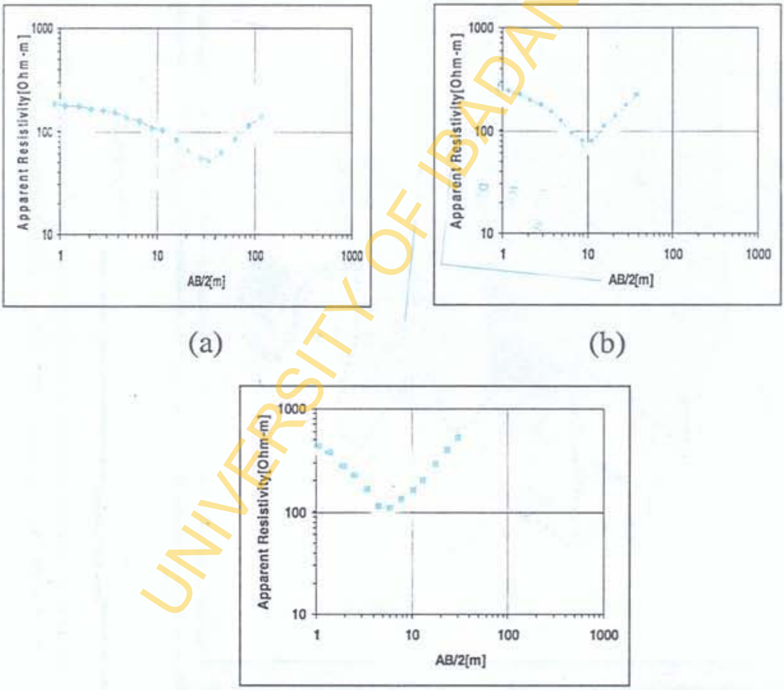


Fig. 44: Map of Ibadan metropolis showing VES locations.

Table 9. Computer interpretation of representative VES curves from Ibadan for different groundwater potential zones

Loca-tion	Layer Resistivity (Ω -m)				Layer Thickness (m)			Depth to geoelectric basement (m)	Ground-water potential
	1	2	3	4	1	2	3		
Oke-badan Estate	171	122	41	191	1.1	5.7	23.4	30.1	High
Odo-Ona Elewe	204	58	527		1.9	12.4		14.1	Intermediate
Ojoo	450	61	1440		1.0	3.6		4.6	Low

Examples of VES curves from Ibadan are presented in fig. 45. From an analysis of the results of this extensive investigation, we have divided the study area into four groundwater potential zones, namely: high, medium, low and poor, respectively (fig. 46). The high groundwater potential zones tend to correlate with mostly the quartzite and quartz schist while the low groundwater potential zones were recorded in areas with very shallow overburden without evidence of basement fractures in the gneisses. However, field examples from geophysical data and borehole drilling report have shown that in areas delineated as low and poor groundwater potential yields, it is still possible to isolate localized anomalies, such as linear fractures, if detailed investigation is carried out.



(a) (b)

(c)

Fig. 45: Representative VES curves from Ibadan. (a) Okebadan Estate (b) Odo-Ona Elewe (c) Ojoo.

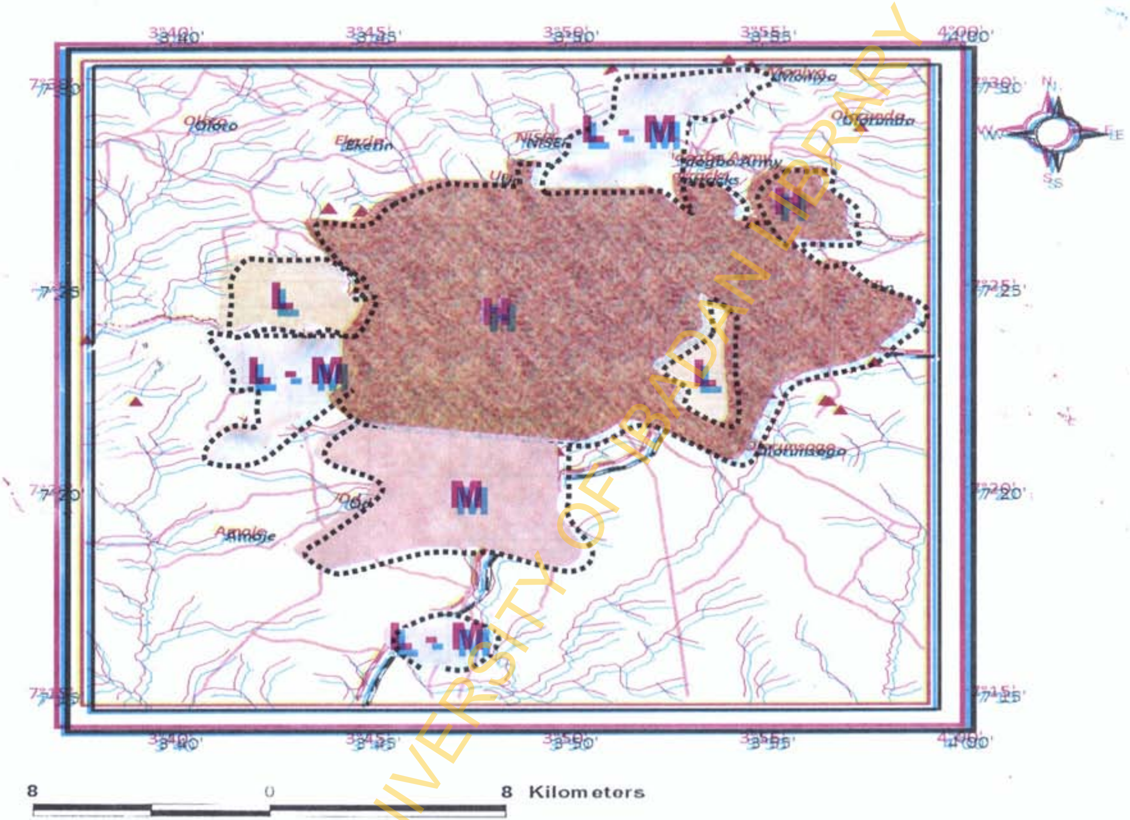


Fig. 46: Map of Ibadan metropolis showing the groundwater zones. H represents high groundwater potential; M represents medium groundwater potential while L represents low groundwater potential.

The groundwater potential will impact the choice of residential accommodation since a prospective tenant/ occupier of a housing unit would be interested in the availability of water supply through borehole or dug well since the public water supply is generally unreliable (Olatubara, 2008)

Aspects of Groundwater Quality

An integrated study, involving geologic mapping, hydro-chemistry and electrical geophysics, was carried out in Ibadan to characterize the groundwater in a typical low-latitude environment underlain by Precambrian crystalline basement complex rocks (Olayinka *et al.*, 1999). The water sampling points are shown in fig. 47. Chemical analyses of the groundwater show that the mean concentration of the cations is in the order $Na^+ > Ca_2^+ > Mg^{2+} > K^+$, while that of the anions is $Cl^- > HCO_3^- > NO_3^- > SO^{2-}_4$. Five different groundwater groups were identified in the metropolis, namely: (i) the Na-Cl, Na-Ca-Cl, Na-Ca-(Mg)-Cl, (ii) the Ca-(Mg)-Na-HCO_3-Cl, Na-Ca-HCO_3-Cl and Ca-HCO_3-Cl; (iii) the Ca-(Mg)-Na-HCO_3, Ca-Na-HCO_3, (iv) the Ca-Na-Cl-(SO4)-HCO_3 and (v) the Ca-(Mg)-Na-SO_4-HCO_3. The respective groups reflect the diversity of bedrock types and consequently, of the products of weathering. Most of the water samples were unfit for drinking on account of the high NO_3^- content.

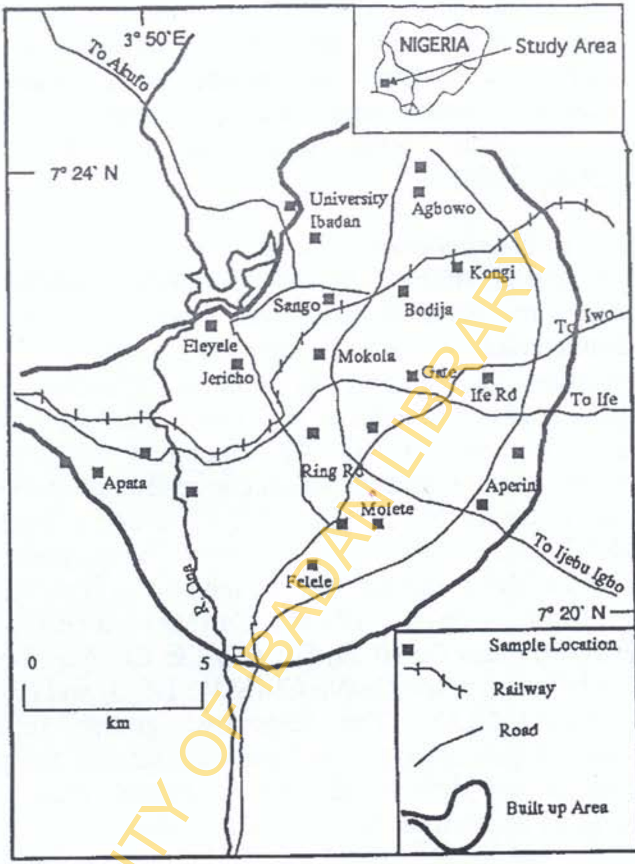


Fig. 47: Location map of Ibadan study area, showing the water sampling point (inset: Generalized map of Nigeria) (After Olayinka *et al.*, 1999).

The piezometric surface map prepared from the static water level values is presented in fig. 48. This can aid an understanding of the subsurface flow trend. Ground water flows from higher energy levels towards lower energy environments provided the energy is essentially the result of elevation and pressure (Davis and DeWiest, 1966). Accordingly, the groundwater elevation in the study area controls the direction and mode of the subsurface flow. That is, flow is generally from regions of increasing head to that of decreasing head. The entire area is dominated by a series of gently and steeply undulating rises and falls in the water level elevation. Since the subsurface flow direction is usually from the rises to the falls, the domes would be expected to act as points of recharge, while the basins are principally the discharge points. These suggest that the subsurface environment in the northeastern part has the highest potential for groundwater.

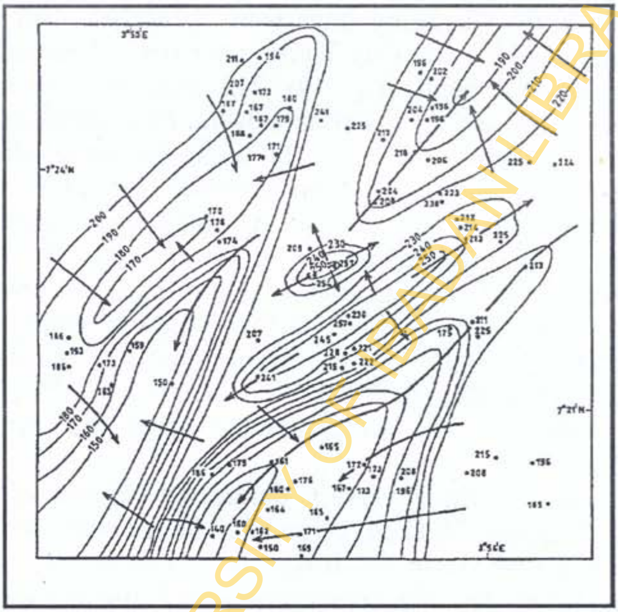


Fig. 48: Piezometric-surface map of Ibadan metropolis. Values inside the plot are in metres above the mean sea level (After Olayinka *et al.*, 1999).

Group VI: Environmental Geophysics

The knowledge obtained from the research in 2-D geo-electrical modeling and imaging has been applied to solving some problems related to the environment, notably those concerning waste disposal and groundwater occurrence and utilization.

Geoelectric Imaging at an Abandoned Dump Site
A geoelectrical imaging of an abandoned waste dump site (Orita Aperin) in Ibadan was carried out with the aim of determining how accurately surface electrical measurements could delineate the influx of leachate into groundwater and nearby surface water. The imaging is expected to reveal the heterogeneous material compositions as well as the attendant complex biogeomorphic processes in a landfill/dumpsite environment.

Eight electrical imaging lines were measured, using the Wenner Array and a Campus Tigre meter was employed for resistance measurements (fig. 49). The minimum electrode spacing was 5 m, and the maximum 30 m. Four traverses (T_1 – T_4) were measured directly on the waste dumpsite with T_2 being the longest at 140 m. Two traverses T_5 and T_6 were measured at the lower elevation of the dump site to ascertain the ingress of the leachate towards the lower side of the dump site. Traverse seven (T_7) and eight (T_8) was made at a primary school on the western side about 300 m from the waste dump site to serve as a control for the former data sets. To obtain the true two-dimensional distribution of soil resistivity, the apparent resistivity data were inverted using the program RES2DINV.

The results of the inversion delineated regions of low resistivity (less than 20 Ω-m) believed to be leachates derived from decomposed waste for image lines conducted on the abandoned waste (fig. 50). On the other hand, the 2-D models obtained for the control lines (fig. 51) are a reflection of the lateral variations in the thickness of the regolith derived from the chemical weathering of the underlying crystalline bedrock. It should be noted that the RMS error in the calculated data is less than that for the lines measured over the waste dump. Considering the surface topography of the area, it can be expected that there would be high concentration of the leachate towards the lower elevation; hence the adjoining stream is prone to pollution. This, no doubt, can also influence pollution of groundwater system.

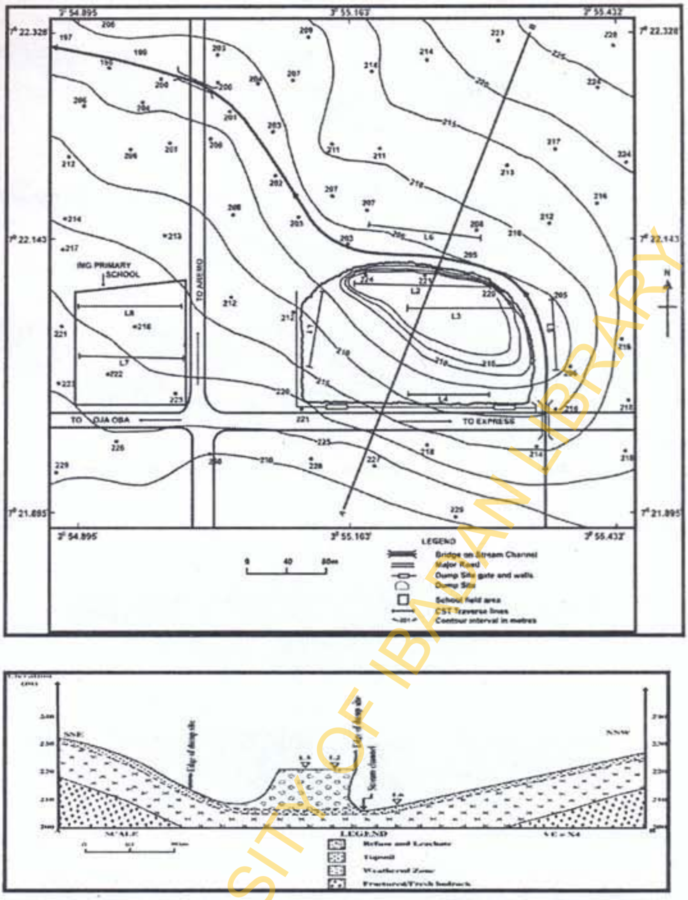


Fig. 49: Orientation of traverses, Aperin waste dump site, Ibadan (upper diagram) and a vertical profile through a line of section A-B.

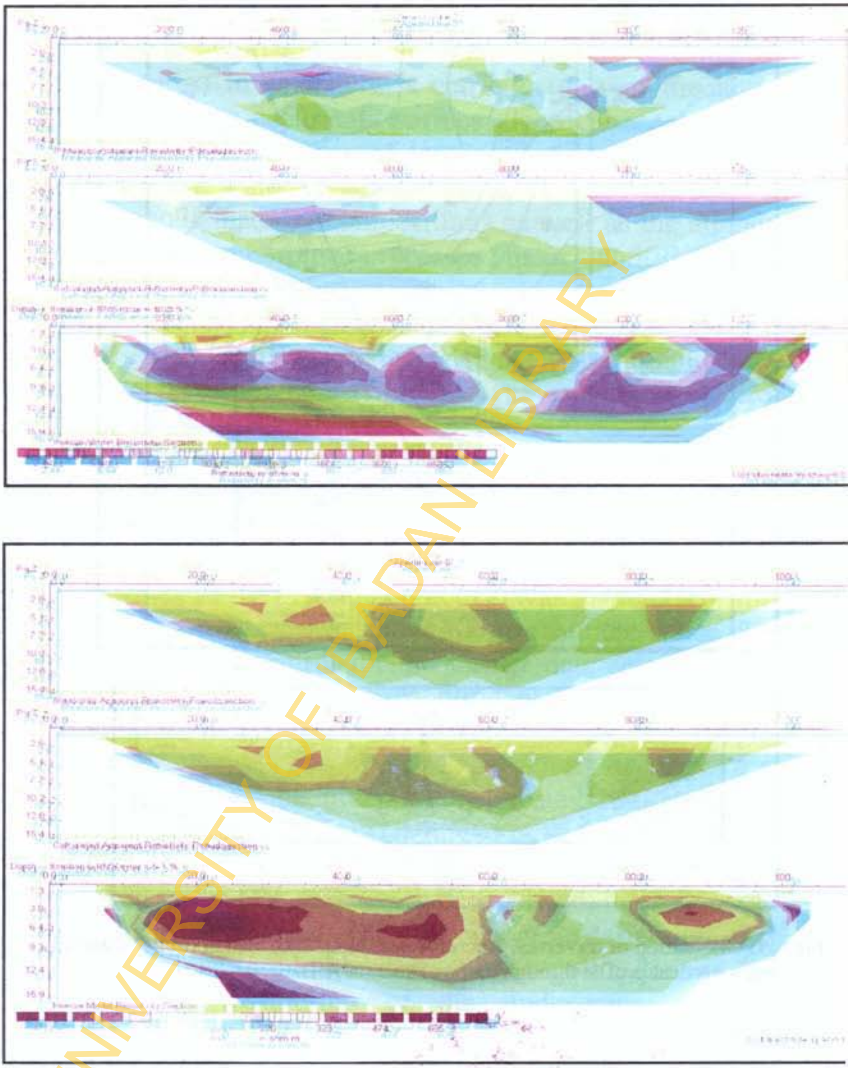


Fig. 51: Inverted resistivity section for control line 8, Aperin Waste Dump Site (Oladunjoye and Olayinka, 2010a).

Environmental Assessment of Sewage Disposal System

In Nigeria, sewage disposal constitutes an important source of environmental pollution. Apart from the design consideration, most systems are misused or overused. This is particularly the case in urban areas where, because of population and space limitation, systems designed for a single household are commonly used by two or more households. This often results in malfunctioning and a short life span of the system, and, in consequence, environmental problems. Unfortunately, there is no standard regulation on the operation and use of sewage disposal systems as well as their distance from water-supply wells. Thus, to forestall greater health hazards, efforts need to be directed toward developing a reliable approach for assessing and predicting environ-mental pollution arising from sewage disposal systems.

Amidu and Olayinka (2006) evaluated a geophysical approach to mapping pollution from sewer systems. The study involved geoenvironmental studies, using 2-D electrical-resistivity imaging and geochemical analysis around a septic tank in the Senior Staff Quarters on Sanders Road, within the University of Ibadan campus (figs.52 and 53). According to available data, household wastes have been discharged into this system daily since about 1961. Thus, some level of environmental impact was expected. Electrical resistivity techniques can be effective methods of imaging and clarifying subsurface structures and delineating contaminated zones. Corroborative evidence is often provided by geochemical analyses of soil, rock and water samples. However, previous researchers have focused largely on the chemistry of surface water and groundwater (Adepelumi *et al*., 2001; Olayinka and Olayiwola, 2001). The sampling of soils from pits dug at selected locations within the study area was the geochemical approach used in the work. The objectives of the study include assessing the impact of the sewage disposal system on the environment, determining the reliability of the electrical-resistivity method in imaging pollution plumes in areas underlain by the crystalline

Basement Complex rocks, correlating subsurface geologic structures with geophysical anomalies, and making recommendations to improve the design and construction of septic tank systems in order to prevent or at least reduce environmental hazards.

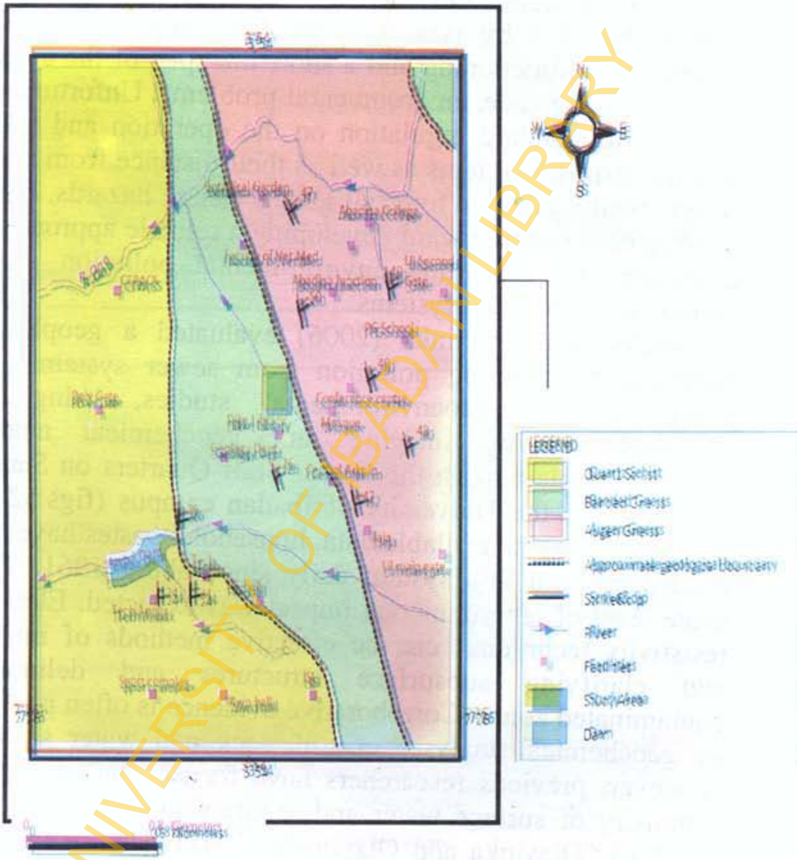


Fig. 52: Geological Map of the University of Ibadan Campus (After Oladunjoye, 2010).

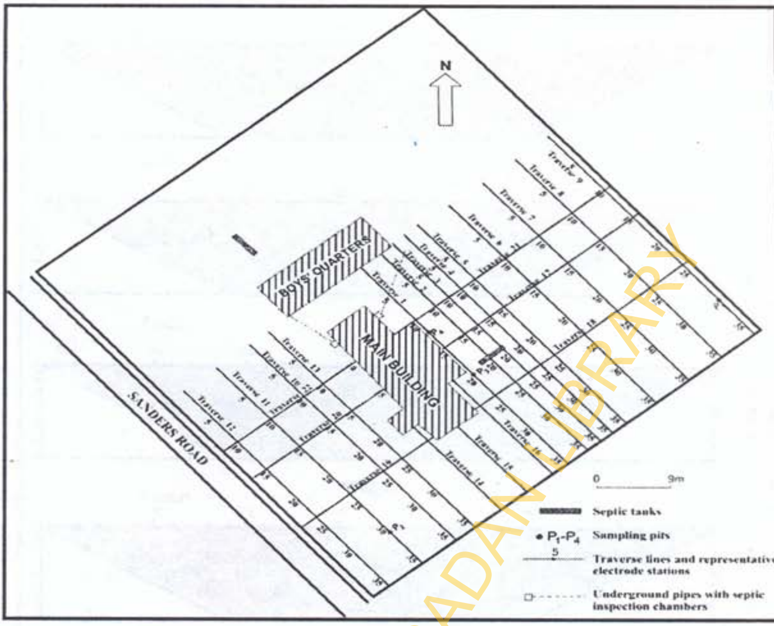


Fig. 53: Survey plan of the study area within University of Ibadan, showing traverse lines and sampling pits (After Amidu and Olayinka, 2006).

The resistivity survey results yielded low values at locations close to the septic tank, which are likely to be impacted areas. For locations at greater distances away from the septic tank, high values were obtained (figs. 54 and 55). These geoelectrical results correlated with the conductivity values recorded for soil samples. More corroborative evidence was provided by the chemical analyses. The concentrations of Pb, Fe, Cu, and Cr, and, to some extent, nitrate, were relatively high in soil samples obtained in close proximity to the septic tank (fig. 56). This is attributed to the effects of the sewage effluent. The results demonstrate that the approach presented in our work holds promise as a tool for pollution mapping in a Basement Complex environment.

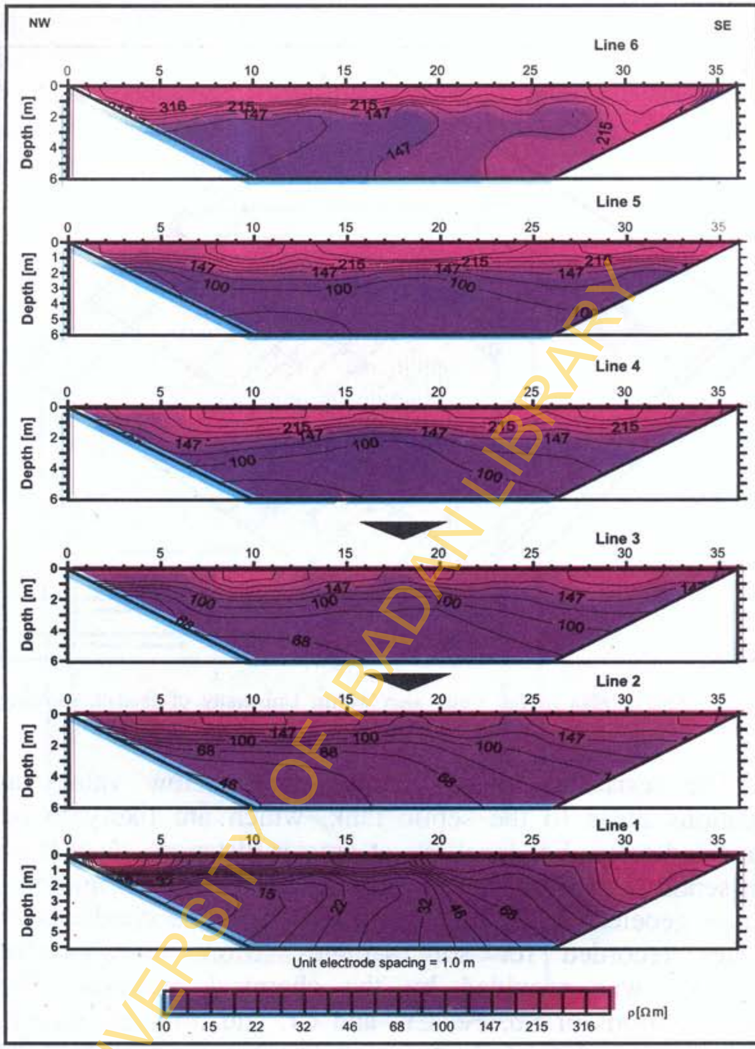


Fig. 54: Inverse model resistivity sections for Traverses 1 to 6. The position of the septic tank is indicated by the inverted triangle on Traverses 2 and 3 which crossed the septic tank (Modified after Amidu and Olayinka, 2006).

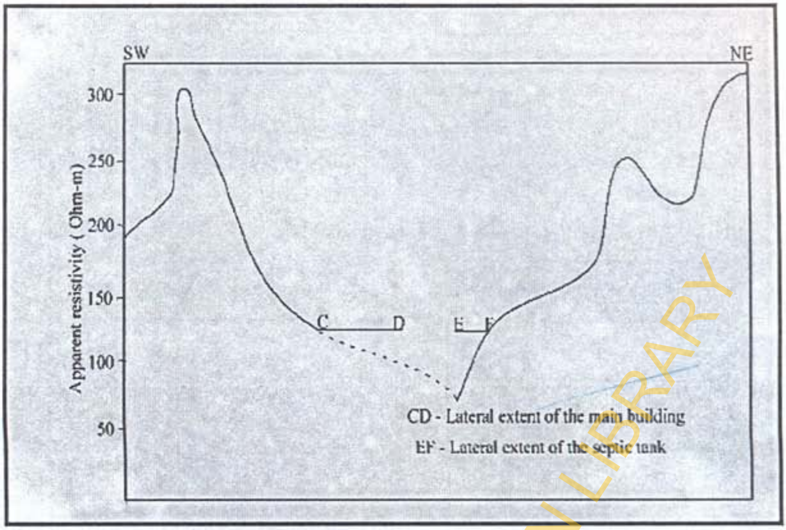


Fig. 55: A SW-NE -oriented profile on iso-apparent resistivity map at a=3 m. (after Amidu and Olayinka, 2006).

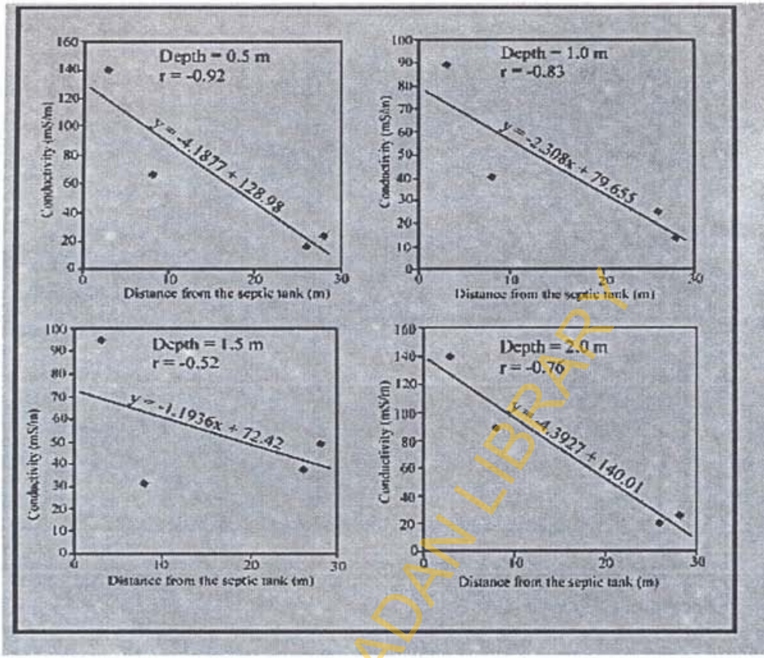


Fig. 56: Regression plots of conductivity variation at each sampling depth with distance from the septic tank (After Amidu and Olayinka, 2006).

Corrosion Potential along a Pipeline Route in the Niger Delta

In recent years, field investigations and research studies have identified vulnerability to corrosion among buried metal structural components. Existing steel pipes that have been exposed during excavation for new construction have revealed severe corrosion damage in many instances. Corrosion as it relates to buried pipeline is the process of natural forces working to restore the iron in the steel pipe, through rusting, to its original stable form of iron oxide, or native iron ore, which requires a preventive measure (Coburn, 2003). Deterioration of underground pipes, due to corrosion or mechanical failure, is of increasing concern to users in both the public and private sectors. In order to minimize corrosion rate, an understanding of the general conditions of the environment in which the material resides will assist in predicting corrosion control; for instance, protective coating or cathodic protection (Bakhvalov and Turkovskaya, 1965). Electrical resistivity method has been found to be suitable for assessing conductivity of environment where such steel pipes are laid (Agunloye, 1984; Adesida and Fatoba, 2005; Olayinka *et al.*, 2005; Olayinka and Oladunjoye, 2005).

In studying the variations in the resistivity distribution of the soil with depth along a proposed 70 km pipeline route in Bayelsa and Delta States (fig. 57), the Wenner and Schlumberger arrays were adopted for topsoil and subsoil resistivity determinations, respectively.

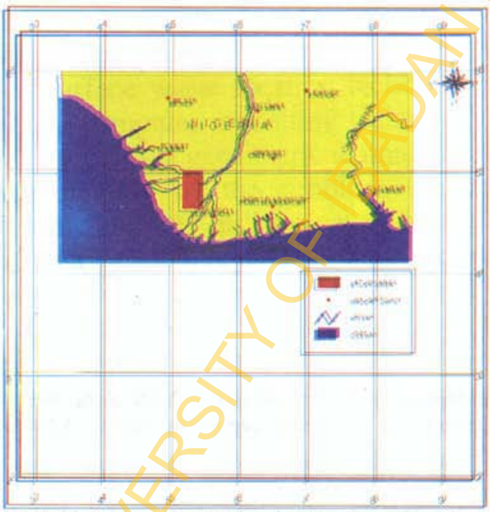


Fig. 57: Map of southern Nigeria showing the study area.

The apparent resistivity from the 85 Wenner measurements along the pipeline route ranges between 3 and 265 Ω-m. The very low values obtained in some test points have been attributed to the influence of saline water, and these portions are dominated by mangrove plant with many creeks. Other areas with relatively low resistivities are characterized by swampy/ marshy land. The upland areas have relatively high apparent resistivities. The subsoil resistivities for the 85 test points range between 2 and 233 Ω-m, with a mean of 48 Ω-m. The VES curves are typically H-type, with the thickness of the subsoil ranging between 1.6 and 17.5 m, with a mean of 6.3 m (fig. 58 and table 10). It may be noted that the terminal branch of the curves rises very steeply.

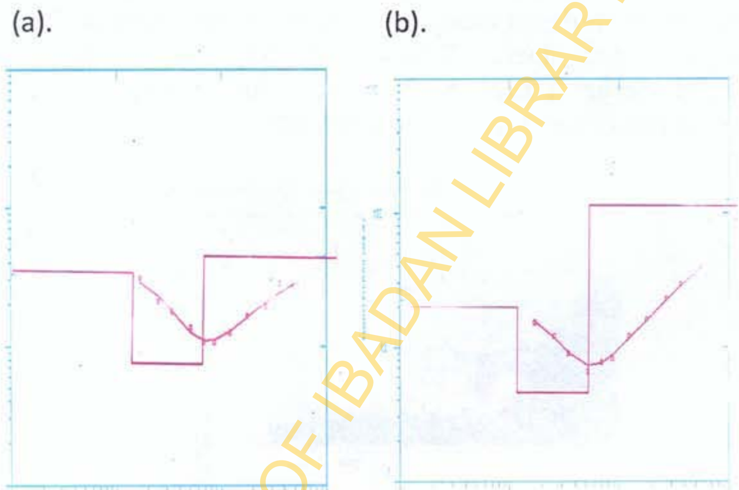


Fig. 58: Layer model interpretation of representative VES along the proposed pipeline route (a) upland area (b) mangrove environment. (After Olayinka and Oladunjoye, 2005).

Table 10. Interpretation of Representative VES Curves along the Pipeline Route

Location	Layer resistivity (Ω -m)			Layer thickness (m)	
	1	2	3	1	2
Upland	331	77	443	1.3	4.6
Mangrove	23	5	125	1.1	3.5

A plot of the subsoil resistivities against distance along the proposed pipeline route (fig. 59) clearly shows the variations of resistivity across the entire length of coverage. This is an indication that the structures to be buried along the route will pass through subsoil of diverse geological conditions and environmental vulnerability. Hence, appropriate cathodic protection/protective coating should be installed with piping or structures to be buried along such pipeline route.

Two-Dimensional Geoelectric Response of a Hydrocarbon-Impacted Sand Formation

The environmental impact of oils spills is a major problem in the oil-producing communities of Nigeria. As part of a programme to test the application of geophysics as a non-invasive subsurface waste location technique, we employed laboratory and computer modelling techniques to investigate the usefulness of 2-D geoelectrical imaging in providing a better understanding of the problem (Olorunfemi *et al.*, 2001b). A simulated oil spill tank was carefully designed in the Department of Geology, Obafemi Awolowo University, Ile-Ife and constructed to resemble an oil spill as closely as possible (fig. 60). Five electrical traverse lines were established in the tank. Measurements were made with the Wenner, pole-pole, and dipole-dipole arrays for electrode spacings 2, 4 and 6 cm along five traverses. In addition, dipole-dipole data were measured for five levels of the pseudosection along one of the traverses. The dipole-dipole data were inverted, using a SIRT algorithm. The apparent resistivity maps show that with any of the four arrays used, the hydrocarbon-impacted sand is identified as a high apparent resistivity anomaly. Inversion of the dipole-dipole data indicates that while the limits of the spill can be accurately defined, its depth extent may be slightly overestimated (figs. 61 and 62).

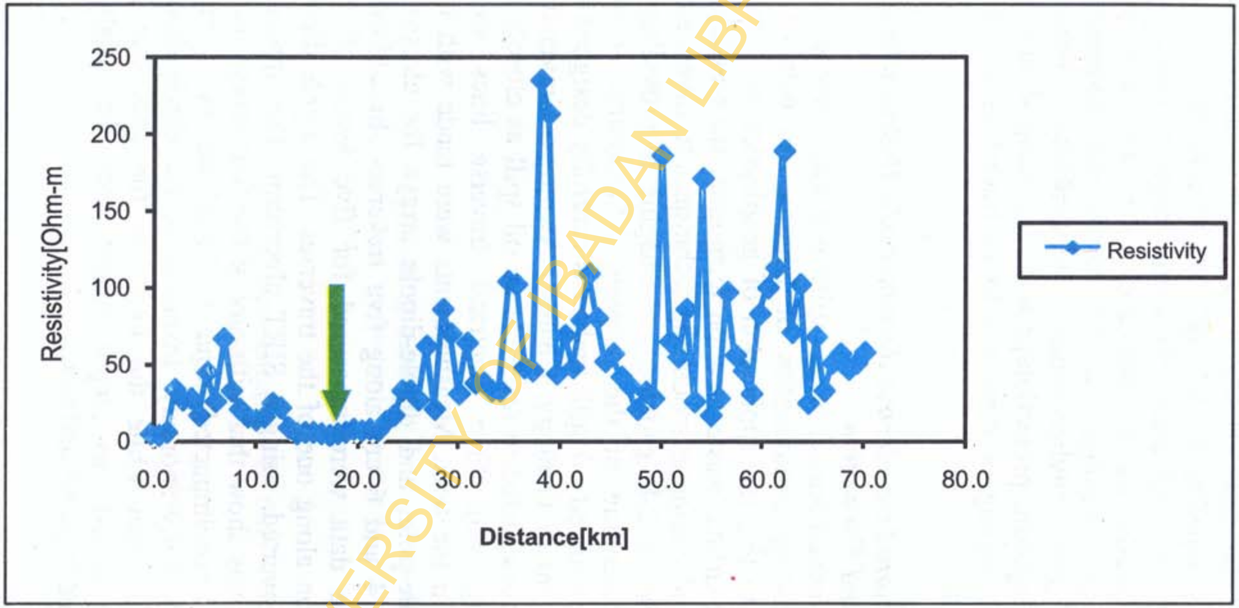


Fig. 59: Plot of subsoil resistivities against distance along the proposed pipeline route (After Olayinka and Oladunjoye, 2005).

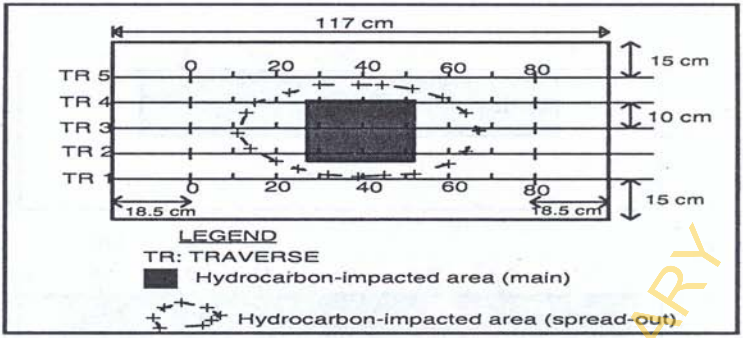


Fig. 60: Plan map of model tank showing hydrocarbon-impacted zone (After Olorunfemi *et al.*, 2001b).

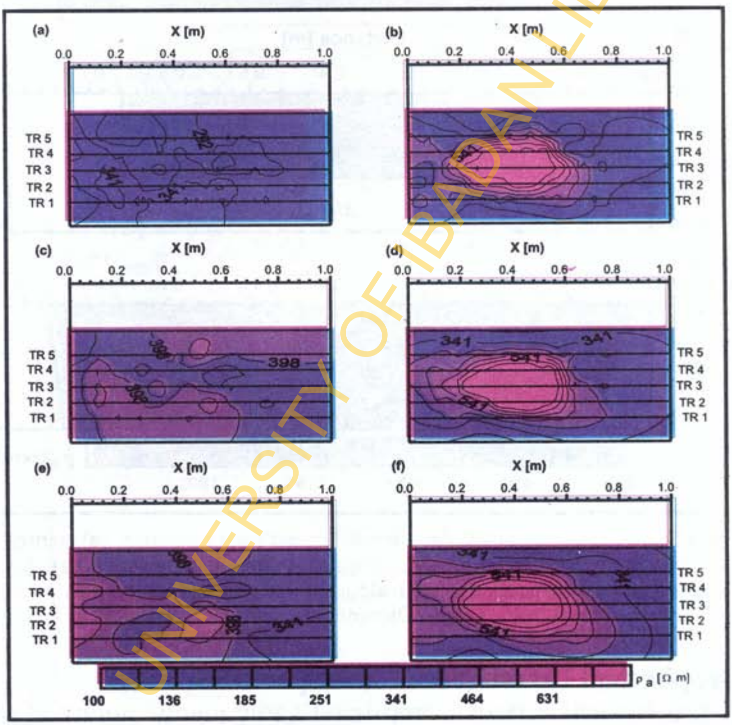


Fig. 61: Apparent resistivity maps for the Wenner array. (a) and (b) a = 2 cm; (c) and (d) a = 4 cm. (e) and (f) a = 6 cm. the left-hand panels are data for the pre-impact sand formation; the right-hand panels are the corresponding data for the post-impact sand (After Olorunfemi *et al.*, 2001b).

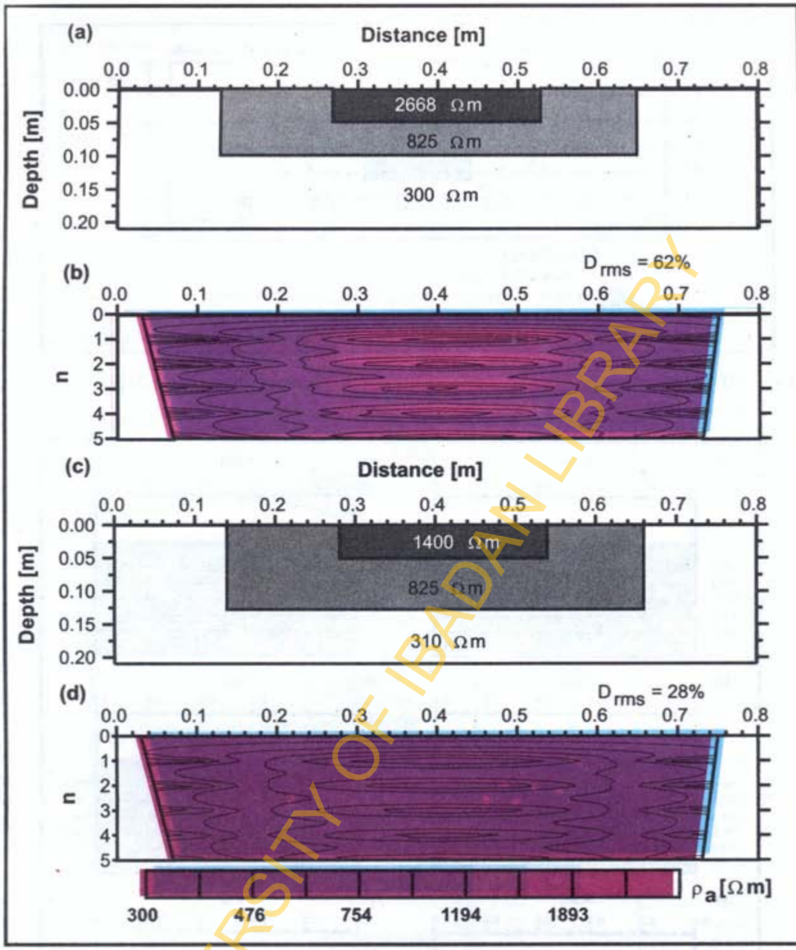


Fig. 62: 2-D resistivity image for the post-impact sand formation. (a) starting 2-D model. (b) pseudosection data calculated from the model in (a). (c) 2-D model after 10 iterations, SIRT algorithm. (d) pseudosection data calculated from the model in (c). (After Olorunfemi *et al.*, 2001b).

Geophysical Investigation of Suspected Springs

A geophysical survey, comprising spontaneous potential (SP) and electrical resistivity methods, was conducted at suspected spring sites in Ajegunle-Igoba, north of Akure, in order to understand their nature and feasibility for groundwater development (Olorunfemi *et al.*, 2001a). The area is underlain by Precambrian crystalline basement complex rocks, with the dominant rock type being porphyritic granite. A regional geological map of the area is shown in fig. 63. The settlement, with a population of about 1000 in 1996, experiences groundwater seepages during the peak of the rainy season, between June and September. It was the need to understand the nature of the groundwater seepages in the village and also an evaluation of the feasibility of developing the groundwater resource that necessitated the geophysical survey. The geophysical investigation comprised self potential (SP) and electrical resistivity measurements (fig. 64).

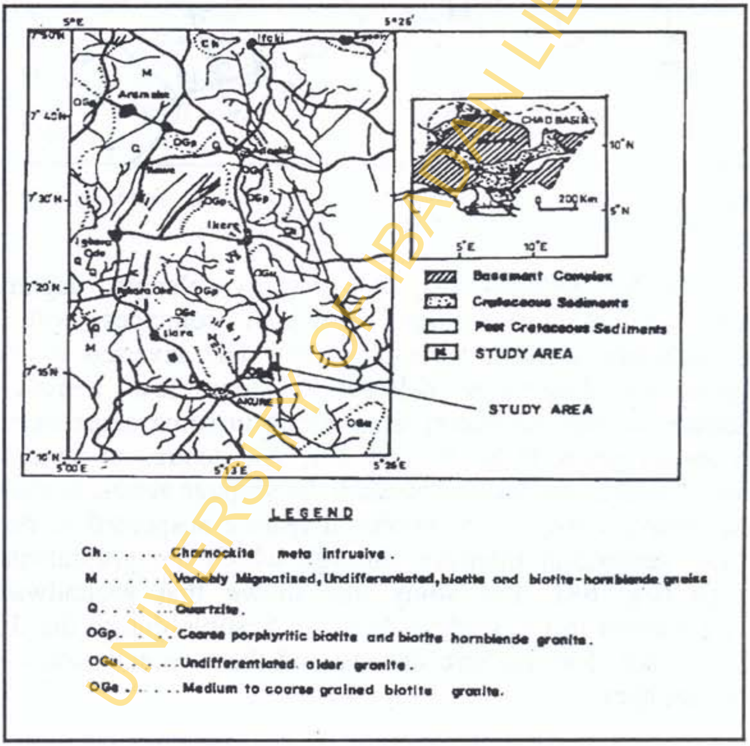


Fig. 63: Regional geological map of the Akure-Ado-Ekiti area (Adapted from Nigerian Geological Survey Agency).

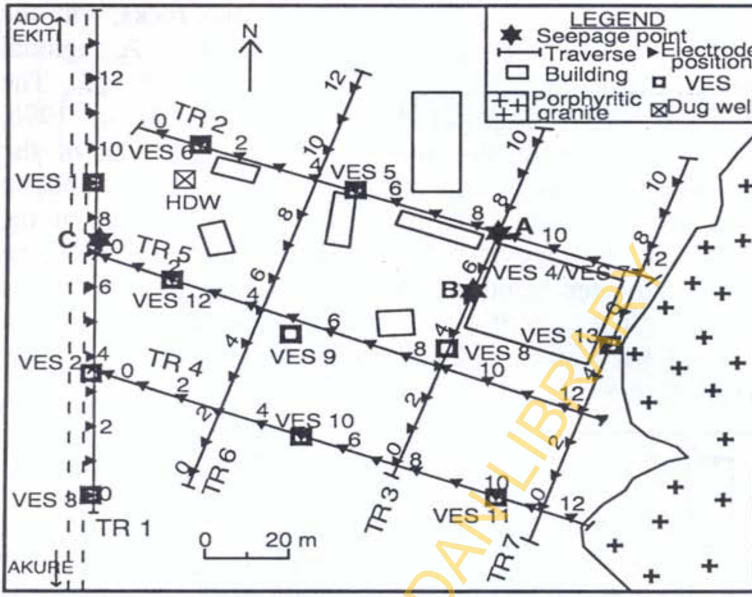


Fig. 64: Enlarged map of the Ajegunle-Igoba area, near Akure, showing the geophysical traverses (Olorunfemi *et al*., 2001a).

The SP profiles display short wavelength negative amplitude anomalies, one of which coincides with a groundwater seepage zone (fig. 65). The inverted dipole-dipole pseudosections delineate distinct low resistivity closures within the overburden, which in some cases extend to the basement (figs. 66 and 67). The centres of some of these closures are located beneath the seepage zones. Some of the centres correlate, to evolve a feature suspected to be a major geological interface through which the groundwater seeps (fig. 68). The study has shown that groundwater development in the study area is not feasible due to the thin overburden, low fracture density and the seasonal nature of the seepages.

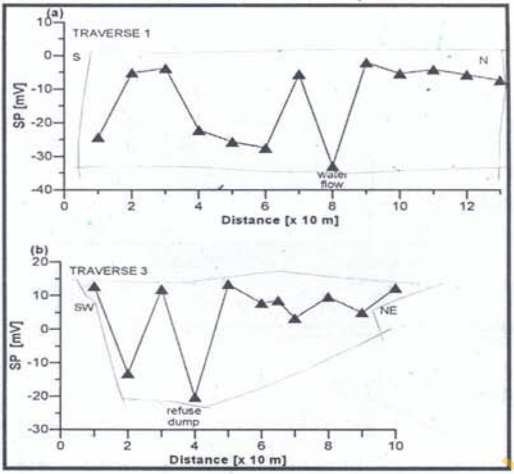


Fig. 65: SP profiles measured along two S-N lines at Igoba, near Akure. The position marked 'water flow' was observed in the field. (After Olorunfemi *et al.*, 2001a).

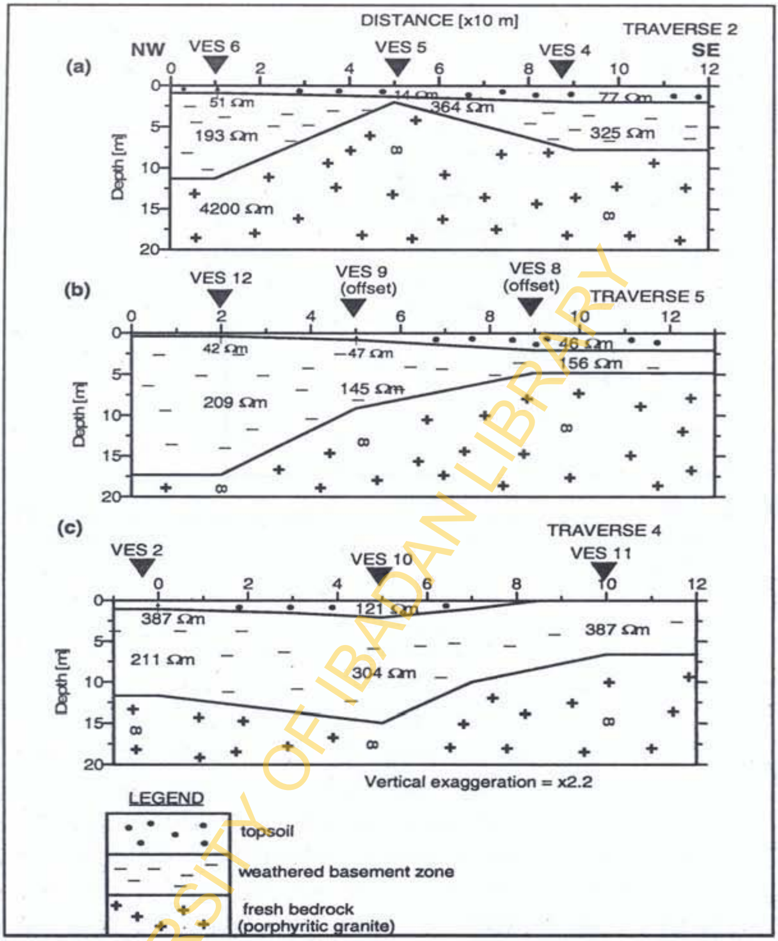


Fig. 66: Geoelectric section along three NW-SE traverses at Igoba (After Olorunfemi *et al*., 2001a).

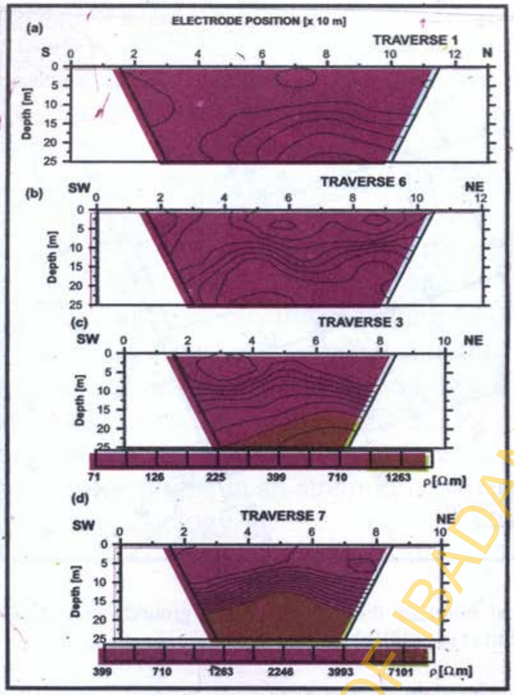


Fig. 67: Inverted 2-D models along Traverses 1, 6, 3 and 7 at Igoba (After Olorunfemi *et al*., 2001a).

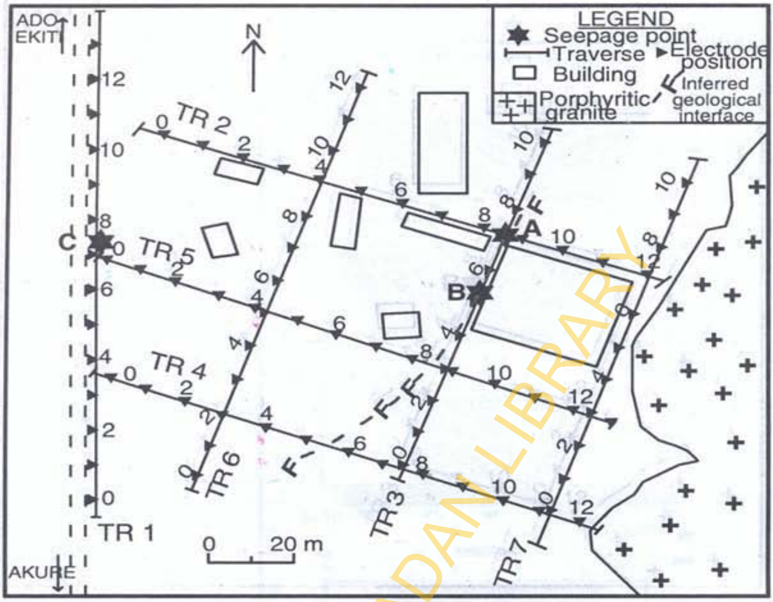
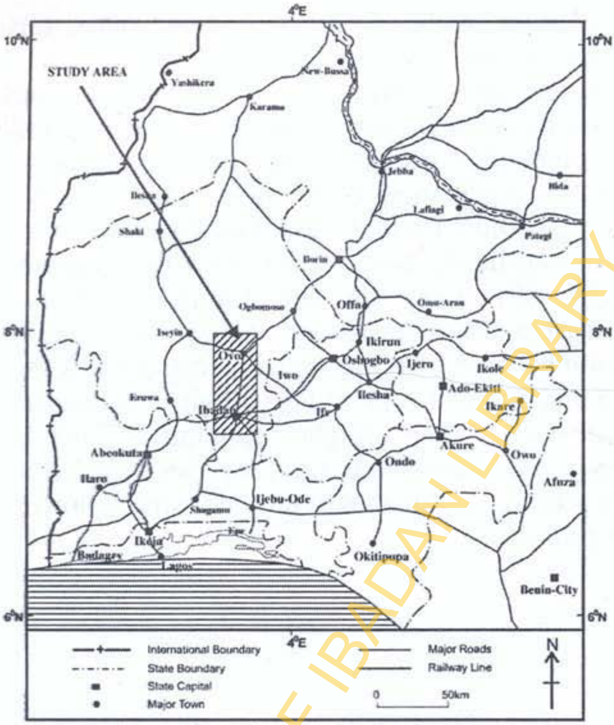


Fig. 68: Inferred geological interface through which the groundwater seeps at Igoba (After Olorunfemi *et al*., 2001a).

Group VII: Engineering Geophysics

As part of engineering site investigation in areas underlain by crystalline basement complex rocks, drilling of exploratory boreholes is often embarked upon by consulting engineering firms to determine the depth to bedrock and the nature of the overburden materials. Too frequently, however, exploratory work depending solely on borehole drilling is so poorly planned that the results are inadequate or misleading. It has been shown that geophysical surveys are efficient and cost-effective in providing the required geotechnical information (Gokhale and Dasari, 1984; Adeduro *et al*., 1987; Ojo *et al*., 1990; Olorunfemi *et al*., 2000; Olorunfemi, 2008). Geophysical techniques measure a much larger volume of the subsurface material than boreholes. Methods that can be used to determine the depth to and the constituent of the bedrock include gravity, magnetic, resistivity, ground radar, seismic refraction and seismic reflection (Sharma, 1997).

In order to assess the cost-effectiveness of surface geophysics as a complementary technique to borehole drilling in site investigation, a geoelectrical survey involving a total of 30 Schlumberger vertical electrical soundings (VES) was conducted at the Ojoo (Ibadan) and Ilora-Oyo sections of the proposed Ibadan-Ilorin dual carriageway in Southwestern Nigeria (fig. 69) (Olayinka and Oyedele, 2001). The maximum current electrode spacing (AB/2) was 100 m while the separation between adjacent sounding centers was short at between 15 and 20 m, thus providing a high sampling density of the measured data. Eight exploratory boreholes, terminating at the bedrock interface, had been drilled at the four bridge points in an attempt to provide information on the subsurface geology.



Location map of the study area showing the major urban centres

Fig. 69: Location map of the Ibadan-Oyo road geophysical survey (After Olayinka and Oyedele, 2001).

Apparent resistivity pseudosections from the sounding data have provided semi-quantitative information on the resistivity distribution. Inversion of the sounding data was also undertaken, this being constrained by the borehole information. The VES interpretation indicates that the depth to bedrock is generally shallow at less than 20 m, with a mean of 9.6 ± 4.1m, the saprolite (comprising sandy clay) has a resistivity within the range 40 to 125 Ω-m, with a mean of 75.1 ± 26.1 Ω-m (fig. 70). These results are in agreement with the borehole drilling information, with the correlation coefficient between the depth to bedrock from borehole drilling and that determined from the VES interpretation being high ($R=0.97$; $p<0.0001$) (fig. 71).

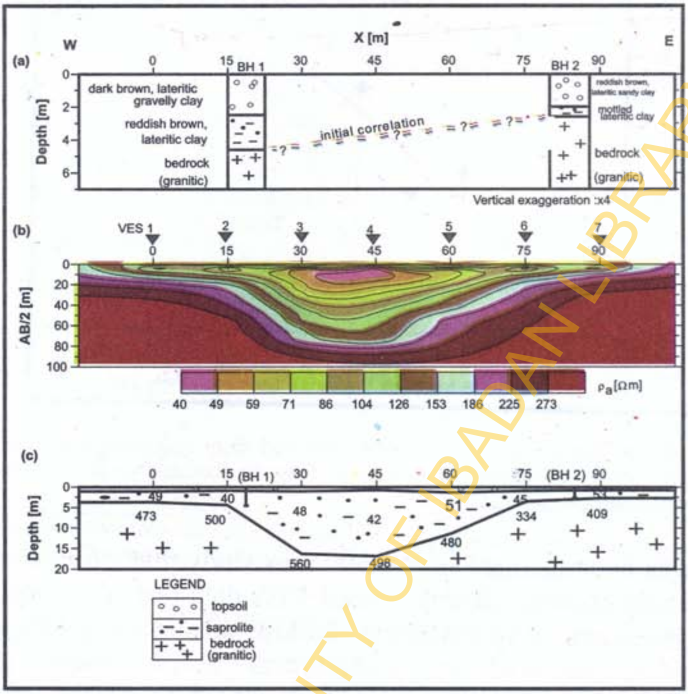


Fig. 70: Representative geoelectric section from the Ibadan-Oyo road. (a) correlation of two lithologic sections (b) Apparent resistivity pseudosection compiled from vertical sets of the Schlumberger sounding data (c) Geoelectric section interpreted from the VES data. (After Olayinka and Oyedele, 2001).

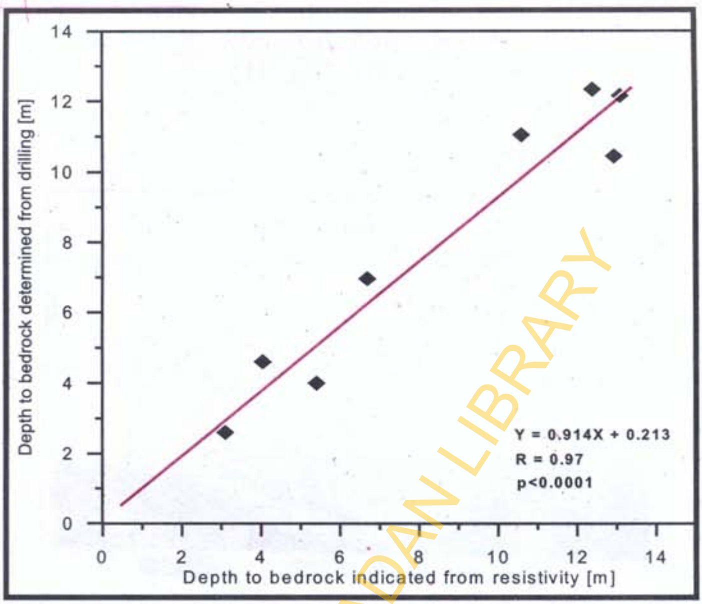


Fig. 71: Correlation of depth to bedrock indicated from resistivity and depth determined from drilling for the survey along the Ibadan-Oyo Road (After Olayinka and Oyedele, 2001).

It was demonstrated in our previous study that, compared to borehole drilling, closely spaced VES data provide a cost-effective technique in obtaining shallow subsurface geologic information required in geotechnical investigations. A comparison between the cost of geophysical survey and borehole drilling in the light of current realities (table 11) still confirms this assertion.

Table 11. Cost Comparison between VES Survey and Borehole Drilling as an Exploratory Tool in Engineering site investigation in the Ibadan Area

Exploratory tool	Extent/scope of exploration	Cost Justification		Total Cost (₦)
Geophysical survey	Comprehensive survey involving VES + VLF + resistivity imaging plus data analysis, computer interpretation and report writing	Lump Sum		100,000.00
Bore hole drilling	2 No boreholes at a site	10 m of overburden @ ₦10,000.00/m per borehole	100,000.00 per borehole	200,000.00
		3 m of competent bedrock @ ₦30,000.00/m per borehole	90,000.00 per borehole	180,000.00
	TOTAL			380,000.00

(*Source*: various consultant geophysicists and borehole drilling companies).
Note: The prices quoted are valid as at January, 2010.

Group VIII: Integrated Geophysical Investigation at a Geological Transition Zone

I recall that my first and only time of appearing in court was in May 1995 when I was invited as an 'Expert Witness' to the High Court of Oyo State in a suit involving a client (the plaintiff) and a borehole drilling company (the defendant). The client awarded a contract to the defendant for the drilling of a water-supply borehole at Isonyin, near Ijebu-Ode. The drilling company commenced the job but later ran into some technical hitches, and the challenges thus encountered prevented a successful completion of the borehole. When the matter could not be resolved amicably, the case ended in the court. The Ijebu-Ode area has been known to be a complex geological transition terrain between the Precambrian Basement Complex in the north and the Cretaceous Eastern

Dahomey Basin in the south. The existing geological map of the area is shown in fig. 72.

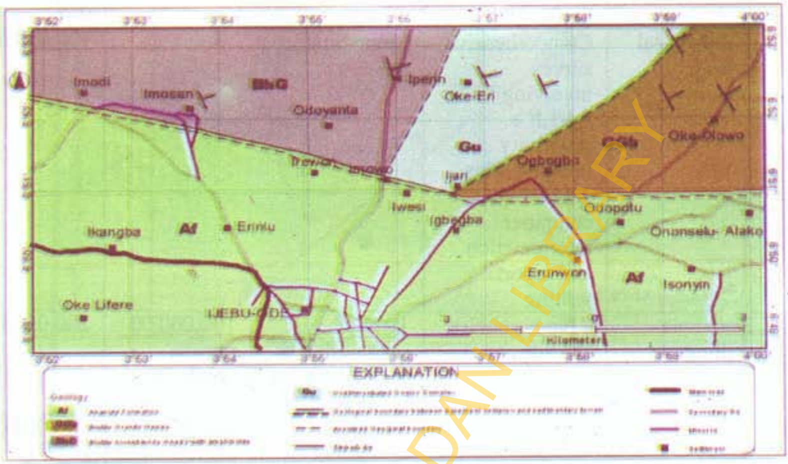


Fig. 72: Existing geological map of the Ijebu-Ode area, southwestern Nigeria (after Nigerian Geological Survey Agency).

We employed an integrated geological, geophysical and satellite imagery mapping to investigate the areas with a view to establishing the geologic control on the groundwater resource. High Resolution Aeromagnetic (HRAM), Very Low Frequency Electromagnetic (VLF), Vertical Electrical Sounding (VES) and Enhanced Thematic Mapper plus (ETM+) were used (Olayinka and Osinowo, 2009). The geophysical and composite Landsat data were subjected to methodical data processing techniques and employed to study the terrain's subsurface in terms of structures, lithologic distribution, basement topography and hydrogeology. The resistivity of the lateritic overburden ranges from 10 to 41 Ω-m, which indicates high clay content. Geotechnical investigations, such as soaked and unsoaked CBR result range from 70.3 to 83.9%, and 12.9 to 31.6% respectively, indicating percentage reduction in strength with wetness of 55.7% - 83.8%. The result suggested that the swelling clay content of the laterite is high and has the potential to prevent adequate groundwater percolation from rainfall. Euler deconvolution solution gave depth to magnetic source between 1 and 77 m, which agrees with borehole information.

Representative VES curves from the study area are shown in fig. 73. A schematic representation of the nature of ground water accumulation in the Ijebu-Ode area is shown in fig. 74. A synthesis of all the available geological, geophysical, and borehole information has helped in generating the revised geological map (fig. 75).

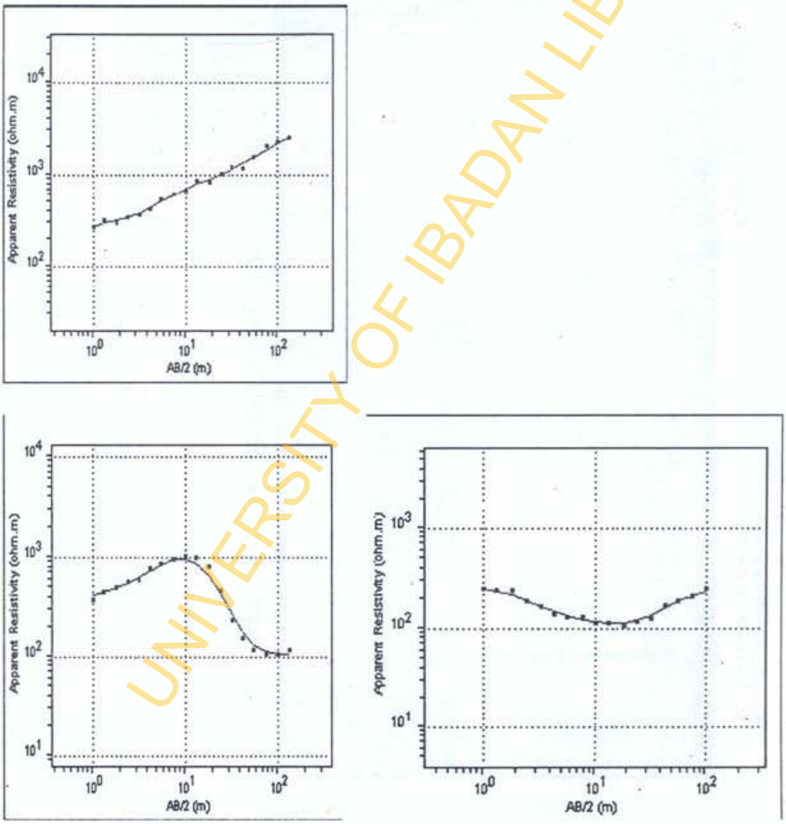


Fig. 73: Representative VES Type Response Curves from Ijebu Ode area (After Olayinka and Osinowo, 2009).

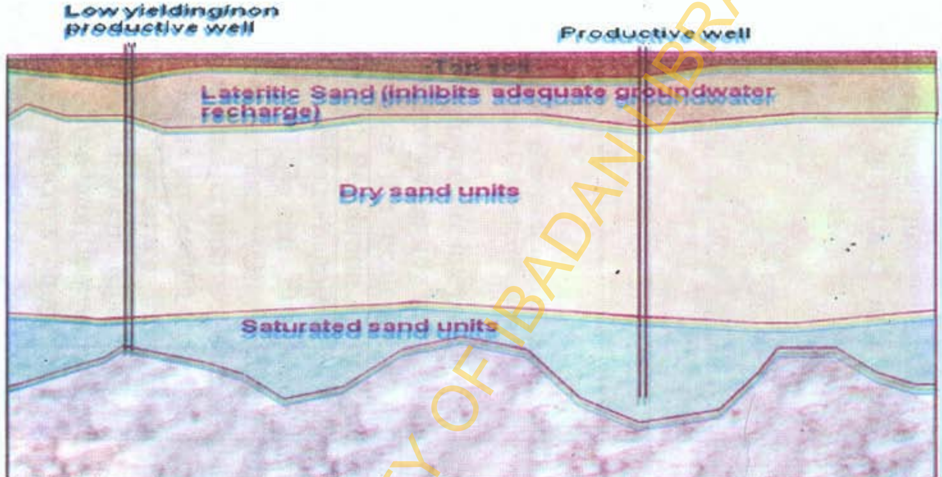


Fig. 74: Schematic geometry model showing effect on groundwater accumulation in the area around Ijebu-Ode (not to scale) (After Olayinka and Osinowo, 2009).

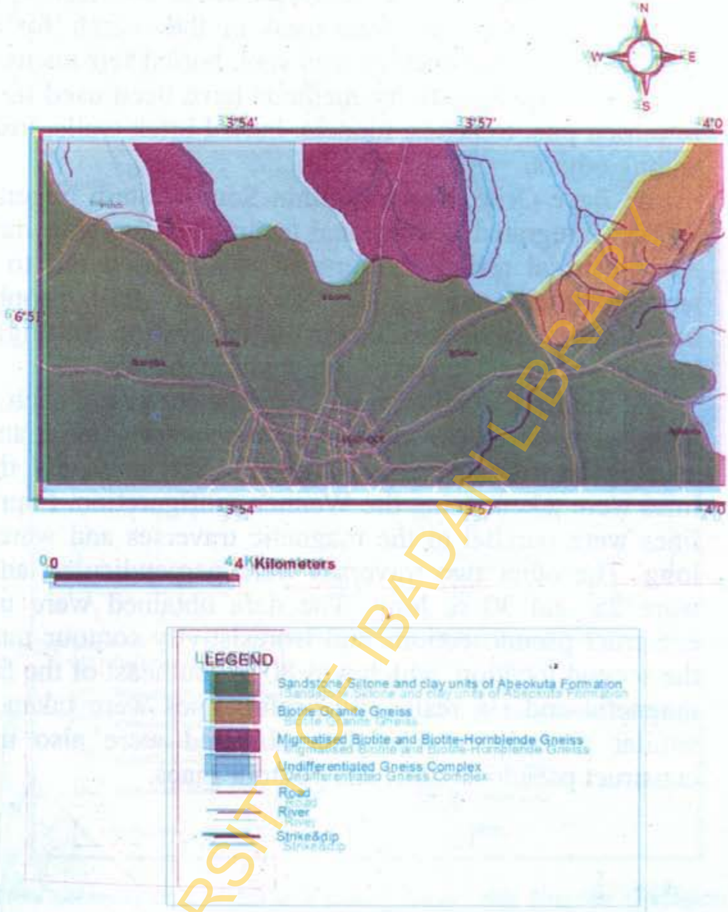


Fig. 75: Revised geological map of the Ijebu-Ode area (After Olayinka and Osinowo, 2009).

Group IX: Archaeological Investigation

In the past, archaeological investigation generally utilized the trial and error method or random test pitting. This technique is time-wasting, tedious and not necessarily accurate. Thus the need to introduce faster and more accurate methods became evident (Xu and Noel, 1991).

The use of geophysical methods for archaeological investigation is a recent development in Archaeology. The magnetic method has been used in the search for buried magnetic materials such as iron slag, buried ferrous materials and fired clay. Resistivity methods have been used in search of buried pits, trenches, tunnels, buried brick walls, iron slag, among others.

At Ijaye-Orile, located within Southwestern Nigeria (fig. 76), an integrated geophysical technique involving magnetic and electrical resistivity surveys, was carried out to locate archaeological materials. Results of the geophysical investigation were verified, using excavation (pitting). Two locations were selected for study within the site.

At the first location, nine magnetic traverses, each 100 m long, were run north-south at station intervals of 1 and 5 m spacing between traverses (fig. 77). Six resistivity traverse lines were taken, using the Wenner configuration. Four of the lines were parallel to the magnetic traverses and were 55 m long. The other two traverses were perpendicular, and they were 25 and 30 m long. The data obtained were used to construct pseudosections and isoresistivity contour maps. At the second location, which was 80 m southeast of the first, 12 magnetic and six resistivity profile lines were taken, using similar procedures. The data obtained were also used to construct pseudosections and contour maps.

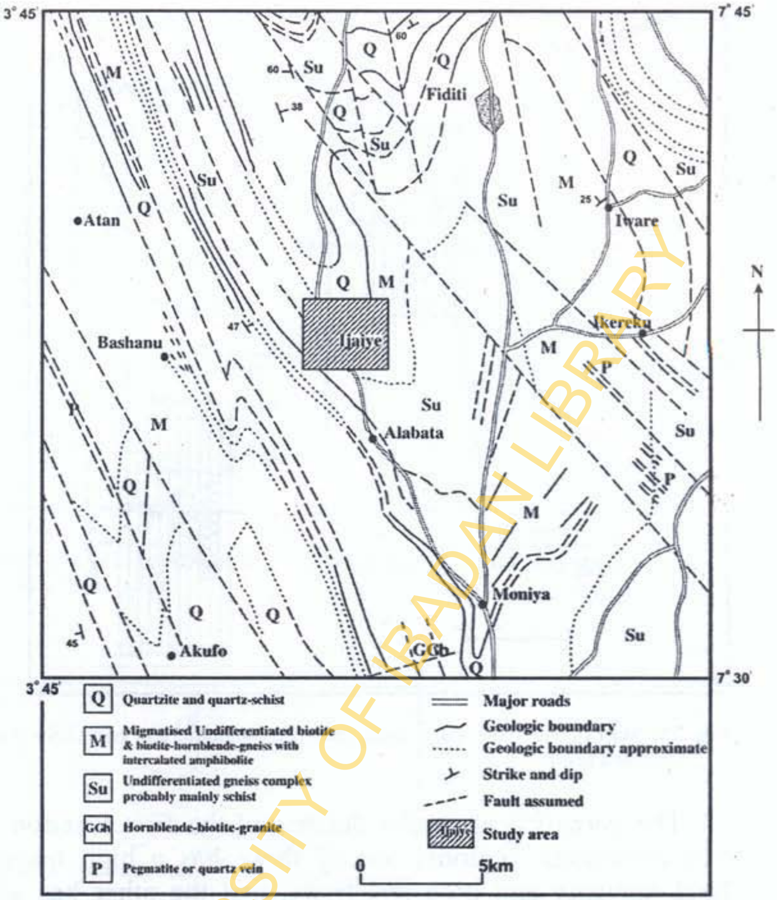


Fig. 76: Geological map of the area around Ijaiye (after Nigerian Geological Survey Agency).

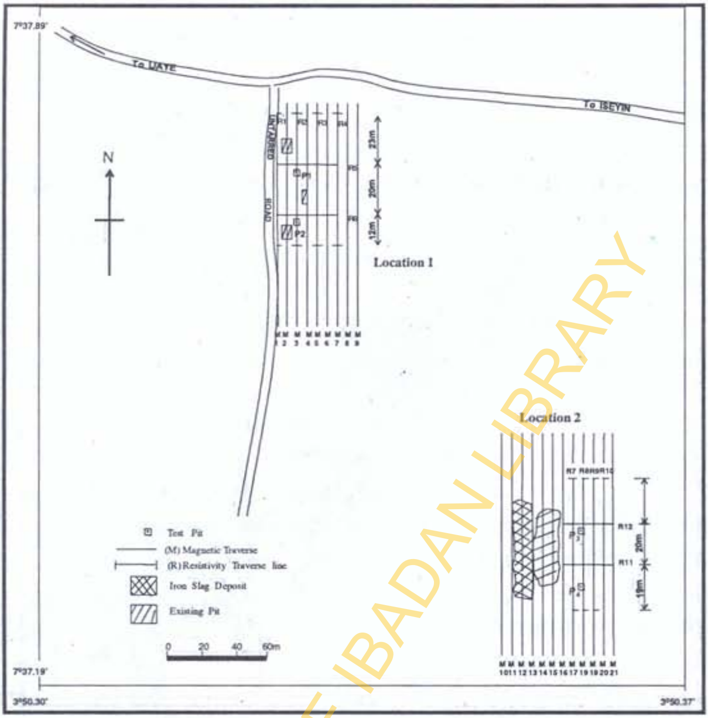


Fig. 77: Map of the Ijaye study area, showing magnetic and resistivity traverse lines and test pits.

The geophysical results delineated the first location into two anomalous regions; one of these has a high magnetic field intensity and high resistivity, and the other has a low magnetic field intensity and low resistivity (figs. 78 to 80). At the second location, a high magnetic field intensity was generally observed. Excavation carried out yielded a large amount of archaeological materials (iron slag and pottery) at high magnetic field intensity and high resistivity regions, and a small amount of archaeological materials at low magnetic field intensity and low resistivity regions. Thus, geophysical anomalies correlated with the excavation results. The results demonstrate that geophysical methods hold great promise as a tool in archaeological investigations.

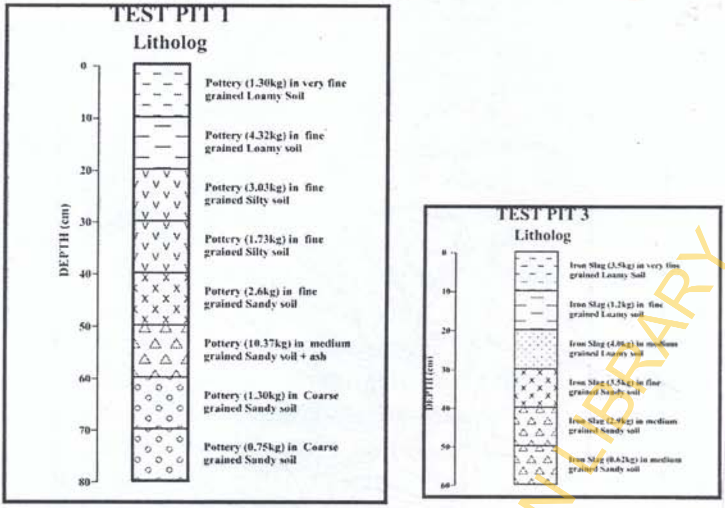


Fig. 78: Litholog showing soil type and archaeological materials in (a) Test Pit 1 and (b) Test Pit 3, Ijaiye.

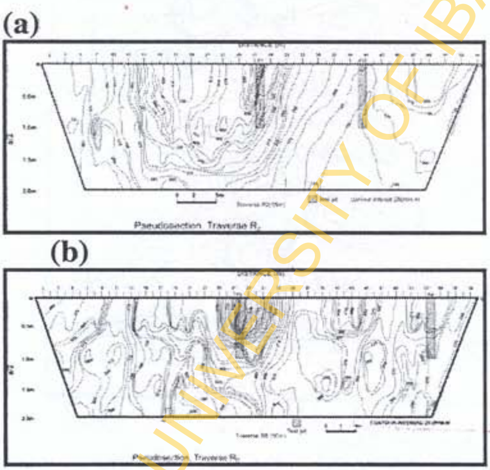


Fig. 79: Apparent resistivity pseudosection for (a) Traverse R2 and (b) Traverse R8 at Ijaiye (After Zuru *et al.*, 2010).

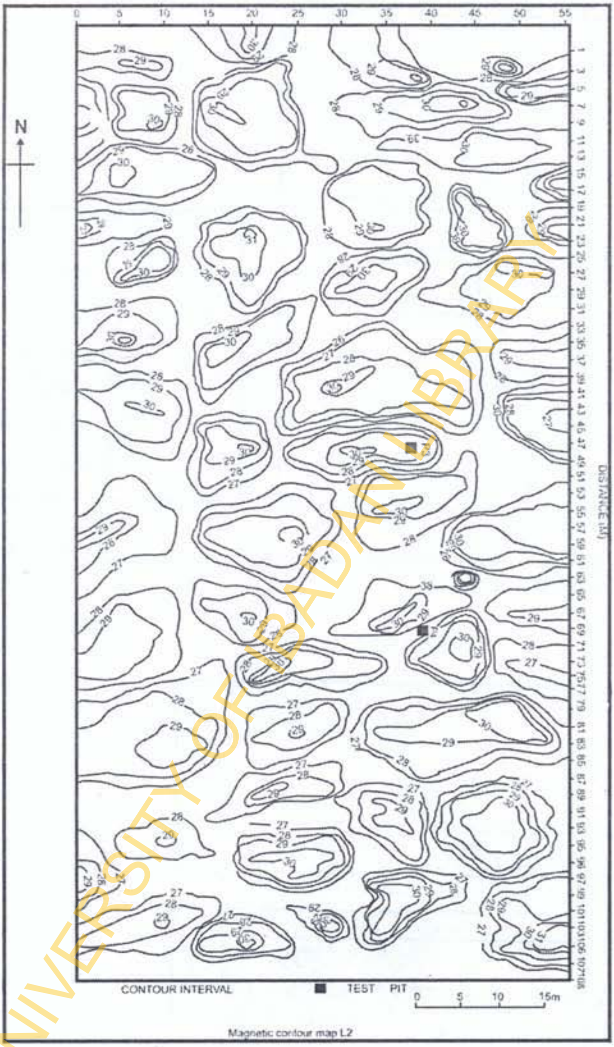


Fig. 80: Magnetic data from Ijaiye.

Group X: Geoelectric Imaging of a Valley Bottom Soil in Relation to its Agricultural Significance

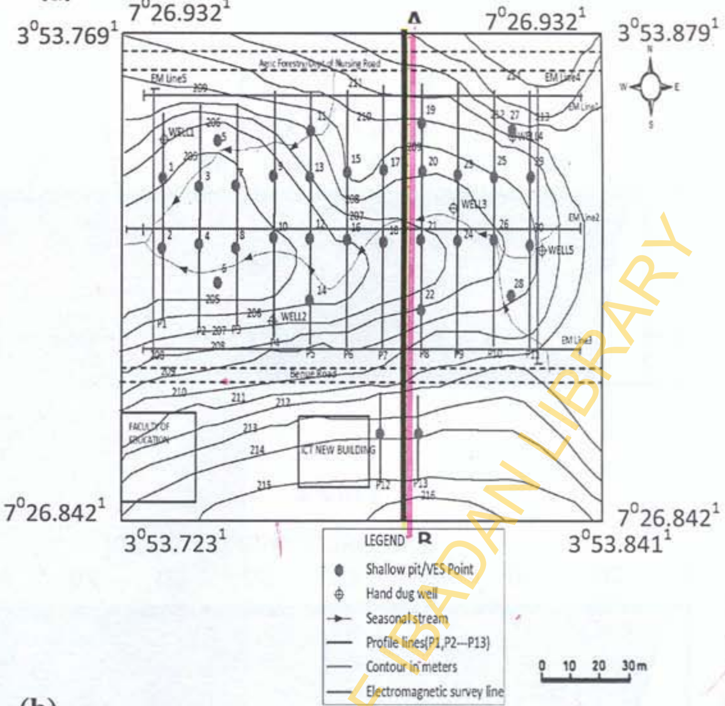
Recently, the capability of geophysical techniques to monitor processes. For instance, water flow in the vadose zone, water uptake by roots, sap flow in trunks) have been emphasized (Michot *et al.*, 2003; Al Hagrey *et al.*, 2004; Olayinka and Oladunjoye, 2005). To achieve such objectives, a 2-D imaging/repeated time-dependent (time lapse) measurement, using electrical resistivity method is often adopted. This is expected to give a pictorial view of the dynamic behavior of water regime in such environment. Also, Besson *et al.* (2004) used the method to investigate the effects of tillage on soil properties. Their findings show that soil water, structure, and, even, root zones can be observed by high-resolution geoelectric and radar studies. It is also revealed that the processes of penetration and uptake of water by the roots can be monitored under favorable conditions.

Valley bottom soils are formed by the influence of pedogenic processes whose characteristics are different from those of well-drained soils. They are widely distributed throughout all the agro-ecological zones of Africa and many other parts of the world (Andriesse, 1986). The soils are particularly common in Nigeria and cover about 5% of the cultivable land. The potentials of the valley bottom for high and sustainable agricultural production hinge mainly on their inherent characteristics of shallow water, deposition and accumulation of organic matter and residual available moisture for farming. However, the soils have been little studied and hence under-utilized, especially in southwestern Nigeria. With the increasing population and high demand for fixed land for agricultural and non-agricultural uses, there is no doubt that the valley bottom soil, if properly utilized, would enhance agricultural productivity, especially during the dry season (Ekemezie, 2002).

To this end, a combined 2-D resistivity imaging survey and determination of hydrological parameters of a valley bottom soil within the University of Ibadan that has been in use continuously for over 20 years as part of the training programme plot for undergraduate students of Agriculture was carried out. Imaging data were measured along 11 lines, with a minimum inter-electrode spacing of 1 m (fig. 81). The elevation ranges between 206 and 212 m above mean sea level. Control data were obtained along two lines nearby, where the bedrock is the same but at a higher elevation. Soil samples were collected from 30 shallow pits at depths of 0.5, 1.0 and 1.5 m, respectively.

The results of the inversion of pseudosection data along the imaging lines show preponderance of lenses of sandy clay/clayey sand with resistivity values at less than 50 Ω-m (fig. 82), while that at the control site is much higher. These pockets of lenses gave rise to perched aquifer system within the valley bottom. The natural moisture content ranges between 3.3 and 27.4% with a mean of 12.2% which accounts for the low resistivities observed on the imaging lines (fig. 83). The porosity values range between 9.9 and 36.8%, with a mean of 14.4%. These are characteristic of sandy clay soil, which predominate in the study area. The coefficient of permeability of the samples ranged between 9.61×10^{-7} and 1.007×10^{-5} cm/sec, which corresponds to sandy clay soil. This study has demonstrated that the combined use of electrical imaging and determination of hydrological parameters can be employed to characterize a vadose zone. It has been shown that changes in electrical properties of the soil are associated with variations in moisture content and that there exists a close relationship between lenses of sandy clay material and the recharge processes within the valley bottom soil. Hence, it is possible to farm throughout the year without much irrigation. Owing to the high water retaining capacity of this soil, flooding at the peak of raining season could constitute an environmental problem in the area.

(a)



(b)

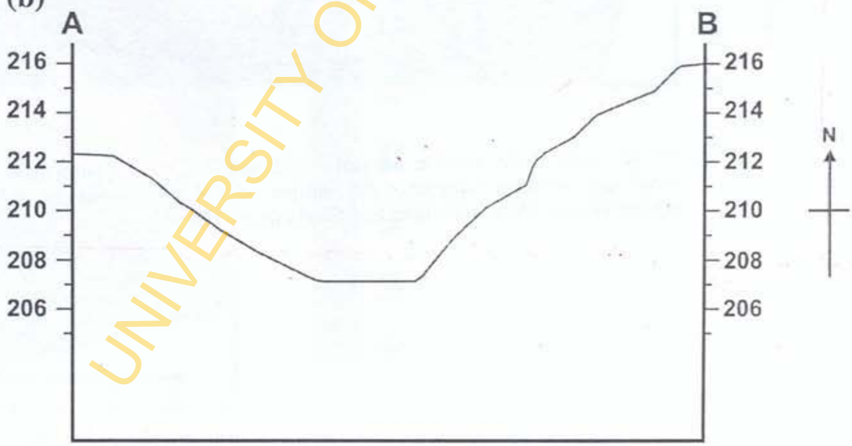


Fig. 81: (a) Location map of the survey area at the Faculty of Agriculture Practical Year Training Programme farm, University of Ibadan (After Olayinka and Oladunjoye, 2005). (b). Surface topography along a N-S line of section in the survey area. Elevations are in metres above sea level.

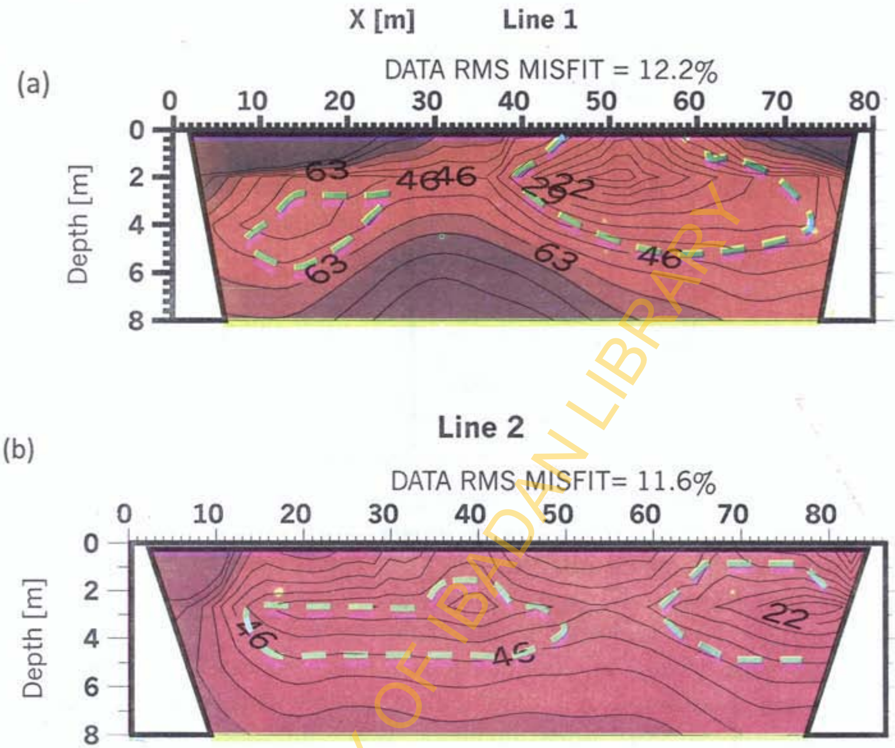
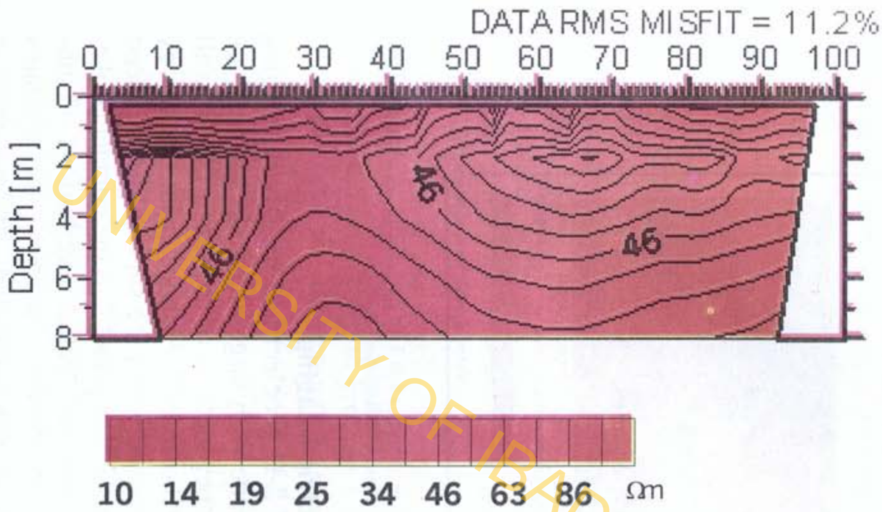


Fig. 82: Inverted model section for lines 1, 2 and 7. The discontinuous curve inside the sections represents the outline of the low resistivity, perched aquifer system (After Olayinka and Oladunjoye, 2005).

(c)

Line 7


DATA RMS MISFIT = 11.2%
0 10 20 30 40 50 60 70 80 90 100
Depth [m]
0 2 4 6 8
46
46
10 14 19 25 34 46 63 86 Ωm

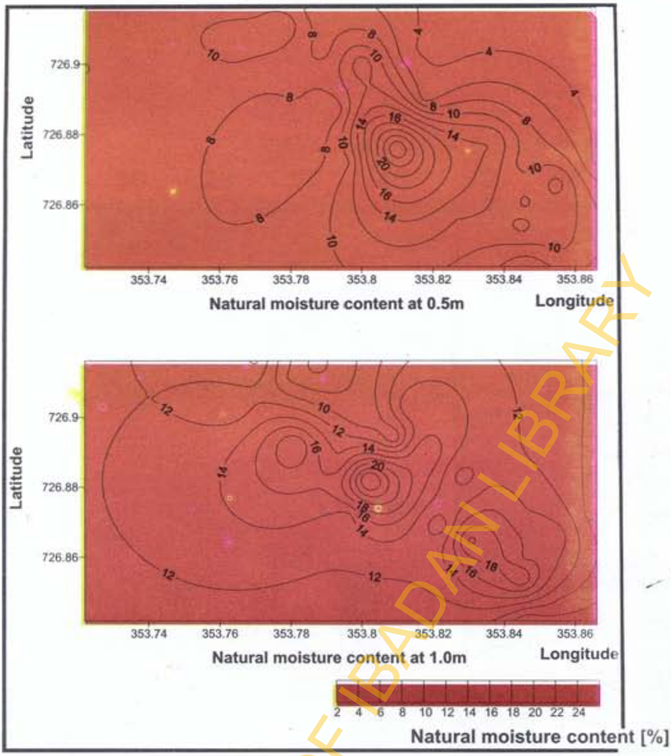


Fig. 83: Soil moisture contents at depths of 0.5 m and 1.0 m as obtained from shallow pits (After Olayinka and Oladunjoye, 2005).

Group XI: 3-D Geoelectric Imaging

The major limitation of 2-D geoelectrical resistivity imaging is that measurements made with large electrode spacings are often affected by the deeper sections of the subsurface as well as structures at a larger horizontal distance from the survey line. This is most pronounced when the survey line is placed near a steep contact with the line parallel to the contact (Loke, 2001). Geological structures and spatial distributions of sub-surface petrophysical properties and/or contaminants commonly encountered in environmental, hydrogeological and engineering investigations are inherently three-dimensional (3-D). Thus, the assumption of the 2-D model of interpretation is commonly violated. Images resulting from 2-D geoelectrical resistivity surveys can contain spurious features due to 3-D effects. This usually leads to misinterpretation and/or misrepresentation of the observed anomalies in terms of magnitude and location; and the 2-D images produced are only along the survey lines and not the entire investigation site. Thus, geometrically complex heterogeneities cannot be adequately characterized with vertical electrical sounding or 2-D electrical resistivity imaging alone. Hence, a 3-D geoelectrical resistivity survey with a 3-D model of interpretation, where the resistivity values are allowed to vary in all the three directions, namely vertical, lateral and perpendicular directions, should in theory give a more accurate and reliable results.

Orthogonal set of 2-D geoelectrical resistivity field data, consisting of six parallel and five perpendicular profiles, were collected in an investigation site at the Teaching and Research Farm, University of Ibadan, using the conventional Wenner array (Aizebokhai *et al.*, 2010). The survey was conducted with the aim of investigating the degree of weathering and fracturing in the weathered profile, and thereby ascertaining the suitability of the site for engineering constructions as well as determining its groundwater potential. Seven Schlumberger soundings were also conducted on the site to provide 1-D layering information and supplement the orthogonal 2-D profiles. The observed 2-D apparent resistivity data were first processed individually and then collated into 3-D data set which was processed using a 3-D inversion code. The 3-D model resistivity images obtained from the inversion are presented as horizontal depth slices (fig. 84). Some distortions observed in the 2-D images from the inversion of the 2-D profiles are not observed in the 2-D images extracted from the 3-D inversion. Moreover, grid orientation effects are removed by the collation of orthogonal set of 2-D profiles.

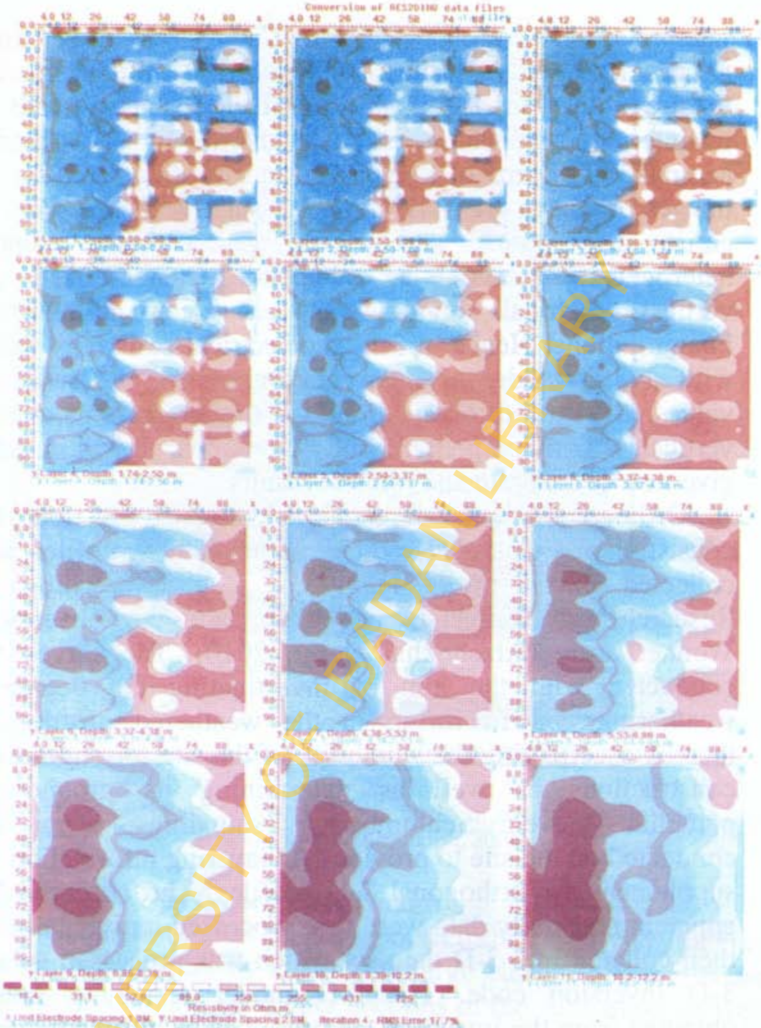


Fig. 84: Horizontal depth slices obtained from the 3D inversion of orthogonal 2D profiles using smoothness constrained least-squares inversion, UI Teaching and Research Farm, Ibadan, Nigeria (After Aizebokhai *et al.*, 2010).

Group XII: Petroleum Geophysics

The research conducted in petroleum geophysics was aimed at providing a better understanding of the subsurface geology of the Tertiary Niger Delta. The studies involved prospect mapping, reservoir delineation and seismic modeling using 3-D seismic data and well log information. The fundamental principles of seismic reflection and refraction is shown in fig. 85 while a stratigraphic succession in the Niger Delta is presented in fig. 86.

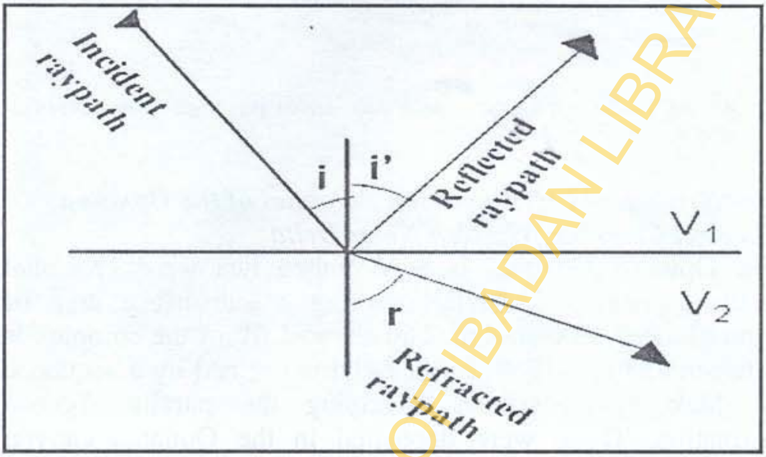


Fig. 85: Illustration of the law of reflection (incident angle I = reflection angle r) and Snell's law (sin i /sin r = V_1/V_2) (From Sheriff, 1989)

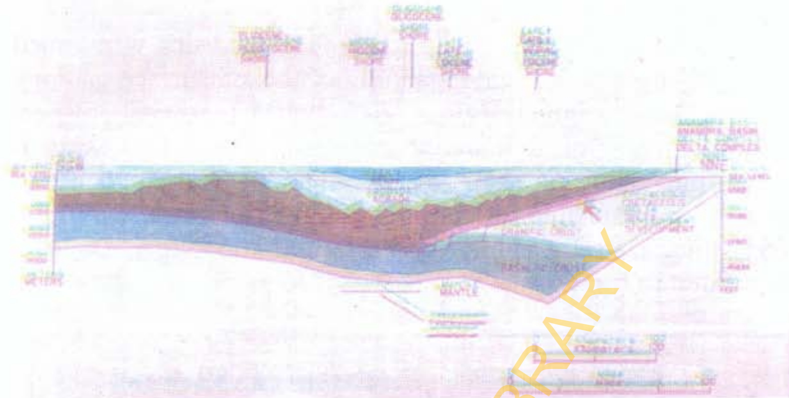


Fig. 86: SSW-NNE geological cross-section across the Niger Delta (Modified after Bustin, 1988).

Stratigraphy and Hydrocarbon Potential of the Opuama Channel Complex, Western Niger Delta

The Opuama Channel is a V-shaped headward erosional feature, trending SW-NE, covering a subsurface area of approximately 100 sq. km. The channel fill of the complex is between 457 and 1758 m thick and is defined by a sequence of thick marine shales overlying the paralic Agbada Formation. These were deposited in the Opuama canyon during the global late Oligocene-early Miocene rise in sea level. Using about 600 km of 3D seismic lines, complemented with biostratigraphic, geochemical and well log information, this study aimed at determining the geometry, stratigraphy and hydrocarbon potentials of Opuama Channel Complex, one of the major palaeochannel systems within the Tertiary Niger Delta Complex (Adejobi and Olayinka, 1997). Based on reflection configuration, termination or continuity of events, shape and amplitude, four seismic facies units were identified in the area. It has been shown that, apart from structural plays, strong possibilities exist for stratigraphic plays, including truncation plays, canyon fill and drape structures. Moreover, it has been established that the hydrocarbon potentials of the Opuama Channel are substantial (figs. 87 to 89).

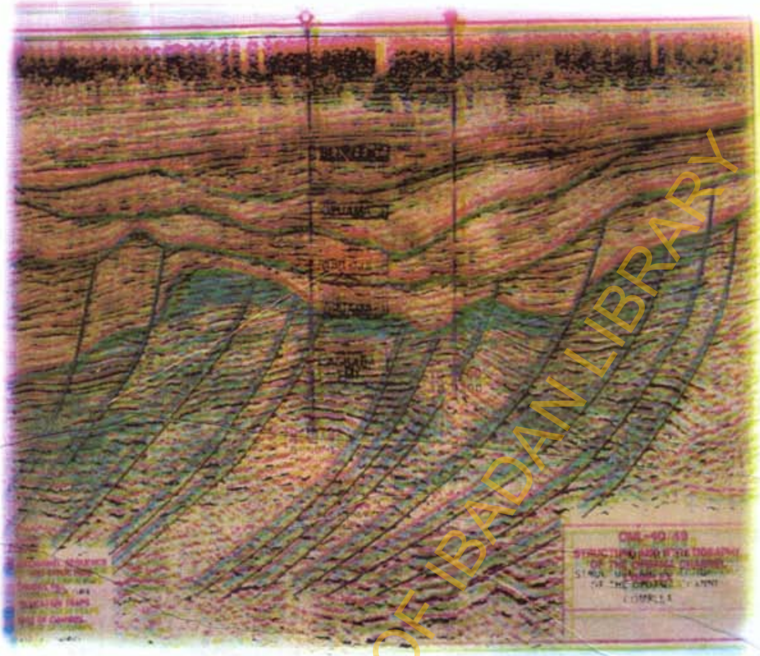


Fig. 87: Structure and stratigraphy of the Opuama Channel Complex, western Niger Delta (After Adejobi and Olayinka, 1997).

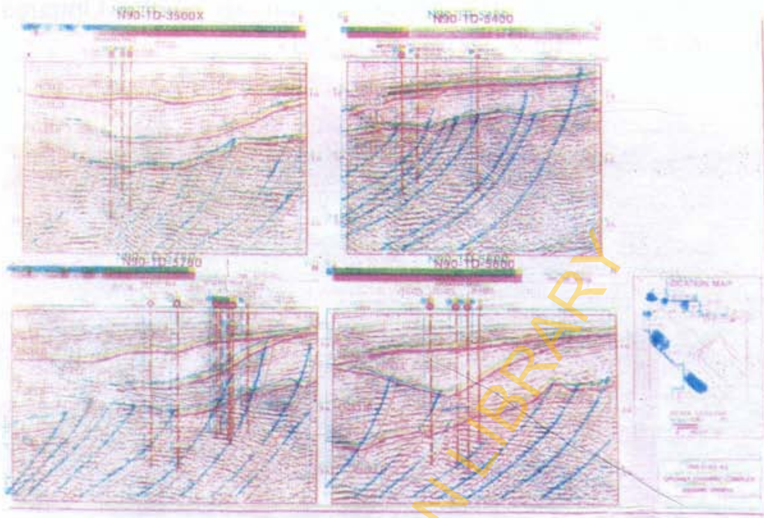


Fig. 88: OMLs 49/40 Opuama Channel Complex (Seismic Panel) (After Adejobi and Olayinka, 1997).

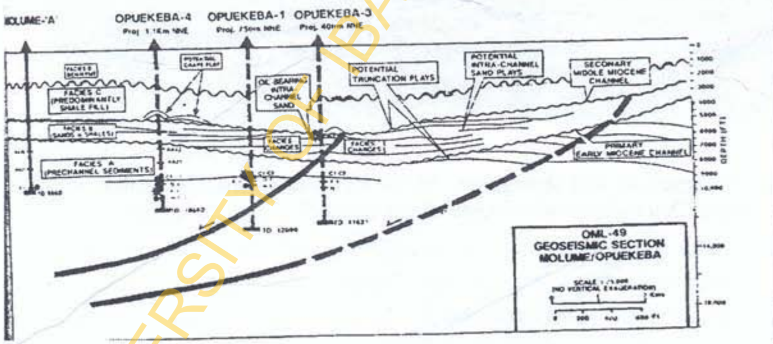


Fig. 89: OML 49 Geoseismic section of Molume/Opuekeba (After Adejobi and Olayinka, 1997).

Use of Kriging for Estimation of 2-D Permeability Distribution in a Hydrocarbon Reservoir

Knowledge of the permeability of reservoir rocks is invaluable for several exploration and production purposes in the petroleum industry. The conventional way for determining this parameter invariably requires the drilling of several wells, which is very expensive. Olayinka and Chapele-Oletu (1998) employed the krigging technique in calculating the 2-D permeability distribution in oil fields in western Niger Delta. Kriging is based on a statistical model of a phenomenon instead of an interpolating function. It uses a model of spatial continuity in the interpolation of unknown values based on values at neighbouring points. The study area is shown in fig. 90.

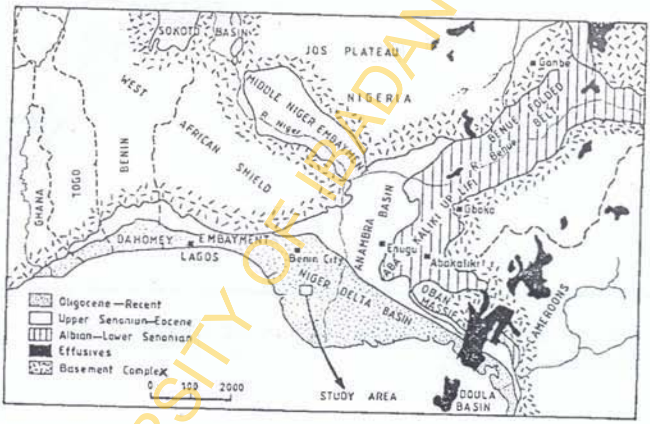


Fig. 90: Location of study area (Adapted from Whiteman, 1982).

The procedure entails obtaining the semi-variance that corresponds to the distance between the wells and the successsive grid points. Three hydrocarbon-bearing horizons, belonging to the paralic Agbada Formation, within the depth intervals of 7450 and 8250 ft sub sea, were considered. The permeabilities, thus determined, were found to be high at greater than 0.2 Darcy; this is in agreement with results from other parts of the Niger Delta (figs. 91 and 92).

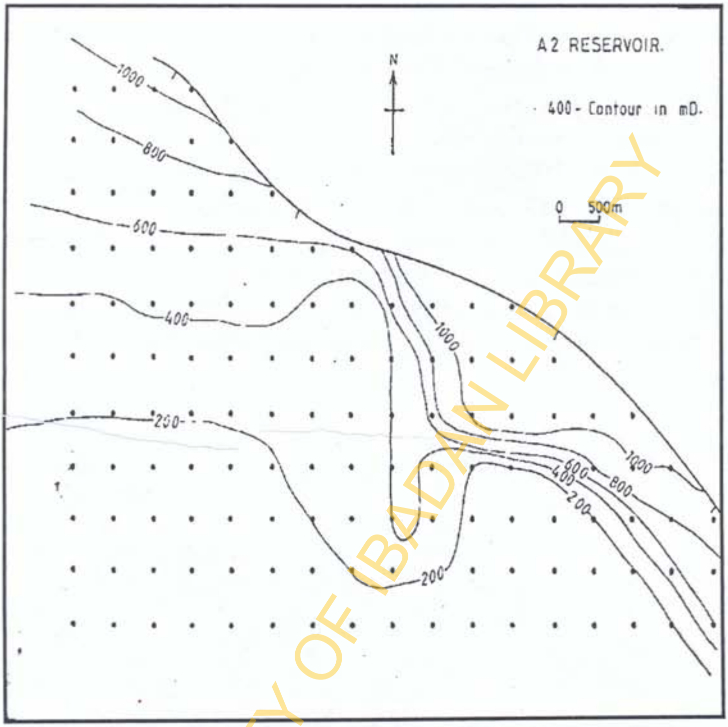


Fig. 91: Permeability distribution for the A2 reservoir (After Olayinka and Chapele-Oletu, 1998).

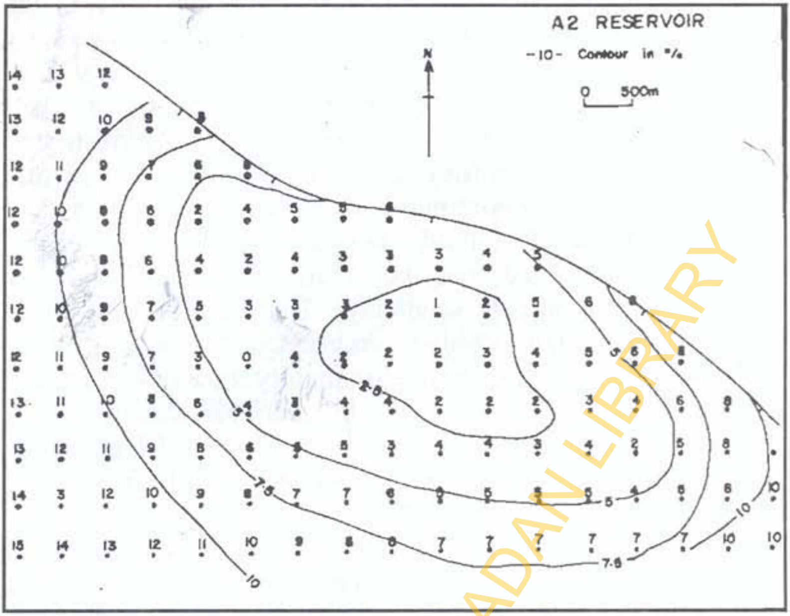


Fig. 92: Percentage error in the determination of permeability shown in fig. 91 (After Olayinka and Chapele-Oletu, 1998).

The results have shown that the kriging technique provides a reliable and cost-effective alternative approach to estimate the 2-D permeability distribution, even when there is a paucity of well data, with the error within the prospective zones being less than 10%.

Seismic Impedance Character of the Weathering Layer in Eastern Niger Delta

Forty-nine uphole and refraction surveys were carried out at three prospect areas in eastern Niger delta in order to obtain information about the weathering thickness, weathering velocity and the impedance character of the weathering layer (Olayinka and Chukwuma, 1998). The data were acquired, using an ABEM Terraloc and a MC-SEIS 1600 m portable 24-channel seismograph system in the form of uphole velocity survey and refraction profile. The recorded slanting times were corrected to vertical time. Using the depth of the geophone, a time-depth curve is plotted and different velocity functions computed (fig. 93). Eleven of the experiments show typical three-layer cases comprising the weathering layer, intermediate layer and the subweathering layers, respectively. Thirty seven of the profiles indicated two-layer cases, while one showed a single continuous layer. The driller's logs and experimental results used to define the near-surface stratigraphy indicated that the weathering layer is mainly mud, sand, or mixed sand/clay. The intermediate layer consists mostly clay, pebbly or coarse sand and gravel, while the subweathering layer is predominantly a sandy formation. The weathering thickness is highly variable, ranging from about 0.5 to about 27.8 m, with an average of 7.1 m. Areas with thin weathering layer are suspected to be stable areas or erosional surface. There is a general increase in the weathering thickness from the river channel to the swamp and towards the upland areas. The velocity and seismic impedance are also variable and show no relationship with the weathering thickness but depends largely on the environment of deposition and the composition of the weathered materials.

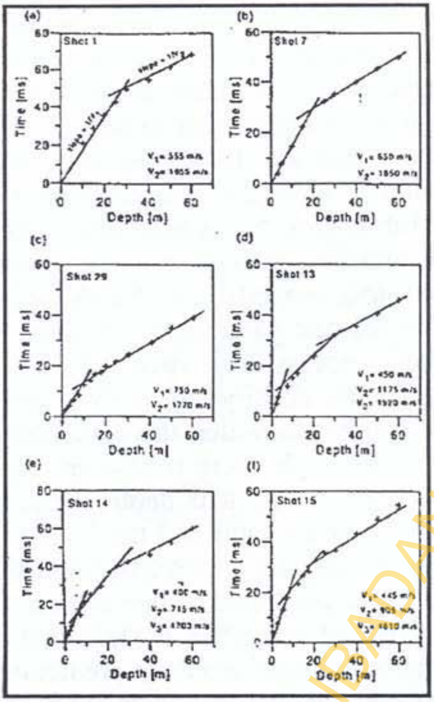


Fig. 93: Examples of time-depth plots from the uphole and refraction survey conducted in eastern Niger Delta (After Olayinka and Chukwuma, 1998).

The average compressional wave velocity and the average seismic impedance of the weathered layer are 751 m s^{-1} and 1244 kg m^{-2} s^{-1}, respectively. The second layer has an average compressional wave velocity of about 1585 m s^{-1} and an average seismic impedance of 3093 kg m^{-2} s^{-1}. The uphole time, weathered layer velocity and thickness, thus derived, are very useful for static correction against time anomalies caused by near-surface variations. The information provided on weathering layer characteristic could form part of a data base for seismic data processing and groundwater exploration, as well as in foundation investigations in the study area.

Generation of Rock Property for Seismic Modelling

While it is often required to choose realistic values of rock properties to use in seismic modeling, petrophysical relationships among rock properties exist in the literature. However, the fact that rocks in a particular region are unique in the manner these properties are distributed suggests the need for the determination of empirical relationships for the common sedimentary lithologies. Olayinka and Akinlabi (1999) examined the interdependence between seismic parameters and rock physical properties in a field offshore western Niger Delta. The seismic parameters, obtained from wireline logs include the compressional wave velocity (V_p), shear wave velocity (V_s), bulk density (ρ), V_p/V_s ratio and Poisson's ratio (σ). The results show that the compressional wave velocity increases with depth; there is also an increase in the density and shear wave velocity with depth, while there is a decrease in both the Poisson's ratio and the V_p/V_s ratio. The differences between the measured and predicted densities are less than 3%. Similarly, the predicted compressional wave velocities differ from measured velocities by less than 5%. These imply the reliability of the local trends in predicting the rock properties. The trends of the bivariate plots were compared with published trends, and they show that the local data follow similar trends but have different variabilities (figs. 94 to 99).

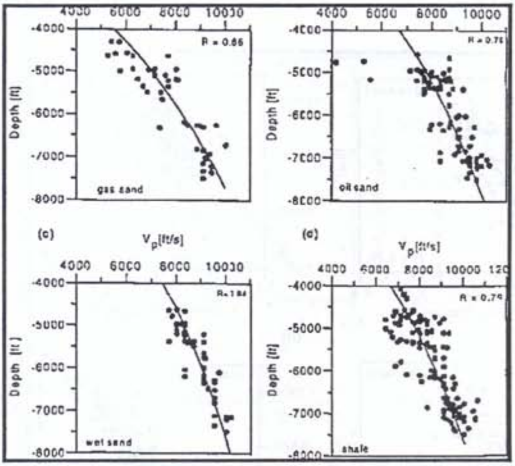


Fig. 94: Compressional wave velocity-Depth cross plot for the study area, offshore western Niger Delta (After Olayinka and Akinlabi, 1999).

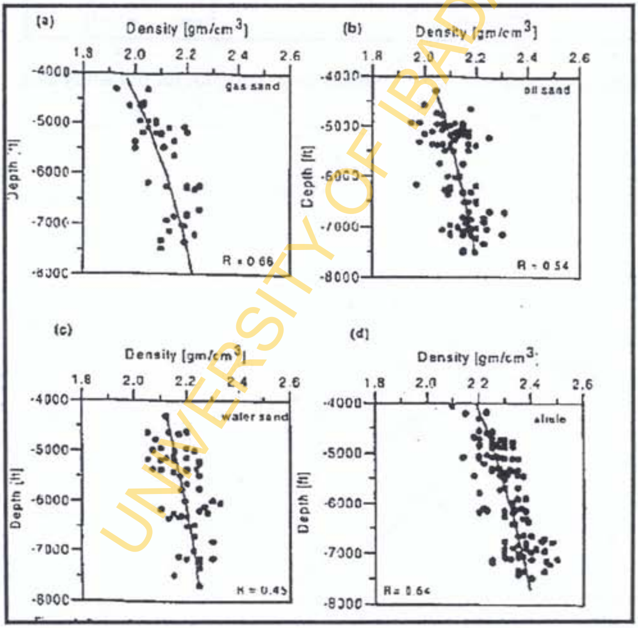


Fig. 95: Density-Depth crossplot for the study area (Olayinka and Akinlabi, 1999).

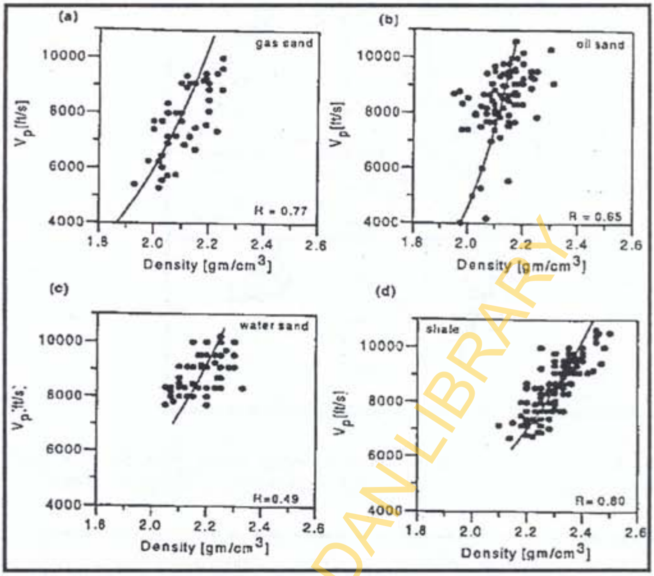


Fig. 96: Density-Compressional wave velocity crossplot for the study area.

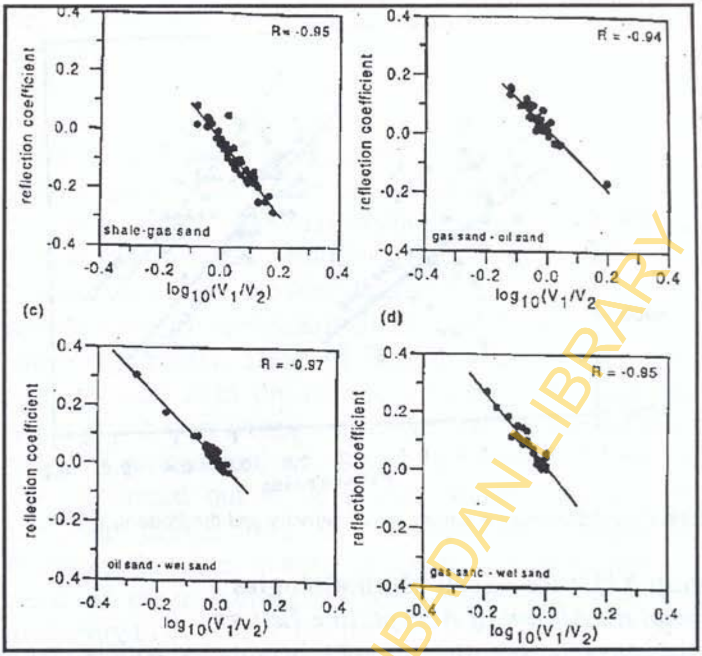


Fig. 97: Correlation between the reflection coefficient at interfaces and the respective compressional wave velocities.

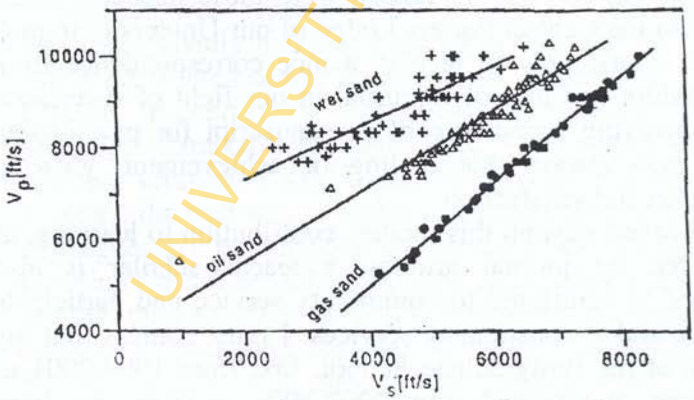


Fig. 98: Correlation of the compressional wave and shear wave velocities

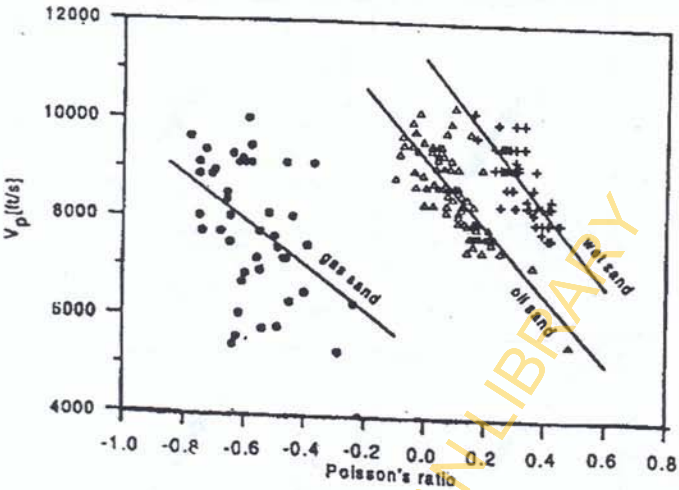


Fig. 99: Correlation between the P-wave velocity and the Poisson's ratio.

Group XIII: Research Methodologies

Beyond an Album of Acceptance Letters

In the days before the internet became a widely available mode of communication, surface mails were in vogue in the University of Ibadan, and, in fact, in most parts of the world. As budding scholars, some of the happiest moments that we enjoyed so much here at Ibadan were those instances when we got to the Central Porters Lodge of our University to pick up our letters, only to receive a nice correspondence from some Editor-in-Chief of a journal in our field of specialization conveying acceptance of a manuscript for publication. There was always that feeling of achievement, growing reputation and satisfaction.

However, beyond this modest contribution to learning, as evidenced by journal articles, a teacher-scholar is also expected to contribute to community service and participate in value-added consultancy services. I must confess that my sojourn at the Postgraduate School, first from 1999-2001 as Sub-Dean, and second from 2002-2006 as Dean, has been most fulfilling and rewarding in this regard. As an academic who by providence has found himself in administration, I have, along with other scholars, made some modest contributions especially in aspects of research methodology. The original intention was to further expose our colleagues to recent developments in grantsmanship, by learning from the experience and expertise of leaders in such matters. Among others, I spoke with three highly respected members of our University community who supported the idea. These were Professor Olufemi A. Bamiro (now the Vice-Chancellor), Professor Adedoyin Soyibo (currently, Director, Centre for Enterpreneurship and Innovation) and Professor Oladimeji Oladepo (currently, Dean of Public Health). The workshop was eventually held on 16 and 17 July, 2003 and the first publication in this category was the one on the planning and writing of grant-winning research proposals (Bamiro *et. al.* 2003). It turned out to be a well-attended event, with the participants drawn from all the Faculties/Institutes/Centres, requesting that we mount follow-up programmes for the benefit of other colleagues who might not have had the opportunity to be part of the programme.

During my first year as Dean, we had much difficulty at the Executive Committee of the Postgraduate School in considering the draft of abstracts of theses and dissertations. For many of our research students, the fear of the Executive Committee was literarily the beginning of wisdom! I still remember vividly that one evening in October 2003, when I was away to the Federal University of Technology, Akure, as External Examiner, I had cause to ruminate over this seemingly intractable problem. Then, I had a brain wave on a possible solution. I said to myself that as a community of scholars, the best way to tackle any knotty issue was to invite colleagues to a roundtable and brainstorm. On my return from the Akure trip, I broached the idea of organizing a workshop on the theme '*What is a PhD thesis?*' to some of our colleagues, including the then Dean of the Faculty of the Social Sciences, and currently the Deputy Vice-Chancellor (Academic), Professor A.A.B Agbaje. All of them felt it was a good idea and promised to contribute in one way or the other to its actualization. I was naturally very excited by this and the workshop was eventually held in February 2004. From this emanated our publication on 'Guidelines to Writing a Doctoral Thesis' (Olayinka *et. al.* 2004).

At one of the plenary sessions of that workshop, a Session Chair and then Deputy Vice-Chancellor (Administration), Professor Olusoji Ofi, while commending the organisers of the interactive session, did say that there was still something missing in what we had done, hitherto, in so far as writing a research thesis is just one of the major outcomes of research. In his well-considered view, it would be worth the while if we could look at the entire research process itself. About that same time, I came across an advert in The *Guardian* on a Workshop on Research Methodology by the National Postgraduate Medical College. It then became obvious that we should plan toward a major, more encompassing Workshop. It took us a lot of planning and we eventually held the Workshop from 1 to 5 November, 2004. The materials were subsequently published as a book on 'Methodology of Basic and Applied Research' with some 34 contributors drawn from all our various Faculties and the College of Medicine (Olayinka *et al.*, 2006).

One major outcome of these Workshops, which gladdens my heart till today, was our ability to evolve a uniquely home-grown *University of Ibadan Manual of Style* (UIMS). The ultimate objective of the guide is to achieve consistency in the presentation style of academic writing. As a composite simplification of some standard style sheets, this unified style of referencing is highly recommended for all postgraduate students within the University of Ibadan Postgraduate system, and their colleagues in sister universities. The credit for the design and development of the UIMS is due to three of my colleagues, Dr. Aderemi Raji-Oyelade, Professor Temitope Alonge and Dr. E. Oluwabunmi Olapade-Olaopa (Raji-Oyelade *et al.*, 2006).

Our professional cum learned society, the Nigerian Association of Petroleum Explorationists (NAPE) observed that not many Nigerian geoscience scholars were winning competitive research grants from international bodies. Based on our modest accomplishment at the University of Ibadan, I was commissioned to write a book to attempt to solve this problem. Eventually, we came up with '*A Guide to Preparing Research Proposals in the Geosciences*' (Olayinka, 2005) which was published by Mosuro and funded by NAPE under her NAPE-University Assistance Programme. It is gratifying to note that since the publication came out and was widely disseminated by the association, a positive improvement in grant-winning ability of geosciences scholars has been reported (Kunle Adesida, 2009, personal communication).

I have been teaching aspects of the course 'GEY 701: Methodology of Geological Research' to our MSc students in the Department of Geology for about 20 years now. It is gratifying to note that the experience one has acquired in Research Methodology, courtesy of our Postgraduate School, has been most beneficial in enriching the course.

Since completing my tenure at the Postgraduate School, I have received invitation from many sister institutions in Nigeria, Ghana, Senegal, South Africa and the United Kingdom to share my thoughts on aspects of grantsmanship and University research management (Olayinka, 2006; Olayinka, 2007; Olayinka, 2008). Along with the work of several others, Ibadan is now rightly acknowledged as a leader in this emerging profession.

Given the recognition that research management can contribute to better governance of research, increased impact and help to attract the much-desired external funds from abroad, there is need to develop internationally recognized professional skills base in the field. This can be provided through continuous professional development. However, these skills are usually not acquired through the regular University curricular. There is currently a dearth of training on practical issues. Ibadan is expected to provide leadership in this direction, and the fact that we host the secretariat of the West African Research and Innovation Management Association (WARIMA) is an advantage in this direction.

Fieldwork is recognized as a basic tool in the training of students of Geology. Esso Exploration and Production Nigeria Limited organized a training-of-trainers workshop for lecturers of Geology from various Nigerian universities in Benin City in February 2007. The book of proceedings, co-edited by Dr. Daniel O. Lambert-Aikhionbare, FNMGS, FNAPE, and my humble self, have since been published. I also contributed a chapter on best practices in the planning and execution of geological field mapping (Olayinka, 2009).

Discussions and Conclusions

Sustainable development is on the front burner of Nigeria's agenda like in most developing countries where serious challenges, in terms of health, resource and environmental sustainability, poverty alleviation, and related quality of life issues, are faced by citizens. The research challenges facing researchers in these regions are therefore extremely complex. They, in most cases, need an interdisciplinary or partnership approach, and should be researched at a local level to ensure relevant outcomes. The research outputs need to be translated effectively for social benefit. The positive side to this is that we researchers are also perfectly positioned amongst a unique convergence of issues to be researched, and with improved access to support structures and resources, we can be world leaders in our fields, making a real impact on development through our research outputs.

Water quality management is an issue that must be given top priority. One of the measures that can be taken for the protection of groundwater includes waterproofing the base of any leachate stream and the stream bed to prevent infiltration of the effluent. Secondly, there should be continuous monitoring using geoelectrical imaging to provide early warnings as to the presence of potential pollution. Thirdly, the effluents should be treated to meet the standards established by the National Environmental Standards and

Regulations Enforcement Agency (NESREA), the Oyo State Environmental Protection Agency. Fourthly, there should be launching of public awareness campaigns and convincing the relevant authorities at the local, state and federal levels as to the need to undertake groundwater protection measures.

Some 47 years ago, our foundation Head of Department had concluded his inaugural lecture in the following manner:

> I think these few words may have served to indicate the bright future for geology as a profession in Nigeria. I hope that they also may have indicated that the graduate from a Nigerian university is far better trained for the task before him than colleagues, Nigerian and expatriate, with degrees from overseas. He has not only a special knowledge of the geology of his country, but he is also adapted to operating in an environment in which he was born and has learnt to understand (Reyment, 1963).

Perhaps, not much has changed since then. We currently have a crop of very bright students, and it is gratifying to note that the learning and teaching environment in our university is improving. I am happy to report that the quality of our intakes has improved considerably in the last three sessions. A major reason for this obviously is the post-UME screening which the university introduced about four years ago; thanks to a major policy shift of the Federal Ministry of education, then led by Mrs. Chinwe Obaji as the Honourable Minister. For the first time in recent memory, all the 38 students that registered for the 100 level in Geology during the 2008/2009 session passed and were eligible to proceed to the 200 level in the current session. I was extremely delighted when as the Acting Dean of Science I had cause to present their results to Senate at the meeting of Monday, 4 January, 2010 (See Senate Paper No 5377). It was also helpful that our class size is moderate and conforms with the prescription of the Council of the Nigerian Mining Engineers and Geoscientists (COMEG). Although one realizes that there is a lot of pressure on universities to expand access, we should not do this at the expense of quality. In simple words, Ibadan should resist pressure to admit students beyond our carrying capacity. I learnt reliably that one of the criteria employed by Esso Exploration and Production Nigeria Ltd (EEPNL) in selecting our department as one of the beneficiaries of the EEPNL-Universities Partnering Programme was our small class size. This has remained one of our major benefactions in recent years. Falase (2010) has discussed extensively on this in his valedictory lecture presented at this same venue exactly three weeks ago.

Ibadan took a strategic decision a few years ago to reduce undergraduate intakes while at the same time expand the postgraduate intake. Ultimately a 60:40 postgraduate: undergraduate student mix is envisaged. This, in our humble view, should be adhered to in spite of the pressure to increase undergraduate admission.

By the special grace of God, I earned my first degree in Geology from this university some 29 years ago, and I have also been on the academic staff for some 22 years now. I make bold to say that the curriculum that we run today in our Department is not in any way inferior to the one I passed through as an undergraduate. I am aware that our curriculum is well above the Minimum Academic Standard prescribed by the National Universities Commission (NUC). It is also comparable to what obtains in reputable and famous sister departments elsewhere. This is the truth of the matter! Our current academic staff strength of 19 is respectable enough. We also have 10 members of the technical and administrative staff who provide necessary support. For this, I thank the current and the immediate past administrations of the University for allowing us to recruit many young and promising academics to strengthen the department. I am aware that some of these colleagues were head-hunted from sister Universities on account of their special talents and great potentials. However, like Oliver Twist, we ask for more, especially as there are many areas of specialization that one would ordinarily expect in any modern Department of Geology. These include Field/Regional Geology, Igneous and Metamorphic Petrology, Sedimentology, Petroleum Geology, Structural Geology, Geochemistry, Economic/Mining Geology, Biostratigraphy, Geophysics, Photogeology, Remote Sensing, Engineering Geology, Hydrogeology, and Environmental Geology, among others.

As at the time of my appointment as a Lecturer Grade II in April 1988, there was no lecturer of Applied Geophysics in the Department due to staff retirements. My self-imposed mandate was to immediately take up teaching and research in this area and deepen it to become a viable area of specialization. I started teaching the only undergraduate and five postgraduate courses in this applied/exploration geophysics. By November 1990, I had successfully completed the supervision of three MSc candidates. Till date, I have supervised a total of 76 MSc and 3 PhD candidates in Applied Geophysics, Hydrogeology and Petroleum Geology. Four other PhD candidates will soon start the registration formalities for their theses. The candidates have been mentored to present their research findings at local and international conferences, and some of them have won awards in the process. Many of them are now gainfully employed in various universities, oil exploration/production/service companies, the Nigerian Geological Survey Agency (NGSA), mining companies, and the like. Along with other colleagues, we have built up the Applied Geophysics Group in the Department. I salute the industry, hardwork and perseverance of my three younger lecturers-colleagues in the group. Our MSc programme in Applied Geophysics is highly regarded and heavily subscribed. It has, perhaps, one of the most stringent entry requirements in the University of Ibadan Postgraduate School system: in the last 10 years or so, the minimum admission requirement has been a Second Class (Upper Division) BSc in Geology or Applied Geophysics, in addition to satisfying all other conditions stipulated by the School. We will continue to strive to maintain this standard.

During the last quarter of 2007, our Department had cause to prepare for NUC Accreditation as we earned an 'Interim Accreditation' with a disappointing Programme Score of 61% during the previous 2005 Accreditation exercise. I realized that one of the criteria is 'Employer's Rating' to which a maximum score of 3 points has been allotted by the NUC. I was determined to secure the maximum point from this, given what I knew of our pedigree. Among the people I contacted was the Head of Department of Geology, Baylor University, Waco, TX, USA, under whom one of our former students, Sikiru Amidu, BSc (First Class) 2000, MSc 2005 (Ibadan), was then a research scientist and PhD student. He had replied, in an e-mail which he sent directly to the Vice-Chancellor of the University of Ibadan, that:

> Sikiru is well-suited and exceptionally well-prepared to conduct research projects, given his previous geological and geophysical training acquired in his native Nigeria. He is very hard-working. He has given many public presentations on his research at regional and national meetings. We are proud to have him as a member of our Geology Department and Geophysics Program at Baylor University.

He has since completed his PhD. Similarly, Wasiu Olayinka Popoola, BSc (First Class) 2007, has just finished his MSc in Petroleum Geosciences, with distinction, at Imperial College. Both ex-students of ours, whom we are exceedingly proud of, are now employed with an international oil exploration/ production company based in Lagos. There are many other success stories of our former students who are doing well in various areas of human endeavour, both at home and abroad. This is a confirmation of the saying that '*if it is from Ibadan, it must be good quality*'. It may be noted in passing that we scored the maximum 3 points under 'Employer's Rating', and we were granted Full Accreditation by the NUC as part of the 2007 exercise, with a more respectable Programme Score of 89%. I must confess that I felt deeply relieved when the outcome was announced.

We have been involved in fund generation from alumni, alumnae, corporate institutions and friends of the Department of Geology. The money mobilized during such campaigns has been used to upgrade our teaching and learning facilities and the environment which is now more user-friendly. We believe that benefactions can play a vital role in supporting the training of successive generations of students. Many of our alumni and alumnae were requested to join the history of philantrophic support and help us continue to transform the lives of our students. Through this focused charitable programme of fund raising, many have joined our community of graduates who are proud to know they are supporting one of the finest teaching, research and life opportunities in the geosciences in the world.

The Association of Ibadan University Geologists, better known as *Ibadan Geologists*, comprising alumni/alumnae of the Department provided a state-of-the-art Petrological Microscope Laboratory in the Department in March 2007. The endowment comprises two trinocular research microscopes and 21 binocular microscopes, with camera attachments, valued at Ten Million and Five Hundred Thousand Naira (₦10, 500,000.00). We are improving the teaching, learning and research environment. The entire departmental complex was re-painted and refurbished in March 2008 at a cost of Two Million, One Hundred Thousand naira (₦2,100,000.00) which was raised from donations.

We attracted the Esso Exploration and Production Ltd to fund a Field Mapping Project, in conjunction with the Nigerian Geological Survey Agency. Through this initiative, a brand-new 18-seater Toyota Hiace Field Vehicle, valued at Four Million, Five Hundred Thousand naira (₦4,500,000.00), was donated to the Department in February 2008. A thin-section machine was provided to the Department, and our senior Technologist was sponsored by Esso to undertake a week training course in Scotland in June 2008. The Department is benefiting to the tune of Seventy Five Million Naira (₦75,000,000.00) over the three-year duration of this project.

We have been very lucky with the Endowment of Prizes. At the last count, there are 13 such prizes and awards that have been endowed in perpetuity to the benefit of our deserving students. We created the *Department of Geology Occasional Publications Series* in March 2007, with three academic titles already published. The Mosobalaje Oyawoye Library, named after the foremost African Geologist and first African Head of our Department, Professor M. O. Oyawoye, DSc (Ibadan) (Honori causa) has received a major facelift, in terms of computer hardware and software, recent journal collections and current books.

However, the challenges of geoscience education in Nigeria include the low level of funding, poor quality of students admitted into the universities on account of the declining quality of education at the primary and secondary school levels, poor quality and inadequate staff (both teaching and non-teaching), decaying and ageing facilities, limited access to ICT infrastructure and equipment, incessant power outage, limited exposure to fieldwork, poor orientation of students, indiscipline among staff and students, as well as cultism. Specific areas of collaboration between Nigerian Universities and the Oil and Gas Industry include fieldwork support, Students' Industrial Work Experience Scheme (SIWES), scholarship and bursary awards, staff exchange programme, consultancy, provision of infrastructure/equipment and instructional materials, endowment of professorial chairs, donation of field vehicles and sponsorship to academic and professional fora, ICT facilities, geoscientific database, development of appropriate curriculum in consultation with the NUC, COMEG and other stakeholders to serve as standard.

Establishment and operation of Geoscience departments are capital intensive. However, the impact of the oil and gas industry, especially through the intervention of NAPE-University Assistance Programme, on geoscience education, has been salutary and positive. There are now individual and corporate sponsors, including oil companies and the Petroleum Technology Development Fund (PTDF), giving scholarship, equipment, field vehicles, and professorial chairs.

The NGSA, under the indefatigable leadership of its Director-General, Professor Siyan Malomo, FNMGS, FAS, has been extremely pro-active in fostering a much desired collaboration and bridging the artificial bridge between the NGSA and the respective Departments of Geosciences in our Universities. Many senior academics now have the opportunity to spend their sabbatical/study leave at the NGSA, while countless NGSA geoscientists are also encouraged to register for higher degrees in our universities. This is most commendable, and there is no doubt in my mind that it is a win-win situation for all the parties involved.

Although there is need to create more opportunities for young people who desire university education, in widening the access, efforts must be made to ensure a high standard of training. Proprietors of Universities (Federal and State Governments and Private institutions) should increase their level of funding for Geoscience programmes. The Federal Government should increase the level of funding to her universities in order to complement funding from other sources.

There is an urgent need to improve the working conditions in the universities in order to attract and retain bright scholars. There should be mentoring of emerging scholars by the more established academics. Alumni and alumnae of each University should participate actively in improving the teaching and research environment of their *alma mater*.

Staff (teaching and non-teaching) in higher institutions should put in their best to ensure a very high quality of graduates who are employable and/or can be self-employed, while academic staff should strive to devote adequate time to research which would subsequently improve effectiveness in their other core mandates of teaching and value-added consultancy and services. Best practices in pedagogy, including methods developed for use in large, introductory-level courses, need to be identified, communicated and broadly implemented.

Geoscience curricular at all levels need to embrace the Earth System science approach. Geoscience curricular must be aligned with national priorities to increase impact and perceived importance of the Geosciences. Workforce skills need to be emphasized, including quantitative expertise, the ability to communicate complex information in writing and orally and the ability to work on interdisciplinary teams. Public-Private Partnerships should be strengthened in order to have more collaboration between the Universities and the Oil and Gas Companies. The establishment of Centers of Excellence and Centralised Research Laboratories in selected universities would attract better funding and consultancies from the private sector. The improvement of the basic research capabilities of universities would also enhance the Nigerian Content Development (NCD) drive of the government for the oil and gas industry. Students and faculties are enjoined to promptly apply for research grants. Information about workforce needs and career prospects should be provided to recruit qualified candidates into Geosciences disciplines and motivate students to excel.

There is a need to re-examine the limited access to ICT infrastructure and equipment as this has created problem for the academics and students of the geosciences to tap from global network of ideas and knowledge.

Library facilities should be updated. Students and staff must be able to use internet facilities to access resource materials, which may not be available locally. The focus should be the production of world-class graduates and not local champions. Each department of geology should have a functioning library. The classrooms must be fully integrated with cyber-infrastructures for effective teaching and learning. Sponsoring of Train- the- Trainers workshops, seminars and courses by companies' staff should be extended to University teaching and technical staff.

The carrying capacity of each academic department should not be exceeded in order to maintain an optimum staff/ student ratio, and the regulations on admissions and staff/student ratios stipulated by the NUC and professional bodies, like the Council of Nigerian Mining Engineers and Geoscientists (COMEG), should be strictly enforced. The post-UME screening of prospective students should be continued and fine-tuned to enhance quality intakes into the universities. Heads of Geosciences Departments should have effective input to the admission list of prospective students as is the case at the University of Ibadan. Inter-university exchange programmes with foreign universities should be encouraged.

There is no doubt that this University acknowledges the importance and contribution of Professorial Inaugural Lectures (PIL) as a pinnacle in the production of knowledge in the everyday business of the University as one among many universities of world-wide reputation in research, teaching and research-based/value-added consultancy activities. Falase (2005) identified two critical roles PIL play in the life of a university. First, the lectures are expected to highlight some of the research findings that may be of great value to the academic world, budding entrepreneurs, industrialists and government. Second, the lectures can showcase to the outside world (that is the town) the academic attainments of individual lecturers and the entire university (that is the gown).

I wish to add other incidental roles. Our PIL contribute towards maintaining an active academic environment. They serve as proof or demonstration of the academic's leadership quality. Moreover, they serve as a source of inspiration and motivation for our undergraduate and postgraduate students, as well as emerging scholars, including faculty members in this and other sister universities, thus providing a veritable vehicle for mentoring. Nonetheless, one has observed that there is still a lacuna with the structure of our PIL, as there is neither a policy document nor a guideline moderating the preparation and presentation of the lecture. It, therefore, becomes apparent that we need to strengthen the process of organizing our inaugural lectures. To rectify this, I humbly propose that our University should establish a "*Senate Committee on Professorial Inaugural Lectures*".

If I have in any way met some of the aforementioned functions of PIL, the efforts of this wonderful audience to attend the lecture would not have been in vain, and the confidence reposed in me by all those who have encouraged me in this enterprise would not have been misplaced.

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I like to thank my creator, the Almighty God, through Jesus Christ, my Lord and Saviour, who has made today's lecture and our modest contributions possible. He has been especially kind and generous to an unworthy son like my humble self. To Him alone be all the honour, glory and adoration.

I acknowledge, with gratitude, my parents, Mr Gabriel Olayinka Ojimi and Mrs Florence Mopelola Olayinka, both of blessed memory, for my strict Christian upbringing, especially during the formative years in what is referred to, in geological parlance, as the *Ilesha Schist Belt*. They taught me the virtues of honesty, hardwork and the fear of God. These have stood me in good stead, both in times of peace and turmoil. I remain ever grateful to 'Baami' and 'Yeemi', respectively. I want to make one special note of thanks to my

mum. I am here today largely because of her aspirations and sacrifices for my siblings and me. Although I may not have been able to meet with her high expectations from me, I have tried to approximate them. My siblings, Mrs Alice Foluke Ajidahun, Niyi Olayinka, Niran Olayinka, Kehinde Olayinka and their spouses, have been very wonderful in their support all these years. They have always intervened at critical periods in my career, and I remain ever so grateful for the exceptional love, care and understanding.

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I thank my role models who mentored me when I was a young boy growing up in the 1960s and 1970s. These were people one looked up to, and they have never disappointed. In this regard, special mention must be made of Mrs Bola and Mr Adejumoke Oni, Mrs C. Nihinlola and Prof Olakanmi Abimbola, and Mrs Bola (of blessed memory) and Mr Segun Agboola.

I thank my teachers at the University of Ibadan during my undergraduate days. I recall, with nostalgia, Mr Dugdale who taught us Mechanics as part of our Preliminary Year Physics. He, in particular, impressed me with his punctuality in class, an attribute I so much appreciated then and have also tried to emulate and implement in my own little ways since I became a member of the Faculty some 22 years ago. Dr S.C. Garde taught me 'Classical Physics I' during the 1978/79 session and I enjoyed his classes which rekindled my interest in later years to specialize in Geophysics.

I am grateful to Dr Anna Thomas-Betts, my MSc Course Coordinator at Imperial College, who taught me Mathematics for Geophysicists and Exploration Geophysics, and believed much in my ability and potential. She did much to encourage me to register for a PhD soon after the Master programme,

and in later years, she gave me a strong recommendation for the Humboldt Fellowship.

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I acknowledge, with gratitude, the sponsorship received from the Committee of Vice-Chancellors and Principals of United Kingdom Universities, the German Academic Exchange Services (DAAD), the Alexander von Humboldt Foundation and the Association of Commonwealth Universities.

I thank my good friend, Dr Babajide Bamkole, for his comradeship during the good days we spent together in the West Midlands, when both of us were research students.

Many individuals have made my stay at the University of Ibadan as a faculty member very interesting. They include my former teachers and my senior colleagues and bosses in the Department of Geology- Prof. T.A. Badejoko, Prof M.A. Olade (both of whom have since retired) and Prof A. A. Elueze. I publicly acknowledge the contribution of Prof T.A. Badejoko for believing in me and insisting on putting me up for Professorship in 1999, against my personal wish and ambition to apply for the grade of Reader and then possibly attempt the full professorship after at least three years. In his opinion, my publications in learned journals were far in excess of the minimum required for a full professorship. Thank God that the Faculty, and the University Appointments and Promotions Committees as well as all the Internal and

External Assessors agreed with his sound judgment. I was subsequently promoted to the grade of Professor with effect from 1 October 1999. I remain eternally grateful, Sir.

My colleagues in the Department who have contributed towards the creation of an enabling environment for me to thrive include Dr A.F. Abimbola, Dr G.O Adeyemi, Dr I.M. Akaegbobi, Dr Moshood Tijani, Dr A. T. Bolarinwa, Dr Mathew Nton, Dr Gbenga Okunlola, Dr Gbenga Ehinola, Dr Gbenga Boboye, Dr Bunmi Adeigbe, Dr A. S. Olatunji, Mr Mutiu Adeleye, Mr Ibrahim Oyediran and Mr Ayo Jayeoba. I am also grateful to all the members of the non-teaching staff for their support.

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In closing, I give all the honour and adoration to my good God, the eternal rock of ages, my creator, who made me in His own image. He remains the greatest imager of all times. Without His protection, today's celebration would probably have remained all but a figment of my imagination.

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