BENEATH THE WAVES: RESOLVING AMBIGUITIES IN THE PETROLOGIC SUPERMARKET

By

PROFESSOR VICTOR MAKINDE
Professor of Applied Geophysics

Department of Physics
College of Physical Sciences
Federal University of Agriculture, Abeokuta

FUNAAB INAUGURAL LECTURE
Series No. 95

Wednesday, 20th November, 2024

FUNAAB INAUGURAL LECTURE

FUNAAB INAUGURAL LECTURE

Series No. 95

by

Professor of Applied Geophysics
(Professor of Applied Geophysics)

This 95th Inaugural Lecture was delivered under the Chairmanship

of

The Vice-Chancellor

Professor Olusola Babatunde Kehinde, FGSN, FIHS
B.Sc. M.Sc., Ph.D. (Ibadan)

Published Wednesday, 20th November, 2024

ISBN 978–978–768–899–4

FUNAAB INAUGURAL LECTURE SERIES

Professor Victor Makinde
(Professor of Applied Geophysics)
Department of Physics
College of Physical Sciences
Federal University of Agriculture, Abeokuta

BENEATH THE WAVES: RESOLVING AMBIGUITIES IN THE PETROLOGIC SUPERMARKET

PROTOCOLS

The Vice Chancellor,

Deputy Vice Chancellor, Academic,

Deputy Vice Chancellor, Development,

Registrar,

Bursar,

Librarian,

Dean, College of Physical Sciences,

Deans of other Colleges and Postgraduate School,

Directors of Centres and Institutes,

Head, Department of Physics,

Heads of other Departments,

Members of the University Senate,

Members of the Academia within FUNAAB and from other Institutions,

Non-Teaching Staff of FUNAAB,

Family Members and Friends,

Special Guests and friends of the University,

My Lords Spiritual and Temporal,

Gentlemen of the Press,

Distinguished Ladies and Gentlemen,

Great FUNAABITES.

PREAMBLE

In the name of my most trusted friend, my God, my Creator, Creator of the universe, and the God of abundance who gave me the opportunity to visit this land of sunshine, the land of light. I welcome all.

It is with great delight therefore that I welcome everyone to this 95th Inaugural Lecture Titled "Beneath the Waves: Resolving Ambiguities in the Petrologic Supermarket"; in which we will be undertaking an excursion, making remote insight into the Earth using quantitative geophysical methods.

This lecture is 3rd from the Department of Physics, 8th from the College of Physical Sciences and the 95th in the university. Physics thrives on the strength of imagination, mathematics and computation. These will not be lacking today.

This lecture is divided into six sections namely: Introduction, Contribution to Knowledge, Immediate gains from Geophysics, Recommendations, Conclusion and Acknowledgement.

Mr. Vice Chancellor, Sir, kindly permit me to give a brief rundown of the essentials of this lecture.

1.0 INTRODUCTION

We live in a world that knocks our mind with all sorts of questions to which we almost always do not get answers or clues. It is a world where we see light but are kept in the dark; more questions, few answers shrouded in cloud; more confusion, more searches for solution – a physical world of virtual reality, a world of illusion and opposites where all you exhibit and hold on to does not actually belong to you; you drop all at the exit point, goes away empty handed and memory wiped off with the invisible eraser called time.

1.1 Definition of Terms

Mr. Vice Chancellor, Sir, in order to properly situate this lecture, I will want to give some explanations of some basic concepts.

1.1.1 Waves

In the layman's language, waves are pulses at ir(regular) intervals transferring energy from one point to another along a wave train. A wave field is observed on a plane, the surface of the earth, and the goal is to create a two- or three-dimensional model of the scattering objects to one side of (beneath) the plane (Claerbout, 1985). The easiest to comprehend is the seismic wave. Velocity inhomogeneity, diffraction, interference, and multiple reflections are ubiquitous features of seismic propagation though they are rare in common visual experience. Wave packets carry these bundles of energy in time and space with the whole quantity of information embedded.

Waves generally are of the form $\mathbf{y = y_m \sin \theta}$ where $\mathbf{y_m}$ is the amplitude of the wave.

1.1.2 Supermarket

Supermarket is a general warehouse or superstore or large shop through which goods are sold. People choose what they want from the shelves and pay for it as they leave (*Oxford Advanced Learner's Dictionary*, 2024).

The evergreen Book of Life states that "But in a great house there are many vessels, some to honour, some to dishonour (2 Tim. 2:20).

1.1.3 Ambiguity and Petrology

Ambiguity is a situation of being opened to more than one interpretation. It means to resolve ambiguities means the ability to find unique solution to an otherwise ambivalent situation while Petrology is the scientific study of rocks.

1.2 Geophysics and its Origin

Geophysics as a science gets one prepared ahead of occurences; it is usually not intended for remediation but mitigation. The art of geophysics started from its use in the military to discern how far or close enemy forces are from one's location. Then it was done by putting one's ear to the ground and picking the signals through wave motion within the earth structure. Another common use was in estimating how deep or shallow a pool of water or a flowing river is by observing the spacing of the wavelets crests as the wave propagates through the water when a small pebble is dropped into the body of water. This is basic Physics.

Geophysics has proved itself to possess the clearest and cleanest techniques of detecting or finding locations of minerals, water, among other things useful to man, within the earth structure without having to break rocks or destroy anything. This is done by using relevant principles of Physics and Mathematics to access the location and assess its volume and quality remotely. Geophysics is a diverse science. It is a very plastic discipline. At its best it has the rigour of physics and the vigour of geology (Bullen, 1975). It also stands on the analytics of Mathematics and power of Computation. Its subject is the Earth. It tries to find out how the Earth works, its composition and how it has changed over time.

Broadly speaking, *geophysics* is the application of physics to investigations of the Earth, Moon and planets. It is thus related to astronomy. In simple terms, *geophysics* is the application of Physics principles to solving geological problems. While geologists read the rocks, geophysicists explore the Earth for the economic benefit and prosperity of man. Geophysics therefore enables us to make remote insight into the Earth's subsurface.

In different areas of the world, geophysics means different things to different people. To the layperson, geophysics means many practical things. For the Nepalese, Californians and Icelanders, it is earthquakes and volcanic eruptions; for Chinese and Americans, it is sinkholes, for people of Texas, Alberta and Niger Delta, it is oil exploration; for Russians, it is permafrost and gas exploration; for other Africans, especially in the drought prone areas, it is groundwater hydrology and minerals exploration; for Arabians, it is exploring for oil and water. Geophysics is therefore one discipline, many applications, different techniques.

1.3 Areas of Application of Geophysics

i. Engineering geophysics – Application of geophysical methods to the investigation of sub-surface materials and structures that are likely to have (significant) engineering implications.
ii. Environmental geophysics – Application of geophysical methods to the investigation of near surface bio-physico-chemical phenomena that are likely to have (significant) implications for the management of the local environment.
iii. Archaeo-geophysics – geophysics in archaeology
iv. Bio-geophysics – Geophysical manifestation of microbial activity within geological materials.
v. Agro-geophysics (the use of geophysics for agriculture and soil science). Perhaps the newest branch is agro-geophysics, which has emerged over the last few decades.
vi. Forensic geophysics, forensic geoscience (geoforensics – the application of geophysical methods to investigations that might come before a court of law).

vii. Glacio-geophysics (geophysics in glaciology).
viii. Hydro-geophysics (geophysics in groundwater investigations) (Lorie, 1997).

All these fields also overlap.

The Earth is viewed as an operational system of interacting spheres. These spheres include the Geosphere (the solid body of the Earth), the Atmosphere (the gas envelope surrounding the Earth), the Hydrosphere (water in all its forms at and near the surface of the Earth), the Cryosphere (frozen water part of Earth), and the Biosphere (life on Earth in all its forms and interactions, including humankind). They all move together as one entity bound together to the solid centre by gravitational forces.

The major concern in this discuss is the petrologic superstore/ supermarket having many layers of different materials, called earth materials or the earth for short, deposited at various periods of time, called the geologic time. The Earth is therefore seen as wearing a coat of many layers/colours. This is our geophysics laboratory.

1.4 The Expanding Universe

The Universe, along with the cosmic microwave background, that formed just after the big bang birth of the cosmos 13.8bn years ago, comprised galaxies; the major well known ones are the Milky way, Andromeda, Antennae, Backward, Black eye, Bode's among others. Galaxies also comprised many Solar systems; solar systems, in turn, have planets within them.

Our galaxy is the Milky Way galaxy; our solar system is one is one of the 3916 solar systems within the Milky Way galaxy (https://www.greenmatters.com). There are also, according to the latest data (https://www.greenmatters.com19 Jan. 2023), about 5,241 confirmed exoplanets, which are planets that exist outside our solar system. The Milky Way galaxy likely has between 100 and 200 billion planets, but there are perhaps many, many more. This galaxy is moving at a speed of about 2.1 million km/hr (https://nightsky.jpl.nasa.gov), moving roughly in the direction on the sky that is defined by the constellations of Leo and Virgo. The Earth is located in one of the spiral arms of the Milky Way (called the Orion Arm) galaxy, which lies about two-thirds of the way out from the centre of the galaxy. Here we are part of our Solar System - a group of eight planets, as well as numerous comets and asteroids and dwarf planets which orbit the Sun (https://coolcosmos.ipac.caltech.edu). The Earth itself orbits the sun at a speed of about 30 km s^{-1} and rotates at about 1,670 kmh^{-1}.

Distances between galaxies are measured in light years (ly).
1 light year is a distance calculated using $x = vt$; that is,

1 light year = $3 \times 10^8 \times 365 \times 24 \times 3600$ m =
9,460,800,000,000,000 m (9.4608×10^{15} km)

The universe is expanding at a rate, known as Hubble constant, H_0 of 67.4 ± 0.5 (kms^{-1} $(Mpc)^{-1}$) using Planck and cosmic background data, while it is 73.5 ± 1.4 using the local approach. The *Doppler effect*, also provides evidence that the universe is expanding. The observed frequency of light from a star (i.e., its colour) depends on the velocity of its motion relative to an observer on Earth. The colour of the star shifts toward the red end of the spectrum (lower frequency) if the star is receeding from Earth and toward the blue end (higher frequency) if it is approaching Earth. The colour of light from many distant galaxies has a “red shift,” implying that these galaxies are receding from the Earth. This has been proved RA*dio* D*etection* A*nd* R*anging* (radar*)* measurements.

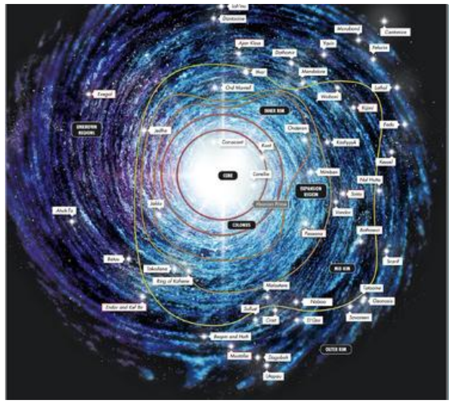


Figure 1: The galaxies and the entire endless space around them constitute the Universe

1.4.1 The Planets

The planets within our solar system are in two categories. These are:

(i) the terrestrial rocky Inner Planets: Mercury, Venus, Earth and Mars; small, lying close to the Sun, and having high densities; and

(ii) the gaseous Outer Planets: These are the Great planets and Pluto namely: Jupiter, Saturn, Uranus, Neptune, which are far from the Sun, large and having low densities; and [Pluto].

The Asteroid Belt lies between the two.

The planets revolve about the Sun in the same prograde sense, which is counterclockwise, when viewed from above the ecliptic plane. The rotations of the planets about their own axes are also mostly prograde. The exceptions are Venus, which has a retrograde rotation; Uranus, whose axis of rotation lies nearly in the plane of its orbit; and Pluto, whose rotation axis and orbital plane are oblique to the ecliptic.

Each planet is roughly twice as far from the Sun as its closest neighbour (Bode's law).

The Sun has almost 99.9% of the mass of the solar system, but the planets account for more than 99% of the angular momentum (Lowrie, 1997).

1.5 The Earth

One universe, tens of galaxies, thousands of solar systems, millions of planets, yet one abode for human life in this form, then the Earth must be a special place of interest to its creator, the owner of the universe (Gen. 2:15).

The Earth is located at about 150 million km from the sun. This distance, called an astronomical unit (AU), is a standard unit of measurement in astronomy. Earth is one AU from the sun. The planet Jupiter is about 5.2 AU from the sun – about 778 million km.

Distances between planets in our Solar system are measured in Astronomical units (AU).

1 AU = orbital distance between the Earth and the Sun = 149,597,871 km

It is the largest and most massive of the rocky inner planets, dwarfed only by the gas giants beyond the Asteroid Belt. Its diameter is about 12,700 km, and its mass is about 5.97×10^{24} kg. In contrast, Jupiter, the largest planet in the solar system, has a diameter of 143,000 km, with a mass of about 1.898×10^{24} kg.

Earth is an oblate spheroid having a polar radius of 6357 km and a slightly greater radius of 6378 km at the equator. In addition to bulging in the middle, Earth's poles are slightly flattened. The geoid is the imaginary equipotential surface which approximates to the msl, It describes the model shape of Earth, and is used to calculate precise surface locations. The Earth has one natural satellite, the moon. Earth is the only planet in the solar system to have one moon. Venus and Mercury do not have any moons, for example, while Jupiter and Saturn each have more than a dozen.

Table 1 gives the parameters of the Earth and its co-planets

Planet	Mass $M [10^{24}$ kg]	Mass relative to Earth	Mean density [kg m^{-3}]	Equatorial radius [km]	Sidereal rotation period [days]	Polar flattening $f=(a-c)/a$	Obliquity of rotation axis [°]
Terrestrial planets and the Moon							
Mercury	0.3302	0.0553	5,427	2,440	58.81	0.0	0.1
Venus	4.869	0.815	5,243	6,052	243.7	0.0	177.4
Earth	5.974	1.000	5,515	6,378	0.9973	0.003353	23.45
Moon	0.0735	0.0123	3,347	1,738	27.32	0.0012	6.68
Mars	0.6419	0.1074	3,933	3,397	1.0275	0.00648	25.19
Great planets and Pluto							
Jupiter	1,899	317.8	1,326	71,492	0.414	0.0649	3.12
Saturn	568.5	95.2	687	60,268	0.444	0.098	26.73
Uranus	86.8	14.4	1,270	25,559	0.720	0.023	97.86
Neptune	102.4	17.15	1,638	24,766	0.671	0.017	29.6
Pluto	0.125	0.0021	1,750	1,195	6.405	—	122.5

Source: Lowrie (1997).

1.5.1 The Earth Structure and Plate Tectonics

About 4.6 billion years ago, Earth formed from a hot cloud of dust orbiting a blazing sun. As the planet cooled, dense elements became concentrated in the core of the planet, while lighter elements formed the mantle. A thin, rigid crust formed at the surface. A constant heating and cooling cycle in the mantle drive plate movement on Earth's surface. Heat working is way out from the core of the planet fractured the crust into irregular tectonic plates that are constantly in motion.

The structure of the Earth is divided into three: the crust, mantle and core. They are called the trinity of the Earth structure.

The Crust, a cold, thin, brittle outer shell made of rock, is the Earth's outer surface. The crust is very thin, relative to the radius of the planet. The crust makes up less than 1 percent of Earth by mass, consisting of oceanic crust and continental crust. Human activities are largely above and within the crust.

Continental crust is composed of silica-rich rocks and is an average about 35 to 70 km thick. It is made up of many different types of igneous, metamorphic, and sedimentary rocks. The average composition is granite, which is much less dense than the mafic igneous rocks of the oceanic crust.

Oceanic crust is made of dark, silica-poor rocks like basalt. It is thinner and more flexible than the continents, extends about 5 to 10 km beneath the ocean floor. It is composed of magma that erupts on the seafloor to create basalt lava flows or cools deeper down to create the intrusive igneous rock gabbro.

The crust's chemical composition includes 93 elements, but only 8 of them represent as much as 99.5% of its mass. It is assumed that, in percent by weight, oxygen represents 46.6%, silicon 27.72%, aluminium 8.13%, iron 5.00%, calcium 3.63%, sodium 2.83%, potassium 2.60% and magnesium 2.08%. (Clark, 1971) The major minerals in the earth are: olivine, augite, hornblende, biotite, calcium-rich plagioclase (anorthite), sodium-rich plagioclase (albite), potassium-rich feldspar (commonly orthoclase), muscovite, quartz, and calcite.

The lithosphere is the outermost mechanical layer, which behaves as a brittle, rigid solid. The lithosphere is about 100 km thick. The lithosphere includes the crust and the uppermost mantle, which are both brittle. Since it is rigid and brittle, when stresses act on the lithosphere, it breaks. This is what we experience as an earthquake.

The asthenosphere as a division is also based on mechanical properties. It is a partially molten upper mantle material that behaves plastically and can flow.

The crust is covered by a series of constantly moving tectonic plates. New crust is created along mid-ocean ridges and rift valleys, where plates pull apart from each other in a process called rifting. Plates slide above and below each other in a process called subduction. They crash against each other in a process called faulting.

Tectonic activity such as subduction and faulting has shaped the crust into a variety of landscapes. Earth's highest point is Mount Everest, Nepal, which soars 8,850m in the Himalaya Mountains in Asia. Mount Everest continues to grow every year, as subduction drives the Indo-Australian tectonic plate below the Eurasian tectonic plate. Subduction also creates Earth's deepest point, the Mariana Trench, about 11 km below the surface of the Pacific Ocean. The heavy Pacific plate is being subducted beneath the small Mariana plate. Plate tectonics are also responsible for landforms such as geysers, earthquakes, and volcanoes. Tectonic activity around the Pacific plate, for instance, creates the Ring of Fire. This tectonically active area includes volcanoes such as Mount Fiji, Japan, and earthquake-prone fault zones such as the west coast of the United States.

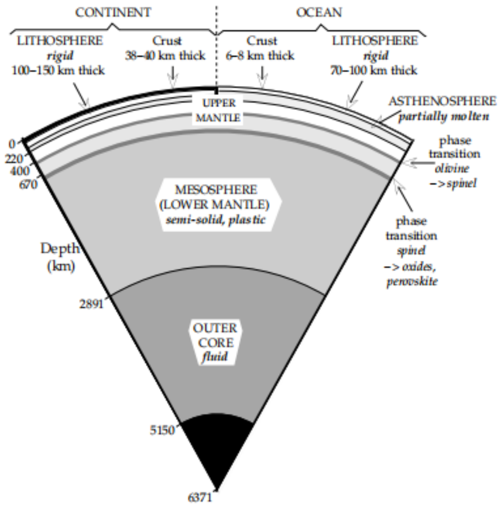


Figure 2: Simplified layered structure of the Earth's interior showing the depths of the most important seismic discontinuities.

There are 12 major tectonic plates, these are: Antarctica, Africa, Eurasia, India, Australia, Arabia, Philippines, North America, South America, Pacific, Nazca, and Cocos; and several minor plates such as Scotia, Caribbean, Juan de Fuca (Lowrie, 1997).

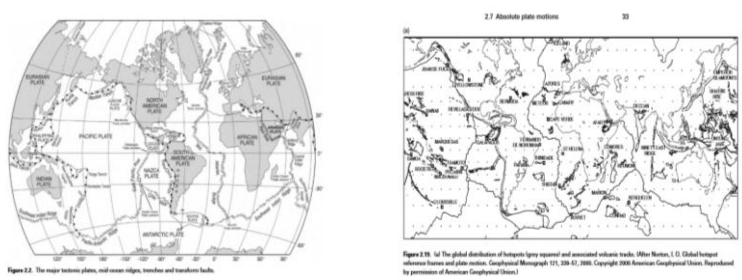


Figure 3: (a) The major Tectonic Plates

(b) The Plates and the Earthquake Zones

The Earth's *interior* is a complex structure of superheated rocks. Three major layers: the dense core, the bulky mantle, and the brittle crust. No one has ever ventured below Earth's crust. Earth's core is mostly made of iron and nickel. It consists of a solid centre surrounded by an outer layer of liquid. The core is found about 2,900 km below Earth's surface, and has a radius of about 3,485 km. A mantle of heavy rock (mostly silicates) surrounds the core. The mantle is about 2,880 km thick, and makes up a whopping 84 percent of Earth's total volume. Parts of the mantle are molten, meaning they are composed of partly melted rock. The mantle's molten rock is constantly in motion. It is forced to the surface during volcanic eruptions and at mid-ocean ridges.

The Mantle is divided into Upper Mantle and Lower Mantle. It is composed of dark, dense rock, similar to oceanic basalt. It represents about 68 percent of Earth's mass. The deeper you go inside the Earth, the hotter it gets. Mantle material near the cold outer crust is about 700℃, while rock near the Earth's core heats up to about 4000℃. Evidence from seismic waves, heat flow, and meteorites show that the mantle made of solid rock; while heat flow by conduction from the core, and convection through the mantle makes the mantle to be hot.

At the planet's centre lies a dense metallic core. Calculations indicate that the core is about 85% iron metal with nickel metal making up much of the remaining 15%. Also, metallic meteorites are thought to be representative of the core. If Earth's core were not metal, the planet would not have a magnetic field.

The core is divided into two, namely: the outer core, which is liquid, is about 2092 km thick; and the inner core, which is about 2414 km thick. Both the inner and outer cores consist primarily of iron and nickel and are extremely hot with temperatures ranging from 4000–5000℃. The core is mostly iron metal. The core makes up about 31% of the Earth (Cloud, 1988).

The inner core is under intense pressure, which keeps it solid despite high temperatures. Evidence from seismic waves show that the outer core is liquid and the inner core is solid because S-waves stop at the inner core. The strong magnetic field is caused by convection in the liquid outer core. The heat that keeps the outer core from solidifying is produced by the breakdown of radioactive elements in the inner core (Cloud, 1988).

There are five discontinuities inside the earth, these are:

i) Conrad Discontinuity**:** Transition zone between upper and lower Crust.
ii) Mohorovicic Discontinuity**:** Transition zone between the Crust and Mantle.
iii) Repiti Discontinuity**:** Transition zone between Outer mantle and Inner mantle.
iv) Gutenberg Discontinuity**:** Transition zone between Mantle and Core.
v) Lehman Discontinuity**:** Transition zone between Outer core and Inner core.

Earth is a rocky body constantly moving around the sun in a path called an orbit. Earth and the moon follow a slightly oval-shaped orbit around the sun every year.

Each journey around the sun, a trip of about 940 million km, is called a revolution. A year on Earth is the time it takes to complete one revolution, about 365.25 days. Earth orbits the sun at a speedy rate of about 30 kms^{-1}. At the same time that it revolves around the sun, Earth rotates on its own axis. Earth makes one complete rotation about every 24 hours. Earth rotates unevenly, spinning faster at the Equator than at the poles. At the Equator, Earth rotates at about 1,670 kmh^{-1}, while it rotates at 1,180 kmh^{-1} at 45° North. Earth's rotation causes the periods of light and darkness we call day and night. The part of Earth facing the sun is in daylight; the part facing away from the sun is in darkness. If Earth did not rotate, one-half of Earth would always be too hot to support life, and the other half would be frozen. Earth rotates from west to east, so the sun appears to rise in the east and set in the west. In addition to Earth's revolution and rotation periods, we experience light and darkness due to Earth's axis not being straight up-and-down. Earth's axis of rotation is tilted 23.5°. This tilt influences temperature changes and other weather patterns from season to season.

The Earth's physical environment is often described in terms of the spheres: the magnetosphere, the atmosphere, the hydrosphere, and the lithosphere. Parts of these spheres make up the biosphere, the area of Earth where life exists.

The Earth's magnetosphere describes the pocket of space surrounding our planet where charged particles are controlled by Earth's magnetic field.

The Earth's atmosphere is a blanket of gases enveloping Earth and retained by our planet's gravity. Atmospheric gases include nitrogen, water vapor, oxygen, and carbon dioxide. The atmosphere is responsible for temperature and other weather patterns on Earth. It blocks most of the sun's ultraviolet (UV) radiation, conducts solar radiation and precipitation through constantly moving air masses, and keeps our planet's average surface temperature to about 15° Celsius. The atmosphere has a layered structure. From the ground toward the sky, the layers are the troposphere, stratosphere, mesosphere, thermosphere, and exosphere. Up to 75% of the total mass of the atmosphere is in the troposphere, where most weather occurs. The boundaries between the layers are not clearly defined, and change depending on latitude and season.

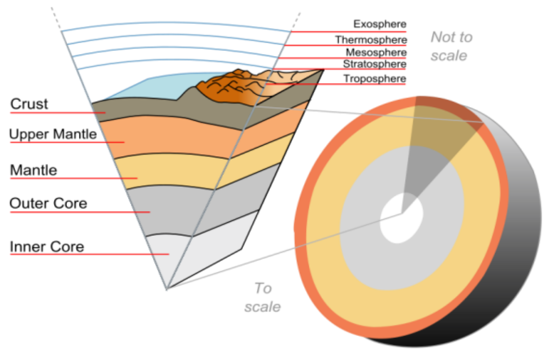


Figure 4: Structure of the Earth and its Atmosphere

The hydrosphere is composed of all the water on Earth. Nearly three-fourths of Earth is covered in water, most of it in the ocean. Less than 3% of the hydrosphere is made up of freshwater. Most freshwater is frozen in ice sheets and glaciers in Antarctica, the North American island of Greenland, and the Arctic. Freshwater can also be found underground, in chambers called aquifers, as well as rivers, lakes, and springs. Water also circulates around the world as vapour. Water vapour can condense into clouds and fall back to Earth as precipitation. The hydrosphere helps regulate Earth's temperature and climate. The ocean absorbs heat from the sun and interacts with the atmosphere to move it around Earth in air currents.

The lithosphere is Earth's solid shell. The crust and the upper portion of the mantle form the lithosphere. It extends from Earth's surface to between 50 and 280 km below it. The difference in thickness accounts for both thin oceanic and thicker continental crust. The rocks and minerals in Earth's lithosphere are made of many elements. Rocks with oxygen and silicon, the most abundant elements in the lithosphere, are called silicates. Quartz is the most common silicate in the lithosphere – and the most common type of rock on Earth.

Almost all materials on Earth are constantly being *recycled*. The three most common cycles are the water cycle, the carbon cycle, and the rock cycle.

The water cycle involves three main phases, related to the three states of water: solid, liquid, and gas. Ice, or solid water, is most common near the poles and at high altitudes. Ice sheets and glaciers hold the most solid water. Ice sheets and glaciers melt, transforming into liquid water. The most abundant liquid water on the planet is in the ocean, although lakes, rivers, and underground aquifers also hold liquid water. Life on Earth is dependent on a supply of liquid water. Most organisms, in fact, are made up mostly of liquid water, called body water. The human body is about 50 to 60 % body water. In addition to survival and hygiene, people use liquid water for energy and transportation. The third phase of the water cycle occurs as liquid water evaporates. Evaporation is the process of a liquid turning into a gas, or vapour. Water vapour is invisible and makes up part of the atmosphere. As water vapour condenses, or turns back into liquid, pockets of vapour become visible as clouds and fog.

Eventually, clouds and fog become saturated, or full of liquid water. This liquid water falls to Earth as precipitation. It can then enter a body of water, such as an ocean or lake, or freeze and become part of a glacier or ice sheet. The water cycle starts again.

The carbon cycle involves the exchange of the element carbon through Earth's atmosphere, hydrosphere, and lithosphere. Carbon, essential for all life on Earth, enters the biosphere many ways. Carbon is one of the gases that make up the atmosphere. It is also ejected during the eruption of volcanoes and ocean vents. All living or once-living materials contain carbon. These materials are organic. Plants and other autotrophs depend on carbon dioxide to create nutrients in a process called photo-synthesis. These nutrients contain carbon. Animals and other organisms that consume autotrophs obtain carbon. Fossil fuels, the remains of ancient plants and animals, contain very high amounts of carbon. As organisms die and decompose, they release carbon into the ocean, soil, or atmosphere. Plants and other autotrophs use this carbon for photosynthesis, starting the carbon cycle again.

The rock cycle is a process that explains the relationship between the three main types of rocks: igneous, sedimentary, and metamorphic. Unlike water in the water cycle and or carbon in the carbon cycle, not all rocks are recycled in different forms. There are some rocks that have been in their present form since soon after Earth cooled. These stable rock formations are called cratons. Igneous rocks are formed as lava hardens. Lava is molten rock ejected by volcanoes during eruptions. Granite and basalt are common types of igneous rocks. Igneous rocks can be broken apart by the forces of erosion and weathering. Winds or ocean currents may then transport these tiny rocks (sand and dust) to a different location. Sedimentary rocks are created from millions of tiny particles slowly building up over time. Igneous rocks can become sedimentary by collecting with other rocks into layers. Sedimentary rocks include sandstone and limestone. Metamorphic rocks are formed when rocks are subjected to intense heat and pressure. The rocks change (undergo metamorphosis) to become a new type of rock. Marble, for example, is a metamorphic rock created from rock that was once limestone, a sedimentary rock. The hardest rock on earth is metamorphic rock type and the hardest mineral on earth is diamond. Metamorphic rocks are known to be the hardest as they are rocks that have changed through heat and pressure as a more solid dense rock. Diamond is the hardest mineral as it is the most difficult to break or cut.

1.5.2 Eras on Earth

Earth's history is divided into time periods. The largest time period is the supereon, and only applies to one unit of time, the Precambrian. Eons, eras, and periods are smaller units of geologic time. Thus we move from Periods to Eras to Eons to Supereons.

Most of Earth's history took place in the Precambrian, which began when Earth was cooling and ended about 542 million years ago. Life began in the Precambrian, in the forms of bacteria and other single-celled organisms. Fossils from the Precambrian are rare and difficult to study. The Precambrian supereon is usually broken into three eons: the Hadean, the Archaean, and the Proterozoic.

We currently live in the Phanerozoic eon.

The first major era of the Phanerozoic is called the Paleozoic, and the Cambrian is the first period of the Paleozoic era. "The Cambrian Explosion of Life" was the rapid appearance of almost all forms of life. Paleontologists and geologists have studied fossils of archaea, bacteria, algae, fungi, plants, and animals that lived during the Cambrian period. The Cambrian was followed by the Ordovician, Silurian, Devonian, Carboniferous, and Permian periods. The Mesozoic era began about 251 million years ago. This was the era when dinosaurs flourished. The Mesozoic has three periods: the Triassic, the Jurassic, and the Cretaceous.

We currently live in the Cenozoic era, which began about 65 million years ago. The Cenozoic is generally marked by three periods: the Paleogene, the Neogene, and the Quaternary. We live in the Quaternary period, which began about 2.5 million years ago. All ancestors of *Homo sapiens* (modern humans) evolved during the Quaternary. Our current era is the Cenozoic, which is itself broken down into three periods. We live in the most recent period, the Quaternary, which is then broken down into two epochs: the current Holocene, and the previous Pleistocene, which ended 11,700 years ago. It is speculated that the end of Earth will come with the end of the sun; expectedly that in a few billion years from now.

Table 2: Geological Time Scale

Eon	Era	Period, subera	Epoch, subperiod	Age (Ma)
Phanerozoic	Cenozoic	Quaternary Q	Holocene	0.01
			Pleistocene	1.8
		Tertiary TT	Pliocene	5.3
			Miocene	23.8
			Oligocene	33.7
			Eocene	54.8
			Palaeocene	65.0
	Mesozoic	Cretaceous K	Late	99.0
			Early	144
		Jurassic J	Late	159
			Middle	180
			Early	206
		Triassic Tr	Late	227
			Middle	242
			Early	248
	Palaeozoic	Permian P	Late	256
			Early	290
		Carboniferous C	Pennsylvanian	323
			Mississippian	354
		Devonian D	Late	370
			Middle	391
			Early	417
		Silurian S	Late	423
			Early	443
		Ordovician O	Late	458
			Middle	470
			Early	490
		Cambrian ϵ	Merioneth	
			St David's	
			Caerfai	543
Proterozoic	Late	Hadrynian		~1000
	Middle	Helikian		1800
	Early	Aphebian		
		(Canada)		2500
Archaean	Late	Kenoran	Transvaal Shamvaian	
	Middle		Witwatersrand Bulawayan	
	Early		Pongola Belingwean	
		Pilbara	Barberton Sebakwian Isua	
		(Canada) (Australia)	*(S. Africa) (Zimbabwe) (Greenland)*	~4000
		Zircons in Jack Hills (Australia)		
		Origin of Earth		~4560

1.5.3 Ingredients for Life

Earth is the only known place in the universe to support life. It has all the ingredients for life proportionately and adequately. Enough information about other planets in our solar system have been gathered by scientists to know that none can support life as we know it. Life is not possible without a stable atmosphere containing the right chemical ingredients for living organisms: hydrogen, oxygen, nitrogen, and carbon. These ingredients must be balanced – not too thick or too thin. Life also depends on the presence of water. The Earth's atmosphere: nitrogen (78%), oxygen (21%), argon, carbon dioxide, neon; and Average Temperature of 15°C. Jupiter, Saturn, Uranus, and Neptune all have atmospheres made mostly of hydrogen and helium. These planets are called gas giants, because they are mostly made of gas and do not have a solid outer crust. Jupiter's moon Europa has a thin atmosphere rich with oxygen. It is likely covered by a huge ocean of liquid water. Some astrobiologists think that if life exists elsewhere in the solar system, it will be near vents at the bottom of Europa's ocean. Io is another probable source of life among the moons of Jupiter. Mercury and Mars have some of the right ingredients, but their atmospheres are far too thin to support life. The atmosphere of Venus is too thick – the planet's surface temperature is more than 460^0 Celsius.

1.6 Exploring the Earth's Subsurface

1.6.1 Methods of Geophysics

All the basic principles and laws of Physics find applications in geophysics. This is evident in gravity, seismic, electrical methods among a host of others. These find applications in Engineering, Environmental, Groundwater and Mining. Techniques of geophysics such as Tomography also find application in Medicine.

Geophysics is a tool which can be utilised in solving geologic/ hydrogeologic problems.

i) It measures properties that are not unique to a particular soil or rock type but broad physical parameters that must be interpreted in terms that the end user will understand.
ii) Because there is rarely a unique geophysical solution, then to ensure success, every geophysical survey must be conducted within an appropriate geologic framework.

1.6.2 Objectives of Geophysical Surveys

These are to:

i) Remotely map changes in subsurface geologic and hydro-geologic conditions;
ii) Recognize and map economic resources;
iii) Optimize locations exploration, exploitation and for drilling wells;
iv) Knit together information from boreholes into formations.

1.6.3 Geophysical applications

These can be in the areas of:

i) Global Geophysics.
ii) Exploration Geophysics in measuring specific physical properties of the earth to determine subsurface conditions and typically locate an economic resource (typically oil, gas and minerals but also includes water).
iii) Characterization Geophysics by remotely mapping changes in subsurface geologic, engineering and hydrogeologic conditions through mapping distribution and properties of aquifers and aquicludes.

Geophysical methods can either be Active or Passive.
They are classified as Active when they

i) Artificially generate a signal;

ii) Transmit the generated signal through the Earth and record changes to the signal, such as in Seismic reflection and refraction surveying; and Direct current electric methods and controlled source electromagnetics.

They are classified as Passive when they

i) On their own, detect variations in the natural fields associated with the Earth, such as in Gravity and Magnetic surveying

1.6.4 Geophysical Methods and their Operational Physical Properties

The operational physical properties associated with common geophysical methods are:

i) Electrical and Electromagnetic: Electrical conductivity/ resistivity of the subsurface.
ii) Gravity: Density of earth material.
iii) Magnetic: Magnetic Susceptibility of mineral/material.
iv) Seismic: Seismic velocity/ attenuation.
v) Ground Penetrating Radar: Dielectric constant.

1.6.5 Typical Geophysical Survey

There are quite a number of survey kinds/dimensions that are undertaken in Geophysics. These are:

1-Dimensional (1-D) Sounding

Which measure variation in properties, usually with depth, at one physical location on the surface, such as in vertical electrical sounding which gives borehole-like result.

2-Dimensional (2-D) Profiling - 2D

Which measure variation in properties along the surface of a 2D cross section must consider line orientation, usually perpendicular to anticipated major anomaly or strike of target.

2½-Dimensional Mapping (2½-D

Usually involves extrapolating between a number of parallel profiles join all points of equal value with isoline (equivalent to contours on a map).

3-Dimensional Mapping (3-D)

In which there is a grid of survey points simultaneously recording live for every source initiation.

4D-3D

Which is when 3D data is acquired using time lapse.
Interpretation of geophysical data is displayed in ways such as Charts, Contour Maps, or 3D.

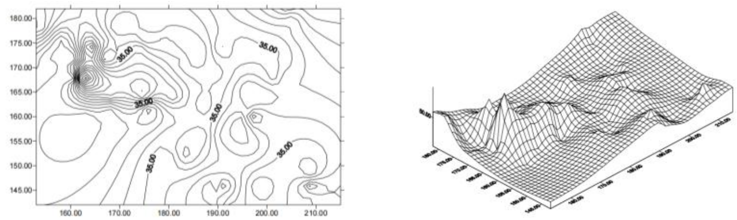


Figure 5: Contour Map and 3D Relief Spatial visualization of Result
These enable spatial visualization of the result of interpreted data.

1.6.6 Geophysical Target Properties and Signatures

These are the properties of interest when conducting Geophysical surveys. These include: Density, Magnetic Susceptibility, Velocity (p and s wave), Attenuation, Resistivity, Relative Dielectric Constant, Rock Type, Pore (fluid) Content, Geometry, Thermal conductivity and Radioactivity. The major methods include:

i) Seismic Method: Density, ρ, shear modulus, μ, and bulk modulus, k play vital roles in wave propagation. In homogeneous, isotropic media, the velocities of compression and shear waves can be described in simple terms of elastic moduli and density.

$$V_p = \sqrt{\frac{\left({}^4/_3\mu + k\right)}{\rho}} \qquad V_s = \sqrt{\frac{\mu}{\rho}}$$

Shear Modulus (μ) and Bulk Modulus (k) are respectively given as $\mu = \frac{\tau}{\varepsilon}$ and $k = \frac{\Delta P}{\Delta v / V}$

The equations show that fluids and gases do not allow the propagation of S waves.

Any change(s) in the density, shear or bulk moduli will therefore cause a change in shear and compression velocity.

(ii) Magnetic Method: The magnetic force, known as Coulomb force, experienced between two magnetic monopoles is given by

$$F_m = \frac{1}{\mu}\frac{\rho_1 \rho_2}{r^2}$$

where μ is the magnetic permeability; and ρ_1 and ρ_2, are the charge strengths of two magnetic monopoles.

(iii) Gravity Method: The gravitational force, experienced between two masses, is given by the Newton's law of gravitation.

$$F_g = \frac{Gm_1 m_2}{r^2}$$

iv) Electrical Resistivity Method: The current, I flowing through a wire, of resistance R and the voltage or potential, V required to propagate the current is given by Ohm’s law V = IR

where R is directly proportional to length, L and inversely proportional to cross-sectional area, A of the wire. The resistivity, ρ of a material, found to be a more useful concept is given as:

$$\rho = \frac{RA}{L} \text{ or } \rho = \frac{VA}{IL}$$

2.0 CONTRIBUTIONS TO KNOWLEDGE

In my sojourn in academics:

2.1 Development of New Techniques

Mr. Vice Chancellor Sir, kindly permit me to highlight the areas of my contribution to knowledge in the field of Geophysics.

2.1.1 Self Potential Method

The self-potential (SP) method is a natural electrochemical geophysical method in which electrochemical processes cause ore bodies to act as batteries (Sittig, 1980). The separate but simultaneous reduction of oxidation of oxidizing agents near the surface and the oxidation of reducing agents at depth causes electric current to flow (Sato *et. al*., 1960). The ore body itself however, only serves as a conductor transferring electrons from the reducing agents to the oxidizing agents; it does not in any way participate directly in either reaction. In order for the above reactions to occur, there must be in existence, differences in oxidation potential of ground water at different depths, thus causing the surface of the area over the top of the ore body to have a negative potential with respect to the surrounding area (Sittig, 1980). As a consequence, electric current flow from the higher potential to the lower. The currents penetrating the conductivity contrast on the boundary generate a secondary surface charge on the boundary. The self-potential is thus the sum of the potential due to the primary double layer and that due to the secondary surface charge (Eskola and Hongisto, 1987).

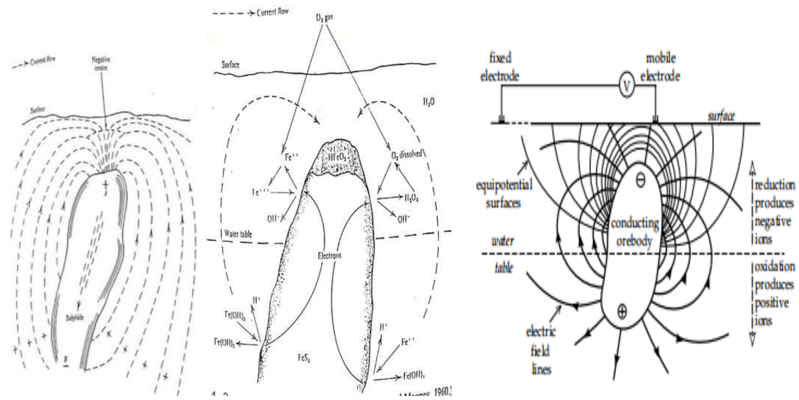


Figure 6: Conduction Mechanism in Sulphide Bodies

By this process, the self-potential method can be considered to be an electrical method.

The immersion of two dissimilar metal electrodes in a homogenous solution causes a potential difference, known as the electrolytic contact potential to be set up between the electrodes. This electrolytic contact potential, along with the static self-potential, is among the basic causes of the large potentials associated with certain mineral zones; they are known as mineralization potentials (Makinde, 1987). These mineralization potentials are especially pronounced in zones where sulphides, graphites and magnetites are available; they are the main interest when prospecting with the self-potential method (Telford *et. al*., 1976; Parasnis, 1979). The streaming mineralization potentials gives rise to an ohmic potential drop within the country rocks, and hence result in SP actualisation (Sato *et. al*., 1960). The potential observed at the field point therefore depends exclusively on the distance of the observation point from that source, and is not, in any way modified, except if the source itself changes (Makinde, 1987). The aim of self-potential (SP) surveys therefore, is to explore rocks or minerals, especially metallic sulfides, which reveal themselves as SP anomalies hidden in the regional field and/or masked by the topographical effects (Abdelrahman and Sharafeldin, 1997).

Meiser (1962); Bhattacharya *et. al*., (1981); Murty *et. al*., (1982); Rao *et. al*., (1983); and Pal, (1983), reported various methods of accomplishing quantitative interpretation of SP data over some most commonly used models in SP profile interpretation, which include, polarized rod and sphere, horizontal cylinder and the thin dipping sheet, among others.

Makinde (1987) considered the SP problem as a dipole problem and therefore approached it from the perspective of basic Physics.

In deriving the expression for the thick dike SP anomaly, some vital assumptions were made, which clearly specify the conditions under which the expression and its derivatives remain valid.

(i) It is assumed that the thick dike is uniformly polarized.

(ii) It is also assumed that the thick dike is of infinite strike extent with the upper and lower edges assumed to be at depths *h* and *H* units below the plane of observation (Grant and West, 1965; Telford *et al*., 1976).

(iii) It is also assumed that the thickness of the dike is uniform throughout its depth and strike extents.

2.1.1.1 The spontaneous polarisation potential

The equation discussed here is derived from basic electrostatic principles in Physics.

The electrostatic potential at any distance r from any charge q is inversely proportional to r and is directly proportional to q (Figure 7a); it is thus given by

$V \propto \frac{q}{r}$; that is, $V = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{r}$ (1)

Where ε_0 is the permittivity of free space ($\varepsilon_0 = 8.854 \times 10^{-12}$ Fm^{-1}).

If we assume the buried source to be an electric dipole having two equal and opposite charges –q and +q placed r_1 and r_2 distant from the field point, the law of summation yields the value for the potential V at the field point as:

$V = \frac{1}{4\pi\varepsilon_0} \cdot [\left(\frac{-q}{r_1}\right) + \left(\frac{+q}{r_2}\right)]$ that is, $V = \frac{q}{4\pi\varepsilon_0} \cdot \left(\frac{1}{r_2} - \frac{1}{r_1}\right)$

Hence $V = \frac{q}{4\pi\varepsilon_0} \cdot \left(\frac{r_1 - r_2}{r_1 r_2}\right)$ (2)

where q is the charge; r_1 is the distance of charge –q from the field point;
r_2 is the distance of charge +q from the field point; and ε_0 is the permittivity of free space

It can be seen from fig. that $r_2^2 = x^2 + y^2$; $\sin\emptyset = \frac{y}{r}$; and $\cos\emptyset = \frac{a+x}{r}$

From these it was found out that
$r_1^2 = r^2 + a^2 + 2ar\cos\emptyset$ and $r_2^2 = r^2 + a^2 - 2ar\cos\emptyset$

For an elemental dipole for which r>>a, $r_1 r_2 \approx r^2$; $r_1 + r_2 \approx 2r$ and $r_1 - r_2 \approx 2a\cos\emptyset$

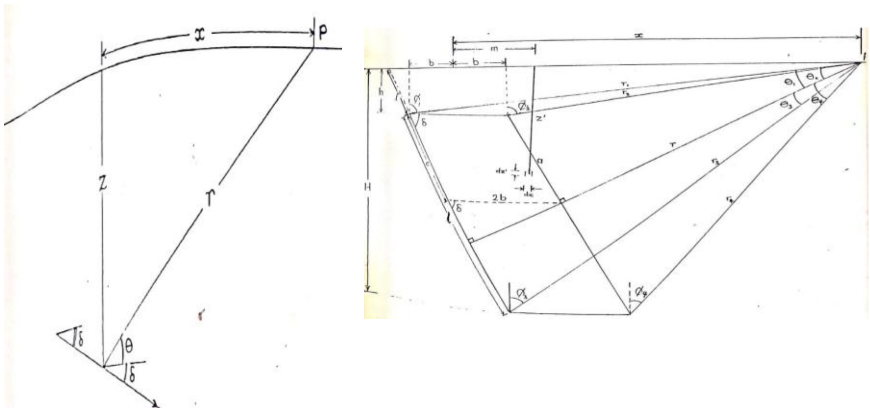


Figure 7: (a) Parameters of SP Potential for a 2D Source (b) Parameters of the Thick Dipping Dike

Hence $$V = \frac{2qa\cos\emptyset}{4\pi\varepsilon_0} \qquad (3)$$

However, 2qa = p and $\emptyset = \theta + \delta$

Hence $$V = \frac{p\cos\emptyset}{4\pi\varepsilon_0 r^2}\,\hat{\imath} \qquad (4)$$

The dipole moment, p, per unit volume, v, is denoted by P, so that p = Pv; then,

$V = \frac{P}{4\pi\varepsilon_0}\int_v \frac{\cos\emptyset}{r^2}\,dv$; that is, $V = \frac{P}{4\pi\varepsilon_0}\frac{\iiint_{xyz}\cos\emptyset}{r^2}dxdydz$;

For a 2-D source, the potential given above can be re-written as

$$V = \frac{P}{4\pi\varepsilon_0} \frac{\iiint_{x-\infty z}^{\infty} \cos\emptyset}{r^2} dxdydz; \qquad (5)$$

From Figures 7a and b, some parameters are obvious, amongst which are:

$$\cos\emptyset = \left(\frac{x\cos\delta - z\sin\delta}{r}\right); \quad r = \sqrt{x^2 + y^2 + z^2}$$

Putting $n^2 = x^2 + z^2$. then $r = \sqrt{n^2 + y^2}$

Hence $V = \frac{P}{2\pi\varepsilon_0} \iint_{x\,z} \frac{x\cos\delta - z\sin\delta}{x^2 + z^2}\, dxdz$ (6)

This equation fully takes into consideration P, the dipole moment per unit volume, also called the electric polarisation.

2.1.2 The SP Anomaly for a Thick Dipping Dike

Figure 7b shows the thick dipping dike with all its parameters defined.

Taking limits $h \leq z' \leq H$ that is, - b + (z' – h) cot $\delta \leq$ x' $\leq$ b + (z' – h) cot δ

This gives (7)

$$V = \frac{P\sin\delta}{2\pi\,\varepsilon_o}[Z]$$

where Z encompasses all the associated parameters

The synthetically obtained profiles using the derived analytical expression for SP anomaly and its horizontal gradient over thick dipping dikes can be compared with profiles obtained by other authors, either as observed over buried sulphide bodies, or as generated using other methods. This is to aid or facilitate the development of a quantitative interpretation of SP data over such a body as the thick dike.

The horizontal gradient anomaly was obtained using

$$\boldsymbol{V_x = \frac{dV}{dx}}$$

$$V_x = \frac{P \sin\delta}{2\pi\,\varepsilon_0} \ln \frac{r_1 r_4}{r_2 r_3} \qquad (8)$$

These equations can be used to model self-potential method as they transform the self polarisation potential from being an electrical method to being a potential theory method.

2.1.2.1 Comparison of the anomaly profile and its horizontal gradient

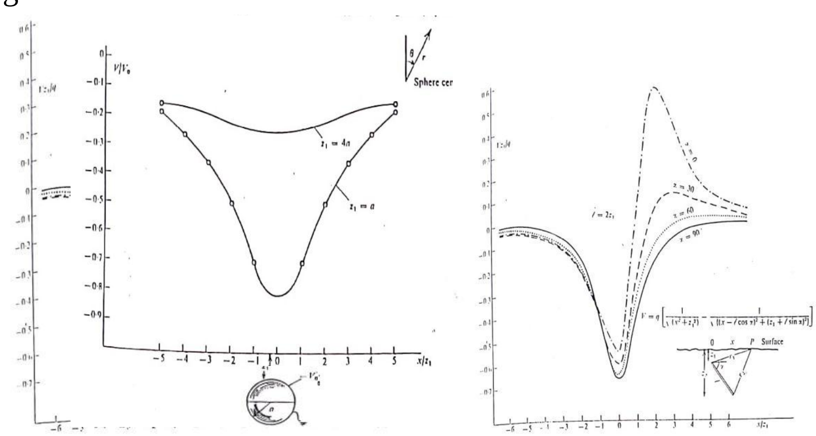


Figure 8: (a) SP Anomaly (b) SP Gradient

2.1.2.2 Computer synthesis of the idealized anomalies

The horizontal gradient V_x of the thick dike SP anomaly given by equation (7) is made up of two parts:

i) the constant part K, and ii) a variable part g(x), which depends on the value of x, since r_1, r_2, r_3, and r_4 are all functions of x. The equation can therefore be written as

$V_x = K\, g(x)$ where $K = \frac{P}{2\pi\varepsilon_0}$ and $g(x) = \sin\delta \ln\frac{r_1 r_4}{r_2 r_3}$

V_x is also dependent on the value of δ, as this parameter affects the value of the anomaly on the profile, and the shape of the anomaly.

The thick dike SP anomaly is also made up of two parts:

i) the constant part K, which does not vary with x, the horizontal distance on the profile measured from the point on the profile vertically above the centre of dike's top surface, and
ii) a variable part f(x), which depends on the value of x.

The equation can be rewritten in the form V = K f(x)

$$V = \frac{P \sin\delta}{2\pi\,\varepsilon_o}[Z]$$

where $K = \frac{P}{2\pi\varepsilon_0}$ and $f(x) = \sin\delta\ [Z]$

The term sin δ outside the parenthesis in the expression for f(x) should actually form a part of that for K as this too is a constant for a given dike and does not vary with x.

Figures 9 to 12 present the computer generated synthetic SP profiles based on equation (7), the value of K has been set as unity here while the distance, width, and depth extent parameters are all relative to h, the depth to the top of the dike surface. In other words, the distance parameter x is actually computed here as x/h, and the width parameter b is computed as b/h; likewise, the depth extent parameter H is computed as H/h.

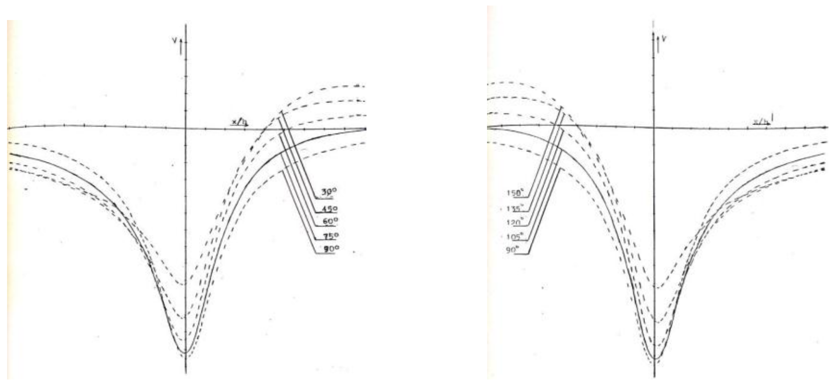


Figure 9: Typical Anomaly Profile for b/h = 0.5, H/h = 4

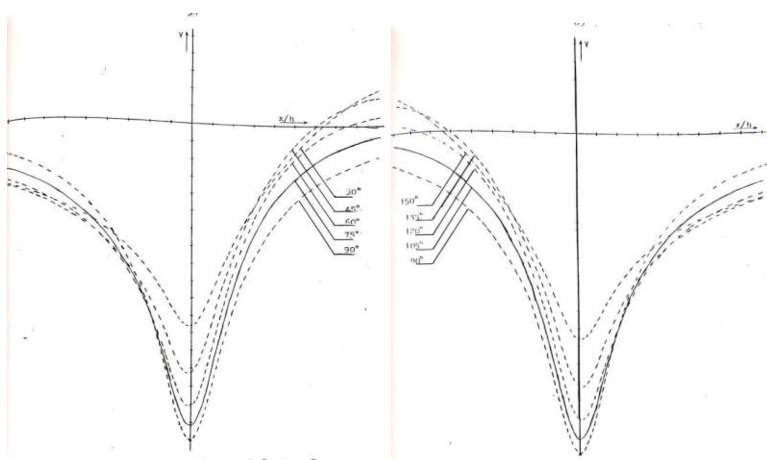


Figure 10: Typical Anomaly Profile for b/h = 0.5, H/h = 6

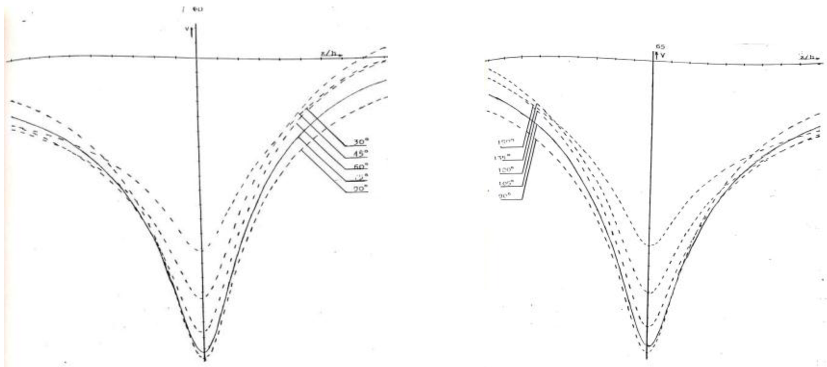


Figure 11: Typical Anomaly Profile for b/h = 0.5, H/h = 8

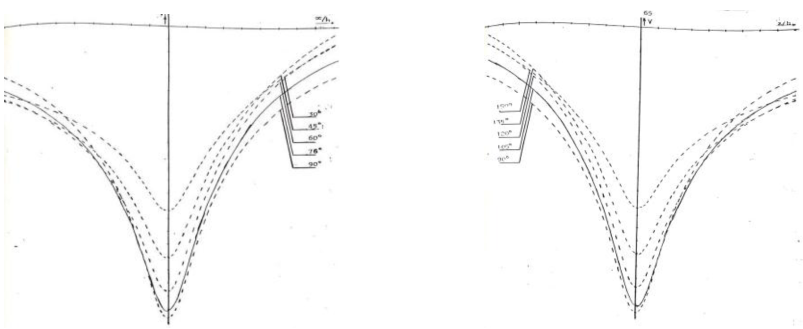


Figure 12: Typical Anomaly Profile b/h = 0.5, H/h = 10

Similar construct for b/h = 1.0, 1.5, 2.0 and further can be made and interpreted.

The typical SP anomaly profiles in Figures 9 to 12 have been computed for x/h = 0 to ±10 at intervals of 0.2. The values of other parameters chosen for generating these curves are as follows: b/h = 0.5, 1.0, 1.5, and 2.0; H/h = 4, 6, 8, and 10; and δ = 30^0, 45^0, 60^0, 75^0, 90^0, 105^0, 120^0, 135^0, and 150^0.

2.1.2.3 Corresponding horizontal gradient

The derived horizontal gradient was synthetically generated for various values of b/h, H/h and δ. The corresponding graphs of Figures 13 to 14 were obtained.

Some important observations, which include anomaly shift and displacements as a result of variation in the values of b/h, H/h and δ were made.

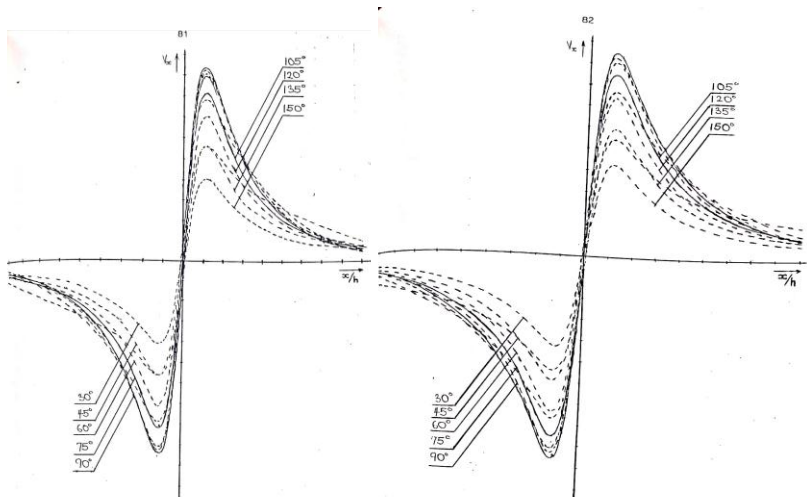


Figure 13: Typical SP Gradient profile in millivolt per metre for a) b/h = 1, H/h = 4 b) b/h = 1, H/h = 6

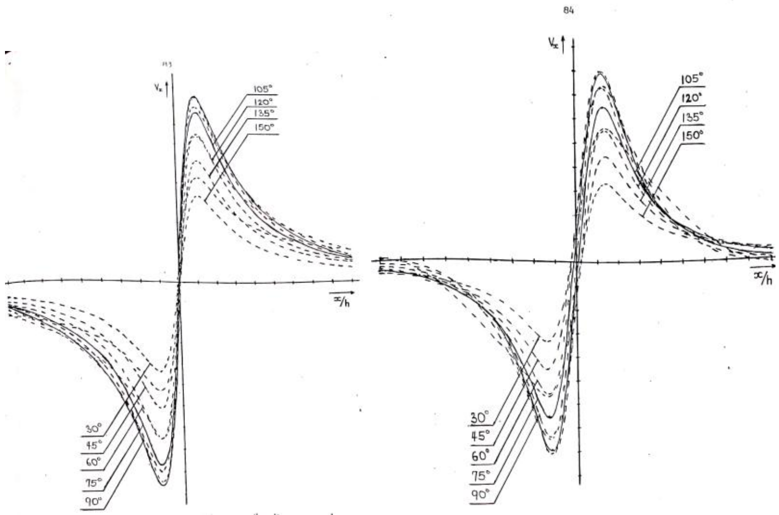
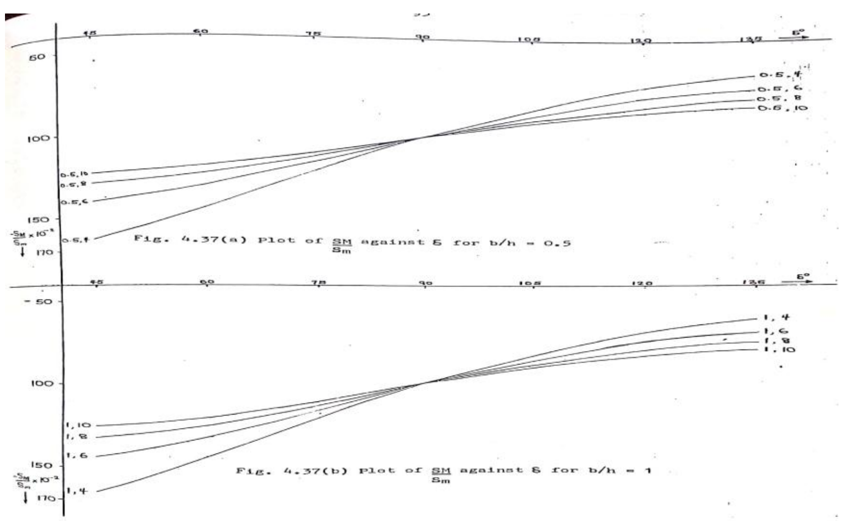


Figure 14: Typical SP Gradient profile in millivolt per metre for a) b/h = 1, H/h = 8 b) b/h = 1, H/h = 10



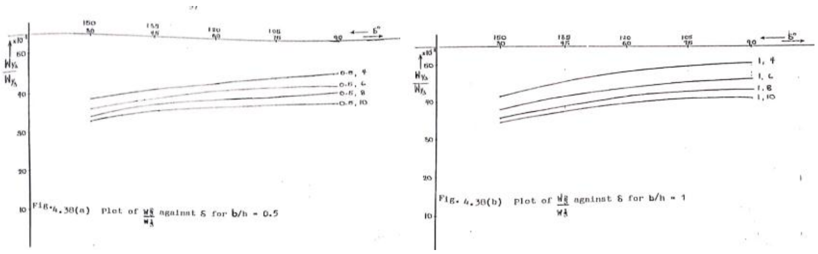


Figure 15: Nomograms for interpreting Self Potential Anomaly

2.1.3 Reduction to Thin Dike

In practice, the thick dike is observed to become a thin dike when b/h << H/h. However, theoretically, the thick dike anomaly expression reduces to that of the thin dike when $r_1 \rightarrow r_2$, $r_3 \rightarrow r_4$, $\phi_1 \rightarrow \phi_2$, $\varphi_3 \rightarrow \phi_4$ It also orientates from being dipping to being vertical when $\delta = 90^0$; becoming a slab when $\delta = 0^0$ and b/h >> H/h. This gives

$$V = \frac{Pt}{2\pi\,\varepsilon_0} \ln\frac{r_1}{r_3}; \qquad \text{where } t = 2b \qquad (\text{cf:} \quad V = \frac{\rho}{\pi}\ln\frac{r_1}{r_2}) \qquad (9)$$

2.2 Development of a Variant of the Two-electrode Method

There are different forms of the 2-e systems, either as focused or unfocussed combinations. This discuss is on the unfocussed combination of two current electrodes in which one feeds current into the ground and the other acts as the current return electrode. Thus, each electrode doubles as the current and as a potential electrode. Salient points of the principle and theory of this variant of the two-electrode (2-e) system, which has been found to be a very simple and relatively accurate with numerous advantages over the conventional four-electrode (4e) methods (arrays) are presented.

2.2.1 B*asic Assumptions*

The basic assumptions made in developing this method include:

i) The earth material in each layer sampled by the current from the current electrodes is homogeneous and isotropic;
ii) The earth materials or layers are horizontally stratified;
iii) Each current electrode is a point source or sink;
iv) Each electrode separation, L is assumed to sound a new layer although some of these layers, by the closeness of their k values, are expected to, in reality, indicate their belonging to the same layer;
v) The mode of electrical conduction in the earth material is assumed to be ohmic.

The current pattern in a uniform half-space extends laterally on either side of the profile line. Viewed from above, the current lines bulge outward between source and sink with a geometry similar to that shown. In a vertical section the current lines resemble half of a dipole geometry. In three dimensions the current can be visualized as flowing through tubes that fatten as they leave the source and narrow as they converge towards the sink. Figure shows the flow pattern of the current in a vertical section through the "tubes" in a uniform half-space.

In order to evaluate the depth penetration of current in a uniform half-space we define orthogonal Cartesian coordinates with the x-axis parallel to the profile and the z-axis vertical. Let the spacing of the current electrodes be L and the resistivity of the half-space be p. The horizontal electric field E, at (x, y, z) is

$$E_x = \frac{\partial U}{\partial x} = -\frac{\partial}{\partial x}\left[\frac{\rho I}{2\pi}\left(\frac{1}{r_1} - \frac{1}{r_2}\right)\right] \quad r_1 = (x^2+y^2+z^2)^{1/2} \text{ and}$$

$$r_2 = ((L-x)^2+y^2+z^2)^{1/2} \tag{10}$$

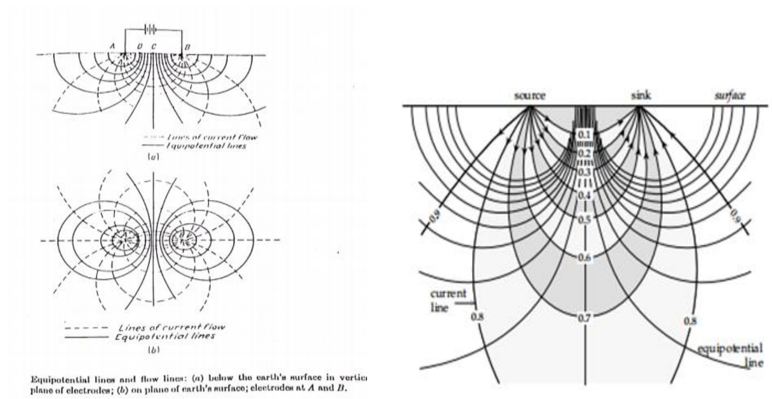


Figure 16: Cross-section of current "tubes" and equipotential surfaces between a source and sink (after Van Nostrand and Cook, 1966).

For the two current electrodes involved, a top view imagination of the pattern formed by both the current lines and the equipotentials show coaxial concentric circles. The homogeneity assumptions lend a lead to the analysis of the problem in a situation where there is a sharp departure from the (homogeneous) nature of the top surface or of an underlying bed from the (homogeneous) nature of the overlying bed. In which case, it is expected that the slope of a supposed straight line graph will change when the underlying bed is of a different material or composition from that of the overlying bed. The assumption that the pattern of current flow between the two current electrodes form a hemispherical bowl of volume $v = \frac{2}{3}\pi r^3$ implies that the volume increases with increasing electrode separation.

In deriving a suitable formula for the proposed 2e arrangement based on the stated assumptions, Figures 17-18 are necessary in understanding the volume of the earth material trapped within each current hemisphere or near-spherical bowl as the current electrode is varied.

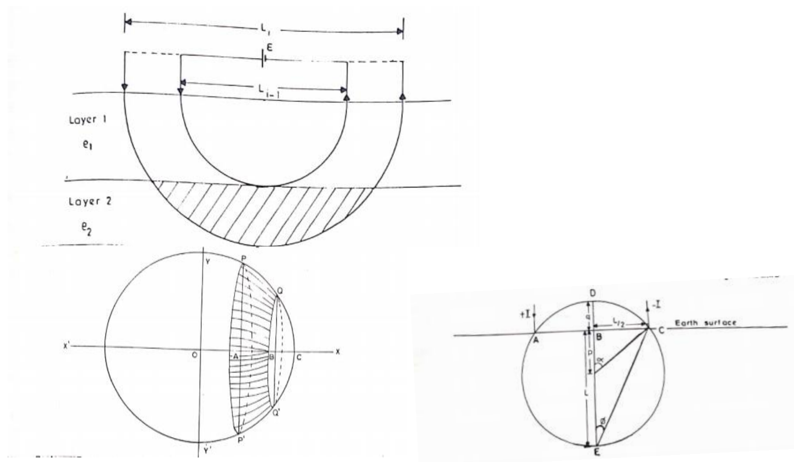


Figure 17: (a, b, c) Geometry for determining volume of earth trapped within a layer using the hemispherical model

By considering the electrode spacing L_{i-1} and L_i in Figure 17a and calling into play the assumptions, it is observed that part of the hemisphere described by the separation L_i is of resistivity ρ_i; the remainder (shaded part) is of resistivity ρ_2. This shaded part is a spherical cap. It therefore implies that the sum of the volumes of the spherical cap of resistivity ρ_2, and the unshaded part of the hemisphere, of resistivity ρ_1, makes up the totality of the hemispherical bowl. Considering that part of the hemispherical bowl having resistivity ρ_2, it is necessary to apply the expression for the volume of part of a sphere between two parallel planes to compute the volume of each layer traversed by the current flow. This same consideration is applicable to the near-spherical bowls.

The equation of a circle is $x^2 + y^2 = r^2$

The equation of a sphere is $v = {}^4/_3\, \pi\, r^3$

This implies that the volume of a hemisphere is $\frac{2}{3}\pi r^3$, where r is the radius of the sphere of which the hemisphere is a part of.

In figure 17b, let the quadrant YOC of the circle $x^2 + y^2 = r^2$ rotating about OX describe a hemisphere. Let two parallel planes whose distances from O be given by OA = a and OB = b, mark out the segment whose volume v is required.

Using $v = \int \pi y^2\, dx$

(rotation about the x – axis, volume of solids of rotation, then given that $y^2 = r^2 - x^2$

$v = \int_a^b \pi\,(r^2 - x^2)\,dx = \pi\,[r^2x - \frac{1}{3}x^3]_a^b = \pi(b - a)[r^2 - \frac{1}{3}(b^2 + ab + a^2)]$

If b = r, the part of the sphere becomes a spherical cap.

Therefore, $v = \pi(r - a)[r^2 - \frac{1}{3}(b^2 + ab + a^2)]$ (11)

When a = 0, the spherical cap becomes a hemisphere (Abbott, 1980).

This result was then applied to both the hemispherical and near-spherical models.

Taking the approximate probing depth at electrode spacing L, and applying this to the principal model of interest, we have then,

$r^2 = (\frac{1}{2} L)^2 + p^2 = (L^2 + 4p^2)$

From the theorem of product of intersection of chords of a circle, AB.BC = DB.BE, that is, (½ L)(½ L) = qL, then

$$q = \tfrac{1}{4} L$$

In determining the volume of part of sphere in empty space, the geometry of Figure 17c shows that the volume of the spherical cap simplifies to $v_{cap} = 0.033854\pi L^3 = 0.106356L^3$

and the volume v of part of sphere within the homogeneous earth is

$$v = 0.2916667\pi L^3 = 0.9162978L^3$$

This represents the volume of part of sphere within the homogeneous earth.

Considering the situation whereby part of the current flowing in the near-spherical bowl of volume $v = 0.9162978L^3$ is trapped within a layer of resistivity ρ_1, and the remainder is trapped in a region of resistivity ρ_2 such that it forms a spherical cap within the second layer, then

$v^{**} = 0.9162978L^3 - v^*$ where v^* is the volume of spherical cap formed in layer 2.

This equation represents the volume of the remaining part entrapped in layer of resistivity ρ_1.

In the case of more than one layer, for a given L_i, the bulk resistivity of the j^{th} layer is given by

$$\rho_j = \frac{\sum_{i=1}^{n} \rho_i v_i}{\sum_{i=1}^{n} v_i}; \qquad i = j = 1, 2, 3, \ldots\ldots, n \qquad (12)$$

where n is the number of layers sampled by the current at maximum electrode separation, L.

Thus, for a two-layer case, if the electrode separation L_{i-1} gives a bulk resistivity ρ_1, and the electrode separation L_i gives a bulk resistivity ρ_{2b}, then $\rho_{2b}v = \rho_1 v_1 + \rho_2 v_2$

that is, $\rho_2 = \frac{\rho_{2b}v - \rho_1 v_1}{v_2}$; where ρ_2 is the true resistivity of the second layer.

This equation can be used to compute the resistivity of the new layer defined by the new sounding separation L_i for the two–layer case. This was appropriately extended to the n-layer case. The equation was also used to define the stripping process for this method; it also validated the possibility of stripping technique in electrical method.

The "specific resistance" approach was conceived to graphically delineate one layer from the other without necessarily going through the rigours of massive calculation following patterned algorithm.

The 2-e method developed has some advantages over the conventional 4-e arrays:

i) The array is simple and easy to implement.
ii) More sampling points can be established even within a certain portion of entire spread.

2.2.2 The Laboratory Investigations

After evolving the theory of the variant of the 2-e method, the model was first tried on some laboratory models to test the workability and reliability of the method in the vertical electrical sounding (VES/depth profiling) mode especially, and also the horizontal electric profiling mode. The experimentation was aimed at investigating the capability of this variant to delineate horizontally-laid earth materials, and hence to determine its ability to correctly estimate the layer thickness and layer resistivity accurately.

In modelling resistivity methods in the laboratory, suitable conducting media, which permit the flow of electric current are used as the layer media. Geologic structures are usually simulated by small-scale models of a size small enough to be readily handled in the laboratory. In a situation whereby the medium itself is being investigated, the real earth situation is suitably configured using suitably scaled homogeneous, isotropic electrolytes and earth materials.

In the laboratory modelling experiment, a Perspex tank of dimensions 100.2 cm × 80.0 cm × 50.0 cm (Figure 18) was used.

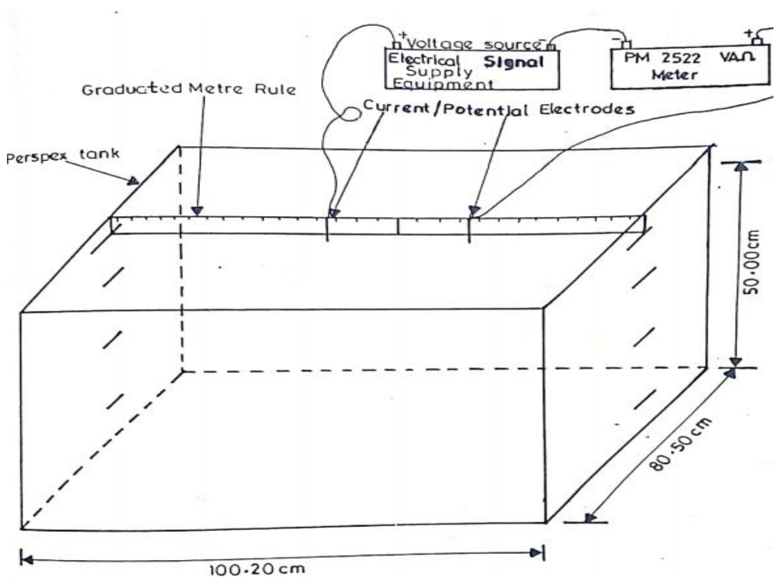


Figure 18: The Model Tank

Experiments were conducted to:

i) determine the operating frequency of the method. It was found that frequencies 30, 40 and 60 Hz gave very stable readings of voltage and output current. Laboratory model study data collected over water at 0, 40 and 50 Hz are very close and the intercepts are about the same. The implication of this is that the method can operate effectively between 0 and 60 Hz, but preferably below line frequency. In the field survey, operating frequency was restricted close to, but greater than the dc voltage for effective penetration and breaking barriers that could be posed by skin depth effect.

ii) the scaling factor of the model system following the method adopted by Mwenifumbo (1980). Using the combination of the equation of continuity V $\tilde{\nabla}$. Jc = 0 and Ohm's law $J_c = - \sigma V \varphi$ where J_c is the conduction current density and φ is a scalar potential; we arrived at L/L' = α; M/M' = β; T/T' = τ and I/I' = ϵ; where the primed quantities represent the full scale system and the unprimed represent the model system. Thus, we arrived at $\rho' = 10^{-1}\rho$.

iii) the tank characteristics over water, mixed soil, lateritic clay and river sand using different electrode spacing of 2, 5, 6, 10, 15, 30 and 90 cm at frequency 0, 10, 20, 30, 40, 50, 60, 90 and 125 Hz. Capacitive coupling effect was also investigated.

iv) the tank wall effect as well as the effect of the bottom of the tank; as part of precautions taken.

v) Control experiments, majorly using other standard methods, to check reliability of results, were also conducted.

Table 3: Computed Resistivity Values using various methods

	Resistivity Values (Ωm)			
Earth Material	Wenner	2-e	Tube	Metre Bridge
Water	31	34	38	40
Lateritic Clay	33	32	34	33
River Sand	844	1000	1721	4788
Mixed soil	524	217	245	55

2.2.3 Multi-layered Earth Model Experiments

Two and three-layer earth models were experimented upon in this work using the transparent Perspex model tank. The base of the model tank served as the electrical basement over which the earth materials used were laid in horizontal layers. Some homogeneous and isotropic earth materials, namely River Sand, Lateritic Clay and Mixed-soil were variously combined to form one and two-layer overburdens over the Perspex "basement". Current at a fixed low frequency was injected into the layers from a power supply unit through copper electrodes driven 2 mm into the topmost earth material layer. The voltage, V, developed across the layers of earth materials and the current, I, flowing through the earth materials being sampled or sounded at different electrode spacings, L, were measured using a Phillips digital multimeter. The "bulk resistance": and the "bulk resistivity" of each of the various layers of earth materials used were calculated using the expressions earlier derived (Ajayi and Makinde, 2001), that is,

$R = V/I$ and $\rho_b = 0.1473RL$

The resistivity data thus generated were plotted against electrode spacing on a semi-log graph sheet. Given that the thickness of a particular layer is z, and the resistivity of the surface layer is ρ_0, then according to Keller and Frischknecht (1966), the resistivity of the earth material was determined from the relationship

$$\rho_z = \rho_0 e^{\pm kz} \qquad (10)$$

where k is a parameter defining the rate (increase or decrease) of resistivity with depth.

Considering the case where k is positive, then the bulk resistivity ρ_b of the sampled material at a particular electrode spacing L, given the depth of current flow in the earth to be z (= h), is given as $\rho_b = \rho_0 e^{\pm kh}$

Taking the natural log of both sides of equation 10 gives $\mathit{ln}\ \rho_b = \mathit{ln}\ \rho_0 \pm kh$

Experimental investigations show that for this variant, h = $^L/_2$. Therefore,

$$\mathit{ln}\ \rho_b = \mathit{ln}\ \rho_0 \pm k\ ^L/_2 \text{ or,} \qquad \mathit{ln}\ \rho_b = k\ ^L/_2 + \mathit{ln}\ \rho_0 \qquad (11)$$

This equation is of the form y = mx + c when the graph of ρ_b is plotted against $^L/_2$ on a semi-log paper.

The graph of the natural log of "bulk resistivity", ρ_b against the half electrode spacing, ½L, that is, ln ρ_b – $^L/_2$, was then plotted for each model data point. The resulting graph(s) show segmentations corresponding to the number of geoelectric layers present, that is earth materials laid in the model tank. Hence, information on the number of geoelectric layers present in the model can be distinctly deduced from the number of segmented lines present in the graph. By making a direct projection of the point(s) of intersection of adjacent segments of the graph over the electrode spacing axis, enabled the direct estimation of the depth to interface/layer thickness, h and subsequently the depth, H to the basement.

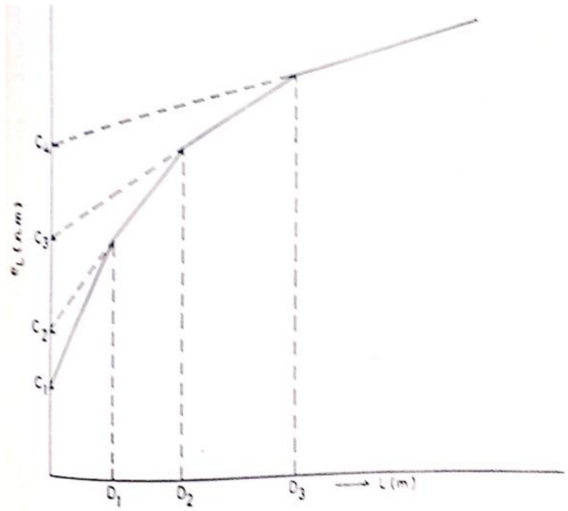


Figure 19: Graph of Bulk resistivity against electrode spacing, showing segmentation of the layers

Equation 11 also made possible the estimation of resistivity ρ_0, of the top layer, which is the intercept of the graph on the vertical axis. By using a composition regime tied to the geological assessment of the earth materials' combination/ geology of the field site, the resistivity values of the underlying layers can be calculated. The figs next show the obtained graphs for different combination of earth materials experimented upon.

The graphically obtained layer thickness of the modelled layers, taking Lateritic Clay over River Sand over Perspex as an example, was well within very reasonable accuracy of ±2% – ±5%. The layer resistivity values obtained for these modelled layers were also, in addition to their being very accurate, within the expected trend of $\rho_1 < \rho_2 < \rho_3$ for the model.

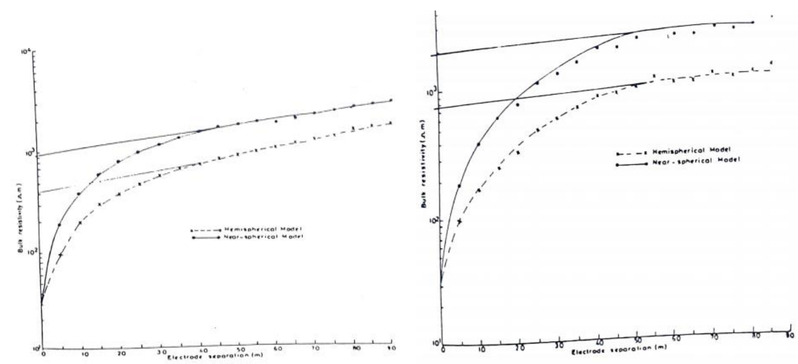


Figure 20: Graph of ρ_b against L for a) Water on Perspex (2-layer case) b) Lateritic Clay on Perspex

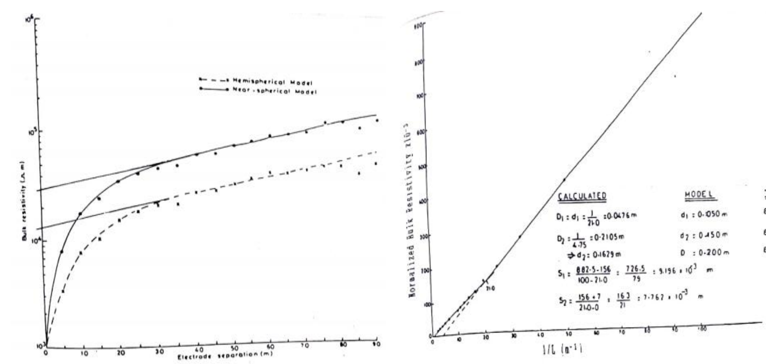


Figure 21: (a) Graph of ρ_b against L for River Sand on Perspex (b) Graph of normalized ρ_b against L^{-1}

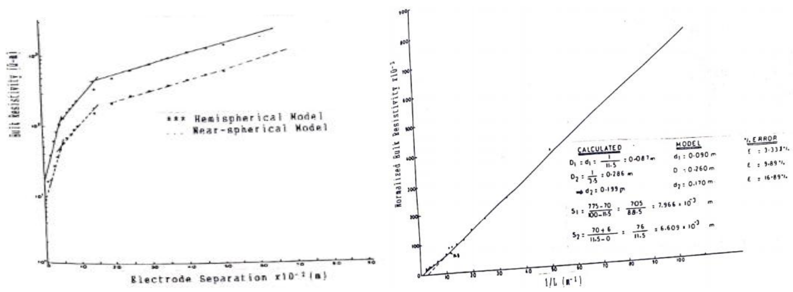


Figure 22: Typical graph of (a) ρ_b against L for 3-layer case (b) normalized ρ_b against L^{-1}

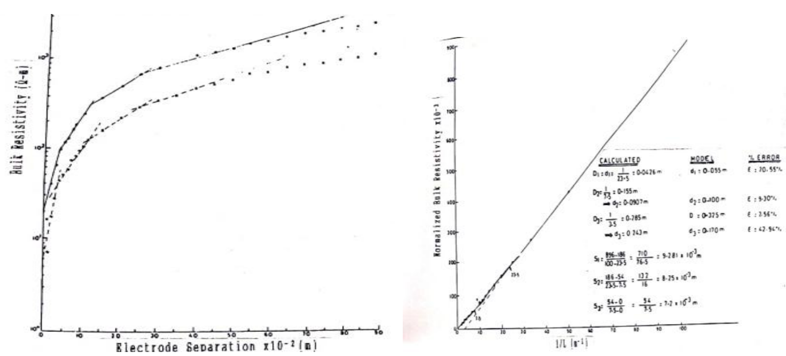


Figure 23: Typical graph of (a) ρ_b against L for 4-layer case (b) normalized ρ_b against L^{-1}

2.2.4 Horizontal Profiling Experiment

Ability of this 2-e variant to delineate vertical contacts was investigated. An arrangement whereby a block of lateritic clay, 35 cm in length, 50 cm wide and 50 cm thick was sandwiched between two blocks of river sand was made as shown in figure. 24 to 26. Horizontal profiling using the four-electrode Wenner array with a = 2 cm and a = 5 cm were then ran across the tank along the middle of the tank parallel to the long axis of the tank.

Similar profiles were run using the two-electrode array with L = 2 cm and L = 5 cm respectively. The results of the horizontal profiling using both arrays are shown in Figures 24 and 25. The results show that the 2-e variant delineated the different portions as much as the Wenner array did. The contacts between the blocks of River Sand and the block of Lateritic Clay were well defined, and accurately too, by the 2-e variant. Furthermore, the measured resistivity values and resulting curves of both the 2-e variant and the Wenner array were very much comparable. The 2-e variant therefore promises to be a good substitute for the 4-e Wenner array in use for horizontal profiling.

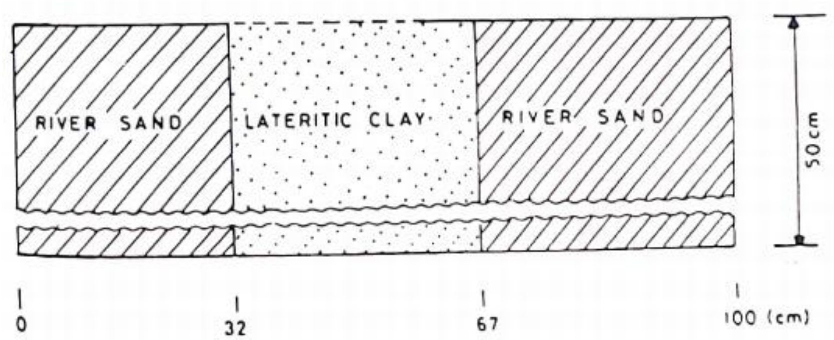


Figure 24: Emplaced Earth Materials with Lateritic Clay sandwiched between two blocks of River Sand

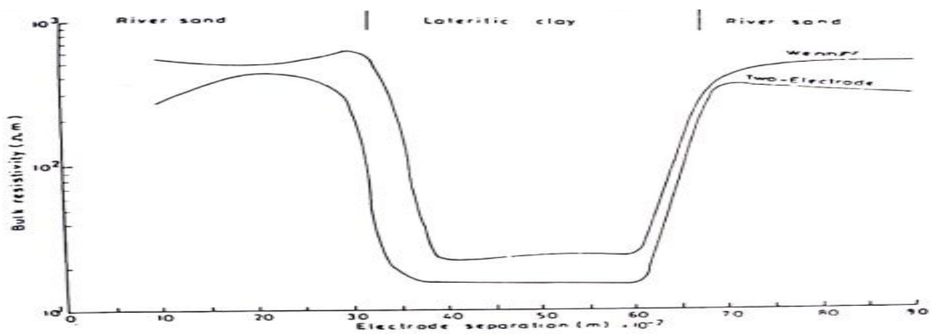


Figure 25: Graph of ρ_b against L for a = 2 cm (Wenner) and L = 2cm (2-e)

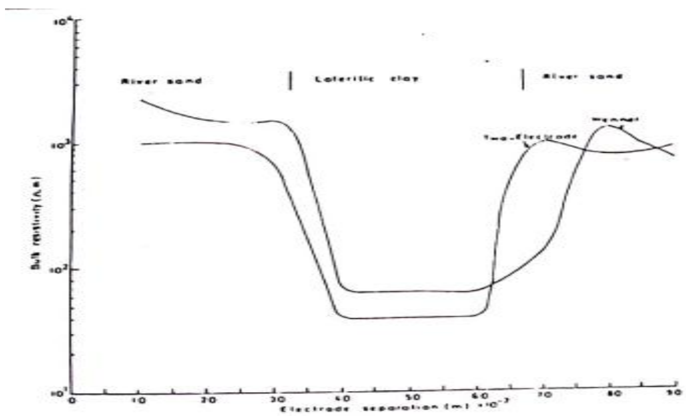


Figure 26: Graph of ρ_b against L for a = 5 cm (Wenner) and L = 5cm (2-e)

2.2.5 Field Investigations

The field investigations of the method were kick started at the Kubanni village borehole. The borehole was drilled by Messrs Preusag Nigeria Ltd. The borehole was known to be logged and highly productive. Figure 27 shows the borehole log indicating the number of layers and the corresponding earth materials.

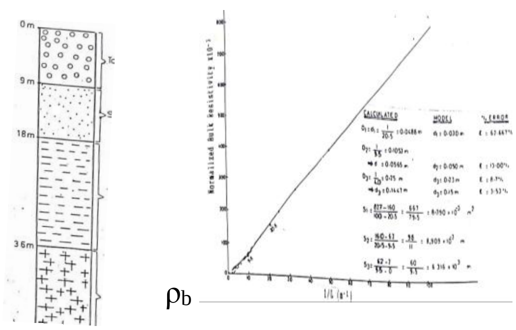


Figure 27: (a) Kubanni borehole log (b) Normalised ρ_b against L^{-1}, and (c) graphs of ρ_b against L.

Figures 27 (b), (c) shows the graphically obtained layering and thicknesses obtained using the variant of the 2e method under discussion.
Interpretation of data obtained showed that

A) Around the peripheral area of the location of the borehole (Figure 27),

i) for the comparative four-electrode Schlumberger array: $\rho_1 = 75\ \Omega$m, $h_1 = 8.0$ m; $\rho_2 = 26\ \Omega$m, $h_2 = 11.5$ m; $\rho_3 = 232\ \Omega$m, $h_3 = 19.0$ m; $\rho_4 = 1991\ \Omega$m, $h_4 = \infty$; H = 38.5 m.

ii) for the two-electrode variant: $\rho_1 = 52\ \Omega$m, $h_1 = 7.0$ m; $\rho_2 = 42\ \Omega$m, $h_2 = 11.0$ m; $\rho_3 = 355\ \Omega$m, $h_3 = 19.5$ m; $\rho_4 = 1590\ \Omega$m, $h_4 = \infty$; H = 37.5 m.

B) Within the general Jamaa' Kubanni village, away from the borehole area/vicinity (Figure),

i) for an independent survey by Shemang (1990), $\rho_1 = 217\ \Omega$m, $h_1 = 8.0$ m; $\rho_2 = 56\ \Omega$m, $h_2 = 36.0$ m; $\rho_3 = 991\ \Omega$m, $h_3 = \infty$; H = 44.0 m.

ii) or the comparative four-electrode Schlumberger array: ρ_1 = 72 Ωm, h_1 = 8.04 m; ρ_2 = 26 Ωm, h_2 = 31.52 m; ρ_3 = 991 Ωm, $h_3 = \infty$; H = 39.56 m.

iii) or the two-electrode variant: ρ_1 = 45 Ωm, h_1 = 6.0 m; ρ_2 = 432 Ωm, h_2 = 29.0 m; ρ_3 = 1159 Ωm, $h_3 = \infty$; H = 35.0 m

.

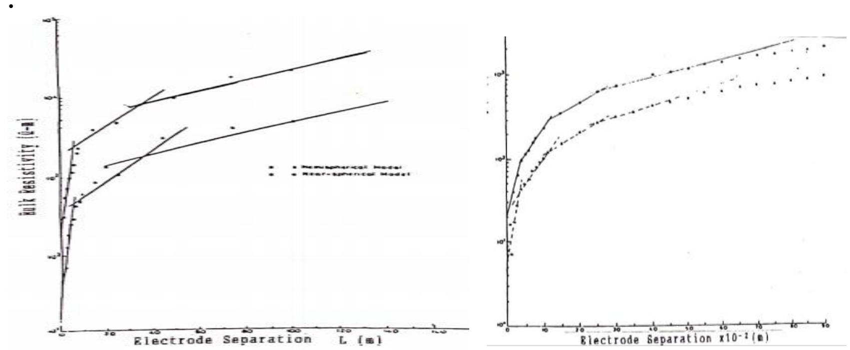


Figure 28: Graph of ρ_b against L (a) at the borehole site, and (b) at another part of the Jama'a Kubanni Village

Further investigations on the viability of this variant was undertaken in comparison with other methods and four electrode methods in project works undertaken in Kogi East and the FCT. The results obtained were highly encouraging, and confirmed the variant to be successful and settled.

Other investigators, such as Yusuff and Umego (2014), Bachama *et al.* (2017) amongst others had put the method to test and found it comfortably comformable.

Bachama *et al.* (2017) commented thus: The Ajayi-Makinde two-electrode array, used in this work, has proved to be effective as a new geoelectric prospecting method. The depth-to-basement values obtained in this study compared well with those obtained by previous workers in the Kubanni Basin.

In the words of Yusuf and Umego (2014), the method has high depth of penetration, delineated accurately the subsurface layers and was easy to handle in the field. The method was found to be effective and highly successful.

The patent of this method was done in the year 2001.

2.3 Delineation of Geologic Boundaries

Activity concentration of radionuclides is higher in basement complex than in sedimentary terrain. This is because the major constituents of basement complex, granite, contain high concentrations of uranium, thorium and potassium. Coker *et al.* (2013) developed a technique of delineating geologic boundaries using geo-radiometric method by applying radiometric surveys to delineate between sedimentary terrain and basement complex along Abeokuta-Sagamu Road. Hand-held radiometric equipment was used to take measurements along traverses mapped out between the Governor’s office, Oke Mosan and Police College, Kobape along Abeokuta-Sagamu expressway. Furthermore, NaI(TI) detector crystal, coupled to a Camberra series 10 plus multichannel analyser (MCA) was used to analyse the soil samples collected from Sagamu (Sedimentary terrain) and Abeokuta (Basement Complex). Activity concentrations of Radium, thorium and potassium in the soil samples, coupled with the radiometric readings obtained using the hand held dosimeter were used to determine the extent of the transition zone and hence the boundary between the two geologic formations.

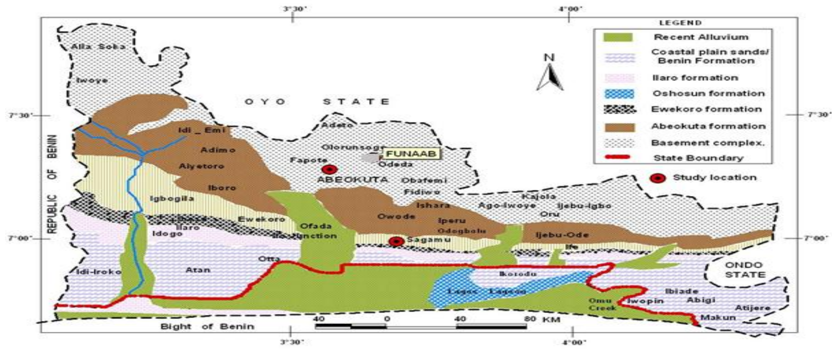


Figure 29: Geological map of Ogun State showing the study locations

Table 4: Activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil samples along Abeokuta-Sagamu Road

Soil samples	^{226}Ra (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	^{40}K (Bq kg^{-1})
1	37 ± 6	52 ± 11	80 ± 7
2	43 ± 9	37 ± 8	62 ± 11
3	41 ± 12	50 ± 13	71 ± 9
4	22 ± 7	41 ± 20	64 ± 13
5	39 ± 11	24 ± 6	52 ± 6
6	20 ± 3	33 ± 9	43 ± 10
7	17 ± 6	40 ± 11	47 ± 8
8	25 ± 10	39 ± 5	52 ± 12
9	46 ± 5	31 ± 7	83 ± 5
10	15 ± 7	20 ± 9	39 ± 8
11	32 ± 8	55 ± 14	39 ± 11
12	40 ± 12	46 ± 11	60 ± 9
13	35 ± 9	38 ± 7	53 ± 7
14	29 ± 6	30 ± 10	40 ± 5
15	24 ± 13	58 ± 14	66 ± 13
Mean	35 ± 20	43 ± 26	72 ± 48

2.4 Collaborations and Students' Works Supervision

Mr. Vice Chancellor, in the few years I had worked here, I have had the opportunity of supervising many students; more than

120 at undergraduate level, and more than 24 at post graduate level. I served as the major supervisor in the Ph.D programme of about 10, and co-supervisor to about 3. I feel delighted that God has helped these ones to successfully graduate and serving in good positions within and outside the country, especially in parts of Africa, Europe and the Americas. I particularly enjoyed the cooperation of many of my colleagues, not only in COLPHYS but also in other Colleges who together, we supervised these students and collaborated to write papers. I am greatly indebted to them.

2.4.1 Groundwater Investigation and Subsurface Characterisation

Water is an essential commodity; it is one of the core ingredient for the sustenance of life. In a typical well/borehole, the flow rate is variable so also is the water quality. The yield is usually intermittent or seasonal, not sustainable through the seasons, and the well is usually of medium to high depth.

In an ideal well, the flow rate is high, water quality is good, the yield is sustainable through seasons, and the well need not be unnecessarily deep; it could even be shallow and still possess all the mentioned properties.

Focus are thus fractured bedrock, coarse channel fill, weathered bedrock, perched water tables and high porosity/permeability confined units, porosity (primary and secondary), density, pore fluid amount and type.

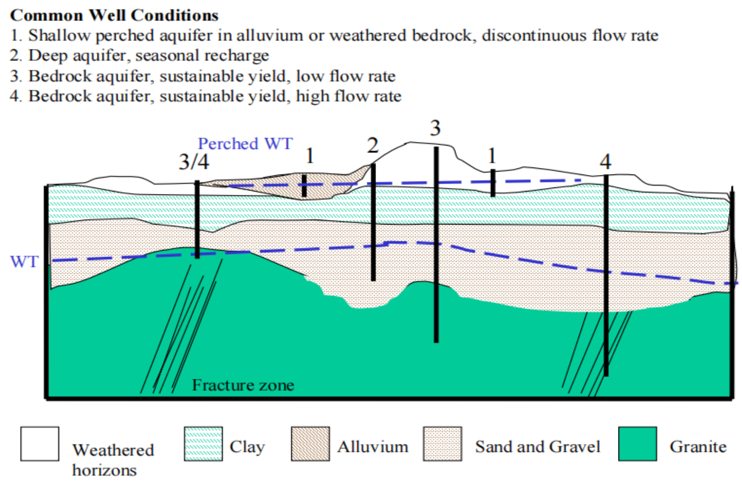


Figure 30: Typical Well Condition

2.4.1.1 Groundwater potential and subsurface characterization of Oke-Badan Estate, Ibadan

The groundwater potential and subsurface characterization of Oke-Badan Estate, Alegongo Area of Ibadan, SW Nigeria was Investigated using VES technique conducted at 21 locations Coker (2006) within the Estate. The study identified weathered and fractured horizons underlying the VES stations. It also showed that about 25% of the study area has poor groundwater potential; however, there is good prospect for groundwater development in the study area where the depth to basement is relatively thick and has favourably low resistivity values. The productive groundwater potential zones were identified at the central eastern part, and as isolated patch at the western part of the study area (Coker *et al.*, 2010).

Makinde *et al.* (2012) carried out hydro-geophysical interpretation of the VES data obtained by Coker (2006) and (Coker *et al.*, 2010). The interpretation showed three distinct layers, namely topsoil, weathered and fractured layers whose thicknesses were determined to overlie the fresh basement. The interpreted resistivity data were used to prepare the longitudinal conductance map, hydraulic conductivity map, transmissivity map, overburden map and aquifer thickness map. These maps were used to evaluate the groundwater potential as well as the groundwater protective capacity rating of the study area. The study advised that wildcat drilling should be avoided as the possibility of borehole failure in this area is very high.

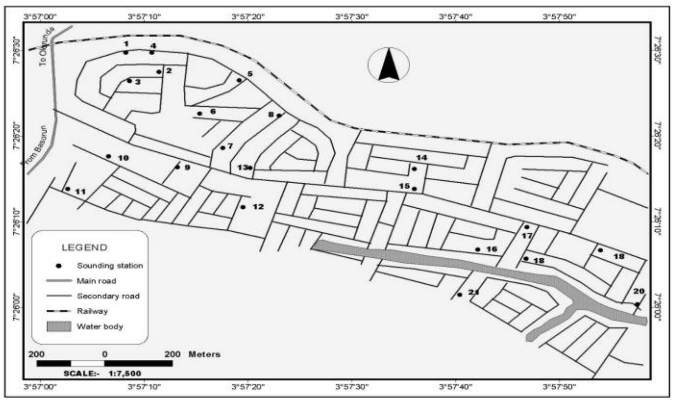
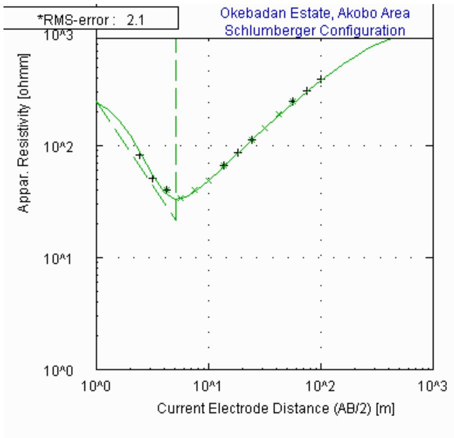
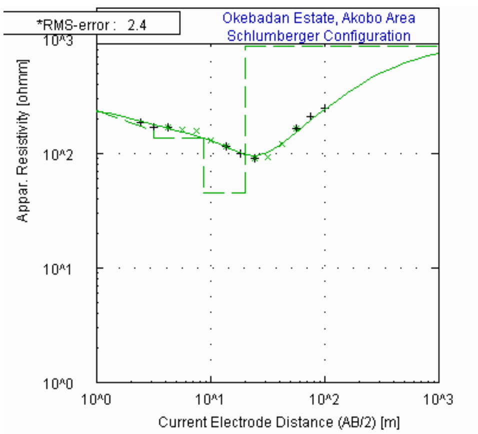


Figure 31: Location Map of Oke-Badan Estate, Alegongo showing the Sounding Points



No	Res	Thick	Depth
1	289.6	0.9	0.9
2	21.4	5.0	5.9
3	1317.5	--	--

Figure 32(a): Typical three layered VES curves



No	Res	Thick	Depth
1	697.6	0.9	0.9
2	136.9	6.7	7.6
3	23.1	7.2	14.8
4	1061.6	--	--

Figure 32(b): Typical four layered VES curves

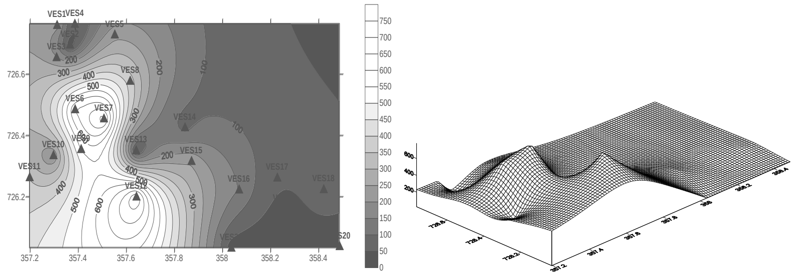


Figure 33: Typical Weathered layer resistivity 2D/3D maps

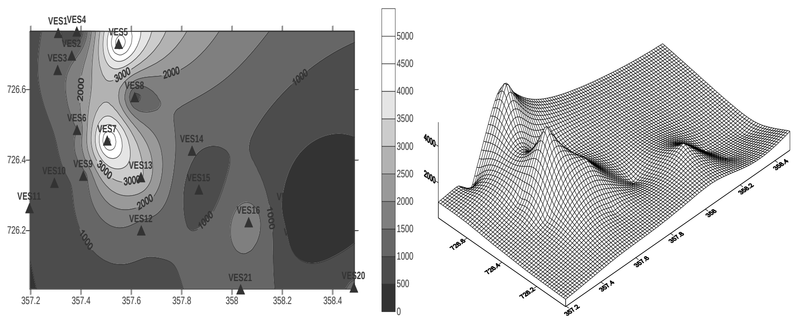


Figure 34: Typical Bedrock layer resistivity 2D/3D maps

2.4.1.2 Investigation of 40 sites in Yobe State, Nigeria

Makinde *et al.* (2010) carried out geophysical investigation at 40 sites in four broad locations in Gashua, Bursari, Bade and Jakusko LGAs of Yobe State, Nigeria, aimed at determining favourable sites for drilling of boreholes to be used as recharge sources for the supply of water for use in irrigation works. The VES Interpretation made showed that the area has thick overburden thickness and the minimum drilling depth should range from 90 to 110 m. Drilling report confirmed abundance of water at the specified depths; boreholes drilled are still highly productive all year round.

2.4.1.3 Groundwater resource investigation in Odeda LGA, Ogun State, Nigeria

Adeleke *et al.* (2015) addressed issues related to groundwater resource investigation in Odeda Local Government Area of Ogun State, Nigeria. Groundwater recharge and the recharge coefficient were determined using empirical methods applicable to the tropical zones. Related climatological data between January 1983 and December 2014 were obtained from Ogun-Oshun River Basin Development Authority (OORBDA), Abeokuta, Ogun State, Nigeria. The results showed that groundwater recharge for the area was 194.7 mm/year, evapotranspiration was 1296.2 mm/year and recharge coefficient was 20.2% for the study area. The result showed that about 11% of the rainfall infiltrated the aquifer, 73% was lost to evapotranspiration, and 16% ended up as run-off. Effort should therefore be made to reduce run-off and evapotranspiration in the area.

2.4.1.4 Evaluation of groundwater potential of Odeda LGA, Ogun State, Nigeria,

Makinde *et al.* (2016) interpreted 30 VES sounding points conducted using the Schlumberger electrode array for the evaluation of groundwater potential of Odeda Local Government Area, Ogun State, Nigeria. Four geoelectric layers were identified within the subsurface of the study area. The overburden thickness varies from 5.9 to 39.0 m across the study area. This was used to prepare the groundwater potential map which was found useful in the zoning of the area into low, medium and high groundwater potential zones. The study showed that about 60% of the study area falls within the low/medium rated groundwater potential zone while the remaining 40% constituted the high groundwater potential zone.

In essence, the groundwater potential rating of the area is generally low.

2.4.1.5 Aquifer protection studies and g/water vulnerability assessment in Abeokuta South LGA of Ogun State

Ishola *et al.* (2016) carried out aquifer protection studies and groundwater vulnerability assessment in Abeokuta South Local Government Area of Ogun State, Nigeria. Vertical electrical Soundings (VES) were carried out at twenty-eight locations with the aim of characterizing the aquifer and evaluating the groundwater potentials of the area as well as assessing its potential risk in contaminant seepage by determining the aquifer hydraulic properties and protective capacity of the overburden rock materials using calculated Dar-Zarouk parameters. Groundwater analysis was carried out to investigate the water quality for both dry and wet seasons in the study area. Interpreted geoelectric model results show that the subsurface units in the area are dominated by clayey sands of various grades, sandy clay, weathered basement and fresh basement. Existing boreholes located within the study area are characterized by confined aquifer while some are unconfined under pressure between relatively impermeable materials. Calculations of the Dar-Zarouk parameters showed that the aquifers are characterized by high transverse resistance and low longitudinal conductance, which implies that the aquifers are highly permeable with significant specific yield and storativity.

2.4.2 Mineral Prospecting

2.4.2.1 Delineation and assessment of quality of PR deposit at Oshosun, Ifo, Ogun State

Aina (2019) delineated the lithology, thickness, elemental compositions and quality of the PR deposit at Oshosun, Ifo in Ogun State, Nigeria. Vertical Electrical Soundings (VES) were conducted in the study area using Schlumberger array. It also revealed that the PR deposit has considerable concentrations of essential elements required to improve soil characteristics. However, it is of low economic value and does not have high potential of being used as feedstock for fertilizer and phosphoric acid production because of its low P_2O_5 content.

2.4.2.2 Investigation of the Ogun Phosphate Rock (OPR) Reserve in Oja-Odan

Adeleke (2022) investigated the Ogun Phosphate Rock (OPR) reserve in Oja-Odan, Southwest Nigeria Oja Odan phosphate deposit. His findings showed that the quality of phosphate from that deposit is high. The total average phosphorus content analyzed as P_2O_5 was found to be 27.85 % which fell within the standard optimal value (26-35%). This is much comparable with the quality of phosphate from the Sokoto Phosphate deposit, which quality is. This study revealed that Ogun Phosphate Rock has high potential of being used as feedstock for fertilizer and phosphoric acid production due to the high content of P_2O_5 suggesting that the deposit is of high economic value.

2.4.2.3 Investigation of activities of small-scale miners in parts of Oke-Ogun Area, Oyo State

Aluko (2021) investigated activities of artisanal or small-scale miners, which had resulted in the degradation and pollution of the environment due to inadequate knowledge of locating, identifying and quantifying the mineral deposits. The study was aimed at mapping out mineral deposits in parts of Oke-Ogun Area and assessing the level of pollution for past and ongoing mining activities. The study identified mineral deposits and assessed environmental impacts of mining activities in the study area and showed various levels of pollutions which might require regulation.

2.4.2.4 Evaluation of radionuclide and heavy metal concentrations in the pit soils of quarries

Jegede (2019) evaluated and analysed the radionuclide and heavy metal concentrations in the pit soils of selected quarries in Abeokuta using Hyper Pure Germanium (HP-Ge) gamma-ray spectrometer and atomic absorption Spectrophotometer respectively. The study revealed that the health risks associated with the heavy metal content of the quarry pit soil were low, while the radionuclide concentrations were relatively high and the use of pit soils in building constructions should be done with caution. The implication of this is that the gravels, granite and soils being used in building construction should be well tested for radioactive materials.

2.4.2.5 Investigation of existence and quality of iron ore deposit at Gbede village, Oyo State

Ogunkoya (2019) investigated the existence and quality of iron ore deposit at Gbede village, South-Western Nigeria. A 2D Electrical Resistivity Imaging (ERI) was undertaken using five (5) profiles separated 50 m apart to determine the lateral extents of the deposit. A total of twenty-five (25) Vertical Electrical Sounding (VES) using Schlumberger array was conducted arising from the results obtained from the 2D electrical profiling. The Physico-chemical analyses of water samples from proximal wells were conducted to corroborate the VES results. The magnetic susceptibility was found to be between 0.0025-0.75 m^3/kg, which showed that the deposit is likely to be of mixed grade and iron ore. The result of geochemical analyses showed that the soil samples were rich in silica, iron III oxide, and mica. The study identified iron deposit locations and offered geologic information about the iron ore deposit in Gbede.

2.4.2.6 Analysis and interpretation of airborne and ground gravity data of Gbede, Oyo State

Adewumi (2023) carried out detailed analysis and interpretation of airborne and ground gravity data of Gbede, South-Western Nigeria, using integrated techniques to characterize the subsurface for mineral potential deposits and evaluate its depths at varying locations. Ground gravity survey was carried out (in the E-W direction) in Gbede, using the LaCoste-Romberg Gravity Meter G-309. Geochemical analyses of Iron-Ore samples were also carried out to determine the ore's mineralogy, chemical composition and the level of soil contamination using Energy-Dispersive X-ray Fluorescence (ED-XRF), X-ray diffraction (XRD) and Atomic-Absorption Spectrophotometer, respectively. The ED-XRF Spectrometric result showed low mean concentration of 0.33% for CaO while a high mean concentration of 41.79±8.66% was obtained for Fe_3O_4, which indicated that the deposit belonged to the magnetite facies, and is of high quality. It revealed that Gbede Iron deposit lied at low depths, which can be easily exploited for usage in iron and steel industry for economic growth.

2.4.3 Environmental Geophysics and Contamination Problem

Engineering and environmental geophysics are becoming increasingly important in the management of our environment.

A further major advantage of the use of environmental geophysics in investigating sites is that large areas of the ground can be surveyed quickly at relatively low cost. This provides information to aid the location of trial pits and boreholes.

In mapping abandoned industrial sites, identifying sink holes location, or dump sites for instance, while locating trial pits and boreholes may provide a means of accessibility to the contaminant, it will not however be able to give a mapping and assessment of the lateral and vertical extent of the advancement or progression of the contaminant plumes underground and how it has impaired the underground water system. The easiest method to give continuous monitoring will therefore be the application of geophysical techniques.

Figure 35: Dumpsite within Residential Area

In essence, by experience and exposure, it is dangerous to build near sources of contaminants such as dumpsites and factories giving out effluents. The underground water system would be impaired no matter how long it will take except if the source of contamination is cut off, even in areas where underground petrol tanks are leaking.

2.4.4 Subsurface Characterisation, Foundation Stability and Failures

In order to mitigate building collapse or road failure, it is necessary to carry out geophysical studies characterizing the subsurface and therefore complement the soil analysis work and give a lead to structural engineering works in buildings and road work. Some of such investigations are here reported.

2.4.4.1 Investigation of a proposed Lecture Theatre at FUNAAB

A combined geophysical and geotechnical investigation of a then proposed Lecture Theatre at the Federal University of Abeokuta, was carried out for the purpose of characterizing, understanding and hence evaluating the competence of the subsurface formation/structure as foundation materials. To image the subsurface, Electrical Resistivity Imaging (ERI) and soil analysis techniques were adopted. Four geoelectric layers, namely topsoil, sand clay/clayey sand, weathered rock and fractured/fresh basement were delineated from the geophysical results.

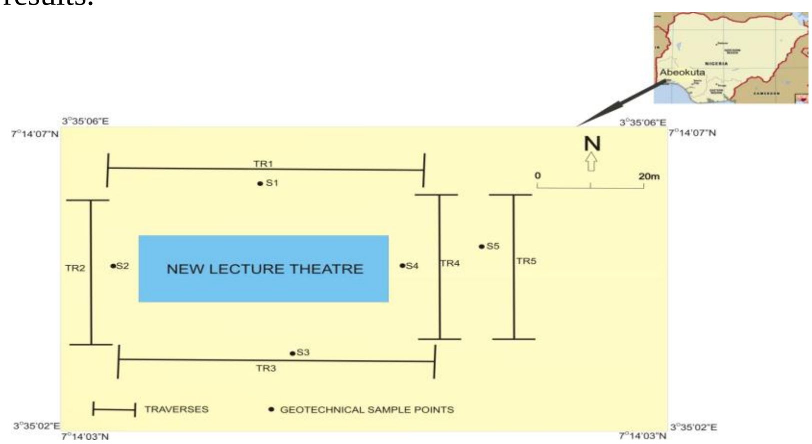


Figure 36: Data Acquisition Map of the Study Area showing Traverses and Geotechnical Sample Points.

Electrical resistivity imaging was carried out along five (5) profiles laid around the proposed lecture theatre location (Figure 36) in order to delineate the resistivity of the subsurface materials. The resistivity data were recorded using PASI-Earth (16GL-N) Terrameter, 220m long, at inter-electronic spacing ranging from 10m to 50m.

The collected resistivity data were processed by means of Earthimager modeling software in order to give 2D geo-electrical data inversion. The starting mode was constructed directly from the field measurements and data were processed to produce colour cross-sections which indicate variation of earth resistivity values with depth.

The geotechnical method on the other hand employed the use of Auger to collect five disturbed soil samples. The samples were preserved in a labeled polythene bags and transported and kept at the Department of Civil Engineering soil laboratories, Federal University of Agriculture, Abeokuta.

For all the soil samples collected, methods of testing soils for engineering parameters were conducted in accordance with B. S. 1377. In this study, the tests conducted include natural moisture content, liquid limit, plastic limit, plastic index, swelling potential.

Figures 34 to 41 show the inverted resistivity sections of the electrical resistivity imaging for the *interpretation of results* obtained. All the profiles presented have relatively high resistivity value greater than 450 ohm-m as the topsoil inferred as laterite/sandy material with a thin thickness of value less than 2m.

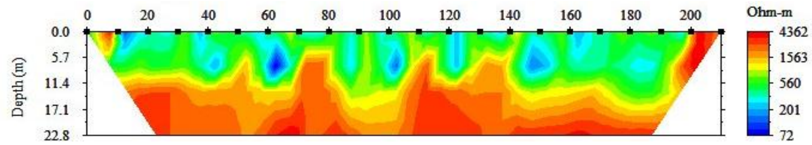


Figure 37: Inverted Resistivity Sections along Traverse 1

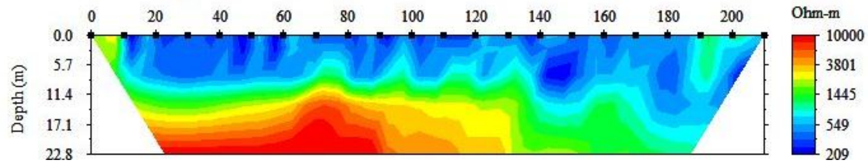


Figure 38: Inverted Resistivity Sections along Traverse 2

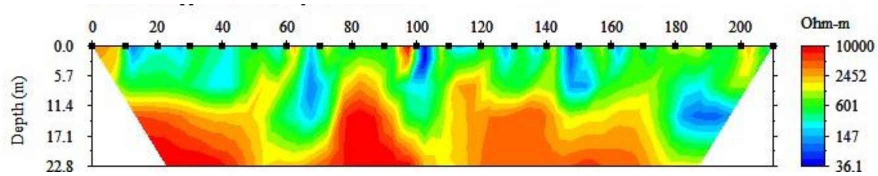


Figure 39: Inverted Resistivity Sections along Traverse 3

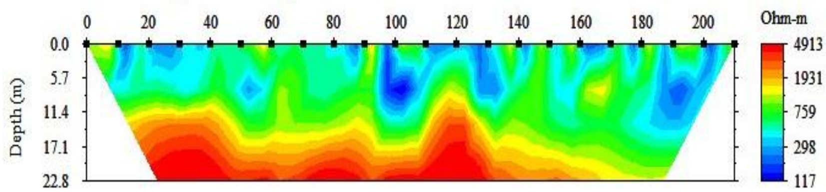


Figure 40: Inverted Resistivity Sections along Traverse 4

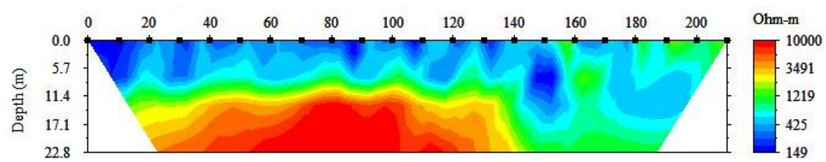


Figure 41: Inverted Resistivity Sections along Traverse 5

The summary of the *geotechnical results* is shown in Table 1. The natural moisture content of the tested soil samples gave a range of values from 10.40 – 15.89%. The result shows that at its natural state, the natural moisture content of the soil in the area is relatively low. Jegede (2000) says moisture variation is generally determined by intensity of rain, depth of collection of sample and texture of the soil.

Table 5: Summary of the Geotechnical Results

Sam-ple No	Natural Moisture Content %	Percentage Passing (0.075mm)	Liquid Limit %	Plastic Limit %	Plastic Index %	Swelling Potential
1	15.89	43.27	15.4	0 NP	15.4	4.28
2	14.69	31.61	20.9	13.3	7.6	1.32
3	10.40	39.59	9.99	0 NP	9.99	2.26
4	12.75	35.75	17.2	9.3	7.9	3.82
5	11.92	41.16	11.3	0NP	11.3	2.75

The percentage finer (percentage passing 0.075 mm) of tested soil ranges from 31.61 to 43.27%. Thus the average value is 37% which is closer to the maximum value of 35% recommended by Federal Ministry of Works and Housing (FMWH, 1972) for a foundation material, hence the soil samples for the study is rated as fair to good sub-grade foundation material. Akintorinwa and Adeusi (2009) says that soils that are largely made up of fine particle are likely to have poor geotechnical properties as foundation materials than soils that are largely made up of coarse particle.

The liquid limit of the soil samples, the plastic limit of soils and the plastic index (Liquid Limit-Plastic Limit) of the soils ranges from 9.99-20.9%, ONP – 13.3% and 7.6-15.4% respectively.

The recommended value by the Federal Ministry of Works and Housing (FMWH, 1972) for liquid limit, plastic limit and plastic index are 50%, 30% and 20% respectively. In the study area, it is shown that the maximum value of the liquid limit is 20.9% less than 50%. Adesodun and Kolade (2000) says that liquid limit value greater than 50% is interpreted as poor foundation materials but if less than 50%, it gives clay type called kaolinitic in nature which is not a big threat to foundation.

The plastic limit value range between ONP-13.3% thus the location with non-plastic (NP) has very low clay content and the maximum value is less than 30% thus the location is safe for foundation structures. The maximum plastic index value of 15.4% recorded in the study area is less than 20% thus, the tested soil samples are of low consistency limits indicating low percentage of clay content in the soil hence, it shows a good engineering property since the higher the plastic index of a soil, the less the competency of the soil as a foundation material.

The swelling potential was calculated using non-linear relationship between plastic index (PI) and swelling potential (S) given by Gromka 1974 with equation: $S = (2.16 \times 10^{-3})\ PI^{2.44}$. The value is range between 1.32-4.28 interpreted as low to medium using the categorization proposed by Ranaganatham (1965) and Adesodun and Kolade (2000).

Integration of *geophysical and geotechnical results* show that all the five traverses of electrical resistivity images highlight a sub-surface of sandy materials sand witched by pockets of clay. The presence of non-plastic in the plastic limit parameter in the study area depicts a very low clay content which is safe for foundation works/structures.

The topsoil constitutes the layer within which normal Civil Engineering foundation is founded. The layer is composed of laterite and sandy materials.

Foundation competence of the topsoil can be qualitatively evaluated from layer resistivity and geotechnical parameter. According to Akintorinwa and Adeusi, 2009, the higher the layer resistivity value, the higher the competence of the delineated topsoil units, followed by clayed sand and sandy clay being the least competence.

The Federal Ministry of Works and Housing (FMWH, 1972) says the higher the geotechnical parameters of a soil, the lesser the competence of the soil as a foundation material hence, the recommended value for liquid limit, plastic limit, and plastic index are 50%, 30% and 20% respectively.

In the study area, the values recorded are lower and falls within recommended value and thus the higher the competence of the soil as a good foundation material.

The geophysical electrical resistivity imaging revealed maximum of four geoelectric layers within the study area which comprises of topsoil, sand clay/clayey sand, weathered rock and fractured rock/fresh basement. The topsoil’s are generally and majorly composed of laterite and sandy materials.

The geotechnical results show that the soil samples are gradually of low material moisture content and relatively low clay material as revealed by the plastic index of the soils within the area, which is less than 20% and interpreted as low consistency limits and the soils exhibited low to medium swelling potential indicating low percentage of clay content in the soil. The results of the geotechnical method showed that the soil has relatively low clay content.

Hence, an integrated geophysical and geotechnical investigations offer very useful approach for characterizing subsoil and thus can provided information in early preparation before foundation structures are made on the land.

It was then concluded that the subsurface on which the 2,500 seater building structure was to be located is safe, healthy, and fairly competent for any engineering works (Coker *et al.*, 2013). Results of the geophysical survey showed that the competence of the subsurface is not in doubt, the building is safe, healthy and in good standing.

Mr. Vice Chancellor Sir, Ladies and gentlemen, it is concluded from the integrated results that the subsoil on which the lecture theatre structures is sited within the study area is safe and fairly competent for any engineering work; and here we are today in the building erected on that geophysically surveyed area, the Professor Olaiya Balogun Lecture Theatre. The building is therefore in good standing.

2.4.4.2 Foundation failure investigation at an educational institution in Sagamu, Ogun State

Coker *et al.* (2013d) used Electrical Imaging technique to investigate foundation failure at an educational institution site in Sagamu, SW Nigeria. by taking seven traverses of Wenner configuration and two VES per traverse. The geophysical results revealed four geoelectric sequences, namely: topsoil, sandy clay, clay and coarse sand within the study area. The 2D inverted resistivity of the profiles shows that the foundation depths of the site are predominantly characterized by clay and sandy clay soil. Many buildings in the site show several cracks, from root to roof, and uneven settlements of the structures are invariably attributable to the presence of clay. The presence of clay is viewed as being inimical to foundation health due to its low load bearing capacity and its uneven expansion and contraction when it absorbs and releases water.

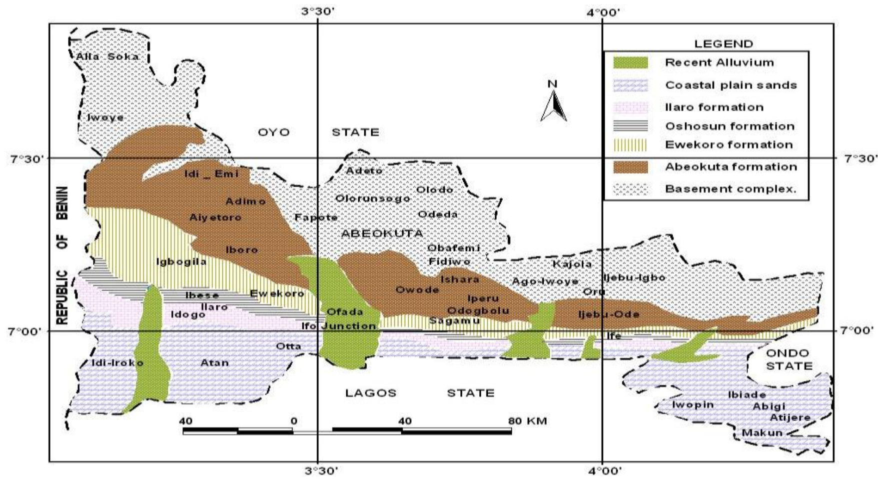


Figure 42: The Geological Map of Ogun State

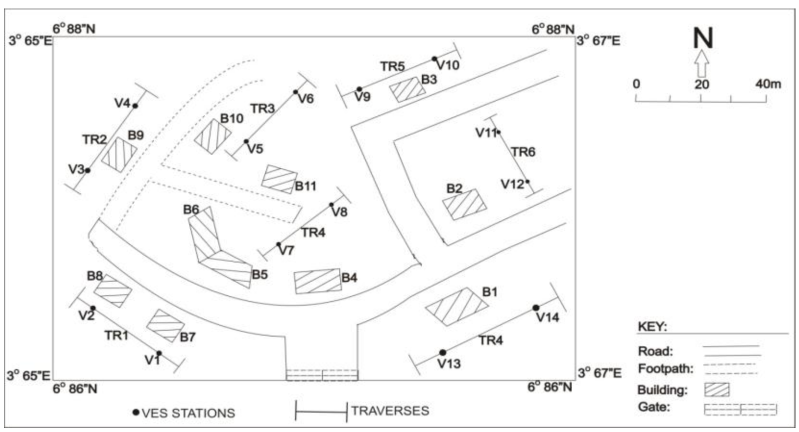


Figure 43: Data Acquisition Map of the Study Area Showing Traverses and Vertical Electrical Soundings (VES).

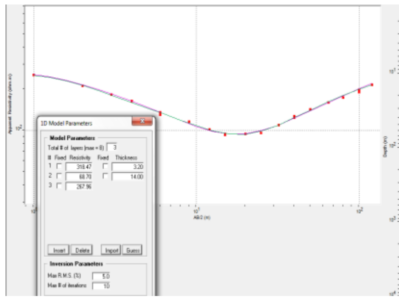


Figure 44: Typical 3 Layers Type Sounding Curve

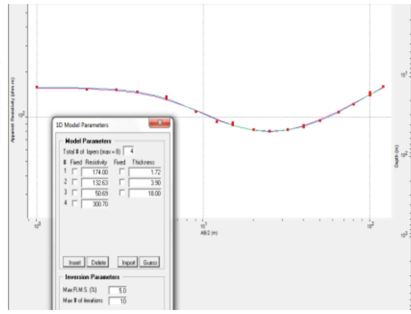


Figure 45: Typical 4 Layers Type Sounding Curve

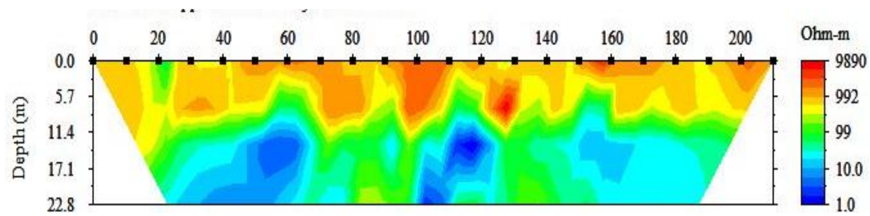


Figure 46: Inverted Resistivity Sections along Traverse 1

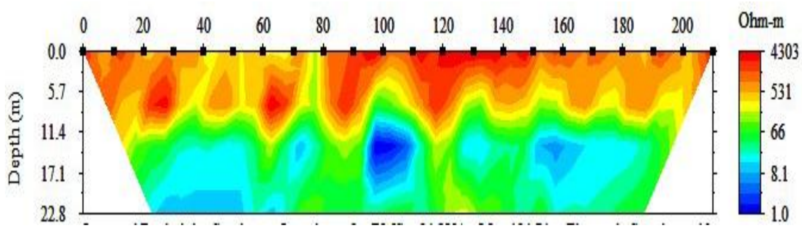


Figure 47: Inverted Resistivity Sections along Traverse 2

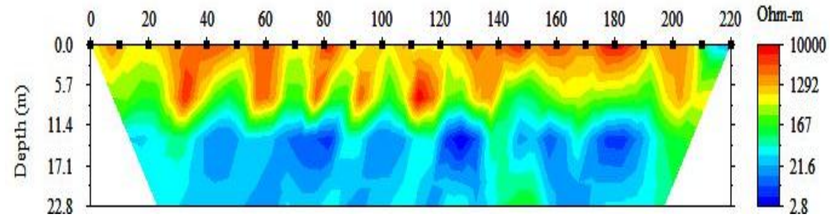


Figure 48: Inverted Resistivity Sections along Traverse 3

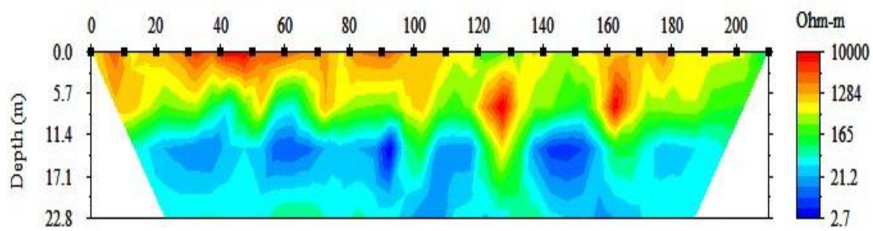


Figure 49: Inverted Resistivity Sections along Traverse 4

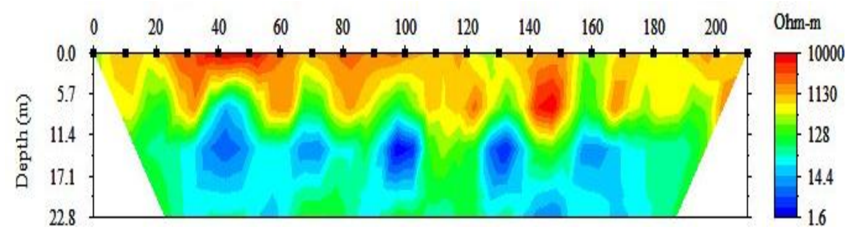


Figure 50: Inverted Resistivity Sections along Traverse 5

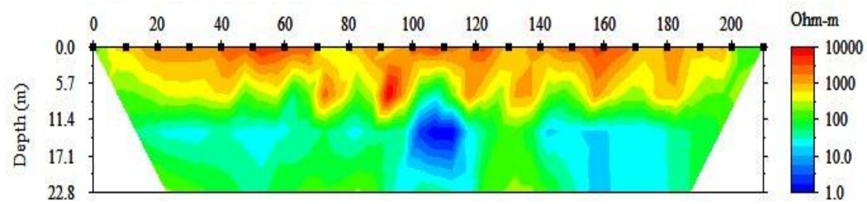


Figure 51: Inverted Resistivity Sections along Traverse 6

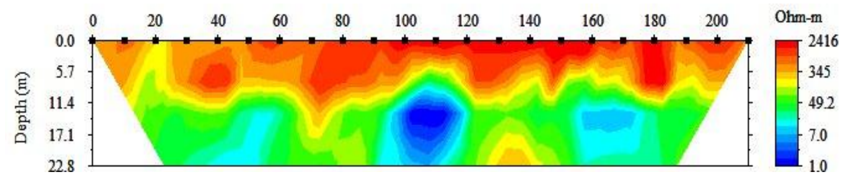


Figure 52: Inverted Resistivity Sections along Traverse 7

2.4.4.3 Characterising the subsurface structure and identifying cause of dampness visible on some buildings

The Supervisors and a group of 400 Level students, 2023/2024 Set, worked along the PG School/COLERM Phase 2 Axis). The aim was to characterise the subsurface structure and identify the cause of dampness seen on the footwalls of some of the buildings. The result of the 2D pseudosection suggests a subsurface profile with a more conductive (possibly clay-rich or moist) surface layer, transitioning into more resistive bedrock at depth.

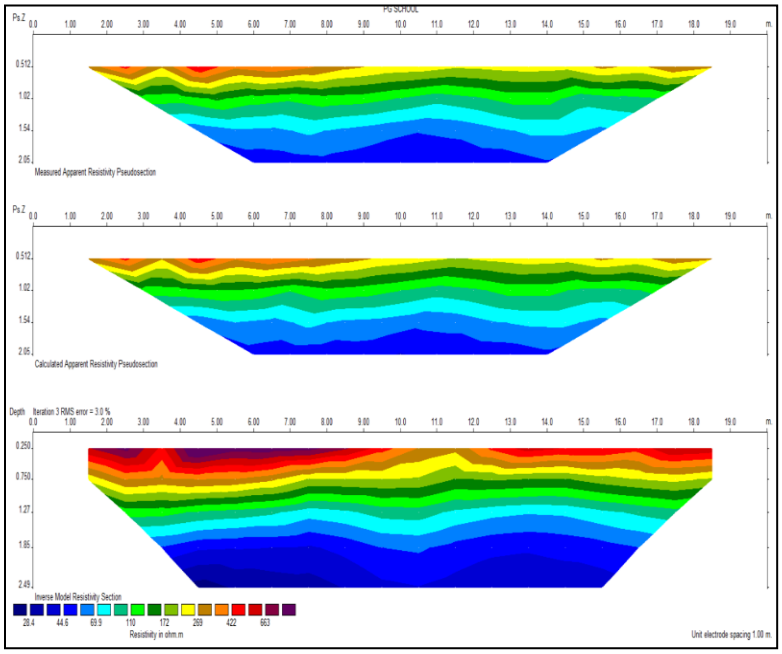


Figure 53: Composite Plot of Pseudo-Section Result of 2D Resistivity Inversion

The high resistivity values at deeper levels likely correspond to the competent granite or migmatite, consistent with the geology of the FUNAAB area as depicted in the map. The lateral variations in resistivity might indicate differences in weathering, moisture content, or lithology, possibly related to faulting or other geological processes. Based on the geophysical data and geological context, buildings in this area will experience dampness in their foundations. Borehole trapping and pumping machine failure can also be experienced if there is creeping and the casement does not reach the maximum depth.

The low values near the surface indicate high moisture content, meaning that the water table is high, which can lead to damp conditions in the foundation, potentially causing structural damage and deterioration. Unless proper waterproofing measures, robust construction techniques, and effective drainage systems are employed, the building's integrity may be compromised, resulting in costly repairs and maintenance. It is recommended that repair works on the cracks (if any) be done and affected damp areas be replastered. All visible cracks and damaged plaster should be repaired using appropriate materials that are resistant to moisture. Drainage around the building should be improved.

2.4.4.4 Investigation of the agricultural soils of Eweje Farm Settlement and IAR&T Farm (Agricultural Geophysics)

Aikhuele (2024) investigated the agricultural soils of Eweje Farm Settlement (Odeda LGA, Ogun State, Nigeria) and IAR&T Farm at Odogbolu (Ikenne LGA, Ogun State, Nigeria).

His findings indicate that the soil in Eweje farm is composed of sandy clay soil that extends to a depth > 2.5 m with saturated zone for planting of crops. SHC variation is controlled by the presence of moisture content (MC). A soil with high SHC exhibited low temperature change and vice versa. This indicate that the soil in Eweje farm is good for crops as the temperature will not affect the crops much.

At the IAR&T Ikenne farm, the SHC of the soil can be classified as moderate range (1.67 – 2.90 mJ/mK) (Reynolds *et al*, 2007), indicating that the soil is good for crop germination, and that deep-rooted plants can be cultivated in the farmland. Based on the optimal value required for infiltration rate as suggested by Reynolds et al., 2007 to be 1.8 to 18.0 cm/hr, the soil in the study area indicate abundance as an effect of low infiltration and drainage to allow adequate water sorption into the soil matrix.

2.5 Effects of Sub-Surface on Building

2.5.1 Cracks, cracks everywhere (The poor do cry)

This example was taken as a split shot of a building in distress as a result of its being located on a near surface aquifer. This kind of occurrence is no respecter of any building, be it bungalow or high rise, pavement and footings of the building are not spared for as long as the foundation sits on incompetent layer, clay, or a near surface aquifer.

Figure 54: A simple bungalow in distress

2.5.2 Sinking Building (The rich and government also cry)

The impending situation, of this building, although not much physically visible at that time, was first observed in 1990. Most students called it then “the sinking building”. Egwonwu, Ibe and Osazuwa, in 2011, therefore conducted a thorough investigation of the high rise hostel building (Egwonwu *et al.* 2011).

The study site is a three-storey students' hostel building which consists 48 rooms in a university. It was constructed in 1975 using masonry blocks. The topography of the building's site is relatively flat with a minor gentle slope trending in north-south direction. Vertical, diagonal and horizontal cracks are shown on most parts of the building walls. Some of the cracks are rooted from the building's foundation; however, some diagonal cracks which are rooted at the corners of the building have put the superstructure at high risk.

Electrical resistivity imaging was carried out along eight (8) profiles laid around the building under study in order to delineate the resistivity of the subsurface materials. The technique was used so as to delineate the overburden, weathered zones, fractured columns and where possible, the bedrock at the site. Apparent resistivity data were collected with a Lund Imaging system comprising *Terrameter SAS 4000* and Electrode Selector *ES464* which is a relay switching unit having 42 electrode takeouts. Six (6) out of the eight (8) profiles for the resistivity survey were laid in N-S direction while the other two (2) were laid in W-E direction. Electrode spacing ranged from 1.50 m to 5.00 m depending on the length of each profile which depended on available space.

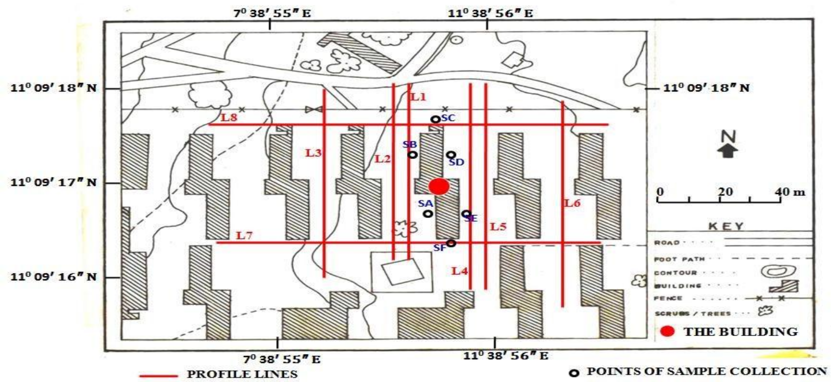


Figure 53: Study Site showing the profile lines occupied for the investigation and the points of sample collection

RES2DINV Ver.3.4 issued by "Geotomo Software" was used for the processing of the raw data. The software automatically determines a two-dimensional (2-D) resistivity model of the subsurface (Griffiths and Barker, 1993). A forward modeling subroutine was used to calculate the apparent resistivity values, and a non-linear least-squares optimization technique (deGroot-Hedlin and Constable 1990, Loke and Barker 1996), was used for the inversion routine based on the smoothness-constrained least-squares method (Sasaki, 1992).

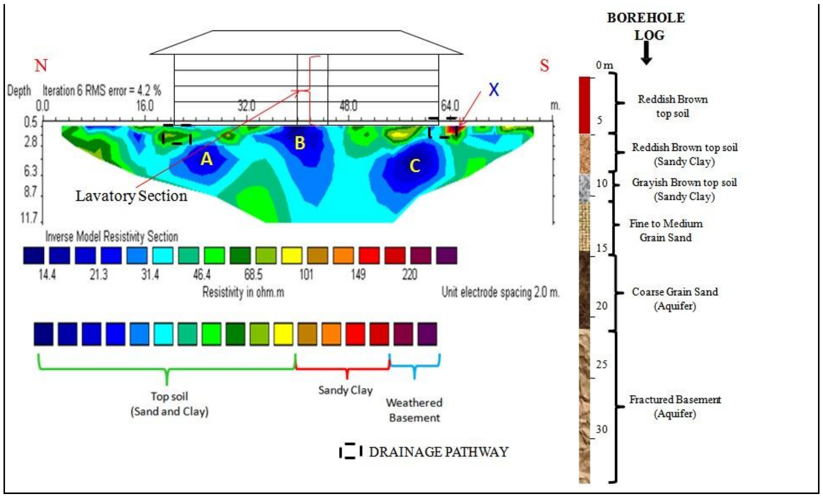


Figure 56**:** Typical 2D Inversion Model Resistivity Section

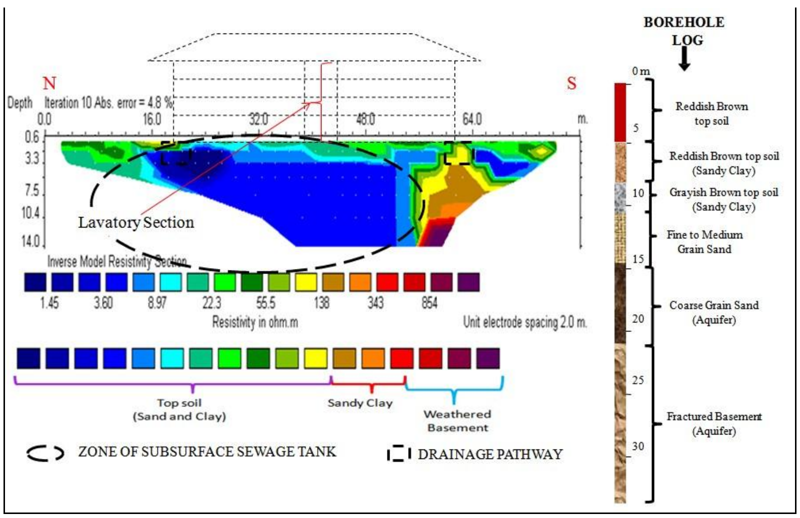


Figure 57: Typical 2D Inversion Model Resistivity Section

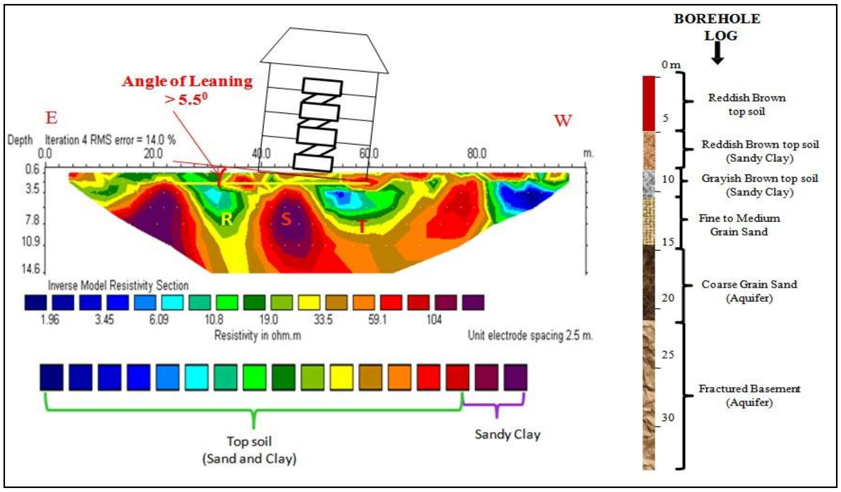


Figure 58: Typical 2D Inversion Model Resistivity Section

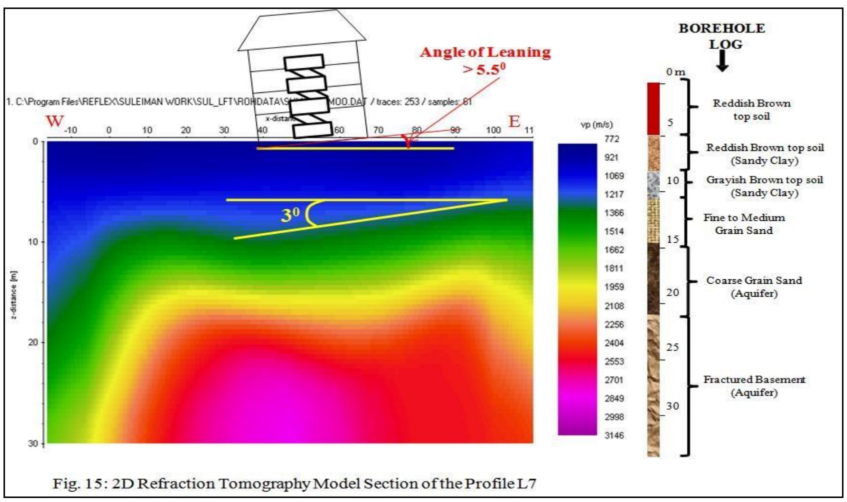


Figure 59: Typical 2D Refraction Tomography Model Section

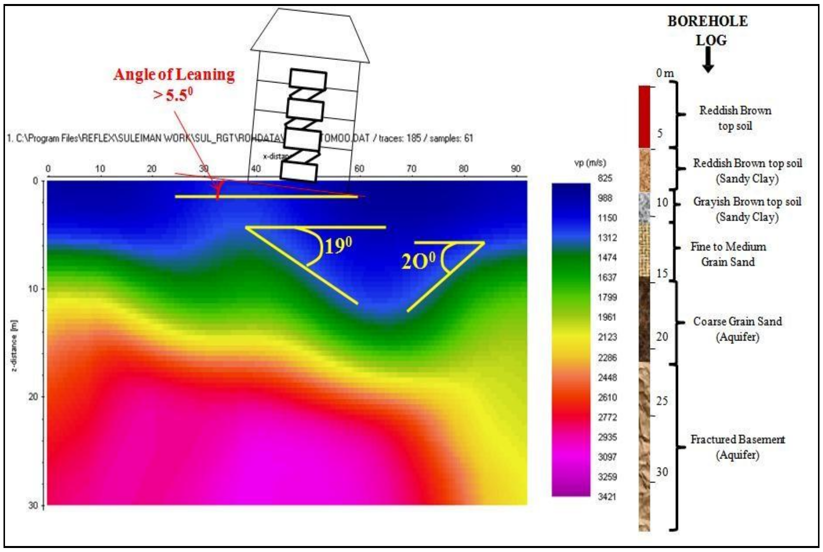


Figure 60: Typical 2D Refraction Tomography Model Section

The building foundation is therefore compromised. It is therefore clear that, not that this building was constructed with substandard material but that the subsurface had issues which eventually caused the loss of this multi million Naira building, however, this time at no cost to lives due to early observation, vigilance and prompt action.

2.5.3 Remediation of Distressed Building

The Lecture Theatre shown was built on a large aquifer. According to history, initially the pavement and inner floor of the building was breaking up and giving way.

Figure 61: Lecture Theatre sited on aquifer

However, as a way of remediation, borehole was drilled into the underneath to extract the water from beneath. Observation was that large volume of clean water flows from underneath the building almost throughout the year for many years, until recently when the flow ceased, probably due to blockage of the conveying pipe as new constructions came around the building or another sign of low underground recharge. For the long years that the flow was active, two things were noted (i) the breakup ceased and the pavement restored (ii) in the years when the flow was not strong and the flow duration short, slight drought and general water shortage were observed in the city. This therefore served as a seasonal variation monitoring system.

The lessons to learn are that:

i) Everyone who intends to build would make a wise decision by undertaking geophysical surveys for adequate planning of space and peace of mind, even if government did not request for it before approval of building plan.

ii) New approaches to construction of buildings should be made, especially to perimeter pavement, drainage and lavatory effluent discharge.

3.0 CONCLUSION

One of the ethics of Geophysical research and practice is that under no circumstance should one divulge critical information, especially of subsurface resources, about our country to foreign elements. This has implications for national security. However, foreign tricks in the form of grants, assistances etc., cohesion in the form of visibility and indexing, among others, have made some to be swayed away from this vital aspect of academic research. This is also applicable to other disciplines. The GMO issue is something we should be very careful about in order not to mortgage the future of our race, kill the natural cultural seeds, put our offspring into perpetual bondage and slavery, if not that they could be wiped off the surface of the Earth eventually.

The creator of this universe had taken time to test the viability of life on Earth starting with simple life to complex one. From plant life to dinos to humans; the most destructive are the humans. Who comes next. We should tend this planet for it to sustain us for long. Man should be careful not to destroy himself.

4.0 RECOMMENDATIONS

The following recommendations are made based on my experience in the field of Geophysics.

4.1 Suggestions to Government

Nigeria is a country highly blessed and endowed with great resources, both human and material.

i. Mining activities in the country should be highly regulated for government to get maximum benefit from her natural resources. All mineral sources in the country should be coded in line with international standards and good practices.

ii. More water projects should be executed for communities not presently served by municipal pipe-borne water projects.

iii. Delivering water of good quality is very necessary; sourcing for this rest solely on the shoulder of geophysicists. Drilling of boreholes should be regulated to avert future disaster. For research purposes and policy buildup, organisations and drillers should be compelled to log and register any borehole drilled so that somebody can take responsibility for work done.

iv. Government should greatly discourage the setting up of dumpsites and other pollutant sources such as petrol stations around living areas and communities in order to avoid contamination of groundwater sources and minimize health risks.

v. Geophysics is becoming a good ground for providing mass employment, especially in water and solid mineral prospecting. The field should therefore be made attractive to youths. Its cost of service should also be regulated to encourage people to go into it.

vi. Geophysics equipment are highly expensive; there is need for better funding, equipment buildup, and support from government for institutions offering geophysics programme.

vii. A specialized institution of the training of geoscientists, geophysicists in particular, will need to be put in place. An institution such as the Federal School of Survey, Oyo, can be converted to a university of geophysical sciences under the supervision of the appropriate ministry should be put in place; this can be replicated in other zones of the country

4.2 Suggestions to the University

i) This university should be proud of its geophysics programme as taught at postgraduate level in the Physics Department. It has trained many geophysicists serving in many companies and institutions of higher learning. It also has many young seasoned geophysicists in the Physics Department who will form the backbone of development of this institution. Geophysics is a discipline that demands very strong knowledge of Physics, Mathematics and Computation with support from Electronics and Geology. This should flow down to the undergraduate level, making the Discipline to stand on its own.

ii) Geophysics equipment are pretty expensive. Standard training equipment should therefore be purchased and geophysics laboratories set up for the training of our students; field school vehicles (not cars) important for field work while field assistants and technicians are highly needed for follow-up.

iii) Geophysics unit should be incorporated into the physical development team of the university, being made to carry out geophysical survey first and work with relevant units in sister departments to handle the geotechnical aspect to deliver long lasting infrastructures.

iv) College of Earth Sciences should be established in this university. This will house the Departments of Geology, Geophysics, Geochemistry, Meteorology, Marine Science and Technology, Remote Sensing and Geo-Information Science; all these as stand-alone departments without any being subdued under another. This University is equally overripe for expansion and yearning for the setting up of Departments of Building, Computer Engineering, Biomedical Engineering, Medical Physics, Physics with Electronics, to mention but a few.

5.0 ACKNOWLEDGEMENTS

I thank the Vice Chancellor, Professor O. B. Kehinde and his management team for the good work they are doing and for the opportunity given to me to make this presentation.

I wish to acknowledge all my teachers from Primary to Tertiary School. I specially thank my Headmaster, Mr. Bamiduro, who used to come every morning to my parents and take me to stay with him throughout the day. I ended up becoming omo headmaster and got enrolled.

I thank all my secondary school teachers who drove sense into my brain.

I appreciate all my Instructors and lecturers. Immense thanks to Prof. P.C. Pal, who brought me into Geophysics and all other lecturers Baba Prof. T.O. Aro, Prof. D.K. Bamgboye, Prof. J.O. Oyinloye, Prof Balogun Chike-Obi, Prof J.J. Fletcher, Dr. Joe Ogunniyi, Profs C.O. Ajayi, S.B. Ojo, I.B. Osazuwa, M.N. Umego, Dr. Peter Sule, among others. I appreciate my benefactors Profs S.A. Alagbe, B.W. Jimba, T.C. Akpa, Dim1, Dim2, I.O.B. Ewa, Victor Obiosio, Najime, Tunji Solomon, Lohdip, Kola Lawal, Kola Ibikunle, Paul Eseyin, Ayo Onifade, among others.

I thank my dutiful, disciplined parents, our good friends, who held tight my siblings, myself and others who lived with us like the sun held the planets under rules, good behaviour and conduct. May their souls rest in perfect peace.

I thank my siblings for being great friends and being good examples to me. May their souls rest in perfect peace.

I thank my uncles and big Daddies with our mummies on all sides: Prof. Ogungbile, Daddy Aremu (Agbe o gbinyo), Prof. Afolabi Adedibu and all my other ‘egbons’, uncles and aunties. My younger ones along that line, I say thank you. I thank my in-laws: Baba Prof. S. O. and Mama Prof. (Mrs) T. O. Ojo, and my younger ones from that end and their family members, Uncle Deji Ojo, I thank you for being here today.

I appreciate all my friends, classmates and coursemates: Profs M. O. Ajewole, Bola Eleruja, O. Adetogun, and others along that line; Captain Funsho Ampitan, and others. General Paul Adefisan, Ikpehia and others along that line.

I appreciate all the people I came across here and all others I made in different places; wonderful people, good people, great people.

I cannot but thank my “brothers” and their spouses: Dr. Peter Matemilola, the Olanloyes, Macaulays, Ajogbejes, JayKing, among others.

I thank Demolant, Aussie and children, Nath, Glo and children, so also Biola, Ronke and children. Mr. and Mrs Morounke Mannie-Udoh and children, Mrs. Olatunji and children, Dr. Mrs Hamzat and children, Profs Sowemimo, Soretire, Idehen and Aderibigbe and families, I salute you all. Prof. Ufoegbune and other members of BISCOM B, PG School, I enjoyed working with you.

I thank Prof. Goke and Prof. Helen Bodunde, and Prof. Olufemi and Prof. Comfort Onifade, who took us in when we first got here.

I appreciate all my then students, now colleagues and friends, who gave me the opportunity to guide their thoughts and supervise their work; they are many but those I can remember and constantly in touch with, I list: Prof. J.O. Coker, Drs. S.A. Ishola, T.J. Aluko, O.O. Adeleke, Femi Adewumi, Charles Ogunkoya, D.O. Aikhuele, Seyi Jegede, Abel Oladejo, H.A. Edunjobi (in whose work I served as a co-supervisor), Johnson O. Aina, Osita Anyanwu, Agboola Ayobami and a host of others.

All my colleagues in the Physics Department and the College, and all our non-teaching staff are highly appreciated.

I acknowledge and appreciate those with whom I had co-supervised students: Prof. J.K. Adesodun, Prof. A.O. Eruola, Prof. B. Bada, Prof. J.O. Busari, Prof. A. Adetunji, Prof. O. Akinyemi, Prof. B. Kuye, Prof. J. Akinyele, Prof. A. Badejo, Drs Olurin and Ganiyu (AbdulG), Adebambo, Egunjobi and Kehinde Ajayi, the engine valves of Physics, for being highly disciplined, dutiful and always available to help. I also thank Profs. Adebayo, Badmus and Akinlami for their support always; so also, Pastor Ishola, Mr. Akinnuoye, Mr. Macaulay, Mrs. Usidame, Mal. Umar, Mr. Akinbola, Mrs. Soaga, Mrs. Jeje and Mr. Omigbenle.

I thank all my colleagues in the Physics Department and in the College and all our non-teaching staff.

I thank those with whom I had co-supervision of our students: Prof. Adesodun, Prof. Eruola, Prof. Bada, Prof. Busari, Prof. Adetunji, Prof. Akinyemi, Prof. Kuye, Prof. Akinyele, Prof. Badejo and Dr. Ganiyu.

I also thank all those with whom I had joint publications and therefore contributed to my success: Profs. Mustapha, Okeyode, Akinboro, Adetunji, Layade, Alabi and Alatise.

I thank Dr (Mrs) Akinhami and Prof. Soretire, especially for her exemplary headship and comforting words. I thank my former HODs; Prof. G.A. Adebayo and Prof. B. S. Badmus.

I specially appreciate my Dean, Prof. Akinwale for his good heartedness, Mrs Akinhanmi, so also once again. Prof. Mustapha. Really, you have all been good to me. Thank you all for your brotherliness, good leadership and partnership.

I specially thank my present HOD, Prof. Itunu Comfort Oloyede.

I thank Pastors Oyetoran, Ayangunna, Ojo, Olukitibi, Adeosun, Adewunmi; Alh. Akanbi, Prof. Sherif Adewuyi and all other friends, brothers and sisters from all faiths, Pastors, Sheiks, Imams, etc. I also thank all members of the Bible Society of Nigeria (BSN), Gideons International and other church members.

I appreciate the strong presence of the Nigeria Institute of Physics, led by her President, Prof. J.O. Coker.

I give my respect to all my departed friends and colleagues, principal among whom are Drs. John Adigun, Albert Ehiozuwa, Segun Oduleke an C.O. Oyedeji, Profs. Femi Onifade, Femi Odekunle, K. Okeleye and Bimbo Ladokun; Mr C.Y. Obieje, Uncle Paul Babalola, Justin, Mal. Umar, and a host of others I might have forgotten or never knew had passed on. May God grant them eternal rest.

To members of my nuclear family, beginning with Prophets Elijah and Elisha (Taiwo and Kehinde). Thank you for being good children and teachable. May God bless you and continue to take you to higher heights. To my wife, the Vice President and my own jewel of inestimable value, Folasade Adeola, Mama Yer'Sam. I most sincerely thank you for being part of the journey of my life and success story. I appreciate you for not stressing me. I pray God to bless you with sound health and long life.

Ladies and gentlemen, the trajectory of life ends at death and finally terminates in the petrologic supermarket, to join others who had lived and gone before. It is at that point that the equation of life as given in Eccl. 2:11 will be better understood.

Therefore, it is not of him that willeth, nor of him that runneth, but of God that sheweth mercy (Rom. 9:16). For this God is our God for ever and ever: He will be our guide from now even unto death (Ps. 48:14). To all who will come forward after me, to present their inaugural lectures, I wish you well.

To God Almighty, I say thank you.

APPRECIATION

Whatever God does, is well done.

I sincerely, once again thank the Creator of the Universe, the God of abundance and of all possibilities, for making this happen.

I cannot thank God enough for my country Nigeria. I thank my country for also giving me the opportunity to be, for the tuition free education given to me over the years and for the goodwill, despite all odds. GOD BLESS NIGERIA.

I want to appreciate all teachers, and in general, all staff in our tertiary institutions, especially those who do their work conscientiously.

I appreciate all the institutions that invested and produced me. Thank you.

Walter Rodney wrote brazenly on "How Europe underdeveloped Africa". I know the spectacle will be worse if one should write on "How Africans underdeveloped Africa", or worse still on "How Nigerians underdeveloped Nigeria", "Recolonisation of Africa by Africans" and still much worse on Recolonisation of Nigeria by Nigerians". All in all, it still points to one fact, according to Ayi Kwei Armah that: *The Beautiful ones are not yet Born.* We can lay the good foundation now, for the beautiful ones to be born tomorrow. Today, the words of Ngugi Wa'Thiogo still resonates – Weep not Child. Nigeria will walk and work.

To God Almighty, I say again, Thank you Sir.

Thank you all for being here with me.

6.0 REFERENCES

Abbott, P. (1980). *Calculus.* Hodderand Stoughton, London.

Abdelrahman, E.M. and Sharafeldin, S.M. (1997). A Least-Squares Approach to Depth Determination from Self-Potential Anomalies Caused by Horizontal Cylinders and Spheres. *Geophysics* 62: 44-48.

Abdelrahman, E.M., Ammar, A.A.B., Hassanein, H.I., and Hafez, M.A. (1998). Derivative Analysis of SP Anomalies. *Geophysics* 63: 890-897.

Adanu, E.A. and Schneider, M. 1988. "Hydrogeology and Aquifer Simulation of the Basement Rocks of Kaduna-Zaria Area, Northern Nigeria". *Adv. Water Resource,* 11.44-47.

Adeleke, O.O. (2022). Investigation and Evaluation of Reserve Estimates of Ogun Phosphate Rock in Oja-Odan, Ogun State, Southwest Nigeria using Integrated Methods. Unpublished Ph.D. Thesis. Federal University of Agriculture, Abeokuta, Nigeria.

Adeleke Oluseyi O., Victor Makinde, Ayobami O. Eruola, Oluwaseun F. Dada, Akintayo O. Ojo and Taiwo J. Aluko (2015). Estimation of Groundwater Recharges using Empirical Formulae in Odeda Local Government Area, Ogun State, Nigeria. *Challenges* 2015, *6*, 271-281; doi:10.3390/challe6020271 ISSN 2078-1547. www.mdpi.com/journal/challenges

Adesodun J.K. and Kolade, O. (2000). Adesodun, J.K. and Kolade, I.O (2000). Variation in Rheological Properties of Tropical Alfisol in Southwest Nigeria. Proceedings of The 26th Annual Conference of The Soil Science Society of Nigeria, Ibadan, pp. 68-72.

Adewumi, O.O. (2023). Structural and Depth Characterisation of Iron-Ore Deposit at Gbede, Oyo State, Nigeria using Integrated Techniques on Gravity Data. Unpublished Ph.D. Thesis. Federal University of Agriculture, Abeokuta, Nigeria.

Aikhuele, D.O. (2024). Investigation of Soil Moisture Content of Farmlands in Basement and Sedimentary Formations of Ogun State, Nigeria using Integrated Geophysical and geotechnical Methods. Unpublished Ph.D. Thesis. Federal University of Agriculture, Abeokuta, Nigeria.

Aina, J.O. (2019). Geophysical and Geochemical Investigation of Oshosun Phosphate Deposit in Ifo, Ogun State, Southwest Nigeria. Unpublished M.Sc. Dissertation. Federal University of Agriculture, Abeokuta, Nigeria.

Ajayi, C.O. and Makinde, V., (2000). The "Ajayi-Makinde Two-Electrode D.C. Resistivity Array". *A Brief Brochure to the Patent Office, Abuja.*

Akintorinwa, A. and Adeusi, O. (2009). Akintorinwa, O.J., and Adeusi, F..Integration of Geophysical and Geotechnical

Investigations for a Proposed Lecture Room Complex at the Federal University of Technology, Akure, SW, Nigeria. *Jour. of Applied Sciences*, 2(3), pp. 241-254.

Alagbe, S.A. (2002). "Groundwater Resources of River Kangimi Basin, North-Central, Nigeria". Environmental Geology, 42:404-413.

Aluko, T.J. (2019). Mineral Deposits Mapping and Environmental Assessment of Mining Activities in Some Parts of Oke-Ogun Area, Southwestern Nigeria using Geophysical and Geochemical Methods. Unpublished Ph.D. Thesis. Federal University of Agriculture, Abeokuta, Nigeria.

Anderson, R. N. (1986). Marine Geology: A Planet Earth Perspective. New York: Wiley.

Brown, G. C. and Mussett, A. E. 1993. The Inaccessible Earth, 2nd edn. London: Chapman and Hall.

Bachama, Y.D., Ahmed, A.L. and Adamu, A. (2017). Geoelectrical Investigation for Groundwater Potentials of the Main Campus of Ahmadu Bello University, Zaria using the Ajayi-Makinde Two-Electrode Array. *FUW Trends in Science and Technology Journal.* www.ftstjournal.com e-ISSN: 24085162; p-ISSN: 20485170 April 2017: Vol. 1 No. 1A, pp. 271-275.

Beatty, J. K., Petersen, C. C. and Chaikin, A. (eds) (1999). *The New Solar System*, 4th edn, Cambridge, MA and Cambridge: Sky Publishing Corp and Cambridge University Press.

Bhattacharya, B. B. and Roy, N. (1981). A Note on the Use of a Nomogram for Self-Potential Anomalies. *Geophysical Prospecting* 29: 102-107.

Blakely, R. J. (1995). *Potential Theory in Gravity and Magnetic Applications*, Cambridge: Cambridge University Press.

Brown, G. C., Hawkesworth, C. J. and Wilson, R. C. L. (eds) (1992). *Understanding the Earth*, Cambridge: Cambridge University Press.

Bullen, K. E. (1975). *The Earth's Density*, London: Chapman and Hall.

Burland, J.B., Broms, B.B., and De Mello, V. (1977). "Behaiviour of Foundation and Structures": In: Procedings of The 9th

International Conference of Soil Mechanics. Session 2. Tokyo, Japan.

Cathles, L. M. (1975). *The Viscosity of the Earth's Mantle*, Princeton, NJ: Princeton University Press.

Cattermole, P. and Moore, P. (1985). *The Story of the Earth.* Cambridge: Cambridge University Press.

Chilton, P.J. and Smith-Carrington, A.K. (1984). "Characteristics of Weathered Basement in Malawi in Relation to Rural water Supplies". In: Challenges in African Hydrology and Water Resources. D.E. Wallings, S.S.D. Foster, and P. Wurzel (editors). 57-72. Proceedings of the Harare Symposium, IAHS Publication No. 144.

Clark, L. (1985). "Groundwater Abstraction from Basement Complex Areas". In: Greenbaum 1992, Okereke, C. S., Esu, E. O. and Edet, A. E. "Groundwater Investigations: Experiences in parts of Cross River State, SE Nigeria". *Water Resources: Journal of Nigeria Association of Hydrogeologists,* 4(1&2):10-20.

Clark, S. P. J. (1971). Structure of the Earth. Englewood Cliffs, New Jersey: Prentice-Hall.

Cloud, P. (1988). *Oasis in Space: Earth History from the Beginning.* New York: Norton.

Coker J. O., Mustapha A. O., Makinde V. and Adesodun J. K. (2013). Application of Radiometric Surveys to Delineate between Sedimentary Terrain and Basement Complex: A Case Study of Sagamu and Abeokuta, South Western Nigeria. *Journal of Natural Sciences Research, 3(13):* 13-17. Published by International Institute for Science, Technology and Education, Romania Available online at http://www.jiste.org

Coker, J.O., Makinde, V. and Olowofela, J.A. (2010). Correlation of Geoelectric Sections with available Borehole Logs of Oke-Badan Estate, Ibadan, SW Nigeria. *International Journal of Physical Sciences, IJPS, 2(1);* 45-57. Published by Blackwell Educational Books, Nigeria.

Coker, J.O., Makinde, V., Adesodun, J.K and Mustapha, A.O. (2013a). Integration of Geophysical and Geotechnical Investigation for a Proposed New Lecture Theatre at Federal

University of Agriculture, Abeokuta, South Western Nigeria. *International Journal of Emerging Trends in Engineering and Development* 3(5); 338-348 Published by RS Publications Available online at http://www.rspublication.com/ijeted/ijeted_index.htm

Coker, J.O., Makinde, V., Mustapha, A.O. and Adesodun, J.K. (2013b). Electrical Resistivity Imaging for Foundation Failure Investigation at Remo Secondary School, Sagamu, South-Western Nigeria. *International Science Investigations Journal* 2(4): 40-50 Published by ISI Journal New Mexico, USA Available online at http://www.isijournal.info

Coker, J.O., Makinde, V., Mustapha, A.O. and Adesodun, J.K. (2013c). Application of Geophysical Methods in Foundation Failure Investigation: A Case Study of Metro Hostel, Camp Area, Abeokuta, South Western Nigeria. *Nature and Science* 2013; 11(11); 103-109 Published by Marsland Press, New York, USA Available online at http://www.sciencepub.net/nature

Coker, J.O., Makinde, V., Mustapha, A.O. and Adesodun, J.K. (2013d). Electrical Resistivity Imaging for Foundation Failure Investigation at Remo Secondary School, Sagamu, South-Western Nigeria. *International Science Investigation Journal* 2013; Vol. 2 (4): 40-50.

Coker, J.O., Ogunpola, A.E., Ajibade, O.M., Alabi, A.A., Olurin, O.T. and Makinde, V. (2020). Assessment of Groundwater Pollution around Dumpsite in Ewu-Elepe, Lagos, Southwestern Nigeria using Integrated Geophysical Methods. *Journal of Scientific Research and Development* Vol. 19(1) pp. 292-307. A bi-annual Journal Published by the Faculty of Science, University of Lagos, Nigeria. http://jsrd.unilag.edu.ng/index.php/jsrd

Cole, G. H. A. (1986). *Inside a Planet.* Hull: Hull University Press. Holmes, A. 1965. Principles of Physical Geology. New York: Ronald Press.

Cox, A. (ed) (1973). *Plate Tectonics and Geomagnetic Reversals*, San Francisco, CA: W .H. Freeman.

Cox, A. and Hart, R. B. (1986). *Plate Tectonics*, Boston, MA: Blackwell Scientific.

Davies, G. F. (1999). *Dynamic Earth: Plates, Plumes and Mantle Convection*, Cambridge: Cambridge University Press.

deGroot-Hedlin, C. and Constable, S.C. (1996). "Occam's Inversion to Generate Smooth, Two-Dimensional Models from Magnetotelluric Data". *Geophysics*, 55:1613-1624.

Dobrin, M. B. and Savit, C. H. (1988). *Introduction to Geophysical Prospecting*, 4th Edition, McGraw-Hill, New York.

Du Preez, J.W. (1956). "Origin, Classification and Distribution of Nigerian Laterite". GSN Report No. 810.

Edet, A. E., Teme, S.C., Okereke C.S., and Esu, E.O. (1994). "Lineament Analysis for Groundwater Exploration in Precambrian Oban Massif and Obudu Plateau, S.E. Nigeria". *Journal of Mining and Geology*, 30(1):87-95.

Edwards, L.S. (1977). "A Modified Pseudosection for Resistivity and Induced – Polarization". *Geophysics*, 42:1020-1036.

Egwuonwu, G.N., Ibe, S.O., and Osazuwa, I.B. (2011). Geophysical Assessment of Foundation Depths around a Leaning Superstructure in Zaria Area, Northwestern Nigeria using Electrical Resistivity Tomography. *The Pacific Journal of Science and Technology, Vol. 12:* 472-480.

Eskola, L., and Hongisto, H. (1987). A Macroscopic Physical Model for the Self-Potential of a Sulphide Deposit. *Geoexploration,* 24: 219-226.

Federal Ministry of Works and Housing (1972). Highway manual part 1 Road design, Federal Ministry of Works and Housing, Lagos.

Federal Republic of Nigeria (2014). *National Policy on Education*. Lagos: NERDC.

Gowd, S.S. (2004). Electrical Resistivity Surveys to delineate Groundwater Potential Aquifers in Peddavanka Watershed, Anantapur District, Andhra Pradesh, India; *Jour. of Envir. Geol*., 46:118-131.

Graffith, D.H. and Barker R.D. (1993). "Two-Dimensional Resistivity Imaging and Modeling in Areas of Complex Geology". *Journal of Applied Geophysics*, 29:211-226.

Grant, F. S. (1982). Gamma Ray Spectrometry for Geological Mapping and for Prospecting, in Mining Geophysics. Workshop by Paterson Grant and Watson Limited.

Grant, F. S., and West, G. F. (1965). *Interpretation Theory in Applied Geophysics*. McGraw-Hill, New York, N.Y.

Grey, D.R.C., Chilton, P., Smith Carrington, A.K. and Wright, E.P. (1985). "The Expanding Role of Hydrogeologists in the Provision of Village Water Supplies: An African perspective". *The Quarterly*.

Gromako, G.J. (1974). Review of Expansible Soil. *J. of Geotechnical Engineering Division*, Vol. 100, No. GT6: 667-686.

Gubbins, D. (1990). *Seismology and Plate Tectonics*, Cambridge: Cambridge University Press. Advanced Level

https://coolcosmos.ipac.caltech.edu

https://Doi.Org/10.1080/10256016.2023.2285002 Taylor and Francis.

https://nightsky.jpl.nasa.gov

https://www.greenmatters.com

https://www.greenmatters.com19 Jan. 2023

Ike, E.C. (1988). Late-stage Geological phenomena in the Zaria Basement Granites. A Review in the *African Journal of Engineering Geology*, 18(1):13-24.

Ishola, S.A. (2020). Characterization of Groundwater Resource Potentials using Integrated Techniques in selected Communities within Ewekoro Local Government Area, South-West Nigeria. Unpublished Ph.D. Thesis. Federal University of Agriculture, Abeokuta, Nigeria.

Ishola, S.A, Makinde, V., Okeyode, I.C., Akinboro, F.G., Ayedun, H. and Alatise, O.O. (2016). Assessment of Pollution Hazards of Groundwater Resources in Abeokuta North Local Government Area, Ogun State, Southwestern Nigeria. *Journal of Natural Sciences, Engineering and Technology, JNSET*. Published by Federal University of Agriculture, Abeokuta, Nigeria.

Ishola, S.A., Makinde, V., Aina, J.O., Ayedun, H., Akinboro, F.G., Okeyode, I.C., Coker, J.O., and Alatise, O.O. (2016). Aquifer Protection Studies and Groundwater Vulnerability Assessment in Abeokuta South Local Government Area, South-West Nigeria.

Journal of the Nigerian Association of Mathematical Physics. 33; 347-362 Published by the Nigerian Association of Mathematical Physics Available online at www.nampjournals. org; www. tnamp.org

Jegede, G. (2000). Effect of soil properties on pavement failure along the F 209 Highway at Ado-Ekiti South Western Nigeria. *J. of Construction and Building Materials*, Vol. 14: 311-315.

Jegede, O.A. (2019). Analysis of Radionuclides and Elemental Concentrations in Pit Soils of Selected Quarry Sites within Abeokuta, South-West Nigeria. Unpublished M.Sc. Dissertation. Federal University of Agriculture, Abeokuta, Nigeria.

Jegede, O.A., Olaoye, M.A., Olagbaju, P.O., Makinde, V. and Badawy, W.M. (2023). Radiation Risk Assessment of Quarry Pit Soil as Construction Material in Abeokuta, Nigeria: Implications for Environmental and Public Health. Isotopes in Environmental and Health Studies.

Jones, M.J. (1985). "The Weathered Zone Aquifers of the Basement Complex Areas of Africa". *The Quarterly Journal of Engineering Geology*, 18: 35-46.

Kearey and Brooks (1991). *An Introduction to Geophysical Exploration.* Blackwell.

Kearey, P. and Vine, F. J. (1996). *Global Tectonics.* Oxford: Blackwell Publishing.

Kearey, P., Brooks, M. and Hill, I. (2002). *An Introduction to Geophysical Exploration*, 3rd edn, Oxford: Blackwell Publishing.

Keller, G.V. and Frischknecht, F.C. (1966). Electrical Methods in Geophysical Prospecting Pergamon Press. New York.

Koefoed, O. (1979). Geosounding Principles 1: Resistivity Sounding Measurements. Elsevier Science Publishing Company: Amsterdam, The Netherlands.

Koefoed, O. (1984). Resistivity sounding measurement. Published by Elsevier Scientific Publisher Co. New York, pp. 28-34.

Le Pichon, X., Francheteau, J. and Bonnin, J. (1976). *Plate Tectonics*, New York: Elsevier.

Lillie, R. J. (1999). *Whole Earth Geophysics: An Introductory Textbook for Geologists and Geophysicists*, Englewood Cliffs, NJ: Prentice Hall.

Loke, M.H. and Barker, R.D. (1996). "Rapid Least-Squares Inversion of Apparent Resistivity Pseudosections by a Quasi-Newton Method. *Geophysical Prospecting*, 44:131-152.

Lowrie, W. (1997). *Fundamentals of Geophysics*. Cambridge: Cambridge University Press.

Makinde V., Adeleke O.O., Eruola A.O., Okeyode, I.C., Akinboro, F.G. Alatise, O.O. and Dada, O.F (2017). Impact of Climate Change on Groundwater Resources in Odeda Local Government Area, Ogun State, South-west Nigeria. *The African Review of Physics* (2017) 12: Special Issue on Applied Physics in Africa pp 0001-13. Published by The Abdus Salam International Centre for Theoretical Physics (ICTP). Available online at https://aphysrev.ictp.it/index.php/aphysrev/rt/metadata/1391/524

Makinde V., Coker J.O., Aina J.O, Akinboro F.G., Okeyode I.C., Alabi A.A., Layade G.O., Ogunkoya C.O. and Bello A.M. (2016). Derivation of the Thin Dike Self-Potential (SP) Expression from the Thick Dipping Dike Expression *Journal of the Nigerian Association of Mathematical Physics*, 35; 287-290 Published by the Nigerian Association of Mathematical Physics Available online at www.nampjournals.org; www.tnamp.org

Makinde, V., Eruola, A.O., Ganiyu, S.A., Olurin, O.T., Adeleke, O.O., and Aikhuele, D.O. (2016). Evaluation of Groundwater Potential of Odeda Local Government Area, Ogun State, Southwest Nigeria. *Journal of Natural Sciences, Engineering and Technology, JNSET*. Published by Federal University of Agriculture, Abeokuta, Nigeria.

Makinde, V., Ishola, S.A, Akinboro, F.G., Okeyode, I.C., Agwuegbo, S.O.N., Ozebo, V.C., Coker, J.O. and Aina, J.O. (2016). Evaluation and Analysis of Geoelectric Parameters of Abeokuta South Local Government Area, Ogun State, South West Nigeria. *Journal of the Nigerian Association of Mathematical Physics*, 35; 275-286. Published by the Nigerian Association of

Mathematical Physics Available online at www.nampjournals.org; www.tnamp.org

Makinde, V. (1987). Synthetic Self-Potential Profiles over Thick Dipping Dikes. Unpublished M.Sc. Thesis. University of Ilorin, Ilorin – Nigeria.

Makinde, V. (1996). Laboratory and Field Investigations of a Variant of the Two-Electrode d.c. Resistivity Array. Unpublished Ph.D Thesis, Ahmadu Bello University, Zaria.

Makinde, V., Alagbe, S.A., Coker, J.O. and Bello, A.M.A. (2010). Determination of Borehole Sites for Extensive Irrigation Work in Yobe State, Nigeria. *Journal of American Science,* 6(2); 58-61 Published by Marsland Press, New York, USA. Available online at http://www.americanscience.org/

Makinde, V., Coker, J.O. and Oyedele, K.F. (2012). Hydrogeophysical Mapping of Oke-Badan Estate, Ibadan, SW Nigeria. *International Journal of Basic and Applied Sciences, IJBAS,* 1(1): 11-20 Published by Centre for Rural Development, Ecology and Environmental Development, Ethiopia Available online at http://www.crdeep.org

Massonnet, D. (1997). Satellite radar interferometry. *Sci. Am.,* 276, 46-53.

McCurry, P. (1970). "The Geology of the Zaria Sheet 102 S.W. and its Region". In: Mortimore, M.J. (ed.), Department of Geography Occasional Paper, No.4. Ahmadu Bello University: Zaria, Nigeria.

Meiser, P. (1962). A Method of Quantitative Interpretation of Self-Potential Measurements. *Geophysical Prospecting,* 10: 203-218.

Milsom: Field Geophysics, (1996). Open University Press.

Murty B. V. S. and Haricharan, P. (1982). Nomogram for the Complete Interpretation of Spontaneous Profiles over Sheet-like and Cylindrical Two-Dimensional Sources. *Geophysics*, 50: 1127-1135.

Mussett, A. E. and Khan, M. A. (2000). *Looking into the Earth: An Introduction to Geological Geophysics*. Cambridge: Cambridge University Press.

Officer, C. B. (1974). *Introduction to Theoretical Geophysics.* New York: Springer.

Offodile, M.E. (1983). "The Occurrence and Exploitation of Groundwater in Nigerian Basement Rocks". *Journal of Mining and Geology*, 20(1&2):131-146.

Ogunkoya, C.O. (2019). Investigation of the Existence and Quality of Iron ore Deposit at Gbede Village, South-Western Nigeria Unpublished Ph.D. Thesis. Federal University of Agriculture, Abeokuta, Nigeria.

Oreskes, N. and Le Grand, H. (eds) (2001). *Plate Tectonics: An Insider's History of the Modern Theory of the Earth*. Boulder, CO: Westview Press.

Oxford Advanced Learner's Dictionary, ELBS (2024).

Pal, P. C. (1983). Rapid Gravity Interpretations by Nomograms. *Geoexploration*, 21: 203-220.

Parasnis, D. S. (1975). *Mining Geophysics.* Elseviers Scientific Publishing Co., Amsterdam, pp. 80-89.

Parasnis, D. S. (1997). *Principles of Applied Geophysics*, 5th edn, London: Chapman and Hall.

Press, F., Siever, R., Grotzinger, J. and Jordan, T. (2003). *Understanding Earth*, 4th edn, San Francisco, CA: W. H. Freeman.

Ram Babu, H.V. (2003). Relationship of Gravity, Magnetic, and Self-Potential Anomalies and their Application to Mineral Exploration. *Geophysics,* 68: 181-184.

Ram Babu, H.V. and Rao, D.A. (1988). A Rapid Graphical Method for the Interpretation of the Self-Potential Anomaly over a Two-Dimensional Inclined Sheet of Finite Depth Extent. *Geophysics,* 53: 1126-1128.

Ranaganatham, B.V. and Satyanarayana, B. (1965). A rational method of predicting swelling potential for compacted expensive clays. Proc. 6th International Conf. Soil Mech. Found. Engr; Vol. 1, pp. 92-96.

Ranalli, G. (1995). *Rheology of the Earth*, 2nd edn, London: Chapman and Hall.

Rao, D. A. and Ram Babu, H. V. (1983). Quantitative Interpretation of Self-Potential Anomalies due to Two-Dimensional Sheet-like Bodies. *Geophysics* 48: 1659-1664.

Reynolds, J.M. (1997). *An introduction to applied and environmental geophysics*, Wiley & Sons Ltd.

Sasaki, Y.M. (1992). "Resolution of Resistivity Tomography Inferred from Numerical Simulation".

Sato, M. and Mooney, H. M. (1960). The Electrochemical Mechanism of Sulfide Self-Potentials. *Geophysics*, 25: 226-249.

Sharma, P. V. (1997). *Environmental and Engineering Geophysics*, Cambridge: Cambridge University Press.

Shemang (1990) Shemang, E. M. Jr. (1990): Electrical Depth Soundings at Selected Well Sites within the Kubanni River Basin, Zaria, Nigeria. Unpublished MSc Thesis, Ahmadu Bello University, Zaria.

Sittig, M. (1980). Geophysical and Geochemical Techniques for Exploration of Hydrocarbons and Minerals. NOYES Data Corp. Park Ridge NJ USA, pp. 110-112.

Stacey, F. D. (1992). *Physics of the Earth*, 3rd edn, Brisbane: Brookfield Press.

Telford, W.M., Geldart, L.P., Sherif, R.E., and Keys, D.A. (1990). *Applied Geophysics.* 2nd Edition. Cambridge University Press: New York, NY.

van Nostrand, R.G. and Cook, K.L.(1966). Interpretation of Resistivity Data. United States Geological Survey Professional Paper 499.U.S. Government Printing Office, Washington D.C.

Watts, A. B. (2001). *Isostasy and Flexure of the Lithosphere*, Cambridge: Cambridge University Press.

Wright, J.B. and McCurry. P. (1970). "Geology of Zaria and its Region (sheet 102 SW)". In: Mortimore, M.J. (ed.), "Zaria and its Region". Occasional paper No. 4 Published in Department of Geology, Ahmadu Bello University: Zaria, Nigeria, 5-12.

Yusuf, D.B. and Umego, M.N. (2014). Effectiveness of the Ajayi-Makinde two-electrode array as a geoelectric prospecting method in depth-to-basement determination. *Global Pure & Applied Science, 20:* 65-76.

Zohdy, A.A.R; Eaton, G.P. and Mabey, D.R. (1974). Application of surface geophysics to groundwater investigations. Collection of Environmental data published by the Department of the Interior Geological Survey, Book 2, page 9.