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APPLIED GEOPHYSICS:
THE SUBSURFACE AND THE TREASURES

By Bankole D. Ako, FNMGS

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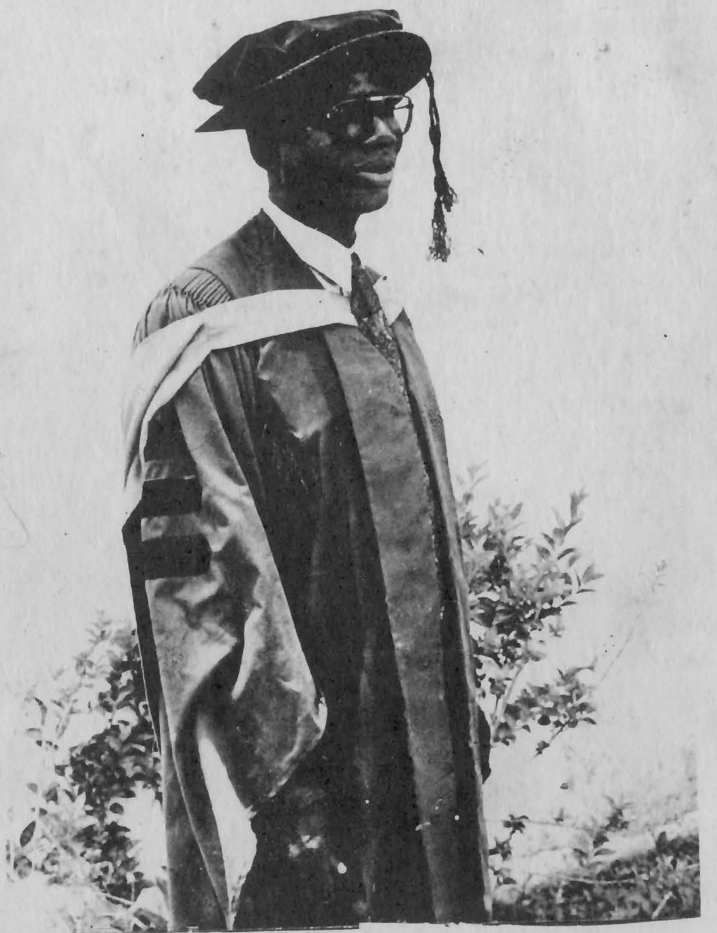

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INTRODUCTION

Mr. Vice-Chancellor, distinguished colleagues, ladies and gentlemen, I welcome you all to this trip through the mineralised subsurface in a most appropriate vehicle by name APPLIED GEOPHYSICS.

Applied Geophysics

According to Read and Watson (1970) " The Science of Geology deals with all matters concerning the earth. It provides descriptions of the materials - the rocks - of which the earth is made and discusses their origins. It traces the effects of various forces upon these rocks, forces deriving their energy from the earth itself or from the sun. It studies the way in which the rocks are arranged in the accessible part of the earth. It is very much concerned with the types of fauna life found in the rocks and with the evolution and habitats of this life. It endeavours to determine the limits of land and sea during past ages and so to trace an unending succession of lost geographies. All branches of this broad science are interconnected; further they draw copiously upon physical, chemical and biological sciences.

Balogun (1991) defined Physics as the Science that deals with matter and energy. Physics studies force, motion, heat, light, sound, electricity, magnetism, radiation and atomic structure.

Geophysics can thus be regarded as having its derivation from Geology and Physics.

Jakosky (1950) defined Geophysics as a study of the physics of the earth with special reference to its physical properties, structure and composition. Kalashnikov (1968) states that Geophysics studies the structure, properties and processes of the whole earth from the physical point of view employing *physicomathematical* method. Dobrin and Savit (1988) designate Geophysics as the study of the earth using physical measurements at or above the surface. Geophysics deals with all aspects of the earth, its atmosphere, and space (Telford *et al.*, 1990).

It is evident from the above definitions that Geophysics covers solid body (crust), hydrosphere and the atmosphere.

The aspect of Geophysics being considered in this lecture is that which has to do with the main body of the earth, not the hydrosphere and atmosphere. The issue here is Applied Geophysics; which has to do mainly with finding solutions to geological problems using physical principles. It is also often referred to as exploration geophysics.

Applied Geophysics is used mainly for the search for minerals (metallic, industrial and carbonaceous), oil, gas, and water; for geological mapping, engineering and environmental studies.

Applied Geophysics in this context can be grouped into two viz:

The Surface Techniques

These are - Magnetic
Gravity
Seismic (Refraction and Reflection)
Electrical (Spontaneous potential, resistivity and induced polarization)
Electromagnetic (frequency-domain, transient or time-domain and phase component)
Radiometric
Miscellaneous - chemical and thermal.

Surface here includes ground, aerial and marine surveys.

The Borehole (Subsurface) technique

These include all those listed above for the surface techniques. The major difference is that these tools are run in boreholes and are thus assumed to be in direct contact application.

Table 1 shows the physical parameters often measured and the corresponding geophysical methods.

Table 1: Physical Parameters measured in Applied Geophysics

Physical Parameter	Geophysical Method
1. Magnetic Susceptibility	Magnetic
2. Magnetic Permeability	Magnetic and Electromagnetic
3. Density	Gravity
4. Velocity of body waves	Seismology / Seismic
5. Conductivity/Resistivity	Resistivity and Electromagnetic
6. Dielectric constant, natural Electrical Potential and Chemical Polarization	Spontaneous potential and Induced Polarization
7. Radioactivity	Radiometric
8. Temperature gradient	Thermal and Spontaneous Potential

Now that we know a bit about the physical parameters of earth materials that form the basis for using the various techniques of applied geophysics, it is important to give a brief description of these methods.

DESCRIPTION OF APPLIED GEOPHYSICAL METHODS

As stated earlier, the exploration geophysical methods commonly used are: Magnetic, Gravity, Seismic, Electrical, Electromagnetic and Radiometric methods.

Magnetic method

This is perhaps the oldest known method of exploration geophysics. It was first used in Sweden to map iron ores in 1640. Theoretically, it is dependent on the variations in the earth magnetic field that are due to changes of structure, magnetic susceptibility of magnetic minerals in earth materials.

These magnetic materials when present in the various rock types impose the appropriate degree of magnetisation on the rocks. Thus, sedimentary rocks have low values of magnetic susceptibility and hence the least magnetisation when compared to the igneous or metamorphic rocks, which invariably have higher content of magnetic minerals. Consequently, ground, marine and /or aeromagnetic surveys are often employed for reconnaissance investigation for oil/gas, geological mapping, and direct search for magnetic ores (e.g.Iron ore).

Although instrumentation, and interpretation of data have improved greatly, there are still some uncertainties which can be reduced with availability of geological information. The unit of measurement is usually in *gamma* or *nanotesla*.

Gravity method

The use of the gravity method is based on the variation of gravity values at different locations on the earth's surface. This is apparent from Newton's law of gravitation and the spherical shape of the earth. The variation is usually minute and also depends on the density of earth materials. This difference, known as density contrast is what is measured by the very sensitive balance called gravimeter or gravity meter. The unit of measurement is *milligal* or *gravity* units.

The gravity method is also used as a reconnaissance tool for petroleum prospecting, geological mapping, mineral investigation, determination of the internal structure of the earth, and groundwater studies. It is a unique non-drilling method for the estimation of ore reserve. Because gravity data is affected by latitude, elevation, distance from the centre of the earth amongst others, there is often the need for adequate geological information to reduce the ambiguity in interpretation. It must be mentioned that aerogravity measurement is now a reality in addition to ground, marine and borehole measurements as in magnetics.

Seismic method

The seismic method utilizes the fact that elastic waves also known as seismic waves (body waves) travel with different velocities in different rocks. The seismic method consists of two techniques - seismic refraction and seismic reflection. Thus, the principle of both techniques is to initiate seismic waves at a point - the shot point and compute at a number of other points the time of arrival of the energy in milliseconds that is refracted or reflected in accordance to Huygen's principle and Snell's law.

Seismic refraction

This techniques was first used in the Gulf Coast, for mapping of salt domes about 1923. In this technique the detecting instruments (seismometers or geophones) record seismic signals at a distance from the shot point that is large compared with the depth of the horizon to be mapped. In refraction work, velocity must increase with depth to successfully employ the technique in mapping the subsurface. The obtained data is plotted as time distance curves from which layer velocity and depth are determined. Although the refraction techniques recorded tremendous successes in oil prospecting through mapping salt domes, it is now rarely used for petroleum exploration. The refraction technique has wide application in Engineering geological and groundwater investigations and in the search for industrial minerals.

Seismic reflection techniques

The first attempt to prove the applicability of the seismic technique was made in 1927 in Oklahoma (Jakobsky,1950). This technique has become by far the most widely used geophysical tool. It remains the major prospecting tool of the petroleum explorationists. In reflection seismic, the seismic body waves generated in the earth by a near surface explosion, mechanical impact or vibration are detected by seismometers or geophones placed at the surface after such waves have undergone reflection from interfaces between subsurface formations having different physical properties (acoustic impedance). Consequently, the variations in the reflection times from place to place are presented as seismograms. With appropriate correction carried out, the depth to reflecting interface can be computed and the disposition of subsurface structures determined from the seismograms.
The reflection technique comes closer than any prospecting technique to providing a structural picture of the subsurface comparable to what could be obtained from a great number of boreholes in close proximity (Dobrin and Savit,1988).

This technique in its present state is used not only to locate and map such features as faults, reefs, anticlines and salt domes which are often sought after in the petroleum industry, but also for identifying subsurface formation lithology, detecting hydrocarbons and gas directly. Apart from the petroleum industry, the seismic reflection techniques is also sometimes used for groundwater investigation, engineering geological work and environmental studies.

Electrical methods

Of all the geophysical methods, the electrical methods can be said to have much greater variety. With the electrical methods, potentials, currents and electric fields which occur naturally or are introduced artificially in the earth can be measured. This variety is made possible in turn by the enormous variation in the electrical properties of earth materials. The major electrical properties of earth materials are conductivity (resistivity), dielectric constant and magnetic permeability.

Electrical methods include the natural source techniques (Spontaneous or self-potential, telluric currents and magnetotelluric and AFMAG (audio frequency magnetic fields), the artificial source techniques which include mainly the electrical resistivity, induced polarization and the electromagnetic methods.

The self-potential method is used to detect the presence of certain mineral and metallic ore bodies mainly massive sulphides that react with subsurface fluids (electrolytes) in such a way as to generate electrochemical potentials. Because fluid movement and pressure gradient within the earth (electrokinetic coupling) and temperature gradient in subsurface fluids (thermoelectric coupling) give rise to self-potential anomalies, SP is also used for groundwater prospecting,engineering geological studies (e.g. leakage along dam axis, detection of buried spring, etc.) and for geothermal studies.

Telluric and magnetotelluric methods are also natural source techniques and they have been found to be the only effective method of oil and gas exploration in areas where seismic methods are inapplicable; for example, areas where multiple sheets of volcanic rocks overlie the sedimentary section (Dobrin and Savit, 1988).

The electrical resistivity method is designed to yield information on earth materials (rocks. minerals, etc.) having anomalous electric conductivity. Consequently, conductors (true metals), semi-conductors (most minerals) and insulators (rocks, water, oil, gas, etc.) which exhibit some degree of resistivity contrasts are good targets. The resistivity method is thus widely used for geological mapping, mineral investigation, engineering geological studies, groundwater prospecting, geothermal studies, environmental studies and for determination of water and hydrocarbon saturation in borehole geophysics in the petroleum industry. It is also used for oil and gas exploration in the formal USSR.

The induced polarization method is based on the degree of polarizability of the earth materials. Essentially it results from the interactions at the contact of metallic minerals exhibiting electronic type conductivity and formation electrolytes, as well as variations in the mobility of ions in fluids throughout a rock structure. It remains the best geophysical method for mapping disseminated sulphides. It is sometimes used in combination with the resistivity method to map saline water intrusion into fresh water aquifers in groundwater and environmental studies.

Electromagnetic methods detect anomalies in the inductive properties of the earth's subsurface rocks (Dobrin and Savit,1988). The success of the electromagnetic methods is based on conductivity and magnetic permeability of the earth materials. Hence, an alternating voltage that is introduced into the earth by induction, from transmitting coils (often referred to as transmitters) either on the earth's surface, air or borehole generates an induced potential in the subsurface which has its amplitude and phase shift measured and recorded by detecting coils (receivers).

Electromagnetic methods vary in their field operation and interpretation of data. The methods are used extensively in geological mapping, mineral investigation, groundwater prospecting and environmental studies. They also complement the resistivity logs in borehole geophysics.

Radiometric method

The radiometric method is based on radioactivity of rocks. The radioactivity of rock is in turn dependent on the presence and content of radioactive mineral, mainly Uranium, Thorium and Potassium in rocks. The method is used in the search for radioactive ores and minerals, for geological mapping (especially aerosurveys) and for lithologic identification in borehole geophysics (groundwater and petroleum industries).

The consideration of the various methods of Applied Geophysics here have been mainly descriptive and not as technical as it ought to be. I sincerely hope that with your appreciation of the rudiments of Applied Geophysics, we can now continue our trip into the subsurface.

THE SUBSURFACE

To the lay man the subsurface is synonymous with the subsoil. The subsoil is commonly defined as "a layer of shattered and partly weathered rock between the soil proper and the bedrock" (Whitten and Brooks, 1975). In the present context the subsurface refers to the portion of the earth known as the Crust.

Figure 1 shows the internal structure of the earth. Three distinct regions are evident. These are the core, mantle and crust. To appreciate this subdivision, it is pertinent to discuss briefly the origin of the solar system, the earth, hence the formation of the core, the mantle and especially the

crust which is the outer superficial layer of the earth and here termed the "subsurface"

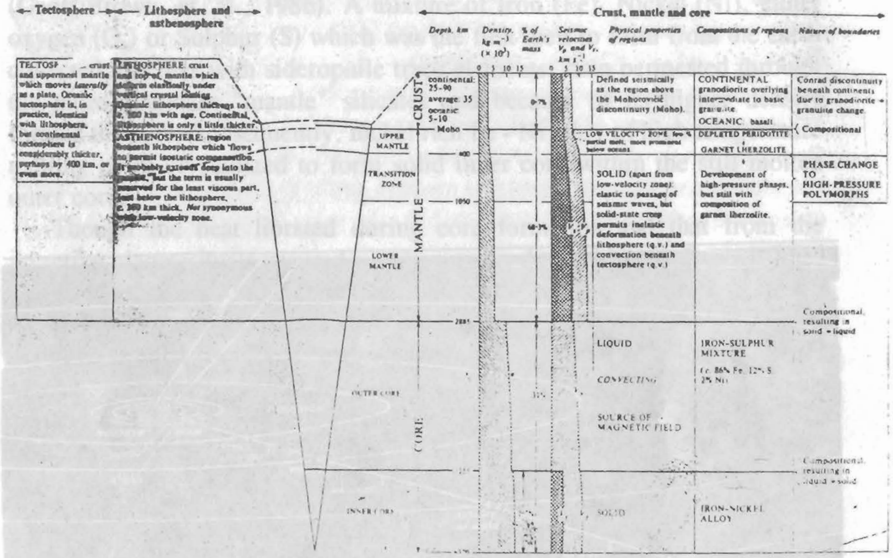

Fig. 1: The internal structure of the Earth (After Brown & Mussett, 1981).

The Formation of the Earth

According to Geoff Brown *et. al.* (1986) about 4600 Ma ago a super explosion took place in a nearby part of our Galaxy (the milky way Galaxy) and added short lived as well as stable isotopes to an interstellar cloud of hydrogen and Helium; with a small proportion of heavier elements. The pressure resulting from the explosion probably initiated the contraction of the cloud which was probably large enough to form nearby stars.

A portion of the cloud contracted into what is generally referred to as the "Primitive solar Nebula" (PSN), a rotating disc of matter which with increased temperature ignited hydrogen converting it to helium thus forming the Sun which is regarded as the nucleus of the solar system. The mixture of gas and dust in the outer part of the PSN got fractionated by strong radial temperature gradient, as a result, material accreting to form planets tended to contain progressive more low temperature condensates further from the sun. Thus most of the terrestrial planets including the earth formed in a region low in volatiles.

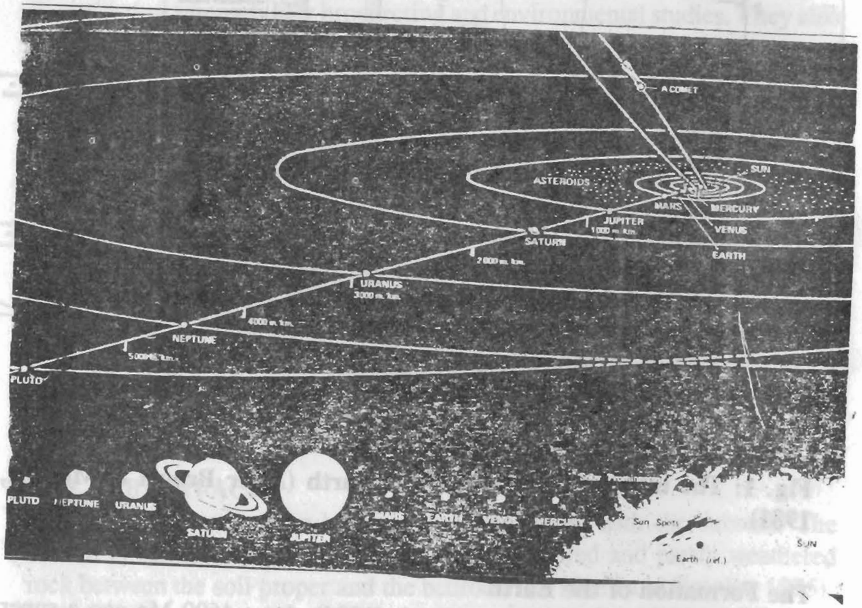

Fig: 2: A diagrammatic summary of the Solar System (After Peter Harris, 1971).

Figure 2 shows diagrammatic summary of the solar system. Two major groups of planets are shown. These are:

(i) The terrestrial planets (Mercury, Venus, Earth and Mars)

(ii) The major planets (Jupiter, Saturn, Uranus, Neptune and Plato)

The study of the solar system is complex but fascinating. However, since I am here more concerned with the earth and its crust attention will now be focused on the earth.

The Earth

After the formation of the planets, the primitive earth underwent several temperature changes due to conversion of kinetic energy to heat and the decay of short-lived radioisotopes (e.g. ^{26}Al inherited from the supernova (Geoff Brown, et. al., 1986). A mixture of Iron (Fe), Nickel (Ni), either oxygen (O_2) or Sulphur (S) which was the first melt to form from the earth collected together with siderophile trace elements, then permeated through the more abundant "mantle" silicates and because of its higher density formed the core. Subsequently, nickel rich Fe - Ni alloy of high temperature melting point crystallized to form solid inner core within the still molten outer core.

Though the heat librated during core formation and that from the accreting planetesimals ensured a molten earth, the rapid rate of temperature loss resulted in the formation of thin, solid skin of peridotitic composition - The MANTLE (Fig. 1).

A rigid outer shell or lithosphere developed above the plastic convecting mantle. At the early stages of the formation of the earth this lithosphere, partly the **CRUST** was not only quite thin (a few kilometres) but was unstable and kept being re-absorbed into the underlying mantle. However, about 3900 Ma ago the first unsinkable granitic crust had formed. This remains the most chemically fractionated constituent of the lithosphere till date.

Since the period mentioned above other geological processes such as sea-floor spreading, plate tectonics have effectively changed the composition and thickness of the present day crust which I am now set to discuss

The Crust

The earth's crust is the most accessible and best studied part of our planet. It has been found to be the most complex in both its physical and chemical nature. It contains a wide range of rock types from relative purity of some sedimentary rocks to complex chemical mixtures such as igneous basalts and granites.

Fortunately the internal structure of the earth was derived mainly from geophysical data. It was from interpretation of earthquake seismological data and then explosion seismology that the earth was subdivided into a solid inner core of Fe - Ni alloy followed by a liquid outer core of iron-sulphur mixture, lower mantle, transition zone, upper mantle and then the crust (Fig. 1). The crust is divided into the oceanic and continental crust. It is the continental crust that is of relevance in this lecture. The continental crust has a complex layered structure. Its thickness varies from about 25 to 90 km with an average of 35km. and is defined seismically as the region above the Mohorovicic discontinuity (MOHO). Apart from the MOHO, a more diffuse discontinuity occurs within the crust at depths ranging from 10 to 30 km known as the Conrad discontinuity. It can be traced under most continental regions and it divides the crust into the upper and lower crust with seismic P-wave velocities (V_p) in the ranges 4.7 km sec^{-1} and 6.5 to 7.8 km sec^{-1} respectively.

The average composition of the upper crust is granodiorite or quartzdiorite with a density of 2700 to 2750 kgm^{-3} and an average V_p of 6.25 km sec^{-1}. The lower crust seems to be mainly intermediate to basic granulite composition (Brown & Musset, 1981).

The upper crust is usually the most variable layer with the uppermost few kilometres of material ranging from relatively unmetamorphosed volcanic and sedimentary rocks to medium-grade metasediments. This is the unseen mineralised subsurface that is the play ground of the Applied Geophysicists.

THE TREASURES

From the foregoing discussion of the crust, it is evident that it is likely to be the major store house of a variety of ores waiting to be discovered, mapped and exploited for the benefit of mankind. Ores are rocks or minerals that can be mined, processed and delivered to the market place or to technology at a profit. Ores are generally subdivided into the categories of non-metallic, energy and water. However the term **TREASURES** as used in this text refers to metallic, non-metallic, energy and water. These are widely distributed in the rocks of the earths upper crust - the subsurface.

According to Gulbert and Park Jr (1986), the presence of minerals and metals in the earth's crust was explained in the early Greek and Roman civilisations mainly by hypotheses postulated by philosophers. Some of these hypotheses suggested

- an animated earth that breathed ores or gave of metallic exhalations as a regular function of "earth metabolism";
- that ores existed in the form of subterranean "golden tree" whose twigs and branches were various kinds of metals and whose trunk and rocks led down to the centre of the earth;
- Ore deposits were generated by celestial powers such as the sun's rays or astrologic planetary influences.

Consequent upon these early perception about the origin of ores (i.e. treasures) mysterious forces were also called upon to detect them. Thus, methods such as the divining rod, forked twigs, witching and dowsing were used for prospecting. Subsequent scientific studies have shown that there are geographic regions of the earth characterised by the occurrence of numerous mineral deposits all with the same characters; such regions are termed **METALLOGENIC PROVINCES** (Clifford, 1971). Examples of such areas include Zambia rich in copper, South Africa rich in Gold and Nigeria rich in Tin. However, because of better understanding of various tectonic events, it is now possible to relate ore deposits not only to the age of rocks and rock types but also to the structural setting or regions of the environment. Thus we now have **TECTONOMETALLOGENIC UNITS**; which include the older fairly stable regions - **OLDER CRATONS OR SHIELDS** and younger geologically active zones - **YOUNGER OROGENS OR MOBILE BELTS**. Whereas the mobile belts are known for specific minerals e.g. Copper, Tin, Lead and Zinc etc. the same cannot be said for the shield areas.

Thus minerals like gold, chromium, diamond, asbestos etc. which are commonly found in the shield areas also occur in cratons that have been involved in the younger orogenic episodes. Consequently, we have more localised provinces of mineral concentration termed **METALLOGENIC PROVINCES** within the major units.

The complexity of environment of ore formation and deposition has now given way to the latest concepts and techniques in geochemical and geophysical exploration.

The success of Applied Geophysical method(s) is /are now dependent on mapping the targeted mineral as well as determining the subsurface geology. It is this link between applied geophysics and geology that is fascinating.

APPLIED GEOPHYSICS AND GEOLOGY

Geophysics has been defined as the study of the earth by quantitative physical methods especially by surface magnetic, gravity, seismic, electrical and radiometric methods. Applied geophysics is the use of the above named methods in the search for minerals, energy (oil and gas) and water with the objective of economic exploration.

The targets being sought for are the minerals themselves, geological structures, such as, faults, fractures, joints, intrusions, anticlines, weathered zones and other features that favour the deposition and accumulation of the relevant minerals. The host rock is of extreme importance here. Generally rocks can be classified into igneous, sedimentary and metamorphic types. Apart from the variability of the physical parameters of the rocks, the minerals which are guests in these rocks also modify these parameters and impose their physical peculiarities.

Thus the magnetic susceptibility of igneous rocks are highest (Av = 8 -

25 x 10^3 SI). followed by those of metamorphic rocks Av = 0.9 x 10^3 SI), and the least values are those of sedimentary rocks (Av = 0.9 x 10^3 SI). The values for minerals are quite low except those of the iron minerals e.g. Pyrrhotite (Av = 1500 x 10^3 SI) ilmenite (Av = 1800 x 10^3 SI) and magnetite Av = 6000 x 10^3 SI). The density values also follow the same pattern viz igneous rocks (Av = 2.61 - 2.79 g cm^{-3}). metamorphic rocks (Av = 2.74 g cm^{-3}) and sedimentary rocks (Av = 2.50 g cm^{-3}). Metallic minerals have average values of 2.45 - 8.10 g cm^{-3}; non-metallic minerals excluding petroleum and water have values of 1.19 - 4.47 g cm^{-3}. The value for water is often taken as 1.00 g cm^{-3} and that for petroleum is between 0.6 - 0.9 g cm^{-3}.

Seismic velocities are generally greater in igneous and metamorphic rocks than in sedimentary ones except when weathered. Table 2. shows typical values. In sedimentary rocks, they tend to vary with depth of burial, age, fluid content and porosity.

Table 2: Seismic wave velocities in rocks (after Parasnis, 1986)

	V_P ms^{-1}	V_s ms^{-1}
Air	330	
Sand	300 - 800	100 - 500
Water	1450	
Limestones & Dolomites & other deep seated rocks	4600 - 7000	2500 - 4000

Figure 3 shows the typical ranges of resistivities of earth materials. It is evident that the resistivity of solid minerals depends on their formation, geological history and weathering. In sedimentary areas, resistivity depends on porosity, water saturation and its chemistry, and clay content. Resistivity decreases with increase in water salinity and clay content.

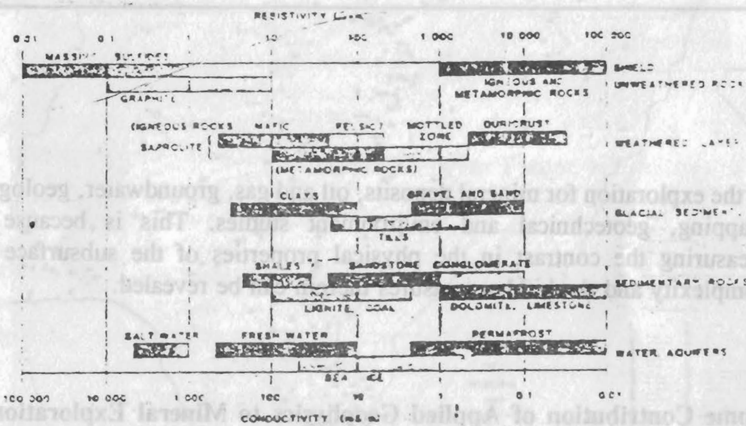

Fig. 3: Typical ranges of resistivities of earth materials.

Radioactivity is generally higher in sedimentary rocks and metamorphosed sediments than that in igneous and other metamorphic rocks except in potassium - rich granites. Radioactivity increases with increase in clay content of sedimentary and metamorphosed sedimentary rocks (Table 3). In view of the contrast in the physical parameters of materials, application of geophysical methods if anything must be accorded priority.

Table 3: Background radioactivity in rocks (after Telford *et al.* 1990)

Rock	Ci/g($x10^{-12}$)
Hornblende	1.2
Granite	0.7 - 4.8
Basalts	0.5
Olivine	0.33
Marble	1.9
Quartzite	5.0
sandstone	2 - 4
Slates	3 - 8
Dolomites	8
Chalk	0.4

in the exploration for mineral deposits, oil and gas, groundwater, geological mapping, geotechnical and environment studies. This is because by measuring the contrast in the physical properties of the subsurface the complexity and the hidden treasures therein can be revealed.

Some Contribution of Applied Geophysics to Mineral Exploration in Nigeria

Let us now look into how applied geophysics has contributed to mineral exploration in Nigeria.

According to Ojo (1995), "Nigeria is endowed with numerous mineral resources both metallic and industrial. However, owing to the low level of exploration of the country for mineral deposits, the known reserves of metallic minerals are small but few of them are significant enough for economic exploitation. The industrial minerals which are found in commercial quantities in all geological environments in the country form a reserve from which raw materials can be locally sourced for existing local industries and even for new ones".

Figure 4 shows the mineral map of Nigeria with the geology in the background. The minerals shown include metallic, non-metallic(industrial), gemstones and energy. Water as usual has been taken for granted.

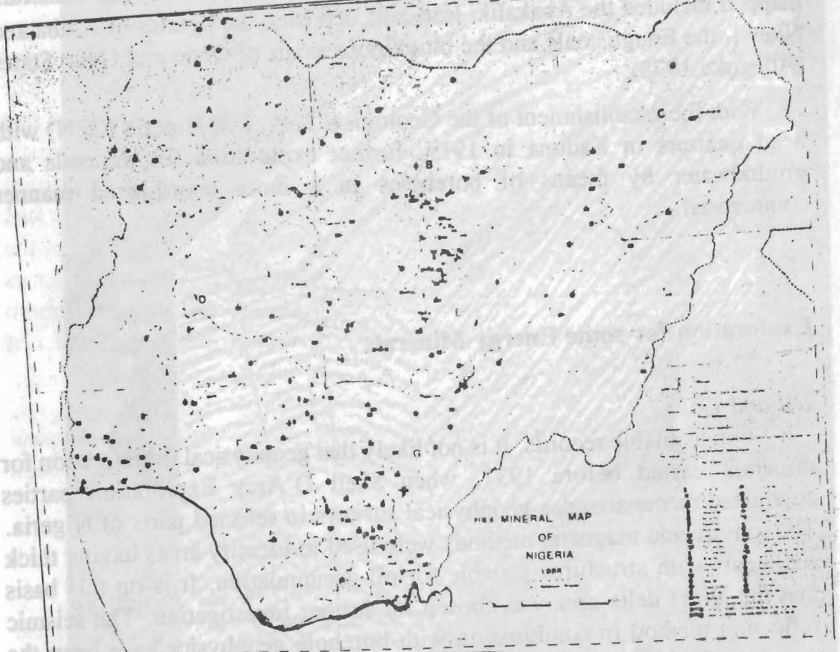

Fig. 4: Mineral Map of Nigeria.

The metallic minerals include Gold, Iron ore, cassiterite, columbite, lead-zinc, graphite, manganese, vanadium, Nickel, Copper, Chromite, Pyrochore, Molybdenum, Tantalite, wolframite and Tungsten. The gemstones are Emerald, Aquamarine, Ruby, Sapphire, Amethyst, Garnet, Topaz, Fluorspar and Tourmaline. The industrial minerals are: limestone, dolomite, marble, kaolin and other clays, feldspar, barytes, diatomite.

quartz, silica sand, gypsum, zircon, talc, sillimanite, kyanite, asbestos, magnesite, salt, bentonite, phosphate and soda ash.

The energy minerals include oil and gas, coal, uranium and tarsands. With this variety of minerals,one expects an advanced geophysical exploration practice in Nigeria.

It is on record that the study of geology of Nigeria commenced in 1903 with the establishment of the Mineral Surveys of Southern Nigeria Office, London. Two surveyors were charged with the responsibility of exploiting and collecting mineral specimens of the protectorate. In 1904, the Mineral Surveys of Northern Nigeria was established. Both surveys worked between 1903-1913 and 1904-1911 respectively. Some of the important minerals mapped included the Abakaliki lead-zinc deposits, the lignites of Asaba and Nnewi, the Enugu coals and the bituminous sands of Ondo and Ogun States (Adegoke, 1978).

With the establishment of the Geological Survey of Nigeria (GSN) with head quarters in Kaduna in 1919, further exploration for minerals and groundwater by means of boreholes in a more coordinated manner commenced.

Exploration for some Energy Minerals

Oil and Gas

From available records, it is not likely that geophysical investigation for minerals started before 1937, when Shell D'Arcy Exploration parties conducted reconnaissance geophysical surveys in selected parts of Nigeria. The gravity and magnetic methods were used to identify areas having thick sediments with structures suitable for oil accumulation. It is on this basis that the Niger delta area was chosen for further investigation. The seismic reflection method in combination with borehole geophysics have been the main geophysical methods in use. The initial method was 2-D seismic which has in the mid 80s given way to 3-D acquisition techniques, data processing and interpretation. All the modern and sophisticated techniques of data acquisition, processing and interpretation have also become routine in the Nigeria oil industries. The practice has resulted in a much better understanding of the subsurface geology of the various prospects and has improved the success rates in drilled oil wells (Fig.5). Thus, the various oil companies in Nigeria especially Shell, Elf, Mobil, Chevron, Texaco, Agip, BP Statoil etc. including NNPC and some indigenous companies are now moving into new and perhaps more difficult areas such as the frontier sedimentary basins e.g. Chad, and Benue and the Deep water sector of

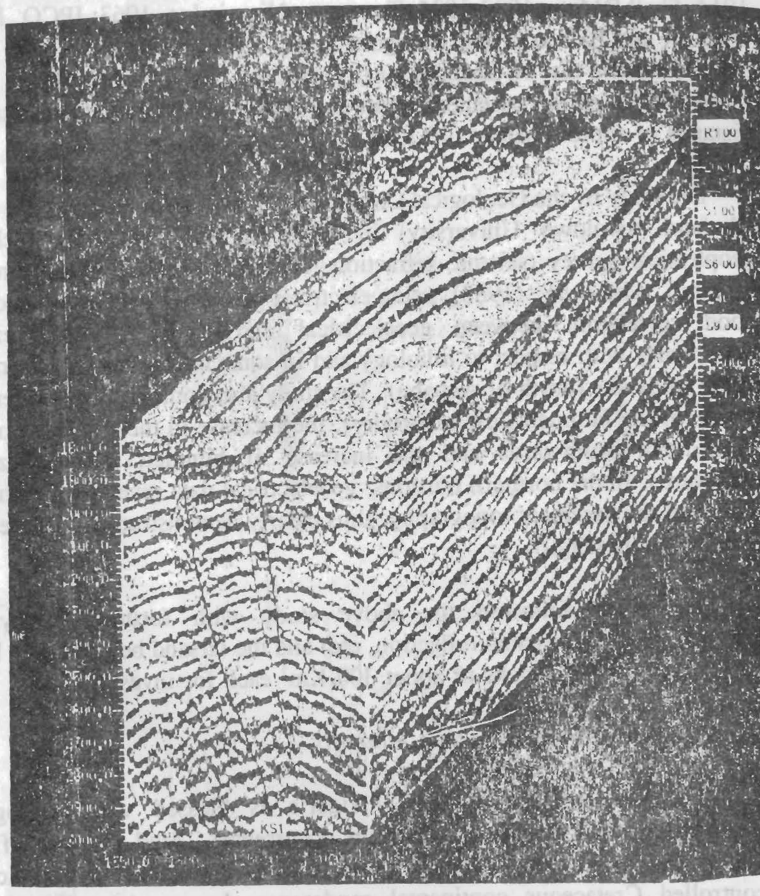

Fig. 5: Krakama R1.00 clipped horizon on Landmark SeisCube (Courtesy SPDC).

Nigeria. Our university the "Great Ife" by 1976 produced the first set of indigenous B.Sc. (Hons) graduates of Applied Geophysics and has not stopped ever since. With a virile postgraduate programme "Great Ife" can rightly claim to have a sizeable number of high calibre, well trained geophysicists occupying top positions in the various oil companies, including NNPC and the oil contracting firms. It is gratifying to be part of those who initiated the Applied Geophysics programme and still sustains it here at Ile-Ife.

Bitumen

Oil sands or Tarsands have been known to occur in South-Western Nigeria especially in parts of Ondo, Ogun, Edo and probably Lagos states since early 1900s. Various workers (Nigerian Bitumen Corporation, 1908-1914, Shell D'Arcy 1922-1935. Tennessee Nigeria Inc. 1963; IPCO, 1965; Durham and Pickett, 1966, Adegoke *et al.* 1974, 1976, 1978, and 1980) have confirmed that oil sands occur in Cretaceous sediments overlying block faulted Precambrian basement rocks east of Ijebu-Division, Ondo State, a distance of approximately 110 Km.

The study by the Geological Consultancy Unit of University of Ife (now Obafemi Awolowo University) in 1980 for the first time included geophysical survey (seismic refraction, electrical resistivity and borehole logging). Ako *et al.*, (1983), using electrical resistivity data concluded that good correlation between geoelectrical and geological data exists, particularly with respect to lithology and in some cases bitumen saturation at the study site (north of Agbabu). The study also confirmed the water wet nature of the bitumen (low resistivity), the increase in the thickness of the overburden southwards and the increase of bitumen-saturated zones westwards. In the northern portions, geoelectrical data revealed the uneven nature of the basement topography, thus clearly demonstrating the effect of block faulting (Fig.6).

NNPC has followed the above study with further geophysical exploration work (seismic reflection, etc) and the tarsand belt has now been partitioned into 17 blocks of about 300 Km^2 each for investors.

Uranium and other Radioactive Minerals

According to Ojo, (1980), "Nigeria is blessed with geological environments favourable for uranium occurrences. Acid granites of the basement complex ore, in places overlain by structurally and tectonically controlled Cretaceous continental sandstones. In many localities, this geological setting is intruded by acid volcanics which form traps for uraniferous solution solutions being transported by underground water. Such ares abound in the Northeastern, Central, Northwestern and Southeastern parts of Nigeria. These have been located as a result of ground followup of anomalies resulting from earlier air-borne radiometric surveys. The author (Ako) remains one of the first indigenous geophysicists to participate in such a project in early 1974, when attached to Faireys Survey of England that flew the Southeastern part of the country.

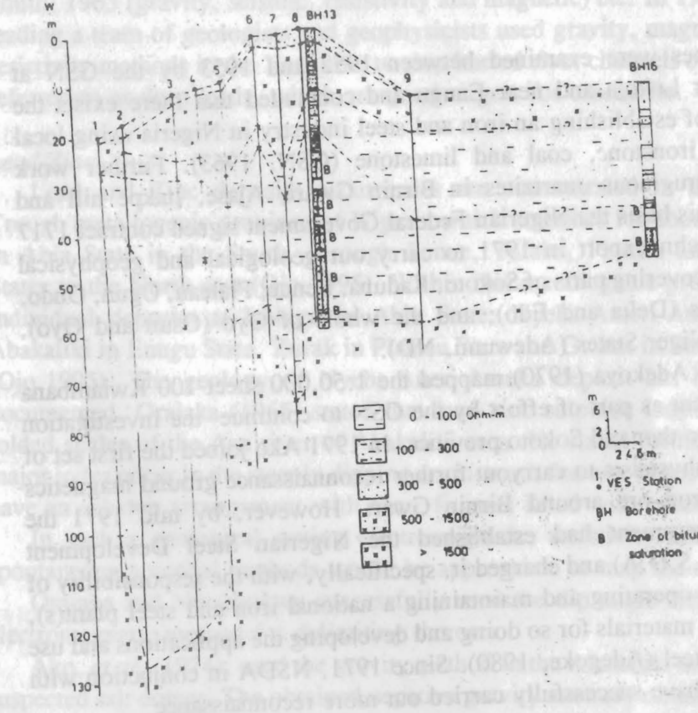

Fig. 6: Geoelectrical section and borehole data along traverse (TS-1).

Solid Minerals

Solid minerals include metallic and non-metallic or industrial minerals. The metallic minerals include minerals like gold, silver, tin, iron. We also have the massive sulphides, e.g. Pyrrhotite, pyrite, chalcopyrite, galena etc. Sphalerite and Hematite are also often classified under massive sulphides. Disseminated sulphides include mainly porphyry copper and/or molybdenite, with associated minerals, like chalcopyrite, chalcocite, bornite, pyrite etc. The industrial minerals include limestone, marble, asbestos etc.

To the geophysicists a massive sulphide body is defined as a very dense, typically very conductive and frequently magnetic occurrence. Thus, magnetic, gravity, electromagnetic, self-potential and resistivity methods would be suitable for their search. A disseminated sulphide body is defined as sulphide scattered as specks and veinlets through rock and constituting not over 20% of the total volume. Hence density contrast is often small, magnetic susceptibility is variable but low except when magnetite is present. Conductivity is invariably low. Hence, the electrical method especially the induced polarization method is unique in this case.

Some of the important metallic minerals in Nigeria include: Iron Ore, Lead-Zinc, Gold and Cassiterite.

Iron

Ironstones were examined between 1952 and 1953 by the GSN at Agbaja near Lokoja and near Enugu and concluded that there exists the possibility of establishing an iron and steel industry in Nigeria using local sources of ironstone, coal and limestone (GSN, 1963). Further work revealed ferruginous quartzites in Birnin Gwari, Ajase, Itakpe hill and Maru. On this basis the Nigerian Federal Government signed contract 1717 with the Technoexport in 1971 to carry out geological and geophysical exploration covering parts of Sokoto, Kaduna, Benue, Plateau, Ogun, Ondo, Bendel states (Delta and Edo); and the whole of Oyo (Osun and Oyo), Kwara and Niger States (Adewumi, ND).

Ako and Adekoya (1970) mapped the 1:50,000 sheet 100 Kwiambana S.W. Quadrant as part of effort by the GSN to continue the investigation for iron ore in then old Sokoto province. In 1971 Ako joined the first set of Russian geophysicists to carryout further reconnaissance ground magnetics survey for iron ore around Birnin Gwari. However, by mid 1971 the Federal Government had established the Nigerian Steel Development Authority (N.S.D.A) and charged it, specifically, with the responsibility of constructing, operating and maintaining a national iron and steel plant(s), procuring the materials for so doing and developing the applications and use of iron and steel (Adegoke, 1980). Since 1971, NSDA in conjuction with the Russians have successfully carried out more reconnaissance aeromagnetic surveys on scale 1:200,000, ground magnetic and gravity followups which have resulted in the mining of iron ore at one of many economic deposits discovered (e.g. Ajabanoko, Chokochoko and Agbade Okudu). Mining of iron ore is currently taking place at itakpe in Kogi State. Although a steel plant now operates at far below installed capacity at Ovwian -Aladja in Delta State, the dream Ajaokuta Steel plant which is meant to use the local iron ore as feed stock is yet to be completed. Is this the "Nigerian or Russian factor"?

Cassiterite

The Mineral Survey of Northern Nigeria began work in October 1904 and later saw tin (cassiterite) deposits which were earlier reported by the Royal Niger Company. The geological survey started further exploration for tin in the Jos plateau in 1919.

Cassiterite occurs in Nigeria mainly as placer deposits in alluvials. There are also known large sub-basalt reserves of cassiterite on the Jos Plateau (Plateau, Kaduna, Bauchi and Kano States), while rich pegmatite deposits exist in Kwara, Ondo and Osun States (Ojo,1995).

Du Preez (1948) carried out the first geophysical work, electrical resistivity survey to map the weathered bedrock for cassiterite. Others include those of Shaw and Cole (1959) (electrical resistivity); Masson-Smith, 1965 (gravity, seismic, resistivity and magnetic) etc. In 1973, Ako, leading a team of geologists and geophysicists used gravity, magnetics and resistivity methods in the Vom area to map buried river channels commonly referred to as deep leads, which are good targets for cassiterite.

Lead-Zinc

Lead and Zinc deposits occurrences are concentrated in the Benue Trough metallogenic province of Nigeria which stretches for about 600Km in Abia State in the South, through Benue, Taraba, Plateau and Bauchi States to the North east (Ojo,1995). Within this metallogenic province are individual deposits at Ishiagu in Abia State; Nyeba-Ameri-Ameka near Abakaliki in Enugu State, Zurak in Plateau State and Gwana in Bauchi State (Ojo,1995). The geology of Nyeba-Aneri-Ameka deposit has been well documented. Orajaka (1965) stated that lead zinc sulphide iodes occur in folded shales of the Asu river of Abakaliki area. He stated further that the major iodes occur in the steeply dipping north-south fracture zones and often have an echelon arrangement with some fissures filled with saline water.

In such a geological setting electromagnetic, resistivity and perhaps spontaneous potential methods would be appropriate to map the ore.

Orajaka and Nwachukwu successfully used the dip angle technique of electromagnatic method for delimiting the ore.

Ako, *et al.* (1974), used the gravity method in the Abakaliki area to map suspected salt domes. The obtained negative gravity anomaly obtained in the area correlated with the shales in contrast to the dolerites close to Abakaliki about 16km northwest of Nyeba. It is gratifying to learn that the spontaneous potential method has been successfully used in delimiting lead-zinc ore in the Nkpume Akwaoku base area where high positive anomalies indicate lead-sinc deposits (ABEM, Communication).

Gold

Gold is known to occur in areas of undifferentiated metasediments, basement and older granites. The Minna, Kaduna, Zaria and Ilesha fields are the most important ones.

Earlier geological investigation in the Itagunmodi and Ilesha fields areas of Osun State by De Swardt (1954 and (1953); Hubbard (1963 and 1975) revealed probable sulphide mineralization in the Itagunmodi/Ilesha area in addition to confirming the reported occurrence of alluvial and eluvial gold deposits. In 1963 and 1965 respectively, Canadian Mineral Survey limited carried out aeromagnetic and airborne electromagnetic reconnaissance surveys of Itagunmodi/Ilesha area on behalf of the Geological Survey of Nigeria. Ade-Hall, (1965) also carried out some ground magnetic and Turam surveys mainly in the Itagunmodi area. The results of these surveys only revealed possible superficial conductors, with no success at finding a definite evidence for massive sulphide mineralisation. In 1975, the Department of Geology, University of Ife embarked on a regional mineral exploration programme of the Ile-Ife/Ilesha areas with Ifewara area as the target zone because of the interesting and complex rock relationship. Ako et al (1975), consequently started a systematic geophysical mapping of the Ifewara area using electromagnetic, magnetic, self-potential and resistivity methods. Results obtained thus far (Ako *et al.* 1978; Ako, 1981, 1982 and Adewusi, 1988) suggest lack of massive sulphide mineralisation associated with gold but the presence of disseminated sulphide. It therefore means that our survey strategy must change.

However, north of Ifewara a systematic survey (geophysical, geochemical and geological) embarked upon by the Nigerian Mining Corporation has been quite successful.

According to Ojo, (1995), areas which had been thought to have been mined out are now confirmed to still contain some good quantities of gold. Also primary deposits which were written off in the late 50s are now found to contain economic reserves of gold.

Limestone and Marble

Limestone deposits are fairly wide spread in the Cretaceous sedimentary basins of Nigeria (e.g. Shagamu, Ewekoro, etc., Fig.4). The search for raw materials principally limestone for a cement factory in Ondo Province of the former Western State of Nigeria began about 1970 when the Geological Survey of Nigeria drilled two boreholes at Arimogija area of Owo Division. Further, similarly inconclusive work was done by Metals and Minerals (Nig.) Limited in 1976. However, results from both studies delimited thin limestone bands, generally less than 2 m in thickness. Detailed geological and geophysical works carried out in the Arimogija - Okeluse area by the Department of Geology, of the University of Ife in 1978 discovered a fairly extensive limestone sequence, averagely 5 - 6 m thick in the Okeluse are. of Owo Division, where there had been no reported existence. The drilling programme was based on the results of an earlier geoelectrical survey led by Ako in 1978.

In the Igbeti area of Oyo State marble is found to occur within an interbedded series of quartzites and gneisses intruded by the granite series and migmatised in places. The marble outcrops as discrete lens-shaped bodies in a narrow zone within the quartzite close to its western boundary with the gneiss. The bodies are invariably bounded by chalcedony and are traceable along the channels of Olokun, Elera and Yegun rivers. Using geoelectrical profiling Ako, (1980) confirmed the existence of two earlier mapped bodies and discovered a third approximately 10Km in length striking NNE, with an average width of 91 m and a thickness of 12 m. The well documented southern body at Igbetti has a lateral extent of 304 m and a thickness of 6 m. Similarly, discoveries have been made based on geophysics at Elebu, Kwara State and Igarra, Edo State over the years by our group at Ife.

Asbestos

Asbestos is also a very important industrial mineral: Reported occurrences are in Kastina Province. Wright and Ogezi (1978), have reported small bodies of serpentinite within finely banded biotite rich gneiss and schists, which pass rapidly outwards to more massive quartzofeldspathic gneisses and migmatites. The weathered serpentinite bodies contain coarse anthophyllite asbestos (Casey, 1956; Macleod, 1964; Wright and Ogezi, 1978) which have subsequently formed target for detailed exploration by the Geological survey of Nigeria. The preferential weathering of the asbestos containing serpentinite and schist makes them good targets for resistivity survey. Consequent upon the results of earlier geological mapping, pitting, trenching GSN 1973), magnetic, and some electrical resistivity work (Ige,1972), at Shemi, Dan-Bido, Ako (1973) followed up with a detailed resistivity survey. The results obtained (Ako,1980) show the weathered schist (host to the asbestos) as a more extensive body than was inferred from geological data.

Extensive investigation for clays have also been carried by our group (e.g.Ifon, Arimogija, Uteh etc. in the mid 1970s).

Water

The mineral map of Nigeria does not show water as a mineral. However, water is one of the most important but often assured to be always and ever available mineral. Consequently, to most of us the search for investigation for water looks ridiculous when there are streams, rivers, lagoons and even the Atlantic ocean close by. What about rain water during the wet season? The occurrence of water is classified into surface and underground components. (Fig.7).

The surface component is fairly well studied and understood. The same cannot be said for the underground component commonly known as groundwater. The major problem associated with the study of ground water is its inaccessibility. Like the name suggests it occurs in the subsurface (our target in this lecture) accumulating in reservoir rocks, (sands, gravels, silt, limestone etc) in sedimentary rocks, and in weathered overburden, joints, fractures and fault zones in crystalline basement rocks. Groundwater as a source of public water supply has attained considerable important as a result of its large volume(97%) of occurrence irrespective of climatic conditions and normally good quality. In terms of quality, groundwater is usually low in organic and anthropogeneous pollution except in areas of shallow coarse aquifers.

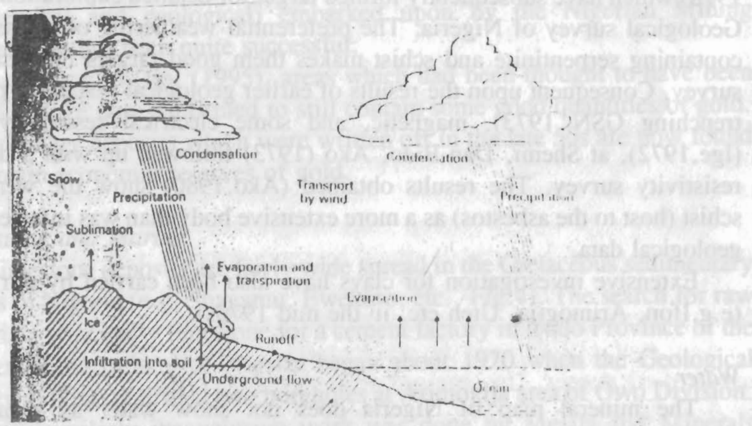

Fig. 7: Schematic representation of the hydrologic cycle (After Domenico, 1972).

Fortunately, groundwater occurs in somewhat similar geological environment as petroleum, thus the fundamental problems in hydrogeophysics (that is, application of geophysics in hydrogeology) are similar to those problems met with in petroleum exploration. These problems which include locating suitable groundwater aquifers, the determination of aquifer geometry and continuity, estimating hydrological properties and water quality, can therefore be solved with most geophysical methods employed in the petroleum industry. Consequently, two approaches are generally adopted in hydrogeophysics; these are surface and borehole geophysical methods. The most used surface techniques are electrical resistivity, seismic refraction and shallow reflection, electromagnetic and to a lesser extent gravity and magnetic methods. The subsurface methods include almost all the geophysical borehole logging techniques (see Scot-Keys and MacCary, 1971). The advantages of the application of geophysical laboratory measurements on drilled-core samples to determine aquifer properties have been discussed extensively by various authors (see Emerson, 1969; Worthington & Baker, 1972; Olorunfemi & Griffiths, 1985 etc.). The application of the above techniques are very relevant to the situation in Nigeria where there is also greater dependence on groundwater. Figure 8 shows a simplified map of groundwater environment of Nigeria.

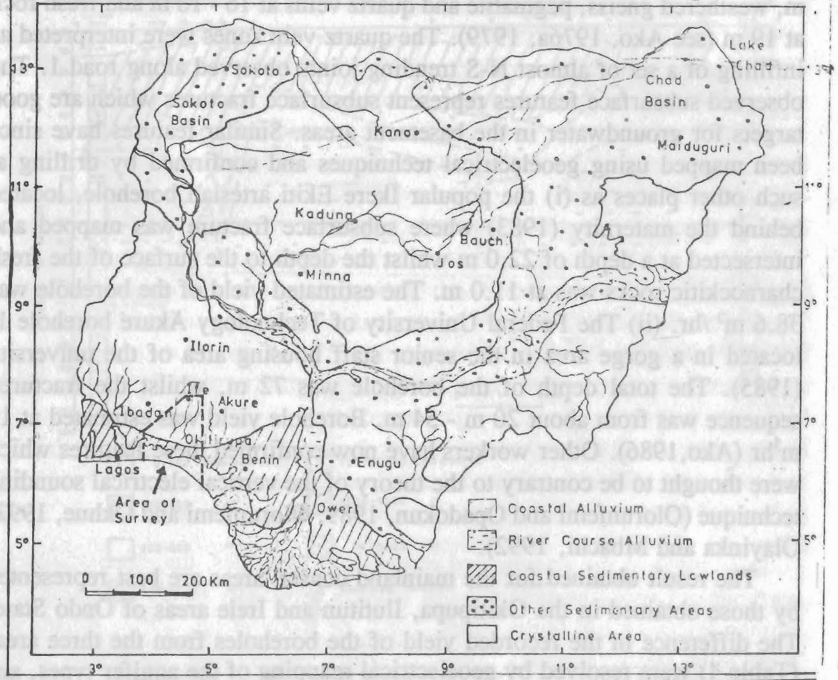

Fig. 8: Simplified map of groundwater environments of Nigeria (After GSN, 1961).

For a long time, exploration, for groundwater was restricted to areas of the country immediately underlain by crystalline rocks (hard rocks), because of the erratic nature of groundwater occurrence in them (e.g. Jones, 1952, 1954; Cratchley, 1960; Olowu, 1962; Ako, 1973), while it was generally believed that wild cat drilling would succeed anywhere in the sedimentary environment no matter the terrain (e.g. Du Preeze 1951, 1952; Jones, 1955, Jones, 1956, Table 5).

To properly articulate the observed erratic nature of groundwater occurrence and quality in both the basement and sedimentary environment, Ako in 1976 started a systematic geophysical investigation for groundwater in parts of South-western Nigeria. The area covered was about 544m^2 approximately 960 Km East of Lagos covering the coastal Alluvium, Coastal sedimentary lowland and crystalline areas (fig.8).

Seismic refraction and electrical resistivity methods were used in the basement area, whilst only the resistivity technique was used in the sedimentary terrains.

The results from the basement area revealed very interesting features. At Ife a weathered horizon was mapped within fresh rock. This observation correlated with the results of an earlier geoelectrical foundation work along the Opa dam axis; where drilling revealed bedrock of fresh rock first at 12 m, weathered gneiss, pegmatite and quartz veins at 16 - 18 m and fresh rock at 19 m (see Ako, 1976a, 1979). The quartz vein zones were interpreted as infilling of a set of almost N-S trending joints observed along road 1. The observed subsurface features represent subsurface fractures which are good targets for groundwater in the basement areas. Similar features have since been mapped using geoelectrical techniques and confirmed by drilling at such other places as (i) the popular Ikere Ekiti artesian borehole, located behind the maternity (1983) where subsurface fracture was mapped and intersected at a depth of 22.0 m whilst the depth to the surface of the fresh charnockitic rocks was at 11.0 m. The estimated yield of the borehole was 38.6 m^3 /hr. (ii) The Federal University of Technology Akure borehole 1, located in a gorge area in the senior staff housing area of the university (1985). The total depth of the borehole was 72 m, whilst the fractured sequence was from about 20 m - 54 m. Borehole yield was estimated at 15 m^{3}hr (Ako,1986). Other workers have now confirmed these features which were thought to be contrary to the theory of the vertical electrical sounding technique (Olorunfemi and Opadokun, 1989; Olorunfemi and Okhue, 1992 Olayinka and Mbachi, 1992).

The result obtained for the mainland coastal areas are best represented by those obtained in the Okitipupa, Ilutitun and Irele areas of Ondo State. The difference in the recorded yield of the boreholes from the three areas (Table 4) were resolved by geoelectrical mapping of the aquifer types, and geometry (fig. 9).

The prolific and safe aquifer in the Okitipupa area is at a much

shallower depth (50 m) than its equivalent at Ilutitun (80 m) whilst the clay sequence is thicker (70 m) at Okitipupa than at Ilutitun (20 m). The obtained results thus revealed why some of the boreholes drilled by the Ondo State water corporation on wild basis cat failed. It was also found that some of the aquifer at Irele are more of silt with intercalations of peat hence the often obtained poor borehole yields (Ako, 1979, 1983a, 1986).

In the area of coastal alluvium (Atijere, Aiyetoro etc.) the mapped subsurface was a sequence of alternating sands and shales. Borehole yields were good (Table 4), but the quality of water was rather poor (saline water) in some of the aquifers. Many of the boreholes drilled on the basis of speculation had to be abandoned

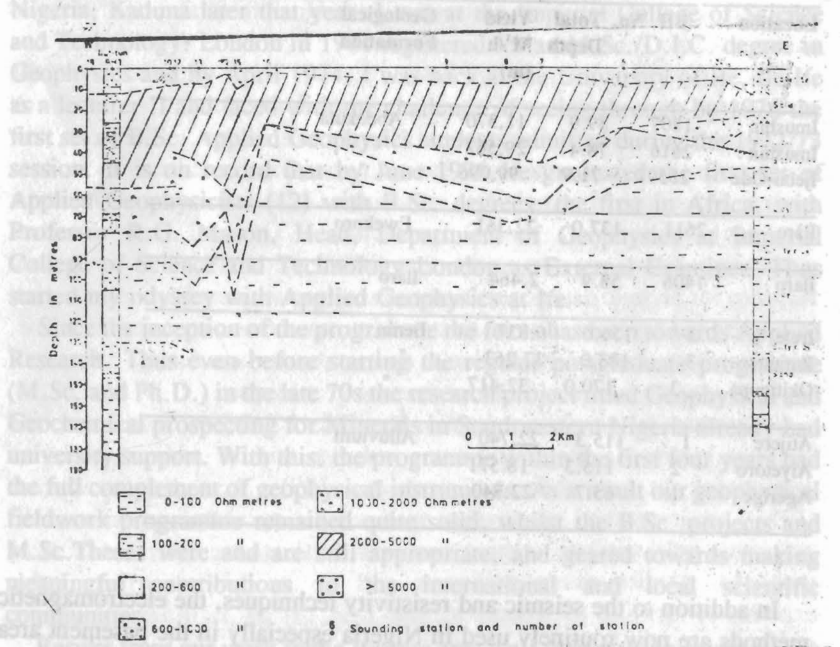

Fig. 9: Geoelectric section and drilling results along the Ilutitun/Okitipupa Profile.

because of saline water intrusion. Several other geophysical surveys in areas with very complex subsurface geology (e.g. Gombe, Sheda, Darazo etc.) have been very successful (Ako and Iyioriobe, 1984; Ako and Osondu, 1986; Ako and Olorunfemi, 1989).

The few case histories considered here are to show that geophysical investigation for groundwater is important and necessary in all terrains prior to drilling. In the basement area irrespective of thin or thick overburden the existence of faults and fracture improves substantially the yield of boreholes (Ikere Ekiti, Akure).

In the sedimentary terrains the effects of facies changes, saline water intrusion and aquifer suitability can easily be determined (Okitipupa, Ilutitun, Atijere). In the volcanic environments (e.g. Jos Plateau), it is possible to map buried rival channels which are the only sources of high groundwater yield.

Table 4: Borehole characteristics sedimentary formations, Part of South-Western Nigeria (After Ako, 1979)

Location	**BH. No.**	**Total Depth**	**Yield M^3/h (m)**	**Geological Formation**
Imushin	1807	89.9	11.370	Abeokuta
Imushin	2616	78.4	29.562	"
Ijebu-Ode	25597	71.9	99.096	"
Ilaro	2611	137.0	22.361	Ewekoro
Ilaro	1406	58.9	2.464	Ilaro
Irele	3	156.0	6.837	Benin
Ilutitun	3	183.0	37.263	"
Okitipupa	3	170.0	32.417	"
Atijere	1	115.3	22.740	Alluvium
Aiyetoro	2	115.3	18.571	"
Agerige	1.	65.7	22.740	"

In addition to the seismic and resistivity techniques, the electromagnetic methods are now routinely used in Nigeria especially in the basement area to map fractures and faults (Edet, 1987, de Rooy *et al.*, 1987, Amadi and Nurudeen, 1990, Olayinka, 1990). It seems the message has finally gotten to our planners. If nothing, the Federal Ministry of water Resources and the River Basin Authorities now insist on pre-drilling geophysical investigations for groundwater in all terrains. It is also nice to learn that the same Ministry

at long last may soon commission the study and mapping of saline water intrusion into fresh water aquifers in the coastal regions. It is my hope that qualified, knowledgeable and competent people with integrity will be given this most important task. It will be unfortunate if the confusion and forgery of geophysical field data which characterised the National Borehole Programme Phase I is again allowed.

Mr. Vice-Chancellor, distinguished ladies and gentlemen our trip through the subsurface is almost at its end, but permit me to briefly talk about Applied Geophysics at Ife.

APPLIED GEOPHYSICS AT IFE

The Department of Geology started as a separate Department in 1966, although the first set of students had been admitted a year earlier. I was one of those who got into the University of Ife, in September 1966 to take a degree in Chemistry or Geology. I flirted with both programmes until my second year when I opted for geology thinking of the good life awaiting me in any of the oil companies on the completion of my course. Suffice it to say that I finished in June 1969, found myself in the Geological Survey of Nigeria, Kaduna later that year. I was at the Imperial College of Science and Technology; London in 1971 registered for an M.Sc./D.I.C. degree in Geophysics and by April 1974, I was back at the University of Ife, Ile-Ife as a lecturer II and faced with the challenge of seeing through by 1976 the first set of B.Sc. Applied Geophysics students admitted during the 1972/73 session. It is on record that by June 1976 Ife graduated the first set of Applied Geophysicists (12) with B.Sc. degrees; the first in Africa, with Professor R.G. Mason, Head, Department of Geophysics at Imperial College of Science and Technology London as External Examiner. Thus started my odyssey with Applied Geophysics at Ife.

Since the inception of the programme the focus has been towards Applied Research. Thus even before starting the regular postgraduate programme (M.Sc. and Ph.D.) in the late 70s the research project titled Geophysical and Geochemical prospecting for Minerals in Southwestern Nigeria already had university support. With this, the programme within the first four years had the full complement of geophysical instruments. As a result our geophysical fieldwork programme remained quite solid, whilst the B.Sc. projects and M.Sc.Theses were and are still appropriate, and geared towards making meaningful contributions to the international and local scientific communities.

Results from our work in the Ifewara area have continued to open up new thinking regarding the structural setting and mineralisation of the area (Ako *et al.*, 1978; 1982 and 1983; Adewusi, 1988; Fatoke, 1995).

Hydrogeophysics is another area where our group has made very significant contributions. We have shown that the subsurface structure though complex can be elucidated if data acquisition strategy is appropriate and interpretation is painstaking. Thus areas where prospects for groundwater have been regarded as minimal or impossible have turned out to be prolific (for example Ikere, Akure, Sheda(Abuja), Darazo (Bauchi). Ikare etc (Ako, 1983b; Ako and Iyioriobhe, 1984; Ako and Osondu, 1986; Olorunfemi and Olorunniwo,1985; Olorunniwo and Olorunfemi, 1987; Adebayo, 1995).

Meaningful work has also been carried out in petroleum related topics viz: Ofor, (1982); Okpikoro, (1990); Nwaeri, (1990); Ali (1992) Fasuyi, (1993); Oluwasusi, (1994); Onanuga (1995).

Our contributions to engineering geological work have also been worthwhile for example Ako, (1976a); Ako and Ajayi, (1976); Olorunniwo and Malomo, (1982); Adeduro, Ako and Mesida, (1987); Olorunfemi and Mesida, (1987); Ako, (1989).

Our group has also made significant contributions to geological mapping and related subjects (Adepoju,1988; Onyechi, 1989; Adepelumi, 1996).

The geophysics group working within the Geological Consultancy Unit has made valuable contributions to the geological/engineering geological survey of the new Federal Capital Territory, investigation of local raw materials for rock polishing, cement manufacture, fertilizers and Bitumen to name a few.

These modest achievements have recently been crowned with the endowment of a professorial chair in Applied Geophysics by the Shell Petroleum Development Company of Nigeria Ltd. (SPDC). With this new development, our research focus has also now been broadened to include modern techniques of seismic data acquisition (3-D), interpretation (Seismic sequence stratigraphy, lateral prediction/AVO) and environmental geophysics. Since we are aware that SPDC has inhouse expertise and facilities for seismic data acquisition and interpretation and our group is yet to acquire the sophistication in terms of instrumentation required for same, our immediate area of contribution to this symbiosis is in further training of required Geophysicists and Environmental geophysics.

Environmental geophysics implies the study of shallow subsurface, the interface between geology and man, and also has the wider meaning of determining the surroundings (Greenhouse, 1991). According to Steeples (1991), environmental geophysical methods are to address environmental problems, help mitigate existing concerns, evaluate the extent of existing problems, predict where pollutants will go in the subsurface, guide exploratory drilling programmes, and help design facilities to prevent environmental problems.

Environmental problems can be associated with surface and underground pollution sources. Underground pollution sources are related to the flow of fluids. In most cases, the fluid flow involves liquid, but sometimes the problem is with movement of a gas or gases (Steeples 1991). Because geophysical methods can detect fluids directly, determine shallow

stratigraphy, geologic structures and relative permeability, they are useful tools for environmental studies.

Both the electrical and electromagnetic methods are relatively cheap and are the most used geophysical methods for environmental studies.

Certainly, the activities associated with oil/gas exploration and production affects the environments of operation. More often than not, there is the disruption of the ecosystem (vegetation and animals), partial destruction of farm-lands, pollution of rivers, streams, ponds and groundwater. Groundwater pollution is not quite visible.It is sometimes quite slow, may be limited or wide spread in extent and can have a permanent effect on fresh groundwater aquifers and sources of recharge. Groundwater pollution in the oil industry results not only from exploration activities (drilling and completion) but also from production activities (existing oil/gas fields, flow stations, injection wells, spillage/leakages along pipe lines and other installations). The pollution could therefore be from oil and/or brine.

How often and detailed are the attempts to ascertain this phenomenon of subsurface pollution is a question I want us to ponder about and answer. Have our earlier and ongoing impact assessment studies (EIA) been directed at subsurface pollutions? If so, how often have we repeated such measurements and what methods have we used and over what areas?

It is about time we embrace environmental geophysics as a faster cheaper and efficient way of tackling pollution problems.

Whether we like it or not, society is getting more conscious of the need to have a good environment and it is time we respond. The oil companies should please support our effort to go into this aspect of Applied Geophysics.

In the words of Brooks and Bowles (1993), " or Exploration Geophysicists, environmentalism has come to determine, - like it or not - how we approach our primary task of finding energy resources. The challenge for those of us whose primary tasks are to fund and develop natural resources is to do so economically while under public scrutiny and abiding by the iofty stands of environmentalism. In terms of actions, the oil industry can continue supplying the energy demand, we suggest that even though we've come a long way from the practices of the early 1960s, we must go even further in consideration of the environmental impact our operations have and plan them so that the inevitable effects are temporary or insignificant".

These words are meant for all those concerned with the exploration for and exploitation of subsurface treasures".

Ife has made some efforts but the future challenge demand more. Can "Ife" face these challenges? It is doubtful especially with the present lack of motivation for our young and very bright graduates to go to the Ph.D. level and join the Academia. The Geology Department which had over 25 academic staff a few years back is left with only 10. Three of these are geophysicists, the youngest being a 1976 graduate. Nigeria needs to ponder over this. Although other universities have since joined "Ife" in this noble experiment, unfortunately, the staffing situation and facilities available are not encouraging. "Great Ife" it is hoped will be able to meet the future challenges.

CONCLUDING REMARKS

In this lecture, I have only scratched the surface in introducing you to "Applied Geophysics, the subsurface and the Treasures". To my professional colleagues the technicalities have barely been touched, the complexity of the subsurface not discussed, and many more treasures that exist have not been mentioned. Nevertheless, from this lecture it is clear that Applied Geophysics is the tool that looks into the subsurface prior to drilling and unravels the structures and treasures therein. Perhaps this why some of our colleagues in the Department call us magicians.

Permit me to quote from *The Guardian* of Wednesday 14, 1996,"Nigeria is very rich in various kinds of commercially viable solid minerals - Alhaji Kaloma Ali, Hon. Minister of Solid Minerals Development. In the said supplement on the Nigerian Mining sector the Minister further stated:

- "A national policy on solid Minerals development is underway;
- Intensive geological efforts to explore for exploitation, all the nation's mineral resources"

No mention of Applied geophysics.

Also from *The Guardian* of Friday, February 9, 1996 in a Market Report titled"Solid minerals to revive nation's economy" by Ade Ogidan it was stated therein "The bowel of Nigerian's sector of mother earth is abundantly blessed with solid minerals. *Survey efforts on these vital resources in the country have been low but by the last estimation Nigeria sits on $1,000 billion (N85,000 billion) worth of solid minerals.*

Ojo, as the President of the Nigerian Mining and Geosciences Society in 1995 in his opening address to the 31st Annual Conference of the NMGS held at Calabar stated "Nigeria is endowed with numerous mineral resources both metallic and industrial. *However, owing to the low level of exploration of the country for mineral deposits the known reserves of metallic minerals are small but a few of them are significant enough for economic exploitation*".

Then what is really wrong? Ete Daniel in his article titled Creating Solid Mineral Wealth in *The Guardian* of Thursday, 8th February,1996 gives an appropriate answer "Over the decades government inaction in creating sustainable investment policy for the development of the country's solid minerals has been manifest in poor funding of existing mining ventures even as the government itself accounts for 95 per cent of the investment in the

mining sector. *This also extends to funding of geological surveys and exploration work to establish new discoveries and reserves"*

Evidently, only the oil industry appreciates the need for intensive thorough, detailed predrilling exploration and pays to sustain same. Clearly applied geophysics is the tool.

It is indeed time for all other establishments (including government) involved in the mineral industry to embrace Applied Geophysics as one of the most important exploration tools prior to drilling and exploitation.

The universities running Applied Geophysics programmes should be well equipped an funded.

Geophysical exploration projects should be assigned to such Departments and time limits to submit reports given.

The Ministries of Solid Minerals, Water resources, FEPA, Mining Corporation, Geological Survey should be well funded to carry out exploration work. These establishments must in turn liase with the universities for manpower development in applied geophysics, planning of exploration strategies and geophysical data interpretation.

The oil industry and Solid Mineral industry must also now take advantage of the capability of environmental geophysics in solving environmental problems.

MR. Vice-Chancellor Sir, respected colleagues, ladies and gentlemen, this is the end of our short trip to the subsurface to have a peep at the treasures. However, before we leave let me thank all those who have in one way or the other made today a reality.

I wish to express my appreciation to all my teachers and lecturers who introduced me to the Alphabets A,B,C. and ensured I understood enough to continue. My sincere thanks to Professor O.S.Adegoke who played a vital role in ensuring I got serious with my work as an undergraduate and has always supported my aspirations ever since.

To my Colleague and dear friend Dr. G.A.O. Arawomo, I say thank you for those many days of upliftment in Rm I 14.

To my class of 1969 what started as a joke has today come to pass, I thank you all for your faith in my ability.

I wish to express my appreciation to Gulf Oil Company (now Chevron), the British Council, successive University Adminstration, Agip and others who paid for my education, and various trips abroad and to Shell Petroleum Development Company of Nigeria Ltd. for endowing the Chair in Applied Geophysics that I occupy.

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