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AGE AND ENVIRONMENTAL INDICATION OF ANCIENT SEDIMENTARY ROCKS

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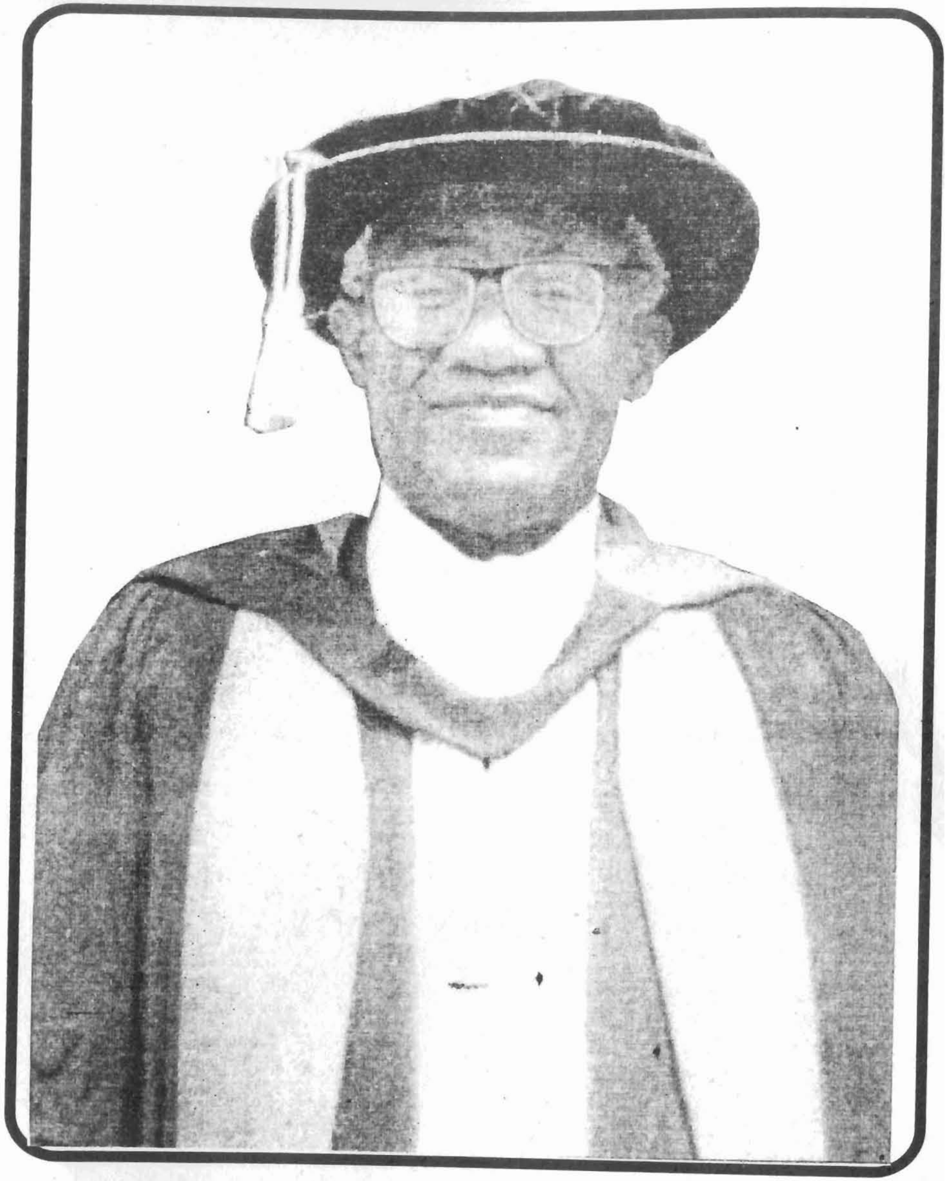

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I. INTRODUCTION

Mr. Vice-Chancellor, Sir, I have chosen as the topic of this inaugural lecture, "*Age and Environmental indicators of Ancient Sedimentary Rocks*", in order to present a discourse on the subject matter and furthermore to show how my research contributions in over two decades have addressed the two key words "*Age*" and "*Environmental*" deductions in rocks of the Lower Cretaceous to Paleogene ages (about 100 to 35 MY-million years) in Nigeria. I have confined myself to these strata in that older sedimentary rocks are not available onshore until the mid-Albian to Cenomanian (about 100MY) when the first marine depositional cycle began in the southern part of the Benue basin. Before then, much of Africa and South America were united in a continental landmass called Gondwanaland. I have utilized microfossils recovered from some of these ancient sedimentary strata, carried out detailed analyses of their constituent lithology and the sedimentary structures preserved in them, in order to make age and paleoecological deductions (i.e. past environments of deposition) about such rocks.

The focus in this lecture will therefore be on those objects which are sometimes contained in ancient sedimentary rocks of the Earth's crust and which assist us in determining their ages and the environments of deposition. These are *fossils*, the actual remains of animals and plants that once lived on the surface of the Earth, or evidence of their existence. Fossils, therefore, are the imprints of leaves, shells of invertebrate animals, parts of complete skeletons of vertebrate animals, the trackways of animals imprinted on sedimentary rocks or even entire carcasses of animals buried and preserved in ice through natural causes (e.g. that of the wooly mammoth – *Mammuthus primigenius* of Russia, a relative of the modern Elephants). This is in contrast to their being once referred to as "*mystical objects*", "*devices of the devil placed in the rocks to delude men*" or "*objects engulfed by the Biblical Flood*" during the Middle Ages when religious dogmatism was the rule and any rational scientific explanation of the environment was considered as heresy and was punished by death.

Age and paleoenvironmental deductions in ancient sedimentary rocks are vital to exploration for fossil fuels such as coal, petroleum and natural gas, because such deposits are formed from the remains of organic life buried in such sedimentary rocks, over several millions of years ago. In addition, sedimentary rocks hold some vital minerals and ores (such as phosphate rock for fertilizers, limestone and gypsum for cement production, halite or salt for cooking, and a variety of sulphates, and borates for the chemical industry) which are necessary for our economic survival and prosperity. In order to advance our knowledge in these directions, we need to give consideration to those basic principles which form the foundation or keys to the understanding of the past. They form the "bedrock" for relative age determinations and paleoenvironmental deductions. It is also pertinent at this point to have a basic understanding of our planet Earth in which such records of the past are preserved for posterity.

II. THE EARTH, KEYS TO THE UNDERSTANDING OF THE PAST AND SYNCHRONIZATION OF PALEONTOLOGICAL AND GEOLOGICAL DATA

Our planet, Earth, is one of the nine planets which orbit around the sun, to make up the solar system. The others are *Pluto, Neptune, Uranus, Saturn, Jupiter, Mars, Venus* and *Mercury*. The field of geophysics (study of the earth's interior), especially seismology, has provided for us the internal structure of the earth. Based on seismological evidence, the Earth is composed of three unequal but concentric layers, namely, the core, the mantle and the crust (Fig. 1). The crust is of importance to man because it is the only layer we have direct, but partial access to while the others are inaccessible to us. Since the crust is our home, we depend on it for all resources than the inaccessible mantle or core. The outer layer of the crust is made up a discontinuous sedimentary cover which is variable in thickness and composition and is made up of materials derived from the primary rocks through surface agents of erosion and deposition. This layer though insignificant in relation

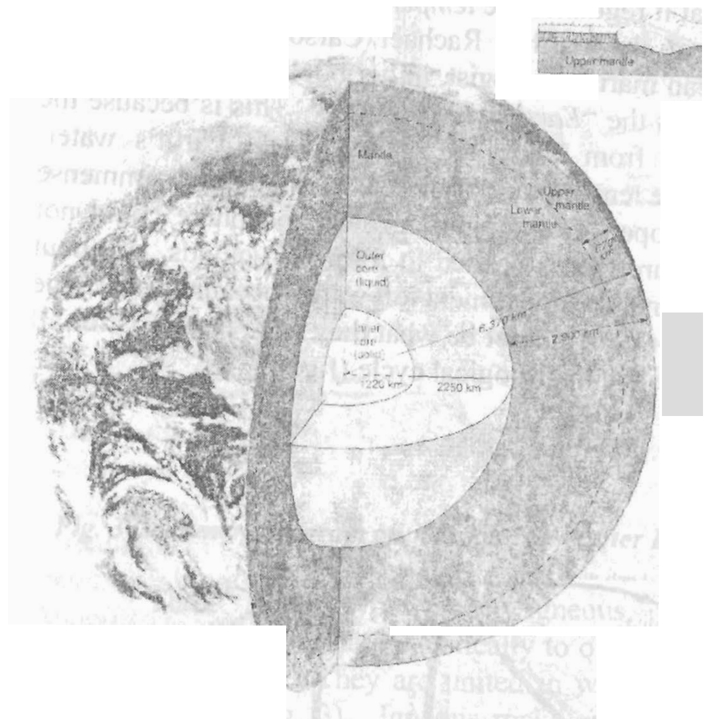


Fig. 1. Earth Interior (after Plummer and McGeary, 1996)

to the overall radius of the Earth, yet is of great importance to man for agriculture, for construction materials, for fossil fuels, for some mineral resources, and to a large extent for water. This sedimentary layer, therefore, provides the basis for our survival and together with the solid crust amount to no more than 0.5 percent of the radius of the Earth. Two other zones, the *hydrosphere* and the *atmosphere* are important. The hydrosphere comprises all aquatic bodies such as *lakes, rivers, lagoons, estuaries* and the seas. The atmosphere on the other hand, forms the gaseous envelope that surrounds the surface of the planet Earth. The hydrosphere is very important to mankind and all plant and animal life in that it regulates the *temperature*, the *winds* and *water* on the surface of the Earth. Rachael Carson (1961), the late eminent American marine biologist, in her book, "*The Sea Around Us*" described it as the "*Earth's Thermostat*." This is because the hydrosphere apart from being the source of all Earth's water, controls the surface temperature of the Earth. Without its immense surface which is open to evaporation, the atmosphere could not take up the moisture that is needed to form rain clouds. Without marine currents and the movement of warm oceanic water, the climates of the world would not be what they are. The basis for all such circulations is the hydrological cycle (fig. 2).

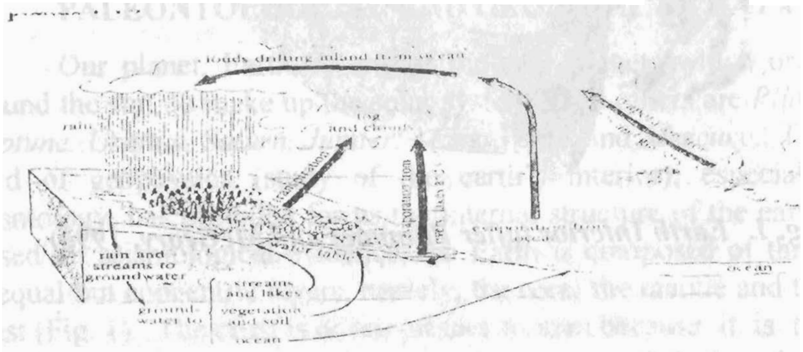


Fig. 2 – The hydrological cycle (after Bell et al., 1989).

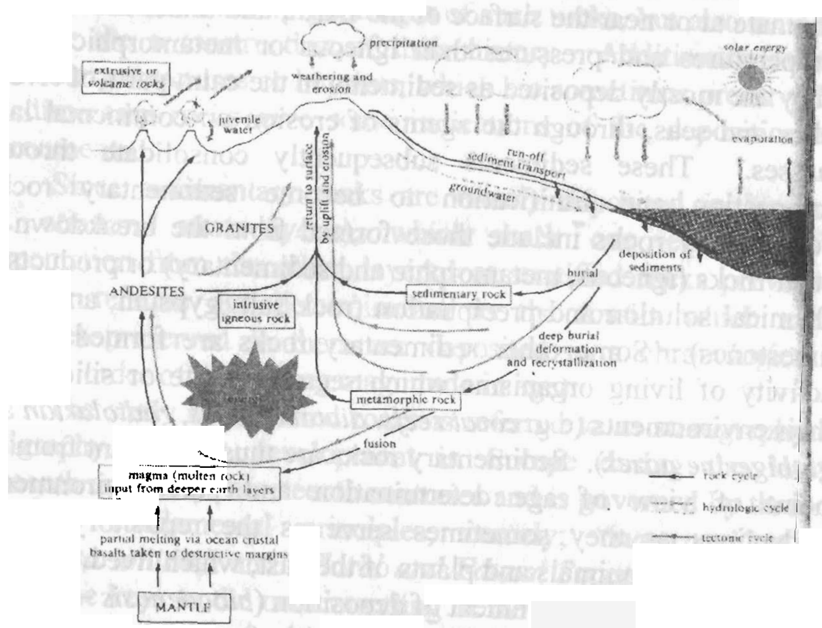


Fig. 3 Summary diagram of the rock cycle (after Bell et al., 1989)

Three rock types, the igneous, metamorphic and sedimentary, which relate genetically to one another constitute the crust of the earth. They are united in what is referred to as the "Rock Cycle" (fig. 3). Igneous rocks crystallize from a molten liquid called magma produced from within the interior of the earth. Metamorphic rocks are those sedimentary or igneous rocks which, once formed have been changed more or less by being placed in a different physical environment due to pressure and temperature changes. They have however not been melted. Sedimentary rock is that formed from sediment such as sand, clay, gravel and other particulate matter or those in solution through the processes of compaction, lithification or evaporation.

This lecture is devoted to sedimentary rocks which originate at or near the surface of the Earth, and under much lower temperatures and pressures than igneous or metamorphic rocks. They are mostly deposited as sediments in the calm parts of rivers, lakes and seas, through the agents of erosion on continental land masses. These sediments subsequently consolidate through compaction and lithification to become sedimentary rocks. Sedimentary rocks include those formed from the breakdown of other rocks (igneous, metamorphic and sedimentary) or products of chemical solution and precipitation (rock salt, gypsum, and some limestones). Some other sedimentary rocks are formed by the activity of living organisms which secrete calcite or silica from their environments (e.g. *coral reefs, diatomaceous, radiolarian* and *globigerine oozes*). Sedimentary rocks are thus important from the point of view of age determination and paleoenvironmental deductions as they sometimes serve as the repository of the remains of the animals and plants of the past, which lived, died and got buried in the environment of deposition (*biocoenosis* – together in life) or were post mortally transported after death to be buried and preserved in another environment different from the one in which they lived and died (*thanatocoenosis* – together in death). Organisms with hard parts are more favourable to fossilization (or preservation as fossils), but sometimes soft tissues have been found preserved as fossils under unusual conditions. The famous Precambrian (over 600 million years) Ediacara beds of Australia and the Burgess Shale of British Columbia (540 to 520 million years), are examples, where well preserved insects, worms, and other soft bodied invertebrate fossils are known. So also is the *Solnhofen lithographic limestone* of Bavaria, Germany, famous for the records of the earliest birds with feathers, called *Archaeopteryx*, belonging to the Jurassic (i.e. 190 – 150 million years ago). In addition, whole carcasses of the wooly mammoth (*Mammuthus primigenius*, that roamed the arctic plains of Russia many thousands of years ago, are now known as they have been found preserved in ice, even with substances on which they fed.

Organic remains thus found in sedimentary rocks not only provide basis for estimating the ages of such rocks, but also sound basis for the reconstruction of their history. Additionally, the sedimentary structures or imprints, which are sometimes preserved in sedimentary rocks give some indications of the depositional environments.

Since sedimentary rocks are mostly deposited in layers (Lat. stratum, strata-layer/s), which mark one episode of sedimentation from the other, layered or stratified rocks provide basis for relative age determination as the fossils which are sometimes preserved in them are deposited in a chronological order (i.e. order of decreasing magnitude in age).

The study of stratified rocks is referred to as stratigraphy. Stratigraphy had its development in Europe during the late eighteenth and early nineteenth centuries and is governed by three basic but fundamental principles, namely; "*superposition*", "*uniformitarianism*," and "*Floral and Faunal Succession*," which serve as the keys to the understanding of the past. The "*Principle of Superposition*", proposed in 1669 by Niels Stensen, a Danish Physician (whose latinized name was, Nicolaus Steno) states that "*in any undisturbed succession of strata, the oldest is at the base and the youngest is at the top.*" Steno was also the Archbishop of Denmark. This principle was formalized in 1815 by James Hutton. The second principle, called "*uniformitarianism*" was proposed in 1795 by James Hutton. The principle emphasizes that the dynamics of the processes responsible for past geological events are essentially the same as those operating today. This is summed up by his statement that, "*we find no sign of a beginning – no prospect for an end*". The lesson here is that nature behaves in a uniform fashion throughout time. By studying the present, one can infer the behaviour of past processes. "The present therefore is the key to the past." What uniformitarianism has advocated as being uniform are the physical and chemical laws which govern geological activities and not the rates of geological processes. For example, ancient volcanoes should have released pyroclasts, gases and deposited ash layers and lava flows, just as modern ones do when they erupt. The third principle, *"Faunal and Floral succession"* was formulated by William "Strata" Smith, commonly called the "Father of Stratigraphy", a famous road engineer and surveyor in 1799. Smith's idea was that *"fossil plants and animals succeed each other in a definite and determinable order and that any period of geological time can be recognized by its respective fossils."* In a general sense, this means that rocks with identical fauna and/or flora are of the same age irrespective of the distance between local sequences in which they are found and not withstanding the differences in the physical characteristics at the different localities. For example, limestone and shale from different local sequences and with identical fossils are suggestive of the same age, even though dissimilar in lithology. This biological scheme of dating or determining the ages of sedimentary rocks which was introduced by William Smith had as basis the theory of organic evolution which unfortunately had not come to light at the time that he put forward his principle of faunal and floral succession. It is therefore logical to say that this significant finding of William Smith provided the inspiration and impetus to Charles Darwin in understanding all that he saw during the voyage of the Beagle and the subsequent development of the Theory of organic evolution.

"The Theory of Organic Evolution" was independently formulated by Charles Darwin and Alfred Russell Wallace (a young naturalist, who was then working in the Dutch East Indies – the present Indonesia), in 1859. Organic evolution which states that *"in the fossil record, smaller and simpler animals and plants occur in the oldest formations and are succeeded in later formations by structurally and functionally more complex animals and plants"*, has provided the rational explanation to the basic understanding of the principle of faunal and floral succession. Organic evolution presented a revolutionary view of the living world and implied that the diversity of life on Earth had resulted from natural and random processes, and not, as was previously

believed, from creation. Furthermore, it emphasized that organisms have evolved into almost every conceivable possibility in their adaptive radiation. It therefore advocates a dynamic continuous model. It opposes the fact that:

(i) life was spontaneously generated;
(ii) that it arose by special creation; and
(iii) that it reached the earth as living matter from some other source in the universe.

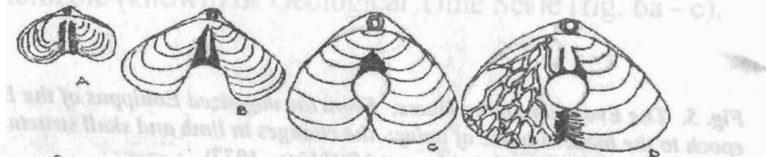
The regularity of changes in species of fossils through successive layers of rocks is one of the strong lines of evidence that support the theory of evolution. Much as it is not my intention in this lecture to generate some controversy on evolution and creation and the tenets of the various religious orders, I wish to state that there are evidences from *comparative anatomy* (such as homologous structures), *embryology* and *paleontology*, which are used to support organic evolution. Such evidences, however, do not distract us from our beliefs. The organs that agree in fundamental structures are said to be homologous (*from Gr omologia – agreement*). For example, bones, muscles, internal organs, and vestigial structures (e.g. appendix, mesenteries and ear muscles in man) are homologous structures, which are in agreement in fundamental plan but may be functional in some animals, while they are non-functional in others and may also vary in size in different animals. Man is said to have an *"anatomical misfit"* because his viscera have not been properly supported by his posture. All other mammals, except man and the apes walk on all their limbs, with the body in a horizontal position, and the delicate mesenteries that hold the various organs in place are well fitted to the horizontal posture. In standing upright, man has brought the mesenteries into inadequate and inefficient position and as a consequence, he suffers from *"fallen stomach"*, *"prolapse of the womb"*, *"paunchiness"* (being wide around the waist) and *"hernia"*.

It has thus been argued, by some evolutionary biologists such as Gaylord Simpson, Edwin Colbert and Ruben Stirton that if human beings were indeed created, they would not have been given useless and dangerous appendages, which are functional in other animals, but not functional in man. Furthermore, that the human body would hardly have been given the most inefficient and troublesome visceral supports of all mammals. Such vestigeal structures, however, are used to show that man is related to other animals by common descent from ancestors in which these structures were functional.

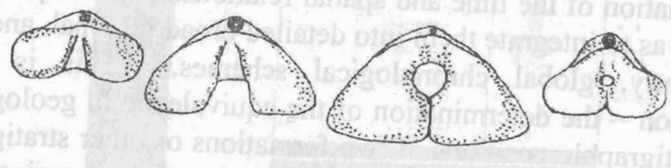
Embryology provides another evidence in support of organic evolution. The biogenetic law states that "*ontogeny (development) recapitulates phylogeny.*" that is ontogeny (or development) repeats briefly (and in many cases imperfectly) the racial history. The amphibians are believed to have evolved from the fishes on the basis of embryology. The common toad, *Bufo regularis*, provides a basis for this repetition or recapitulation. It lays its eggs in water and these hatch into tadpoles that are in essential respects fish-like, breathing by means of gills and having no lungs or limbs. But during growth the gills are resorbed, lungs are formed, legs bud out from the body, and, after a transition period, the animal may leave the water to spend the rest of its days on land. This metamorphosis (i.e. change in form) implied that the remote ancestors of the amphibia were fishes, from which they descended by migrating from the water to the land, with all the modifications which that migration imposed. The amphibians were never able to improve on this habit and so, throughout the ages, have returned annually to the water to spawn. This is to enable them to reproduce themselves and hence continue with their existence.

Paleontology is also used to support evolution because some individuals or lineages provide evidence of linkage between one morphological group and another. For example, *Baculites*, a Late Cretaceous Ammonite (that lived 75 to 65 million years ago) is coided in its early part but straight shelled at a latter stage, thus

indicating that it developed from a coiled ancestor. The "keyhole" Jurassic brachiopod, *Pygope*, like *Baculites* has preserved a record of its own ontogeny. The adult shell has a hole passing through its middle, like the hole in a "doughnut". The stages in the growth is as illustrated by *Pygope diphyoides*, a modern form in Fig. 4a. The recovery as from the Jurassic and Cretaceous rocks of Europe have shown that the racial development did follow the course of *P. diphyoides* (see Fig. 4b). Also in the lineage of the Equidae (the horses), evolutionary developments were in the direction of the reduction in the number of toes on limbs, increase in length and size of limbs and modifications in the structure, size and dentition of the skull (fig. 5). These developments were to facilitate efficient speed, ability to support the body weight and to cope with a larger volume of food required by increasing body weight. The modern horse *Equus equus* is thus standing on one toe, which is called the hoof.



4a. Pygope diphyoides (A-D), individual shells representing four growth stages.



4b. Pygope: adult shells of distinct species from successive geologic ages showing the racial history. E, F, G (Jurassic) and H (early Cretaceous)

Fig. 4. Individual and racial history of the keyhole brachiopod, Pygope.

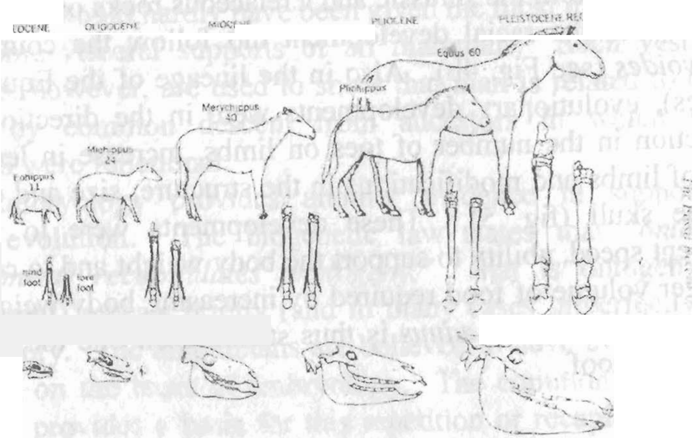


Fig. 5. The Evolution of the Horse. From the dog-sized Eohippus of the Eocene epoch to the modern horse of today: the changes in limb and skull structure. (from Storer, Usinger, Mybakken and Stebbins,, 1977).

The ultimate aim of stratigraphy therefore, is the determination of the time and spatial relationships of sequences of strata so as to integrate them into detailed broad regional, and more importantly, global chronological schemes. This is called correlation – the determination of the equivalence in geologic age and stratigraphic positions of two formations or other stratigraphic units in separated areas. Correlation is also the determination of the contemporaneity of events in the geologic histories of two areas. Correlation is carried out using not only the physical characteristics of the sediments, but more importantly, the organic remains of ancient life (called fossils) preserved in the sediments.

Correlation by fossils is embodied under the Principle of Faunal and floral succession, which is controlled by organic evolution. It is based on very *short-lived* species of plants and animals which are known to exist during a specific period of geologic time. Such a fossil is called an index fossil and it allows the geologist to correlate the rock in which it is found with all other rock layers in the world containing that fossil.

Many fossils are of little use in time determination because the species thrived during too large a portion of geologic time. Sharks, for example have been in the oceans for a long time (over 400 MY). The discovery of a shark's tooth is not helpful in determining the rocks's relative age. Since a geologist is likely to find several different fossils in a rock, such a fossil assemblage is generally more useful in determining the relative age of the rock than a single index fossil.

It is obvious from the foregoing that fossils have provided basis for evolutionary development and this has served the purpose of rock subdivision and age determination as embodied in the Phanerozoic (known) or Geological Time Scale (fig. 6a - c).

Fig. 6a. The Geological Times scale – To true scale to show the relative length of the Eras.

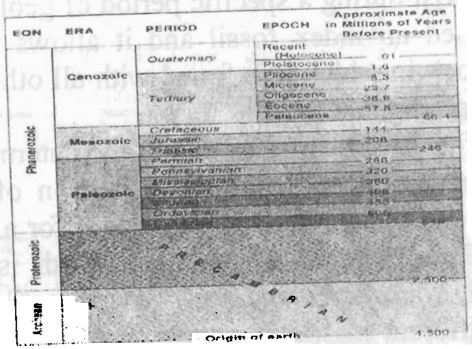


Fig. 6b: Geologic Time Scale – Not to scale but to highlight the epochs of the Tertiary and Quaternary.

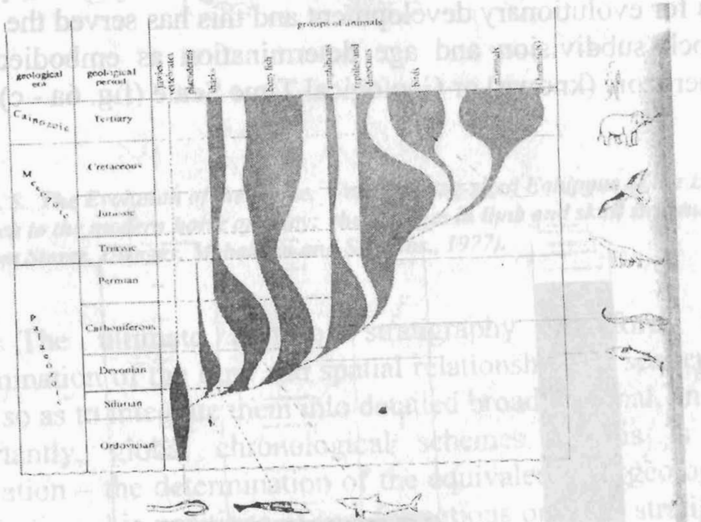


Fig. 6c. Geological ranges of the vertebrates to show when the various groups of animals evolved from each other. The width of each group indicates the approximate number of species living at the time (after Bell et. al., 1989).

III. THE AGE OF THE EARTH, THE MISSING FOSSIL RECORD AND PALEOENVIRONMENTAL DEDUCTIONS OF ANCIENT SEDIMENTARY ROCKS

Both astronomy and geochemistry have estimated the age of the Earth to be between 3,000 and 5,000 million years. Meteorites, the naturally occurring mass of matter from outer space are estimated at 4,500 million years, while the oldest dated rock on Earth (from northwestern Canada) is about 3,964 million years. This last estimate has put the minimum age for the formation of the Earth's crust to be not less than 3,900 million years.

Philosophical, theological and scientific propositions had been made to account for the age of the Earth. The Brahmins of India speculated that the world is eternal (i.e. without beginning or end). The Christian world of the Middle Ages, held the view that creation occurred only about 6,000 years ago. This belief was based on the assumption that the Old Testament Scriptures constituted a complete and literal history of the world. This view was given added authority about the middle of the seventeenth century by certain Anglican Churchmen. One of such was Dr. John Lightfoot, a distinguished Greek scholar and Vice-Chancellor of Cambridge University, who in 1642 deduced that the moment of creation was "9.00 o'clock in the morning on September Seventeenth". He did not give the year of creation. However, in a later chapter of the same work in 1644, he stated that it was 3,928 B.C. Furthermore, Archbishop James Ussher, Primate of Ireland, in 1658, wrote: "in the beginning God created Heaven and Earth, Genesis 1, verse 1, which beginning of time, according to our chronologie, fell upon the entrance of night preceding the twenty third day of Octob. in the year of the Julian Calendar, 710 (i.e. 4004 B.C)." This position of Archbishop Ussher was repeated in many later editions of the Authorized English Version of the *Bible* and thus was incorporated into the dogma of the Christian Church. For over a century, thereafter, it was considered as heresy to assume more than 6,000 years for the formation of the Earth and all its features. This view is still held by some Christian theologians till today.

It was under this influence that Geology grew up and during its early years supernatural explanations were invoked for natural phenomena. For example, the glacial drift, which was widespread over Western Europe, was attributed to the Biblical Flood. Even Mountains were believed to have arisen with much violence and noise. Even rocks several thousands of meters above sea level and containing fossils similar to modern marine organisms found in many parts of the world were attributed to a world-wide inundation that drowned all the earth's mountains in a matter of days.

The age of "*theological idealism*", subsequently gave way to scientific reasoning in which several lines of evidence were used to calculate the age of the Earth. Examples include calculations based on the annual rate of sedimentation which was thought to be constant, annual rate of saltiness of sea water in which the primary ocean was lacking in salt, the counting of rhythmic annual banding (varves) in some sedimentary rocks. The oldest age deduced for the Earth, by any of these methods was about 100 million years. These early attempts also fell wide off the mark, not because of poor logic but because not enough critical information was yet available. Inspite of this shortcoming, steady progress was made through them, in that it was later realised that the acceptance of factual evidence of Earth history did not in any way conflict with religion. This is because religion is based on faith while science is knowledge obtained by observation and testing of facts. Both are not antagonistic to one another.

Since fossiliferous rocks provide relative ages of rock formations, a geologist who has an average knowledge of fossil chronology is in a position to make a fairly accurate estimate of the time (range) in which the rocks he or she is studying belongs. The only problem, however, is that the phanerozoic scale of rocks represents about 600 million years, thus leaving us with a great gap

when we take the age of the Earth as estimated above into consideration (see Fig. 6a - c).

Below the Phanerozoic which can be dated by the use of fossils, is the Precambrian, which is devoid of recognizable fossils. but can be dated by radiometric dating techniques on account that the rocks mostly contain radiogenic minerals. Radiometric dating offers a dependable means of keeping time because the average rate of disintegration is fixed and does not vary with any of the physical changes in physical and chemical conditions that affect most chemical or physical processes. The principle is somehow simple. The rates of decay of all common radioactive isotopes are constant and are known from accurate laboratory measurements on pure samples. If the amount of a radioactive isotope present in a material when it was formed is known, then the age of that material is calculated from its present radioactivity, using the known decay rate for that isotope.

In order to estimate the age of a rock sample by the radioactive dating method, a mineral within the rock has to be found that contained atoms of a radioactive isotope when it originally crystallized. Each parent atom eventually decays to a daughter isotope which is retained in the same crystal.. To find out how old the rock is, samples of the radiogenic minerals can be dissolved to get them into solution. The parent: daughter ratios of the isotope can then be measured with a mass spectrometer.

Each time a particular radiometric date is used to calibrate some part of the stratigraphic column, a similar age can be applied to equivalent rocks which contain fossils. Also in a uniform series of sedimentary rocks, if radiometric ages can be found for several horizons in a sequence, the age range of the rocks between can be estimated by interpolation (i.e. make additional age deductions for them).

Several radioactive decay processes have formed the basis of geological dating of rocks, among which are the following:

(i) Uranium ^{238} – Lead ^{206} (Half life 4.51 Billion years).
(ii) Uranium ^{235} – Lead ^{207} (Half life 0.71 Billion years).

(iii) Thorium ^{232} – Lead ^{208} (Half life 13.9 Billion years).
(iv) Potassium ^{40} – Argon ^{40} (Half life 12.4 Billion years).
(v) Rubidium ^{87} – Strontium ^{87} (Half life 50.0 Billion years).

Apart from knowing the ages of rocks, especially sedimentary rocks, it is also significant to know the environments in which such rocks were formed. This is provided by paleoecological analysis. *Ecology* is defined as the "*interaction of living animals and plants with their physical, chemical and biological environments*." Paleoecology on the other hand is the "interaction of ancient animals and plants with their physical, chemical and biological environments." Paleoecological studies are handicapped by sparse preservation of ancient organisms. In addition many of the organisms that are preserved in the fossil state are largely extinct and as such we do not know what their vital needs were during their life time. In order to make some valid paleoecological deductions, we need to rely on empirically derived concepts (relying on observations and experiments), multiple techniques of investigations and a diversity of ideas and observations.

In defining and reconstructing ancient sedimentary environments, reference is made to present day environments based on the principle of uniformitarianism, which emphasizes that environmental dynamics have remained relatively constant during geological time. In addition, sediments and sedimentary rocks often reveal primary structures which may be related directly to the depositing medium, and form as the sediments are laid down or after the actual sediment deposition. Such primary inorganic sedimentary structures as cross-stratification or cross bedding, ripple marks, mud cracks, sole markings and graded bedding assist in interpreting the environments in which the sediments or sedimentary rocks were formed (Fig. 7).

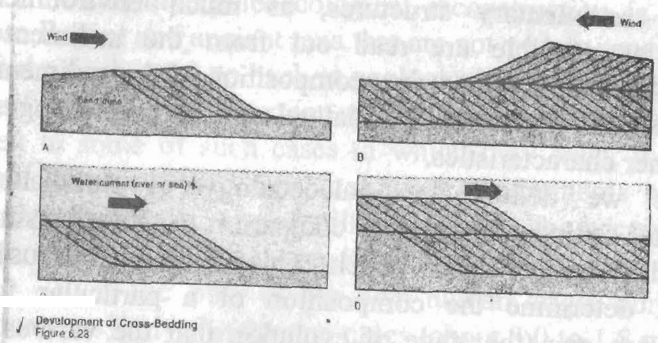


Fig. 7a: Development of Cross-Bedding

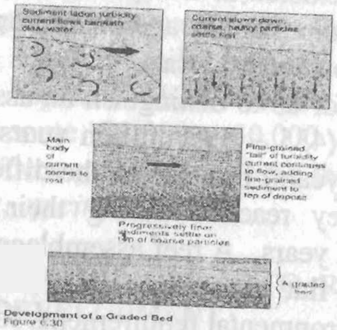


Fig. 7b: Development of a Graded Bed

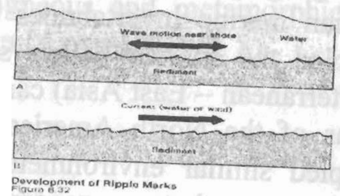


Fig. 7c: Development of Ripple Marks

Apart from sedimentary structures, as much environmental information as possible are read out from the sediment or sedimentary rock using gross size, composition of the sedimentary grains and cement and systematic lateral and vertical changes in these and other characteristics.

Once we deduce the paleoecology of one ancient environmental setting, we can then compare it to that of a similar one from a different geological epoch. This is possible because the factors that determine the composition of a particular fossil assemblage are *age* (the stage of evolution that the various life forms in the assemblage had reached at a particular time), the *environment* (the physical, chemical and biological influences exerted by the environment where the assemblage lived) and *geography* (the broad, regional distribution of life, of which the assemblage is part, and which existed at that place at that time). These three variables are very important in age determination and the paleoecological deductions on ancient strata.

It is therefore possible for us to distinguish an assemblage of mollusks from the Silurian (435 – 395 million years) from a Miocene one (23 - >5 million years) because of the difference in evolutionary stages which they reached during their time of separation of about 400 million years. A reef assemblage can also be distinguished from a tidal flat assemblage of the same age because there are different environmental requirements for the two environments. Even assemblages from the same environment and of the same age can be discriminated on the basis of differences in broad geographic distribution of the organisms. For example the Permian marine invertebrates (280 – 235 million years) which occupied the ancient Tethys sea (that stretched from Gibraltar-Mediterranean – East Asia) can be discriminated from the Permian faunas of the North American continent, on account that both occupied similar environments are of the same age, but from different seas that are geographically distinct. This observation can be attributed to differences in the geographical distribution of animals and plants as existed then and the way they are also today.

Generally, paleoecological reconstruction is workable in those Recent and ancient taxa that are not widely separated in time. But the further we go back in geological time, the fewer and fewer fossil taxa that have extant species or genera for us to refer to. Even in some of such cases in which they exist, we are uneasy about assuming that their ecological requirements had remained the same over, say, tens of millions of years ago because the rate of factors that control them may have changed.

Even the story of our own human origin during the Late Pliocene to Early Pleistocene times (about 3.0 to 1.8 million years) according to Leakey (1976) has not been without any controversy. Recent discoveries made from the Olduvai Gorge, in Tanzania, strongly suggest that there may have been at least three contemporary species of hominids (*Homo habilis, H. erectus* and *H. sapiens*) which probably lived side by side. Based on the theory of competitive exclusion, two of these species seemed to have become extinct, while the third H. sapiens evolved into *Homo sapiens sapiens*, which we are. The *Homo sapiens* probably evolved some 100,000 to 50,000 years ago. By about 35,000 years ago, modern man had become the sole hominid species on Earth (Leakey, *op cit.*).

IV. CONTRIBUTIONS TO RESEARCH AND MANPOWER DEVELOPMENT

I have focused my research contributions in over two decades on the Nigerian sedimentary basins. These basins cover approximately half the surface area of the country, while the remaining half is occupied by igneous and metamorphic rocks which are classified as the Basement Complex (Fig. 8).

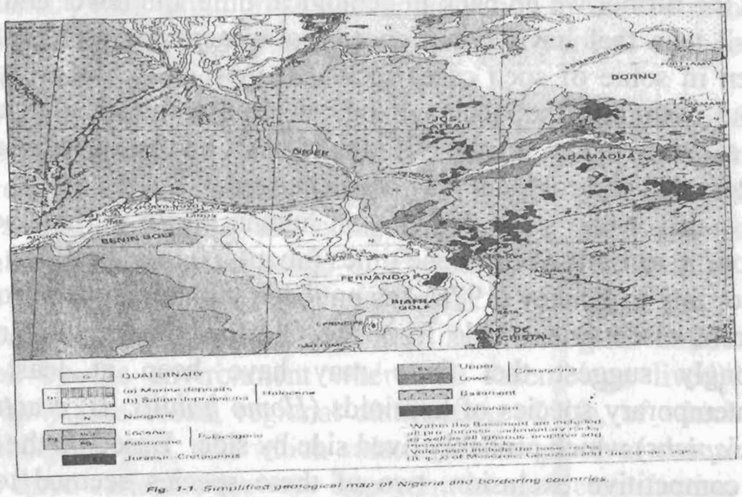


Fig. 8. Simplified geological map of Nigeria and bordering countries.

The sedimentary basins of Nigeria, Benin Republic (ex Dahomey), Togo, Ghana and the Senegal – Cote d'Ivoire owe their origin to the splitting of the Gondwana supercontinent which once united all these places, some parts of South America, Antarctica, India and Australia before the Early Cretaceous (Fig. 9).

Fig. 9. Reconstruction of the original position of Gondwana continents (after Adegoke, 1978)

Research on the Cretaceous – Tertiary sequences in Nigeria has centred on different aspects by various workers. Paleogeographic reconstructions of such sequences had been discussed by the following (Murat, 1972; Machens, 1973; Kogbe, 1976; Offodile, 1976, Petters, 1978 and Ojoh, 1992, among others). The transgression and regression phenomena which led to the deposition of these sequences had also been discussed (Hancock and Kaufman, 1979; Salami, 1984, 1987 and 1990; and Haq *et al.,* 1987).

In general, what we observe in the disposition of the Cretaceous – Tertiary sequences of Nigeria is the thickness of sediments as we move southwards, thus culminating in a thick sequence of about 12 kilometres of sediments in the central parts of the Niger Delta (Fig. 10). This has shown a southward advance of the shoreline since the first marine depositional cycle began in the southern part of the Benue basin. This is called progradation.

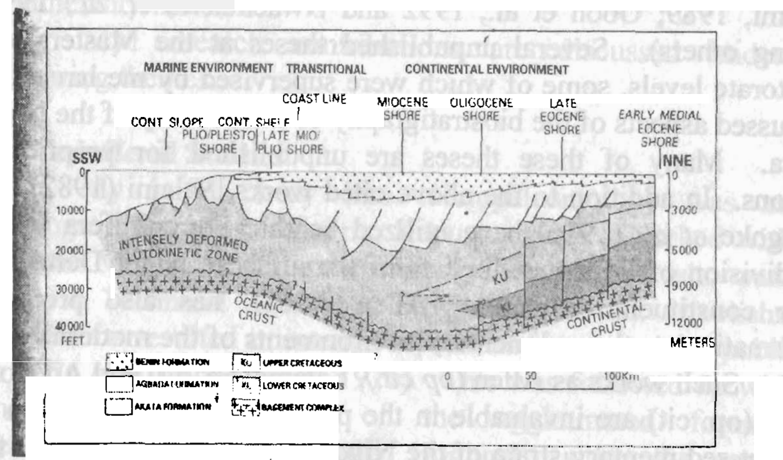


Fig. 10. Structural Section in Niger Delta Complex (after Merki, 1972).

The Tertiary section of the Niger Delta has been extensively studied due to its petroliferous nature and mostly by oil industry workers. Such aspects as sedimentology (Weber, 1971), synsedimentary tectonics (Merki, 1972), subsurface geology (Short and Stauble, 1967; Frankl and Cordry, 1967), lithofacies relations (Oomkens, 1974), petroleum geology (Weber and Daukoru, 1975, Evamy *et. al.,* 1978; Orife and Avbovbo, 1982), and structural geology (Hospers, 1965, 1971, Burke, 1972 and Doust and Omatsola, 1989) have been discussed by the above mentioned workers among several others.

Due to the cooperation which was facilitated by the Department of Petroleum Resources, the oil industry has extended to the academia, in recent years, subsurface sedimentary materials which have provided opportunities for further research into the Niger Delta, especially in the field of biostratigraphy (Jan du Chene and Salami, 1978; Petters, 1979; Ogbe, 1982; Oboh and Salami, 1989; Oboh et al., 1992 and Nwachukwu *et. al.,* 1992, among others). Several unpublished theses at the Masters and Doctorate levels, some of which were supervised by me have also discussed aspects of the biostratigraphy of the Tertiary of the Niger Delta. Many of these theses are unpublished for proprietary reasons. In addition to the above cited works, Salami (1982) and Adegoke *et al.* (1976) have utilized benthic Foraminifera in the subdivision of Recent sediments of the offshore Niger Delta into their constituent biofacies. Allen (1965), has also provided information on the sedimentary environments of the modern Niger Delta. Such works as Allen (*op cit.*), Ṣalami (*op. cit*) and Adegoke *ét al.* (op. cit) are invaluable in the paleoecological evaluation of ancient sedimentary strata of the Niger Delta because some of the constituent microfauna and microflora extracted from these recent sediments have also been found in rocks ranging downward to the Miocene and Oligocene (i.e. > 5 – over 35 MY). They have thus assisted other biostratigraphers in the paleoecological deductions on such strata.

Thrust of Research

I have focused my research into micropaleontology, biostratigraphy and paleoenvironmental analyses. I have utilized micropaleontological objects (Foraminifera and palynomorphs) because for most economic geologic work such as exploration for petroleum, the indicative or index fossils should be small, preferably microscopic in size. This is because the specimens of rock obtained in drilling and coring, during exploration, are so small that they reveal only the microscopic fossils. Larger fossils are usually missed or include fragmental forms that cannot be easily identified. Micropaleontology is the branch of paleontology that deals with microscopic fossils. Paleontology reconstructs vanished animals and plants. It also attempts to understand their modes of life, habits, methods of locomotion (i.e. in the case of animals) and their environments. It is that branch of geology for the determination of relative ages and ancient environments of sedimentary rocks.

My research contributions are discussed under the following themes.

Foraminiferal Studies

My initial foray into micropaleontology was at the Geological Survey of Nigeria, Kaduna, where I worked with Dr. Kalman Mehes, an Hungarian micropaleontologist, who was then under a Technical Assistance Programme at that establishment. Our efforts resulted in internal reports and a paper later published in 1976 (see Kogbe *et al.,* 1976). This was followed up with the study on the Biology of the agglutinated foraminifer. *Trochammina* cf. *quadriloba* Hoglund, under the renowned American micropaleontologist, Professor Zach Arnold, at the Department of Paleontology, University of California, Berkeley. U.S.A. between 1972 and 1974. This foraminifer which was maintained in a temperature controlled laboratory for about two years was to enable details of biology, ecological requirements and information on ontogeny to be studied, so as to be able to make phylogenetic deductions about it in relation to other species in the genus. The results from the study, have shown that fossilized tests of Foraminifera cannot resolve most of the critical problems of ancestor-descendant relationships in paleontology. Furthermore that the role of the nucleus and other environmental parameters in shaping the phenotypic characters of an organism, such as the Foraminifera, cannot be resolved from fossilized tests alone. It is therefore essential for studies on living Foraminifera to be integrated with those on fossils in order to have better understanding of phylogenetic issues.

Another area of my research with Foraminifera is the analysis of Recent marine to brackish water sedimentary strata to the solution of paleoenvironmental problems of ancient sedimentary strata. In this regard the studies carried out alone and with others on the continental shelf and slope sediments of the Gulf of Guinea (courtesy of M.V. Mees Cremer Expedition samples) are worthy of mention (Salami, 1982 and Adegoke, *et al*., 1976). The latter of the two papers has enabled us to subdivide the continental shelf and upper slope sediments into five biofacies, namely:

(i) Nearshore Turbulent Zone Biofacies (0 to 8.75m) made up of Barrier face biofacies (with slow rate of deposition) and the littoral biofacies (with higher rate of sedimentation).

(ii) Upper Continental Shelf (inner Neritic) Biofacies (8.75 to 35m) (with slow to rapid rate of sedimentation).

(iii) Mid-Continental Shelf (Middle Neritic) Biofacies (35.0 to 87.5m) (with slow rate of sediment deposition).

(iv) Lower Continental Shelf (Outer Neritic) Biofacies (87.5 to 210m) (with slow rate of sediment deposition); and

(v) Upper slope (Bathyal) Biofacies (210 to 810m).

The work reported above was well received at the First International Benthonic Foraminiferal Conference held in Halifax, Nova Scotia, Canada, in 1975. It was a major contribution to the Gulf of Guinea Research Project funded by the University Research Committee to one of us (O.S.A).

Further work carried out by me in 1982 has shown that the upper slope (Bathyal) biofacies can further be subdivided into four other distinct biofacies, based on relative abundance and depths of first and last appearances of benthonic foraminifera (i.e. FAD – first appearance datum and LAD – last appearance datum). We have also observed among the benthonic foraminiferal species that variation in size and ornamentation are related to minor changes in temperature, which decrease with depth. Furthermore, that samples from submarine canyon locations contain admixed fauna from both the littoral and bathyal environments. Such mixing of fauna being due to hydrodynamic conditions, during mudslides or turbidity currents, which contribute to mixing relatively shallow water microfauna of the littoral and neritic with the deep water microfauna of the bathyal zone of the ocean.

Our research has further shown the fluvial and marine parameters which affect sedimentation off the Niger Delta. Our findings revealed that the wave-generated and wave and tide generated longshore drift currents influence coastal erosion and deposition off the Niger Delta. These currents move westwards and eastwards off the Niger Delta and influence coastal erosion and sedimentation, such that as sediments are deposited, they are subsequently eroded. Unless there are barriers to impede such erosion, it will continue unabated.

The erosion of the "Bar Beach", in Lagos, is a good case in point. Erosion of the Bar Beach has proceeded, over the past few decades to the extent that what was once a recreational facility and tourist attraction to many people in Lagos and environs has become lost through coastal erosion exacerbated by current land use patterns in which the protective mangrove forest that once fringed the coastine have been destroyed and sand filled for major housing programmes such as the Lekki Peninsula and other new housing activities (Ajah etc.), thus exposing the coastline to severe littoral drift and longshore drifts. Consequently, sections of Victoria Island, especially Ahmadu Bello Way and surrounding areas are under severe environmental threat because properties in these areas are sometimes flooded due to the surge of the Atlantic ocean on the eroded coastal sand bars that formed the Bar Beach and other beaches in the area (e.g. Alpa beach).

It will be recalled that during the rule of General Sani Abacha, the Federal Ministry of Works under General Abdulkareem Adisa awarded contracts worth over two billion naira to a consortium of construction companies, for the reclamation of the Bar Beach and surrounding areas. This contract like others before it or after it awarded by our former Military and civilian rulers have not provided any respite to coastal erosion and the attendant ecological and environmental damages. The sands which are normally won from the continental shelf by major dredging and hydraulic engineering companies for salvage operations are subsequently returned to the same continental shelf and other areas within a relatively short span of time through coastal erosion.

So much debate has been generated in the media as if the problem of coastal erosion is intractable. This is not the case. What is lacking is the moral will to address the problem. It is more disturbing that both the Lagos State Government and the Federal Government of Nigeria are yet to agree as to how the problem is to be financed and solved. It was recently reported that part of what was approved by the national assembly for the project had been vired into addressing some other ecological problems in other parts of the country. One probable solution is the construction of groins or jetties, perpendicular to the shoreline as has been done in many coastal cities in other parts of the world. However, there is need for a multidisciplinary team of geoscientists, oceanographers, civil and hydraulic engineers to correctly identify the problem and proffer appropriate solution. The approach of hydraulic sand filling is not the solution. It merely provides ready jobs for the contractors.

Biostratigraphic Research

With profound gratitude I wish to acknowledge the immense contributions of Dr. N.F. Hughes, of blessed memory, my

Ph.D thesis supervisor at the Department of Earth Sciences, of the University of Cambridge, England. His painstaking attention to details has been the guiding principle in my research and postgraduate supervision. I happened to have been his only Ph.D student from Africa. He worked assiduously to produce eminent palynologists and palynostratigraphers. May his soul rest in peace. Amen.

Palynostratigraphy is an aspect of biostratigraphy where plant microfossils and phytoplankton are employed as basis for age determination, stratal zonation and paleoenvironmental deductions.

A second area of my research therefore is the biostratigraphic analysis of upper Cretaceous and lower Tertiary strata based on Foraminifera and/or palynomorphs, using them for the determination of ages and the environments of deposition of the strata from which they have been recovered. In this regard, sequential, qualitative and quantitative analyses of the microfossils as well as detailed lithologic study of the strata were carried out. To mention some examples, Jan du Chene and Salami (1978) deduced that continental (certainly deltaic) environment existed behind the coastline of the mangrove, at the top section of Nsukwa-1 well, while the lower section of the same well denoted brackish to marine environment of deposition using the constituent microfauna, microflora, lithofacies relations and mineralogy. The age of the deposit was deduced as upper Eocene (about 40 millionyears). Furthermore, Salami (1990) deduced that the Anambra trough of southeastern Nigeria and the southern part of the Benue trough were inundated by a major swamp, whose flora contributed to the extensive sub-bituminous to bituminous coal deposits in these areas. The same swamp flora prevailed in southwestern Nigeria at these times (Campano-Maastrichtian i.e. some 75-65 million years ago) but the environment was not anoxic (reducing) in nature for coal formation (Salami, 1983). Similar view is corroborated in the upper Maastrichtian Abeokuta Group which began as a deltaic swamp association but suffered occasional incursion of sea water, especially in the Araromi

Formation (Salami, 1987). Odebode and Salami (1986) using constituent palynomorphs were able to extend the range of the Odukpani Formation of the Calabar Flank to the Albian (over 100 MY) contrary to the Cenomanian – Turonian (about 100-90MY) deduced by other workers using mainly Foraminifera and Ammonites (Reyment, 1965; Zaborski, 1993). Other publications in this area are the following (Salami, 1984a, b, c, 1985, 1986; Oboh and Salami, 1989; Oboh *et al*., 1992, and Nwachukwu *et al*., 1992).

Palynostratigraphy and Palynofacies Analysis

My third area of research is palynostratigraphy and palynofacies analysis. This is the use of ancient plant and animal microscopic remains (such as plant spores, pollen grains, dinoflagellate cysts, foraminiferal inner linings) as well as vegetal remains (palynomacerals or phytoclasts) in age determination, stratal zonation and paleoenvironmental deductions. Palynofacies analysis is an integral part of sedimentary basin evaluation by most petroleum exploration and development companies because it assists in the reconstruction of ancient depositional environments (Habib, 1979; Lorente, 1990; Denison and Fowler, 1980; Masran and Pocock, 1981; Combaz, 1964; Parry *et al*., 1981 among others). Apart from research publications in this area (Salami, 1984a, 1986, 1990), I have carried out two proprietary studies for the Shell Petroleum Development Company (SPDC), Warri in 1992 and 1995 respectively. The first was a pilot study, while the other was a contract study executed through UNIFECS (the Consultancy Services Centre of Obafemi Awolowo University, Ile-Ife). For example in Salami (1984a), I was able to show that the miospore assemblage was dominated by angiospermous pollen, while pteridophytic spores are less significant. During marine incursions the dinoflagellate cysts altered the dominance of angiospermous pollen. This is summarized in Fig. 11. Palynofacies analysis also contributes to the petroleum source potential of sedimentary strata as the amount, colour and

composition of organic matter from such strata provide useful information in exploration.

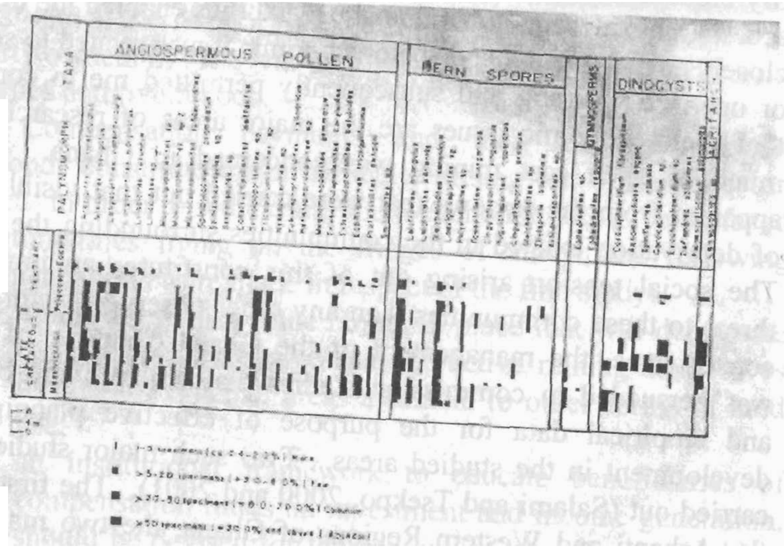


Fig. 11: Palynofacies diagram of the Late Cretaceous and Early Tertiary of South-Western Nigeria.

Geoenvironmental Studies

Between July, 1998 and June, 2001, while I was on a sabbatical leave and leave of absence without pay, respectively, at the University of Ghana, Legon, I took up appointment as the first occupant of the Chair of Geo-environmental Studies, in that institution, for the purpose of studying and proffering solutions to environmental problems related to open cast mining in Ghana. In addition I contributed to the design of the M.Phil. Environmental Science degree programme in that institution and taught Environmental Geology in that programme. I also served as External Examiner for several Masters thesis on Environmental Science to the Institute of Mining and Mineral Engineering of the University of Science and Technology, Kumasi. I supervised Masters and Doctorate theses at Legon. Through this appointment, I worked closely with the Ghana Chamber of Mines, the organization to which most mining companies in Ghana belong. My close association with the Chamber of Mines facilitated easy access to most productive mine sites, and thus enabled me to study closely environmental and socio-economic issues related to surface or open cast mining and subsequently permitted me to conclude that socio-economic issues are the major areas of research in as much as open cast mining was concerned in Ghana. It was apparent from the reviews that were carried out that visible signs of deprivation existed in the communities surrounding the mines. The social tension arising out of this constitutes an immediate threat to these communities than any other observed factor. As a consequence, the management of the Ghana Chamber of Mines was persuaded to commission studies that will provide baseline and empirical data for the purpose of effective planning and development in the studied areas. Two such major studies were carried out (Salami and Tsekpo, 2000 and 2001). The first was in the Ashanti and Western Regions of Ghana, the two major gold producing regions of Ghana. The second study was in the Brong-Ahafo region, an area of Ghana noted for agricultural production (infact a major food basket of Ghana) to which mining concession had been acquired and exploitation was to commence after our study. This latter study was unique in that it was about open cast gold production in a geographical location noted for agricultural production. The introduction of open cast mining will thus compete directly with farming for land use.

The "*Global Gold Exploitation Fever*" brings to the forefront the conflict between globalization and local action. Gold exploitation brings out the major issues about environmental management, which is a global as well as local concern and also the infringement of land rights and the uprooting of cultures which are of local concern. The concerns which the above two studies have brought out include real and anticipated land use conflict, environmental degradation, displacement of communities, influx of migrant population to mining areas in search of employment and

the attendant socially unacceptable behaviour in mining communities, such as rapid deterioration of infrastructure (due to population explosion), spread of sexually transmitted diseases (STDs and HIV/AIDS), poor compensation for farmers and property owners in the event of destruction and disruptions of their properties and livelihoods.

Compensation payments and their use to support livelihoods constitute major difficulty arising out of the land use conflict. In order to redress the socio-economic issues being faced by communities living on the fringes of mines, the following recommendations were made in respect of the first study:

(i) a land use policy must be put in place that will demarcate concessions into active and non-active mining areas so as to make non-active areas available to other forms of land use;

(ii) an institutional framework to educate beneficiaries of compensation funds on investment and income generation, should be devised for those living in mining communities, in order to avoid wastage and subsequent rent-seeking behaviour;

(iii) efforts must be intensified to identify and promote alternative livelihood strategies in the communities in the catchment areas of the mines;

(iv) priority in local government infrastructure development programmes should be given to communities living on the fringes of mines because they are exposed to much environmental degradation; and

(v) a national policy should be evolved that will integrate agriculture and allied industry with mining.

The second study was equally important because production had not started as of the time the study was concluded. As such it will afford a comparison of the benchmark data with future conditions when the company is fully operational and may therefore point to the positive impact of mine operation or otherwise. The results of the baseline study will assist the company to assume corporate social responsibilities for her activities. Additionally, the baseline data will be available for planning activities at the local and national government levels. Furthermore if the socio-economic impact of the project is reviewed at different stages of the mining project, it will provide valuable information to government to make informed judgement about environmental and socio-economic issues.

The two studies that have been summarily discussed above have practical applications to the Niger Delta where oil exploration and exploitation activities had been carried out and are still being carried out since the past four decades with nothing tangible to show in the rural communities of the area except chronic poverty. The region has attendant environmental and socio-economic problems due to many years of neglect. Such studies as discussed above should be encouraged by the several multinational oil and gas companies that are exploiting the area for these natural resources. In addition there should be proactive efforts in the implementation of the results of such studies so as to help dampen the regular acts of "sabotage" and "confrontation" that normally disrupt production in the local communities. To combat restiveness and the feeling of total abandonment by the various communities of the area, the oil and gas companies should desist from playing the elites against the less priviledged members of the communities through the awards of seemingly juicy contracts. Rather, they should engage all stakeholders in constructive dialogue to find more sustainable ways for the delivery of social infrastructures and promotion of livelihood strategies. The companies will also need to find means of training and upgrading the skills of the idle youths of the area so as to be seen to be making proactive contributions to their being gainfully employed. This is because *unemployment, poverty, denial of social infrastructures and social justice* are the root causes of restiveness in the Niger Delta petroleum province.

Mr. Vice-Chancellor. Sir, let me also say that in addition to my research endeavours in this University and elsewhere, I have

been fully involved in manpower development at the graduate and postgraduate levels in the past three decades at the Department of Geology of this University. Permit me also to make a digression on a matter of great concern to me. It has been an arduous task for me and others to attract the young and brilliant minds that we trained, to serve as replacements to most of us in the academia because our Universities have become mere shadows of what they were during the sixties to the late seventies, due to regressive but chronic underfunding. The quality of scholarship has gone down because the facilities to sustain excellence are no longer there. Even the socio-political environment in which we now find ourselves is stifling scholarship. The country is held hostage by "political jobbers", contractors and the "nouveau rich", whose sources of wealth can mostly be traced only to "sustainable corruption". Let me also say that the experience from other countries that have made laudable contributions to humanity is that intellectualism will need to be harnessed for the promotion of development in any nation including our own. Permit me further to comment on the proliferation of private universities and the "culpable" role of the National Universities Commission in ensuring the "destruction" of our public universities. I believe strongly that the Committee of Vice-Chancellors of Federal Universities has a role to play in arresting this "madness" otherwise posterity will not look kindly to it. What we need is adequate funding, replacement of aged facilities, expansion of physical facilities and expansion in staff training. I do not think that government should abandon its primary responsibility. Additional efforts to attract external grants, endownments etc. will merely serve as supplementation and not primary sources of funding. What I see as a major challenge to these emerging universities is manpower. Public universities according to NUC's statistics have just a third of the academic manpower that should service them. Where then will the manpower come from to service these proliferating universities. Is it our desire to debase university education in Nigeria, and thus render our products ineligible for further university education in other countries of the world?

SUMMARY

I have in the course of this inaugural lecture shown that fossils are not fortuitous in ancient sedimentary rocks. They are the actual remains or traces of organisms that lived in the past and got preserved in such ancient sedimentary rocks, which served as their repository due to suitable conditions for fossilization. They are therefore not "mystical objects" or "devices of the devil which have been placed in such rocks to delude men" as were conceived during the Middle Ages.

Since plant and animal fossils are arranged in rocks of the geologic column in a chronological order but not randomly and also provide evidence of linkages between certain morphological groups, they have thus provided a chronostratigraphic basis for the subdivisions of the rocks of the geologic column, especially the section that contain fossils. They have also permitted us to synchronize geologic events in different regions of the world, in the past, through correlation. The remaining section of the geologic column that is devoid of fossils, is amenable to radiometric age determination, on account that they sometimes contain radiogenic minerals, which form the basis for radiometric age determinations.

Ancient organisms have responded to such orderly or sequential arrangement due to organic evolution, the guiding principle for the Principle of Faunal and Floral Succession, one of the fundamental principles guiding age determination in ancient sedimentary rocks.

The chronological arrangement of ancient organisms as well as the paleoenvironmental deductions of their depositional environments are vital to exploration for fossil fuels (coal, petroleum and natural gas) because they are formed from the remains of organic life that were buried in such sedimentary rocks over several millions of years ago. In addition such rocks do

sometimes contain vital minerals and ore deposits needed for our economic survival and prosperity.

I have in the course of my research endeavours in over three decades carried out age and paleoenvironmental analyses of some Cretaceous to Tertiary strata in the Southern Nigeria sedimentary basin using such micropaleontological objects as Foraminifera and palynomorphs. Some of such studies have been highlighted in this inaugural lecture. In addition I have contributed to manpower training in the geosciences and many of my former research students are making valuable contributions in the petroleum industry, the service industry, as well as in the academia (both locally and abroad).

Mr. Vice-Chancellor, Sir, Distinguished Ladies and Gentlemen, I thank you for your attention.

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