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ANCIENT SEAWAYS, SEDIMENTS AND THEIR RECORDED HISTORY IN NIGERIA

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I. INTRODUCTION

SEDIMENTARY ROCKS are layered rocks which were originally deposited as sediments (sand, mud, clay, carbonates, etc.) in near-horizontal sheets over the surface of accumulation. The sediments are derived from the break down of all other forms of rocks and are transported into the sedimentary basin by various agents the most important of which are water and wind. The layers or strata may become consolidated subsequently to form rocks (sandstone, mudstones, shale, limestone, etc.).

The study of stratified rocks is termed stratigraphy. Stratigraphy as a discipline grew up haphazardly in Europe during the nineteenth century. Attempt to standardize the practice began with the First International Geological Congress held in Paris in 1878 and is still in progress today. As a result, only a few basic principles or laws have so far been evolved.

Stratigraphic study has three main aspects, each of which is founded on one of the three basic principles. The first aspect, sedimentary petrography is essentially descriptive. It involves the detailed description of local sequences of strata including their composition, texture and structure or attitude. From these data, the local sequence of events (geological history) can be deciphered. The guiding principle here is the *Principle of Superposition,* first formulated by Nicolaus Steno, a bishop in 1669. Briefly, it states that in any undisturbed succession of strata, the oldest stratum is at the base and the youngest at the top. The validity of this principle has been amply demonstrated by studies of sedimentation.

The second aspect of stratigraphy is the determination of the time and spatial relationship of sequences of strata and the integration of the local details into broad regional and, more importantly, global chronological schemes. This is called correlation and it 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. Historically, correlation by fossils has been the most important and most widely used. It has its foundation in the *Principle of Faunal Succession* formulated by the famous road engineer and Father of Stratigraphy, William "Strata" Smith in 1799. Smith's thesis was that groups of fossils, both plants and animals, succeed each other in a definite and determinable order and that any period of time can be recognized by its respective fossils. In a generalized sense, this means that rocks with identical fauna or flora are of the same age irrespective of the distance between the local sequences in which they are found and notwithstanding the differences in the physical characteristics of the rocks at the different localities.

By applying this principle to the study of stratigraphic sequences, it has been possible to construct a standard global chronological scheme to which local sequences in various parts of the world can be referred with a fair degree of accuracy.

Subsequent development of the technique of rock dating based on the rate of decay of minerals has helped to confirm the accuracy of the biological scheme whose real basis is the theory or Organic Evolution.

The third and most important objective of stratigraphy is the synthesis and interpretation of the stratigraphic record. Again, both the physical and biological features of sedimentary rocks are employed in this important aspect which, commonly, we call Historical Geology. It is founded on the *Principle of Uniformitarianism,* first explicitly demonstrated by the Scottish geologist, James Hutton in 1795. In simple language, this principle states that the dynamics of the processes responsible for past geological events are essentially the same as those operating today, that is, "the present is the key to the past." By prudent application of this principle, it has been possible for us to reconstruct ancient distribution of lands and seas (paleogeography), past climatic patterns (paleoclimatology), etc., and to interpret various geological events by careful comparison with modern analogs.

At this stage, you might be wondering why we have to expend so much effort studying sedimentary or other forms of rocks. As already mentioned, sedimentary rocks contain buried in them the record of the organic life through the ages. The record consists of the fossilized remains of animals and plants that died in environments favourable for the preservation of their bodies. Though, in general, organisms with hard parts stand a better chance of being preserved and are, by far the more abundant in the fossil record, preservation of soft tissues under unusually favourable conditions are also known. For example, a few whole specimens of wooly mammoths that roamed the Arctic plains during the last Ice Age are now known. They have been found preserved in ice for several thousand years. As the animals thawed, the blood in them was still fresh, and it was possible to recover for study some of the green vegetation on which they fed before demise.

Similarly, well preserved insects, worms and other soft-bodied invertebrates are known from the Precambrian Ediacara beds (over 600 m.y. old) of Australia and the Middle Cambrian Burgess Shale of British Columbia. Records of the earliest birds with feathers are known from the Solnhofen lithographic limestone (Jurassic, 150–190 m.y. ago) of Bavaria, Germany. It must, of course, be admitted that the conditions under which most of these were preserved were unique indeed.

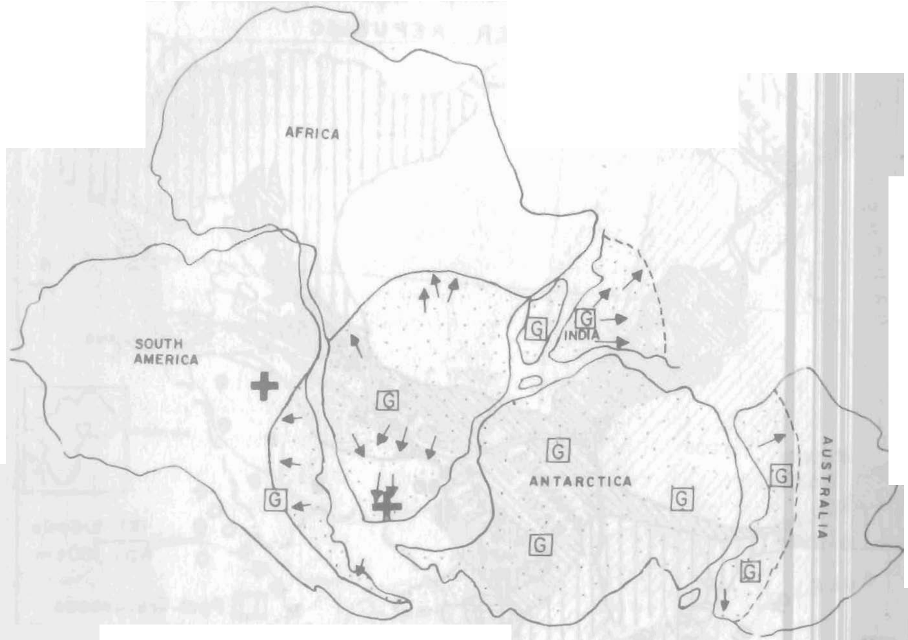


Fig 3 Reconstruction of the original position of Gonduwana continents

Regions affected by the Permo-Carboniferous glaciation.

Localities with recorded occurrence of *Mesosaur*

Occurrence of *Glossopteris* Flora

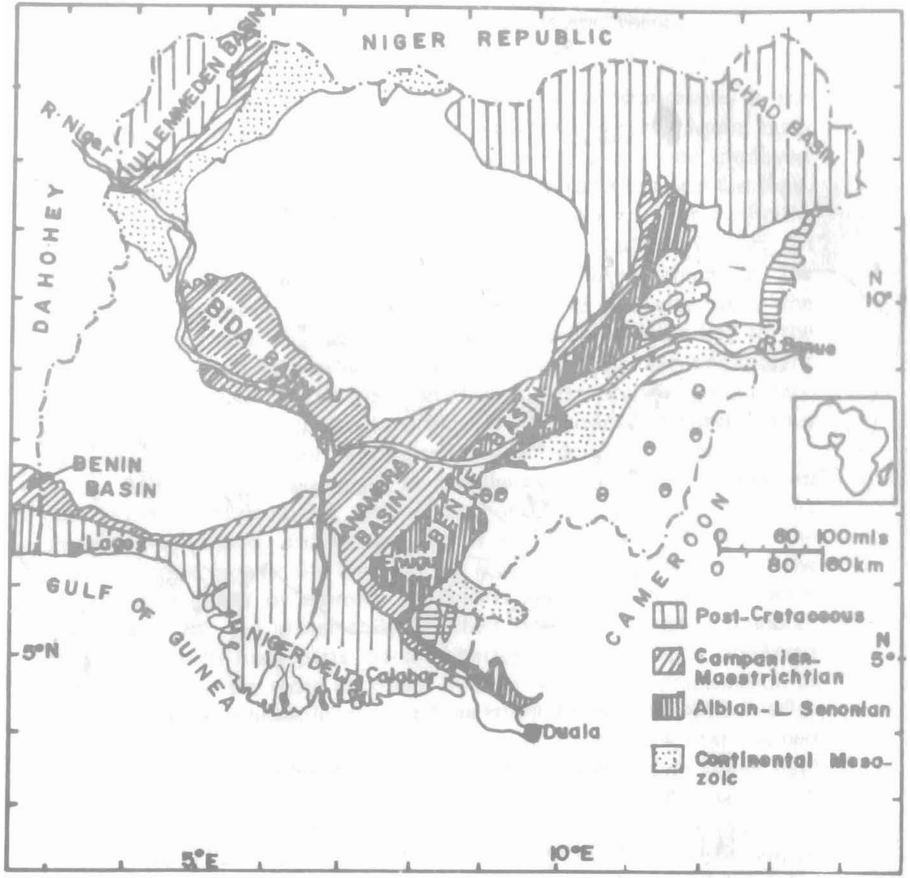


Fig. 1 Generalized geologic ma of Nigeria showing major sedimentary basins.

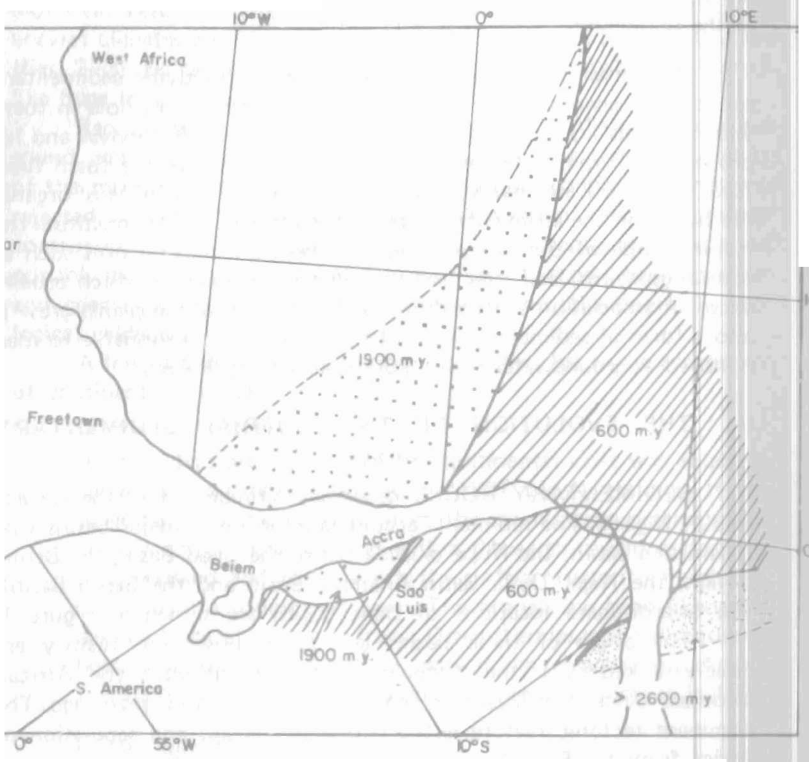


Fig. 2 Ar ocks of similar ages Africa and South America (af Hurl y 1973).

Though the oldest positive record of organic life preserved in rocks dates back at least 3,200 million (3.2 billion) years, (from the Onverwacht Series, South Africa), we did not have a more or less continuous record of past life in sedimentary rocks until Cambrian times about 600 m.y. ago. This "living record of the dead," though scanty, is vital for the reconstruction of the history of the earth. Thus, from the point of view of self enlightenment, and in order to advance our knowledge of the history of the earth on which we live, the study of the sedimentary rocks is indispensable.

The other equally compelling reason for studying sedimentary rocks is the economic considerations. Sedimentary rocks hold in them vital minerals and ores which are essential for man's survival and his prosperity. Perhaps the most important of these are the fossil fuels (coal, crude oil and natural gas), formed from the remains of organic life buried in the sediments millions of years ago. These constitute the major source of our energy. Besides, there are mineral ores such as alluvial gold, tin, lead, zinc and the radioactive minerals which usually occur in association with sediments. The soil on which plants grow is also a form of sediments. Much of the potable water available to man is stored as groundwater in the pore spaces of sediments.

II. THE EVOLUTION OF THE NIGERIAN SEDIMENTARY BASINS

SEDIMENTARY ROCKS cover approximately half the surface area of Nigeria. The sediments accumulated in seven major basins (the Iullemeden Basin, the Nupe or Bida Basin, the Chad Basin, the Benue trough, the Niger Delta Basin Anambra Basin and the Benin Basin). The approximate locations of these basins are shown in Figure 1.

The origin of these basins and their subsequent history are closely linked with the tectonic events that affected the African landmass since the Mesozoic era about 200 million years ago. The dominant tectonic feature is the rifting (break-up) and separation of Africa from the Euro-American landmass and the consequent opening of the Atlantic Ocean.

The widely held views that continents have retained their present sizes and positions through the ages and that ocean basins were ancient and permanent were shattered when Alfred Wegener explicitly proposed, with concerete evidences, the idea of continental drift in 1912 and 1915. The close match in shape of the African and American Atlantic margins had earlier been noted by Francis Bacon in 1620 and Francois Placet in 1658. Antonio Snider-Pellegrini in 1858 was the first to suggest that the identical coastlines were two sides of a formerly continuous landmass.

Apart from the close fit of the continental margins, other lines of evidence advanced by Wegener to support continental drift included the distribution of past faunas and floras (e.g. the occurrence of the *Glossopteris* flora in Africa, Australia, India, Madagascar and South America and the restricted occurrence of *Mesosaurus,* a Permian amphibious reptile in Brazil and South Africa), the distribution and ages of rock types, and geological structures such as the root of ancient mountain belts on both sides of the Atlantic Ocean, the pattern of ancient climates and the pattern of the Permo-Carboniferous glaciation (figs. 2–3). He depicted the continents as sailing through oceanic crust like huge ice rafts, driven by the earth's rotation.

Because some of the evidences advanced by Wegener were not sound and, more importantly, because of the unsatisfactory nature of the mechanism for drifting proposed by him, continental drift was rejected by most of his contemporaries. Thus began one of the greatest controversies in the scientific world. The final acceptance of drift was possible only when geophysical data especially that on paleomagnetism and geochronological data overwhelmingly came to support the geological evidences.

A few of the more revolutionary ideas that led to the acceptance of continental drift are:

1. **Convection currents:**

   A more feasible mechanism for continental drift was found in convection currents proposed in 1927 by A. Holmes. It was suggested that heat derived from the spontaneous disintegration of radioactive minerals deep within the earth caused material to melt, expand and rise towards the surface where it spreads out, cools down and descends again. The process has been likened to heating a pot of soup on a flame. Other theories have subsequently been advanced to explain the plate driving mechanism. Among them is the thermal plume and hot spot model of Morgan in 1971.

2. **Paleomagnetism:**

   Geophysical evidences, especially the results of paleomagnetism developed in the 1950s led to acceptance of the idea of continental drift. When new rocks are formed, they are invariably weakly magnetized. The direction of magnetization is usually the same as that of the earth at the time the rock was formed. By careful measurement of the fossil magnetic field of contemporaneous rocks, it is possible to calculate the position of the north and south poles. Pole positions deduced from older rocks on different continents do not coincide (polar wandering). If, however, the continents are put together in their pre-drift positions and their paleomagnetic poles moved with them, the pole positions more or less agree. This conclusively shows that the rocks acquired their magnetism when the continents were together and had since drifted apart, that is, the continents have been moving with respect to a fixed pole.

3. **Paleomagnetic reversals:**

In 1906, it was discovered that some rocks were magnetized in a direction opposite the present earth's field. Combined geologic and paleomagnetic studies finally showed that reversals of the earth's magnetic field occurred commonly in the past and that rocks of the same age had the same magnetization, either normal or reversed. Vine and Matthews explained, in 1953, the basis of the magnetic anomalies. It has since been possible to construct a geomagnetic reversal time scale for the past 80 million years of earth history.

4. **Sea Floor spreading:**

Study of the deep ocean basins soon showed that the earth is encircled by a chain of oceanic ridges many of which are higher than mountains known on land. These crests are called mid-oceanic ridges because they occupied central positions in the Atlantic and Indian Oceans. The mid-Atlantic ridge, for example, stands about 2.5 km above the surrounding ocean bottom. Its crest is marked by a prominent depression. This is a zone of divergence or rifting from which material forming new ocean floor is ejected and carried laterally away at the surface. From a study of the numerous earth quakes occurring along the crack, it is evident that the two sides are moving apart as new material is added, much like a conveyor belt system. As the rocks move apart, new material is ejected which solidifies in the crack. The newly formed rock is magnetized in the direction of the earth's magnetic field. Thus, over the ages, strips of alternately normal and reversely magnetized rocks are present on either side of the mid-Atlantic ridge. Geochronological data has also shown conclusively that equivalent strips on both sides are of the same age (Fig. 4).

The velocity of spreading plates on each side of the mid-oceanic ridge varies from about one centimeter to as much as 8 or 10 centimeters per year. In terms of geologic time, this means that new ocean floor is added to each side of the mid-oceanic ridge at the rate of between 1 and 10 km per million years. The magnitude of the effect of the above can be better visualized if the process were reversed. The Pacific Ocean floor which is about 15,000 km (10,000 ml.) wide would be completely

closed in 100 million years (average spread rate 8 cm per year). Similarly, using the much lower average spreading rate of 2 cm per year obtained for the south Atlantic Ocean, the entire Atlantic ocean basin which is about 5,500 km. wide would be completely closed in 138 million years.

5. **Plate Tectonics:**

This is the most revolutionary concept yet advanced to explain global tectonics. It has been shown that the crust of the earth consists of a series of rigid plates fitted together like a jig-saw puzzle. In fact, the location of earthquake belts is one of the surest tools for deciding the location of plate boundaries.

The rigid outermost portion of the earth which is divided into plates is called the *lithosphere*. It is about 100 km thick. A plate can either be completely oceanic or made up of both oceanic and continental crust.

The material below the lithosphere is called the *Asthenosphere*. It includes a low velocity (seismic) zone constituting an area of incipient melting within the mantle. It is this property of the asthenosphere that allows the plates of the lithosphere to move about on its surface.

The basic assumptions of Plate Tectonics are:

(i) That large areas of the earth's crust act as rigid plates on a sphere each of which undergoes no significant internal deformation and on which there are no hroizontally directed tectonic processes.

(ii) Each plate is in relative motion with respect to the other plates on the surface of the earth. The net motion of all plates is, however, zero.

Significant deformations occur only at the plate boundaries. There are three types of plate boundaries:

(a) *Divergent* plate boundaries where crustal material is being generated, for example the mid-Atlantic ridge (fig. 4).

(b) *Subduction* zone junction where one plate over-rides the other, the subducted plate being destroyed in the asthenosphere.

There are three varieties of the latter:

– Oceanic *versus* oceanic plate junction (fig. 5a). This gives rise to island arcs.

– Oceanic *versus* continental plate junction (fig. 5b). This gives rise to volcanic mountain chains as on the western seaboard of the Americas (the Andes).

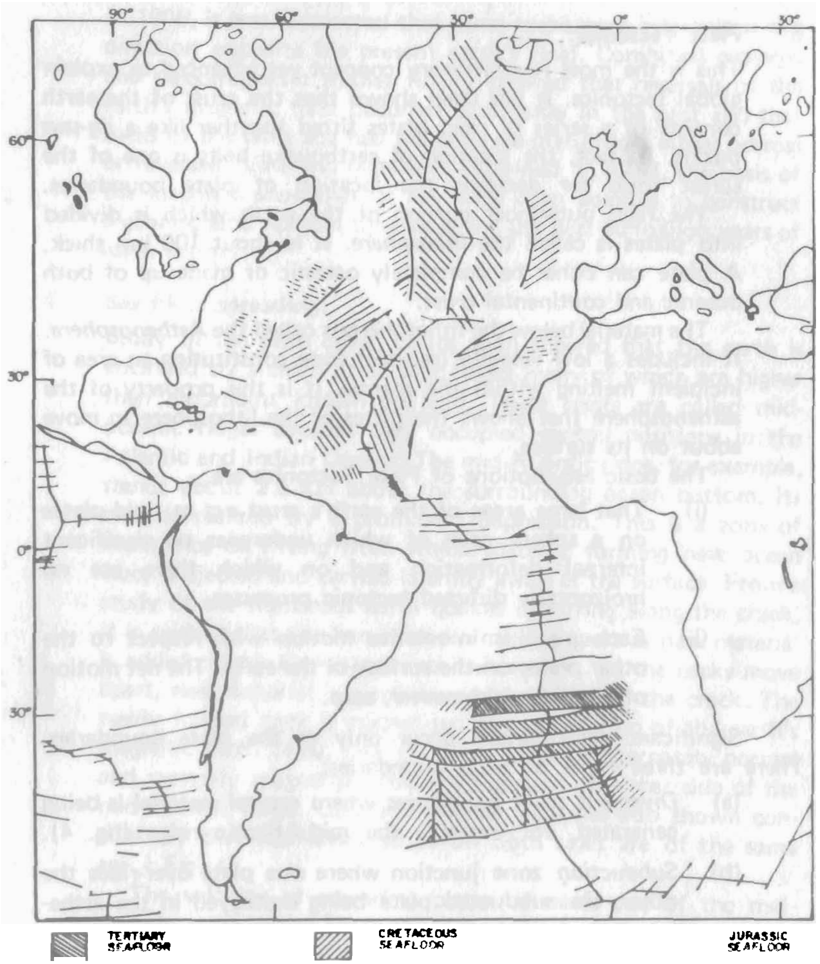


Fig. 4 Major fracture zones and ages of the oceanic basement of the Atlantic

Continental *versus* continental plate junction (fig. 5c). This gives rise to the formation of folded mountain belts as seen, for example, in the formation of the Himalayas when India collided with Asia.

(c) *Transform* fault zone where two plates slide past one another but with crustal material neither created nor destroyed, e.g., San Andreas fault.

The Opening of the Atlantic Ocean.

Let us now come nearer home to the subject of our enquiry – the origin of the sedimentary basins of Nigeria.

Evidences abound to show that the present continents of America, Africa and Australia together with India and Arabia continued as one giant landmass called *Pangaea* until about 200 million years ago. Rifting followed by drifting occurred subsequently. Initially we had the northern supercontinent, *Laurasia* separated from the southern landmass, *Gondwana* by the ancestral Tethys sea or *Panthalassa* as it is often called (fig. 6).

The separation of North America from Africa started during the early Jurassic about 190 million years ago. The north Atlantic ocean was already established (as evidenced by the presence of normal marine strata) between the two blocks about 170 million years ago).

Similarly, South America separated from South Africa slightly later, *i.e., during the Early Cretaceous about 140 million years ago.* Stratigraphic evidence showed that the South Atlantic Ocean was already well established by lower middle Cretaceous time about 120 million years ago (Ramsay 1971).

Paleogeographic reconstruction of all or part of the Cretaceous-Tertiary sequence has been attempted by several workers. The most important are Reyre (1966); Adegoke (1969, 1977); Reyment (1972); Machens (1973); Adeleye (1975); *Offodile (1976) and Petters (1978).*

Three marine depositional cycles are recognized in Nigeria, the first two of which are confined to the Benue Trough. The first cycle ranged from mid-Albian to Cenomanian and affected only the southern part of the Benue Basin. The second cycle began with an extensive transgression during the Turonian, culminating in the Santonian folding phase. Marine sediments belonging to this cycle are known throughout the Benue trough. They also probably underlie the Chad Basin. During the third and final cycle, *oceanic waters* transgressed the subsiding basins formed as a result of isostatic readjustment to the folding of the Benue Trough. This extensive shallow epeiric sea covered the Benin Basin and the present position of the Niger Delta. An arm of the sea

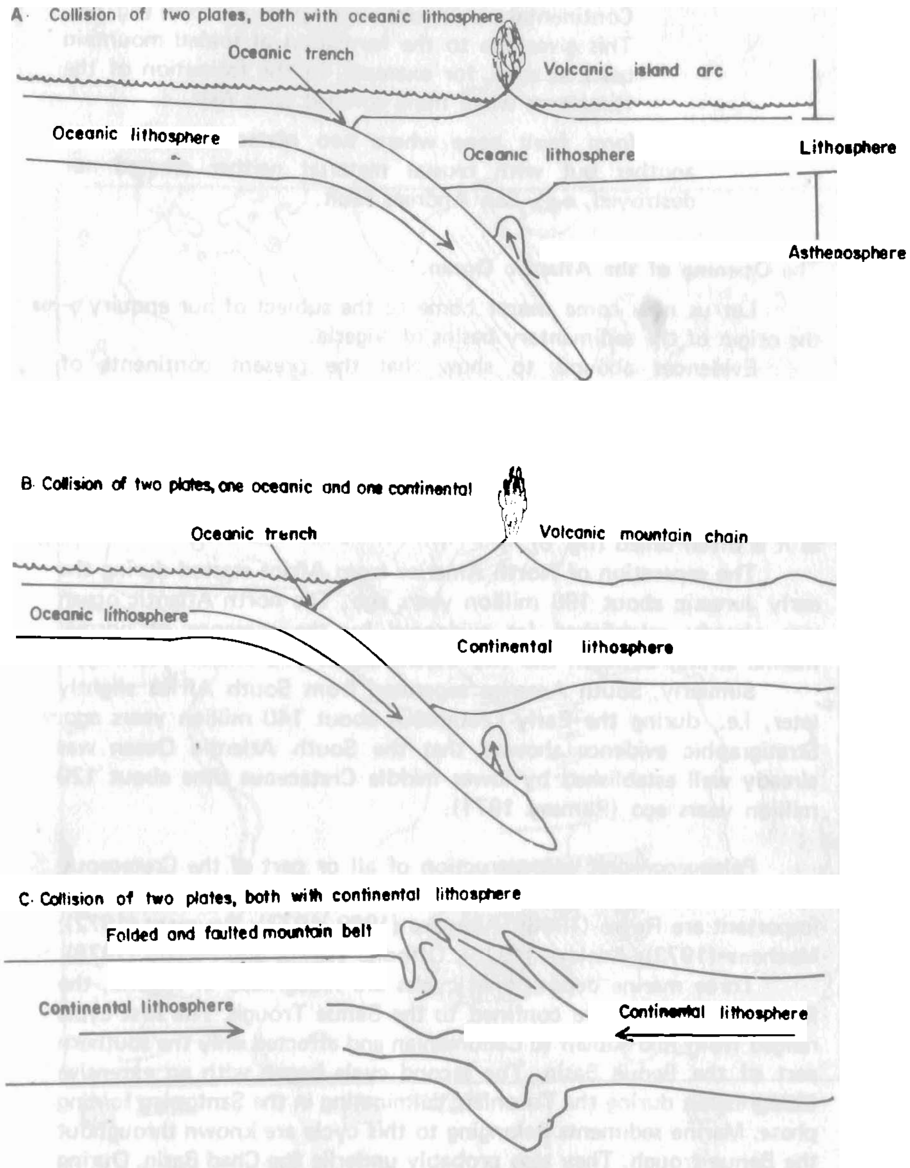


Fig. 5 Types of convergent plate boundaries (after Sawkins et al. 1974).

extended northwards through the Nupe Basin, linking with a southern extension of the Tethys sea and forming an embayment in the Iullemeden basin at least during the Maastrichtian and Paleocene

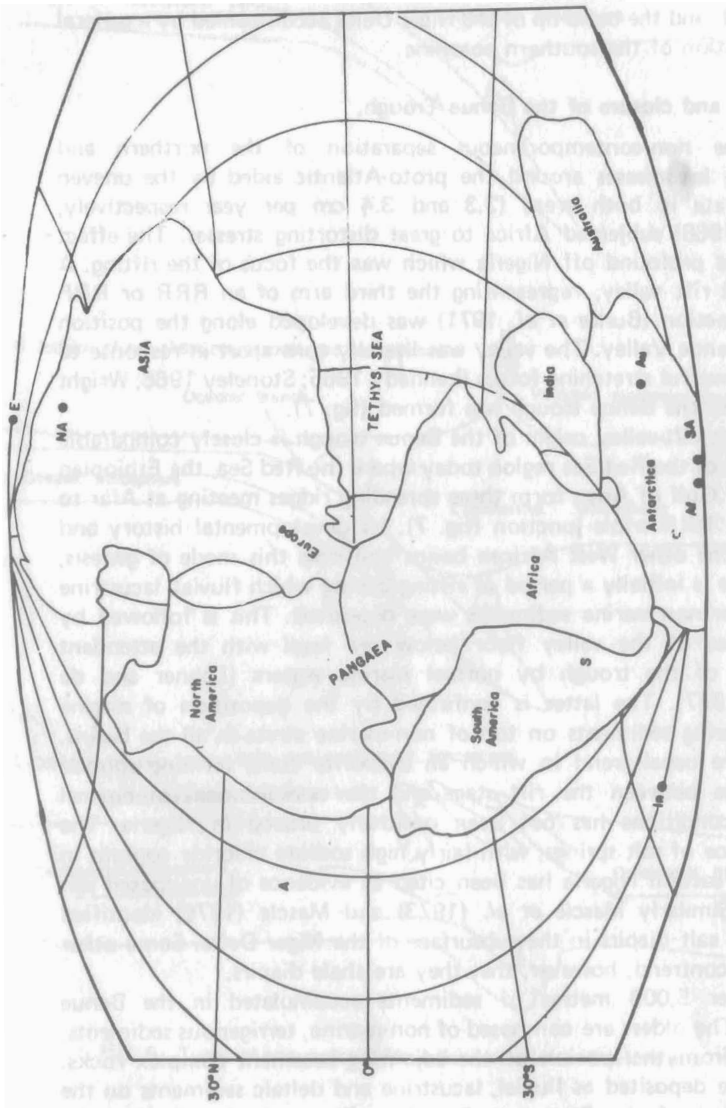
The Eocene witnessed the beginning of a major regressive phase that ultimately led to the breakup of the trans-saharan epeiric sea in the north and the build up of the Niger Delta accompanied by a general progradation of the southern coastline.

Opening and closure of the Benue Trough.

The non-contemporaneous separation of the northern and southern landmasses around the proto-Atlantic aided by the uneven spread rate in both areas (3.3 and 3.4 cm per year respectively, Wright 1968) subjected Africa to great distorting stresses. The effect was most profound off Nigeria which was the focus of the rifting. A tensional rift valley, representing the third arm of an RRR or RRF triple junction (Burke *et al.* 1971) was developed along the position of the Benue Valley. The valley was literally torn apart in response to these powerful stretching forces (kennedy 1965; Stoneley 1966; Wright 1968) and the Benue trough was formed (fig. 7).

This rift-valley origin of the Benue trough is closely comparable with that of the Red Sea region today where the Red Sea, the Ethiopian Rift and Gulf of Aden form three spreading ridges meeting at Afar to form an RRR triple junction (fig. 7). Its developmental history and that of the other West African basins confirms this mode of genesis, viz: there is initially a period of rifting during which fluvial, lacustrine and other non-marine sediments were deposited. This is followed by subsidence of the valley floor below sea level with the attendant invasion of the trough by normal marine waters (Lehner and de Ruiter 1977). The latter is confirmed by the deposition of marine fossil-bearing sediments on top of non-marine strata in all the basins. The more usual trend in which an evaporite (salt) forming episode intervenes between the rift stage and the establishment of normal marine conditions has not been positively proved in Nigeria. The occurrence of salt springs, with fairly high sodium chloride content in parts of eastern Nigeria has been cited as evidence of unexposed salt domes. Similarly Mascle *et al.* (1973) and Mascle (1976) identified probable salt diapirs in the subsurface of the Niger Delta. Some other workers contrend, however, that they are shale diapirs.

Over 5,000 metres of sediments accumulated in the Benue trough. The oldest are composed of non-marine, terrigenous sediments, derived from the erosion of the adjoining basement complex rocks. These are deposited as fluvial, lacustrine and deltaic sediments on the eroded top of the Basement Complex. These continental deposits



● Paleomagnetic pole positions: NA–North America E–Eurasia In–India SA–South America AF–Africa, AU–Australia

Fig. 6 Reconstruction of the supercontinent Pangaea (after Dietz and Holden 1970).

include unnamed basal beds of the Asu River Formation, the Makurdi sandstone and the Bima sandstone (over 3,000 m) in the lower middle and upper Benue valley respectively. It has not been possible to date these beds accurately because of the general absence of diagnostic fossils. A questionable Aptian to Lower Albian age has been suggested.

Figure 8a shows the probable maximum extent of the Albian transgression. The Asu River Formation (1,680 m thick) composed of shales with intercalations of sandstones and occasional sandy shales and limestone were deposited throughout the lower and middle Benue trough. They have been dated Middle to Upper Albian (Reyment 1965). In the northern reaches of the valley deposition of the continental Bima sandstone continued uninterrupted.

The accumulation of over 3,000 m of Asu River sediments suggest an actively subsiding basin. The fully marine nature of the upper parts of the deposits is indicated by the abundant ammonite faunas especially species of *Oxytropidoceras.*

After the Albian maximum, field and faunal evidences indicate that the sea withdrew southwards during the next stage, the Cenomanian. The only marine deposits known for that age is the Odukpani Formation from Calabar area (fig. 8b).

The Odukpani Formation is composed of an alternation of marine shales and limestones which overlie continental conglomerates and sandstones. The latter was recently separated by Adeleye and Fayose (in press) as the Awi Formation. Molluscan and foraminiferal evidence indicate that the Odukpani formation ranges into the Turonian (Dessauvagie 1972).

The second depositional cycle began during the Turonian (about 90–95 million years ago) with a very extensive transgression that covered the entire Benue trough extending into the Chad Basin (fig. 8c). In it was deposited thick sequences of montmorillonitic marine shales with limestone at the base. The sea was relatively shallow and the shoreline oscillated considerably, with transitional and continental sandstones marking the minor regressive and oscillatory phases.

The major sedimentary deposits include the Eze Aku Formation (400–600 m thick) in the lower and Middle Benue overlain by the Awgu shale. The transitional Yolde Formation overlain by the Pindiga, Dukul, Jessu, Sekule and Numanha Formations constitute the depositional sequence in the upper Benue Valley. The sequences are well exposed in the Dediya syncline and adjacent areas (Cater *et al.* 1963).

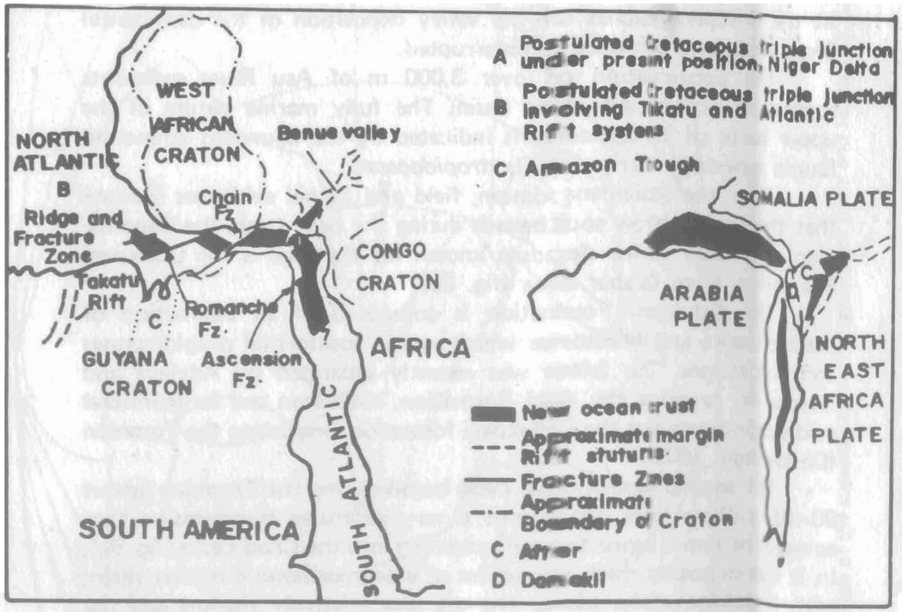


Fig. 7 Map showing Atlantic opening about RRR or RRF triple junction. Compare with Red Sea region (after Burke et al. 1971).

At this stage, direct connection was established with an extension of the Tethys sea which had formed an embayment in the vicinity of Hoggar and possibly Sokoto as early as the Cenomanian (Furon 1963; Reyre 1966). Ammonites from Damergou in the Iullemeden basin share several species in common with those from Pindiga in the Upper Benue valley (Barber 1957; Carter *et al.* 1963).

This Turonian-Coniacian transgression terminated with the inception of a folding phase which began during the Santonian (Carter *et al.* 1963); (Murat 1972). As a result, the Benue trough sediments were uniquely folded into a series of elongated anticlines and synclines (Abakaliki anticlinorium, Afikpo syncline, Lamurde anticline, Dadiya syncline, etc.), whose major structural trend is parallel to the axis of the trough (NE-SW). The closure of the trough was also marked by eruption of over 1,000 m of volvanic rocks, confirming a seismically active rift zone.

The cause of the closure of the Benue trough has been a subject of debate. The consensus is that it resulted from the semi-elastic rebound of the southern half of the African continent in response to the cessation of the differential stresses which were active during continental separation.

The Maastrichtian transgression:

The crustal shortening resulting from the folding of the Benue trough and the crustal thinning, which accompanied the resultant rapid erosion, caused subsidence and graben-type faulting in much of the other parts of Nigeria that had remained in the rift-stage. The Benin Basin, the Bida and Iullemeden Basins subsided. The Anambra platform was downwarped to form the Anambra Basin. The major transgression that followed during the Maastrichtian marked the commencement of the third and final phase of marine deposition (fig. 8c). The oldest fossiliferous marine strata overlying the continental deposits is of Maastrichtian age.

The basal sediments are mostly clastic sandstones which attain thicknesses in excess of 1,000 metres in some coastal boreholes in Western Nigeria. (Afowo 1) and about 300 m in the more northerly interior basins (Bida and Iullemeden). Where complete sections are preserved in the grabens, some of these beds are of Valanginian to Barremian age and have typical Cocoabeach type ostracode assemblages.

In the Benin Basin, the lower beds are essentially fine to medium sandstones referred to as the Abeokuta formation. Bituminous impregnations outcrop within a long linear belt about 110 km long and 6 km wide between Ijebu Ode and the western flank of the Niger Delta. Our work near the outcrop area indicates a reserve of about 31 billion metric tons of tar sand, holding about 540 million tons of recoverable bitumen. The bituminous horizon was dated upper Maastrichtian on the basis of the palynomorph assemblage and the occurrance of *Inoceramus* (Adegoke *et al.* 1976).

Maastrichtian sediments of the Bida basin are composed mostly of cyclothemic sands, siltstone and ironstone. Adeleye (1974) recovered a marginal marine fauna dominated by gastropods thereby confirming the writer's (Adegoke 1969) suggestion that the Maastrichtian seaway extended northward through the Niger valley. Our work in the Lokoja area (Jan du Chene *et al.* in press) shows the presence of several marine dinoflagellate and microforaminifera-bearing horizons. The sediments grade laterally into the marine Nkporo shale of the Anambra Basin which is overlain in turn by the fluviatile, coal-bearing sandstones of the Mamu Formation (90 m), the loose, friable and intensely cross-bedded Ajali sandstone (over 450 m), and the sandy coal-bearing Nsukka Formation. Thin limestone marine horizons occur in the upper part of the latter.

Kogbe (1976) has shown that in the Iullemeden Basin, pre-Maastrichtian continental clastics overlie the Basement Complex. They are dated Upper Jurassic – Early Cretaceous on the basis of some fossil woods. The beds are overlain by the continental to transitional Taloka Formation from which an impoverished fauna of *Modiolus* sp. and *Cardium* sp. was recovered. Overlying the Taloka Formation is the fully marine Dukamaje gypsiferous shales and claystone with its rich assemblage of vertebrate fossils including *Mosasaurus*, the ammonite *Libycoceras* and foraminifera.

There is scanty published information on the geology of the Chad Basin. The Turonian sequence is overlain by the bluish-black Fika shales with a non-diagnostic fish and crocodile fauna. The latter is overlain by the estuarine, lacustrine to deltaic clastic sandstones and oolitic ironstones of the Gombe Formation, laid down on the shoreline of the newly formed Lake Chad.

Though paleogeographic considerations favour the occurrence of a through connection between the southern Atlantic and the Tethys, during the Maastrichtian, conclusive faunal evidence is yet to be adduced to support it.

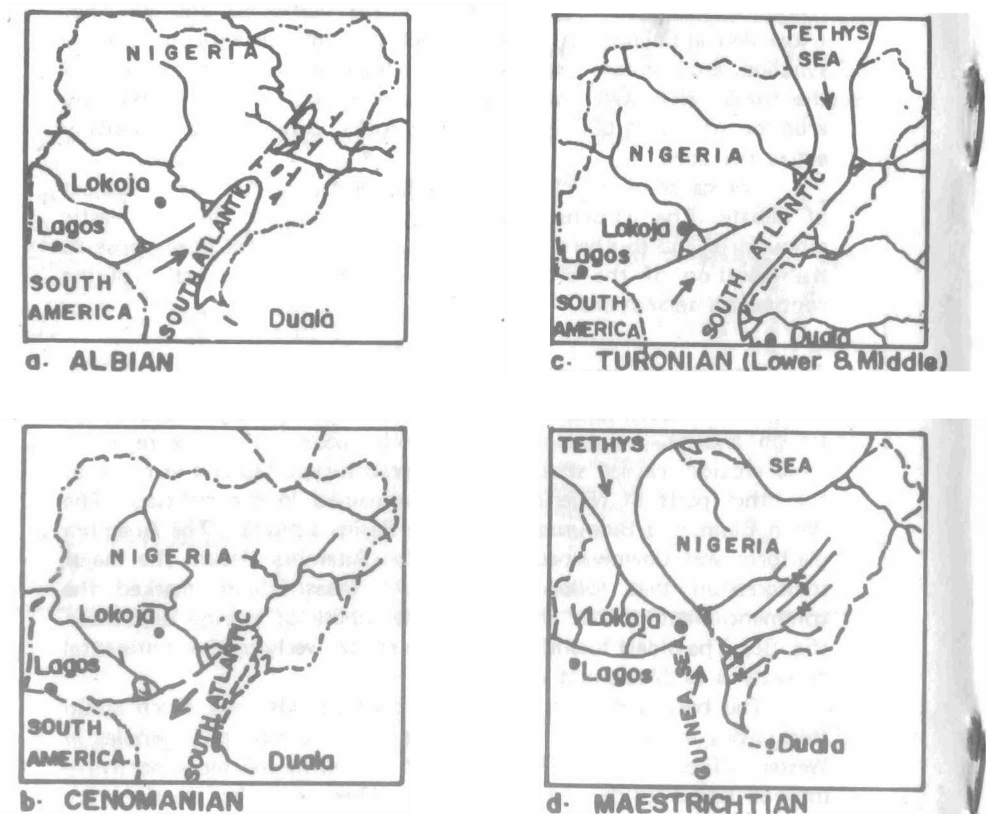


Fig. 8 Paleogeographic map of Nigeria during (a) Albian, (b) Cenomanian, (c) Lower and Middle Turonian, (d) Maestrichtian ages (after Adeleye 1975).

Paleogene-Paleogeography:

The Maastrichtian transgression continued into the Paleocene towards the end of which period a general regressive phase set in (fig. 8d).

Nigerian Cenozoic deposits are deverse and characterized by extremely rapid lateral facies change.

In the Anambra basin, there is unbroken deposition from the top of the Nsukka Formation to the Imo Shale during the Paleocene. The recent record of typical Ewekoro nautiloids, *Cimomia* sp. and *Deltoidonautilus togoensis* Miller and species of *Venericardia, Fimbria* and *Ostrea* within the Formation confirms a Paleocene age and definite correlation with the Ewekoro Formation (Arua and Adegoke, in press).

The Imo shale is succeeded by the Ameki Formation, a trnasitional to marine formation with richly fossiliferous horizons (Newton 1922; Eames 1957), dated Middle Eocene. Several elements of the fauna, for example, *Surculites (Clinura) ingens* (Mayer Eymar), *Plicatula polymorpha* Bellardi and *Raetomya schweinfurthi* Mayer-Eymar show close affinity with fauna of the Eocene of Egypt. A recent record of a new *Deltoidonautilus* with affinities with *D. caheni* of the Landana Eocene indicates that the Tethyan affinity of the Nigerian faunas persisted up till the Eocene and that connections with the Tethys persisted longer than anticipated heretofore.

The Paleogene sequence in the Benin Basin commenced with the deposition of the Ewekoro Formation, a predominantly calcareous sequence exposed in the Ewekoro quarry. It extends westwards throughout the Benin Basin and is known in the popular Republic of Benin, Togo and also in Ghana. There is progressive lateral facies change eastward. It occurs as an alternation of shale and limestone (Araromi shale of authors) near the western flank of the Delta, grading into shale (Imo Formation) in the Anambra Basin to the East.

The Ewekoro limestone exposed in the quarry has been extensively studied by the writer (see Adegoke 1972a, b, 1973, 1977; Adegoke and Dessauvagie 1971; Adegoke *et. al.* 1972, Sachs and Adegoke 1973). The Formation is composed of about 10- 12.5 m of pure, coquinoidal limestone which is sandy near the base where it grades into underlying Abeokuta Formation. Four microfacies units have been recognized; the sandy biomicrosparite at the base overlain by the shelly biomicrite which is largely composed of the shelly remains of marine organisms. This layer yielded most of the fauna recovered from the limestone. The shelly biomicrite is succeeded by an algae rich layer called the algal biosparite. The uppermost unit is an erosional remnant, rich in phosphates and glauconitic pellets, the red phosphatic biomicrite.

At the commencement of the study of the formation in 1967, only about five indeterminate species were recorded. In a recently published monograph (Adegoke 1977), the writer described 221 species of echinoids, molluscs and fishes of which 175 species and subspecies were described as new to science. Generic and suprageneric categories erected included twenty-three new genera and subgenera of molluscs and three new Families.

Perhaps the most significant aspect of the study is the light it shed on the paleobiogeography and affinities of the Fauna.

Figure 9 is a map showing the relative position of continents about the time of deposition of the Ewekoro limestone. The heavy dots indicate areas that share close faunal affinity or identity with the Ewekoro fauna. It is evident that the affinity of the fauna is with the marginal Tethyan faunas of India (Ranikot fauna), Egypt (Upper Mokattam fauna), Gulf Coastal United States, Trinidad (Soldado Rock) and Brazil (Maria Farinha, Pernambuco) rather than with the contemporaneous faunas of neighbouring North Africa and South Africa (Adegoke 1972a, 1977). This identity with India and Egypt was so impressive that Douville (1920, p. 22) coined the term "Indo-africaine" to express it.

The Paleocene fauna of the West African province is homogeneous, the Ewekoro fauna being virtually identical with the fauna of the Apatuema limestone in Ghana (18 out of 27 species in common) and the calcaire *a Togocyamus* in Togo (42 of 59 species in common). At least 20 species occur in common with identical horizons in Senegal but only one each with Maroc and Landana to the north and south respectively.

The Paleocene limestone or alternating limestone-shale sequence in the Benin Basin is overlain by shales (Akinbo Formation) and phosphatic sandstone, mudstone and shale (Oshosun Formation) with a rich Fish fauna. The latter is considered marginal marine to estuarine. The invertebrate fauna recorded by Reyment (1965) and marine benthic and planktonic foraminifera being studied by us indicate lateral equivalence with the Ameki Formation of the Anambra basin.

No records of Paleogene deposits has been reported from the Bida basin. It is very likely that such deposits were laid down as thin veneers on the Cretaceous strata and were subsequently removed by erosion.

In the Iullemeden basin, a limestone facies (the Kalambaina Formation) marked the beginning of the Paleogene. The invertebrate fauna described from the bed are essentially different from the Ewekoro fauna, though, *Gisortia brevis,* some ostracodes and foraminifera (Buser 1966) occur in common. It appears likely that the Kalambaina Formation represents a different stratigraphic horizon and is probably younger than the Ewekoro Formation. The Kalambaina Formation is overlain by a phosphatic shale unit, the Gambia Formation with a foraminiferal assemblage dominated by agglutinated forms. This indicates a near-shore facies and pronounced shoaling as shown by the influx of terrigenous detrital clays. The Gwandu Formation, a clastic fluviatile deposit overlies the Gamba Formation. Farther north in Soudan and Egypt, marine Eocene occurs with close affinities and specific identity with the Ameki fauna of the Anambra basin (see Newton 1922, Eames 1957).

Resolving satisfactorily, the paleogeography of the Paleogene must await further detailed faunal studies in the North African countries especially Libya, Algeria, Soudan and Ethiopia.

In the Chad Basin, continental conditions continued to prevail with the Kerri-Kerri Formation, an extensive lacustrine clastic deposit being the only Paleogene strata known to overlie the Cretaceous strata (Gombe sandstone and Fika shales). *Adegoke et. al. in press.* As sediments are fed in, the Lake Chad continued to shrink.

Neogene Paleogeography:

Continued deposition of lacustrine deposits associated with progressive shrinking of Lake Chad continued in the Chad Basin. The sediments are referred to the Chad Formation. The lower beds have been dated Pliocene – Pleistocene (less than 5 m.y.) on the basis of the occurrence of *Hippopotamus imaguncula.*

No deposits younger than Eocene have been recorded from the Iullemeden Basin. It can, therefore, be reasonably assumed that subsidence ceased as the sedimentary basin was filled up with terrigenous sediments late in the Eocene.

In the Benin Basin, there was continued southward recession of the coastline during the Neogene interrupted by oscillations caused by the Pleistocene eustatic rise in sea level, which accompanied the glaciation.

Two sedimentary sequences have been recognized along the southern coastline, the lignitic Ogwashi-Asaba Formation overlain by the Benin Formation. Both are composed dominantly of terrigenous sandstones with minor intercalations of lagoonal and brackish water shales and siltstones. The Ogwashi-Asaba formation is characterized by the frequent occurrence of coal and lignite bands within an essentially terrigenous cyclothemic sequence. The lithology of the Benin Formation is identical but with fewer and thinner coal and lignite bands. Both represent deposition in fluvial, lagoonal, estuarine and back swamp environment with lush tropical vegetation and mangrove bound lagoons similar to Nigeria's modern coastline.

The Niger Delta and Recent Sediments:

The physical characteristics of sediments, their composition, mode and environment of deposition and the nature of the fossils preserved in them are the most useful tools employed in stratigraphic analyses. The Niger Delta area is one of the best places to demonstrate the application of these principles because, from sedimentological, faunal and floral evidences, the modern Niger Delta has a configuration that is essentially similar to that of the past. An understanding of the subsurface sequence is, therefore, enhanced by comparison with sedi-

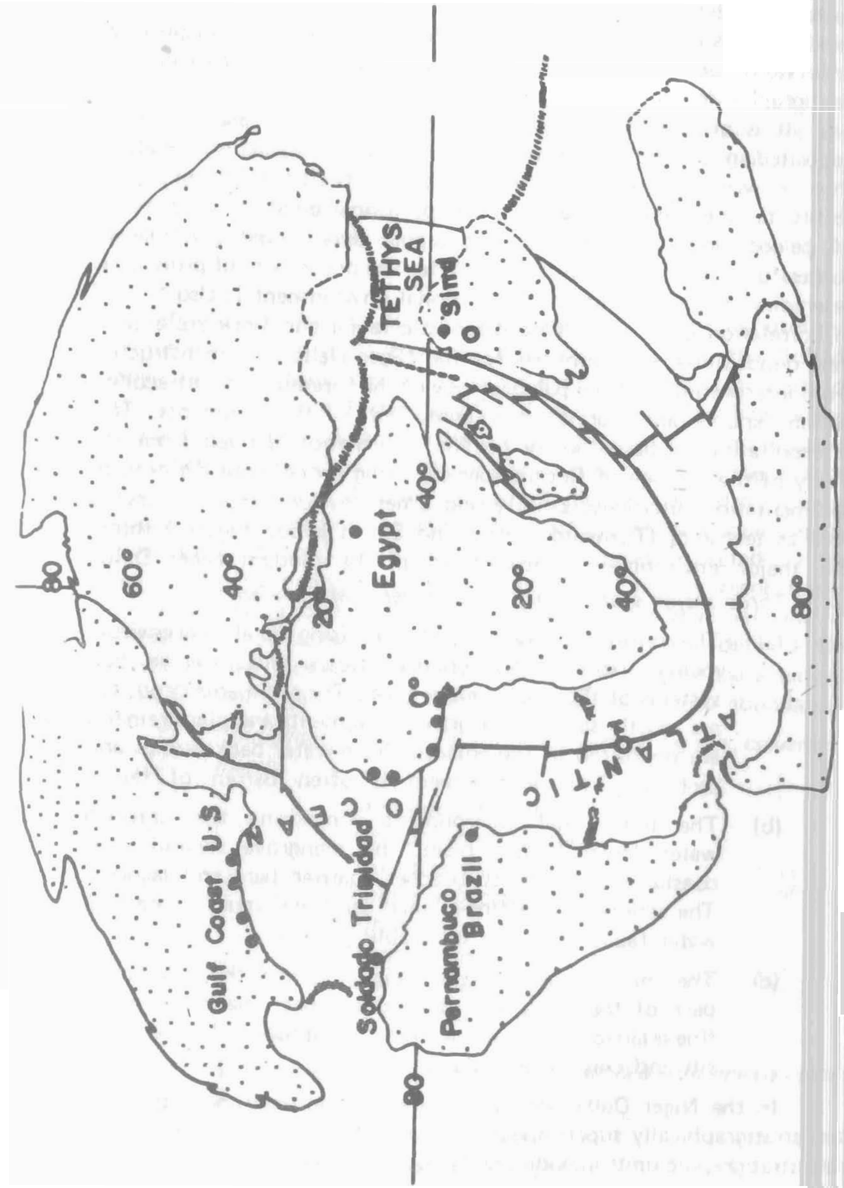


Fig. 9 Continental position about 65 million years ago (after Dietz and Holden 1970). Dots mark places showing close faunal affinity with the Ewekoro fauna.

ments of the Recent Niger Delta (principle of Uniformitarianism).

Oil and gas are deposited in reservoirs consisting of porous strata such as sandstones and limestones. They are generated from source rocks such as marine shales and limestones, and are sealed in place by impervious rock layers such as shales, and trapped by structural and stratigraphic features such as faults, pinch outs, etc.

It is evident from the above, that oil and gas reservoirs were deposited in specific environments and that there is a definite relationship between petroleum occurrence and depositional history. The ability to interprete accurately the depositional conditions by means of paleoecology and related stratigraphic data is indispensable to successful location of areas favourable for the occurrence of productive reservoirs. Knowledge of the depositional environment is also helpful in correlation especially where diagnostic fauna and flora are absent. Past depositional environments for the Niger Delta are reconstructed from interpretation of the paleoecology of the foraminifera, ostracodes, pollen, spores and nannofossils contained in the sediments. This interpretation is based solely on the information derived from the study of the ecology of Recent species, giving proper consideration to sedimentation, lithology, salinity and other environmental factors, as well as tectonics (Tipsword, Setzer and Smith 1966). Figure 1 shows the major environments encountered in the modern Niger Delta.

Three major sedimentary environments are present:

(a) The continental environment comprising the alluvial environments, including the braided stream and meander belt systems of the upper deltaic plain. The sediments deposited are mostly sand. Finer grained sediments and plant remains are deposited in the adjacent fresh-water backswamps and ox-bows. This environment is often barren of fauna.

(b) The transitional environment comprising the brackish water lower deltaic plain, the mangrove swamps, the coastal area with its beaches, barrier bars and lagoons. The sediments are fine-grained sand and mud. A brackish water fauna is almost invariably present.

(c) The marine environment which includes the sub-marine part of the delta and the delta fringe, the deposits are fine-grained being dominantly composed of fine sand, silt and clay. The fauna is marine.

In the Niger Delta, sediments of the three environments above are stratigraphically superimposed. Thus in the subsurface Niger Delta, the stratigraphic units include the Akata Formation (Eocene to Recent) at the base. It is composed of marine shales only. It is overlain by the transitional Agbada Formation (Eocene to Recent) which is composed

of alternating sandstone and shale. The youngest formation is the Benin Formation (Miocene to Recent) composed dominantly of yellow and white continental sands with pebble and clay interbeds. All three formations attain a thickness of about 10,000 metres at the axis of the delta indicating rapid deposition on a rapidly subsiding crust. The major structures include the growth faults, counter regional faults and the associated back-to-back faults. Shale ridges and diapirs are also present. The major structures and common trapping configuration are shown in Figure 11.

Many of the reservoir sands encountered in the Niger Delta are barrier bars or point bars or multiple bars developed one on top of the other.

In order to further advance the knowledge of the depositional environment in the delta area, we commenced in 1968 the Gulf of Guinea project. Supported by generous grants from the University of Ife and the Petroleum Technology Development Fund, we have collected for study over 400 samples from the coastal lagoons and estuaries of southern Nigeria from the Ghana-Ivory Coast border in the west to Bonny in the east, a distance of over 1,200 km. We also received through the kind cooperation of Koninklijke/Shell at the Hague and the University of Miami, Florida, about 340 samples collected by the Mees Cremer Expedition 1958 and the R/V Pillsbury respectively.

Based on a careful analysis of some of this material, and in consideration of some major ecological factors, we defined the following seven biofacies zones (Adegoke et al. 1976) characterized by the following foraminiferal species, in order of relative abundance:

1. *"Indigenous" Lagoonal Biofacies – open lagoon, estuaries, marsh.*

   Ammobaculites spp.
   Haplophragmoides spp.
   Textularia spp.
   Ammonia beccarii
   Rotalia sp.
   Trochammina spp.
   Quinqueloculina spp.
   Cribroelphidium gunteri.

2. *Mixed Lagoonal Biofacies littoral and brackish environment with access to sea.*

   Ammonia beccarii
   Cribroelphidium gunteri
   Quinqueloculina lamarckiana

Bulimina sp.
Cibicides sp.
Discorbis sp.
Eponides sp.
Hanzawaia sp.
Nonionella sp.

3. *Nearshore Turbulent Zone Biofacies – includes barrier face biofacies and littoral biofacies, 0–8.75 m.*

Ammonia beccarii
Poritextularia panamaensis
Cribroelphidium gunteri
Florilus atlanticus
Hanzawaia concentrica
Rosalina floridana
Quinqueloculina bicarinata
Textularia laata
Gavelinopsis praegeri
Epistominella decorata
Textularia gramen
Amphistegina gibbosa

4. *Upper continental Shelf Biofacies – Inner neritic. 8.75–33 m.*

Hanzawaia concentrica
Florilus atlanticus
Poritextularia panamaensis
Cribroelphidium gunteri
Quinqueloculina bicarinata regularis
Quinqueloculina lamarckiana
Rectuvigerina nicoli
Cancris auriculus

5. *Mid-continental Shelf Biofacies – Middle neritic, 35–87.5 m.*

Rectuvigerina nicoli
Poritextularia panamaensis
Eouvigerina peregrina
Cibicides lobatulus
Bulimina marginata
Ammoscalaria spp.
Hanzawaia aff. H. concentrica
Brizalina striatula spinata
Sagrina spp.
Amphicoryna scalaris

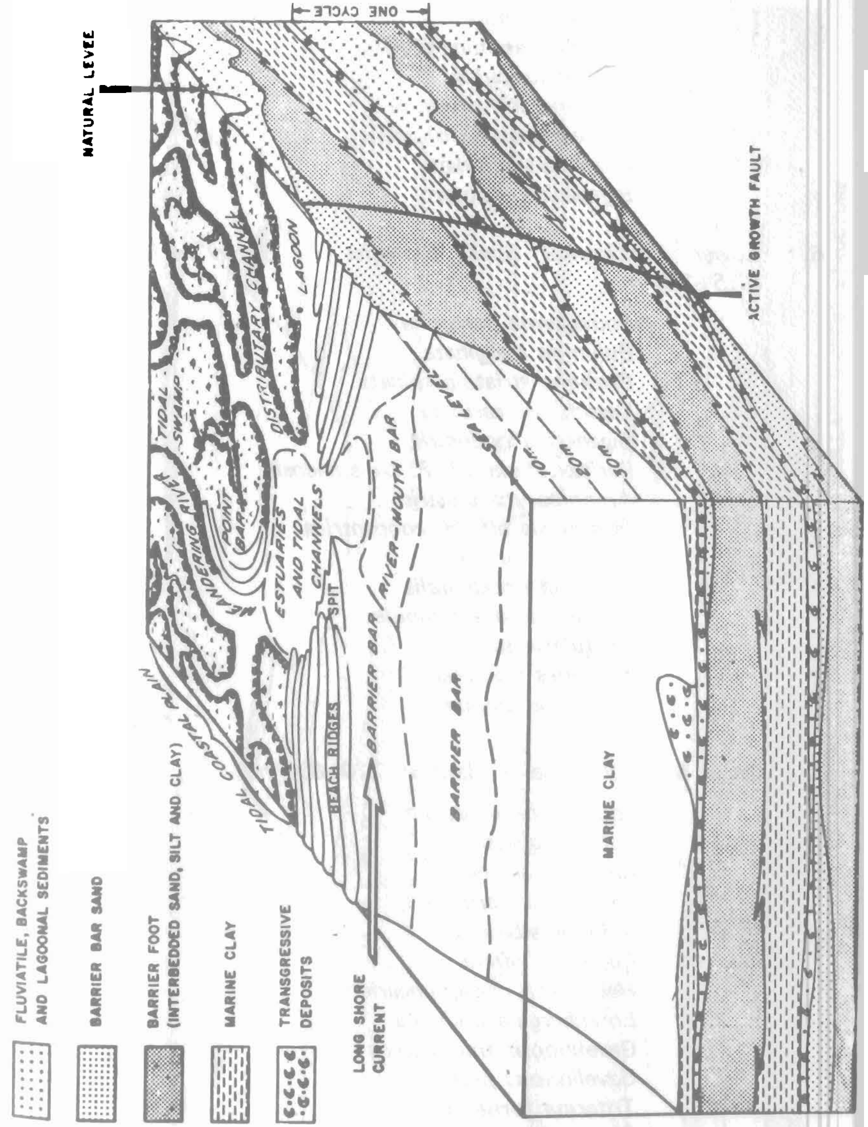


Fig. 10 Block diagram showing coastal geomorphology, cyclic sedimentation and the influence of an active growth fault (after Weber and Daukoru 1976).

Rosalina floridana
Quinqueloculina bicarinata regularis
Bulimina aculeata
Reusella minuta
Spiroplectammina wrightii
Cancris auriculus
Cribrononion advenum
Gravelinopsis transluscens
Brizalina spathulata
Bigenerina nodosaria

6. *Lower Continental Shelf Biofacies – Outer neritic, 87.5–210 m.*

Eouvigerina peregrina
Bulimina marginata
Brizalina striatula spinata
Cassidulina carinata
Bigenerina nodosaria
Poritextularia aff. P. panamaensis
Amphicoryna scalaris
Hanzawaia aff. H. concentrica
Bulimina inflata
Trifarina occidentalis
Sphaeroidinella bulloides
Textularia spp.
Eponides regularis
Textularia granum

7. *Upper Slope Biofacies – Bathyal, 210–800 m.*

Eouvigerina peregrina
Bolivina goessi
Bulimina acculeata
Cassidulina carinata
Bolivina albatrossi
Bulimina inflata
Heterolepa pseudoungariana
Ehrenbergina undulata
Gavelinopsis transluscens
Gavelinopsis praegeri
Trifarina fornasini
Planularia ariminensis
Bolivina alazaensis
Ceratobulimina pacifica

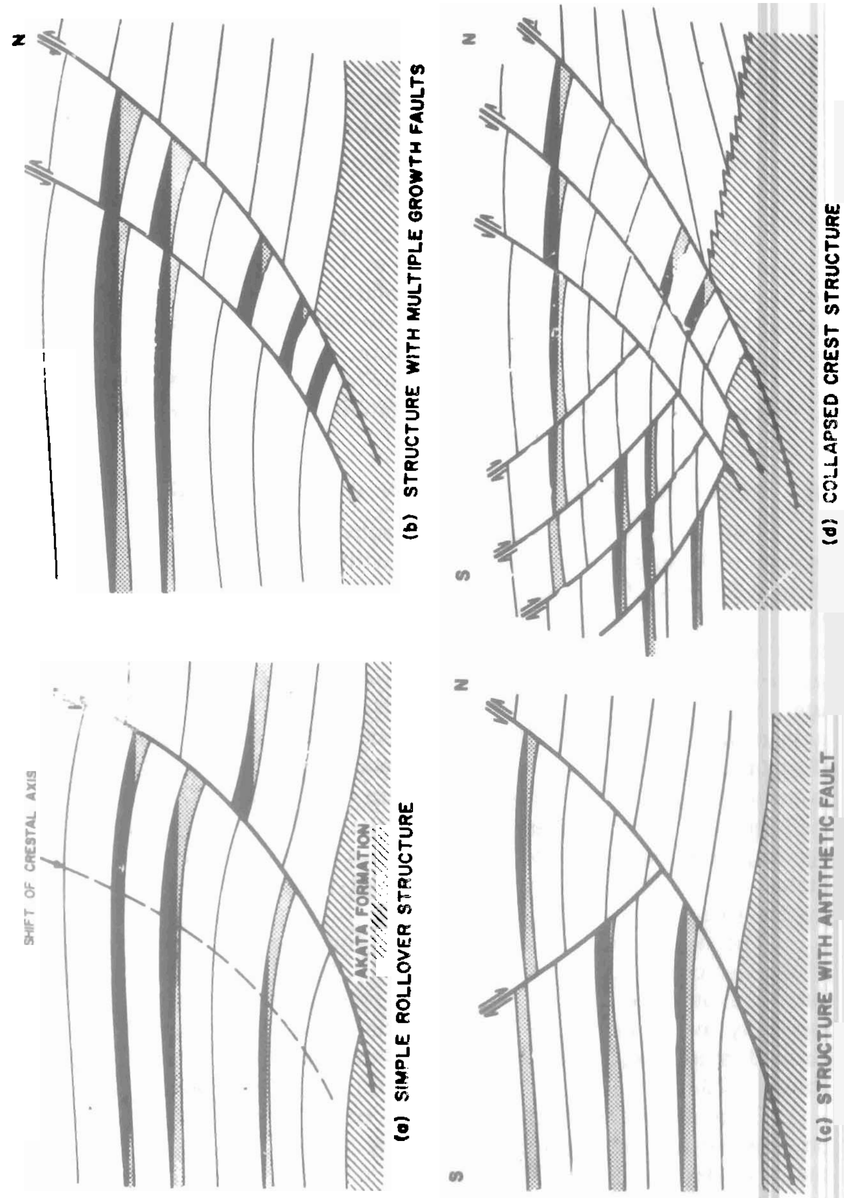


Fig. 11 **Principal types of oil field structures in the Niger Delta with schematical indication of common trapping configurations.**

NOTE: Only a few Reservoir Sands are shown in the schematical sections and the Sand Thickness has been enlarged (after Weber and Daukoru 1976).

Globocassidulina crassa
Amphicoryna scalaris
Epistominella decoratta
Osangularia culter
Hoeglundina elegans
Lenticulina occidentalis
Planulina wuellerstorfi
Melonis barlaeanus
Gyroidina soldanii

Subsequent work has shown that further detailed sub-division of some of these biofacies zones is possible as, for example, we have now been able to recognize five distinct biofacies in the Gulf of Guinea lagoon system alone based on detailed correlation of faunal distribution, salinity and bottom sediment texture.

It is our hope that such detailed environmental work as this will further enhance paleoecological interpretation of sediments in Nigeria.

III. RESEARCH AND TRAINING IN GEOLOGICAL SCIENCES

THE STUDY of Nigerian stratigraphy, and indeed that of the geology of Nigeria, commenced in 1903 with the establishment of the Mineral Surveys of Southern Nigeria by the Colonial Office, London. Two surveyors were charged with the responsibility of exploring and collecting the mineral specimens of the Protectorate. The samples were sent for study and analysis at the Imperial Institute, London. A year later, the Mineral Surveys of Northern Nigeria was established. Both surveys worked between 1903–1913 and 1904–1911 respectively. Most of the economically important minerals especially those occurring in association with sedimentary beds were discovered by them. These included the Abakaliki lead-zinc deposits, the Asaba and Nnewi lignites, the Enugu coals and the bituminous sands of Ondo and Ogun States. In the North, they found alluvial tin, iron ore, salts, and marble (see Okezie 1975).

The next period of intensive work followed the establishment of the Geological Survey of Nigeria in 1919. Its earliest work included detailed exploration of some of the earlier recorded mineral occurrences especially the tin fields, the Enugu coal fields and the Ilesha gold field. Groundwater investigation by means of boreholes was started later about 1928.

Despite the apparently long period of geological work, research on Nigerian sedimentary rocks can hardly be said to have made any but a modest beginning. Thorough and indepth study of the nature described above for the Ewekoro is lacking for most of the rock

formations. Apart from the reconnaissance survey and sketchy descriptions made at the turn of the century, there was a spate of good work by staff of the Geological Survey of Nigeria in the years immediately after World War II. During that period, some Cretaceous and lower Tertiary sequences were described and faunistically diagnosed. Most of the rock names applied were formalized in Reyment's (1965) *Aspects of the stratigraphy of Nigeria*, the best summary of Nigerian stratigraphy produced to date.

This was followed by a long period of virtually no activity until research in the geology Departments of the Universities gathered momentum towards the beginning of this decade. The contribution from the Universities was boosted by the slow but increasingly significant release of data by some major oil Companies beginning with the publication of the "Outline geology of Niger Delta" by Short and Stauble in 1967.

Significant amount of data relevant to the study of the stratigraphy of Nigeria and adjacent countries has been coming from the African Micropaleontological Colloquia, a four-yearly event, the last and 7th in the series of which was held here at the University of Ife in March 1976.

Similarly the International Geological Correlation Programme (IGCP) Project No. 145 on the "West African Biostratigraphy and its correlations" organized by the writer assisted by Professor I. de Klasz, and based here at Ife, has, since its inception in 1976, formed a rallying point for workers all over the world on the stratigraphy of this area.

In order to further enhance the process of information-gathering, younger geologists should be encouraged to tackle goal-oriented problems, preferably those involving field mapping of areas notless than the size of a standard 1:50,000 sheet. Their studies should also be designed to be as comprehensive as possible. Such effort would, if sustained over some years, lead to the availability of geological information on the entire country, at least on reconnaissance basis. More localised and detailed studies can then follow.

It is to be hoped that with the increasing number of active and conscientious researchers and the open door policy now being adopted by some oil companies, the next decade will witness an unprecedented increase in available information on Nigerian geology.

Such hopes will be realized only if the present trend to engage in researches with limited scope gives way to sustained research effort aimed at elucidating major geological problems. Many of the shorter, rather inconclusive papers published occasionally could advantageously be delayed and included as part of a broader regional synthesis.

ter does not
contrast, I
suppor
believe there are occasions when significant results are better communicated in fewer words as, for example, when in collaboration with colleagues, we recorded the first occurrences of *Campanile nigeriense* Adegoke a— Dessauvagie and *Nummulites ewekoroensis* Sachs and Adegoke in 71 and 1973 respectively. The occu *Nummulites* sensu strict in West Africa south of Senegal was st to widely held views. ditionally, both studies, along wi data, led me to su a strong Tethyan affinity for the West African Paleogene faunas (Adegoke 1972a, 1977). The brief study of the predato habit (paleoethology) of some Ameki gastropods by Adegoke a Tevesz (1974) is another case in point.

In orde to effectively prosecute meaningful field-based geolog research, the is need to have better equipped geological laborator a fair r of very efficient technical and other supporting s and better infrastructural facilities for field life.

Team work must also be encour aged for, like in all other field scientific endeavour, geology is inte disciplinary and there is ha ny problem that can be successfully ackled and solved by one per

Let us consider, for example, he determ trata, a problem that is so fundamen al to mea Less than half of the sedimentary ormations lated with reasonably degre racy or on the basi vertible or diagnostic data.

The example of the rri Formation, a ary deposit covering of over 30,000 squ and Bauchi States will help illustrate my point. The ge of the formation was only vaguely reported in the literature a age, mode of deposition and provenance were highly controversial. While most earlier workers suggested a Paleocene age (about 60 million years) based on its stratigraphic position, the latest and most authoritative studies (Burke 1970; Dessauvagie 1975) suggested derivation of the sediments from erosion of the Jos Plateau and consequently a much younger age, Miocene-Pliocene (5–10 million years).

Assisted by a colleague and two of my M.Sc. students (Messrs. Agumanu and Ajayi) we carried out detailed sedimentological and palynological work in the area. The result shows that Kerri Kerri sediments had a poly-directional source. Among the fossil pollen extracted from some horizons in the formation, we obtained among others, *Proxapertites operculatus, Mauritiidites crassibaculatus* and *Costatricolporites reticulatus*. The above show conclusively that the formation was deposited during the Lower Paleocene (Adegoke and others, in press).

In view of the complete absence of fossils from many formations or their poorly preserved nature when they occur, a composite approach using paleontology (both micro and macro), palynology and geochronology will be essential to decipher accurately the ages of most Nigerian formations. The effectiveness of such approach has been shown by the lively dialogue and intensive work that was generated following the initial controversy on the age of the Ewekoro formation. Tangible results have been forthcoming from studies of molluscs and echinoids (Adegoke 1972, 1977), corals (Ogbe 1976), algae (Kogbe 1972), planktonic foraminifera, pollen, sp and nannofossils (Fayose and Asseez, 1971; Jan du Chene *et al.* in press) and radiometric dating using the Potassium-argon method (Adegoke *et al.* 1972).

In order to ensure a continuous supply of well trained Nigerian geologists, a vigorous training programme must be pursued. There are, at present, eight University geology Departments of which the oldest five currently produce between them about 120 geology graduates annually. In addition, Ife University offers the B.Sc. programme in Applied Geophysics.

Faced in 1973 by complaints of over-production of geology graduates by industries, we introduced the one calendar year M.Sc. programme offering a diversified series of options in areas where we anticipated the country would need trained manpower in future. The experiment, which was a success, has continued to attract more students than we can conveniently place, bearing in mind the limited space and equipment available. Our most popular options include Mineral exploration, Sedimentary and Petroleum Geology, Hydrogeology and Engineering Geology. We intend to add Applied Geophysics soon. The products have had no problem in getting absorbed into the market.

Other University Geology Departments will do well to follow this example and establish specialization in some other fields not covered by our effort.

Need for rational geoscience policy:

In order to ensure that training, research and development are effectively prosecured in the best interests of the nation, government should endeavour, even in these days of austerity, to provide generous funds for geoscientific activity particularly in the following areas: stratigraphic and general geological work, coastal and environmental protection, oceanography and maritime research, mineral exploration and energy resources development.

One way of doing this is to establish, without further delay, the proposed Institute of Geological Sciences, a project already approved for implementation during the current National Development Plan.

Much of the researches of the Institute should be mission or goal-oriented. University staff and students should be urged to participate effectively in the work of the Institute.

At the Calabar Symposium on Science for self-reliance, organized by the defunct Natural Sciences Research Council of Nigeria in 1976, I made a call for the launching of an elaborate national nuclear exploration programme. It is hearty to note that since then the National Atomic Energy Commission has been set up and two Universities (Ife and ABU) have been provided with funds to commence training and research in nuclear science and technology. One would like to urge more generous funding for these activities.

As the beginning of an overall plan to evolve a comprehensive energy programme, I initiated a study of the assessment of the energy situation of Nigeria. The preliminary results of this work, which is being carried out by a team comprising one of my M.Sc. students (Mrs. Sijuade) and three other colleagues from the Faculties of Science and Technology, show among other things:

(i) That there is need to intensify the development of nuclear and other alternative sources of energy.

(ii) That there is need for a national energy policy aimed at conserving our wasting energy sources especially oil.

(iii) That there is gross under-utilization of coal, lignite and natural gas, though there are plans for improved utilization of the latter.

Mineral resources development is vital for the economic survival of the nation and, therefore, deserves to receive special consideration. As advised at the Calabar Symposium in 1976, the Government should establish a National Geoscience Advisory Committee with membership drawn from Government, Academic Institutions and industries. Such a body will help formulate national geoscience policies and advise government on the level of funding required for training and research in the earth sciences.

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EXPLANATION OF FIGURES