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"ORGANIC MATTER: THE SOURCE OF OUR WEALTH"

By

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Professor of Geology

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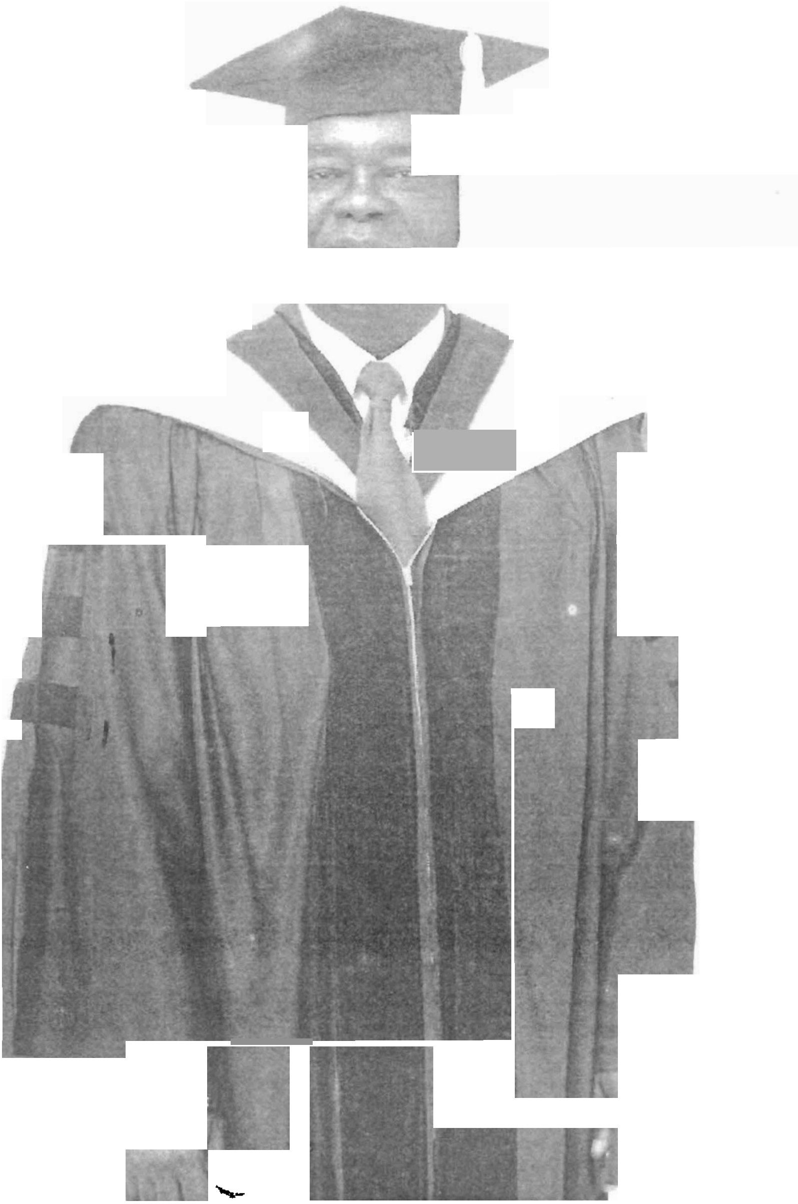

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ORGANIC MATTER: THE SOURCE OF OUR WEALTH

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INTRODUCTION

The Vice Chancellor, Sir, distinguished ladies and gentlemen, I feel honoured to present this 206th inaugural lecture of this great institution titled "Organic Matter: The source of our Wealth". The question may be asked. Is Nigeria a wealthy nation? The answer would be "yes" and "no" depending on individual opinion as it is often said, "beauty is in the eye of the beholder". On a global scale, Nigeria is one of the poor nations with Human Poverty Index (HPI-1) of 40.6 and ranking 76th among 102 developing countries (UNDP, 2006). At the continental level, Nigeria is one of the rich nations on the African continent, being the largest producer of petroleum and having the largest population of 140 million.

I consider Nigeria a wealthy nation irrespective of the problem of leadership and skewed sense of values bedeviling our country and will discuss the relationship between our wealth and organic matter, which is the source. This lecture will also highlight efforts I have made over the years, researching on organic matter and its products for the advancement of knowledge.

DEFINITION: Organic matter to the soil scientist is matter (or material), which came from a recently living organism, which is capable of decay (or the product of decay). It can also be looked upon as anything produced only by living organisms and containing primarily carbon and hydrogen. However, to the Geologist or Geochemist, "Organic Matter" or "Organic Material" refers to material composed of organic molecules or polymeric form derived directly or indirectly from the organic part of organisms (Tissot and Welte, 1984). This definition excludes things like skeletal parts e.g. shells, bones and teeth, which are inorganic matter.

The emphasis here is "organic matter" which is/was synthesized by living (or once living) organisms, deposited and preserved in sediments. The synthesis, deposition and preservation of organic matter in sediments and sedimentary rocks are natural processes, which have been in operation since the early earth's history although conditions for synthesis have changed throughout the Geologic past.

1 HOTOSYNTHESIS: Photosynthesis is the basic process for mass production of organic matter on earth. Essentially it involves a transfer of hydrogen from water to carbon dioxide to produce organic matter (in the form of glucose) and oxygen, with the help of sunlight. The oxygen is derived from water and not carbon dioxide. A simple equation for photosynthesis is given by:

$$6CO_2 + 12H_2O^* = C_6H_{12}O_6 + 6O_2^* + 6H_2O.$$

Autotrophic organisms are able to synthesize complex sugars (polysaccharides) such as cellulose and starch and other necessary constituents. Green plants containing chlorophyll can also form glucose with the help of sunlight by photosynthesis.

Primitive autotrophic organisms such as photosynthetic bacteria and blue green algae were the first organisms for mass production of organic matter. The oldest recorded forms of organic life are about 3.1 to 3.3 billion years old and are bacteria and algal-like bodies from Swaziland Group in South Africa (Schopf et al., 1965; Tissot and Welte, 1984). Similar fossil bacteria (Cyanobacteria) have also been found in Australia (Fig.1).

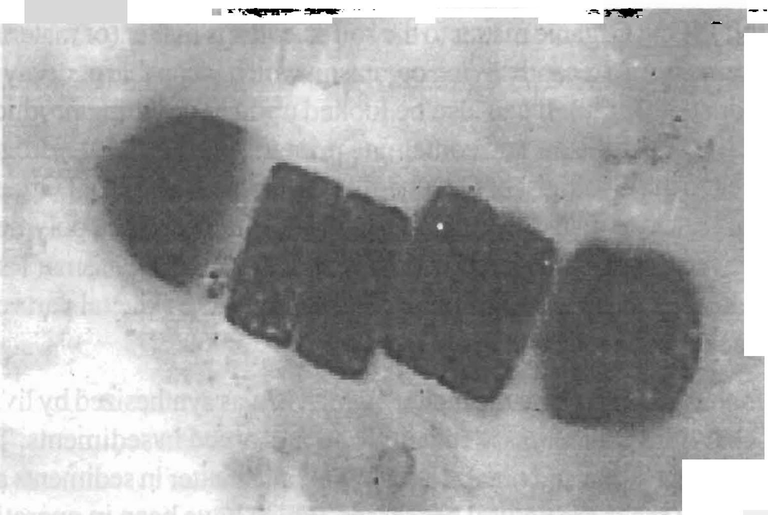


Figure 1: Cyanobacteria from Archean Rocks of Western Australia.
http://www.ucmp.berkerley.edu/bacteria/cyanobacteria/cyanofr.html

The main producers of organic matter in nature have evolved throughout geologic time (about 4.0 billion years). By Cambrian, Ordovician and Silurian times, marine phytoplankton, bacteria and blue-green algae dominated the scene.

The appearance of land plants in Siluro-Devonian (about 435 – 400 million years ago) marked a major stage in the organic carbon budget of the biomass. From then till the Holocene (Recent), marine phytoplankton, zooplankton, bacteria and higher plants are the main producers of organic matter in sediments. Higher organized animals (e.g. fishes) contribute so little organic matter in sediments that they can be practically neglected. This evolutionary sequence is confirmed by the presence of identifiable compounds in ancient sediments and rocks.

RECENT SEDIMENTS: Recent sediments are deposited in a variety of sedimentary environments, ranging from continental (land) to marine (seas or oceans). In the oceans, organic matter occurs as dissolved organic matter; particulate organic matter or as colloidal organic matter (Fig.2). Dissolved organic matter is at least an order of magnitude more abundant than particulate organic matter. The dissolved organic matter is usually adsorbed onto clay surfaces and settles at the bottom. The particulate material settles under gravity while the colloidal material first flocculates to particulate before settling to the bottom. Shells and skeletons of organisms settle as "rain of bodies" when the organisms that bear them die. Usually organisms that live at the bottom of water bodies, either as vagrant (wandering) or sessile (fixed) remove part of the organic matter before incorporation into sediments.

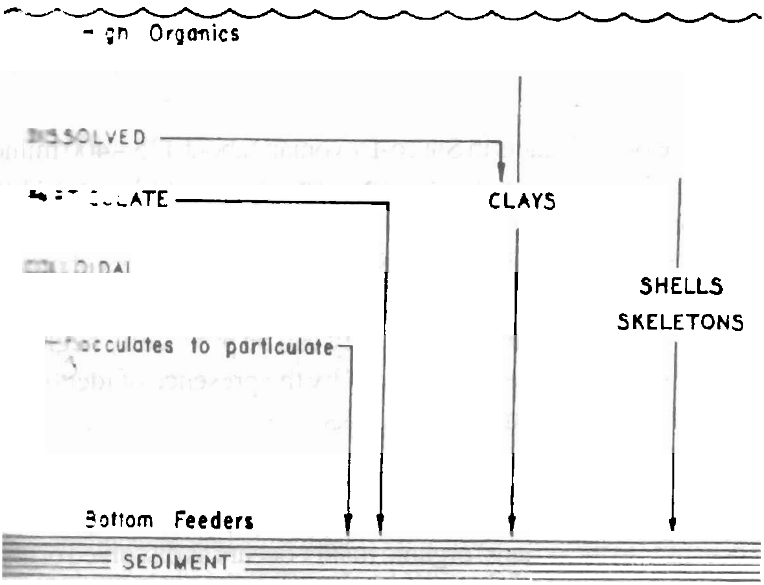


Figure 2: Deposition of Organic Matter in aqueous environment (Barker, 1979)

Factors Controlling Organic Contents:

The organic matter content of sediments and rocks is controlled by certain factors, which include bioproductivity, grain size, physical conditions and rate of sedimentation. The amount of different types of organic matter depends on their productivity in the water column. Regions of upwelling currents, where bottom waters are brought to the surface (e.g. the Humboldt Current west of Peru) are high areas of bioproductivity. In addition, in some areas like near the mouth of large rivers, terrestrial organic matter may be quantitatively important (Barker, 1979).

It has also been established that fine-grained sediments have higher organic matter contents than coarse-grained sediments (Bordorvsky, 1965). This is because the fine-grained sediments have higher surface area, hence greater adsorption of organic matter. Also the environment of deposition of sands is largely oxidizing which is incompatible with high organic contents. In addition, wave action winnows clay-sized particles out of sands and deposits them with hydraulically equivalent particles in quiet waters.

The physical condition of the sedimentary environment also affects organic matter content. Organic matter is unstable in oxidizing environment and is destroyed. Only about 0.1% of organic matter survives into sediments in oxygenated environments, while in reducing environments an average of 4% survive (Tissot and Welte, 1984).

Rock type also has an influence on organic matter content. For example sands form in high energy oxidizing conditions hence they have low organic matter contents. On the other hand, shales are deposited under reducing conditions in quiet waters and have high organic matter content. Carbonates generally have intermediate values.

The rate of sedimentation also controls the amount of organic matter in sediments. At high rates of sedimentation, organic matter is diluted with clastics leading to low organic matter content. At low rates of sedimentation, the organic matter is exposed for a very long time to oxidation, again leading to low organic matter content. Intermediate rates of sedimentation give optimum values of organic matter in sediments (Barker, 1979).

TYPES OF ORGANIC MATTER

Organic matter in sediments can be regarded as remains of past life just like fossils (Welte, 1969). In the laboratory, the organic matter in sedimentary rocks is usually isolated from the host mineral matrix by treatment with hydrochloric acid (Hcl) and hydrofluoric acid (HF) and the kerogen (acid insoluble fraction of organic matter) examined microscopically. Identifiable remains are often found which include spores, pollen, cuticle, woody tissue, dinoflagellate cysts, and amorphous unstructured materials and in some cases recycled material in the form of charcoal (fusain). All these have been largely classified into two major groups – Aquatic (sapropelic or amorphous) and terrestrial (humic) organic matter (Tissot and Welte, 1984; Hunt, 1979).

Aquatic Organic Matter:

Aquatic organic matter (A.O.M.) is generated in the water column and on the sea floor by bottom dwelling (benthic) organisms. Bacteria, phytoplankton and zooplankton are the major producers of aquatic organic matter. Some of these serve as food for other larger aquatic organisms in the upper end of the food chain.

Bacteria have a highly variable composition since they are highly adaptable. They contain essentially 50% proteins, 20% cell membranes (Lipids and lipid like substances) and 10% lipids. The rest is Ribonucleic acid (RNA) and Deoxyribonucleic acid (DNA) (Schlegel, 1969). Phytoplankton includes diatoms, dinoflagellates and algae. They are the most important producers of organic matter in the aquatic environment. Phytoplankton contains essentially lipids. Very little is known about the composition of prominent zooplankton (e,g, foraminifera and copepods). Foraminifera have fat globules (lipids) and some proteins in their protoplasm while copepods are largely chitinophosphatic. It may be suggested that the wax esters in the lipid fraction of marine copepods are probably the main source of long chain alcohols of marine sediments and some ocean surface lipids (Lee et al., 1970).

Aquatic organic matter is hydrogen rich and oxygen poor. It corresponds to type II kerogen of Tissot and Welte (1984). On burial, it generates the range of non-waxy crude oils characterized by n-paraffins with no odd – even preference. This crude usually has a low pour point (lowest temperature at which a crude oil can still flow) and normal American Petroleum Institute (API) gravity (>22^{0}) except when biodegraded or water washed.

Terrestrial Organic Matter:

Terrestrial organic matter is derived from organisms growing on land. Terrestrial higher plants are the third major source of organic matter in sediments, after phytoplankton and bacteria. Higher plants are made of wood, which is composed of 50 – 70% cellulose (a carbohydrate), and lignin. Lipids and proteins are only of secondary importance quantitatively.

Cellulose serves as a source of energy and forms supporting tissues in plants. Higher plants synthesize the largest amounts of cellulose, whereas certain algae, seaweeds and diatoms appear to be devoid of cellulose (Percival, 1966).

Lignin is characterized by its aromatic (phenolic) structure which makes it resistant to biodegradation. In plants, it is synthesized by dehydration and condensation of aromatic alcohols; and provides structural support. Aromatic structures of lignin have been discovered in various species of brown algae (e.g. ***Fucus serratus; F. vesiculosus***) (Manskaya and Kodina, 1975). Lignin has been identified also in pollen and spore (Manskaya, 1970) and mosses (Nilsson and Tottmar, 1967). Woody organic matter is hydrogen poor and oxygen-rich, and corresponds to Type III Kerogen of Tissot and Welte (1984). In the subsurface, rising temperature causes the cleavage of the short side chains of the lignin polymolecule, producing methane and ethane (Barker, 1979; Fig.3). Thus woody kerogen is gas generating.

Leaves contain considerable amounts of lipids and lipid-like substances (waxes, cutin, suberin etc). Waxes, a major component of lipids from terrestrial plants, form the protective layer in leaves. Waxes (Fig.3) are esters of long chain fatty acids and long chain monohydroxy alcohols. Suberin and cutin also play a major protective role in plant tissue. They are highly resistant to degradation and consist mainly of polymerized and cross-linked structures of fatty acids and alcohols (Tissot and Welte, 1984).

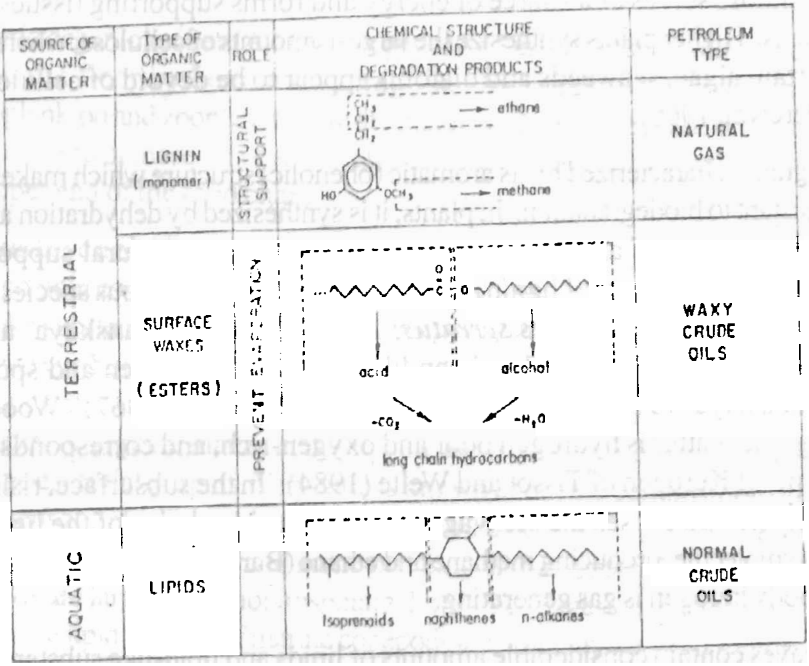


Figure 3: Types of Organic Matter and their degradation products (After Barker, 1979)

On burial, cutin and waxes lose carbon dioxide and generate very paraffin-rich material, in the form of waxy crude oil (Barker, 1979). Thus, in general, aquatic (sapropelic) organic matter of presumed algal origin generates normal crude oils in the subsurface, while terrestrial (humic) organic matter generates gas and/or waxy crude oil. Hence, the proper recognition of organic matter type is of economic importance.

ORGANIC MATTER AND FOSSIL FUELS

Fossil fuels that are of importance to man are oil, natural gas, coal, bitumen and bituminous shales (oil shales). Nigeria is endowed with large deposits of fossil fuels and our economy is largely dependent on them. Fossil fuels have their origin in organic matter. Examples are as follow.

PETROLEUM: Petroleum refers to any gas, liquid or solid which is a mixture of many hydrocarbons and hydrocarbon compounds occurring naturally in rocks. For petroleum to occur in rocks, certain conditions must be met (e.g. presence of a source rock; the source rock must contain organic matter of the right type; the source rock must have been buried to depths where it has experienced optimum temperature conditions; there must be a reservoir rock, with adequate porosity and permeability; there must be a trap, overlain by/ or adjacent to an impermeable barrier (cap rock or seal) and the area must be devoid of large scale tectonic or volcanic activity).

The source rock concept is very important. A source rock is a unit of rock that has generated and expelled oil or gas in sufficient quantity to form commercial accumulation. The term "commercial accumulation" is variable and depends on economics.

Source rocks for petroleum are generally of two types – shales and carbonates. In some cases coal could be a source rock (Hunt, 1991). To qualify for a source rock, the rock must have sufficient organic matter of the right type, and must have generated petroleum, which has migrated. Shales contain an average of 1.2% organic matter while limestones contain an average of 0.56%. This amount of organic matter is sufficient for petroleum generation. The minimum total organic carbon (TOC) value for a shale source rock is 0.5.wt%, and 0.3wt% for limestones. Niger Delta source rocks contain an average of 1.2% TOC.

Petroleum Generation:

The conversion of organic matter into petroleum involves a series of processes (or reactions), which are collectively referred to as **maturation.** Ninety percent of organic matter in sedimentary rocks is Kerogen (an acid insoluble part of organic matter), while the remaining 10% is soluble in organic solvents and is referred to as **bitumen.** The formation of Kerogen is an early diagenetic process, and as the Kerogen matures – a consequence of increased temperature and depth of burial, petroleum is generated from the kerogen.

Thermodynamic studies have shown that in a reducing environment, methane (CH_4) and graphite or carbon (C) are the two stable end products of organic matter diagenesis (Fig.4). One of these (CH_4) is hydrogen rich while the other is hydrogen poor. Thus there is a redistribution of hydrogen in the system resulting in the formation of petroleum and a carbonaceous residue.

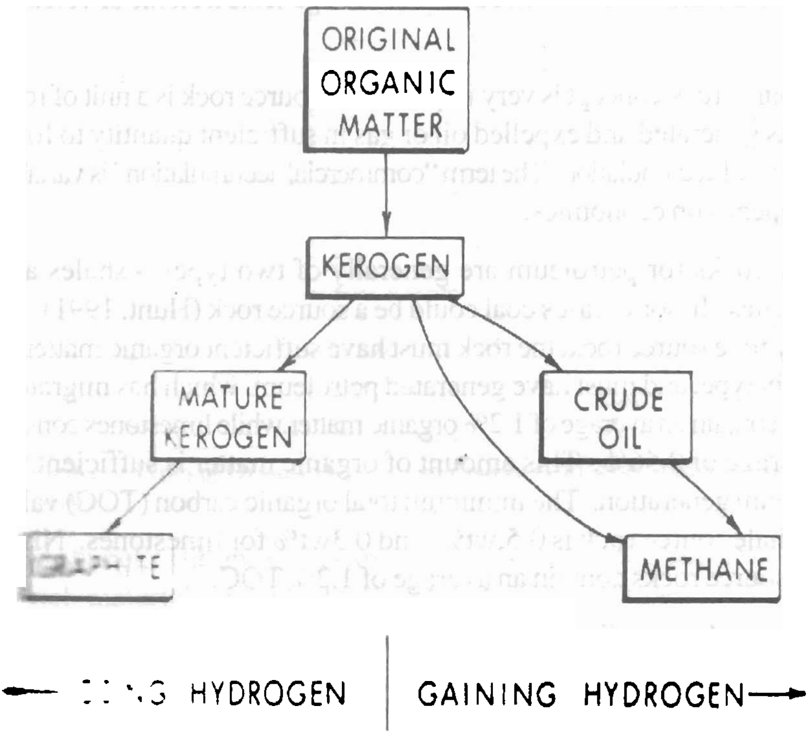


Figure 4: End products of Organic matter diagenesis in a reducing environment (After Barker, 1979)

At the early diagenetic stage, corresponding to depths of about 1.0km and temperatures of less than 50°C (Fig.5), bacteria decompose the organic matter to form biogenic methane. The kerogen is immature at this stage.

With subsequent increase in depth of burial, temperature and pressure increase and the kerogen enters the catagenesis stage. At this stage (1.5 3.5 km depth and temperatures up to 150°C) the kerogen matures and generates oil. The peak of oil generation occurs at about 2.5km depth. During this stage and the next (metagenesis), the larger molecules of the oil are cracked (broken down) to form smaller molecules (gas). The first gas to be formed contains $C_4 - C_{10}$ hydrocarbons and as such is referred to as "Wet Gas". As temperature increases further, wet gas components break down to smaller gaseous molecules ($C_1 - C_3$), which are now referred to as "Dry Gas". The peak of gas formation is about 3.5 – 4km depth. Gas can also be formed directly from kerogen without first being transformed to oil (Fig.4).

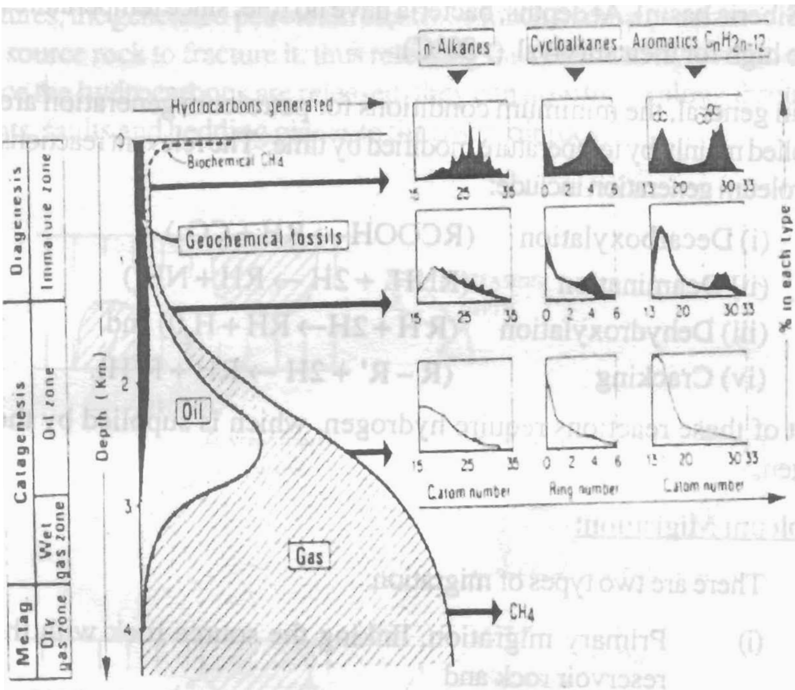


Figure 5. General scheme of hydrocarbon formation as a function of burial of source rock.

(After Barker, 1979)

From the above it is obvious that temperature is the dominant factor in petroleum generation. This has been demonstrated by Philippi (1965).

Pressure has no role to play in petroleum generation. Geologic time (or Age) has a secondary role to play in petroleum generation since older rocks generate petroleum at shallower depths and lower temperatures while younger rocks generate at higher temperatures and deeper (Barker, 1979).

The role of bacteria in petroleum generation is important at shallow depths, where they convert terrestrial organic matter to biogenic gas (or methane). Anaerobic bacteria convert cellulose to methane and carbondioxide. The methane is "dry" and is isotopically light ($\delta^{13}C \approx -90‰$). Biogenic gas can lead to commercial accumulation in some parts of the world (e.g. West Siberia basin). At depths, bacteria have no role, since temperatures are too high for their survival ($>80^0C$).

Thus in general, the minimum conditions for petroleum generation are controlled mainly by temperature modified by time. The relevant reactions in petroleum generation include:

(i) Decarboxylation ($RCOOH \rightarrow RH + CO_2$)

(ii) Deamination ($RNH_2 + 2H \rightarrow RH + NH_3$)

(iii) Dehydroxylation ($R\,H + 2H \rightarrow RH + H_20$) and

(iv) Cracking ($R - R' + 2H \rightarrow RH + R'H$).

Most of these reactions require hydrogen, which is supplied by the kerogen.

Petroleum Migration:

There are two types of migration:

(i) Primary migration, linking the source rock with the reservoir rock and

(ii) Secondary migration into and within the reservoir rock towards a trap.

Once petroleum is generated, it moves (migrates) to where it accumulates (the trap or reservoir).

The mechanisms of migration are not fully understood. Several mechanisms of primary migration have been proposed. These include mechanisms involving an aqueous medium (e.g. true solution, petroleum precursors and micelle formation). Exsolution of dissolved hydrocarbons is a problem, but this occurs at sand-shale boundaries due to salinity contrasts. Some other mechanisms involving migration as a separate oil phase have been proposed. In such cases the kerogen generates enough oil to saturate the water and forms a separate crude oil phase, which moves along. The separate oil phase remains in the center of the pore spaces (which is of least potential energy) forming what is described as a "pore-center network" (Barker, 1980; Fig.6). It is also believed that when kerogen matures, the generated petroleum creates so much internal pressure within the source rock to fracture it, thus releasing the generated hydrocarbons. Once the hydrocarbons are released, they can now move along through joints, faults and bedding planes to the reservoir rocks.

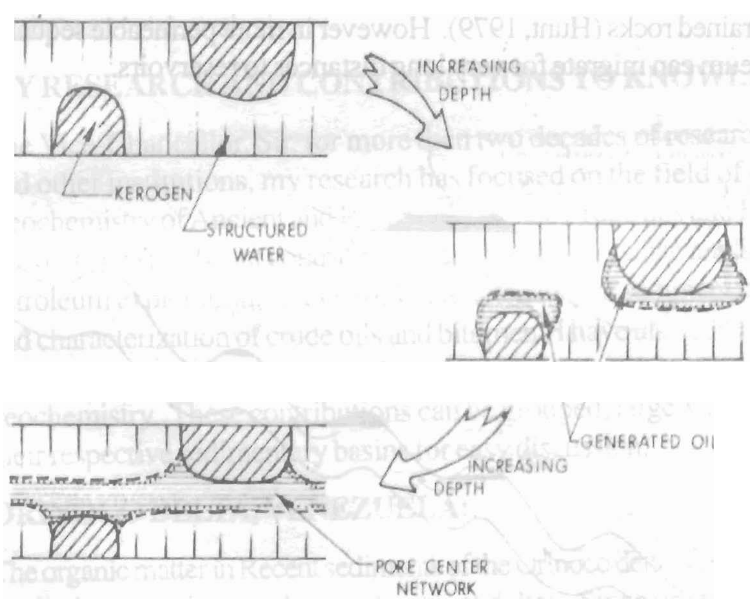


Figure 6: Development of pore center network of hydrocarbons as depth increases (After Barker, 1980).

In the reservoir rocks, subsequent remobilization of the petroleum can take place. This is described as "secondary migration". It is most commonly caused by regional tilting of the structure (or reservoir rock) and; buoyancy is the driving force. Other things that can cause it are (i) the expansion of a gas cap by removal of overburden and (ii) increased water flow rate in the reservoir, which can flush it. Once the petroleum is remobilized it can lead to compositional changes in some cases (e.g. in differential entrapment), leading to gas down dip and oil up dip of structures (Fig. 7).

In general, no single mechanism can account for petroleum migration. Several mechanisms operating at different stages and depths are responsible for moving petroleum from the source rocks to the reservoir rocks and also within the reservoir rocks. **Migration Efficiency** is generally low (1 – 10%). Thus migration does not cause major changes in the composition of source rock extracts, and this is why oil-source rock correlation is possible. The **distance of migration** is in the order of millimeters, inches, tens or hundred of feet or meters but not kilometers for low permeability fine-grained rocks (Hunt, 1979). However in more permeable sequences, petroleum can migrate for very long distances to reservoirs.

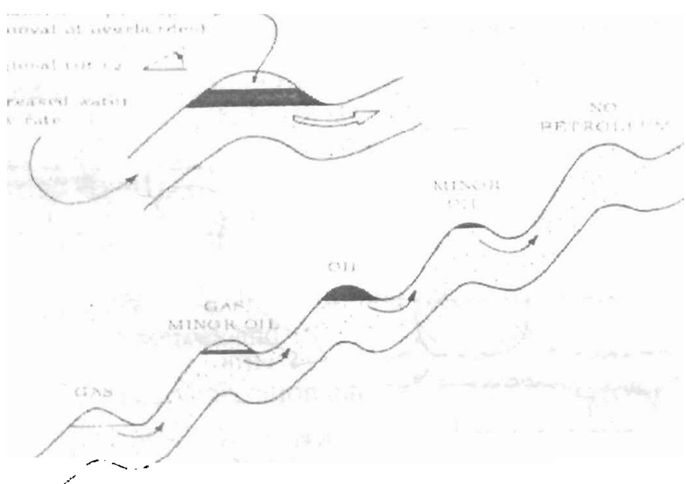


Figure 7: Schematic representation of the possible effects of differential entrapment (After Barker, 1979).

Traps:

Petroleum once formed continues to migrate until it enters into a trap where it accumulates. Any geometric configuration in the subsurface that is capable of holding oil and gas is called a "trap'. It represents a position of least potential energy. Three basic types are common viz: Structural, Stratigraphic and Combination traps. A fourth type called Hydrodynamic trap has been found in some fields.

Exploration Geologists and Geophysicists look for petroleum traps and when drilling tests these traps, then the presence (or otherwise) of oil and/ or gas can be confirmed. Since the drilling of an oil or gas well is very expensive, up to 60 - 90 million dollars in some cases, trap delineation and prioritization must be done with utmost care and requires expertise. Also important is the relative time of trap formation and hydrocarbon generation. If traps are formed before or contemporaneous with petroleum generation and migration, then chances are high that such traps will contain oil or gas. The converse is also true. Hence successful exploration for oil incorporates risk analysis.

MY RESEARCH AND CONTRIBUTIONS TO KNOWLEDGE:

The Vice-Chancellor, Sir, for more than two decades of research in this and other institutions, my research has focused on the field of Organic Geochemistry of Ancient and Recent sediments, Crude oils and Bitumen. I have made significant contributions that are of immediate application in petroleum exploration; source rock characteristics of sedimentary basins and characterization of crude oils and bitumen. I have also contributed in the areas of sedimentology, biostratigraphy and trace elements geochemistry. These contributions can be grouped, largely according to their respective sedimentary basins for easy discussion.

ORINOCO DELTA, VENEZUELA:

The organic matter in Recent sediments of the Orinoco delta was extensively studied as a modern analogue of ancient deltas. Since organic matter is the source of petroleum and other fossil fuels (e.g. bitumen and coal), proper understanding of the type and distribution of organic matter in deltaic settings has obvious economic importance (Nwachukwu, 1981). Orinoco delta sediment samples were collected using a Shipek bottom grab during cruise E-6c-79 of the R/V Eastward. The Coulter Counter technique was used in determining kerogen densities of Recent sediments which are rare in the literature. The variation of these density values within the delta, and the use of kerogen density in typing organic matter were demonstrated (Nwachukwu and Barker 1985a). The sediments contain essentially terrestrial organic matter with densities ranging from 1.32 to $1.72 gml^{-1}$ (with an average of $1.48 g\ ml^{-1}$).

It was also found that Kerogen density varies with offshore distance and depth, decreasing consistently at the rates of 0.015 and $4\ g\ m\ l^{-1}\ km^{-1}$ respectively (Fig.8). The heavy kerogens are associated with shallow nearshore areas while lighter kerogens are found in the deep offshore.

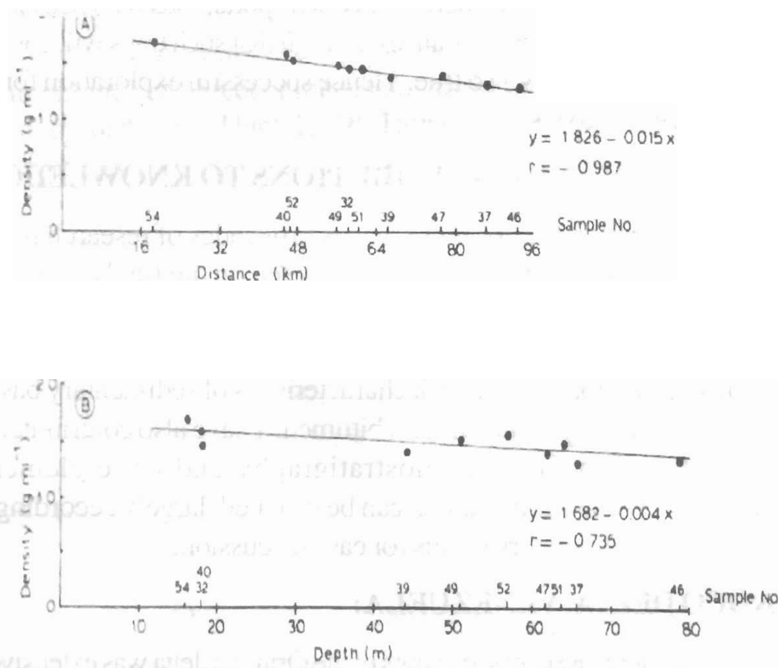


Figure 8: Variation of kerogen density with (A) distance and (B) depth in the Orinoco Delta (Nwachukwu and Barker, 1985a)

This study has demonstrated that density may be one of the factors influencing the distribution of organic matter in recent sediments. In addition, if organic matter is sorted, at least in part, by its physical properties of size, shape and density (which is true) then the sorting will lead to concentration of different types of organic materials in somewhat different sedimentary environments. This in turn could have considerable economic importance because while some types of organic matter generate oil on burial, others generate gas. In many parts of the world, the economics for oil and gas are quite different and it would be very helpful to have an improved understanding of the factors influencing the areal distribution of organic facies.

We also carried out an extended characterization of Orinoco delta sediments to include pyrolysis data for the organic materials associated with various size fractions of the surficial sediments (Nwachukwu and Barker, 1985b).

Pyrolysis techniques have never been used in studying sediment size fractions, although characterization of sedimentary organic matter by pyrolysis is common. We therefore used pyrolysis and pyrolysis – Gas chromatography in studying sediment size fractions for some samples of Orinoco Delta, which we separated by sieving and pipette analysis into seven size fractions from 4ϕ to 10ϕ in 1ϕ units. Total organic carbon (TOC) was also determined for the size fractions.

The sediments averaged 0.98% organic matter with somewhat higher values nearshore. Nearshore samples also had higher organic contents in the coarsest fractions and a decrease in organic matter from coarse to fine sediment fractions. Sediments from further offshore generally show the highest organic contents in the fine fractions (Fig.9). Pyrolysis showed low bitumen content and confirmed that the kerogen is dominantly terrestrial and gas prone. These observed trends are due to the sorting of organic matter by its physical characteristics, with the denser, coarse grained material settling out nearshore and the finer grained material being carried further from shore and settling out with finer-grained sediments.

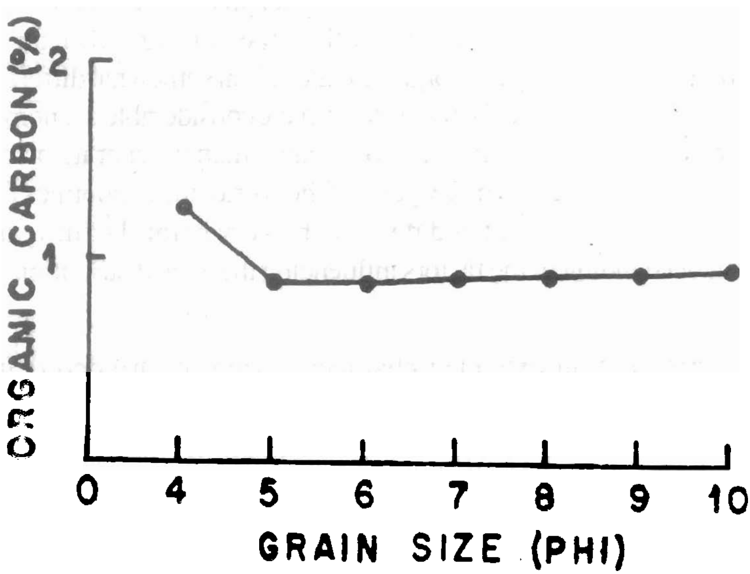


Figure 9: Average organic carbon contents for size fractions of all samples of Orinoco Delta sediments (Nwachukwu and Barker, 1985b)

In another study (Nwachukwu, 1990a), the distribution of solvent – soluble hydrocarbons (bitumen), especially the alkane was used as an index of environmental pollution and as a guide in exploration. This is so because very high concentration of hydrocarbons in bottom sediments could indicate, and possibly confirm, petroleum seepage and hence locate sites for detailed exploration.

The study involved TOC determination, Soxhlet extraction, column chromatography and gas chromatography of the n-alkane fractions and the results are shown in Table 1. TOC averaged 0.84 wt% and decreased with distance offshore. The hydrocarbons are indigenous and there is little or no evidence for contamination by thermogenic hydrocarbons in spite of the close proximity of the huge petroleum accumulations in the Orinoco heavy oil belt.

Table 1: Percentage relative abundance of n-alkanes and isoprenoids of Orinoco delta sediments (Nwachukwu, 1990a).

	n-alkanes																Isoprenoids	
S/No	C_{16}	C_{17}	C_{18}	C_{19}	C_{20}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{27}	C_{28}	C_{29}	C_{30}	C_{31}	PRI	PHY
32	-	1.4	5.3	8.0	8.2	6.1	15.6	7.3	7.2	6.4	8.4	8.8	Tr	12.5	Tr	Tr	3.7	1.1
34	Tr	27.5	18.5	18.0	6.3	3.8	5.7	2.4	1.7	1.4	-	-	-	-	-	-	6.2	8.3
36	-	Tr	4.4	11.0	11.2	8.1	39.9	5.0	9.7	Tr	10.6	-	-	-	-	-	-	-
37	-	7.9	17.6	29.3	12.6	7.0	17.5	4.5	2.0	1.6	-	-	-	-	-	-	-	-
39	-	0.8	3.0	6.9	4.9	8.9	18.5	7.7	7.1	9.1	3.9	12.2	-	18.0	-	-	-	-
40	-	3.4	8.5	9.2	9.5	6.3	15.5	6.3	7.8	6.5	3.5	7.1	-	3.2	-	-	11.9	1.3
41	-	-	1.4	3.9	4.7	6.2	17.8	8.7	7.0	11.7	4.2	12.7	-	21.7	-	Tr	-	-
42	-	-	5.8	5.5	4.8	13.5	26.1	6.7	5.0	7.7	3.3	8.1	-	13.5	-	-	-	-
43	-	3.7	8.3	9.4	9.9	7.4	23.2	5.6	8.2	4.3	7.3	-	-	-	-	-	11.4	1.2
46	-	-	8.3	19.2	18.7	13.2	6.0	4.7	15.4	-	14.6	-	-	-	-	-	-	-
47	-	-	-	11.6	15.0	21.8	15.0	8.0	12.3	16.2	-	-	-	-	-	-	-	-
48	0.9	27.8	18.7	21.7	9.1	4.8	9.6	3.5	2.2	1.7	-	-	-	-	-	-	-	-
49	-	-	2.5	5.6	4.7	8.1	21.1	8.1	7.0	8.3	4.9	11.6	-	18.0	-	Tr	-	-
50	-	-	-	7.7	8.0	10.7	52.9	8.4	7.4	4.8	-	-	-	-	-	-	-	-
51	-	-	-	11.7	13.5	7.8	39.8	10.0	10.0	7.2	-	-	-	-	-	-	-	-
52	-	-	-	6.7	8.3	13.8	42.6	11.5	9.2	7.8	-	-	-	-	-	-	-	-
53	-	-	2.0	5.7	5.8	7.3	15.6	10.0	9.3	10.9	5.1	12.0	-	16.0	Tr	Tr	-	-
54	-	-	0.8	2.9	3.7	15.7	16.4	7.3	6.7	9.7	5.1	11.1	-	20.5	-	-	-	-
55	-	-	2.8	6.3	6.8	7.0	21.4	8.0	7.7	8.1	5.7	10.3	-	15.8	-	Tr	-	-
56	-	1.8	4.8	5.5	6.7	-	20.9	8.4	7.0	9.5	5.2	11.7	-	18.5	-	Tr	-	-
57	-	-	1.5	4.2	4.2	5.8	16.0	8.5	6.8	10.1	4.5	13.8	-	24.5	-	Tr	-	-
58	-	-	-	5.5	6.4	7.6	52.2	11.1	10.1	7.1	-	-	-	-	-	-	-	-
59	-	-	2.8	9.9	9.7	13.0	26.2	12.4	10.3	10.3	-	5.4	-	-	-	-	-	-
60	-	-	1.7	6.1	6.1	9.9	27.8	7.9	6.9	7.5	5.4	8.9	-	11.8	-	-	-	-

S/No = Sample Number; PHY = Phytane; PRI = Pristane; Tr = Trace; - = Not detected or not present

THE BENUE TROUGH, NIGERIA:

The Benue trough (Fig.10) is an important sedimentary basin in Nigeria because of its rift geologic setting and economic minerals potential. The basin's structure and petroleum geology; have been discussed by many workers (e.g. Benkhelil, 1982; Burke et al., 1970; Petters, 1978; Obaje et al., 2004; Akande et al., 2005 among others).

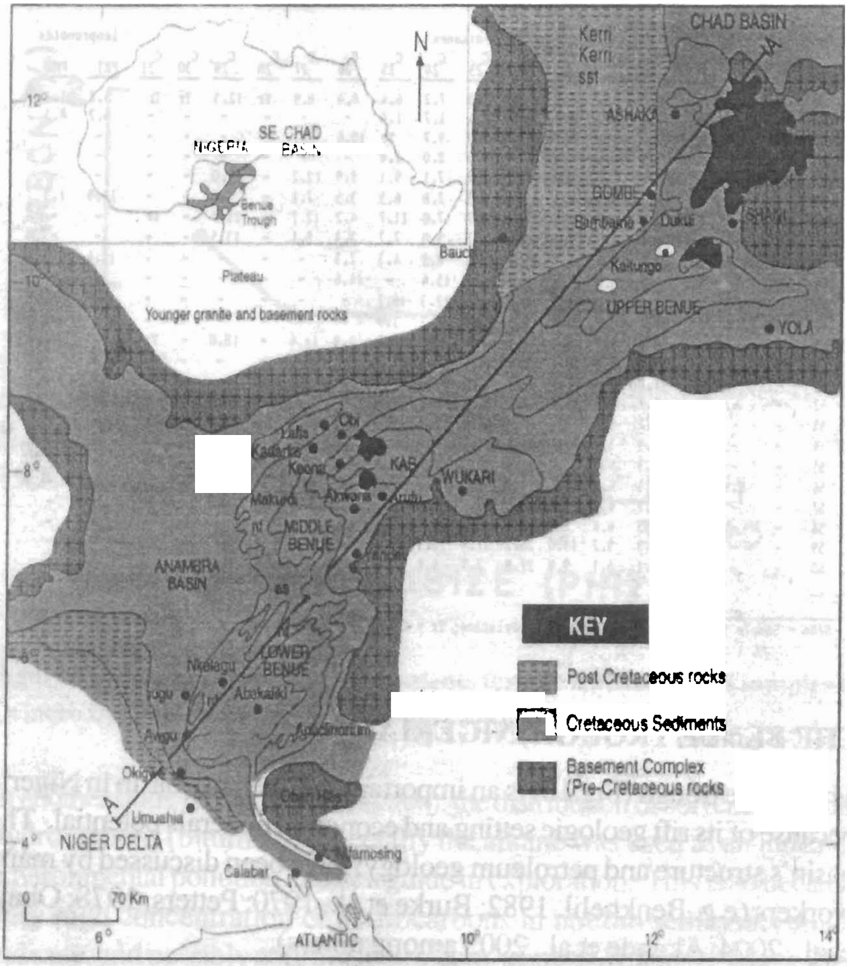


Figure 10 Geological sketch map of the Benue Trough and surrounding areas (modified from Enu, 1986).

Nwachukwu (1985) used the Time-Temperature Index (TTI) technique (Lopatin; 1971; Waples, 1980) to assess the petroleum prospects of the basin. The burial history of the sediments was reconstructed and the sediments matured at four different geothermal gradients ranging from (1.5°F/100ft – 2.7°F/100ft; 2.7° C/100m – 4.9° C/100m). The results showed that the uplifted blocks containing about 6,600ft (2km) of sediment cover are not prospective. The deep basins flanking the uplifted blocks contain thick sedimentary piles with mature source rocks and reservoir rocks. The depth to the "oil window" decreases with increasing geothermal gradient and the sediments mature earlier at higher geothermal gradients.

Optimal depths of hydrocarbon generation in the trough lie between 6,600 and 13,000ft
(2-4km) depth, increasing southwestwards and decreasing northeastwards. Exploration targets within the trough are the sub-Santonian and super-Santonian sediments, especially the Eze-Aku group, Awgu and Nkporo shales because these entered and left the oil-window after the Santonian tectonic phase (Fig.11). The hydrocarbons in the trough will be gas dominated which is a consequence of abundant terrestrial organic matter in the basin and thermal cracking of generated oil. Stratigraphically, gas will occur deeper and oil shallower, except in cases of differential entrapment.

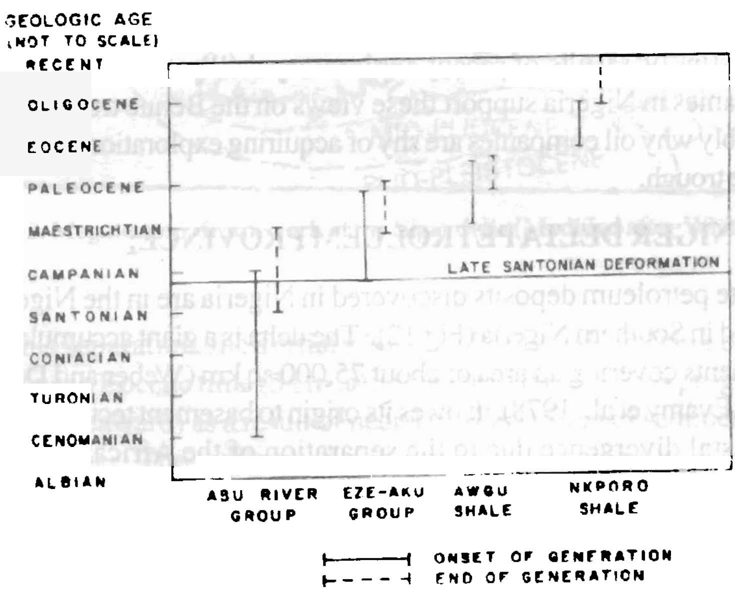


Figure 11: Relative age of the oil window for sediments of Benue Trough (Nwachukwu, 1985a)

The Petroleum Resources of the trough were also assessed by Geologic Analogy and risk analysis (Nwachukwu, 1990b), because: (i) recent exploratory drillings in the Chad and Anambra basins have not been encouraging despite earlier finds of gas and 45^0 API gravity oil in the Anambra basin (Avbovbo and Ayoola, 1981). (ii) Petroleum discoveries in the Benue trough would be cheaper to produce and would increase tremendously Nigeria's proved reserves with consequent increase in ultimate revenue. (iii) It will also suite politically frayed nerves in "security of supply" given the disturbing trends in the Niger Delta, and the perceived pride of ownership by the northern political elites.

Results of this study showed that analogous basins to the Benue trough are petroliferous (e.g. the Sirte basin in Libya and Gulf of Suez in Egypt) and on a worldwide basis only 35% of the basins produce commercial quantities of hydrocarbons. In addition the risk factor in exploration in the Benue trough appears high, with a cumulative probability of 0.175 of striking a commercial deposit. This, coupled with other negative factors (e.g. effects of uplifts and high geothermal gradients) makes exploration in the Benue trough a fairly risky venture.

Interestingly, results of recent exploratory drilling by three major oil companies in Nigeria support these views on the Benue trough. This is probably why oil companies are shy of acquiring exploration leases in the Benue trough.

THE NIGER DELTA PETROLUEM PROVINCE:

To date petroleum deposits discovered in Nigeria are in the Niger delta located in Southern Nigeria (Fig.12). The delta is a giant accumulation of sediments covering an area of about 75,000 sq km (Weber and Daukoru 1975; Evamy et al., 1978). It owes its origin to basement tectonics related to crustal divergence due to the separation of the African and South American continents during the Cretaceous.

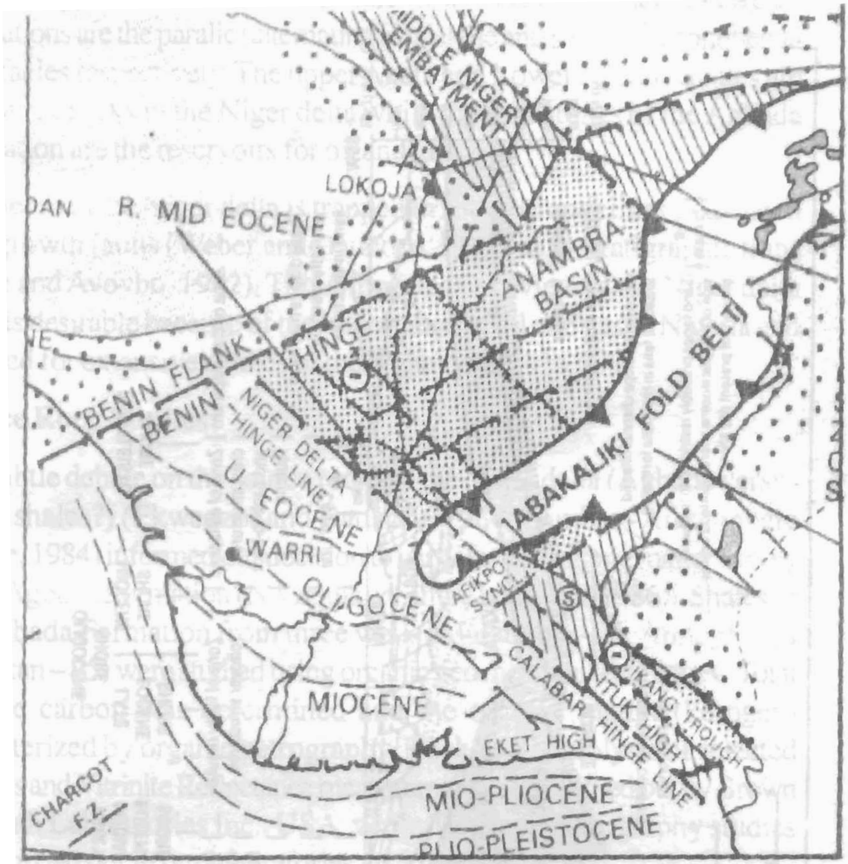


Figure 12: Megatectonic framework of the Niger delta (Modified after Whiteman, 1982)

After this separation, the Tertiary Niger delta started evolving by late Paleocene to Eocene time (54 m .a). Since then the delta has prograded (advanced seaward) as a result of nearshore deposition of sediments by the river Niger. The sediments reaching the delta are derived from the rocks exposed at the valley of the river Niger and its distributaries. The delta contains a lot of terrestrial organic matter (Ekweozor and Okoye, 1980; Nwachukwu and Chukwura, 1986; Bustin 1988) and consists of about 9000 – 12,000 m thick of sediments, which are distributed in three lithostratigraphic units – Akata, Agbada and Benin Formations (Fig.13).

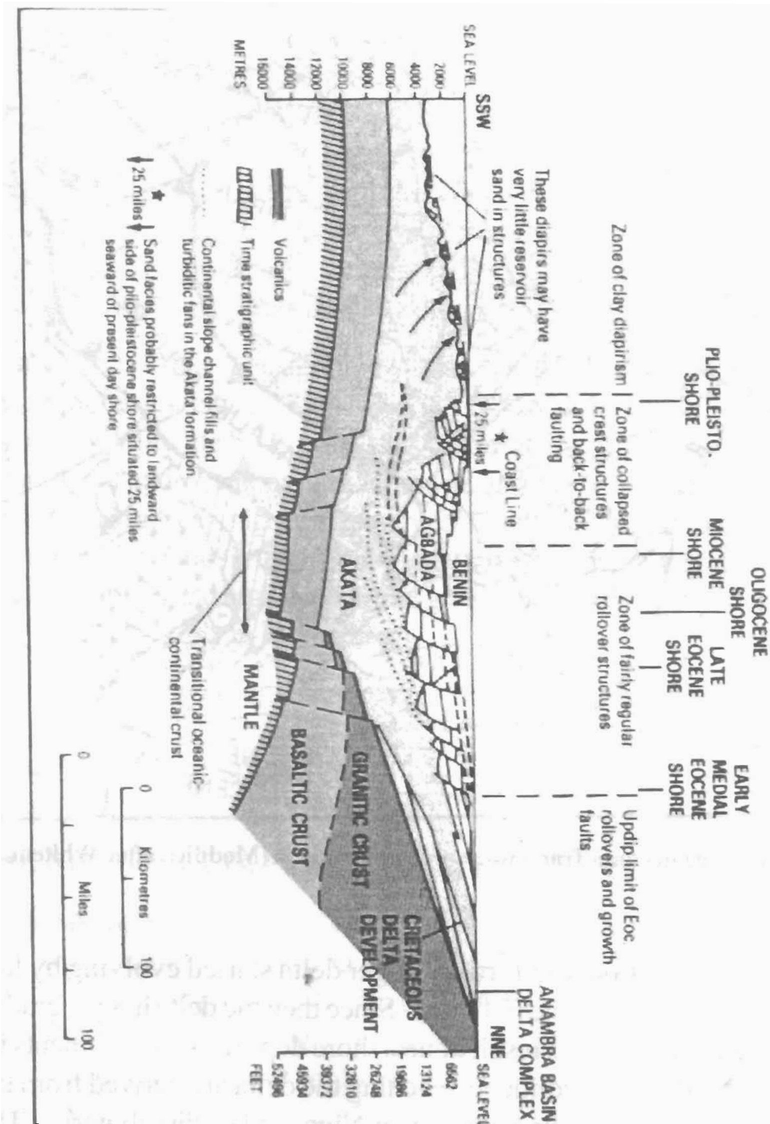


Figure 13: Schematic section of the Niger Delta (After Whiteman, 1982).

The Akata Formation is a marine shale unit, while the Agbada and Benin Formations are the paralic (alternating sandstone and shale) and continental sand facies respectively. The upper Akata and Lower Agbada Shales are the source rocks in the Niger delta while the sandstones of the Agbada Formation are the reservoirs for oil and gas.

Petroleum in the Niger delta is trapped in rollover anticlines associated with growth faults (Weber and Daukoru, 1975) or in stratigraphic traps (Orife and Avovbo, 1982). This simplified overview of the Niger delta basin is desirable because of the importance of oil and gas to Nigeria and the need for extensive studies of the Niger delta.

Source Rock Studies:

The subtle debate on the source rocks of the Niger delta (Agbada versus Akata shales?) (Ekweozor and Daukoru, 1984; Lambert-Aikhionbare and Ibe, 1984) informed our decision to carry out an organic matter survey of the Agbada Formation (Nwachukwu and Chukwura, 1986). Shales of the Agbada Formation from three wells (Makaraba – 26, Abiteye – 13 and Okan – 25) were studied using organic geochemical techniques. Total organic carbon was determined and the organic matter (kerogen) characterized by organic petrography. Rock-Eval pyrolysis of selected samples and Vitrinite Reflectance measurements were carried out by Brown and Ruth Laboratories Inc., USA, while TOC and petrography studies were carried out in our laboratories.

Our results showed that the Agbada shales contain 63% amorphous organic matter; 30% terrestrial organic matter and 7% recycled organic matter and that the kerogens are essentially Type III (humic) organic matter, which is capable of generating gas and waxy crude oil. We demonstrated that the Lower Agbada Shales in the western part of the Niger delta are mature and also showed for the first time, photomicrographs of kerogens of the Agbada Shales,(Fig.14).

Additional geochemical information on Niger delta source rocks was presented in our study of the Parabe – 35 and Mina – 3 wells (Okoh and Nwachukwu, 1997). Total organic carbon (TOC) was determined by the Walkey and Black (1934) method for samples without Rock –Eval pyrolysis data. The kerogen isolated from the shale samples were studied petrographically, while bitumen (soluble organic matter) was extracted from pulverized shales by Soxhlet extraction. These were fractionated using column chromatography, and the n-alkanes analyzed using a Varian 3700 gas chromatograph. Pyrolysis and Vitrinite reflectance measurements on selected samples were carried out by the K.D.M. Institute of Petroleum Exploration, Dehra Dun, India.

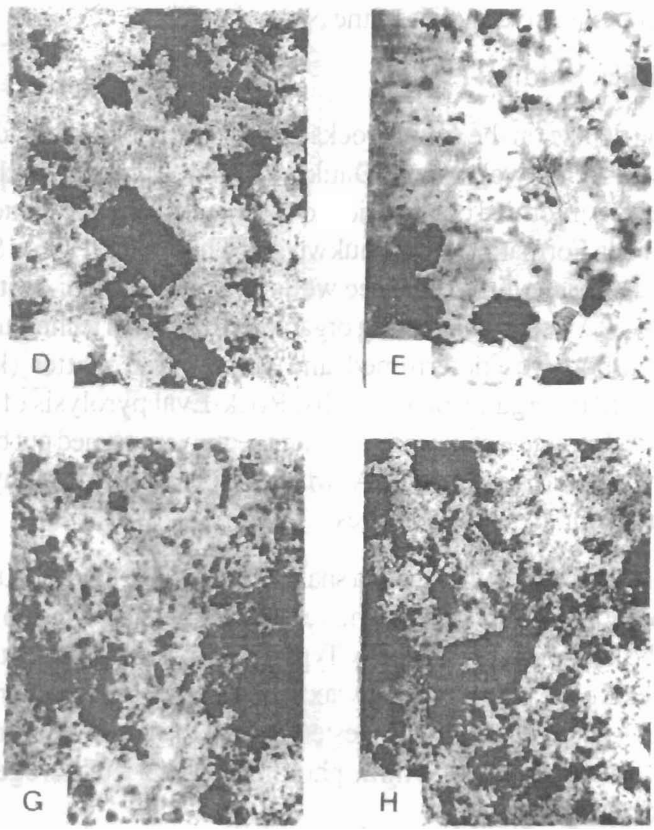


Figure 14: Photomicrographs of Agbada Formation, Niger Delta, Nigeria (Nwachukwu and Chukwura, 1986)

Our results showed that the shales of the Parabe-35 and Mina- 3 wells are fair to good source rocks with adequate amounts of organic matter: TOC of 0.6 – 4.3 wt% and extractable bitumen ranging from 489 – 3487ppm (Table 2). Pyrolysis and petrographic data confirm that the shales contain Type III organic matter with few Type II/III kerogens (Fig.15), and are capable of generating mainly gas and waxy crude oil. Vitrinite reflectance measurements show that the shales are immature to marginally mature at total depths within the lower Agbada Formation, in the western part of the Niger delta.

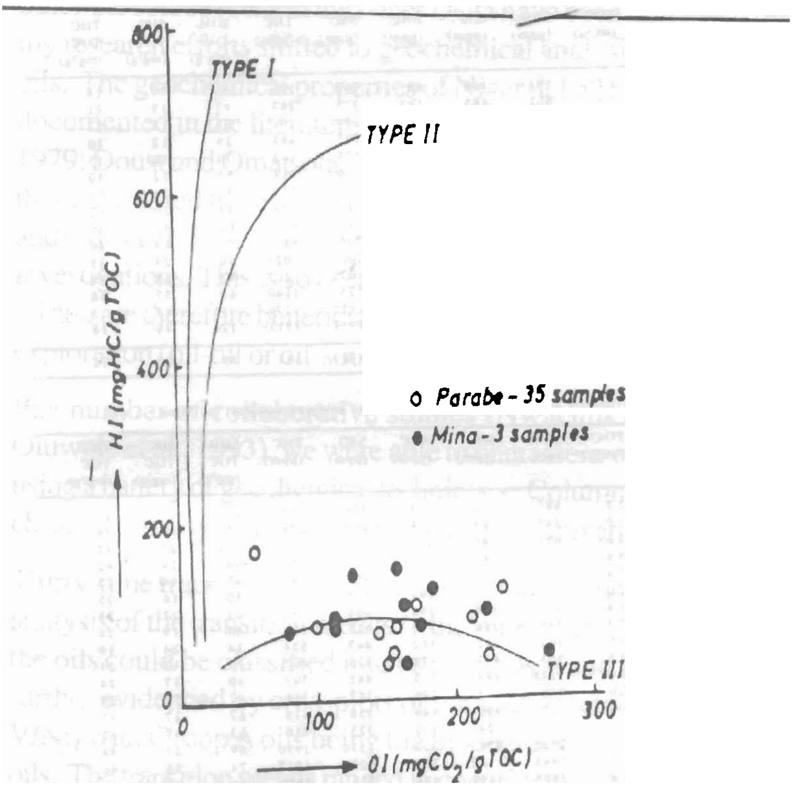


Fig. 4. Van Krevelen - type diagram of analyzed samples

Figure 15: Van krevelen- type diagram of analysed samples (Okoh and nwachukwu, 1997)

Having discussed the organic matter types of Niger delta kerogens, their elemental composition (excluding C, H, O) remained largely unknown. We reported for the first time analysis of 16 Agbada kerogens from 5 wells in the Niger delta for their major, minor and trace elements using Energy Dispersive x-ray fluorescence (EDXRF) spectrometry (Nwachukwu et al., 2000).

Table 2: Gravimetric data and Geochemical ratios of Parabe –35 and Mina-3 Wells, Niger delta (Okoh and Nwachukwu, 1997)

Table 1(a) Gravimetric data and geochemical ratios of analyzed samples (a) Parabe - 35 well

Sample Number	Depth (ft)	Depth (m)	TOC (wt.%)	SOM (ppm)	SHC (ppm)	AHC (ppm)	NSO (ppm)	THC (ppm)	SOM/TOC (mg/g)	SHC/TOC (mg/g)	THC/TOC (mg/g)
1	3030	924	1.2*	594	198	88	108	286	45	17	24
2	4110	1253	1.4*	662	185	102	175	287	47	13	21
3	4230	1289	0.9	498	121	80	280	201	55	13	22
4	4350	1326	3.0	861	176	115	295	485	29	12	16
5	5010	1527	4.3*	1455	439	123	875	562	[illegible]	10	13
6	5310	1618	1.4*	776	302	162	472	414	55	22	30
7	6030	1838	1.7*	952	415	121	415	536	56	24	32
8	6630	2021	1.9*	1348	571	158	619	729	71	30	42
9	7050	2149	1.7	1055	325	137	398	662	62	11	39
10	7770	2368	2.1	1592	700	143	745	813	76	13	40
11	8250	2515	2.9	1717	825	198	700	1023	60	29	35
12	8550	2606	3.2*	2332	1006	256	1070	1262	73	31	39
13	8970	2734	2.4	1668	883	257	525	1140	69	37	48
14	9210	2807	2.3*	2659	1070	200	1150	1270	115	47	55
15	10050	3063	2.6*	3228	1263	250	1332	1513	124	49	58
Average			2.2	1070	444	117	472	561	49	20	26

Table 1(b). Gravimetric data and geochemical ratios of analyzed samples (b) Mina - 3 well

Sample Number	Depth (ft)	Depth (m)	TOC (wt.%)	SOM (ppm)	SHC (ppm)	AHC (ppm)	NSO (ppm)	THC (ppm)	SOM/TOC (mg/g)	SHC/TOC (mg/g)	THC/TOC (mg/g)
1	3520	1073	2.5	685	150	115	338	265	27	6	11
2	3820	1164	1.0	345	162	119	263	279	35	16	28
3	3940	1201	0.6*	642	140	110	402	250	109	23	42
4	4680	1462	0.6	539	141	111	287	252	90	24	42
5	5820	1774	1.9	915	270	175	460	445	45	14	23
6	6000	1829	2.0	1009	314	195	500	509	50	16	25
7	6840	2085	1.4	875	304	163	406	467	63	22	33
8	7620	2323	2.3	986	388	173	425	561	43	17	24
9	7800	2377	3.0	1021	412	162	447	574	34	14	19
10	8100	2469	2.5	985	437	170	376	607	39	17	24
11	8340	2542	2.9	1148	488	215	445	703	40	17	24
12	8520	2597	2.0	948	413	145	387	558	47	21	28
13	8700	2652	1.8	1200	490	148	558	638	67	27	35
14	9000	2743	1.9*	1196	724	132	325	856	63	18	45
15	9420	2871	2.6	2325	850	300	1130	1150	89	33	44
16	9600	2926	3.3	2441	1147	370	800	1517	74	35	46
17	9720	2963	3.2	2895	1492	438	825	1930	90	47	60
18	9840	3000	4.3	3487	1838	438	1218	2276	87	46	57
19	10320	3146	2.8	2525	1282	260	941	1540	90	46	55
20	10740	3274	2.2	2510	1402	250	766	1752	114	64	80
Average			2.2	1444	642	210	565	836	66	27	37

* = Rock Eval Pyrolysis TOC data

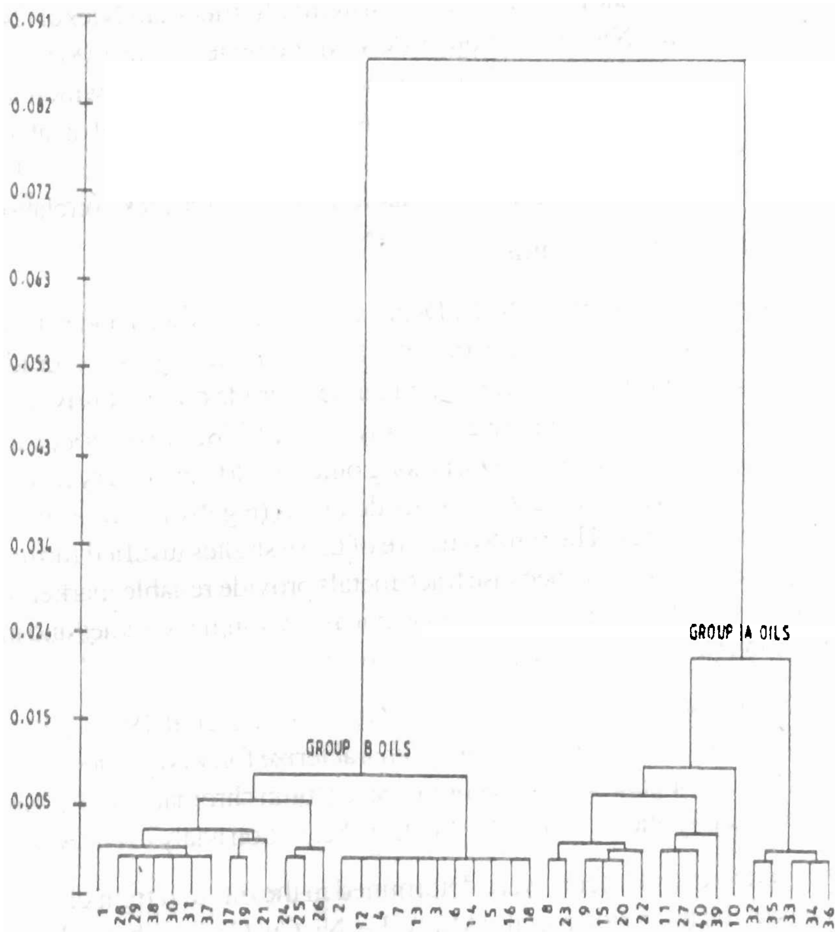
Fifteen elements were detected with concentrations, ranging from 4.74 to 67470.0ppm. Vanadium (V) was consistently higher than Nickel (Ni) with Vanadium – Nickel fraction (V/V + Ni) being less than 1.00 for all samples. This is characteristic of low sulphur source rocks, which are typical of the Niger delta. Apart from constituting a geochemical database this study also established intermetal associations, which were used to infer kerogen - oil associations, which indicate oil – source rock correlation

Crude Oil and Other Studies:

Since the source rocks in the Niger Delta have been fairly well understood my research efforts shifted to geochemical analysis of Niger delta crude oils. The geochemical properties of Niger delta crude oils are fairly well documented in the literature (e.g., Evamy et. al., 1978; Ekweozor et al., 1979; Doust and Omatsola, 1990, among others). However, very few of these discussed trace elements of Niger delta oils (e.g. Ndiokwere, 1983 and Udo et al; 1992). The limited nature of these studies justified further investigations. This is so because trace metals provide reliable marker of oil and are therefore beneficial in depositional environment studies and in exploration (oil-oil or oil-source rock correlation).

In a number of collaborative studies (Nwachukwu et al.1995, 2004; Oluwole et al., 1993), we were able to characterize forty Niger delta oils using a battery of geochemical techniques: Column chromatography, gas chromatography and Instrumental Neutron Activation analysis (INAA).

Thirty-nine trace elements were determined in the oils and tight cluster analysis of the transition metals (Mn, V, Fe, Ni, Cu, Cr, Co) showed that the oils could be classified into two groups A and B (Fig.16). This was further evidenced by crossplots of transition metal ratios (Co/Ni versus V/Ni) with Group A oils being the biodegraded equivalents of Group B oils. The transition metals ranged in concentration from 0.03 – 42.31ppm. We also showed for the first time that Oligocene oils have the highest metal ratios and variations than oils of other ages in the delta. This is a reflection of the variability in source and sediment supply during this period of the geologic past.



NIGERIA OIL DATA, TIGHT CLUSTER, V+NI+CU+MN+FE+CR+CO

Figure 16: Nigerian oil data. Tight cluster using transition elements (V+Ni+Cu+Mn+Fe+Cr+Co) as variables (Nwachukwu et al., 1995).

The concentrations of V and Ni are low (100ppm) which together with the low sulphur content of the oils (0.13 – 0.60 wt %) is consistent with derivation of the oils largely from terrestrial organic matter. Because of the low sulphur in Nigerian crudes they are referred to as "sweet" and in addition to the low trace elements content. they are usually in high demand by international Refiners.

In another related study of 13 crude oils from the Niger delta (Mustafa and Nwachukkwu, 2007), we used column chromatography, gas chromatography and inductively coupled plasma spectrophotometer to obtain comparable trace elements data, and oil grouping (A & B; Fig 17) implying a single petroleum system in the western part of the Niger delta.

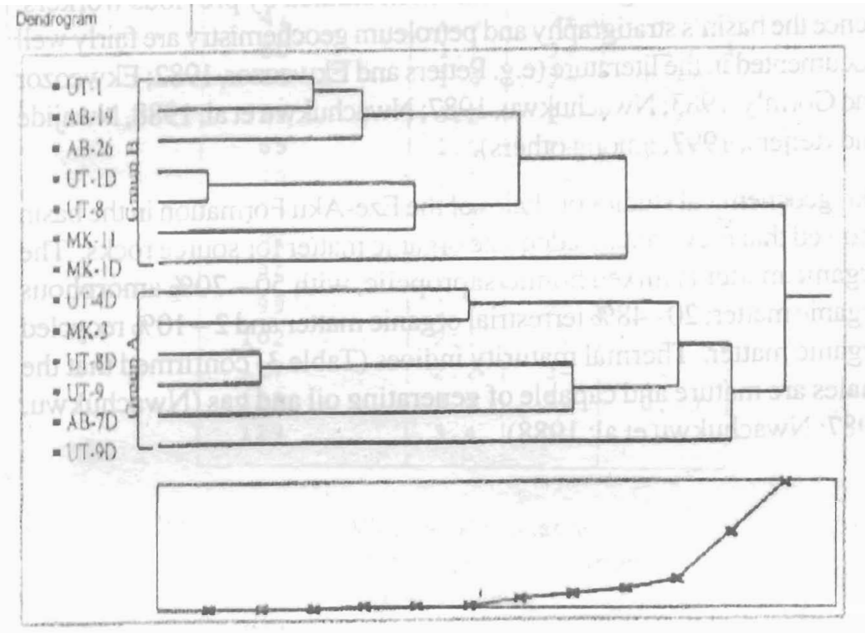


Figure 17: Tight cluster using V/V+Ni variables showing two groups of oils, A & B. (After Mustafa and Nwachukwu, 2007).

We also used petrophysical and decompaction techniques to establish porosity-depth trends and percentage compaction of Reservoir sands in the delta (Nwachkwu and Odjegba, 2001), which showed that the sandstone reservoirs of the Agbada Formation are undercompacted to weakly consolidated. The computed compaction coefficients ranged from 0.0004 m^{-1} to 0.0008 m^{-1} averaging 0.0006 m^{-1}, and have implications for reservoir engineering estimates, since oil production from undercompacted reservoirs requires installation of screens to avoid sand production problems.

ANAMBRA BASIN:

The Anambra basin is located in the southwestern end of the Benue trough (Fig.10) and was initiated during the late Cretaceous tectonic movements in the Benue trough. It contains up to 9km of sedimentary rocks (Whiteman, 1982) and covers an area of about 40,000 km^2. The basin is a potential hydrocarbon-bearing basin and has been studied by previous workers; hence the basin's stratigraphy and petroleum geochemistry are fairly well documented in the literature (e.g. Petters and Ekweozor, 1982; Ekweozor and Gormly, 1983; Nwachukwu, 1987; Nwachukwu et al, 1988, Nwajide and Reijers, 1997, among others).

Our geochemical studies of shales of the Eze-Aku Formation in the basin showed that they contain adequate organic matter for source rocks. The organic matter is mixed humic/sapropelic, with 50 – 70% amorphous organic matter; 20 –48% terrestrial organic matter and 2 – 10% recycled organic matter. Thermal maturity indices (Table 3) confirmed that the shales are mature and capable of generating oil and gas (Nwachukwu, 1987; Nwachukwu et al; 1988).

Table 3: Total Organic carbon, Thermal Alteration Index and Vitrinite Reflectance data for Eze-Aku Shale (Nwachukwu et al., 1988).

Sample Depth (m)	TOC (%)	TAI	Ro (%)
10	2.2	2+	-
17	2.0	2+	-
20	1.4	2+	-
29	1.7	2+	-
41	2.3	2+	-
50	1.1	2+	-
53	1.4	2+	0.60
59	1.2	2+	0.60
65	1.0	2+	0.60
72	1.5	2+	-
74	1.9	2+	-
84	2.0	2+	-
90	1.6	2+	-
99	1.7	2+	-
102	2.1	3-	-
117	2.2	3-	-
123	3.2	3-	0.73
129	3.4	3-	-

Ro = Vitrinite Reflectance.
T.A.I. = Thermal Alteration Index.
\- = Not determined.

Our earlier studies did not assess the petroleum potential of Post-Santonian shales and oils, which are present in the basin. Therefore our geochemical studies were extended to evaluate the aromatic hydrocarbon distribution in the shales and coals and to carry out volumetric estimates of generated hydrocarbons in the basin (Akaegbobi et al., 2000). Twenty- four samples were obtained from two exploratory wells in the basin (Oda River -2 and Anambra River – 2) and analyzed. The results confirmed that Nkporo Shale and Lower Coal Measures (Mamu Formation) are mature within the depth range of 1555 – 2389 m. Volumetric estimates of the hydrocarbons generated by these shales and coals show that about 779 million barrels of oil or 4.57 x 10^{13} ft^3 of gas may have been generated and probably entrapped in the basin. However the basin has a low source potential index (4.02), which makes it an undercharged petroleum system. This accounts for the earlier finds of very light oil (45^0 API) and gas in the basin (Avbovbo and Ayoola, 1981).

These findings have greatly influenced exploration decision-making and strategy in the Anambra basin. It should also be noted that the Anambra basin is one of the in-land basins that have been mapped out into blocks by the Department of Petroleum Resources (DPR) for bidding by oil companies.

THE DAHOMEY BASIN:

The Nigerian sector of the Dahomey (Benin) basin (Fig.18) has a lot of economic interest mainly because of the occurrence of tar sands (bitumen) and limestone deposits in the basin. The bitumen is conventional oil that has been altered (biodegraded) into a tarry highly viscous substance (Fig.19). About 30 – 40 billion barrels of heavy oil in place are present in the basin (Adegoke et al., 1991). My initial research in this basin focused on assessing the source rock potential of the Cretaceous shales associated with the tar sands deposits (Nwachukwu and Adedayo, 1987) and also to provide an insight into the origin of the tar sands (Ekweozor and Nwachukwu, 1989), as these were hitherto speculative. Subsequent research efforts focused on major and trace elements content of the tar sands bitumen using the ASTM method, Fast Neutron Activation Analysis and liquid - gas chromatography (Oluwole et al. 1985) because they contain high concentrations of some elements, which can pose environmental and refining problems (e.g. Vanadium, Chromium, Lead and Arsenic, Nickel, Copper and Zinc).

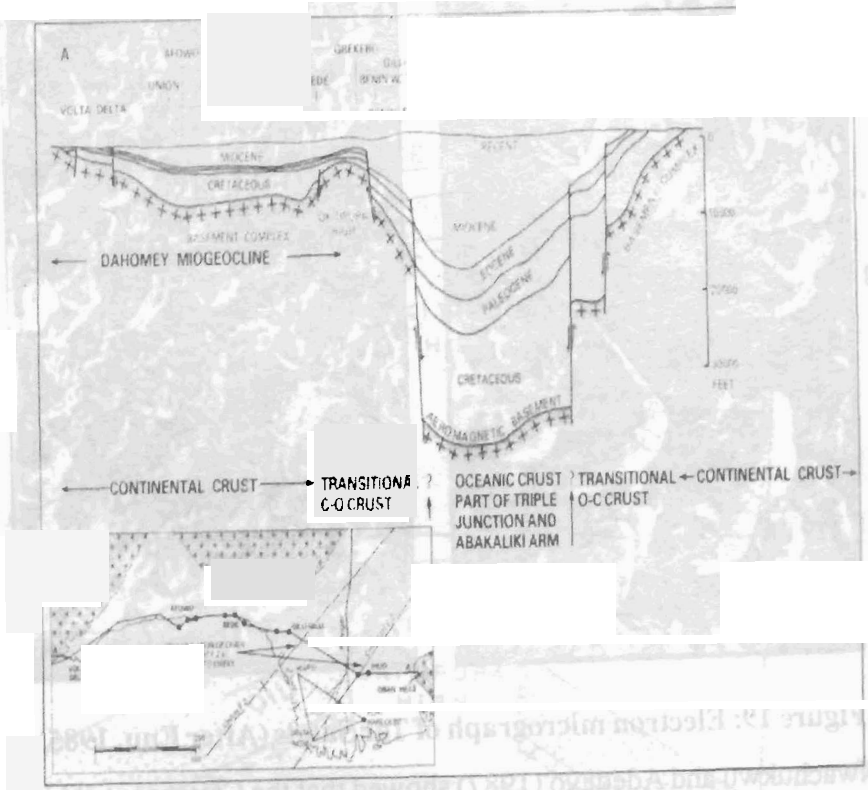


Figure 18: Section showing east-west geological section from Volta delta, Dahomey miogeocline, Niger delta and Oban hills and inset map showing the position of Niger delta triple junction (Whiteman, 1982).

Elemental analysis of the limestone deposits (Obiajunwa and Nwachukwu, 2000a) and the biostratigraphy of the basin (Nwachukwu et al., 1992) were also studied. More recently I have discussed the prospects and problems of exploitation of the bitumen deposits (Nwachukwu, 2003, 2007).

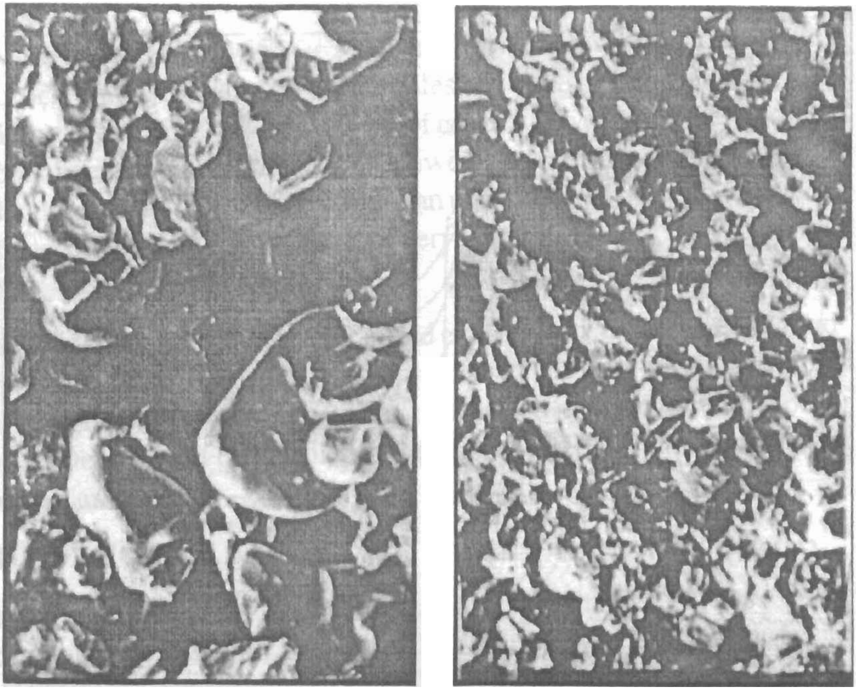


Figure 19: Electron micrograph of Tar Sands (After Enu, 1985).

Nwachukwu and Adedayo (1987) showed that the Cretaceous shales associated with the tar sand deposits contained adequate amounts of organic matter, which are largely sapropelic and immature. As such, they cannot be the source of the vast bitumen deposits of the basin as earlier thought (Adegoke et al., 1980b; Coker, 1982).

We subsequently carried out more detailed geochemical investigation of the tar sands (Ekweozor and Nwachukwu, 1989) involving both bitumen analysis (Sohxlet extraction, gas chromatography/mass spectrometry) and source rock analysis (Total organic carbon, Rock-Eval pyrolysis and Vitrinite Reflection measurements).

This study showed that the bitumen deposits were conventional oil sourced by down-dripping Lower Cretaceous shales offshore Benin Basin, which migrated updip and subsequently encountered meteoric waters leading to its microbial degradation and water washing to its present state (Fig.20). This view is widely accepted.

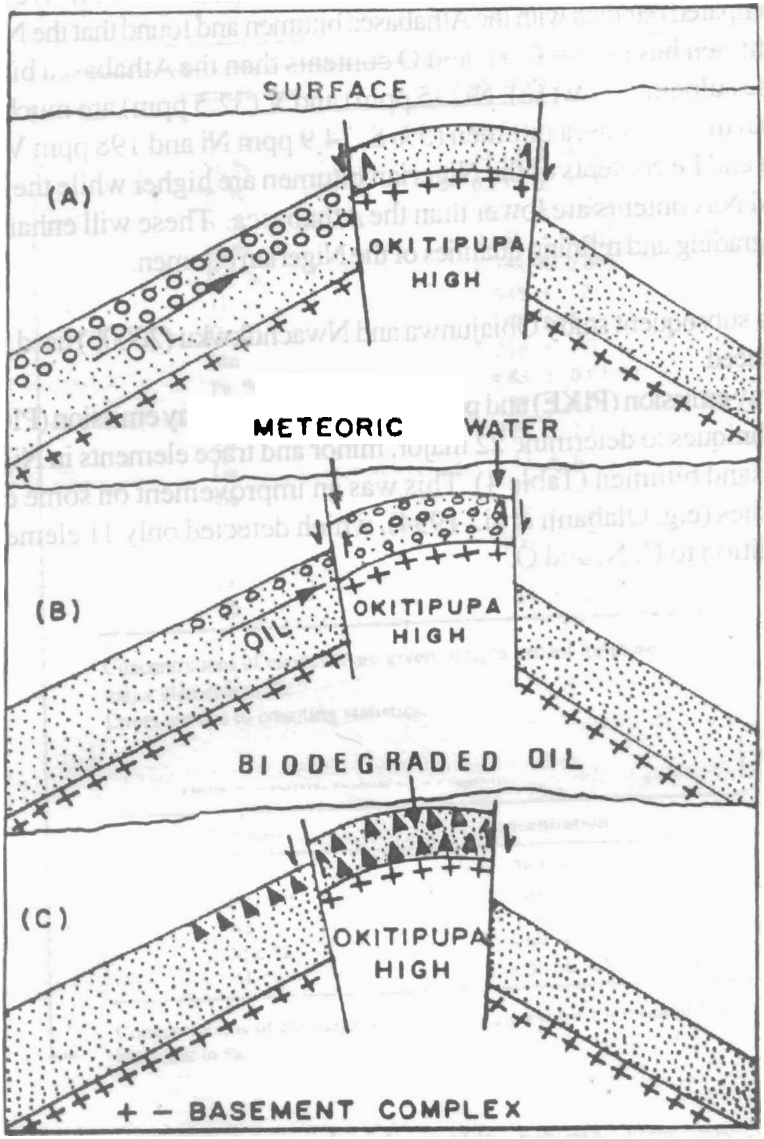


Figure 20: Schematic diagram showing formation of Nigerian Tar sands. (Ekweozor and Nwachukwu, 1989)

Our collaborative efforts pioneered by Profs. O. S. Adegoke and A. F. Oluwole led to the determination of the chemical and trace elements content of the Nigerian Tar sands bitumen (Oluwole et al: 1985). We further compared our data with the Athabasca bitumen and found that the Nigerian bitumen has higher C. H. and O contents than the Athabasca bitumen. The sulphur (1.1 wt %), Ni (35 ppm) and V (32.5 ppm) are much lower than the Athabasca bitumen (5% S, 74.9 ppm Ni and 198 ppm V). The Ca and Fe contents of the Nigerian bitumen are higher while the K, Mg and Na contents are lower than the Athabasca. These will enhance the upgrading and refining qualities of the Nigerian bitumen.

In a subsequent study Obiajunwa and Nwachukwku (2000b) used proton induced
 x-ray emission (PIXE) and proton induced gamma-ray emission (PIGME) techniques to determine 22 major, minor and trace elements in Nigerian tar sand bitumen (Table 4). This was an improvement on some earlier studies (e.g. Olabanji et al., 1994), which detected only 11 elements in addition to C, N, and O.

Table 4: PIXE and PIGME Results of a Nigerian Tar sands sample (Obiajunwa and Nwachukwu, 2000b)

Elements	Concentration
Al, %	10.68 ± 0.03
Si, %	14.13 ± 0.02
P, %	0.233 ± 0.01
S, %	6.12 ± 0.001
K, %	0.656 ± 0.002
Ca, %	0.368 ± 0.002
Ti	545 ± 17
Cr	97 ± 6
Mn	216 ± 7.0
Fe, %	4.83 ± 0.01
Cu	72 ± 8.0
Zn	119 ± 10
Ga	23 ± 6
Ge	17 ± 7
Rb	118 ± 15
Sr	200 ± 17
Zr	70 ± 25
Pb	69 ± 21

Concentrations of elements are given in µg/g except for those of major elements in %.
Errors are due to counting statistics.

[illegible]

Element	Concentration
Li	762 ± 15
F	388 ± 22
Na	174 ± 63
Mg, %	6.09 ± 0.01
Al, %	9.46 ± 0.01

Concentrations of elements are given in µg/g except for those of major elements in %.

The need for detailed elemental analysis of the bitumen arises because of Government intension to use the bitumen as feedstock for the Kaduna Refinery for the manufacture of lube oil and also in the petrochemical industry. Some of these trace elements (Cu, As, Ni) cause corrosion of turbines and refining columns and can also poison refinery catalysts (Oluwole et al., 1993). In addition, some heavy metals (e.g. Pb), which could be present, can pose environmental pollution problems.

I have also discussed in detail the prospects and problems of bitumen exploitation (Nwachukwu, 2003, 2007). The prospects are benefits accruing from large bitumen and tar sands, which are economically mineable or producible and include:

- Synthetic crude (refinery feed stock)
- Asphalt (used in road construction, building construction as sealant).
- Sulphur used in chemical industry
- Pitch (coke) used in the electronics industry
- Vanadium for making steel alloys, springs and high- speed tools and
- Nickel for manufacture of stainless steel (8% Ni); alloy for coinage and as industrial catalyst.

The problems include:

- The mode of occurrence (patchy and discontinuous)
- Uncertainty in reserves estimates, as deeper horizons have not been tested.
- High fluid viscosity at reservoir conditions
- Low reservoir pressure at shallow depths, hence less drive energy and need for pumping among others.

Since development of tar sands and bitumen is different from that of conventional oil, more studies are needed to determine reserves and reservoir parameters accurately. Large reserves and high production rates are the key to economic development.

- Because of the patchy nature of occurrence, extensive subdivision into blocks might be unattractive to Investors.
- Appropriate legislation must be put in place to address environmental issues and security of investment.
- The political environment must be stable to ensure sustained production as

  shut-in's and related problems are negative factors.
- Since bitumen and tar sands development is capital intensive, success also

  requires experienced and capable investors, and
- Tax regimes should be attractive as incentive to investors.

Both surface mining and in situ exploitation techniques could be adopted for the Nigerian deposits. The steam assisted gravity drainage (SAGD) process could be the most appropriate resulting in high ultimate recovery of original oil in place. Because of the high viscosity of the bitumen, upgrading techniques (carbon rejection or hydrogen addition) should be adopted before transportation to refineries and other consumer sites. Also the Orimulsion technique could be used for optimum production and transportation by pipelines and tankers.

Since the development of Nigeria's bitumen deposits is in its infancy, the need for Baseline and/or Environmental Impact Assessment studies is imperative. Government should come up with detailed policies and guidelines on environment issues in order to avoid the sad experience of the Niger delta.

As mentioned earlier, the limestone deposits of the Dahomey basin (Ewekoro Formation) were also analyzed for their major and trace elements contents (Obiajunwa and Nwachukwu, 2000a) using the PIXE and PIGME techniques. The Ewekoro Limestone deposit in Ogun State, Nigeria serves as a source of the major raw material for a large cement company in Southwest Nigeria. Intense industrial activity goes on at the site and large volumes of dust are generated and released into the atmospheric environment. Some recent studies (Adejumo et al., 1994; Akeredolu et al., 1994) have shown that some highly toxic metals were highly enriched in the premises and neighborhood of three cement factories. But the elemental compositions of the limestones are not known. Our study detected 22 major, minor and trace elements in the Ewekoro limestone. Some of these elements contribute to air pollution in the immediate vicinity and environs of the cement factory. The health risks associated with this should be of interests to Government and the Environmental Protection Agency (EPA).

We also used microfauna and microflora in dating subsurface strata penetrated by the Bodashe – 1 and Ileppaw – 1 wells as upper Maastrichtian to Paleocene (Nwachukwu et al., 1992). This paper is a significant contribution to knowledge of the upper Cretaceous and Tertiary biostratigraphy of the Dahomey basin.

OTHER STUDIES:

I have also contributed in the field of Sedimentology. It is well known that the Lagos lagoon system (Fig.21) is the largest of the four lagoons of the Gulf of Guinea (Adegoke et al; 1980a) but had received little attention by researchers. Our effort to sample the bottom sediments of the lagoon from an engine boat was near tragic. Our boat ran into a sand bank at low tide and we were stuck at the middle of the lagoon. With no navigational aid or communication equipment we resorted to fate. The intervention of forces of nature (high tide) increased the volume of water in the lagoon and our boat was freed from the sand bank and we eventually retuned safely to the Lagos University beach at night. Geology can be exiting and risky at the same time. However, our efforts were not in vain since we published the first detailed account of the sedimentology and microfauna of the Lagos lagoon and also showed rapidly changing facies within the lagoon and harbour complex. This study has relevance from the hydrodynamics and engineering points of view.

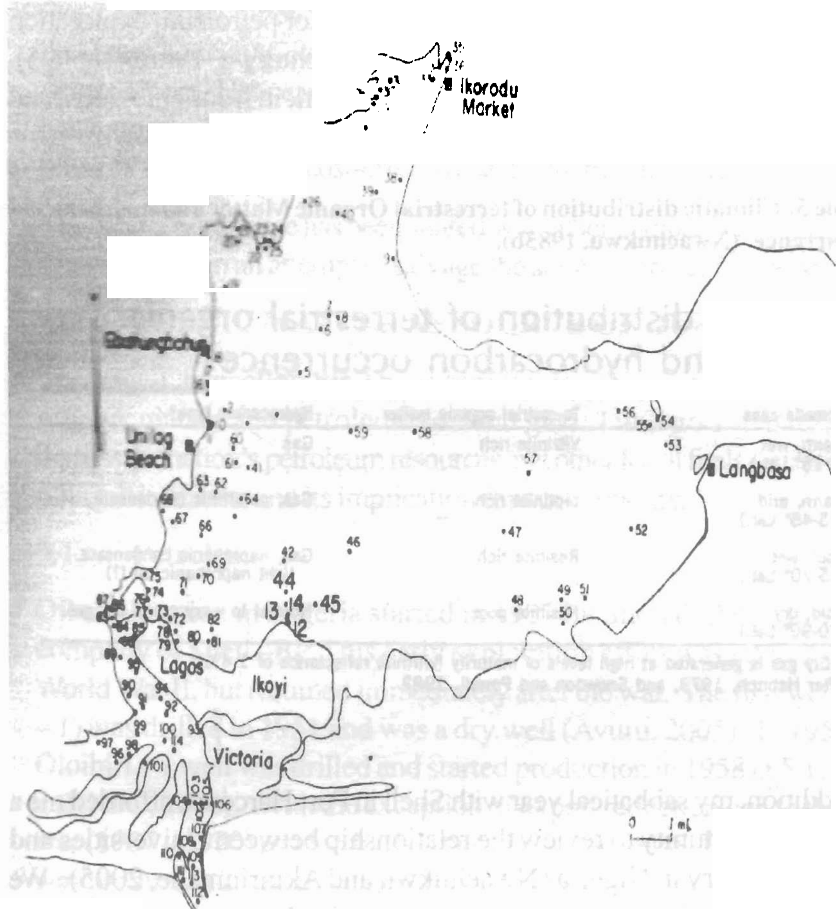


Figure 21: Lagos Lagoon and Harbour showing sample locations (Adegoke et al., 1980a).

Also, we have seen that terrestrial organic matter generates gas and waxy crude oil. These petroleum hydrocarbons form part of the world's petroleum reserves in basins of several continents. It is also common knowledge that climate exerts an important influence on terrestrial organisms and also affects the production, preservation, and distribution of terrestrial organic matter. Since terrestrial organic matter is capable of generating hydrocarbons, a better understating of its distribution as a function of climate (or paleoclimate) could be useful in exploration. On this premise, I was able to propose for the first time a model for petroleum exploration based on source rock paleolatitude date (Nwachukwu, 1985b;Table.5). This study forms a basis for reconnaissance work in frontier regions, and was well received internationally.

Table 5: Climatic distribution of terrestrial Organic Matter and hydrocarbon occurrence (Nwachukwu, 1985b).

Climatic distribution of terrestrial organic matter and hydrocarbon occurrence

Climatic zone	Terrestrial organic matter	Hydrocarbon type*
Warm, wet (0-15° Lat.)	Vitrinite rich	Gas
Warm, arid (15-45° Lat.)	Liptinite rich	Gas, paraffinic condensate, oil
Cool, wet (45-70° Lat.)	Resinite rich	Gas, naphthenic condensate, light naphthenic oil (?)
Cold, dry (70-90° Lat.)	Resinite poor	Normal to waxy crude oil, gas

* Dry gas is generated at high levels of maturity (vitrinite reflectance of 1.4%).
After Habitch, 1979, and Snowdon and Powell, 1982

In addition, my sabbatical year with Shell in Port Harcourt, afforded me a unique opportunity to review the relationship between Universities and the oil Industry in Nigeria (Nwachukwu and Akinrinmade, 2005). We observed that Universities occupy a strategic place in the survival and development of any nation. The level of social and technological advancement of a nation reflects the level of education of her citizens. As such it is only prudent for good corporate citizens to support Universities in manpower development. The current under funding of academic progammes has resulted in brain drain and its attendant consequences and as such the time is ripe for sustained corporate intervention.

We further observed that Shell Petroleum Development Company (SPDC) has played a leading role in this regard over the years, through several schemes (Endowment of Professorial Chairs, Sabbatical attachments, Students Industrial Work Experience Scheme and Student Internship and Research Attachment among others) with the understanding that the company's survival also depends to a large extent on quality manpower development. Hence maintaining mutually beneficial relationships with institutions of higher learning in Nigeria is a key necessity, since the mutual rewards are immense, cost-effective and with minimum risk.

The SPDC experience has been shared with other companies and corporate organizations in an attempt to salvage the situation in our Universities.

3.0 ORGANIC MATTER AS SOURCE OF OUR WEALTH:

The Vice-Chancellor, Sir, I have highlighted the relationship between organic matter, and petroleum (oil and gas). I will go a step further to discuss the nation's petroleum resources and other fossil fuels – all products of organic matter; and its implication for our economy.

3.1. Petroleum

Oil exploration in Nigeria started in 1937 by Shell d 'Arcy the parent company of Shell –BP. This early exploration effort was interrupted by World War II, but resumed immediately after the war. The first well (Imo – 1) was drilled in 1951 and was a dry well (Avuru, 2005). In 1956, the Oloibiri – 1 well was drilled and started production in 1958 at 5,100 bbl/d (NNPC, 2000). With the exception of export reduction due to the civil war (1967 – 1970) production has been on the increase. By 1972 Nigeria was producing 2.0 million barrels per day, from several oil wells and by 1979, production peaked at 2.4 million barrels per day. To date, Nigeria has a proved reserves of 35 billion barrels made of 30 billion barrels (oil) and 5 billion barrels (condensate) with average daily production of 2.4 million barrels per day and installed production capacity of 3 million barrels per day (Daukoru, 2005). In April 2007 Nigeria's oil production dropped to 2.2 million barrels per day (OPEC Bulletin, 2007) mainly because of the problems in the Niger delta.

At the current price of about $70.00 per barrel, daily revenue from oil would be $154 million per day or $56.21 billion/ year. Since Nigeria is in joint venture agreement with the oil companies with about 60% take this will amount to $33.73 billion /yr, excluding revenue from gas, solid minerals and others. This is one of the reasons why Nigeria is regarded as a rich country. Others include her abundant human resources.

Nigeria's proved gas reserve is 187 Tcf made up of Associated Gas (98 Tcf) and Non-associated Gas (89 Tcf) with daily production of 4 Bcf/d making Nigeria the 7th largest gas- producing nation. Because of this vast gas reserves in the Niger delta, it is often described as a gas province rather than oil.

For more than 40 years associated gas released during oil production is flared, more for safety than any other reason. This flaring apart from being a waste of resources also constitutes environmental hazards. From 1958 to 2005 over 5.7 Tcf of associated gas has been produced of which 5.0 Tcf or 88% of the total has been flared (Avuru, 2005). The Federal Government realizing the economic waste and environmental pollution associated with flaring insisted on flares down year of 2008.

In addition the Nigeria Liquefied Natural Gas (NLNG) limited which is a joint venture with other companies (Shell gas B.V, Cleag (Elf) and Agip International) was mandated to harness Nigeria's vast natural gas reserves for export to overseas markets. Thus the gas sector is evolving rapidly form flares to value (Daukoru, 2005). According to Kupolokun (2007), "Between 2003 and 2007, NNPC has worked with its partners to expand from three trains to five trains already, and a sixth train by 2008. The NLNG is now able to supply 22 MTPA to global markets". Continuing he said that the OKLNG and Brass LNG projects would approach the final investment decision by the first quarter of 2008 and on completion would help to ensure the delivery of 32 MTPA by 2011.

Nigeria produces 4 bcf/d of natural gas. At a wellhead price of $5.9/Mcf (U.S. Energy Information Administration, office of oil and Gas) this translates to $23.6 million/d. Assuming a 60% take in the joint venture, this amounts to $14.16 million/d or $5.17 billion/yr revenue on gas alone. Together with oil revenue, this amounts to $38.9 billion /yr which is substantial. The question may then be asked. Is this enormous economic resource utilized for the welfare of the people of our country? Your guess is as good as mine. Perhaps the states of the Nation's roads, health care, education, energy, housing and other infrastructures tell the story.

3.2 Bitumen:

Bitumen is another product of organic matter. Nigeria's bitumen deposits are estimated at 30-40 billion barrels of oil in place. In 1992, for example, Nigeria spent about £216 million to import heavy crude oil from Venezuela at the rate of 50,000 barrels/day. The heavy crude is needed in the Kaduna Refinery where it is used as base oil for blending with products such as grease and lubricants. Developing our bitumen resources will reduce this dependence on imported heavy crude, and further enrich Nigeria's treasury.

3.3 Coal:

Coal is another product of organic matter diagenesis. The difference between petroleum formation and coal is that coal is found where it is formed whereas petroleum migrates. Most coals are remnants of terrestrial higher plants and contain a variety of plant tissues in different states of preservation (Tissot and Welte, 1984). The distinction is usually made of humic coals and sapropelic coals. Humic coals usually pass through the peat stage and are stratified while sapropelic coals do not pass through the peat stage, are not stratified and have a dull appearance.

The process of coal formation is referred to as coalification. Typically, the organic matter passes through the peat stage; through brown coal, lignite, bituminous coal to anthracite. These varying ranks of coal are formed with increasing temperature and depth of burial. Coal accumulating conditions developed in Nigeria towards the close of the Cretaceous period, becoming most important in the Mamu Formation (Upper Mastrichtrain) in the Anambra basin and Lower Benue trough. There are 5 persistent coal seams in the Mamu Formation. Coal played a significant role in Nigeria's economic development in the Sixties. Coal production for domestic use has been concentrated in Enugu. Other coal deposits are in Inyi, Ezimo, Orukpa, Ogboyoga and Lafia. The Nigerian coal is sub-bituminous in rank and Nigeria has coal reserves of 2.75 billion metric tons (NNPC, 2000). The dependence of the Nigeria economy on oil has reduced the local market for coal. The current efforts by Government to privatize the coalmines are aimed at resuscitating the coal industry. Coal is in high demand in most parts of the world as a source of energy, for example in China and Russia. Coal burning in electricity plants is not environmentally friendly because of release of large volumes of CO_2 leading to global warming. This notwithstanding, the coal industry in Nigeria is a potential future revenue earner for the country if the privatization efforts are transparent and successful.

3.4 OIL SHALES:

The occurrence of oil shales has been reported in Lokpanta, Imo State, by Ekweozor and Unomah (1990) and corresponds to the Turonian Eze-Aku Shale. These "shales" are organic-rich laminites, which formed in euxinic environments. They are rich in inorganic carbonates with minor amount of silicates often of volcanic derivation (Eugster, 1985). The 25m thick Lokpanta oil shale contains essentially type I – II kerogen. The total organic carbon is 4.6 – 7.4 wt % and the minimum shale oil content determined by Fisher Assay retorting (Pyrolysis) was 42 litres / tonne, which is the minimum acceptable threshold for economic exploitation. This could be an alternative source of energy as it is being exploited in some parts of the world (e.g. Australia, Brazil, China, Israel and Russia) (McFarland, 2000). Though not fully explored in Nigeria, it is worthy of note that this is an alternative source of energy, which is purely organic in nature.

4.0 CONCLUDING REMARKS:

It can now be seen that Nigeria is blessed with enormous resources that have their origin in organic matter. If the revenues derivable from these resources are utilized by Governments for the welfare of our people, there will be no need for our youths getting involved in antisocial behaviors; the problem of brain drain will be minimized; social and physical infrastructures will be improved upon and maintained; our schools and hospitals will be well equipped: industries will once more be revitalized and unemployment reduced and Nigeria will surely be on her path to greatness as a nation. In addition, as long as Governments treat investment in human development with levity so long will we continue to wallow in ignorance and poverty, irrespective of our wealth from natural resources.

The Vice-Chancellor, Sir, I joined the services of this great institution in 1976 as a Graduate Assistant after relinquishing my job in the oil Industry as a Geologist, because of my belief in a quiet and peaceful life, and the desire to impart knowledge to others. I worked closely with Prof. O. S. Adegoke who taught me the importance of self-reliance and supervised my M.Sc. thesis, which was in the field of micropaleontology. Of course people thought I would continue along this line but I opted for Petroleum Geology – a field that was hard to come by in Nigeria at that time.

I completed my Ph. D at the University of Tulsa, Oklahoma, U.S.A. in 1981 under Prof. Colin Barker – a world renowned Petroleum Geochemist. My Orinoco, delta studies were supported by research grants to Prof Colin Barker, by INTEVEP – Venezuelan Oil Company, the equivalent of NNPC in Nigeria.

On my return to Nigeria, I continued my career as a Lecturer in Geology and rose through the ranks to the professorial cadre in 1997. As a professor, I have contributed in the three key areas of an academic viz: Teaching, Research and Service. For over 25 years, I have taught Sedimentary and Petroleum Geology and other related courses at both Undergraduate and Postgraduate levels.

In this lecture I have discussed my research, which is focused on Organic or Petroleum Geochemistry with other contributions in Sedimentology and Micropaleontology. I have supervised many undergraduate theses, 11 M.Sc. theses (4 of which are co-supervised) and currently supervising 2 Ph. D students. Four of my students (1 M. Sc. and 3 B.Sc.) have won the prestigious Nigerian Mining and Geosciences Society awards for the best theses in Nigerian Universities. Most of them today are high-ranking oil Industry personnel.

My service to the University community includes membership of various Departmental and Faculty committees and currently the Head of Department of Geology. Nationally and professionally, I have served as member of the National Universities Commission (NUC) accreditation Panel to many Universities; as Chairman, Caretaker Committee of Aboh Mbaise Local Government; Editor of the Nigerian Association of Petroleum Explorationists (NAPE) Bulletin; current Chairman, Scientific Committee of the World Petroleum Congress, Nigeria Chapter and Fellow of NAPE.

The Vice Chancellor Sir, permit me to express my gratitude to my supervisors (Profs. O.S. Adegoke and Colin Barker); Dr. B.J. Katz and Chevron Nigeria Ltd. whose financial support saw me to the AAPG Hedberg Research Conference in Rio de Janeiro, Brazil and other Oil Companies (Texaco, Shell, Addax) for their sponsorship to various overseas World Petroleum Congresses.

These modest achievements would not have been possible without the grace of the Almighty God and the support of my immediate family – my wife, Christy and children: Chimaobi Chinedu, Nnamdi and Okechukwu.

Thank you all for listening.

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