THE SOLID MINERAL RESOURCES OF NIGERIA: MAXIMIZING UTILIZATION FOR INDUSTRIAL AND TECHNOLOGICAL GROWTH

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INTRODUCTION

> *"What is this Geology of which we are so proud and confident?*
> *What has it done for the mental or material benefit of the human race?*
> *And on what grounds does it justify its claims to respect in the advance of humanity?"*
>
> *Charles Lapworth*
> *President of the Geological Society of London*
> *(1900 AD).*

The choice of a topic for tonight's lecture has not been easy at all. Should I pontificate on the deplorable state of geoscience departments in our Universities, the dearth of unemployed geology graduates in our system or a plate-tectonic explanation of why most of Nigeria oil is found in the south-eastern and only a token quantity in the south-western Niger Delta, or why most of our solid mineral resources are located in the Northern parts of the country. As a Professor of Geology at ATBU, the above topics fall within the realm of my profession. However, it is as an economic and environmental geologist that I have attained this position. Hence, my choice of subject must necessarily reflect this position. I decided to tell you about the solid mineral resources and resource potentials of Nigeria and how these are being deplored, exploited and applied in modern technology and industry. We shall touch on the promise these mineral raw materials hold in the new millennium for exciting new applications in material science, chemical technology and industry for economic and technological advancement of our nation.

People of the world have long been conscious of the importance of minerals to sustenance of life and solution of problems. After initially using naturally shaped stones, man later perfected the art of pounding and flaking them for improved performance in various applications. Sun-baked clay products were followed by those baked in fire. Lime from limestone, plater from gypsum, mortar from both and natural mineral colours were all used in construction long ago. Asphalt was used as a cementing and water proofing material.

Trading of minerals has been important from the earliest times. We know that salt and amber followed definite trade routes in Europe, Middle East and Africa. The tin of Cornwall in England was reported to be very important to the Phoenician bronze-makers of the eastern Mediterranean. Ancient Chinese bronzes display sophisticated alloying and casting techniques. Gold found in the countries around Zambezi river led the early Egyptians to circum-navigate the African continent, and Aztec and Inca gold and silver were the main source of wealth to the Spanish empire. The scramble for Africa and eventual colonization of the continent by European nations was motivated in part by the search for mineral wealth.

Before the advent of the Europeans to the geographical entity called Nigeria, the inhabitants of the area were utilizing the various minerals in the land to meet their specific needs. For example, the locals were using the ore galena (lead sulphide) for beautification of the faces, iron ore was being utilized for fashioning weapons for hunting and warfare, tin (cassiterite) for making diverse artifacts. It is therefore clear that natural occurrences that become mineral resources are generally man-perceived, man-made and definable mostly in human terms. Furthermore, it may be emphasizing the obvious to say that through history it is now established that civilization depends on agriculture and lithoculture. While the former is clearly obvious, the latter may not be so obvious. But since according to Kelly (1974), this term describes all the activities involved in the extraction of useful products from the rock formations of the earth, it means the exploration and exploitation of mineral resources. All over the world and throughout civilization, man has demonstrated insatiable quest for minerals and mineral products as a result of his sustained curiosity and ingenuity. It is therefore safe to say that man shall tomorrow be finding new ways to satisfy old needs and new ways to satisfy new needs that may arise. Such new ways which as at today are unrecognized will surely become evident with time. New and more complex challenges are to be expected in all aspects of human endeavour in new millennium. Any nation that adopts a posture of complacency shall be taken unawares. It therefore behoves us to prepare for the future on the basis of our needs and our resources as we perceive them today; be on the lookout for new perceptions, new opportunities and new alternatives.

We need minerals for three major human activities:

a) *Life support:* soil, water, salt and fertilizer

b) *Energy generation:* coal, oil, gas and nuclear minerals

c) *Industries:* construction of shelters, industrial plants and machines, research, production and development.

This address will concentrate on solid mineral resource potentials of our nation and assess its adequacy in satisfying (c) above in this next decade and beyond, taking into account our nation's increasing bold steps into industrialization and constant call for self sufficiency.

MINERAL RESOURCE AND RESOURCE POTENTIAL DEFINED:

Mineral Resources

A mineral deposit is physically exhaustible and therefore irreplaceable. The metal extracted from the mineral ore is itself non-renewable. It is therefore imperative to define what we call mineral resource since by so doing we would appreciate how much we need and how much we really have. Mineral resource is definable (US Geological Survey Circular 831, 1980) as "a concentration of naturally occurring solid, liquid or gaseous material in or on the Earth's crust in such form and amount that economic extraction of a commodity from the concentration is currently or potentially feasible". In other words, the mineral resource includes minerals existing in possibility and therefore capable of development into actuality as well as those only surmised to exist. Figure 1a is a schematic classification of resource (U.S.G.S. and US Bureau of Mines) based on the foregoing definition, popularly referred to as the McKelvey Box. The large box represents the resources and within this box, a smaller one represents the reserves. This is that part of the resource whose existence is demonstrated and recoverable at profit under the prevailing deposit knowledge and economic conditions. This figure brings out an important feature of a nation's mineral resources. It is a dynamic entity and we can see that a resource that is not a reserve today may be upgraded to that rank in time to come depending on variables. These controlling factors, often known as the "Five E's" (Bailly, 1982) are as follows:

Existence of a deposit
Extractability of the mineral values
Energy and material requirements for extraction
Environmental acceptability requirements and
Economics of a possible operation

- including availability of capital market demand,
- political and societal constraints.

The point to note is the inter-relationship among the components of mineral endowment, amplified in Figure 1b. In response to variations in the five E's listed above, deposits are continually moving from the "undiscovered" category to the "identified" category as our geological information on the deposit gets better and more complete. Also deposits or parts of deposits are continually moving in either direction between the "economically feasible" and the "subeconomic" categories in response to economic and technological factors. And so, if we now superimpose Figure 2 on Figure 1b, we see clearly that the value of any mineral commodity can be greatly altered by technology and research. With increased technological activity in the area of the commodity, there will be concomitant increase in the demand of the commodity conceived. The converse is also true and we can quickly illustrate this with the story of cassiterite in Nigeria. Cassiterite is the ore from which the metal tin is extracted. Cassiterite production and export from Nigeria reached its all time high during World War II. According to C. J. Evans of International Tin Research Council (ITRC), this was the time when tin usage was put on a sound scientific footing. With the major tin producing countries of the world overwhelmed by the war, the Institute was committed to maximizing effective use of the metal towards war effort. The activities in tin production was consequently at its maximum in those parts of the world free from hostilities. Nigeria turned out to be Britain's principal source of tin for her war effort. The world war over the tin success story has since been reversed, as is demonstrated by the drastic and systematic drop in tin production in Nigeria.

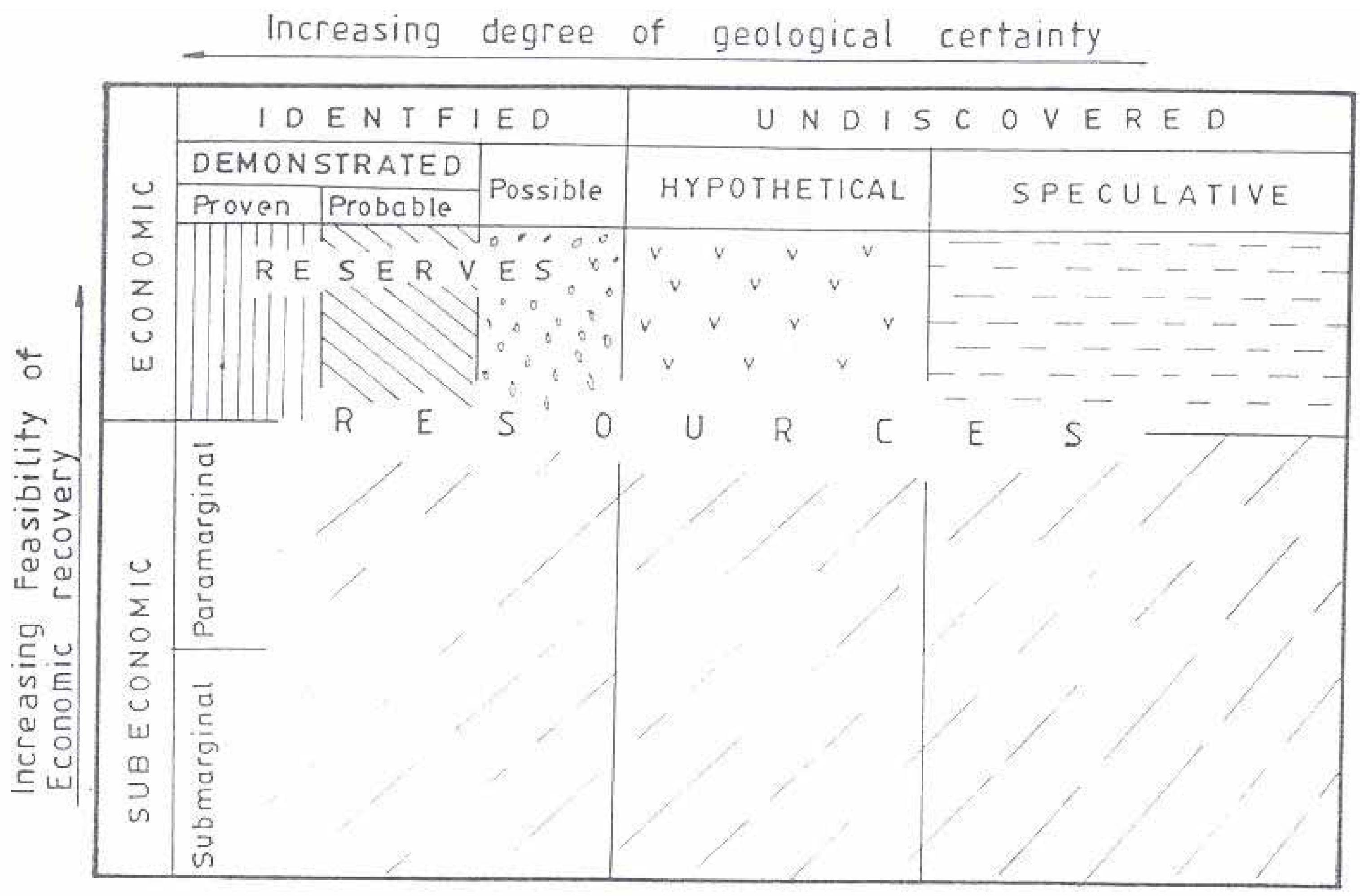


Fig. 1a Classification System For Mineral Resources
Degree of certainty decreases from left to right
Feasibility of recovery decreases from top to bottom.

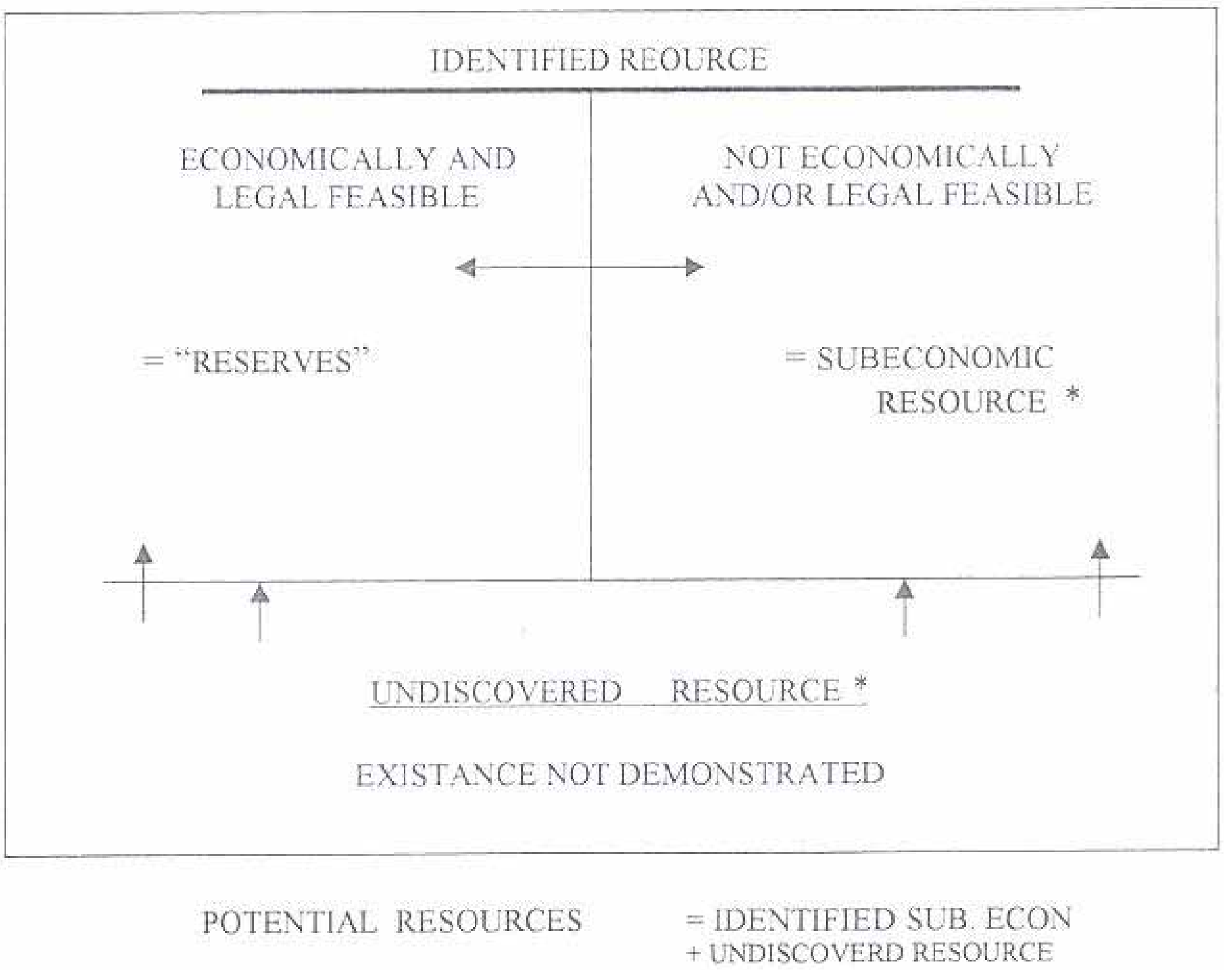


Fig. 1b: Mineral resources Classes

Adequate knowledge of the nation's mineral reserves is essential for planning. With respect to any specific mineral commodity considered to be a reserve, three sub-groupings are possible depending on our knowledge of the mineral deposit, the current mining status and the current market value of the metal sought. Hence, mineral reserve can be (a) Proved: in which all information on the ore grade or tenor, cut-off grade and depth of ore formation are known for the deposit.

(b) Probable in which one or two of the above facts in (a) are lacking.

(c) Possible in which the deposit is merely known to be present but no other details are available.

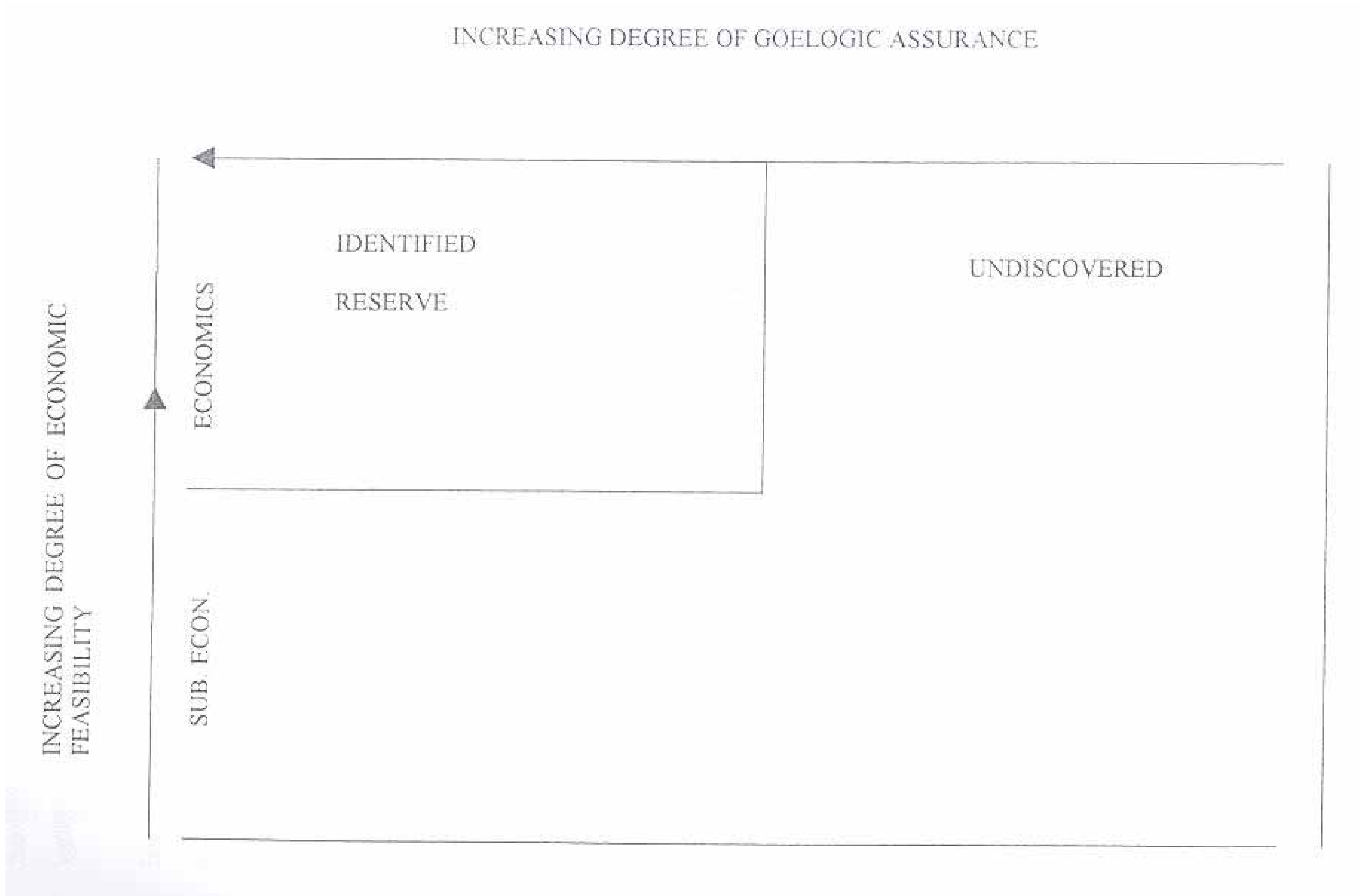


Fig. 2 Research and Technology Increase Reserves

Figure 1a implies that the resource concept exists with respect to an economic and technological references. As these references change, the magnitude of the resources and the reserves concomitantly change. Hence, while the on-going exploitation of mineral deposits results in depletion of the mineral resources, technological innovation in recovery and discovery, improved geologic understanding of the ore genesis and better commodity prices, all together may increase the mineral resource base. Figure 3 illustrates the economic dynamics of mineral resources of a nation. A change in economic reference from e_o to e^* ($e^* > e_o$) displaces downward the boundary separating resources from non-resources, thereby increasing the magnitude of resources. Thus a statement on mineral resources is also a statement of relevant economic and techno-geologic circumstances. The combination of technology, geology and economics in appraisal of resources calls for yet other resource terms.

Resource base: this is the totality of an element as it occurs in its many chemical and physical states within the earth's crust. For example, the resource base for the metal copper will include all occurrences as native copper; oxides and sulphides of copper in magmatic, sedimentary and metamorphic environments.

Mineral Endowment: if now we restrict our copper resource to only sulphides and oxides for which the grade is known (t*); the minimum cut off grade (q*) is known (q* > t*) and the depth of occurrence (h* meters) is also known. Then the total amount of copper in these occurrences is referred to as mineral endowment and could be produced economically at e*.

Potential supply: The total amount of copper in all these occurrences that could be discovered and produced economically at e* constitutes the potential supply.

Reserves of Copper: the amount of copper estimated to be present in all known occurrences producible at e_o is known as the reserves of copper. These terms are illustrated schematically in Figure 3.

Mineral Resource Potential

> *"Better methods for estimating the magnitude of potential mineral resources are needed to provide the knowledge that should guide the design of many key public policies".*
>
> *V. E. McKelvey*

The mineral resource potential of an area is a measure of the likelihood of occurrence of valuable mineral or minerals that may become valuable within the foreseeable future. This likelihood of occurrence is not a measure of the resources themselves and thus cannot be evaluated by reference to the two-dimensional McKelvey Box, Figure 1, which categorises undiscovered resources, the potential, as speculative or hypothetical. The likelihood of occurrence can only be judged by integrating many diverse factors. Some of these factors can be measured while some are cryptic and indefinably esoteric, depending in part on the specific experience and knowledge of the individual making the judgement. Consequently, for well-informed and accurate analysis of the resource potential of any locality, we necessarily have to rely on the judgement of a knowledgeable economic geologist who mentally integrates a wide range of geologic elements in ways that numerical methods cannot yet accomplish. His approach generally involves comparing available geologic, geochemical and geophysical data with those from known and developed ore deposits. The primary objective is to identify geologic environments favourable for the occurrence of mineral resources in the area under examination. Ore deposit models applied meticulously help to flush our incomplete descriptive frameworks and establish whether the basic conditions of ore formation are met. In any area, a large number of ore genetic models must be considered, some selected for closer examination if geologic factors are favourable, some to be rejected if the factors are unfavourable.

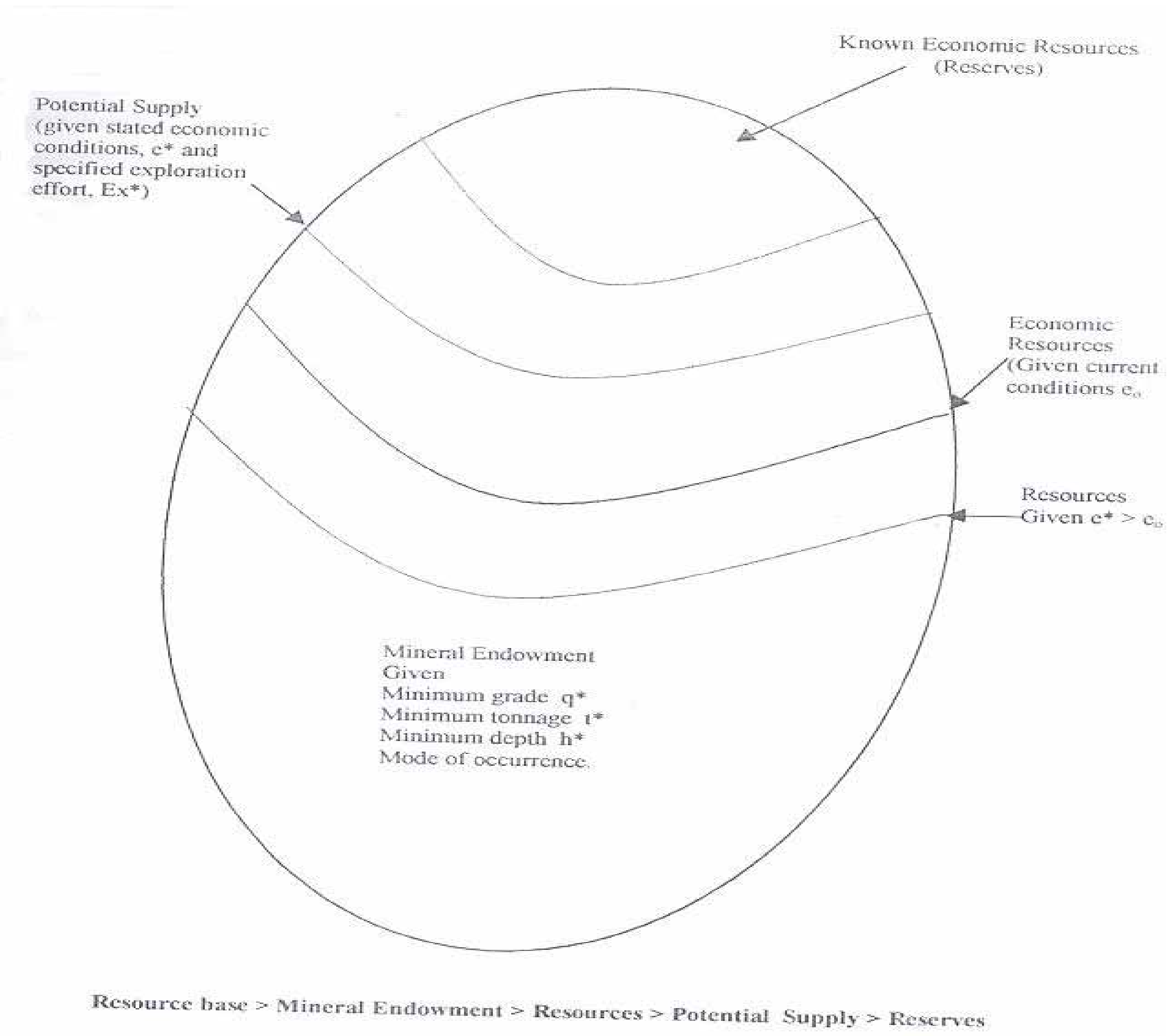


Fig. 3 Mineral Resources Terms (modified from Harris and Agterberg, 1981)

According to Taylor and Steven (1983) the mineral resource potential of any locality can be identified as high, moderate or low.

A high mineral resource potential is deemed to exist where geologic, geochemical and geophysical characteristics favourable for resource accumulation are known to be present, or where enough of these characteristics are present to give strong support to genetic models favourable for resource accumulation and where available evidence shows that mineralization has taken place. This category includes therefore all known mining districts and other areas where available data is enough indicator that mineralized rock exists. Hence, Jos Plateau, the host of the Younger Granites of Nigeria, is easily identified as an area of high mineral resource potential, with respect to Sn and related minerals, so also is the entire length of the Benue Trough with respect to base metal sulphide and salts.

Moderate mineral resource potential exists where geologic, geochemical and geophysical characteristics favourable for resource accumulation are known or can reasonably be interpreted to be present but where evidence for economic ore accumulation is vague or has not yet been found. From our experience with mineralisation in Benue Trough, we see that the area has only moderate potential for uranium mineralization. Where the moderate potential rating is borne out of sparse information, then this rating can be changed in time should superior information be available and/or commodity prices change favourably.

Low mineral resource potential is assigned to localities where geologic, geochemical and geophysical characteristics are unfavourable hence, where requirements for genetic models cannot be supported. This broad category embraces areas with obvious but dispersed and apparently uneconomic mineral resources. Again here we can site the Mona area, Borno state with respect to Uranium mineralisation and the middle Benue Trough with respect to coal mineralization.

Almost all areas of the earth's crust contain mineral commodities of at least some possible economic value were they adequately explored and should a market for that commodity develop. It is therefore illadvisable to class any area as having no mineral resource potential. An area may, however, be classed as having no potential for a particular mineral commodity. It is therefore required in describing an area as high or moderate resource potential to specify the commodity and mode of occurrence. An accurate assessment of geologic environments favourable for ore deposition is essential for reasoned classification of the area's resource potential status. This assessment depends on many factors, the most important among which are:

1. **Favourableness of the host rock:** Certain rocks have physical or chemical characteristics that favour concentration of certain economic minerals. For example, primary tin is characteristically associated with biotite-bearing granites and granite pegmatites of Jos Plateau and diamond is found exclusively in Kimberlites-ultramatic rocks of deep-seated origin).

2. **Presence of favourable structures:** Folds, faults and fractures provide conduits for movement of ore-bearing fluids and eventually deposit them under favourable conditions. For example, the lead-zinc mineralization in Abakaliki is restricted to small fractures in the shale (Orazulike, 1994). Uranium occurrence in Zona is structurally controlled (Suh, 1997) and in Kigom area of Jos Plateau, molybdenite is reported as disseminations in a system of veins and veinlets (Ashano, 2000). Results from the Ningi Burra complex (Orazulike, 2000) shows that primary tin mineralization is restricted to fractures induced by ring dyke system.

3. **Evidence of Mineralization:** One most important of such evidence is action of hydrothermal fluids. The alteration products are easily identifiable and they indicate proximity to ore deposits. In the search for primary tin in Jos Plateau, the identification of greasinisation (a type of hydrothermal alteration) has been an effective indicator for tin mineralization.

4. **Geochemical anomalies:** Concentration of ore-forming elements or tracer elements commonly form easily identifiable halos around ore deposits. Identification of these commonly lead to discovery of an ore body.

5. **Geophysical anomalies:** Variations of magnetic, gravity, radioactivity and electrical fields from established regional gradients help in identifying geologic environmental favourable for resource accumulation.

6. **Isotopic and stratigraphic age data:** These define the relation of mineralizing episodes to the enclosing rocks and structures. Consequently, extrapolation of the information to less well known areas will assist in properly designating the region in resource concept.

It must be further noted that the existence of geological, geochemical and geophysical parameters suitable for a particular type of ore mineralization does not always guarantee the presence of ore deposit. These factors constitute only strong indications while the actual proof for ore deposit comes from drilling or other subsurface methods, that reveal ore tonnage, grade and consequently ore value.

METALLOGENY AND PLATE TECTONICS IN NIGERIA

> *"Having now refuted the opinion of others, I must explain what it really is from which metals are produced".*
>
> *Agricola (1546)*
>
> *DeOrtu et Causis Subterraneorum.*

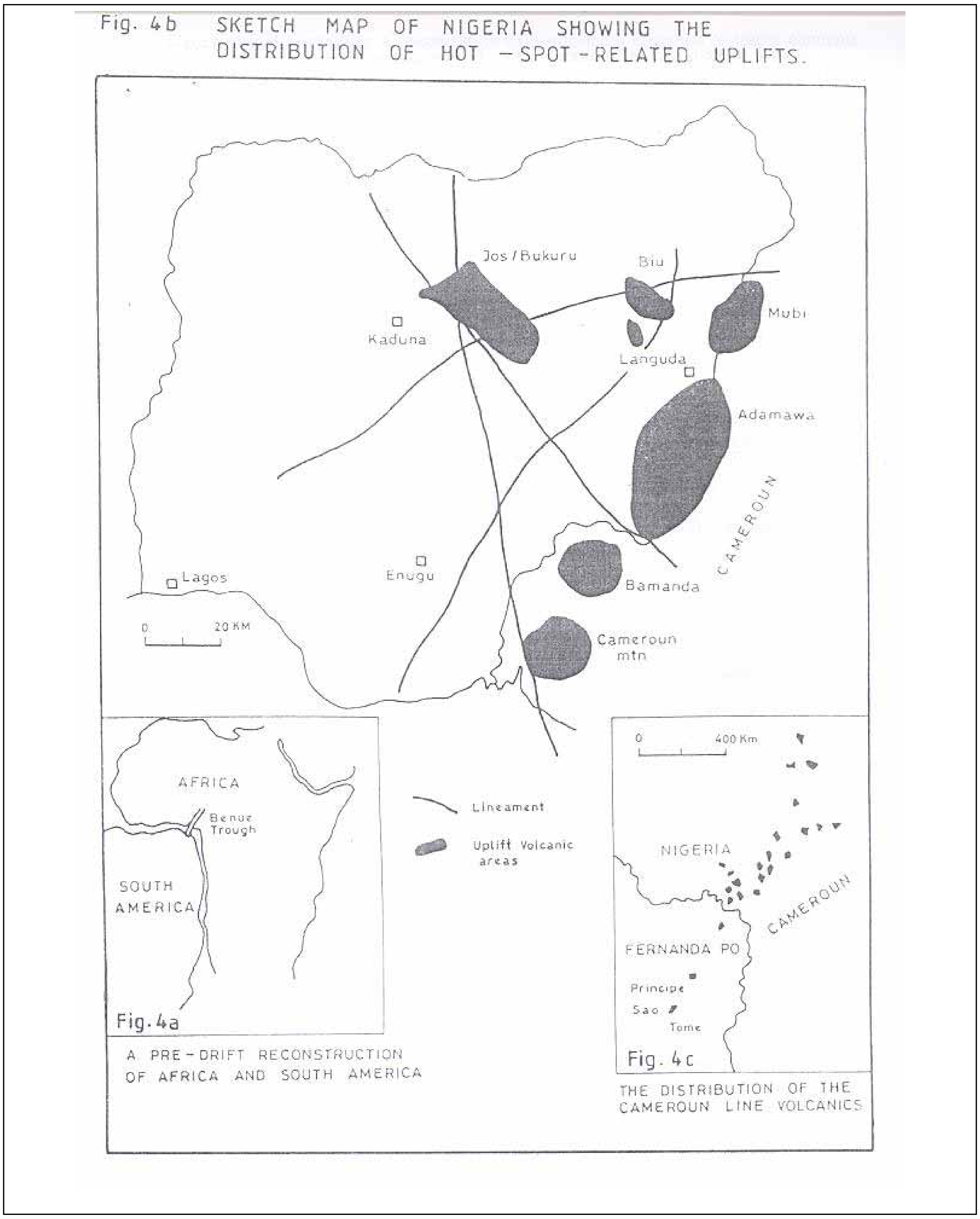
It is a well known fact that all the metals which constitute our present ore deposits can be traced ultimately to the magma. The evolution of the magma is via the process of partial melting of the mantle, the crust or pre-existing rocks and rock materials and this process, we now know, is the consequence of plate tectonics. Consequently, in relating the formation of mineral deposits (metallogenesis) to plate tectonic phenomenon, we are merely looking at an old process from the view point of a new concept.

Prior to the development of modern plate tectonic theories to explain crustal processes-evolution and deformation, the Hall-Dana theory of geosynclines and attendant geological features (magmatism and mountain chains) formed the basis of most geologists' thinking. Ore geologists then were quick to note that many ore deposits occur in geosynclinal regions. They further advanced the hypothesis relating distinct stages of magmatism in the geosyncline evolution to stages of metallogenesis.

Today, the modern plate tectonic theory (Isacks *et al*, 1968; Le Pichon, 1968 and a host of others), presented in the so called "conveyer belt model" of plate movement, demonstrates magma generation at all plate boundaries and each magma/boundary is characterized by particular type of mineral deposition.

Tectonic-Related Ore Deposits in Nigeria

Ore deposits in Nigeria are found in both igneous, metamorphic as well as sedimentary environments. Deposits in igneous rock bodies are exclusively magmatic and syngenetic if disseminated within the igneous rock body (e.g. Sn oxide in the Younger Granites), if found in fractures and veins in igneous rocks the ore is magmatic hydrothermal; epigenetic examples include the stock work deposits of tin and columbite and ores in pegmatites. Deposits in sedimentary rocks are either syngenetic synsedimentary, such as the iron oxide deposits at Udi Hills or they are primary epigenetic-hydrothermal as is the case with the lead-zinc ore bodies in Abakaliki. Also included in this group are the highly economic placer deposits of tin, columbite and associated ore minerals found in Jos Plateau. These are secondary deposits. Ores in metamorphic rocks are of metamorphic origin and include magnetite deposits at Itakpe. All the metals in the above broad types of ores in Nigeria, trace their origin to the igneous rock and igneous activity which, in turn is related to the Cretaceous Tectonism, involving the break up of Africa and South Africa. According to Burke and Dewey, 1973, Michel and Garson, 1972, the process of break up started with the formation of an RRR-triple junction at the join of South America to Africa (Figure 4). Two of these ridges (Rs) developed, thereby causing the South Atlantic and the Gulf of Guinea Arms to spread while the third arm which extends into Nigeria continent failed. The failed arm developed into an aulocogen about 560 km long, after a short-lived period of subduction (Burke and Dewey, 1973). Accompanying the foregoing process which involved spreading, was intra-plate magmatism - hot spot activity taking place in many centers within the African continent (Fig. 4a). Physiographic highs (plateaux) in Nigeria and neighbouring Cameroun are expressions of these hot spot activity. These highs are represented by the plateaux at Jos, Biu, Mubi, Adamawa as well as the mountains at Bamanda and the Cameroun mountains (Figure 4b). The hot spot activity with the characteristic magma types and accompanying ring dyke system are responsible for the deposition of many economic minerals in Nigeria, Niger and Egypt (Sillitoe, 1974).



Tin Deposits at Jos Plateau

Tin mineralisation in the plateau of Jos has been shown to be the result of intraplate magmatism due to hot-spot activity. How-spot-related magmatism provides favourable environment within which ore generating systems can operate. A variety of non-ferrous metal deposits which owe their genesis to hot-spot-related magmatism have been recognised. Tin with the associated minerals deposit in Nigeria is located in the stable Precambrian which were intruded by the Younger Granites in Plateau, Nasarawa and Bauchi States. These are plutons and stocks intimately associated with minor basalts and rhyolite volcanism. The granites appear to be found below their own volcanic ejecta. Most of the primary tin and columbite are found in the biotite granite phase and in pegmatites. Sillitoe (1974) showed that the tin was derived from the mantle as part of the magma that formed the Younger Granite rocks. Cassiterite (SnO_2) and columbite (Fe, Mn)Nb_2O_6, have geochemical affinity with the early volcanic phase of magmatism. Neumann *et al* (1989) suggested that nearly all the primary cassiterite and most of the columbites are associated with and concentrated within the now eroded roofs (volcanic ejecta) of the biotite granites. The source of economic tin today is the accumulation of cassiterite eroded from the roofs and transported to the present sites where they form placer deposits in both ancient and modern stream channels. The columbite-tantalite minerals are ubiquitous in these deposits and constitute important by-products, assaying 15% tantalum as Ta_2O_6 and 85% niobium as Nb_2O_6 (Orazulike and Tenebe, 1997). Other minerals of economic importance associated with tin ore include wolframite ((FeMn)(WO_4)) and beryte ($BaSO_4$) which occur in primary veins with cassiterite. Magnetite, ilmenite, zircon, thorite and monzite ore also found with tin but these are presently sub-economic but may become economic in future.

Lead and Zinc deposits in the Southern Benue Trough

As stated earlier, the Benue Trough is an aulacogen. The formation of an aulocogen is accompanied by deposition of sediments several meter thick. The tectonic history of the Benue Trough has been extensively treated (Ofoegbu, 1985; Ofoegbu and Onuoha, 1991;Burke and Dewey, 1973). The metallogenic consequence of this history is of greater interest in this thesis. Accompanying the thick sedimentary pile-up in the trough is Pb-Zn mineralization. Mineralisation is restricted to cretaceous rocks found in about 48,000 sq. km. of the trough (Figure 5). Workers in the Trough agree that mineralisation is epigenetic and fracture controlled (Orajaka, 1965; Ezepue, 1984; Olade and Morton, 1980; Akande *et al*, 1990; Orazulike, 1994). A definite source of the mineralizing fluid remains to be established. Magmatic hydrothermal have been proposed (Nwachukwu, 1972); while Olade and Morton (1980) prefer remobilized connate waters. Orazulike (1994) used sulphide textural analysis to conclude that at least two generations of hydrothermal fluid were involved in sulphide mineralisation. These deposits fit the classical Mississippi-Valley type Pb-Zn deposits. However, while many Mississippi-Valley type deposits world wide are characterized by extensive, high yield prospects, the Nigeria deposit 15.10 km long has proven reserve of 25 million metric tons; the deposit in Eastern Tennessee is 25 km long and has reserve of 50 million tons, in S. E. Missouri, the deposit is 10,000 km^2 with reserve of 100 million tons.

Economic Pb-Zn mineralisation is restricted to the Southern parts of the Trough. Associated with the Pb-Zn ore are chalcopyrite, siderite, azurite, malachite and marcasite. Upwards to the middle and upper regions of the trough are important deposits of salt, barite, Limestone, and fluorite as well as argentiferous galena and gypsum. All these deposits owe their genesis to aulacogen development which in turn is a tectonic feature.

All other forms of mineral deposits found in Nigeria are largely due to some form of secondary processes. The processes may be sedimentary or metamorphic. These include iron ore deposits, uranium, gold and many varieties of industrial minerals. A careful study of the genesis of each of these deposits will show that the ultimate source of the mineralizing ingredients (metal sulphur, oxygen etc) is from within the earth's interior. There, they are mobilized in the process of magmatism and ultimately exposed as part of primary igneous rocks, the parent of both metamorphic and sedimentary rocks. These, therefore, are remotely related to tectonism.

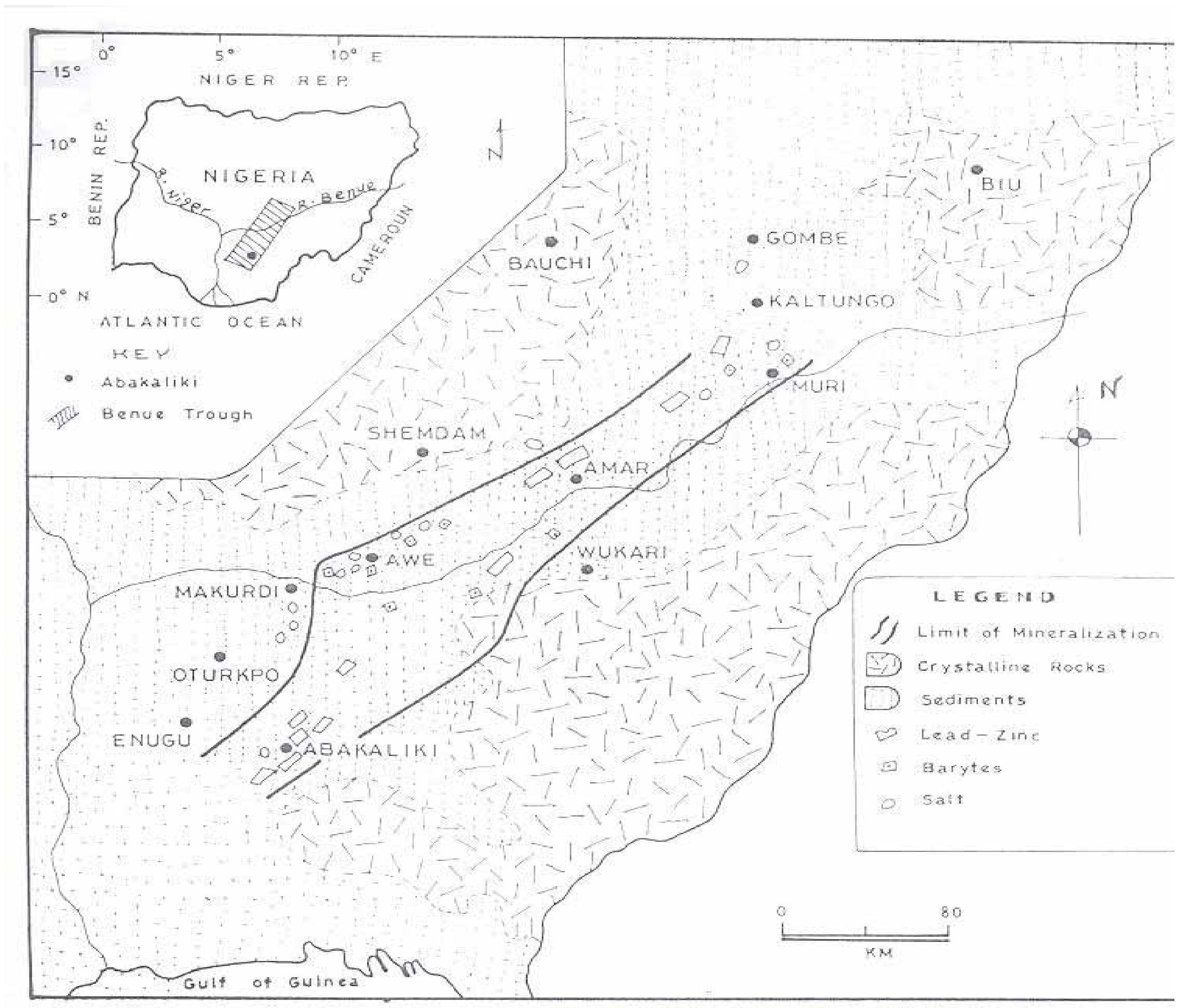


Fig. 5 MINERALIZATION IN THE BENUE TROUGH

NIGERIA’S SOLID MINERAL RESOURCE BASE

Introduction

The Nigeria nation is blessed with abundant mineral resources; fossil fuels and solid minerals. The most popular being the fossil fuels since these constitute the nation’s greatest foreign exchange earner. They have, therefore, tended to overshadow the solid mineral sector of mining industry. Many eminent Nigerian geoscientists in policy making positions have consistently reminded the government to pay adequate attention to the search and recovery of solid minerals abundant in the country. Lukman (1983) outlined the numerous opportunities in the Nigeria solid mineral resource field and called for accelerated and sustained exploration of these commodities. Successive leaders of the NMAS (Nigeria Mining and Geosciences Society) have emphasized and promoted efforts/awareness in the nation’s solid mineral wealth. It is reassuring to note that the government has progressively in recent past years shown great interest in the exploitation of Nigeria’s solid minerals as a means of diversifying our economic base. In the 1996 budget, the sum of 586.79 million naira was allocated to the solid minerals ministry to cater for the survey and quantification of mineral deposits in Nigeria. Of this, N211 million was allocated to the Nigeria Coal Corporation; 211.5 million to Nigeria Mining Corporation for the development of selected industrial minerals and some base metals. In 1999, the activities in this sector have heightened with many multinational companies showing increased interest in going into partnership with government in developing the solid minerals sector of the economy.

Figure 6 is a map showing the distribution of solid minerals in Nigeria. Solid minerals are many types occurring in many diverse environments in response to many diverse geology and geologic events. The resources can nonetheless be discussed under five (5) groups thus:

1. Iron and Iron-alloy metals
2. Non-ferrous Industrial metals
3. Precious metals
4. Metal fuel
5. Industrial minerals

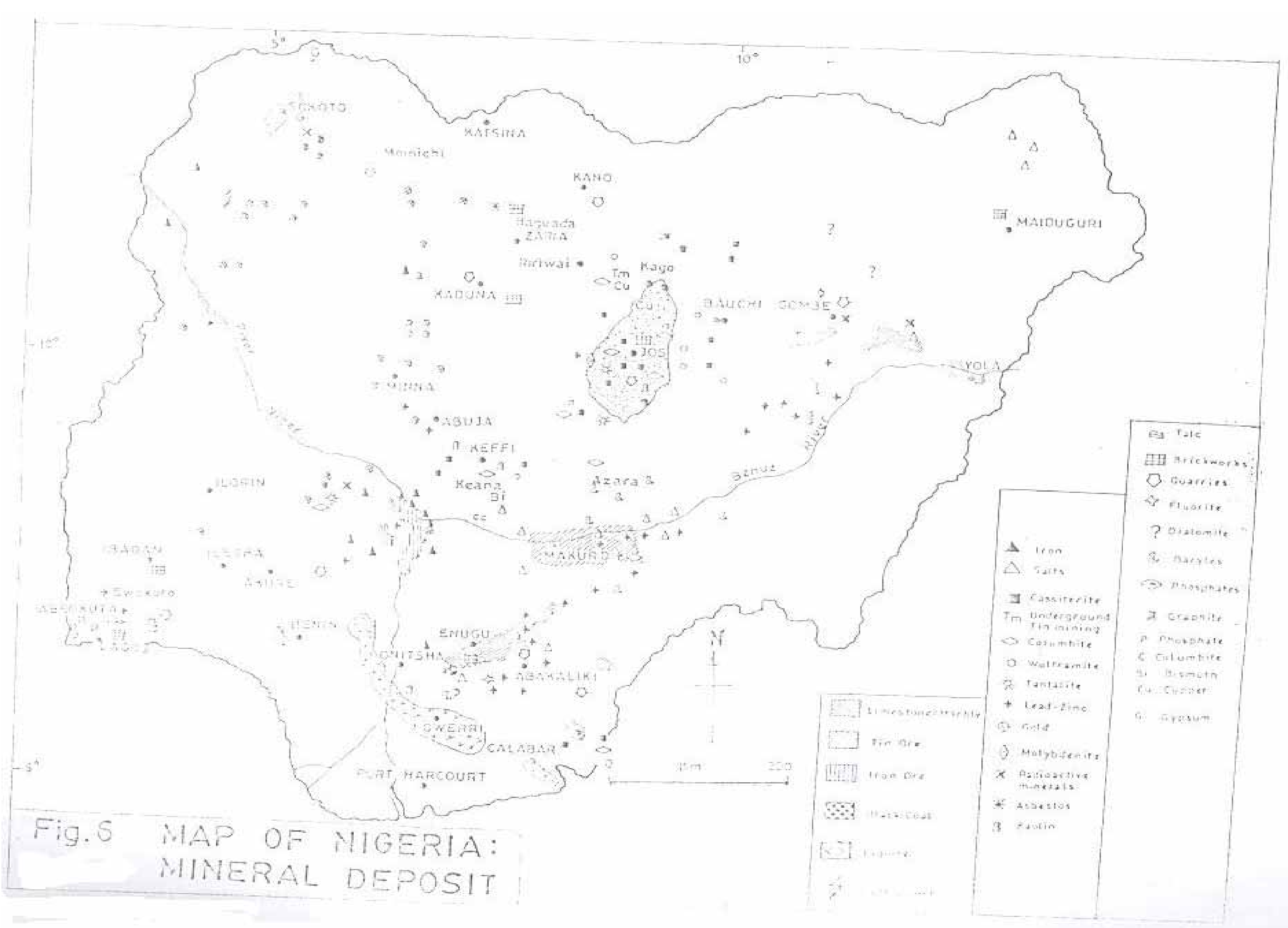


Fig.6 MAP OF NIGERIA: MINERAL DEPOSIT

Group 1: Iron and iron-alloy metals

Iron (Fe) occurring as oxides goethite (FeOOH)

Hematite (Fe_2O_3)

Magnetite (Fe_3O_4)

and also as sulphide Pyrite (FeS_2), Marcasite (FeS_2), Pyrrhotite ($Fe_{1-x}S$).

Manganese (Mn) as	manganite (MnOOH),
	Psilomelane ($BeMn^{2+}Mn_8{}^{4+}O(OH)_4$,
	Pyrolusite (MnO_2)
Chromium (Cr) as:	native metal
	Chromatite ($FeCr_2O_4$)
Nickel (Ni) as	Niccolite (NiAs)
	Buusenite (NiO)
	Pentlendite $(FeNi)_9S_8$
Molybenum (Mo) as	molybdenite (MoS_2)
Tungsten (W) as	Huebnerite [$Mn(WO_4)$]
	Sheelite $Ca(WO_4)$
	Wolframite (Fe, Mn)(WO_4)
Cobalt as	Cobaltite (CoAsS)
	Bieberite $CoSO_4.7H_2O$.

Of the above listed common ore minerals, only those of iron and tungsten have been discovered in commercial amounts in Nigeria. Manganese and chromium have been indicated to be present but not yet proven to be in commercial quantities.

Table 1 shows where these commodities are presently being exploited in Nigeria. As can be seen from this table, a lot of more work needs be done in respect of manganese, chromium, nickel and molybdenum to fully establish the reserves of these commodities. They are all strategic metals whose applications potential in industry and research are many indeed. This aspect will be visited in detail in appropriate section of this presentation.

Group 2: Non-ferrous industrial metals

This contains another group of very important minerals. They include copper, lead, zinc, tin and aluminium bearing minerals. All are found in Nigeria at varying concentrations and different forms.

Copper (Cu): There are between 150 and 180 copper minerals. Of these, the commonest and the most important form mined are native copper (Cu); oxides of copper: cuprite (Cu_2O); tenorite (CuO); and a variety of copper sulphides such as bornite (Cu_5FeS_4); chalcocite (Cu_2S); tetrahedrite [$(CuFe)_{12}Sb_4S_{13}$] and chalcopyrite ($Cu_2Fe_2S_4$).

Lead (Pb) is next in abundance with 120 to 150 lead-bearings minerals known. The commonest lead ore is the sulphide galena (PbS). Other forms are known but don't often occur as ore minerals. An important lead mineral worth mentioning is vanadinite ($Pb_5(VO_4)_3Cl$). This lead mineral is sought, not for its lead but for the strategic metal, vanadium.

Zinc (Zn) is sought as calamine (calamine lotion) also known among mineralogists as hemimorphite: $Zn_4(OH)_2Si_2O_7.H_2O$. The most common occurrence is as sulphide: sphalerite (ZnS) and carborate-smithsonite ($ZnCO_3$). There are at least 52 other zinc bearing minerals.

Tin (Sn) occurs mostly as native metal, tin and in combined form as oxide, cassiterite (SnO_2). Fifteen (15) other tin bearing minerals are known but these occur as trace minerals in rocks of appropriate composition.

Aluminium (Al) is the most abundant metal (element) on the earth's crust, next only to silicon. There are over 360 aluminium-bearing minerals. The most important of all, which is a resource, is bauxite: a hydrous aluminium oxide.

Table 1: Occurrence and Development of Iron and Iron-Alloy metals in Nigeria*

Mineral Ore	Mode of occurrence	Location	Development	Estimated Reserve (tonnes)	Remarks
Iron	Oxides	Kwara	+++++	2.5-3.0 billion	These deposits are currently being exploited
		Enugu	+++	60-80 million undetermined but expected to be quite large	
		Plateau	++	"	
		Sokoto	+	"	
		Kaduna	+	"	
		Bauchi	+	"	
		Borno	+	"	
		Benue	+	"	
Tungsten/Wolfrain	Wolfamite	Bauchi	+	undetermined	Production for Plateau depot ceased about the mid 60's. All other occurrences are merely speculative for now.
		Plateau	++	"	
		Kano	+	"	
		Kaduna	+	"	
Manganese	Manganite & Psilomelane	Kaduna	+	$\geq$ 4 million	Sedimentary Mn is common therefore the C/R occurrence need to be further investigated.
		Zaria	+	"	
		C/River	+	"	
Chromium	Chromite (oxide)	Sokoto	+	?	
		Katsina	+	?	
Nickel	Niccolite	Oyo	+	?	

Molybdenum	Molybdenite (Sulphide)	Plateau	+	?	Molybdenite has been found in commercial(?) amounts in rocks of similar age in Ghana. Must look into the occurrences in Plateau and Bauchi as the Geology is similar to those in Ghana
		Bauchi	+	?	
		Ondo	+	?	

Key to symbols:	+:	Occurrence only indicated. No further work known
	++:	Occurrence indicated. Investigation in progress
	+++++:	Deposit has been fully investigated; Ore reserve, ore tenor, known already being exploited.
	+++:	Investigation underway. Estimated reserve known, ore tenor known.

*Source: Various works including RMRDC (1990) publication; Ogezi, A. E. – Postgraduate Open Lecture Series U.I., 1985: Fed. Min. of Mines & Steel

The availability of the non-ferrous industrial metals as ore minerals in Nigeria is summarized in Table 2. Of the five metal commodities available to us, the exploitation and utilization of tin, lead and zinc appear to have attained their peak. Consequently, the only way the resource base in respect of these can be improved is via research and convention. On the other hand, with respect to copper and aluminium, improved resource base can only be attained through the discovery of new deposits. Hence, a call is made for an accelerated aggressive geochemical exploration programme aimed at discovering new copper, especially the porphyry-type, and aluminium deposits in this country.

Group 3: Precious metals

These are the rarest and most precious metal commodities. They occur most commonly in pure, uncombined form. Members of the group are gold (Au); Silver (Ag) and Platinum (Pt); *Gold* (Au) is found in Nigeria in native form as nuggets in placer formations. There are, however, about nine known gold bearing minerals. These are rare and are encountered as minor accessories in other metal sulphide workings. The value of gold is in its beauty, monetary value and jewellery appeal. It shall not be referred to any more in this paper because of its restricted (if at all) technological importance.

Silver (Ag), like gold, is a prized metal. It occurs most commonly as sulphides, argentite (Ag_2S), andorite ($PbAgSb_3S_6$); alaskaite, ($Pb(AgCu)_2B_{14}S_8$ and another fifty five silver bearing minerals. The most important ore forms are agentite, smithite, sylvanite and acanthite. Unlike gold, however, silver have wider industrial and research application in dentistry, applied sciences and most widely in photographic processes.

Platinum (Pt) occurs as a native metal, usually in association with iron-magnesium, silicate minerals in ultramafic rocks. It is found as dissemination in those rocks but under favourable conditions, the ore can form distinct layer or unit in a layered igneous complex (e.g. in the Stillwater complex, Montana, USA). Only five platinum minerals are known: braggite (Pt, Pd, Nr)S; cooperite (PrS); niggliite ($PtTe_3$) and sperrylite ($PtAs_2$).

Table 2: Occurrence and Development Level of the Non ferrous Industrial Metals in Nigeria*

Mineral Ore	Mode of occurrence	Location (State)	Development Status (+)	Estimated Reserve (tonnes)	Remarks
Copper	Sulphides Oxides	Bauchi	+	Undetermined	Porphyry-type mineralisation goes with Mo. Exploration should be extended to Plateau granites.
Lead and Zinc	Sulphides	Ebonyi	+++	2 – 2.5 million undetermined	Commercial exploitation ceased during the civil war
		Bauchi	+	"	
Tin	Oxide	Plateau	+++++	200,000	Very well developed. Urgent need to discover new deposits.
		Nasarawa	+++++	"	
		Bauchi	+++	"	
Aluminium	Hydrous oxide	Gongola C/River	+ +	underdetermined	All the nation's current need are imported. Accelerated exploration programmes urgently needed.

* Sources: As in Table 1
(+) Symbols as in Table 1

Table 3 summarises the availability of the metals of this group in Nigeria. The major interest of this submission is in the availability of silver because it has diverse industrial and research applications. There is no known deposit of silver ore in Nigeria as at now. Silver occurrences have so far been as accessory minerals in some other sulphide. For example the silver-rich galena occurring around Wukari in Taraba State. All available tools for exploration ought to be mobilized and deployed in the Wukari area to try and discover silver ore deposit. After all, the small amount found in the lead sulphide came from somewhere in the vicinity. We want to locate the source now!

Group 4: Metal fuel

Coal and uranium belong to this group. They are particularly important energy sources for the nations industrialization and national defence: coal for powering the iron and steel works and uranium for providing clean energy at peace time and a source for nuclear weapon in case of hostility. Coal is mined in native form while uranium ore can be found in as many as seventy (70) uranium minerals. The commonest ore minerals are Autunite $Ca(UO_2)_2(PO_4)_2.10\text{-}12H_2O$ together with its metamorphosed form, metaautunite and the simple oxide uraninite (UO_2).

Table 4 summarises the availability of coal and uranium in Nigeria. We note that large deposits of coal are known in Nigeria and the exploitation of this commodity has reached advanced stage and right now exportation has recommenced in earnest. The nation anxiously awaits for maximum utilization of her coal in the all important Iron and Steel industry. Factors dampening this expectation will be dealt with in appropriate section of this lecture.

No uranium ore deposit has been discovered in Nigeria as yet. All we know is that the metal occurs in certain localities in the North-east region of the country. the Nigeria Uranium Mining Corporation (NUMCO) has laboured for many years now to discover an economic deposit but to no avail. Research is however continuing in various aspects of uranium mineralisation in Nigeria. Suh (1997) has shown that uranium occurrence in Sona, Borno is localized in fractures generated during the Pam African Orogen. Search for and study of occurrences require sophisticated micro-tecnique in mineralology.

Table 3: Occurrence and Development of Precious Metals in Nigeria*

Mineral Ore	Mode of occurrence	Location (State)	Development Status (+)	Estimated Reserve (tonnes)	Remarks
Gold	Native Combined with other metals	Oyo (Ilesha) Niger Kwara Sokoto	+ + + +	traces measured in kg	Small quantities have been panned from stream beds.
Silver	Mostly sulphides combined with galena	Taraba	+	no information	There is no known ore deposit of this metal as yet in Nigeria
Platinum	Native sulphide sulphide and arsenide	None yet	=	=	Search should begin with identification of ultramafic "layered?" bodies in the country

* Sources and symbols as in Table 1

This aspect has been addressed exhaustively (Orazulike, 1992) outlining research direction and likely results in the continuing effort to evolve genetic model for uranium mineralisation in this part of the world.

Group 5: Industrial Minerals:

These are minerals sought for and used directly for some industrial purposes.

They include some 107 non-metal, nonfuel minerals that have economic value. This classification pulls together a diverse group of minerals, rocks and derived commodities used by an equally diverse group of industries. Industrial minerals range from abundant materials such as stone and sand and gravel to such highly valued commodities as diamonds, emeralds and rubies. Industrial minerals have proven to be extremely important in the development of the nations economy. In fact, it is now generally recognised that the increased production and utilization of industrial minerals in any geopolitical entity, gives a good indication of the standard of living of that region as shown in improvements in transport and communications, housing and size of the consumer market. A direct relationship exists between industrial mineral production and use and the internal economic growth and activities of a region. It has been shown (Cleva, 1995) that exploitation and utilization of industrial minerals can boost the nations GNP. In the USA, mining industrial minerals contributed approximately $23 billion to the nations economy in 1994. This value accounted for about two thirds of the total value of all domestic non-fuel raw mineral production. Construction minerals accounted for $12.3 billion, followed by minerals used in fertilizer at $4.3 while chemical feedstock yielded $3.2 billion.

Industrial minerals in Nigeria include gypsum ($CaSO_4.H_2O$); limestone ($CaCO_3$); asbestos (a complex, fibrous aluminosilicate) and barite ($BaSO_4$). They are all except (asbestos) chemical precipitates. Others are marble $(CaMg)_2CO_3$; sand, SiO_2; Feldspars (K, Na, Ca) al.SiO_4; kaolin clay; Fire-clay; Diatomite, Phosphates; Kaolin, and Bauxitic clay.

Table 4: Occurrence and Development of Metal Fuel in Nigeria*

Mineral Ore	Mode of occurrence	Location (State)	Development Status (+)	Estimated Reserve (tonnes)	Remarks
Coal and Lignite (brown coal)	Native	Enugu	+++++	350 million	The Coal industry is on a very strong footing. It has gotten even better recently with the new Govt. policy on solid minerals, Nigeria coal is however non coking.
		Abia	++	"	
		Benue	+++++	"	
		Nasarawa	+++++	"	
		Plateau	+	To be investigated	
		Gombe	+		
Uranium	Oxides	Gombe	+	No ore deposit yet	Uranium in Nigeria is still only indicated. NUMCO has apparently given up their search.
		Borno	+		
		Adamawa	+		

* Sources and symbols as in Table 1

a Of all the commodities listed in this table (Table 5) only limestone and clays are fully exploited and fully utilized. Reserve estimates are in billions of tones and exceed domestic need.

Gypsum, a very important additive in the manufacture of cement, is known to occur in many states of the federation. The total reserve is unknown while its chemical quality is only recently being established. One of the commonest industrial minerals of this nation is rocks and rock materials. According to the Nigerian Mining Corporation (NMC) there are nine government-owned quarries in operation in the country. These produce an estimates 75-300 tonnes of stone aggregates per hour for the construction industry. Many more private quarries are scattered over the country, feeding local contractors. In addition to construction, rocks and rock slabs are increasingly used in large quantities as decorative materials. Varieties of granites, (particularly bauchite and bonded greisses) are currently being fashioned into decorative slabs for home/office beautification. It has been shown (Orazulike, 1996) that polished granite slabs and tiles especially bauchite possess high aesthetic value, compares favourably with more familiar marble in beauty and surpasses it in abrasion resistance, toughness and soundness. Attewell and Farmer (1976) have shown that granite is higher than marble on the toughness scale. These rocks and rock materials are revenue-yielding resources waiting to be tapped. Some multinational construction firms are now known to be harvesting these rocks for decorating houses in Abuja. Industrial minerals abound in Nigeria and have for long been virtually neglected in preference to imported materials. The situation is now changing and Table 5 summarises available information on the availability of this commodity in Nigeria.

Table 5: Occurrence and Development of some Industrial Minerals in Nigeria*

Mineral	Mode of occurrence	Location (State)	Development Status (+)	Estimated Reserve (tonnes)	Remarks
Bauxite	Oxides/hydroxide	Gongola C/River	+	undetermined	This is the sole source of Al for our industries and all are presently imported.
Clay many forms	Silicates	All Eastern States; many other states of the Federation	+++++	in billions	Deposits far exceed domestic need. Clay research centre is desirable to find new uses.
Diatomite	Diatoms	Borno	++++	10,000,000	Under-utilised. Research into uses desirable
Gypsum	Sulphate	Gombe Taraba Borno Sokoto Benue	+++	Not yet quantified. Estimated to be very large.	With the FG ban on gypsum importation, exploration and exploitation has picked up in tempo. Require to reach at least 50% of need by 2010.
Limestone	Carbonate	Enugu Bendel Ogun Gombe Sokoto C/River Abia	+++++	In billion	Major cement raw material. Reserve exceeds present industrial needs including use in Steel Plants.
Asbestos	Silicate	Kaduna	+	Small	Detailed studies desirable.

* Footnotes as in Table 1

In the fore-going section, we have examined the availability or otherwise of the solid minerals in Nigeria. Tables (1) – (5) clearly show that Nigeria is blessed with abundant strategic solid minerals. We also see from the above that it is only a very little percentage of these minerals that are being fully harvested and utilized. Specifically, it is only coal and to some extent iron, tin and related metals that are being mined in the solid mineral group. Among the many industrial minerals, only limestone, gypsum and phosphates among as many as thirty (30) industrial minerals and rocks, are fully mined and utilized. The logical question that follows is "Why are these mineral resources, as important as they are, so badly underutilized at the expense of improved economy, enhanced industrialization and self-sufficiency of our specialized agencies – such as the iron and Steel Development Agency and Research Institutes – on these raw materials?" Why is the man not using the material to his advantage? We shall proffer answers to these questions in the next section of this address.

EFFECTIVE UTILISATION OF NIGERIA'S SOLID MINERAL RESOURCES

> *"Only the Resource of man can bring the Resources of the earth to life"*
> *Paul A. Bailly, Occidental Minerals Corporation,*
> *USA. 1981.*

Introduction

Paul Bailly's philosophy quoted above is most relevant to every nation whose mineral wealth is untapped or underutilized. A mineral deposit buried deep down in the earth's crust, may be discovered but not mined, remains buried there and is as good as DEAD. When mined and put into use, it comes to LIFE as it serves man some purposes.

A systematic exploration for solid minerals in Nigeria started in the first decade of this century with establishment of the Geological Survey (GSN) as part of the Ministry of Mines and Power. The GSN produced geological maps of Nigeria on the scale of 1:250,000, covering the whole country and were used mainly for regional survey work. More recently, this agency, now an autonomous parastatal most recently elevated to the status of an Institute under the Ministry for Solid Minerals has produced maps at 1:50,000 scale which are used in mineral exploration. Over the years this agency together with the Nigeria Mining Corporation (NMC) has demonstrated the occurrences of many types of minerals in the country. Many of these are already being exploited, some are being evaluated and yet others are merely known to occur as has been shown in Tables 1 to 5. A mineral map (Figure 6) of the country is a result of the combine effort of all in the solid mineral sector put together by the NMC.

The level of information available with respect to each mineral commodity varies from mineral to mineral. The value of each commodity and the level of utilization depends on the resource of the Nigerian man. A mineral commodity that has been mined or could easily be mined but is not put to some challenging use, is as good as DEAD until man, the inquisitive man, the innovative man puts this mineral to some new use or modifies old applications to solve new problems. The chemical elements in use by the end of 19^{th} century numbered only 22, by 1970, scientific technology and industry, had increased that number to 71, for a 223% increase. Today, as we enter the new millennium, the figure has more than doubled. Many of the elements used in recent years are rare elements, and low-grade ores of rare elements are expected to be used much more in this new millennium. Therefore, further developments in large scale ore dressing and refining technology for low grade ores will open the possibility for efficient uses of large amounts of hitherto uneconomical resources. Clearly mineral resource-availability-utilisation presents a challenge requiring two fold scientific/technical solution.

1. There must be sustained effort to discover new deposits while research should be geared at adapting existing industries to benefit, or use available resource and vice versa. No equipment shall be "obsolete" and no locally obtained raw material shall be "incompatible" with available equipment.

2. New industries must be designed or evolved such that the required raw material is readily available. Otherwise, there should be a policy of gradual technical adaptation or modification of the system with new, improved metals or commodities to keep the system productive.

We shall illustrate the level of under utilization of our mineral resources and the consequences thereof on the nation by reference to selected commodities: Iron, coal, limestone, gypsum and tin. The choice of Iron and coal is informed by the fact that they are the primary raw materials for steel industry, which with tin and its alloys are very essential in the development of many industrial infrastructures and the military system. We choose Limestone and gypsum because these two are the essential raw materials for the cement industry. Cement is one construction material very indispensable to all. We shall now examine the performance of these Iron/Coal-based tin-; and Limeston/Gypsum- based industries in Nigeria and see if there is a lesson to learn to help us adjust as we move into the new decade, to be the better able to tackle our technological and research problems in all systems of the nation.

STEEL PRODUCTION EFFORT IN NIGERIA

The Iron and Steel Industry and Technological Growth

Iron and steel industry is widely acclaimed to be the gate-way to every nations industrialization. Industrial self-sufficiency and economic power of a nation appear to hinge on its possession of a steel industry. In fact, we now know that steel production is an effective barometer for assessing the economic status of developed nations. Figure 7(a), (b) and (c) clearly amplify this statement. The technologically advanced countries of Europe and America are also countries with large steel production (Fig. 7c). We also see that the sites for steel production are areas with large coal deposits (Fig. 7b) and are districts with large iron ore deposits (Fig. 7a). In Africa and Asia, however, districts with large iron ore deposits, (countries at the tip of West Africa and India) including Nigeria, are not known to be steel producing. For some of these countries, it is found that the cost of importation of coal may be far too much for their economies to sustain. Consequently, these countries sell their iron ore, notably to Japan. Japan is the only country that has neither iron ore nor coal deposit in her territory but still has one of the most well established steel producing companies.

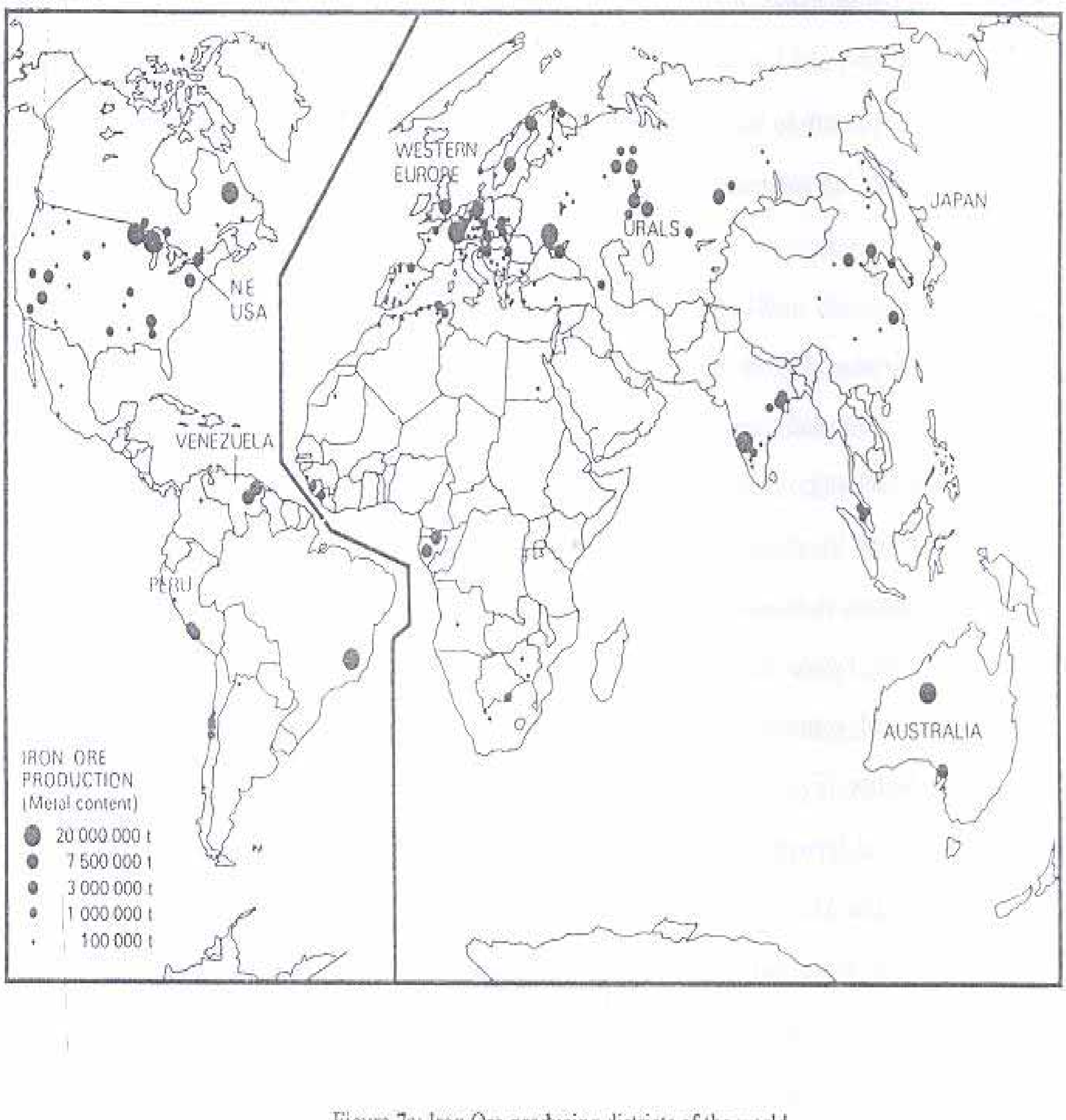


Figure 7a: Iron Ore-producing districts of the world

The role of steel production and its impact on the nation's economy cannot be overemphasized. Self sufficiency in steel and steel products can impact both economic and military power to the nation. It is difficult to imagine a conventional war being waged or threatened successfully without a capability to produce and use great quantities of steel guns, tanks, ships and armored personnel carriers. History informs us that the Prussian occupation of Alsace-Lorraine in 1871, coinciding with a discovery for smelting the vast reserves of Alsation iron ore, in part led to Germany's industrial domination of Central Europe.

In the United States, construction of the St. Mary's River Canal at Sault Ste, Marie in 1855 opened the inexpensive water route of the Great Lakes and brought the largest and richest iron ores known then, those of the Mesabi Range in Minnesota, into easy accessibility to the rich Pennsylvanian coking coal deposits. This began the rise of the USA as a world's leading stell-producer and great industrial power. Britain's rise as the world's leading steel-producing country in the last century was because of the close proximity of high grade coal deposits and rich iron ores.

Nigeria has large deposits of iron ore, coal and limestone, and yet, the nation's dream for steel production remains illusive.

NIGERIA'S STEEL PRODUCTION OUTFIT

The factors that govern the citing of an ideal Iron and Steel industry can be summed.

1. A source of economic iron ore.

2. A source of coal suitable for making coke

3. A source of limestone and other fluxing agents.

4. An abundant energy source for driving machinery

5. Water supply: over 2.7 x 10^5 litres of water are needed to produce 1 (one) ton of steel, as it is used for cooling and operation of machinery.

All five raw materials listed above as essential for sourcing an iron/steel industry are available in large quantities in Nigeria as can be seen from Figure 6 (Map of Nigeria showing iron ore, coal, limestone deposits) Table 1 (for iron); Table 4 (coal) and Table 5 (limestone). Nigeria's coal is non-coking. However, the problem of non coking coal and the availability of coal suitable for our steel works can be squarely and effectively tackled and therefore should not constitute an impediment to the working of an iron and steel industry in the land. It has been suggested (Geol. Surv. Report, 1961) that Nigeria's coal could be made to coke by adding 15% peat.

Recent studies (Obaje, 1997) show that the coal from some of the coal seams of Obi/Lafia coal deposits have reactive maceral contents in the range suitable for coke making.

The Nigerian Government recognises fully the importance of iron/steel production in attaining self-sufficiency through industrialization and maintaining her position of pride in the African continent. She has, therefore, taken bold steps to establish the Iron and Steel complex. This complex is made up of:

1. National Iron Ore Mining Project (NIOMP), Itakpe.

2. Ajaokuta Steel Company (ASC), Ajaokuta

3. Delta Steel Company (DSC), Aladja

4. Three (3) Inland Rolling Mills located at Oshogbo, Jos and Katsina.

The relationship among the four components of the Steel Complex is schematized in Figure 8. It is demonstrated in figure that the success of the steel-making companies depends solely on the success and efficiency of NIOMP operations.

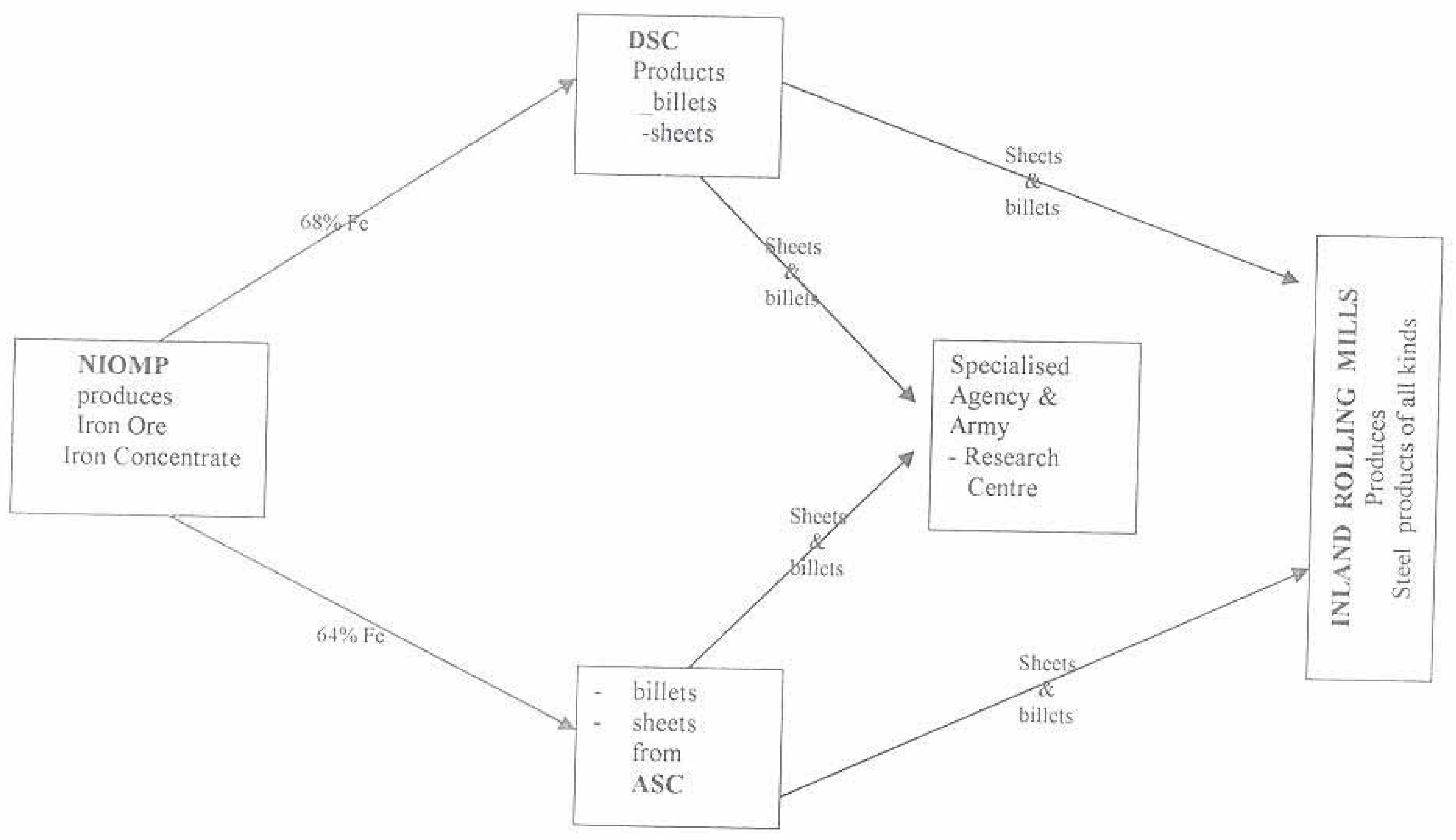


Fig. 8 Materials Flow Chart For The Steel Complex

The National Iron Ore Mining Project has installed plant capacity to mine and process 2.15 million tones of 64.0% Fe concentrate for Ajaokuta Steel Company and 0.55 million tones of 68% Fe super-concentrate for DSC. Total raw iron ore thereby bringing the factory's cumulative stockpile since 1979 to 2.1 million tones. In 1993, the raw ore produced stood at 2.293 million tones. In the 1994-95 production year, ore output declined by 71,014 tonnes or 42.2% from 239,275 tonnes in 1994 to 168,261 tonnes in 1995. The average capacity utilization rate decreased from 2.7% to 2.0% within this period. This unimpressive trend was blamed on inadequacy of working capital and obsolete inefficient machinery. Note that there was no capital expenditure on research for development.

Ajaokuta Steel Company (ASC) was established to produce iron and steel products. The first phase, when completed, was designed to produce 1.3 million tones of liquid steel, using the conventional blast furnace technology. By 1992 some of the plants were completed and commissioned. These include the medium section and structural mill, Wagon Tippler Station and Raw Material handling Conveyor System, Turbo Blower Station, Lime Plant Station and Central Compression Station. Many other components of the system were on their way to completion, such as the Coke Oven by-product plant, Sintering-plant, Alumino-Silicate plant, Blast furnace, Steel Making Complex and continuous Casting Plant. It was then projected that the final phase of this phase 1 of the project would be completed during the first half of 1993. This target was not met. By 1994, the complex had attained about 98% completion. Unfortunately, this all important project, initiated almost two decades ago, has remained stalled at 98% completion as at December 1995. This ASC picture is very disturbing. That this proposed "power house" of the nation's march to industrialization and economic supremacy cannot be "switched on" after twenty years of "preparation" is difficult to comprehend. Only 2% construction/equipment work is needed, we are told!

Given the high speed of technological advances and innovations in equipment design and manufacture, by the time our Steel Complex, designed and initiated 20 years ago is finally commissioned, all the equipment and machinery installations will already be obsolete by the standard of our suppliers!

The Delta Steel Company (DSC) like ASC, was established to produce iron and steel products. The main raw material, 68% Fe super concentrate was to be supplied by NIOMP. Production in 1991 stood at 141,877 tonnes while in 1992 it was 81,651 tonnes, down 60,226 tonnes or 42.4%. The rate of utilization of installed capacity was consequently down from 11.4% in 1991 to 6.2% in 1992. This poor performance was attributed to shortage of raw materials which, because of poor performance of NIOMP had to be imported. In 1993, total production was 49,356 tonnes a further fall by 43.55 over 1992, which was then regarded as an all time low figure. The 1994-95 production year was not better. Total production of billets and rolled products stood at 45,664 and 38,522 tonnes respectively for 1994 and 1995, down by 6,142 tonnes or 18.5%. Capacity utilization fell from 5.0% to 3.6%. This steady decline in production since 1991 has been blamed on high cost of imported input and obsolete equipment.

The Steel Rolling Mills are designed to use steel provided by the Steel Company (DSC); ASC, in this case, to produce steel products such as nails iron/steel rods etc. Consequently, realistically speaking, their adequacy to our industrialization and self-sufficiency in steel-ware for the nation depends on effectiveness of DSC and ASC in supplying the steel billets and rolled products. We shall, therefore, not make any further reference to these since, as the preceding discussion on DSC and ASC shows, for optimal performance, they necessarily have to import billets etc and that's not what they are meant to do!

Table 6 summarises the status of Iron and Steel raw materials production in NIOMP, iron and steel production by ASC and DSC for the 5 years period 1991 to 1995. Figure 9 and 10 present the picture graphically from which (Table 6 and Figure 9 and 10) it is clearly obvious that Iron and Steel production efforts by this nation leaves a great deal to be desired. If this trend is not reversed, this nation may have to depend on importation to satisfy all her iron and steel needs for industrialization and upgrading of her hardware in the year 2000 and beyond. This is a very bad omen and all hands must be on deck to reverse the situation. How can this be accomplished? We shall proffer and discuss some ways out but first let us examine the situation in construction industry.

RAW MATERIAL SOURCING FOR THE CONSTRUCTION INDUSTRY IN NIGERIA

The earliest, commonest and most widely utilized material in construction is cement. It was first introduced during the Dark Ages by engineers of ancient Rome. In 1756, John Smeaton, a British engineer revisited the ancient Rome's cement formula in the construction of the famous Eddystone Lighthouse. In 1824, another Englishman, Joseph Aspidin, patented his formula for Portland cement as used today. The role of cement in industry and industrialization/civilization is self-evident in every city of the world today. Today, in the new millennium, Nigerian engineers and scientists are battling to ensure availability of cement to her population.

Six cement plants make up Nigeria's Cement Industry. These are:

1. West African Portland Cement (WAPCO), Lagos
2. Benue Cement Company (BCC), Gboko.
3. Ashaka Cement Company (ACC), Gombe.
4. Nigerian Cement Company (Nigercem), Nkalagu
5. Bendel Cement Company Limited (BCC Ltd) Okpella
6. Cement Company of Northern Nigeria (CCNN), Sokoto

Raw materials requirement for Cement manufacture are

1. Limestone, $CaCO_3$

Table 6: Materials Production by the Steel Complex in the 5 year Period, 1991 – 1995*

	1991	1992	1993	1994	1995
NIOMP (tones Fe)	213,850	341,500	346,407	239,275	168,261
DSC (tonnes Steel)	141,877	81,651	49,356	45,664	38,895
Utilisation in % (DSC)	11.4	6.2	4.3	5.0	3.6

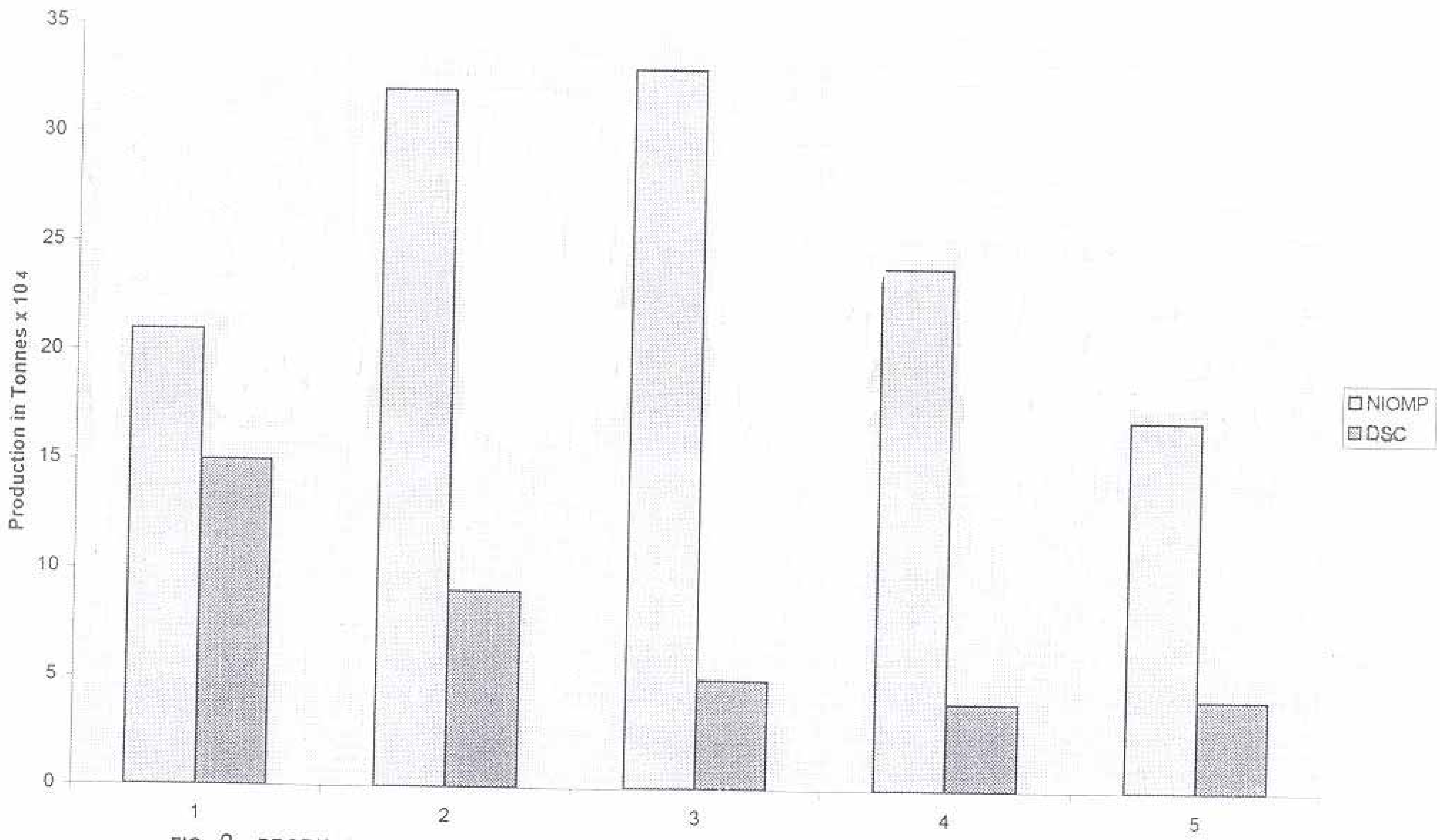


FIG. 9 PRODUCTIVITY AND EFFICINECY OF NIGERIA'S STEEL PLANTS IN THE 5-YEAR. (1991-1995). PERIOD

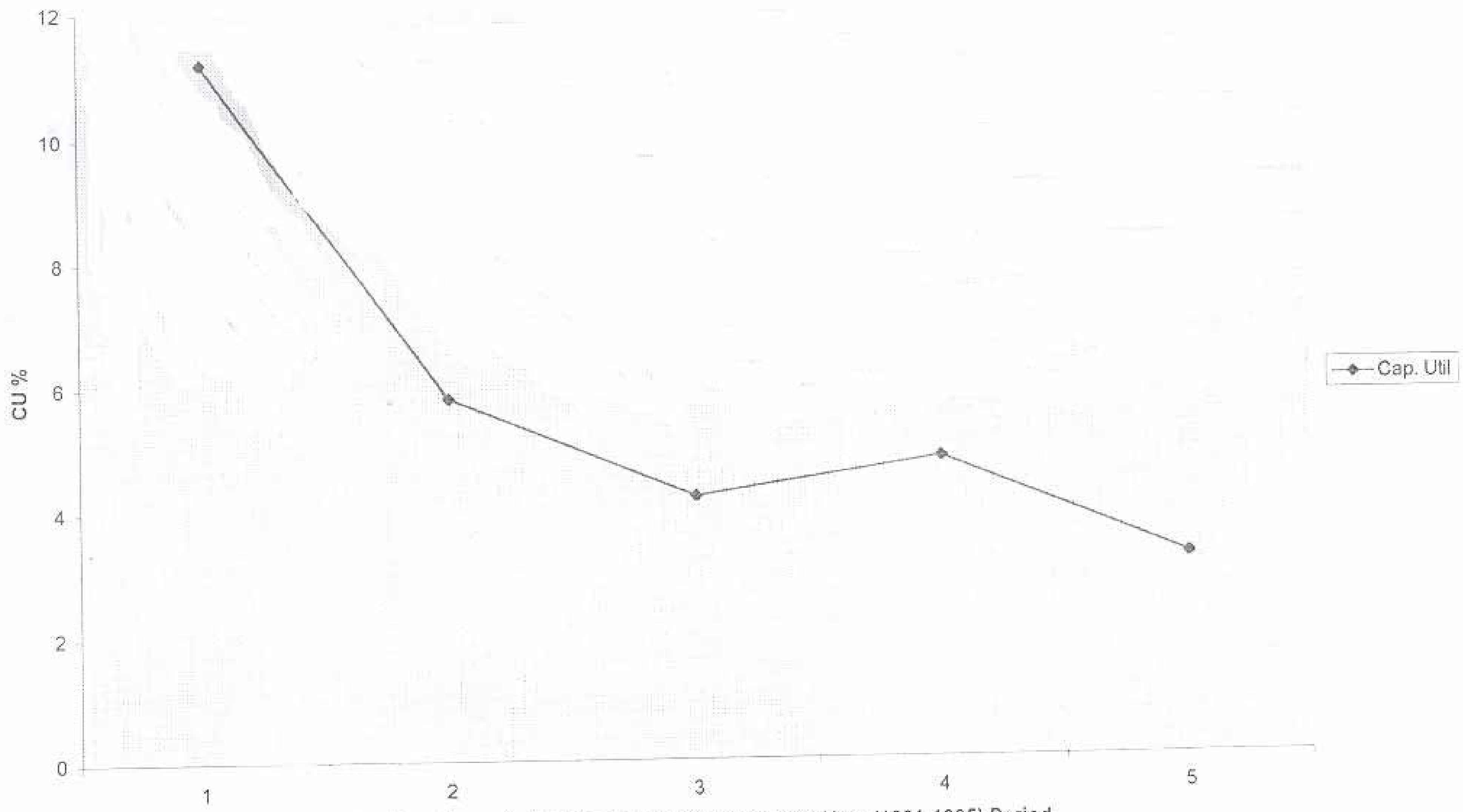


Fig. 10 :Capacity Unitilisation (DSC) in The Five Year (1991-1995) Period

3. Gyp
4. m $CaSO_4.2H_2O$
5. Clay

Limestone is the principal raw material. Very large quantities are needed – 1,265 kilograms of limestone is needed to produce 1 metric ton of Portland cement. It is therefore imperative that cement factories should be built only in the immediate vicinity of large limestone deposits. Table 5 shows the general availability of this commodity in Nigeria. Table 7 is constructed to include the cement companies which use the specific deposits. There is more than enough limestone to service all the cement companies.

Gypsum is an essential raw material input in the cement manufacturing industry. About 7% $CaSO_4.2H_2O$ is used as a fluxing agent. Gypsum deposits are known to occur in Gombe State (Nafada, Mada; Ashaka, Pindiga); in Sokoto (near Sokoto); in Borno (Potiskum); Anambra, in Benue (near Gboko). The actual reserves of this commodity are yet to be worked out in these locations.

The Nigeria Gypsum

Unlike limestone which is mined and optimally utilized, the story of gypsum is different. Gypsum deposits occur in Gombe State (Nafada, Mada, Ashaka, Pindiga); in Sokoto State (near Sokoto town), in Borno (Potiskum); Anambra, in Benue (near Gboko). They occur in veins and along bedding planes within the host formation. Until very recently, all the cement manufacturing companies in this country imported all the gypsum used in their operation. The Ashaka Cement Company, for example, in the late 80s and early 90s, used some 30,000 tonnes of imported gypsum annually. The cost of transporting this tonnage from our shores alone was over three million naira. The cost of this tonnage of gypsum delivered to our shores was at least another five million naira. All these was spent to import instead of utilizing the local gypsum.

Today, with the Federal Government ban on importation of gypsum, the cement companies are using more of the local gypsum which have been shown to be chemically pure and compositionally comparable to the foreign variety. Particularly, Orazulike and Haruna (1997) showed that the Gadaka and Daga gypsum (Borno) as well as the Mada gypsum (Gombe) are nearly 93% $CaSO_4.2H_2O$. The detailed chemical composition is similar to that of gypsum from Adoka (near Gboko), Benue State and those imported from Morocco and Spain. This fact is borne out in Table 8.

Table 7: Limestone deposits and Benefiting Cement Companies in Nigeria*

Limestone Occurrence (State)	Location (Town)	Estimated Reserve (million tonnes)	Company Serviced	Installed Utilisation in tonnes (cement)
Enugu	Nkalagu Odomoke Ngbo	110 64 4	Nigercem	600,000
Ogun	Ewekoro	135	WAPCO	1.5 million
Benue	Ogbolokuta Igumale 10 Yandev 67	10	BCC	900,000
Sokoto	Kambaina	101	CCNN	500,000
Gombe	Ashaka Nafada Kanwa	Large	AshakaCem	700,000
Bendel	Ukpilla	10	BCC Ltd	300,000
Imo	Umu-Obon Ohafia	12	None	-

* Sources: CBN Annual Reports; RMRDC (1990).

Ntekim (1999) and Ntekim and Orazulike (2000) report a similar relationship in respect to the gypsum found in Guyuk Area, Adamawa State.
From Tables 5 and 7, it can be seen that limestone deposits in this country far exceed requirements of the cement industries. The present production of gypsum is estimated at 15 – 20% national requirement. The balance can be imported, and with the local production brought up to 60-65% national need a mix of local with imported at 50:50 gypsum sufficiency in cement production will be attained (Orazulike, 1988). The question now is: Despite the huge deposits of the major raw material needed for cement production in Nigeria, and as much as six cement

manufacturing companies to produce cement, the commodity is still very scarce, very expensive and out of reach of the common man who needs it for modernization of his home. Why is this so?

Let us examine the performance of our cement companies in the five year period: 1991 – 1995.

1. *WAPCO, Lagos:* Production by WAPCO increase by 1.3%, from 1.107 million tones in 1991 to 1.121 million tones in 1992. Installed capacity utilization rate was accordingly slightly up from 68.5% in 1991 to 69.8% in 1992. In 1993, production was down to 1.018 million tones resulting in drop in utilization capacity to 64%. The 1994-95 production year saw a marginal decrease of 0.3% to 1.4 million tones from 1.404 million tones in 1994 (Table 8, Figure 11). Installation capacity of this company was 1.5 million tones of cement per annum.

2. *Cement Company of Northern Nigeria (CCNN):* Sokoto Production by CCNN, Sokoto, declined by 17% in the 1991 – 92 production years from 265,490 tonnes in 1991 to 220,450 tonnes in 1992. The company, therefore utilized only 45% of its 500,000 tonnes installed capacity in 1992 down from 53.1% figure for 1991. The 1993 figures are 210,091 tonnes for production and 42% utilization. The downward trend continued in 1994-95 with 1994 figures at 176,000 tonnes and 35% for production and capacity utilization respectively while in 1995, the corresponding figures were 156,000 tonnes and 32.6%. An overall trend of declining production and utilization capacity in the period under consideration is depicted in Table 9 and Figure 11a and b.

3. *Benue Cement Company (BCC) Gboko:* The 1991 and 1992 production figures were 487,000 and 482,940 tonnes respectively for the BCC.

Table 8: Comparison of Chemical Composition of Gypsum from Nigeria, Morocco and Spain (Data from Haruna, 1998, Table 4.4)

	Gypsum (wt %)		
Composition	Morocco	Spain	Nigeria
SO_3	47.32	44.85	46.7
CaO	33.89	31.44	31.7
K_2O	-	-	0.72
TiO_2	-	-	0.43
MNO_2	0.07	0.20	0.10
Fe_2O_3	0.05	0.16	0.07
SrO	-	-	0.02
Al_2O_3	0.12	053	-
MgO	1.05	0.50	-
SnO_2	0.60	1.50	-
Combined H_2O	15.67	18.38	15.0
$CaSO_4.2H_2O$	95.9	94.7	93.4

Table 9: Performance of Nigerias Cement Manufacturing Companies in the period (1991 – 1997)*

	WAPCO Lagos		Bendelcem Okpella		CCNN Sokoto		Nigercem Nkalagu		Benuecem Gboko		Ashakacem Ashaka	
Year	Production (million tones) (1)	Cap. Util. (%) (2)	(1) tones	(2) %	(1) tones	(2) %	(1) tones	(2) %	(1) tones	(2) %	(1) tonns	(2) %
1991	1.107	68.5	123,744	33	265,490	53.1	139,032	23	487,000	54	798,000	115
1992	1.121	69.8	55,598	18	220,450	45	112,338	19	482,940	53.7	758,574	108
1993	1.018	64	33,412	11	210,091	42	74,726	12	473,309	52.6	770,000	110
1994	1.403	87.7	34,976	13	176,000	35	34,550	6	407,465	45.3	765,000	109.3
1995	1.4	87.5	28,852	10	156,000	32.6	37,903	6	387,744	43.1	612,000	87.4
1996	1.32	81.3	27,799	9	126,500	25.6	22,097	4	462,208	51.3	595,215	85
1997	1.3	80.2	29,405	10	131,506	26.6	16,573	3	364,000	40.4	622,000	88.9

* Data from CBN Annual Reports.

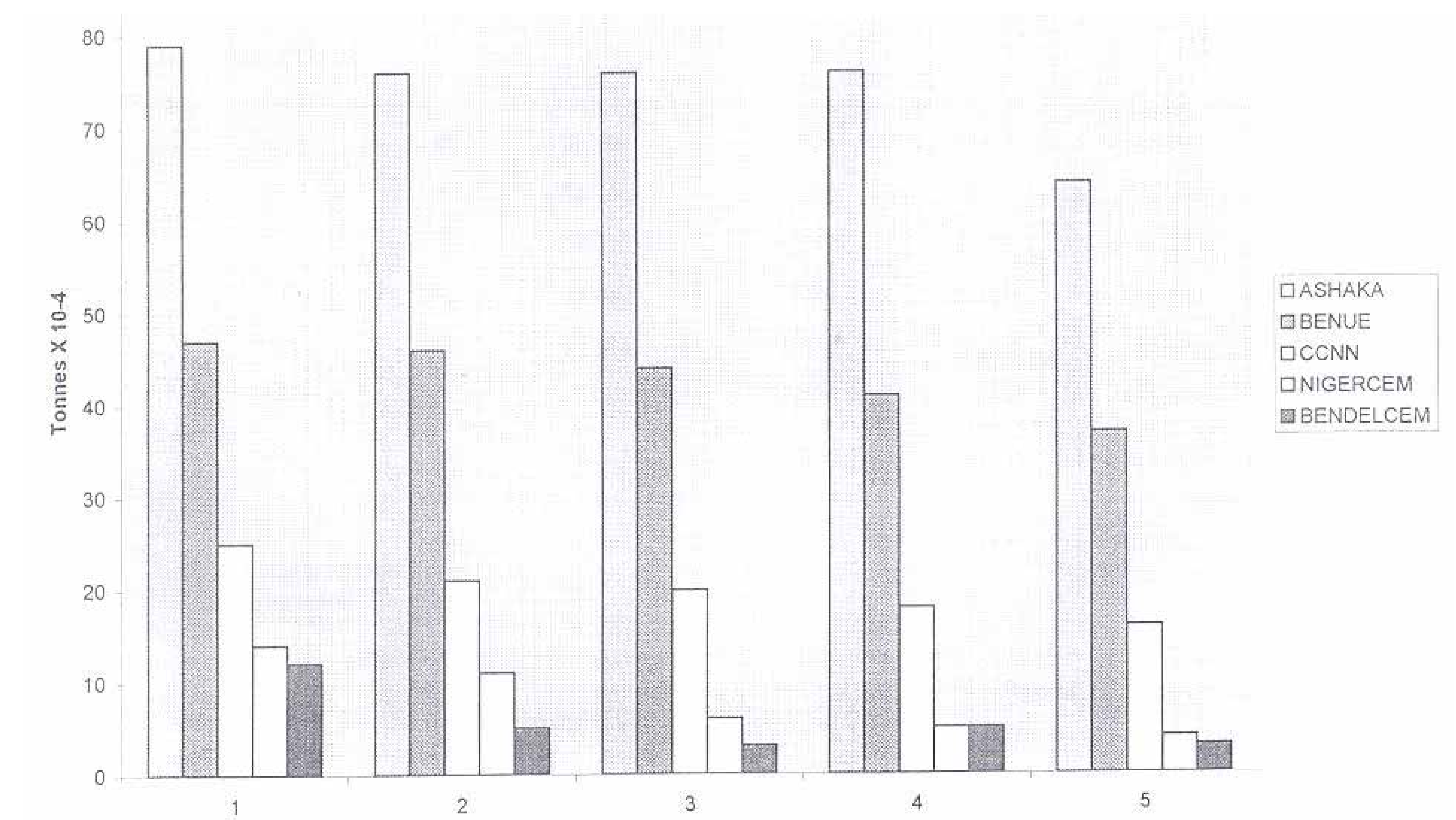


FIG. 11a PRODUCTIVITY OF NIGERIA'S CEMENT MANUFACTURING COMPANIES: 1991-1995

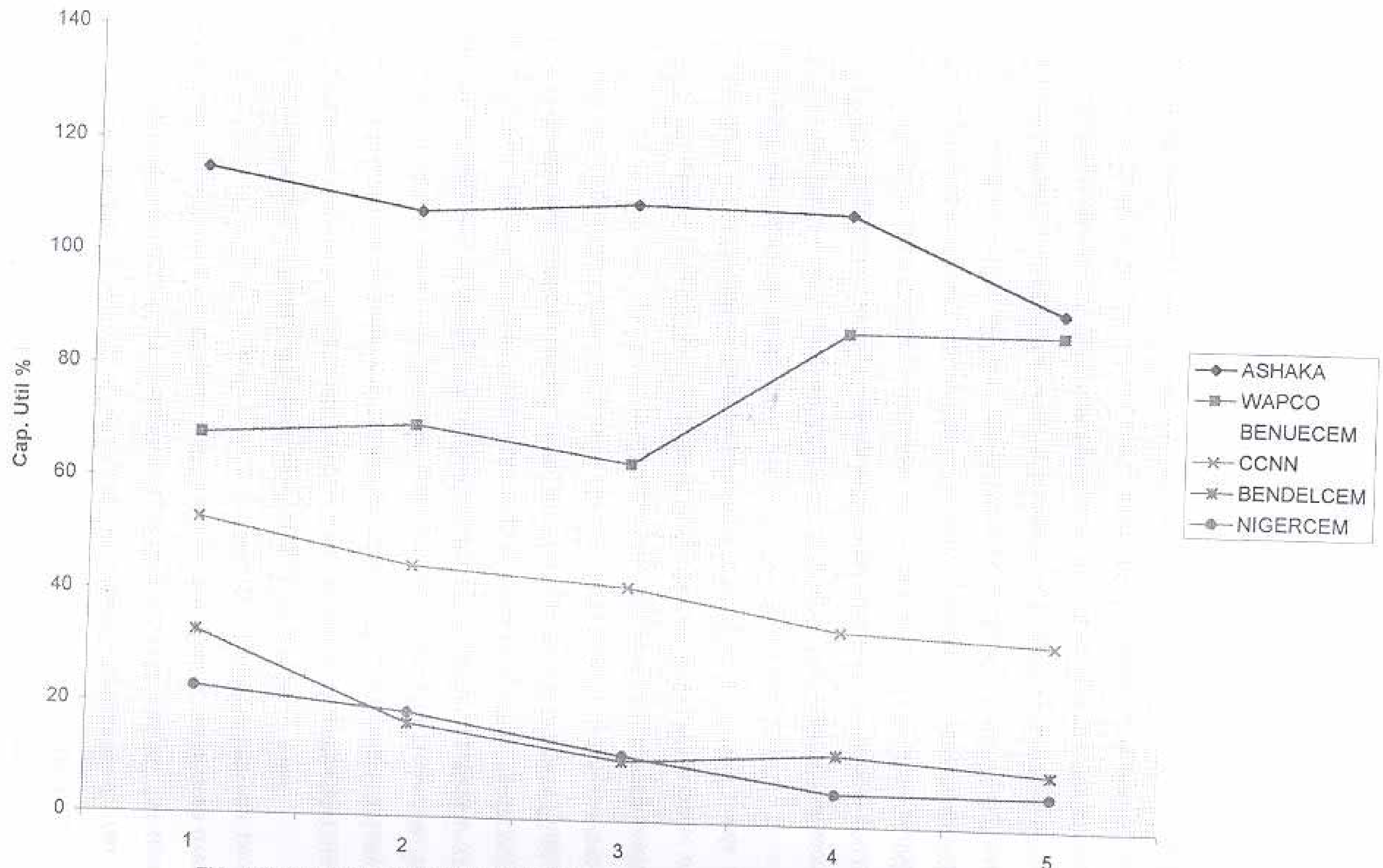


FIG. 11b RATE OF UTILIAZATION OF INSTALLED CAPACITY BY NIGERIA'S CEMENT MANUFACTURING COMPANIES (1991-1995)

Consequently, the capacity utilization rate recorded a slight drop from 54% in 1991 to 53.7% in 1992. However, this "slight" drop has continued to 1995 production year as shown by the figures: 1993 production 473,309 tonnes rate of utilization, 52.6%; 1994 production

407,465 tonnes while rate of utilization dropped further to 45.3%; 1995 production was 387,744 tonnes and much lower utilization rate of 43.1%. Here again we observe an overall trend of declining production and utilization capacity in the five year period under review (Table 9, Figure 11a and 11b).

4. *Bendel Cement Company Ltd. (Bendelcem) Okpella:* The Bendel Cement Manufacturing Company is the smallest of them all with installed capacity of 450,000 tonnes of cement per annum. The production record is very unimpressive. Starting with production of 125,744 tonnes of cement at 33% capacity utilisation in 1991, production systematically dropped to 55,598 tonnes in the following year, 1992; 33,412 tonnes in 1993; 34,976 tonnes in 1994 and in 1995, production was down to 28,852 tonnes, less than 50% of the 1991 figure. The capacity utilization rate systematically plunged down in this period from 33% in 1991, to 18% in 1992, 11% in 1993 down to only 13% in 1994, and very disheartening 10% in 1995. These trends are highlighted in figure 11a and b.

5. *Nigerian Cement Company(Nigercem) Nkalagu:* Nigercem is the second smallest of the cement companies with installed capacity to produce 600,000 tonnes of cement. The performance of this company in the five year period is as discouraging as what we saw in the Bendel cement. In 1991, the company was able to utilize 23% of installed capacity producing then 139,032 tonnes of cement. From 1991 to 1994, the company recorded systematic downward trend in production and utilization capacity as follows: 1992; 112,338 tonnes, 19%; 1993; 74,726 tonnes, 12%; 1994; 34,550 tonnes, 6%. 1995 saw a slight increase in production, (37,903 tonnes) but utilization rate stagnated at 6%.

6. *Ashaka Cement Company (Ashakacem) Ashaka:* Ashakacem is the 2nd biggest of them with installed capacity to produce 709,000 tonnes of cement annually. The company performed much better than the rest in the period under review. It had the best record of production (798,000 tonnes) and best level of utilization capacity (115%). It maintained the lead over the years, producing in 1994, 612,000 tonnes of cement, (more than the production from all the other four put together!) at 87.4% capacity utilization. The impressive production capacity of Ashakacem is demonstrated in Figure 6a, b. Not withstanding the relative supremacy of this company with respect to the others, it does record a decline in productivity and efficiency over the five year period.

Table 9 and Figure 11a and b summarises the production capability, capacity and utilization efficiency of the companies whose job is to provide "concrete" with which we can build our nation. The picture that has emerged from Figure 11 is discouraging. The dream of self-sufficiency in building materials for our teeming population, for civilization/industrialization-roads, bridges etc; for specialized agencies like the military, special task forces ends our dream to be among industrialized nations in our continent, the Nigerian Dream Nation, the realization of this dream will remain elusive if the trend depicted above is not reversed. It is also pertinent to note that the reasons offered by all these companies for the poor performance are

1. Cost of maintenance of obsolete equipment and machinery – frequent breakdown of equipment and machinery unavailability of spare parts (outdated), exorbitant cost of spare parts (when available) and epileptic power supply.

2. Cost or scarcity of imported raw material input, mainly gypsum.

Both problems have technological and scientific approach for their solution. These will be examined later in the next sections of this lecture. Suffice it to say now that the trends in figure 11(a) and (b) must be reversed and drastically so, if we have to confidently build up our cities, maintain our specialized agencies such as the Research institution with materials derived from within by ourselves in the new millennium.

We don't seem to be producing enough steel and steel products so that with acquired technology we can build our own bridges, roads and houses for the citizens. We don't seem to have concrete making capability to meet our needs now and ensure availability in the new millennium. These are despite the fact that our nation is endowed with mineral resources needed to produce these items. These industrial mineral resources are simply grossly underutilized. A look at the "supply and demand" picture for metals derived from sulphides and oxides shows an equally disturbing state of under utilization. This can be illustrated with one of the strategic metals available in our country, cassiterite (SnO_2) or tin oxide.

TIN AS A STRATEGIC RAW MATERIAL

Tin metal is recovered from tin ore cassiterite (SnO_2). Tin is one metal resource for which Nigeria ranks very high in supply to the world. Other notable producers of tin ore for world market are Malaya, Indonesia, Bolivia, Zaire (Democratic Republic of the Congo) and Thailand. Before the oil boom, tin constituted the major mineral resource and important foreign exchange earner for the country. Cassiterite production in Nigeria remained at about 10,000 tonnes annually for several years from a reserve estimated at 250,000 tonnes. A production peak was attained during

World War II when lots of tin, with accompanying tantalum and niobium were used by the colonial masters towards their war effort. Production declined in the 70s to about 3,800 tonnes in 1979, less than 3,200 tonnes in 1981 and to an "all time" low of 1,700 tonnes in 1983. From 1988, the production level became even more "sorry" as we see from Table 10. Only 208 and 203 tonnes of this important commodity was produced in 1994 and 1995 respectively.

Tin Mineralisation

Tin mineralisation in Nigeria is within the Younger Granites of Jos Plateau. They are two types: primary deposits found as disseminations in the biotite granite and pegmatities and placer deposits found among gravel pockets in both ancient and modern stream channels. Most of the tin today is recovered from the placer formations by stripping and open pit mining. Ore grade is high (about 1.5 kgm^{-3}) and beneficiation is by gravity or magnetic floatation or a combination of the two. Associated gangue minerals include magnetite (Fe_3O_4), ilmenite ($FeTiO_3$), Zircon ($ZrSiO_4$), thorite ($ThSiO_4$) and monazite (Le, La, Y, Th(PO_4)). Gem quality beryl and semi-precious gem quality topaz are also associated with the cassiterite.

As mentioned earlier, tin was highly sought for during World War II for its special value in the manufacture of armaments of diverse types. Tin-plate technology allows iron and steel to be coated with tin to provide corrosion resistant metal. The military needed tin for bearing metals, bronze and gun metal. Tin provided soft solders and its close companion tantalum, provides special steels and armour piercing weapon made of tantalum carbide. This commodity is so valuable for technology, yet it is one of the few resources whose future supply is very problematic.

Table 10: Tin and Columbite Production in Nigeria (1998 to 1995) in tones*

	1988	1989	1990	1991	1992	1993	1994	1995
Cassiterite	238	350	313.8	246	148.6	175.0	208.3	203.0
Columbite	51.0	46.0	44.4	35.8	38.2	16.5	17.0	37.0

* Data from CBN Annual Reports; RMRCN Publication 1990

Tin is one metal that is not found anywhere in the US. We are one of the few nations endowed with tin and pity to say, tin industry has been dead for over ten years now. C. J. Evens of the International Tin Research Council (ITRC) on the occasion of the 50th Anniversary of the body advised tin producers and I quote "Bronze technology appears relatively static and a number of other outlets such as tin tubes for packaging and tin-based solders for automotive body-filling were doomed to near extinction. A closer look at these applications in the light of a developing awareness of the properties of tin, tin alloys and tin chemicals revealed that the maximum benefits of these materials were not being exploited" close quotation. By this, a call for continuing exploration and exploitation of tin ore is made. More research is required. The future is great for Nigeria's tin in tinplate and other tin coatings technology; in soldering in development of assorted alloys (tin-zinc; tin-lead; tin-molybdenum and tin-aluminum) which because of their particular properties will be of great value to the military that aims at self-sufficiency in "small-arms" technology in due course, perhaps as soon as the year 2010.

Vice Chancellor Sir, ladies and gentlemen we have in the preceding sections

(1) Reviewed the plate tectonic genetic models for the formation of the mineral deposits in Nigeria. Reviewed the solid minerals status quo in our country and we can on the basis of available statistics conclude that all the resources are available in comfortable amounts to sustain appropriate industries and stimulate and sustain research by inquisitive minds through the year 2000 and beyond.

(2) We also have examined the level of utilization of some of the raw materials resources in the production of "essential inputs" for attainment of desired level of industrialization and development. The essential inputs we examined are Iron and Steel products; concrete production outfits and hardware maintenance and soft ware production potentialities. On the basis of performance of the nations Iron and Steel Complex, the nation's cement manufacturing companies in the five-year period (1991 – 1995), and the situation in tin-mining and tin production sector from 1998 to date, it is obvious that the available raw materials for those companies or agencies are grossly underutilised. We also observe from analysis of the production statistics of these companies in the five-year period, that production of the essential inputs for industrialization and sustenance of civilization has been steadily on the decline. In other words the nations

industrialization pace is retrograde in all facets and within every conceivable system in operation if we agree that Iron and Steel production capability is a reasonable yardstick for measuring development.

The state of affairs summarized above calls for urgent and bold steps to reverse it if we must proudly march through the millennium ready to tackle most of our industrialization research and modernization problems with our own mineral resources. It is a challenge which the nation has abundant and appropriate human resources to face squarely and successfully too. How? The answer will form the third and concluding part of this lecture.

INNOVATION, RESEARCH AND DEVELOPMENT IN MAXIMISING UTILISATION OF THE NATION'S MINERAL RESOURCES.

"Success in exploration requires new ideas and innovation people"

REXCO USA (1979)

"A commercial mineral exploration house is composed of realists who do not pay their geologists for theories".

B. B. Brock

A Global Approach to Geology (1972).

The reasons given by the companies examined in the preceding sections for their poor performance include:

1. Cost of maintenance of obsolete machinery and equipment
2. Cost of unavailability of spare parts
3. High cost of imported raw materials
4. High cost of and/or erratic Energy supply.

Most of the present production plants and equipment for the mineral and mineral-related industries in Nigeria were built long ago in an era of

1. Cheap and dependable energy source
2. Established and dependable sources of replacement parts
3. Cheap and dependable foreign raw material input

Today, all the above conditions appear to have changed or are changing fast. Particularly, given the very fast rate of technological changes world-wide, machines and equipment installed twenty years ago, must necessarily be regularly updated and maintained through research and bold innovative steps.

New processes, new ideas, adaptation and modifications that are consistent with prevailing realities must be evolved in the steel companies, in the cement industries and in the mineral industries. On record is the fact that companies in mineral related industries possess great deal of inertia to change, perhaps because of economic and political uncertainties. Hence they are reluctant to embark on huge expenditure accompanying innovative changes. They prefer to "refurbish" rather than replace obsolete machines. A vicious cycle evolves. The situation never gets better, production diminishes annually until percentage utilization comes to zero.

Research

It is commonly perceived that the conduct of basic research of sufficient quantity and quality leads to technological innovation and economic growth. E. A. Haeffner, an American Resource analyst, 1973, popularized a perception of the innovation process shown here in Figure 12. US National Science Foundation (1976), defined Technological innovation as "all aspects of the process of innovation from conception or generation of an idea to its widespread utilization by society, including activities involved in the creation, research and development and diffusion of new and improved products, processes and services for private and public use". Research and Development influences technological innovation process. It does not, however, determine innovation. It is the inquisitive man, sufficiently motivated and therefore sufficiently committed to finding a solution that determines innovation.

The Federal Government of Nigeria has shown sufficient awareness and commitment to research as a means of improving the level of utilization of her vast natural resources: mineral, agricultural and human alike. This is borne out of the many research institutes we have in this country. Of relevance to the subject of this lecture are:

1. The Raw Materials Research and Development Council of Nigeria
2. National Metallurgical Development Centre
3. Projects Development Institute
4. Federal Institute of Industrial Research
5. National Research Institute for Chemical Technology
6. National Office for Technology Acquisition and Promotion
7. Nigerian Building and Road Research Institute
8. PRODA

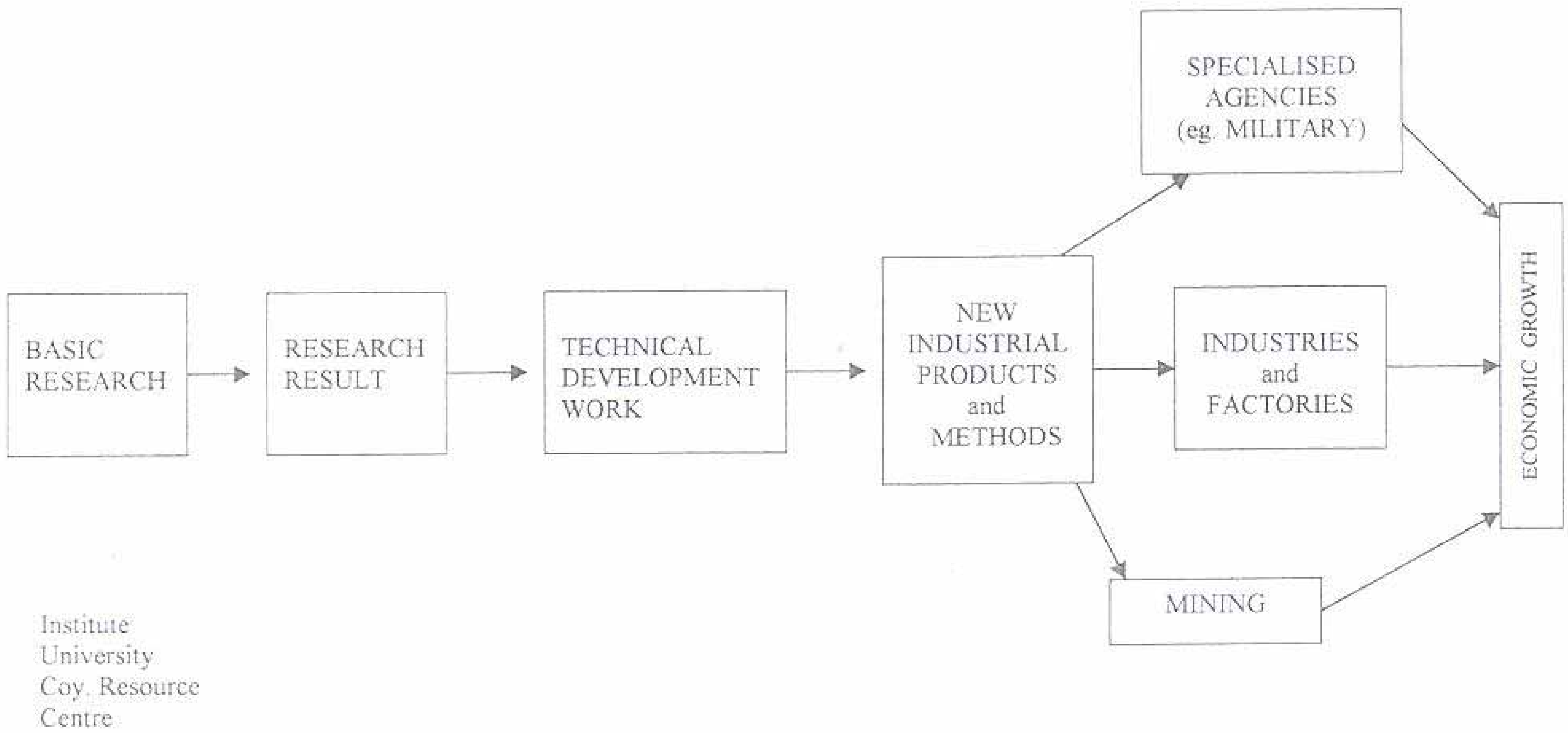


Fig. 12 The Innovative Process and Results
(Modified from Heaffnes, 1973)

We are not in the position to completely assess the performance of these research institutes and their continued relevance to the technological needs of the nation. Suffice it to suggest and strongly too, that these institutes should, carry out an internal honest self assessment of their performance and satisfy themselves that they are fulfilling the aims and objectives for which they were established. In any case these Research and Development Centres/Institutes should be characterized by the presence of by far more laboratories and workshops than administrative blocks, far more men in overalls and crash helmets working in laboratories and workshops than otherwise.

THE ROLE OF PRIVATE SECTOR, SPECIALISED AGENCIES AND PARASTATALS IN RESEARCH AND DEVELOPMENT

Without prejudice to the successes of the research institutes listed in the preceding section, this writer believes strongly that involving the private sector, specialized agencies, such as the Universities and Professional Societies and parastatals will help to guarantee results from the research efforts. In the United States of America, there are no fewer than thirty Industrial Research Associations. Each targeting specific area of endeavour and problem. Hence, there is the Bituminous Coal Research Inc., the Sulphur Research Institute, International Copper Research; Tin Research Council etc., etc. The whole idea is that the research in these establishments are more purposeful and are strictly directed to solving the problem of the particular resource – be it problem of utilization, beneficiation or even marketing. It is therefore desirable for the country to put in place research centers or institutes for the study and research on our strategic minerals such as tin, gypsum, Iron and iron alloys, lead and zinc with aims strictly defined as follows:

1. to discover entirely new uses for the metals;
2. to put in place an improved mining and beneficiation programmes for the minerals
3. to improve existing products and processes to make them more attractive industrially and
4. to counteract or justify the introduction of substitute materials or additives.

Existing manufacturing companies, like the Iron and Steel companies and the Cement Manufacturing companies require as their daughter agency, R & D units whose specific job should be solving the raw material production, machinery and equipment development problems which are peculiar to their performance. For example, the Cement Manufacturers Association of Nigeria should, as a matter of need, establish “Cement Raw Materials Research and Development Centre” such a centre will be funded by the Cement Manufacturing companies in the country. Specific time frame should then be set for the centre to come up with results on such aspects as purification and beneficiation of local gypsum; fabrication of critical equipment components in the country for use in our cement factories. The aim will include identification of technological problems in the system on a continual basis and setting up research and development programme with specified time frame to solve such problems. Avenues should include attendance overseas, workshops of relevant description, regular consultation with the major equipment suppliers to have an up to date information on the technological advancement in the manufacture of such equipment. Refurbishing of equipment should always be a mere short term measure while the R and D should endeavour to come up with locally fabricated replacement of some of the components in the first instance and the whole unit, – no matter how big and complex – within a space of time. This approach is obtainable even in the US mineral industries, where it is known as “incremental new technology” approach.

The nations Steel complex should have a similar arrangement described above. The target will be to eliminate the terminology “obsolete equipment and machinery” in our industries via the avenue of active research and development programme. The present state in Nigeria of non-investment or under investment in R & D arises from inability of industrial firms to appropriate adequate benefits of R & D for themselves. In France, the situation occurred and according to Pavitt (1976), government intervention saved the situation.

The Role of University in General

In the US, and Europe, it is customary, in fact, it is the routine that big companies and corporations establish and maintain research link with the Universities. By this arrangement, Universities with proven track record for research in specific areas are funded by companies to research and come up with solution to specific technological problems of the company. The universities represent the largest pool of scientific expertise in the world. It will therefore be advantageous to industrialization efforts via R & D to bring the university community into closer interaction with the industrial community and with the industrial/technological innovative process. Because the major share of basic science development occurs in universities, while technological development is lodged primarily in industry, the two sectors need to be coupled in the interest of technological advancement, industrialization and economic self sufficiency. It is strongly desirous but certainly not easy or simple for as Fusfeld (1980) summed it, “University-industry relations in Science and Technology is characterized by curious mixtures of Respect and Condescension, of affection and irritation, of strong mutual interactions and barriers, planned and philosophical”.

Role of Geoscience Departments of Universities

All the first and second generation universities of this country as well as the 3rd generation Federal Universities of Technology, and most of the State Universities, have geological sciences department. Those geoscience departments, properly equipped with respect to manpower and functional laboratories, can effectively drive innovation in the mineral industries. For this to happen, the mineral industry must necessarily be disposed to be influenced by the science and technology nurtured in these geoscience departments. A number of salient characteristics of mineral industries affect their rates of technological innovation and the force of impact from external forces on their rates of innovation. Based on activity, the mineral industries can be divided into three and for each, the input of science and technology can be evaluated.

I. Ore deposit-centred industries: Here the competitiveness of an individual firm depends on the type, grade and location of its ore deposit. For example, the base metal deposits of Cu, Pb or Zn as we have in Abakaliki, Southern Benue Trough.

II. Process-centred industries: For this category, competitiveness depends on pre-eminent position with respect to technological process of recovery. Most of the industrial minerals e.g. gypsum or aluminium, requiring innovative ideas only in the mining of the commodity, belong to this group.

III. Market-centred industries: The competitiveness of these depends on pre-eminent product line e.g. iron and steel.

The greatest challenge to the Geoscience departments is posed by ore deposit-centred industries. Ore deposit centred companies generally concentrate on discovery and acquisition of new, pre-eminent mineral deposits. Discovery is achieved only via an aggressive systematic exploration for mineral deposits by geochemical, geological and geophysical exploration methods. Geoscience departments properly funded, can display highest degree of innovation with commensurate results for the industry in the context. Since the competitiveness of a mining company of the ore deposit centred type depends largely on the size and grade of the ore deposit it owns and since geoscience departments are in the position to supply the skilled professionals to find new deposits, establish the grade and deposit size, it makes common sense to assign the responsibility to them. Furthermore, the Geoscience departments and mining engineering departments, should be encouraged to develop process technology for marginal ores so that previously unminable deposit can be converted into profitable ore.

To improve Geoscience/University participation in mineral industry, the following steps should be given serious consideration.

a) The coupling of academic research with recognised industrial needs – this is via well articulated government policies.

b) Stimulate interest among university graduates in industrial research. This can be achieved by increased and directed funding.

c) Encourage industries to play greater role in basic research conducted in the Geosciences departments of our universities.

The Geoscience programmes of the universities are in business of education and training. University research is thus necessarily geared towards education and basic research. Consequently, the university preoccupation is the number and quality of its students and its research productivity. Its responsibility is to the public. On the other hand, industry's fundamental interests are financial viability and profits. The goal of its research is new, improved products, processes and services. Industry's responsibility is to its shareholders. There is need for these two to find a common ground for effective cooperation for mutual advantage. A first step would seem to couple the research institutes and the universities with mineral industries. The industries will employ faculty members and post graduate students, sponsor university research and cooperate with the universities in PG training for degree programmes and in line with the industry's needs. This will be achievable by close cooperation (not competition) among the various parastatals under the solid minerals ministry and the universities Geoscience departments.

Role of the Military System

We take leave to go into this because the military top our nations annual budget allocation. Furthermore, a nation becomes truly great and self-sufficient if it is economically stable and militarily self-reliant.

In the industrialized countries, the main factors hampering innovation in mineral and mineral-related industries is Government Regulations: on environmental, health; and safety. In the developing world countries the factors to contend with are:

1. Choice of headship and personnel or research facility based on favouritism rather than proven research capability.

2. Absence of incentives to researchers

3. Lack of adequate research facilities including infrastructure.

4. Insincerity on the part of "research scientists" with respect to results reported.

The above list is certainly not exhaustive but they constitute what in my opinion, are the main obstacles to effective innovative research effort. The Nigerian military system, by virtue of its training and high level of discipline, is in a special position to mount an enviable and highly technical research and development programme. The military, by the nature of the system cannot be bugged down by (1) – (3) above and in the case of (4) correction and deterrent lesson is easy and decisive. In many nations of the world, the army research corp is on the fore front of research and technological innovations. In the US; for example, NASA (National Aeronautics and Space Administration) is essentially a military research outfit. Many of the precision instruments presently in use in field of geology were developed primarily by the US military for military use. For a military system that is R & D conscious and can boast of functional Research, Development and Production (RD & P) Unit, there should be no obsolete military equipment or machinery. This is because an equipment or machinery that is constantly revised, modified and upgraded using new and improved materials, applying innovative ideas and constantly improving technology, courtesy of RD & P, can never be obsolete. Clearly, the tanks used in the 2nd world war are an improvement on those used in world war I. The tanks in the army's current inventory are certainly not the same that were used in the world war II. In fact, they should not be the same as those available from our suppliers some 25 to 30 years ago. The principle of tank manufacture must have remained basically the same all these years, but the inquisitive man, the innovative researcher, the scientific man has continued to improve on the technology of tank-building to make the tanks satisfy the demands of modern combat.

The concept of "Transfer of Technology" or "Adaptation of Technology" is universally accepted in all areas of human endeavour. However, to fruitfully "transfer" an idea or technology or fruitfully "adapt" an idea or concept, the receiving system such as a firm or the military must have in place, a "well-prepared" and "fertilized" "ground" by way of an established, functioning Research Development and production Unit within itself. The military system knows her specific needs to achieve self-sufficiency in areas of need as soon as practicable. The basic raw materials: iron and steel; tin and tin alloys, tin accessory metals niobium, and tantalum, to name but this few, are resources the country has been blessed with. All that is required is for the military authorities to learn from Pavitt (1976) and avail themselves of the potential value of these resources to special needs of the military. It behoves them, therefore, to put in place Active Research, Development and Production Unit with clearly spelt out mandate to evolve ways these abundant raw materials will be put to the advantage of the military system, within a given time frame.

SUMMARY, CONCLUSION AND RECOMMENDATIONS

Mr. Vice Chancellor, Sir, distinguished professors and other academics, ladies and gentlemen, in this address, I have tried to convince you that the Nigeria nation is blessed with abundant solid mineral deposits. It is also obvious from our thesis that the nation is blessed with abundant human resources capable of tapping the resources to enhance, industrialization and reduce dependence of our industries on the importation of these valuable commodities. In the words of Paul A. Bailly, we have the "human resource" to bring the "Resources of earth" to our advantage. Unfortunately, we do realize that all these metal resources are grossly under exploited and under utilized (with just a few exceptions). The under utilization of these resources is manifested in very poor performance of the strategic industries in our country. Our Iron and Steel industry which is the gate way to the nation's industrialization and economic advancement is presently moribund after inception of construction work nearly two decades ago. The other components of the nations steel complex – Ajaokuta Steel Company, Delta Steel Company and the three inland rolling mills have been declining in productivity for the past five years. The nation's cement manufacturing companies, another pillar of industrialization are equally very unhealthy. Productivity has been on the decline for the past five years and cement has assumed the status of "essential commodity".

The trend of systematic decline in productivity, under utilization of available mineral raw materials by the several industrial arms and special arms must be checked. An aggressive research and development culture must be imbibed as part and parcel of our industrial establishments. Well articulated and clearly defined research, development and production programmes must be put in place by each manufacturing company to ensure continuing research in problem areas and development of essential machinery and equipment from local sources thereby ensure independence in materials acquisition and use by each of the organisations. Research leads to new uses. Many of the nations mineral resources are not being exploited because the foreign markets for the metals are either non-existent or they are uneconomic. There is need to find new, uses for these metals in our industries via research. The success story of the International Tin Research Council demonstrates the validity of the view expressed above.

This nation has the capacity and capability to cruise through the new millennium as an industrialized country, largely self-sufficient in the supply of raw materials (processed or otherwise) for use in our industries. With shear determination and stubborn will to succeed, the system should, in the years ahead, be able to fabricate her software, adapt most of her hardware using internally sourced materials and carefully acquired state of the art technology. My role as a Professor of Geology at Abubakar Tafawa Balewa University is primarily research and training a new generation of geoscientists capable of discovering new mineral deposits and finding out new uses for old mineral resources for industrial and technological growth of our nation. This task is by no means easy but certainly it is as rewarding and satisfying. My final plea is that government should improve the research and teaching environment in the Geosciences to attract scholarly researchers and teachers in the field so that we can fully harvest the "Earth" for better living of our people and national growth.

I THANK YOU ALL.

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