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IN THE SEARCH FOR HIDDEN TREASURES

By

T. R. Ajayi
Professor of Geology

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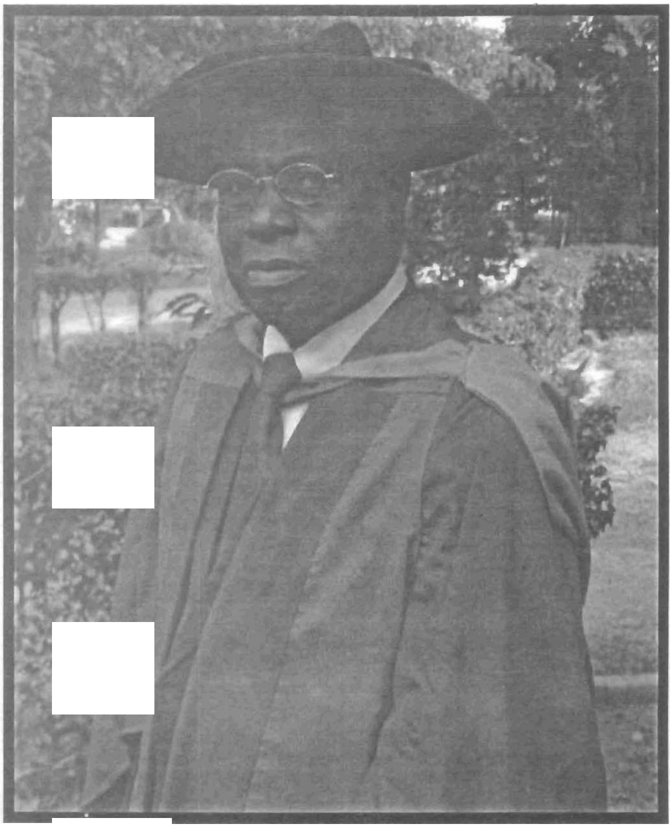

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INTRODUCTION

The word "treasure" means so many things depending on the context. In common usage, treasure refers to "accumulated or stored or hidden wealth in form of money, jewels or other valuables for future use". It is also considered as "valuable or precious possessions of any kind", In the latter context, someone or something considered exceptionally precious such as gem, pearl etc. No wonder people refer to or describe their loved ones as "gem of inestimable value".

Mr. Vice Chancellor Sir. Geologists refer to hidden treasures as those valuable mineral resources (liquid, gas, solid) in the Earth's Crust which need to be searched for (explored), exploited and processed (using appropriate methods) into wealth for the use and benefit of mankind. Human wealth basically comes from agriculture, manufacturing and mineral resources. Our complex modern society is built around the exploitation and use of mineral resources. The driving force of human existence is mineral resources because modern agriculture and the ability to feed an overpopulated world is dependent on mineral resources to construct the machines that till the soil, enrich it with mineral fertilizers and transport the products.

It is important to emphasize at the onset of this lecture that these days, minerals are seen in terms of industrial development, advancing technology and capital movement. They play a very important role in international trade and they are important also as a key factor in any Country's position in the international forum at times of "resources diplomacy".

The great diversity of mineral resources in the Earth's Crust have been the backbone of our cultural changes and the present technological achievement. Mining and recovery of mineral resources has been with us for a long time. Early Paleolithic man found flint for arrowheads and clay for pottery before developing codes for warfare. This was done without geologists for exploration, mining engineers for exploitation or chemists for extraction techniques. Tin and copper mines were necessary for the Bronze

Age, gold, silver and gemstones adorned the wealthy early civilization, and both iron and coal symbolized the industrial revolution.

The discovery of the Earth's mineral resources is the geoscientist's task i.e. the continuous search for new mineral deposits to sustain our standard of living, let alone the affluence enjoyed by a few as reflected by per capita consumption of minerals (Table 1). Table 1 shows clearly that the metal intensity has tended to increase inline with economic growth and as the structure of economics becomes more materials intensive.

To appreciate this, at world population of over 5 billion in 1988, the total mass of mineral produced and consumed was 50 billion tons i.e. the materials actually mined excluding all materials and the energy required facilitating mining. With the estimated growth of world population to 7 billion in 2003 and projected population of 10 billion by 2030, industrial production is predicted to increase 2.6 times if consumption in the developing countries reach the level of developed countries. Skinner (2003) emphasized that society will be unable to maintain its standard of living without continued access to resources provided by the minerals and energy industries. He therefore estimated that in the next 50 years, the world will use 5 times the resources that have been mined to date.

TABLE 1:
GLOBAL METAL CONSUMPTION, 1990 2005 (Metric ton) (A) AND INTENSITY OF METAL CONSUMPTION, 2005 (KG PER CAPITAL) (B)

(A)

YEAR	ALUMINUM	COPPER	LEAD	ZINC	NICKEL	TIN	IRON ORE (MT)
1990	18,009	10,755	5.511	6,671	856	238	976
2005	31,947	16,930	7,524	10,580	1,236	332	1,455
Growth Rates (% CAGR)							
1990- 2005	3.9%	3.1%	2.1%	3.1%	2.5%	2.3%	2.7%

A

	ALUMINUM	COPPER	LEAD	ZINC	NICKEL	TIN
North America	16.6	6.7	4.2	3.6	0.3	0.1
Latin America	3.0	1.0	0.4	1.1	0.1	0.0
W Europe	17.1	9.1	4.2	5.6	1.1	0.1
E. Europe	9.3	3.5	2.3	2.0	0.0	0.1
Asia	3.0	2.3	0.9	1.5	0.2	0.1
Africa	0.4	0.2	0.1	0.2	0.0	0.0
CIS	3.0	2.6	0.4	1.1	0.1	0.0
World Average	4.9	2.6	1.2	1.6	0.2	0.1

Source: Commodities Research Unit, London September, 2006

In considering supply of mineral resources, the world economy is in continuous struggle between two forces advances in technology that enhance productivity of labour and exhaustion of resources that diminishes productivity. In the last two centuries, technology has been the obvious clear victor.

Although, there is the consensus that the magnitudes of global resources of minerals mined for purposes other than energy are such that physical exhaustion need not be a problem, thus sufficiency in global sense is not likely to be a limiting issue, but heterogeneities of geographic distribution will continue to be a major problem. Hence the major issues will be prices and supply of many resources. Skinner (1984) has since predicted as follows that:

(i) Prospecting for new mineral deposits will be most active in countries that have histories of political stability for obvious reasons and

(ii) Search for "hidden ores" will become more intense thus leading to high investment in deep exploration.

What is a mineral?

The word mineral is amongst the most adaptable of all nouns since to various people it has different meaning. For example:

- To a Pharmacist mineral means something combined with

Vitamin

- Rock Collector a mineral is an attractive substance and may be hard enough to take on polish.
- Prospector minerals are of potential economic value.

However to a geologist "a mineral is a naturally occurring homogenous (usually in-organic) solid chemical compound characterized by a definite composition or a restricted range of chemical composition and by a specific regular arrangement of atoms that make it up". They are essentially materials that make up the earth, the extra-terrestrial (meteorites) and lunar surface materials. The two fundamental properties are the crystal structure and chemical composition. Minerals make up a rock just as bricks make up a brick wall in a great variety of arrangement (Fig. 1).

There is the consensus that our planet earth formed by accretion of material formed in the solar nebula. However, the mode of accretion either homogeneous or heterogeneous has been subject of controversy. The Earth as shown by geophysical evidence has a layered structure made up of the core, mantle and the crust (Fig. 2a). The core which compositionally is made up of metallic (iron-nickel alloy) materials lies at the center and it is nearly twice as dense as the mantle, which lies directly above the core. The mantle is a dense, hot layer of semi-solid rock and it is approximately 2,900km thick.

The Earth's Crust is brittle and the outermost surface of the earth that is readily accessible to use for mining and drilling (Fig. 2a). It is literally like a thin skin of an apple. It is very thin compared with the other three layers. It is about 8km thick under the ocean (oceanic crust) and average of 30km thick under the continent (Continental Crust) (Fig. 2b). Widely distributed in it are many different kinds of minerals, found in a great variety of rocks making up the crust. However, the valuable elements of interest (Table 2) are those which some geological processes operated on to segregate or accumulate much higher quantities of the elements (Table 3) than normal (i.e. above the average crystal abundance) These constitute the ore deposits and exploration targets (Fig. 3). Rich deposits of metals are 'ores' whilst the minerals containing these materials are the <u>ore</u>

minerals (Table 4). The ore minerals include sulfides (main group), oxides and silicates. However, some metals viz gold occur in their native state.

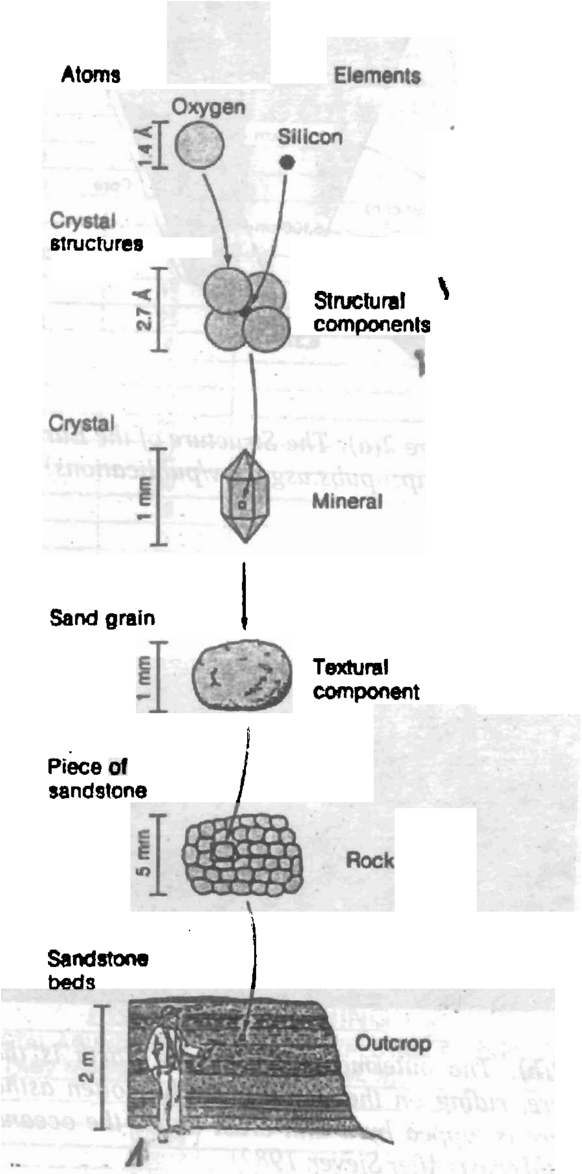


Figure 1: How atoms combine to form rocks. Atoms make up the small structural components that form minerals, which in turn combine to form rocks (After Press and Siever, 1982)

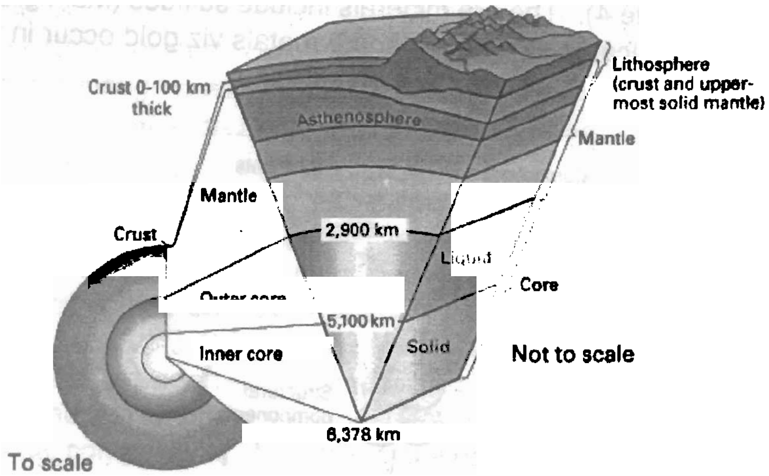


Figure 2(a): The Structure of the Earth (http://pubs.usgs.gov/publications)

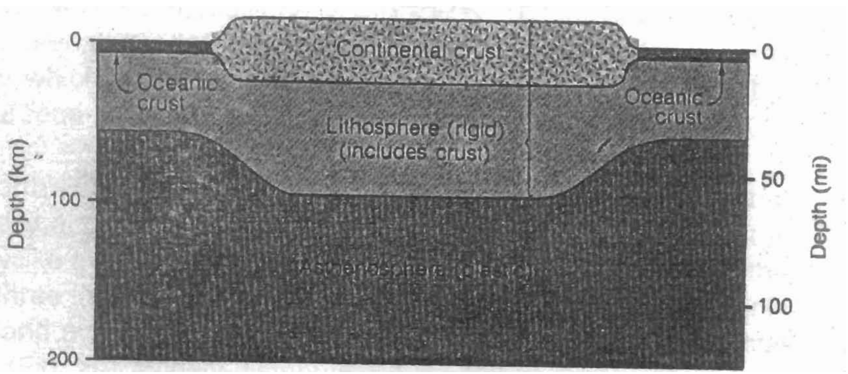


Figure 2(b): The outermost shell of the Earth is the strong, solid lithosphere, riding on the weak partially molten asthenosphere. The lithosphere is topped by a thin crust under the oceans and a thicker continental crust (After Siever, 1982)

TABLE 2: CRUSTAL ABUNDANCE OF ECONOMICALLY IMPORTANT ELEMENTS (Adapted from Siever, 1982)

NAME	CHEMICAL SYMBOL	ATOMIC NUMBER	CRUSTAL ABUNDANCE (Relatively abundant) (% by weight)	CRUSTAL ABUNDANCE (Relatively scarce) (% by weight)
Aluminum	Al	13	8.00	
Iron	Fe	26	5.8	
Magnesium	Mg	12	2.77	
Potassium	K	19	1.68	
Titanium	Ti	22	0.86	
Hydrogen	H	1	0.14	
Phosphorus	P	15	0.101	
Manganese	Mn	25	0.100	
Fluorine	F	9		0.0460
Sulfur	S	16		0.030
Chlorine	Cl	17		0.019
Vanadium	V	23		0.017
Chromium	Cr	24		0.0096
Zinc	Zn	30		0.0082
Nickel	Ni	28		0.0072
Copper	Cu	29		0.0058
Cobalt	Co	27		0.0028
Lead	Pb	82		0.00010
Boron	B	5		0.0007
Beryllium	Be	4		0.00020
Arsenic	As	33		0.00020
Tin	Sn	50		0.00015
Molybdenum	Mb	42		0.00012
Uranium	U	92		0.00016
Tungsten	W	74		0.00010
Silver	Ag	47		0.000008
Mercury	Hg	80		0.000002
Platinum	Pt	78		0.0000005
Gold	Au	79		0.0000002

TABLE 3: CONCENTRATION FACTORS OF SOME ECONOMICALLY IMPORTANT ELEMENTS NEEDED FOR PROFITABLE MINING

ELEMENTS	CRUSTAL ABUNDANCE (%By Weight)	AVERAGE EXPLOTABLE Grade (wt. %)	CONCENTRATION FACTOR
Aluminum	8..00	30	3-4
Iron	5.8	25	5-10
Copper	0.0058	0.4	80-100
Nickel	0.0072	0.5	150
Zinc	0.0082	4.0	300
Uranium	0.00016	0.20	1,200
Lead	0.00010	4.0	2,000
Gold	0.0000002	0.0001	4,000
Mercury	0.000002	0.20	100,000

- Concentration Factor = Abundance in Deposit/Crustal bundance.Sources data from B. J. Skinner, Earth resources, Prentice-Hall, 1969; DA. Brodst. And W.P. Pratt. Mineral Resources of The U.S., U.S. Geological Survey Prof. Paper 820. 1973.

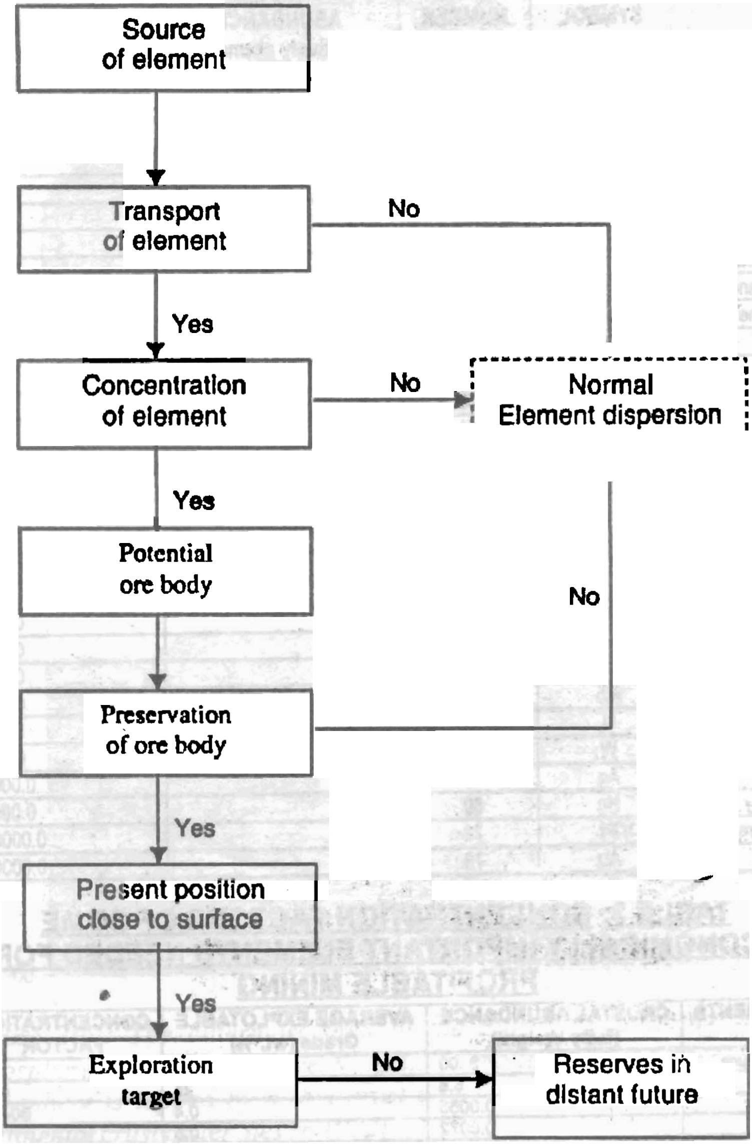


Figure 3: Concept of a model for the formation of an ore body and the creation of an exploration target (modified after Tilsley, 1980)

TABLE 4: LIST OF THE PRINCIPAL ORE MINERALS FOR ABUNDANT AND SCARCE METALS

I THE GEOCHEMICALLY ABUNDANT METALS

Iron	Magnetite, Fe_2O_4 : hematite, Fe_2O_4; goethite, $HFeO_2$; Siderite, $FeCO_3$; pyrite, FeS_2
Aluminium	Gibbsite, H_3A1O_3; diaspore and boehmite, $HAlO_2$; Kaolinite, $Al_2Si_2O_5(OH)_4$; anorthite (calcium feldspar) $CaAl_2Si_2O_8$
Chromium	Chromite, $FeCr_2O_4$
Titanium	Rutile, TiO_2; ilmenite, $FeTiO_3$
Manganese	Pyrolusite, MnO_2; Psilomelane, $BaMn_9O_{18}\ 2H_2O$; cryptomelane, KMn_8O_{16} ; rhodocrosite, $MnCO_3$
Mangesium	Magnesite, $MgCO_3$; dolomite $CaMg(CO_3)_2$
Sodium	Halite, NaCl
Potassium	Sylvite, KCl

II THE GEOCHEMICALLY SCARCE METALS

A Chalcophile Metals

Copper	Covellite, CuS; Chalcocite, Cu_2S; digenite, Cu_9S_5; Chalcopyrite, $CuFeS_2$; bornite, Cu_5FeS_4; tetrahedrite, $Cu_{12}Sb_4S_{13}$
Zinc	Sphalerite, ZnS
Lead	Galena, PbS
Nickel	Pentlandite, $(Ni,Fe)_9S_8$; garnierite, $H_4Ni_3Si_2O_9$
Antimony	Stibnite, Sb_2S_3
Molybdenum	Molybdenite, MoS_2

Arsenic	Arseopyrite, FeAsS; orpiment, As_2S_3; realgar, AsS
Cadmium	Substitution for Zn in sphalerite, (ZnS)
Cobalt	Linnaeite, Co_3S_4; substitution for Fe in Pyrite, (FeS_2)
Mercury	Cinnabar, HgS
Silver	Argentite, Ag_2S; substitution for Cu and Pb in their common ore Minerals (see Copper and Lead)
Bismuth	Bismuthinite, Bi_2S_3

B ***Siderophile metals*** (commonly found in the native form and in the minerals below)

Gold	Calaverite, $AuTe_2$; Krennerite, (Au, Ag) Te_2; sylvanite, $AuAgTe_4$; petzite, $AuAg_3Te_2$*
Platinum	Sperrylite, $ptAs_2$; braggite, ptS_2; cooperite, ptS
Palladium	Arsenopalladinite, Pd_3As; michenerite, $PdBi_2$; froodite, $PdBi_2$
Rhodium	
Iridium	-
Ruthenium	Laurite, RuS_2
Osmium	-

C ***Lithophile metals***

Tin	Cassiterite, SnO_2
Tungsten	Wolframite, $FeWO_4$; scheelite, $CaWO_4$
Uranium	Uraninite (pitchblende), UO_2
Vanadium	Carnotite, $K_2(UO_2)_2(VO_4)_2 . 3H_20$; substituting for Fe in magnetite, (Fe_30_4)
Niobium	Columbite, $FeNb_20_6$; pyrochlore, $NaCaNb_2O_6F$
Tantatum	Tantalite, $FeTa_20_6$
Beryllium	Beryl, $Be_3Al_2(Si0_3)_6$

*These are all tellurides-all with tellurium

WHY MINERAL RESOURCE DEVELOPMENT

Mineral resources are and will always be a source of wealth for any country. Therefore knowing them and utilizing them in the most appropriate way is one of the goals that must be reached in order to achieve progress and development. All resources have three common underlying factors need or demand, supply and its consequences on the environment. Without need, a commodity would not become a resource, hence, need comes first. Skinner (1989), expressed the view that a resource need, quickly can become a resource dependency if fulfillment makes performance of the daily tasks more efficient or makes life safer and easier.

Each one of us, irrespective of where we live has been dependent directly or indirectly on hundreds of natural materials (Fig. 4). Over 70 chemical elements and dozens of specific minerals are processed into products. On the basis of heterogeneity of mineral distribution in the earth's crust, it is hardly surprising that no country in the world today is completely self sufficient with respect to mineral resources.

The global supply and demand makes the continuous search for mineral resources mandatory for the adequate supply of minerals to meet the demand of the exploding population for reasonable quality of life. This can only be achieved through innovative technological exploration techniques particularly for hidden ores (treasures).

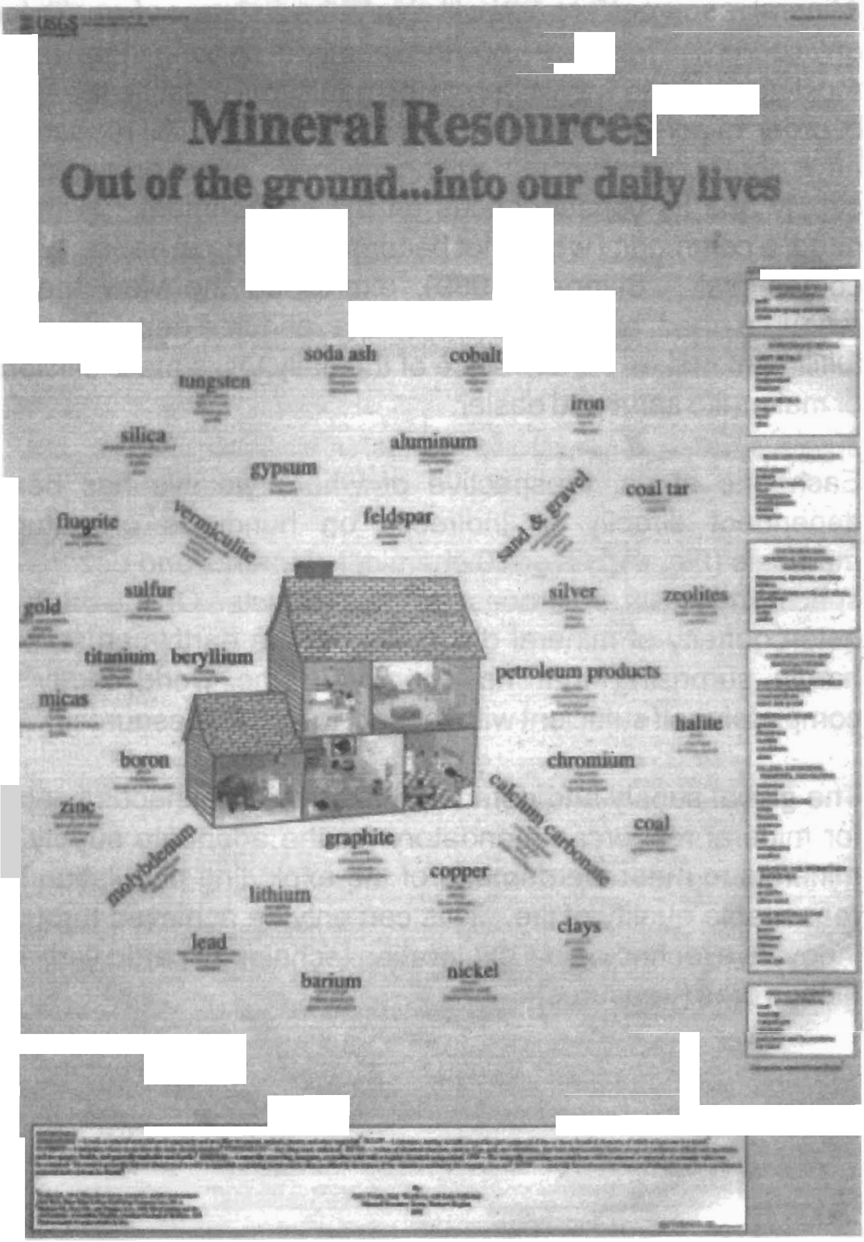


Figure 4: Mineral Resources; Out of the ground…into our daily lives

BASICS

The resources of metals are specific to certain elements. The average crustal abundance of economically important elements (Table 2) show that the metals are grouped into two groups as regards availability. It is noted that there are of course, enormous quantities of any metal available in principle in the earth's crust and in seawater, but the mineral deposits (which we mine) that can be exploited today are characterized by high concentrations. In regional terms, a mineral deposit can be considered as a point at which an element is concentrated many times its crustal abundance. It is the concentration in technologically recoverable form that allows the mineral's extraction and beneficiation at profit. The concentration factor varies from element to element. Table 3 shows the range of concentration necessary to transform crustal abundance to an average ore grade.

The exploitable sources of metals occur as minerals in which the metals are major components such as chalcopyrite ($CuFeS_2$) for copper, cassiterite (SnO_2) for tin and tantalum ($FeTa_2O_6$) for tantalite (Table 4). The first group of metals (those listed as geochemically abundant in Table 4) has concentration factors (the ratio of cut-off grade of one worth exploiting to the average concentration) that are small whole numbers. For example Aluminum with a cut-off grade of 30% gives a concentration factor of 4. For this group (aluminum, iron) there is no need to fear exhaustion. In contrast, the second group presents an entirely different problem. The main mass of these metals is found as trace minerals and are recoverable by processes requiring large amounts of energy and so destructive of the environment that today, are mostly out of reach. Therefore, recoverable concentrations of these scarce metals (Cu, Pb, Zn, Sn, Ta Hg, Ag, Au) occur where ore deposits of the minerals with these metals in abundance occur in workable deposits. The concentration factors of these metals are large. For gold, it is 4,000.

MINERAL SYSTEMS, METALLOGENY AND EXPLORATION MODELS

The process of ore formation belong to a "mineral system" which Wyborn et al., (1994) defined as all geological factors that control the generation and preservation of mineral deposits and hydrocarbon accumulation. There are four important components (Fig. 5).

- sources of the ore fluid, sulfur, ore metals, chloride and other ligands
- a migration pathway
- a chemical or physical trap that facilitates ore deposition or hydrocarbon accumulation
- an outflow zone.

Geological models are based on the knowledge of plate tectonics and local structural controls of known mineralization, hydrocarbon accumulation and other resources. In addition to these is what is known around the processes involved in their formation and the blend of commonly associated geological features.

The basic trend Derry (1979), noted has been to relate mineralization more closely to the conditions prevailing at the time of the formation of the enclosing rocks rather than the later geological events. A well known example is typified by the Noranda massive sulfide deposit of Canada once thought to have originated by hydrothermal replacement that took place millions perhaps hundred of million of years after the volcanic sedimentary host rock was formed.

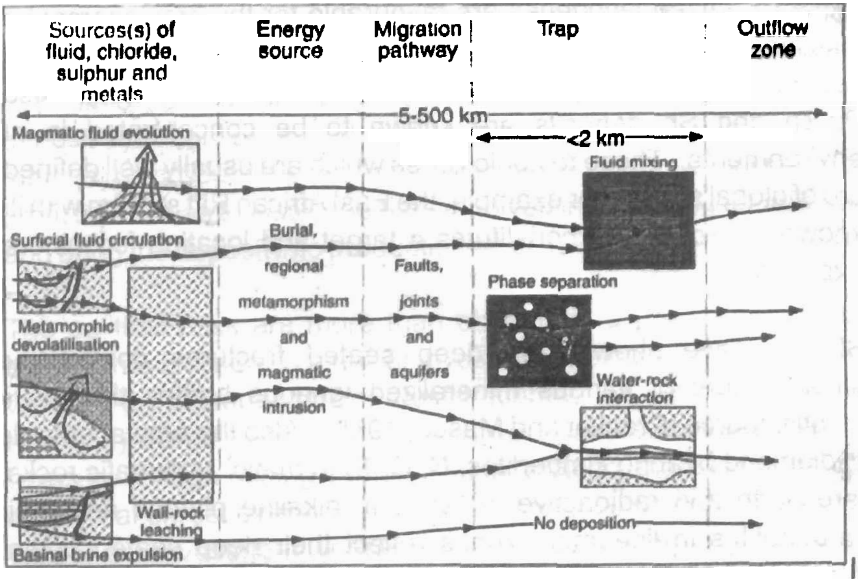


Figure 5: The components of a mineral system (modified from Knox-Robinson & Wyborn, 1997.

Today, most acceptable thesis (theory) is that the initial deposition of such bodies was approximately synchronous with the enclosing rocks, although recognizing that much later, remobilization played critical role where in most cases resulted in changing the final grade and mineral form in direction favorable to economic exploitation. There are many notable examples of the other types of mineralization, which now has shifted generally towards accepting *contemporaneity between ore and wall rock and towards surface or* near surface origin for many metallic deposits. This is a general concept in the selection of areas for concentrated exploration and has contributed significantly to the discovery of individual ore bodies.

Mitchell and Garson (1982) observed that there is an intimate relationship between plate tectonics and tectonic structural control of mineral deposits. It is well known that many ore deposits are developed at plate boundaries related to intercontinental ocean floor spreading and rifting, subduction zones and transform faults, whilst others are set in intracontinental environments after being controlled by major lineaments which are deep-seated structural features (Fig 6). Also, rifts-aulacogenes are favourable for the emplacement of alkaline igneous rocks, carbnonatites, enriched in minerals of economic interest (P, Nb, rare earths, Cu, Th, U, barite etc). Also, Pb-Zn and Sn deposits are known to be concentrated in rift environments. These tectonic zones which are usually well defined, are of global scale. For example, the East African Rift system with its known mineralization constitutes a target and location for mineral exploration.

Studies have shown that deep seated fractures control the emplacement of various mineralized igneous bodies that have mantle source (Crocket and Mason, 1968). Also the emplacements of diamond bearing kimberlites, Ni-Cr-Pt in mafic ultramafic rocks, rare earth and radioactive minerals in alkaline plutons and their carbonatites in lineament zones reflect their deep seated origin. Wright (1970) and Hollister (1975), showed that mineralized igneous rocks of crustal origin e.g. (porphyry Cu occurrences and tin deposits) were controlled and emplaced along fault and fracture systems (Fig.7). Although these two concepts or principles of contemporaneity and plate tectonics are general guides in target selection for exploration purposes they have directly aided exploration. In addition, a demonstration of complete and adequate knowledge of the region is required.

MINERAL EXPLORATION TECHNIQUES

The sequence of operations in an exploration programme is shown (Fig.8). All show the intricate process involved before an ore deposit is located. It is capital intensive and involves high risks. Lukman (1974) classified these risks as technical, economic and political. He aptly described the situation wherein the miner is regarded as a reckless gambler. However, we all know very well that if it had not been for this reckless and enterprising nature of the miner and his preparedness to take calculated risks, the world would have been very different from what it is today.

The technical risks are varied and start with exploration (geological mapping, remote sensing, geochemical and geophysical prospecting) through ore estimation and evaluation to processing. Economic risks is on return on investment i.e. given a mineral deposit that can be mined and technologically extracted, will the metal(s) be produced at profit? In other words, will the expectation on profit be such as to justify the risks involved in searching for minerals and bring the deposit into production when found?

The political risks are more than obvious in a politically unstable environment. There is a risk of investment being taken over with or without fair compensation. Just recently, on 2nd May, (CNN reported). Venezuela nationalized oil block, whilst Zambia increased taxes.for foreign mining companies. In addition, there is the danger of internal unrest over which the investors have no control and may render the investment worthless. In our contemporary situation in Nigeria the developments in the Niger delta region has had serious toll on the activities of the oil companies. Hence, companies therefore expect earlier return on their investment abroad than from investment in their home country.In order to minimize these risks through cost effectiveness, appropriate exploration techniques must be employed in the search for mineral resources.

Mineral exploration or prospecting is a whole of complex actions that lead to the discovery or (rediscovery) of a mineral occurrence and the valuation of its quantity (tonnage) and quality (grade). The purpose of this valuation is to determine the content of the mineral deposit and whether or not development is justified. The justification depends on a number of factors viz: quality. quantity (fade into insignificance) when considered with political, financial, fiscal legal or marketing problems that can make or break the viability of a mineral deposit. This leads to resource definition of Garrett (1977). Thus according to Garrett (1977), a mineral occurrence that is presently subeconomic could be discovered in many years later due to improvements in the economic situation and mineral technology thereby becoming exploitable.

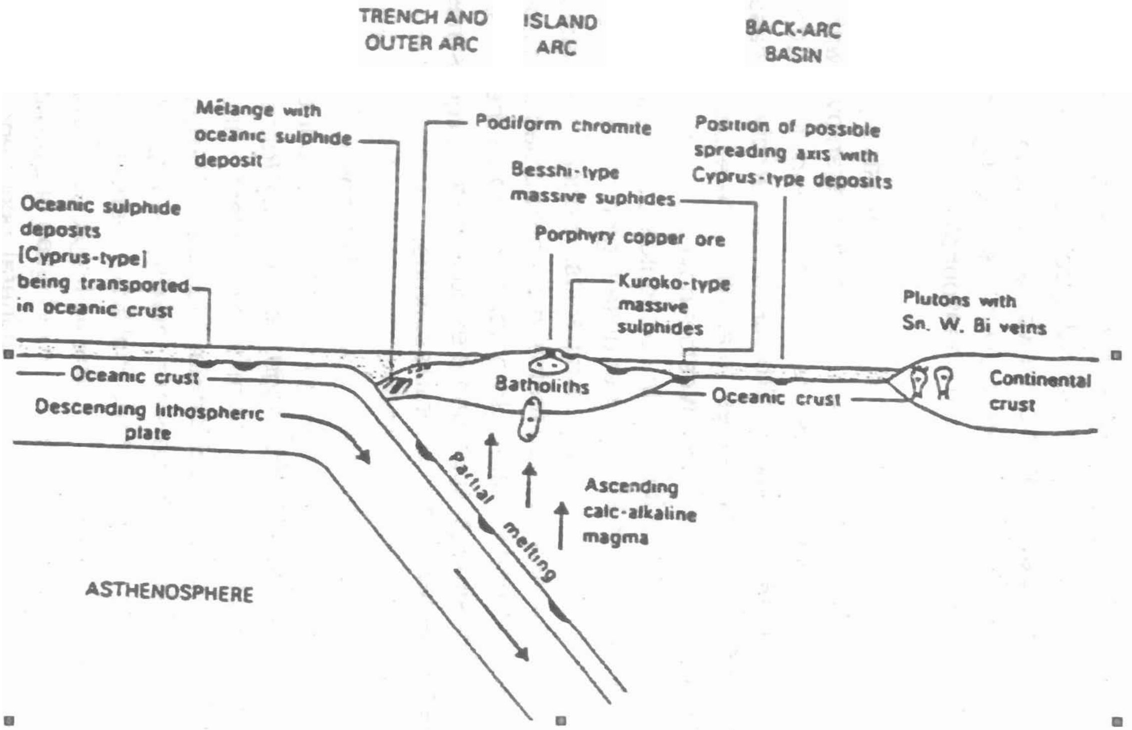


Figure 6: Diagram showing the development and emplacement of some mineral deposits in an island arc and its adjacent regions (Modified from Sillitoe, 1972 a, b)

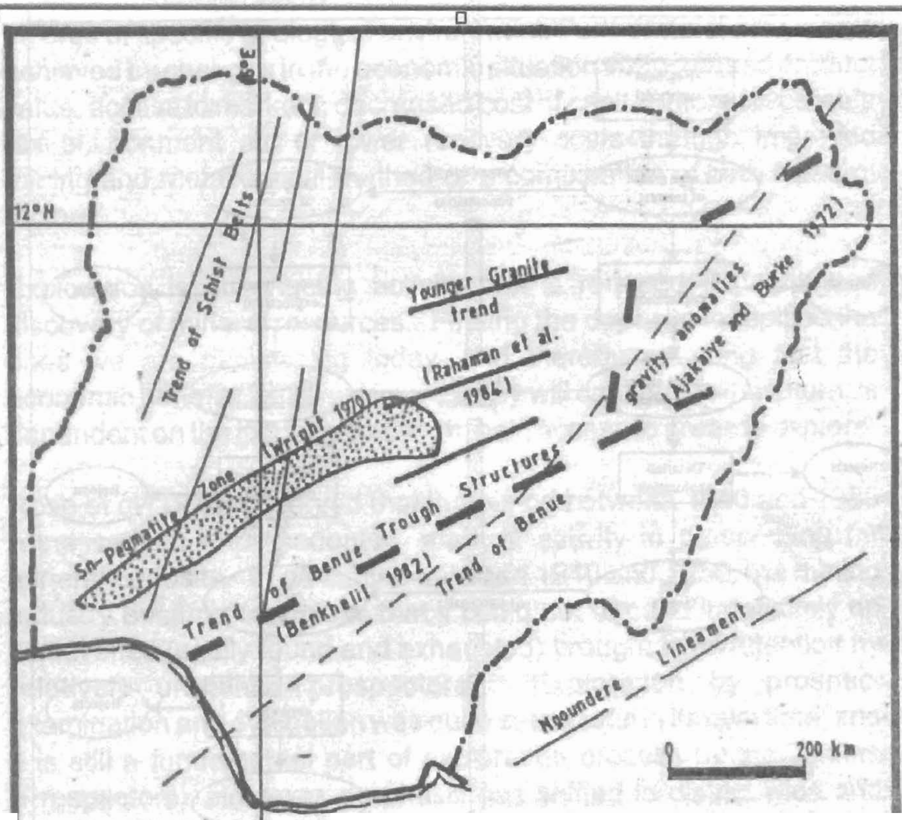


Figure 7: Tin-Bearing Pegmatite zone and regional features of Nigeria (After Wright, 1970).

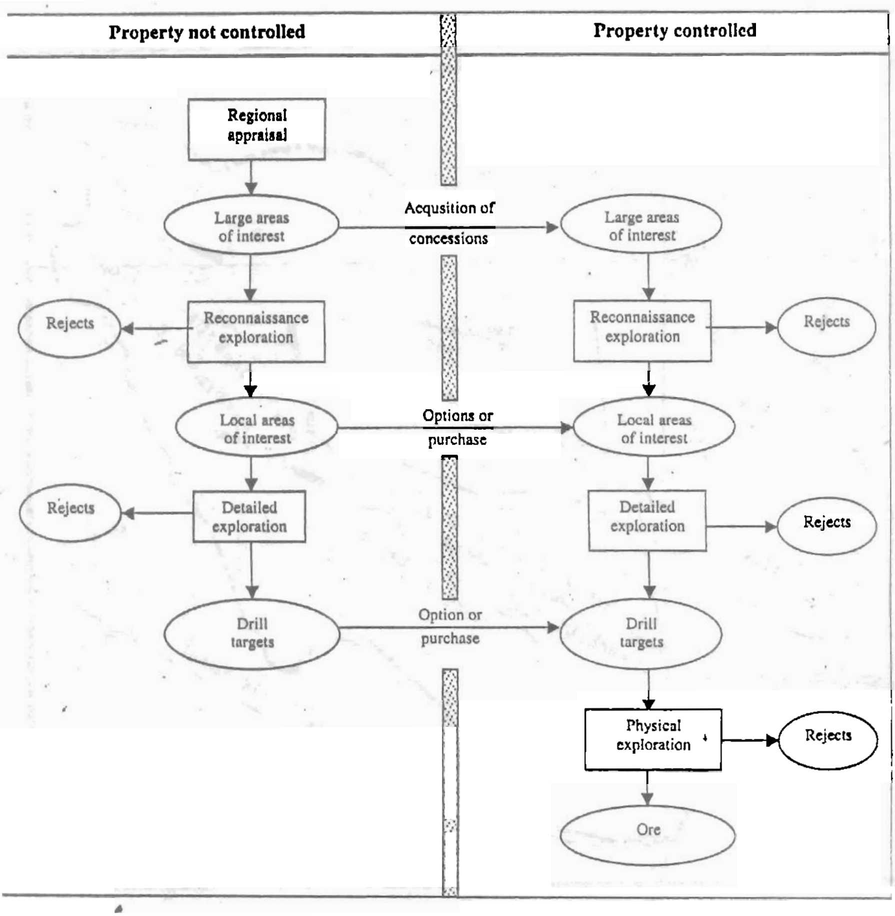


Figure 8: Sequence of operations in an exploration programme (Adapted from Rose, et al., 1979).

In effect, an occurrence can be brought into the resource cartegory with increased exploration effort, either by direct prospecting and various grassroots survey methods, or by a combination of office and field work where the office study leads to a new conceptual model for types of unknown deposit which allows the field work to be focused on ores of specific geological environment. Furthermore, progress is achieved by changes in the economic situation viz increased product value, access to markets, decreased cost of capital, more favourable tax environment etc or lower recovery costs through improved mining and metallurgical method or a combination of both types of factors.

Exploration is an ongoing activity that is required for continued discovery of mineral resources. Finding the deposits to replace the ones we are diminishing today, and thereby ensuring that the economic benefits we all enjoy presently will continue in the future, is dependent on the industry's ability to gain access to areas to explore.

Rose et al (1979) observed that the period between 1940 and 1980 witnessed an unprecedented scale of activity in prospecting for mineral deposits. In particular, between 1940 and 1960, the mining industry became conscious that it could not depend indefinitely on discoveries (easily found and exhausted) brought to its attention by relatively untrained prospectors. Exploration by prospect examination and evaluation was quite successful in its own time; and it is still a fundamental part of exploration process by the Juniors (Prospectors). However, emphasis has shifted to district wide and regional efforts and with the change in emphasis, there has to be change in the role of the independent prospector. This led to decrease in their numbers during the last half of the century, i.e. "their opportunities have shrunk with the depletion of near surface high grade ore deposits. With this situation, most mining companies developed a more consciously organized (systematic) approach to exploration and prospecting and focused attention to development of geologic guides to ore. In addition to the geologic activity, intensive efforts were directed to the development and application of new techniques of mapping geological structures and of detecting ores concealed (hidden) beneath the mantle of organic debris, soil or barren rock. This feature of (hidden treasures) are found in many countries within the tropical rain forest belt which mineral and energy resources lie beneath their forest and deep tropical weathering where in many cases exceed 100 metres thickness thus resulting in scarcity of surface exposures and limits the effective penetration of geophysical sensing.

The search for minerals involves area selection which is followed by careful mapping (field reconnaissance, remote sensing), geochemical sampling, geophysics and then drilling. An area selection in turn depends on the availability of data, the understanding of major ore deposit types and the use of appropriate technology to locate the deposit. Mclaurin (1997) concluded that the essential element in commencing an exploration programme is data. It is widely assumed that the developed world has the best data base and developing world the worst, which is true for basic geological information.

Figure 9 shows the different stages in exploration for an ore body which are largely governed by financial considerations.

Features of the figure are:

- Costs in turn are controlled by the nature of the method applied.
- Its efficiency and the areas that must be covered at a particular

stage of the search

- Fund available at each stage depends on the risk of not repaying

the outlay and the reasonable expected profit from the discovery.

- As the area of search is reduced by exploration and chances of making a find improves so more detailed sophisticated and expensive methods are brought into play.
- A project might be abandoned at any stage if exploration fails to make any significant impact on the risk.
- A geographic information system helps to assess objectively all of the available data throughout the exploration phase and may extend into the evaluation and operation stages.

The various techniques/methods in mineral exploration include:

- Geological field mapping
- Photogeological (Remote Sensing GIS)
- Geochemical
- Geophysical

These methods become increasingly attractive not only because they are able to detect concealed (hidden treasures) but also because they are cost effective particularly when applied to exploration of large areas. These days both geochemical and geophysical methods have developed to the extent that they have become routine use in nearly all mineral exploration programmes, and now account for a major proportion of exploration budget in the pre-drilling stage. The methods are justified by the large discoveries in which they have been an essential link in the chain of discovery. Exploration for mineral resources is therefore considered to be no more a haphazard process based on intuition, individual experience and luck, although all the three still play a role. Since the easily found and exhausted resources (solid minerals) become more scarce, and economic viability of production becomes more stringent, much more scientific basis is required in the search for natural resources. This is expressed in targeting and play generation.

EXPLORATION TECHNIQUES

Geological Mapping

Cooray (1994) stated that geological mapping involves the gathering of information by the field geologist about types, distribution and spatial relationship of rocks and rock materials at or near the surface of the earth and representing that information on maps. A geological map therefore is the representation on a flat sheet of the solid rock beneath our feet of weathered rocks which are seldom exposed at the surface except in highly glaciated areas of the world, mountainous areas, quarries, road cuts, streams and river sections or bare rock slopes.

The field geologist, Corray (1994) is concerned with looking for all the evidence seen on the ground e.g. rock outcrops, weathered

materials, soil and by deducing from such evidence what the solid geology is. This is represented by colours on a coloured geological map and by symbols on an uncoloured map. It is therefore the first step that provides the baseline basic data in exploration upon which subsequent data and effective interpretation depend.
Geological maps are on various scales. In developing countries, they are generally on 1:63, 360; 1:50,000; 1:100,000; or 1:250,000 depending mainly on the scale of topographic base maps available and the amount of information gathered. In the more developed counties, scales of 1:10,000 or more are common. In cases where detailed geological maps are required, they may be on 1:500; 1: 1000, 1:2,500.

The visible benefits of the huge sums of money invested in providing geological maps to the state and the community lies in their uses. The main purpose is to provide basic information on minerals, energy and water resources of any area. It is therefore a potential tool in the exploration, assessment and development of these resources. Such maps show the locations of economic minerals occurrences, mine sites, quarries, both in operation and abandoned. In addition, the solid geology shows which rocks are likely to carry groundwater i.e. the aquifers and the attitude and structures of the rocks as well as their joint and fracture systems. These are factors which determine the rock bearing capacities of the rock. In hard crystalline, non-porous rocks, joints and fractures are the channel ways for groundwater and ore bearing fluids (mineralizing fluids) hence joint and fracture sets are important indicators of groundwater sources in exploration for potential sites for borehole drilling.

In oil exploration, the types of rocks present, their porosity and structures are important in the evaluation of occurrence of oil in any particular area. Furthermore, potential investors in mineral raw materials must have good geological maps on which to base their evaluation of the industrial potential of a mineral. Without such maps, Cooray (1994) noted potential investors are sorely handicapped, not only for information on the mineral resources, but also on the materials needed for infrastructural services such as dimension stones and other building materials. Cooray (1994) thus concluded that, basic geological maps are a prime necessity for a country looking for industrial development based on mineral raw materials.

REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEMS (GIS)

The application of remote sensing and GIS in the survey of mineral resources as a scientific tool has proved very effective particularly at the reconnaissance stage of exploration programmes. The use or choice of any technique, however beneficial, must satisfy three basic requirements to prove its potentials:

- Need for the derived information
- Timeliness of interpretation
- Cost effectiveness compared to other methods.

In essence, the method or technique must meet the specific exploration objectives. Reeves et al (1975) defined remote sensing broadly as the measurement or acquisition of information about some property of an object or phenomenon by means of a recording device that is not in physical or intimate contact with the feature under study. This broad definition however includes amongst others, such exploratory practices as in geophysics, geochemistry as well as astronomy and medical diagnosis.

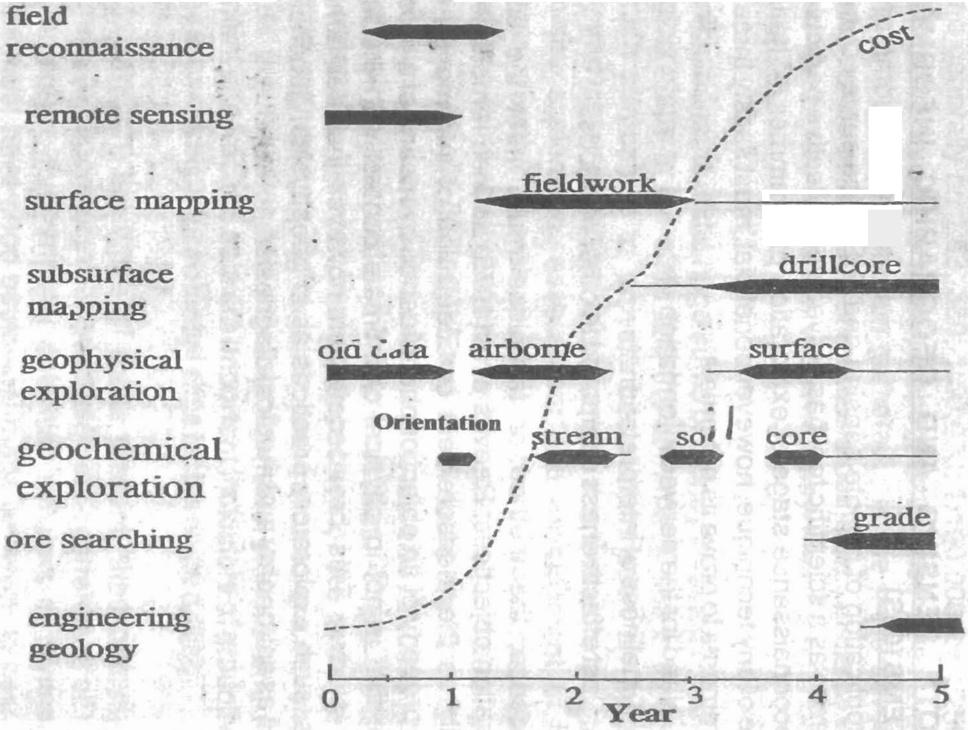


Figure 9: The different stages in the exploration for an ore body are largely governed by financial considerations (Adapted from Durry, 1987)

The term as currently used and in restricted sense denotes the "aerospace practices of measuring the ultraviolet, visible, infrared and microwave radiations emitted and reflected from the surface of the earth and from the atmosphere". In emphasizing the importance of remote sensing Gregory (1977) noted that the gap between remotely sensed data and information needed for mineral exploration will decline as long as government and industry fail to recognize the need for coordinated effort in order to develop future resources of ore much of which lie buried under soil and vegetation.

The mineral industry is a principal user of remotely sensed data. Of the many sensors available, the functionally remote sensing techniques of most interest to immediate potential use in mineral exploration are:

- Aerial Photography
- Side Looking Airborne Radar (SLAR)
- Landsat-Multi-Spectral Scanning Systems (MSS)

However, aerial photography and landsat are known to have been of greatest use in mineral exploration because of their relatively low cost, and are specifically applicable to mineral deposits controlled by structural or stratigraphic (lithologic) factors.

AERIAL PHOTOGRAPHY

This is a conventional low-latitude aerial photography widely used in mineral exploration. These are black and white photographs with high spatial resolution systematically acquired and extensively used in geological mapping of rocks and structure. Both the monoscopic and stereoscopic techniques are used in the interpretation of the black and white photographs and in their relevant geological applications. These are well documented in many studies (see for example Reeves et al., 1975; Allum, 1966).

Although color infrared (CIR) films have been produced, it has led to increase in cost. However, its use is recommended if only specific color contrasts the main interest in the target areas. Anderson (1963) observed that outcrop areas are more readily discerned on color photographs than on black and white at comparable scale. He therefore concluded that color films would be preferable if the criteria for recognition of rocks types were based on color contrasts that might not be separable on black and white films. Studies have shown that both color and false color (CIR) were not effective in identifying rock types (schists and amphibolites) and in distinguishing gossans from soils under arid climatic conditions (Gilberson et al. 1976). The overall consensus is that utility of multiband aerial photography has no advantage over the conventional photography since the former has proved ineffective in mineral exploration, although could provide specific data where the metallic mineralization is known to cause geological and/or botanical anomalies that are detectable with specified film/filter combinations.

Side - Looking Airborne Radar (SLAR)

Although SLAR has less resolution than for cameral systems, it has the unique advantage and capability for imaging through clouds, haze and darkness. It has contemporary application for obtaining timely and moderately detailed data about the terrain under conditions that are not favourable for photography.

SLAR is an active microwave sensing system that illuminates terrain to the side of the aircraft and records the backscatter or reflected returns on either magnetic tape or photographic film.

There are two types of SLAR. These are:

(i) Real Aperture Radar (RAR) which though is less costly but its spatial resolution (30 100m) varies with depression angle, range and altitude; and

(ii) Synthetic Aperture Radar (SAR) this is more expensive because it utilizes elaborate signal processing techniques.

It has been shown that SLAR is most useful for the study of near surface geological features. SLAR images assist in distinguishing surfacial materials, outcrop boundaries, fractures, foliations and other structures. The distinctions between rock types are more apparent in thinly vegetated or arid areas. However in thickly vegetated areas, distinction may be difficult unless different vegetation types are associated with specific rock types.

The synthetic aperture radar (SAR) has been flown over large areas of the remote tropical rain forest where persistent cloud cover precludes systematic aerial photography. The final maps are available in mosaics at scale of 1: 250,000. Such maps are available for parts of Brazil, Venezuela, Colombia, Peru, and Bolivia, Panama, USA and other countries. These maps provide valuable geographic and geological information for large areas about which little was previously known.

The application of this technique for geologic reconnaissance in artic regions of Alaska (Hanks and Guritz (1977) showed that it provided useful geologic information. The authors were able to discriminate between gross lithologic packages, as well as synoptic view of the regional structural framework.

The main value of SLAR systems for mineral exploration is related to the acquisition of regional information about remote, remote poorly mapped areas obscured by persistent cloud. SLAR data can be acquired very rapidly regardless of weather or lighting conditions.

LANDSAT (ERTS)

The systematic and relatively detailed exploration of the world's land areas from space started in July 23rd 1972 with the launching of experimental Earth Resources Technology Satellite (ERTS-1) by NASA. This was followed by similar ones in 1975, 1978 etc. These satellites provide data from 4-band Multi-Spectral Scanner (MSS).

Interpretation of landsat data for mineral exploration is based on the recognition of tonal contrast, shapes, and pattern using standard photo-geologic techniques (Gregory and Moore, 1975). The main value of landsat data in the search for ore bodies lies in the regional view and the moderate level of detail that is presented in either single frame or mosaics.

The information obtained from interpreted landsat can arm mineral exploration with mapping of major geologic units

- discrimination of rock classes (eg. aluminum, sedimentary rocks, metamorphic rocks, granitic gneisses, intrusions, volcanic cones and flows)
- mapping of structures (lineaments)

detection of alteration zones and other broad surface expression of mineralization.

Digital processing of landsat data had been developed to retain textural information in a modified image. These images in arid regions were found useful in discriminating among rock types (Podwysocki et al, 1973; Rowan et al, 1976).

The discrimination of altered zones related to ore bodies had received attention. The use of enhancement of reflectance minima resulting from absorption bands representing ferric iron (primary limonite) and hydroxyl clays. Furthermore, stretched ratio enhancements have been used to discriminate both limonitic and siliceous hydrothermal alterations in Tertiary volcanic complex in Nevada desert. However, both shale and siltstones could not be separated because of similarity in composition.

The analysis of crustal features, which appear as lineaments on landsat images help to define the tectonic environments most favourable for the location of mineral deposits. These environments, Katz (1982) indicated, are the dilational – tensional regimes associated with lineament or fracture-fault systems where ore-bearing solutions and exhalations or ore-bearing igneous rocks can be emplaced. Mineral deposits associated with such lineaments include Pb, Zn, Ag, Sn, Mo, U, Au, rare elements and graphite.

The recognition of crustal features on the scale of landsat images improves the chances of discovering new ore deposits that often can not be identified by any other methods. Of interest also, is the location of deep seated fractures which are potential channel ways for mineralizing solution and ore-bearing igneous emplacement. In particular, recognition of lineament intersections, which represent significant loci or targets for potential mineral exploration, is an invaluable contribution of lineament analysis (Fig. 9, 10). When this is used in conjunction with other available geological, geophysical and geochemical data, they are invaluable in planning mineral exploration programmes.

Landsat lineament analysis has proved to be an excellent tool for reconnaissance exploration in new mineral provinces. It allows for rapid structural-tectonic interpretation of large areas and focuses attention on specific targets. Ability to effectively analyze large areas of potential mineralization at minimum cost makes this technique of particular interest in developing countries embarking on mineral exploration programmes. As a result of its relatively low cost the maxim is that "No regional exploration programme should proceed without preliminary analysis of carefully selected images".

Apart from using images for mapping, geologists also make use of the spectral information to distinguish argillic and propylitic alteration (hydroxyl and non-bearing minerals). Aircraft scanners are known to be discovering new areas of alteration in Australia, Chile and Nevada, which may be related to epithermal gold mineralization.

GEOGRAPHIC INFORMATION SYSTEMS (GIS)

The critical assessment of the information acquired at various stages of exploration to narrow down the search and eventually pinpoint the deposit forms the basis for both planning and application of GIS. The application of GIS therefore, for geological work is best illustrated by exploration. Targeting or play generation approach to exploration does not only set out the regional and local geological factors which favour formation of some resources, it also helps to define the physical and chemical peculiarities and associations involved. It is in the light of the foregoing that GIS has proved to be of tremendous application in geology and mineral resource development.

Virtually all the geological data including coordinates, textural characteristics, structural attributes, attitude, formation boundaries, geophysical, petrophycial, geochemical and biological (paleontology) analytical and paleoenvrionmental data spatially reference data are best displayed through the use of GIS. There is thus the need for the geologists and mineral resource personnel and experts to develop expertise and infrastructure in the varied application of GIS.

Geological data for GIS often take the following forms:

- Values of variables at a point (elevation, geochemical and gravity data, borehole record, direction of dip, etc).
- Continuous records along a line (seismic profiles, airborne geophysical data, etc).
- Units designated as homogenous (lithostratigraphic units, vegetation maps).
- Lines expressing relationship or linear categories (faults, roads, intrusive contacts); and
- Continuous or semi-continuous tone or color lineages (remotely sensed data).

Irrespective of the nature of geological data, it is best presented in map form. These chores that were previously done by hand can now be done faster and more accurately using computers in a GIS medium. The GIS employs two related formats, vector or grid, which is important in map-oriented GIS, and the raster format which is the basis of image-oriented GIS. The later is used in the interpretation of exploration data and in the generation of exploration targets and models of subsurface structures.

Some of the software used in geological application of GIS include: Arc View, Arc Info, Map Info, ER-Mapper and ER-Radar. However, Kenny (1996) noted that currently there is an evolution in spatial data analysis and manipulation that has a great impact on geological sciences. Many spatial analysis functions, once treated separately and analysed by separate software packages can now be found in single spatial analysis software package. It is now common to find functions of Image Analysis Systems (IAS), Vector, Geographic Information Systems (GIS), raster modeling Geographic Information Systems, Computer Aided Design (CAD) systems, geophysical processing software, and 3-dimesnisonal modeling software available in one package.

In a study of a 2.5 dimensional metallogenic GIS analysis of the mt Isa geodynamic transect, Wyborn et al, (1996) showed that most of the major structures that are both associated with mineral deposits and visible in the seismic data are inclined and terminate in mid-crust. They further concluded that the mineralizing fluids were not sourced from the deep levels rather, they appear to have been derived from either sedimentary basinal brines or shallow magmatic and/or metamorphic processes. The major faults are believed to have provided distributory channels for the mineralizing fluids derived from these shallow crustal levels. The results from this study emphasize the role of migration pathways in mineral systems.

GEOPHYSICAL EXPLORATION

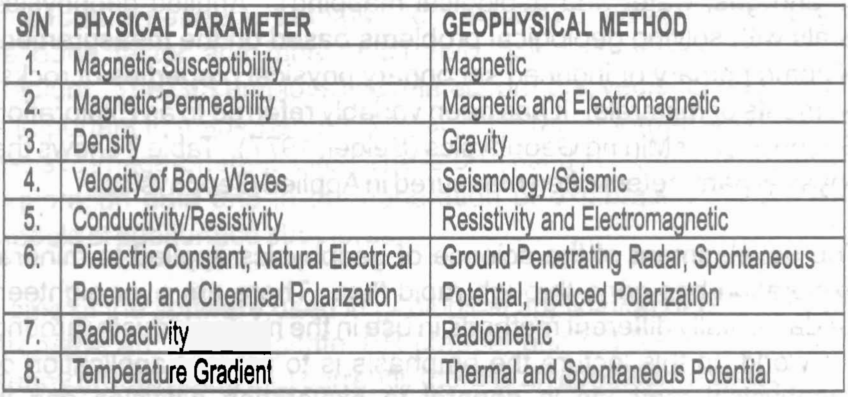
Although geophysics deals with all aspects of the earth, its atmosphere and space (Telford, et al, 1960), it has found great application in the search for mineral resources (Metallic, industrial, oil and gas, water and geological mapping). Applied geophysics deals with solving geological problems based on the measurement of some primary or induced secondary physical properties of rocks, elements or minerals. It has been variably referred to as Exploration Geophysics or Mining Geophysics (Seigel, 1977). Table 7 shows the physical parameters often measured in Applied Geophysics.

The development of the science of geophysics applied to mineral exploration has gone through rapid flux. There are over eighteen fundamentally different methods in use in the mining industry around the world. In this lecture the emphasis is to present application of geophysical methods in general to exploration activities and in particular, in the search for hidden treasures.

In the field of regional geological mapping, the magnetometer has remained the primary airborne geophysical tool indicating the distribution of the various rock types and the minerals through their variations in magnetic susceptibility and remanent magnetization. These days, X-ray spectrometer is a common constant companion of the magnetometer for regional airborne surveys, thus providing basis for the classification of rocks or soil types based on their contents of potassium, Uranium and thorium.

Exploration mining geophysics had been shown to be highly successful in the discovery of buried hidden base metal ore bodies of many types and in many environments. In particular, the Electromagnetic (EM) induction techniques had been the most successful in the search for massive sulphide bodies whilst the Induced Polarization (IP) proved effectively for disseminated sulphides. Massive sulphide bodies commonly have electrical conductivities in the order (1000 10,000 µs/m) which are two to four orders of magnitude higher than those of their host rocks. For large areas with favourable rock types it is suitable to employ airborne EM (known for cost effectiveness) for reconnaissance for target selection.

TABLE 5: PHYSICAL PARAMETERS MEASURED IN APPLIED GEOPHYSICS



S/N	PHYSICAL PARAMETER	GEOPHYSICAL METHOD
1.	Magnetic Susceptibility	Magnetic
2.	Magnetic Permeability	Magnetic and Electromagnetic
3.	Density	Gravity
4.	Velocity of Body Waves	Seismology/Seismic
5.	Conductivity/Resistivity	Resistivity and Electromagnetic
6.	Dielectric Constant, Natural Electrical Potential and Chemical Polarization	Ground Penetrating Radar, Spontaneous Potential, Induced Polarization
7.	Radioactivity	Radiometric
8.	Temperature Gradient	Thermal and Spontaneous Potential

This is followed by other ground-based methods (gravity, IP etc) for detailed exploration and in particular for greater precision of location, which is desirable for drilling purposes. Environments such as in the Canadian Shield where outcrops are few and the soils are of the transported glacial origin, geophysical data alone may have to be relied upon for drilling decision.

This type of exploration approach Airborne Electromagnetic (AEM) has been quite rewarding in the search for strata-bound Cu - Zn and

Pb - Zn deposits particularly in Precambrian environments. Also, similar success were recorded in the exploration for nickelferous pyrrhortite deposits associated with ultrabasic intrusive. Seigel (1977) observed that the success ratio of AEM surveys around the world has been highly variable. In the temperate and artic areas the geophysical conditions are generally good, with little oxidation and only moderately conducting soils. The environment viz: Canadian Shield and in particular the Baltic Shield, which provide good geophysical and physiographic environments for this exploration technique and many major strata bound base metal bodies usually of the Cu - Zn types and Cu - Ni sulphide bodies were discovered using AEM technique.

In contrast, the application of these techniques in areas of deep tropical weathering, such as arid and semi-arid exemplified by Australia, has been far less rewarding because of a number of fundamental adverse conditions amongst which are

- Weathering processes easily oxidize a massive sulphide body to 50m. depth.
- Conductors of graphitic serpentines and saline origin may persist through the ground surface.
- Semi arid and tropical soils are often highly conducting.

The Induced Polarization (IP) method is the primary follow-up electrical exploration tool in ground geophysical exploration for base metal deposits in particular for (disseminated) porphyry copper, contact metamorphic Cu- and strata bound deposits. It is a preferred exploration tool in the search for massive sulphide (Cu-Zn) or nickelferous sulphide deposits in areas with highly conducting surface bodies. Examples of such environments include Australia, South Africa and many wet tropical countries. This method has proved useful in resolving conductors of ionic origin (bedrock, troughs, shear zones) from those of electronic origin (sulphides or graphite). Seigel (1974) reported results of multi-channel time-domain IP, a Magnetic Induced Polarization (MIP) method in the discovery of nickelferious pyrrhotite body in ultrabasic rocks in Kambalda Western Australia, under about 30 meters of oxidation.

The ground Electromagnetic techniques have basically three types of Continuous Wave (CW) systems actively used in field surveys. These include

(i) Vertical loop or tilt method - used for follow-up of AEM in forest areas of high relief.

(ii) The Slingram or Horizontal loop - This is a preffered method for majority of conducting base metal deposits except for very deep ones (>100m) and areas of rugged topography.

(iii) The Turam (fixed source gradient) is best applicable in the search for deeply buried conductors or in rugged terrain. It has recorded successful detection of sulphide bodies under >150m of cover.

In the 1980's the pulse EM techniques (UTEM-EM 37) were developed to allow geophysists probe deeper. There are claims of detection of graphitic conductors below 400m of resistive sandstone in the Athabasca basin, Canada. Also, the discovery of the flat-lying Hellyer massive sulphide in Tasmania below 130m of volcanics is attributed to the drilling of a UTEM anomaly.

The greatest advance started in the 1980s with the development of computing power that has enabled the geophysicist to process and interpret complex geophysical surveys. These days many adaptive programmes with 2D -3D and even 4D on interpretation are available in the market. These have greatly enhanced the quantity, speed of geophysical data interpretation.

The radiometric survey techniques using X-ray spectroscopy provides the geophysicists a unique, powerful, rapid and relatively cheap tool which is direct that it can possibly yield actual U-grades. The methods available include both airborne and ground radiometric uranium exploration techniques. A variant of this technique is the radon soil-gas measurement based on alpha (α) detection which is also popular for uranium exploration particularly with the hope of expanding the range of detection of buried hidden deposits. However, more use has been made of radiometric surveys in geological mapping both in the desert and the tropics. An example of the latter is our study on the Campus where the radon-soil-gas technique was used to map the two faults in the campus (Ajayi and Adepelumi, 2002; Adepelumi et al; 2005).

GEOCHEMICAL EXPLORATION

Geochemistry is broadly defined as the science dealing with the Chemistry of the Earth with the following sub-divisions (Levinson, et. al., 1980)

- Exploration Geochemistry
- Geochronology
- Stable Isotope Geochemistry
- Organic Geochemistry
- Sedimentary Geochemistry

- Hydro geochemistry
- Lunar and Environmental Geochemistry

Regardless of these sub-divisions, the primary aim of geochemistry is to solve geological problems. Goldschmidt generally referred to as the father of geochemistry briefly gave a concise definition as "the study of the amounts and distribution of the chemical elements in minerals, ores, rocks, soils, waters and the atmosphere".

Boyle, (1979) defined exploration geochemistry as the application of geochemical and biogeochemical principles and data in the search for economic deposits of minerals, petroleum and natural gas. Depending on the mode, there are several classifications. However, based on the Earth's geospheres which provide sampling media, it is classified as: Lithogeochemistry, Pedogeochemistry, Hydrogeochemistry, Atmospheric Geochemistry and Biogeochemistry.

Exploration geochemistry is based on the fundamental principle supported by vast amounts of empirical data that the chemical composition in the easily sampled materials of the earth's crust generally exhibit an increase in the vicinity of mineral deposits or accumulation of hydrocarbons from those of similar materials where there is no mineral deposit (barren). These differences which are strongly sought are manifested by the primary and or secondary elemental dispersion halos, trains or fans in these easily sampled materials (rocks, soils, stream sediments, waters, vegetation or even the atmosphere). The search for these differences is carried out by the systematic determination of one element or dozens of elements as well as the determination of such factors as pH, Eh, and conductivity in these samples.

In practical terms, the following problems can be solved with exploration geochemistry.

(i) Location of regional metallogenic zoning and geochemical predictions based on the distribution patterns of chemical elements i.e. the search for indicator elements of ore in stream sediments drainage basins, igneous and sedimentary geologic complexes.

(ii) Search for mineral deposits exposed by erosion and later covered by unconsolidated sediments based on secondary geochemical dispersion halos in stream sediments, alluvial talus deposits, soils, vegetation natural waters and air.

(iii) Search for hidden ore deposits and assessment of ore occurrence at deep levels within the hidden flanks of mineral deposits, which have already been exploited.

(iv) Exploitation for oil and gas.

(v) Solving a range of purely geological problems such as;
    a) geological mapping particularly in areas of deep weathering with poor rock exposures.
    b) determination of inter-relationship of igneous rocks within an intrusive volcanic series.
    c) ascertain requirements of sedimentation and establish stratigraphic correlation in sedimentary suites
    d) study the characteristics of metasomatic processes in various rocks.

(vi) Environmental problems.

In the search for concealed natural resources, the primary objective is to locate some dispersion of elements or compounds sufficiently appreciable above normal to be called an “anomaly” which presumably is indicative of mineralization or hydrocarbon accumulation (Fig. 10(a), 10(b). Basically, exploration geochemistry is the search for abnormal chemical concentrations or geochemical anomalies. This technique is well suited for the search for low grade deposits especially those difficult to recognize visually (viz gold deposits of Carlin Nevada). In environments such as Western Australia, geochemistry has been a fundamental science in the discovery of many world class mineral deposits (Shear hosted Archean lode gold deposits; lateritic and sulphide nickel deposits of Eastern Gold Fields; etc) and a core activity in most current exploration programmes. Western Australia on a world scale, contributes 10% of world's gold production, 11% of Ni, 35% tantalite, 14% of iron-ore and 33% of Zirconium and rutile. It also accounts for 10% of the world exploration expenditure in the Year 2000. The extensive and thick regolith cover found in many parts of this region has presented unique challenges to exploration geochemistry and many new geochemical techniques (e.g. lag and calcretre chemistry, partial extraction and selective leach chemistry) were either developed or tested.

Recently, new advances in mineral exploration mapping are the development of regolith geochemistry as a powerful mineral exploration tool. This development began with work by CSIRO and In Cooperation with Cooperative Research Centre for Landscape Evolution and Mineral Exploration (CRC-LEME). With the knowledge of Australian landscape evolutions applied regolith geochemical studies as a vital part of the strategy in the search for concealed world-class ore deposits. Their work were concentrated on areas of deeply weathered regolith where fresh and mineralized rocks may be covered by many tens of metres of saprolite rock which as been weathered <u>in-situ</u> that its original constitutions is difficult, if not impossible, to identify
The advantage of geochemistry is that it is a direct method which measures the actual element sought or an associated (pathfinder) element in order to detect the anomaly. Historically, the application of chemistry to mineral exploration is not all that new with the reported work of the first successful geochemical prospecting carried out by Giovanni de castro, a Geonese in the middle 15th

century. He observed a particular type of plant that characteristically grew near the veins. Similar plants were found on the hills of Tolfa in Rome. Further work revealed the presence of “alumite float” and later the viens from which it came. This led to the discovery of an important alum deposit.

In the early 1930s, exploration geochemistry gained prominence in Russia and the Scandinavian countries. After the World War II, various methods were introduced into the USA, Canada, Great Britain and other countries where they have since been extensively used in mineral and petroleum exploration programmes by both mining companies and government agencies.

The 1970s witnessed a widespread introduction of cheaper and better analytical methods (AAS, ICPMS) whilst newer techniques were introduced in response to industry demands. For example, the need to locate gold mineralization in Australia during the boom led to the development of the technique, bulk - leach extractable gold (BLEG) sampling for very finely dispersed gold. The technique has a detection level of 1 ppb, and has application in a wide variety of geologic environments. The rapidly expanding scope of geochemistry is largely due to the advances in sampling,

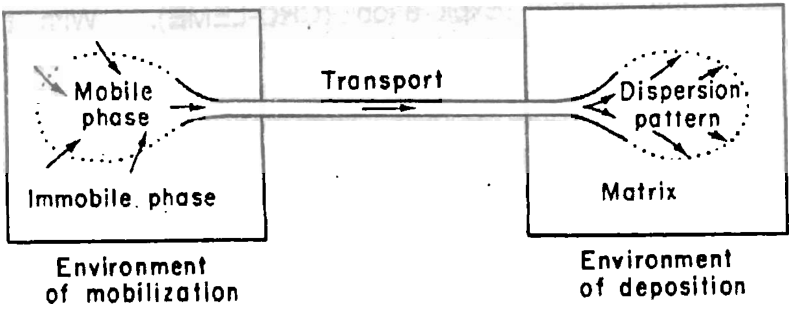


Figure 10a: The dispersion process
(Adapted from Rose, et al., 1979)

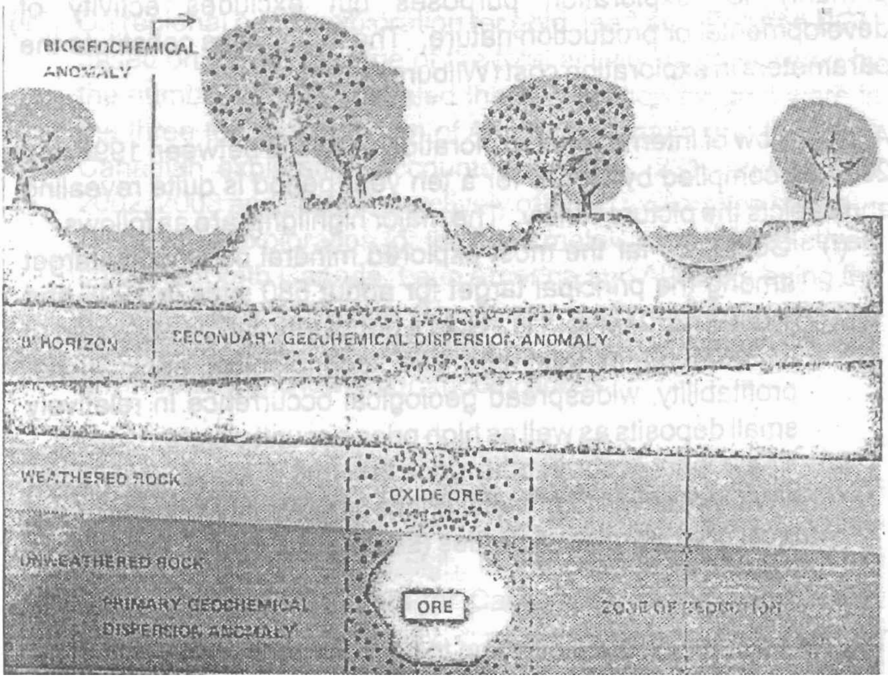


Figure 10b: Sketch showing basic conditions allowing geochemical exploration (After Bradshaw, et al., 1972)

Analytical and computerized interpretational procedures. These advances must be matched with the understanding of the factors affecting the distribution of elements during weathering and dispersion process.

INVESTMENT IN EXPLORATION AND SUSTAIN ABILITY

"Seek and ye shall find" - (Matthew Chapter 7 vs. 7). Exploration is the 'lifeblood' of the minerals and energy industry. Finding new deposits and reservoirs to replace the ones we are diminishing daily and thereby ensuring economic benefits we all presently enjoy will continue into the future, is dependent on the continued investment in exploration by both the industry and government.

Exploration involves the search for new ore occurrences or undiscovered oil and gas and/or appraisal intended to delineate or greatly extend the limits of known deposits of minerals, oil or gas reservoirs by geological, geophysical, geochemical, drilling or other methods. It also includes the construction of shafts and adits primarily for exploration purposes but excludes activity of developmental or production nature. These activities constitute the parameters in exploration cost (Wilburn, 2005).

An overview of international exploration activities between 1995 and 2004 as compiled by USGS for a ten year period is quite revealing and depicts the picture vividly. The major highlights are as follows.

(i) Gold is by far the most explored mineral commodity target among the principal target for about 580 sites in 1995 and 1,800 in 2004 (Fig. 11). Gold's popularity can be attributed to its demand in aesthetic and technological applications, profitability, widespread geological occurrence in relatively small deposits as well as high price per unit weight.

(ii) The impact of commodity price in terms of active exploration sites. (See Fig. 12). Metal prices significantly influenced the level of exploration activities (see Figures for Au, Cu, Ni, and PGM).

There is a tendency for exploration to lag commodity prices by about a year so that when prices increase; exploration in the following year tends to increase. In the case of nickel (Fig. 10c) price decreased from 1995 to1998, then rebounced between 1998 and 2000. The price increased to $6.27/lb in 2004 from $2.7/ib in 2001 primarily owing to increased nickel demand from China. Exploration follows a similar pattern, and activity doubled as Ni price increased during the period 2001 2004.

For the Platinum Group Metals (PGM), exploration activity remained relatively low while prices remained low. In 2000, average prices of ruthenium, rhodium, palladium, and platinum increased by 219%, 120%, 90% and 45% respectively. This was a s a result of increased demand in the automotive sector (Palladium, rhodium), unstable Russian supply (Palladium) and increased use in the aerospace and electronics sectors (ruthenium). Higher PGM prices were followed by an increase in the pace of exploration, even decrease in prices in 2001 and 2002 did not dampen exploration because of expected increases in demand for PGM in the automotive, jewelry, and other industrial applications.

(iii) On regional basis, exploration for gold, lead and zinc and PGM based on the percentage of the total activity as determined by the number of sites revealed that exploration for gold were in the three top regions Latin of America, Canada and the USA. Canadian exploration accounted for 18%, 23% and 30% in 2002, 2003 and 2004 respectively of world exploration budget. The level of exploration for the base metals remained relatively consistent with Canada, Latin America and Australia being the principal regions of focus. The search for Pb and Zn in USA has decreased since 1995 primarily as a result of concern for the environment and lower commodity prices.

Exploration for PGM in 1995 was dominated by Africa (South Africa), however the focus shifted on other countries/Australia, Finland, Russia, Zimbabwe between 2001 and 2004 because prices for platinum continued to remain high. In the case of non-fuel mineral community exploration targets for Canada, Australia, Africa, Latin America and the USA., generally, in all these regions, gold was the most sought after mineral commodity where exploration activities accounted for an overall average of between 56%, 50%, 70%, 60% and 75% in these regions.

The worldwide exploration budget as compiled by Metals Economics Group (MEG) for non-ferrous exploration in 2006 show a steady increase through the early 1990s to a maximum of $5.2 billion in 1997 (Fig. 13) before declining for a five year period when it reached a low of $1.6 billion in 2002 and decline of 63%. Since 2002, the estimated total has risen for four consecutive years to set a new high water mark for worldwide non-ferrous exploration. Based on the analyses of 1,624 companies and using $100,000.00 cut-off, the total budget peaked at $7.13 billion which represents about 95% of worldwide commercially oriented non-ferrous exploration expenditures.

The five year low during the twelve year period has been attributed to the following factors.

- Substantial cutback by the major mining companies

- Negative impact of industry consolidation
- Loss of funding for most junior companies.

However the world wide initial increase in exploration since, is explained by the following factors.

- Increased spending by the major mining companies as they recognized the dearth of new projects
- Significantly reduced industry consolidation from peak levels in 2000 and 2001.
- Increased spending by the junior sector due to higher gold price and the rising investor interest.

As the price of gold continued to rise and as the prices of other commodities began to reach long-term highs, the yearly budget increases by the majors in their struggle to replace mined reserves and the meteoric increases by the juniors pushed the estimated worldwide exploration total to the 2006 high.

The trend in exploration budgets for worldwide non-ferrous metals show that more is being invested in exploration more than a decade ago even inspite of the rising cost

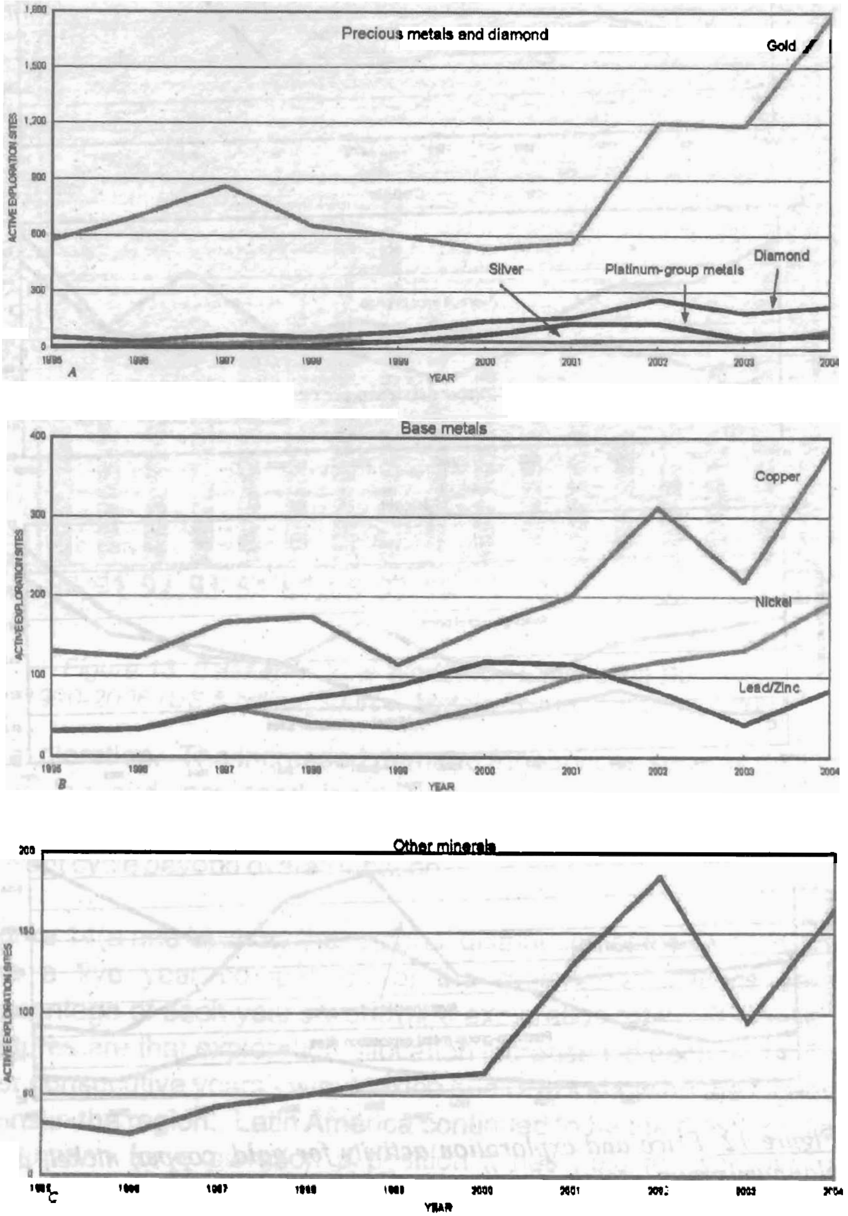


Figure 11. Graph showing principal mineral commodity targets for worldwide exploitation after Wilburn, 2005.

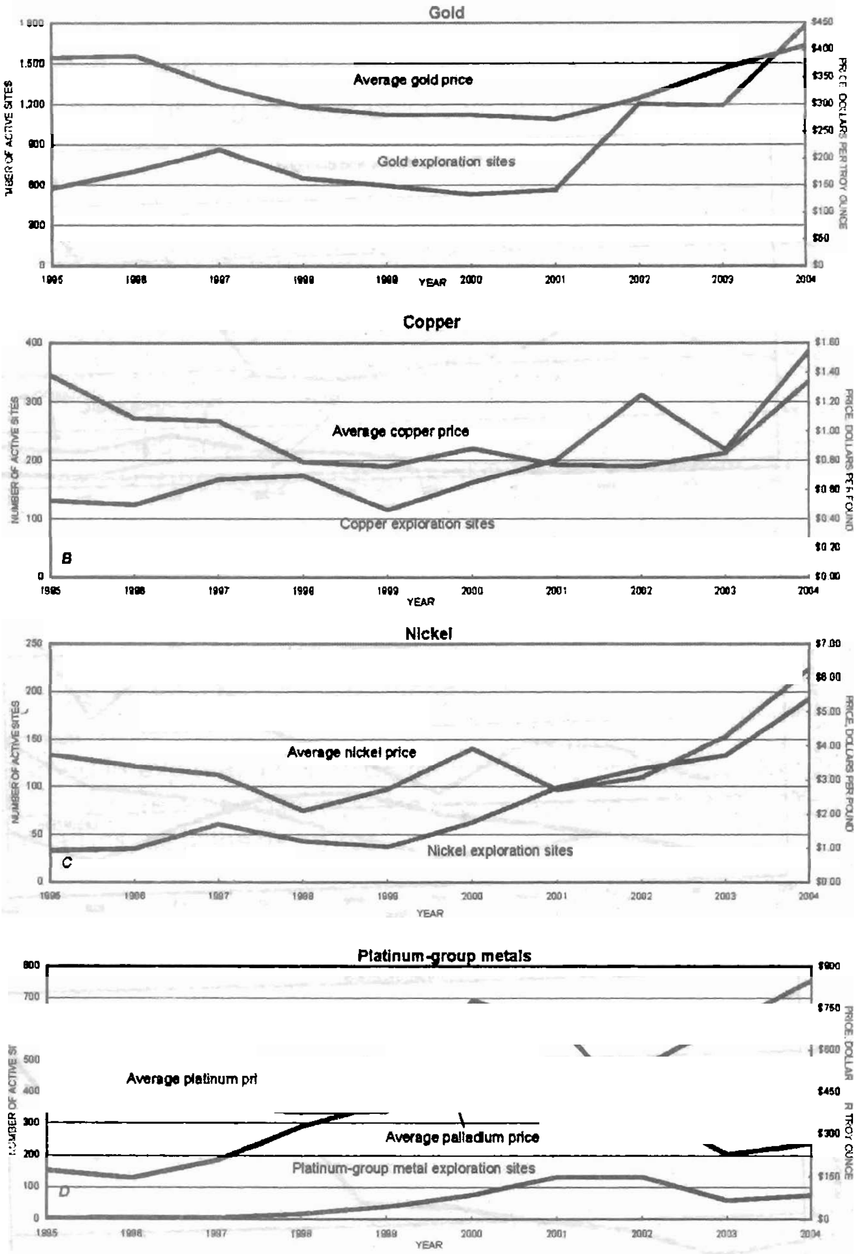


Figure 12. Price and exploration activity for gold, copper, nickel, and platinum-group metals (iridium, palladium, platinum, rhodium, and ruthenium) for 1995 through 2004. Exploration activity is expressed in terms of the number of active exploration sites after Wilburn, 2005.

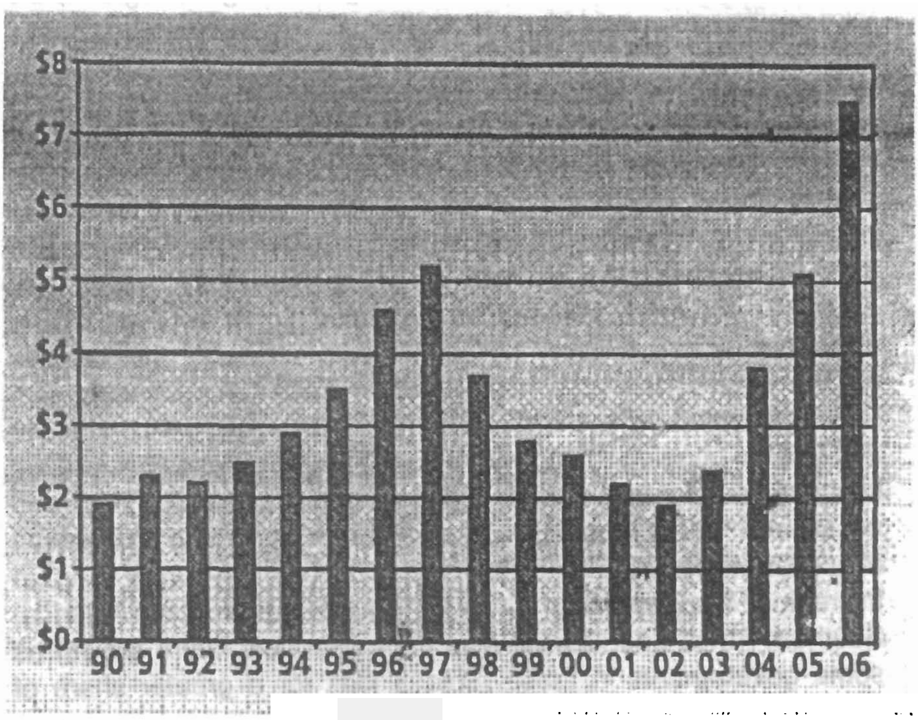


Figure 13: Estimated Total Worldwide Exploration Budgets, 1990-2006 (US $ billion(Source: Metals Economics Group, 2007).

of exploration. The increased demand for services such as drilling, assaying and increased input costs on all things from fuel to geoscientists have significantly increased cost of exploration in the current cycle beyond overall inflation.

Figure 14(a and b) show the regional distribution of the $7.13 billion and a five year comparison of the regional allocations as a percentage of each year's worldwide exploration total. The salient features are that exploration allocation increased in each region for four consecutive years - with Mexico and Brazil showing the highest gains in the region. Latin America continued to be the most popular destination for exploration a position it has held for well over a decade maintaining its lead for the third consecutive year over Canada. The interest in new under explored regions continued to rise in 2006 as highlighted by the increased allocation to the rest of the world regions (Europe, former Soviet Union, Asia and Middle

East) led by substantial increase in Mongolia lifting the region to the third position ahead of Africa which held the third place since 2003.

Another significant feature in the trend is the increased allocation to (Asia, former Soviet Union, Parts of Africa and some Latin America) regions traditionally perceived as to have higher political risk. This shift is partly due to the perception that traditionally lower risk countries are already well explored and the growing acceptance that the discovery of large-scale deposits will be more likely in higher-risk areas. Furthermore, some of the perceived higher risk regions and areas are moving towards political stability although uncertainties such as threat of resource nationalization which dampen exploration remain. Inspite of this, the prediction is that the trend will continue in 2007 as the ongoing struggle to replace reserves makes exploration in emerging markets the norm. For example, the impact of this trend as exemplified by Venezuela shows a fall by 40% in exploration allocation in year 2006 which has shifted her position from 6th to 11th in the region. Also the shift in tax and royalty regimes in South America, Southern Africa and Central Asia may also slow future growth as some governments in these regions look for a greater share of increased mining company revenues.

The exploration budget allocation by target to all commodities (Figs. 15(a and 15b) reveal that gold, base metals, diamond, PGM, and other targets primarily silver, molybdenum, cobalt, mineral sands and industrial minerals reach record levels in 2006. The future trend suggest the continued junior led boom in exploration is largely dependent on the junior companies ability to raise capital if highly motivated by continued strong metal prices which will help to maintain investors interest for the short term. Furthermore, the reserves replacement requirements and growth aspiration of the majors and intermediate companies coupled with the rising cost of replacing reserves through acquisition will ensure that exploration will continue to be important part of these companies' overall growth strategy.

THE MINERAL INDUSTRY IN NIGERIA: EXPLORATION ACTIVITIES AND SUSTAINABLE DEVELOPMENT

Nigeria, like most of the third world (developing) nations is known to be endowed in mineral resources and energy raw materials, particularly oil and gas. The better developed oil and gas sector is dominantly controlled by the foreign multinational oil companies with better access to modern and state of the art data gathering and processing technologies.

The national reserves of crude oil is approaching the 40 billion barrel mark and there is a rapid development of the gas sub-sector with a reserve estimate of over 183 trillion in feet (TCF) far in excess of the proven oil reserve. The hydrocarbon sector

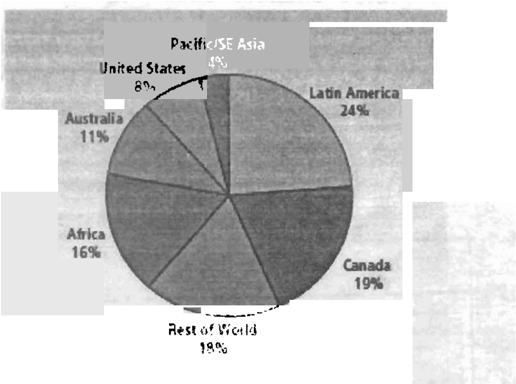


Figure 14(a). Worldwide Exploration Budgets by Region, 2006 (1,624 companies' budgets totaling $7.13 billion), Meta Economics Group, 2007.

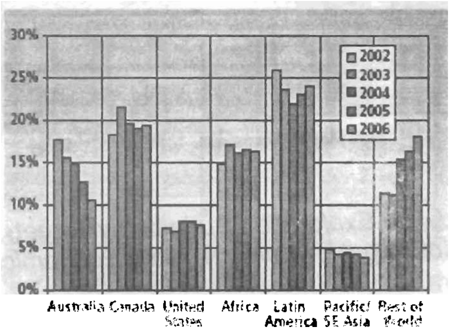


Figure 14(b). Worldwide Exploration Budgets by Region, 2002 - 2006 (as percentage of worldwide exploration), Meta Economics Group, 2007.

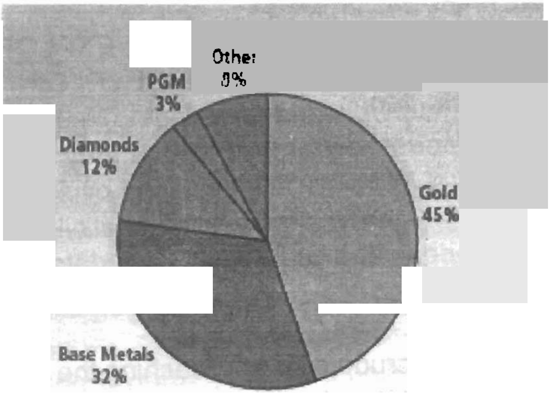


Figure 15(a). Worldwide Exploration Budgets by Target, 2006 (1,624 companies' budgets totaling $7.13 billion), Meta Economics Group, 2007.

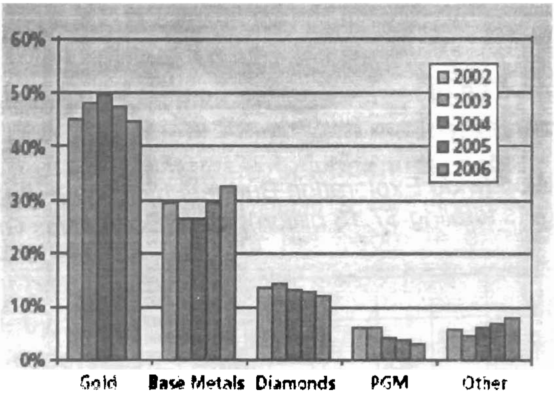


Figure 15(b). Worldwide Exploration Budgets by Target, 2006 (1,624 companies' budgets totaling $7.13 billion), Meta Economics Group, 2007 has continued to dominate the Nigerian economy. Crude petroleum and condensate production in Nigeria exceed that of Kuwait and United Arab Emirates in 2004. This has moved Nigeria up to the position of ninth leading producer in the world (by volume) and has remained Africa's leading oil producer.

The non-oil sector of our minerals industry (solid minerals) by contrast has production and exploration assumed international importance before the 1970s. Ajayi and Adewetan (1981), showed that the revenue from petroleum since 1958 has grown exponentially whilst production as well as revenue from the non-oil mineral sector declined substantially. The sector currently contributes about 0.4% down from 20% in 1960. This unsatisfactory development has amongst other factors been due to:

- Long years of neglect of the sector
- Inadequate capacity;
- Poor infrastructure for exploration and development and Poor and inefficient geological data base.

These problems had been adequately addressed in various fora (see Rahaman, 2004; Malomo, 2004; NMGS Annual Conference Communiqué e.g 2002, 2003, 2004 etc). Also the National Economic Empowerment and Development Strategy (NEEDS) in 2004 identified several constraints on the development of the nation's solid mineral sector which government proposed to address. These included the dearth of proven reserves, illegal mining, the lack of infrastructure, the lack of mineral production and processing capacity smuggling of minerals out of the country, the competitive legal and regulatory structure and unfavourable domestic fiscal policies

In December 2004, the World Bank Group approved the sum of $120 billion Sustainable Management of Mineral Resources Project that would fund some of the NEEDS initiatives in the mineral sector. We are yet to see the impact of these investments if however, they were released to the appropriate organ of government.

To date, about 34 solid mineral commodities at various stages of exploration and exploitation which occur in about 450 locations nationwide (NIMAMOP, 1966) are known. Fortunately, these minerals are distributed in almost all the states of the federation. The mineral commodities broadly grouped are as follows;

Metallic Minerals:	These include Iron, Ferro-alloys and non-ferrous metals exemplified by casterite (tin-ore), iron-over, lead-zinc, Banxite, Nickel, Chromium, Manganese.
Precious Metals:	Gold, Silver, Cadmium
Gemstones:	Aquamarine, Emerald, Rubby, Amethyst, Beryl, Tourmaline.
Specialty Minerals:	Tantalite, Columbite, Lithium.
Mineral Fuels:	Coal, Lignite, Bitumen (Tarsands) Uranium, Thorium.

Non-Metals (Industrial Minerals):

(i) Chemical Subgroup - Salt, Sodium, Carbonate, Sulphate, Potash, Phosphate, Nitrates, Trona.
(ii) Metallurgical and Refractory Subgroup: Fluorspar, Graphite, Marble, Limestone, Dolomite, Refractory Clays etc.
(iii) Abrasive Sub-Group: Corundum Quartzsand Monazite.
(i) Others Manufacturing Subgroup: Asbestos Mica, Talc, Barite, Gypsum.
(ii) Dimension Stones Sub-Group: Granites.

These minerals except for a few (gold, tarsand, Pb-Zn; clays, dimension stones and limestone) where extensive exploration and exploitation had been carried out to some degree and in selected parts dominantly occur as known occurrences. In general, the level of mineral exploration activities in the country is very low whilst the estimated reserves of some are generally small and none is of world class deposits (Table 6). This reflects the very low level of investment in exploration and poor knowledge of the mineral resources endowment. All over the world it has been shown that there is a direct relationship between investment on geoscience and mineral exploration by government on the discovery and production from new mineral deposit. Orife (1987), aptly expressed this view that" the state of the country mineral industry is not quite healthy as it should be. Hence the policy makers in this sector must be told that the country can only get as much out of its solid minerals resources in particular as it is ready to put into it".

TABLE 6:

LOCATION, LEVEL OF DEVELOPMENT AND PROVEN RESERVES OF NON-METALLIC MINERALS

MINERAL	LOCATION (STATE)	LEVEL OF DEVELOPMENT	PROVEN RESERVES (TONNES)
Iron	Kwara (Itakpe)	Fully investigated. Ready for exploitation	182.5 million
	Kwara (Agbaja)	Investigated. But problem with high P_2O_5 content though F_e content is 50%	30.5 million
	Plateau (Muro Hills, Gadabuke)	Under intensive investigation. Highly promising	Not yet determined but believed to be larger than Itakpe
	Imo (Enugu)	Oolitic, iron stone also investigated. Low grade 43% F_e. Earliest mined metal along with tin. Various investigations still highly exploited through open cost mining.	Proven 14,222.5 Estimated 17,874.5
Tin-tantallum Niobium	Plateau, pegmatite's of Central Nigeria	Oldest mined metal though with fluctuating production figures. Notable alluvial deposit.	Proven – 31,772
	Kano	Various investigations latest by Nigeria Tin Mining Company. Highly promising is the Ririwa ri Mine, Kano	
Lead-zinc	Benue, Gongola, Plateau, Bauchi	Investigated at various times. Exploitation and production dates back to 1951 though mining had been on a very small scale	Proven - 711,237 Estimated -16.5 million

MINERAL	LOCATION (STATE)	LEVEL OF DEVELOPMENT	PROVEN RESERVES (TONNES)
Gold	Sokoto, Niger, Kwara, Osun	Mining of alluvial deposits started in 1914. Nigeria ceased to be a producer after a short history of mining 1914 - 1957. Renewed activities at Ife-Ilesha gold field by Nigerian Mining Corporation. Recently mining commenced on a small scale.	Not fully known. Low grade but economically exploitable at present price of gold.
Chromite	Sokoto	Occurrences under investigation	Not known
Manganese	Akwa Ibom, Sokoto	Occurrences reported	Not known
Asbestos	Kaduna	Preliminary exploration	Not yet known
Barytes	Plateau, Benue	Deposit in Azara being mined NMC. Others only preliminary	Azara (130,000). Others not determined
Bauxite	Gongola, Cross River	Not yet explored	Noy yet known
Clay Ball	Imo, Edo, Delta, Akwa Ibom, Rivers, Cross Rivers, Ondo Anambra	Small scale exploitation of some deposits	Up to 50,000,000
Kaolin	Edo, Delta, Imo, Kwara, Plateau, Kaduna, Katsina, Ogun, Kano and Sokoto	Partial to full exploration and evaluation of deposits. Exploitation of some of the deposits	Up to 70,000.000
Fire Clay	Anambra, Katsina, Ogun, Sokoto	Partial exploration and evaluation. Small scale exploitation of some reserves	Up to 20,000.000

Table 6 (contd)

MINERAL	LOCATION (STATE)	LEVEL OF DEVELOPMENT	PROVEN RESERVES (TONNES)
Diatomite	Borno	Extensively explored and evaluated. Small scale exploitation	Up to 10,000.000
Dolomite	Kwara, Oyo, Niger, F.C.T.	Most being exploited	Not yet known
Feldspar	Kwara, Oyo, Ogun, Niger, Kaduna	Partial exploitation and evaluation	Not yet known
Flouspar	F.C.T.	-	Not yet known
Gypsum	Sokoto, Bornu, Anambra	Partial exploitation and evaluation. Small scale mining in Sokoto	Not yet known
Kyanite	Kaduna, Niger	Partial investigation	Not yet known
Limestone	Anambra, Cross River, Benue, Ogun, Sokoto Bauchi, Edo, Delta. Ondo	Most are being exploited	Up to 800,000,000
Marble	Bendel, Oyo, Kwara, Plateau, Benue, Kaduna	Exploitation in all except for those of Plateau and Kaduna	Up to 100,000.000
Phosphate	Sokoto, Ogun, Anambra, Imo, Edo	Full exploration and evaluation in progress	Total not yet known, Preliminary Ogun (100,000) Sokoto 75 million
Glass sand	Edo, Delta, Ondo, Rivers, Lagos, Anambra, Imo	Most have been partially investigated and evaluated	Very large

Table 6 (contd)

MINERAL	LOCATION (STATE)	LEVEL OF DEVELOPMENT	PROVEN RESERVES (TONNES)
Salt	Benue, Anambra, Imo, Cross River, Plateau	Partial investigation	Not yet known
Soda ash	Borno, Kano	No systematic studies carried out yet	Not yet known
Talc	Oyo, Ondo	Partial preliminary investigation	Not yet known
Rock – aggregated and polishing	PreCambrian Basement complex areas of Nigeria	Investigations in S.W. Nigeria	Very large

Data on exploration expenditures or estimates in the country by both government and the very few private companies involved in the solid mineral sector is not available for obvious reasons of lack of continued or sustained activities over many years. However, examples of budgetary allocations by some states yielded positive results. The case of the Ondo State Government's expenditure of 2.8 million naira on the tarsands in the 1980s to cover the 17km^2 area investigated by Geological Consultancy Unit (GCU) of Department of geology, (Adegoke et al 1980). This has remained the only very detailed study to date and the basis of the bidding for bitumen blocks.

In the early days of exploration for iron-ore deposits in the country to provide the needed raw materials in 1970s, airborne geophysical surveys Canadian Airborne Survey covering parts of the country were carried out in 1963. This was followed by detailed ground magnetic studies and geological mapping by the then Nigeria Steel Development Authority (now Steel Raw Materials Agency). The studies subsequently led to the discovery of the Itakpe iron-ore deposit which has been developed and being mined by Nigerian Iron Ore Mining Company (NIOMCO) until the company was sold by the Bureau of Public Enterprises (BPE) following the Reform Programme of the Obasanjo Administration. Other deposits that were studied to levels of estimation of reserves include the Muro Hills and Chokochoko. These deposits are to feed the iron and steel complex plant at Ajaokuta on which the country by 2002 had spent over U$10 billion since its inception in 1979, but still to commence production.

The most recent information on exploration is the recently awarded contract for aerial survey of mineral surveys to obtain reliable geological survey of the country. The cost is about U$ 30.0 million. In addition, the allocation of $165,000.00 by Government to a programme that would fund mineral processing assistance, mining skills development and other training for artisanal and small scale miners.

The cheering development is the newly established Nigerian Geological Survey Agency (NGSA) and the ongoing reform in the solid mineral sector which has culminated into declaring 2007 as the "solid mineral year". This expectedly should change the country's perception and approach to her solid minerals development. Declaration is not just enough but the political will and genuine commitment to make a positive change in all its ramifications is now.

The world wide commitment to continued increased investment in exploration and exploitation as exemplified by the leading nations of Canada, Australia, USA, Latin America which are amongst the leading ten nations in the mineral and or energy raw materials need to be emulated by Nigeria with respect to her solid mineral sector. In the case of Australia, it has been demonstrated that the ability of Australia's minerals and energy to sustain its strong recent growth and expand its contribution to national economic performance in the medium and long terms depends critically on the amount of investment in mineral exploration. The total Australian minerals exploration expenditure in 2005/06 rose by 21% to $2.5 billion and in real terms was estimated the highest since 1997/98 years. The number of minerals and energy development projects indicates that there will be robust growth in the mineral resources sector's productive capacity over the medium term.

The focus now should be to make Nigeria's solid minerals sector become more attractive for investors so that more will take advantage of the reforms as recognized all over the world. The dearth of exploration activities was fully acknowledged by Malomo (2004). He asserted that large areas of Nigeria have not being mapped in detail and many geophysical airborne information available currently are outdated, being about 40 years old. He further observed that none of the mineral targets (solid) identified in Nigeria to date represents unequivocal world-class target of immediate interest to investors. This he affirmed has been due to the fact that the Nigeria Geological survey Department (GSND) carried out little or no mapping and mineral exploration for more than 15 years now. This has led to acute shortage of useful data and information to make informed decision on the merit of investment and reduce their risk.

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Rahaman (2004) succinctly captured the parlous situation on the state of geological investigation and knowledge. He stated that geological data of some sort is available on only about 15% of the country and a large percentage of these data are based on the work done three decades ago. In addition, the data base on which the geological map and our understanding of the geology and the geological process of the rocks have undergone is thus poor. Thus the GSND has not been able to fulfill its traditional role as the national mineral resources centre for data base collection and distribution of the results of the promotional geoscientific research.

Pedro, (2001) observed that in Africa, the lack of basic geologic data and maps is a constraint to doing business because mineral data is an indispensable commodity to stimulate explorationist's interest in any country. The geological survey organizations are the national custodians of mineral data.

The challenges of many developing country which is more pronounced in Africa (Ovadia, 2000) concluded is to present:

(i) suitable and relevant geoscience information in a form suitable for its intended use,
(ii) the information should be at level of quality that meets international expectations, and
(iii) in a manner that is easy to use and cost effective to transmit to target recipients (international or oil companies) in order to attract them to place investment funds in that developing country.

Perhaps we can learn from the experience of USA when on 18th May, 1992, the United States congress and President recognized the utmost importance of geological maps in national economy by passing the national Geologic Mapping Act of 1992 (H. R. 2763) thereby paying the desired attention to the many geoscience policy issues that affect the US people and nation. The Act was brought at a time when there was a serious decline in geological mapping of the country by Federal and State Agencies and by the Universalities and when the need for information about the nature and distribution of rock materials at or near the surface became increasingly critical for her economic prosperity and national security of the United States. This underscores the fact that most developed countries of the world recognize that geological maps are of immense benefit either directly or indirectly to all segments of the society (states, districts local government, private industry, academic circles and general public).

MY CONTRIBUTIONS

Vice Chancellor Sir, I will now highlight some of my contributions since I joined the Department of Geology in February 1972, as the first Graduate Assistant under the academic staff development training programme of the then University of Ife. In October of that year, I was sent abroad for postgraduate studies in Mineral Exploration at McGill University, Montreal, Canada. I successfully completed the M.Sc. (Applied Geology) degree specializing in Mineral Exploration in 1974. At the instance of the department, I returned to join the two man foundation staff of the B.Sc. Applied Geophysics Programme, the first in Nigeria in 1974/75 session. In 1976, the first set of the B.Sc. (Honours) Applied Geophysics students were graduated through the committed services of my humble self and then Mr. B. D. Ako, now Prof. B. D. Ako, the first Alumnus to occupy the Shell Chair of Geophysics in the Department of Geology. It is gratifying to remark that this programme has continued to be very popular and well received by Earth Science employers (Viz: Oil Companies, service companies, River Basins Authorities, and Universities).

By the grace of God, two of our first set of graduates are now Professors of Applied Geophysics (in their own right) in Nigeria; Prof. M. O. Olorunfemi, (Obafemi Awolowo University, Ile-Ife and Prof. C. S. Okereke of the University of Calabar, Calabar. Other Applied Geophysics degree programmes in other universities were patterned after the pioneering efforts of Great Ife.

The Germans who came under the DAAD programme and were involved in the M.Sc. Applied Geology programme left in 1978/79 academic year. I had to switch over to Applied Geochemistry to rescue the Department. This was possible because of my training.

The Department was able to effectively run the M.Sc. (Applied Geology) mineral exploration option.

STUDIES ON THE IFE - ILESA SCHIST BELT

The Ife-Ilesa schist belt of southwestern Nigeria constitutes one of the Upper Proterozoic Schist belts in the Nigerian Basement Complex (Olade and Elueze 1979; Rahaman et al 1981; Turner 1983). These schist belts (Fig. 16) are the main depositories of both alluvial and primary gold deposits. Since gold mining began in Nigeria in 1914, a total of 379,330 troy ounces (approximately 11, 786 kg) of gold were produced up to 1985 (Fig. 17). The reported production figures for 2000 - 2004 were 52, 34, 40, 50 and 30 kg respectively still indicating very low level production and activities.

Mining activities began in the newly discovered Ife-Ilesa gold field in 1942 and the production from this area did contribute significantly to the national output of gold (Fig.17). Until recently the Ife-Ilesa gold field remained the only gold field where active mining activities continued though intermittently until present and with steady declining production.

Although in the period 1933-1946 Nigeria enjoyed a comparatively high level of gold production, the gold fields suffered a very rapid decline because the bulk of the production (about 90%) was from the easily obtainable and exhaustible alluvial deposits. Another feature in the history of gold production is that largely, the exploitation has been on a small scale and carried out by both private companies and interested individuals. This class of prospectors lacked the financial capabilities to carry out industrial mining. Furthermore, until recently, there was no systematic exploration programme initiated in the search for gold and associated metals. These factors also contributed to the decline in gold mining in Ilesa area just as in the older Nigerian gold fields.

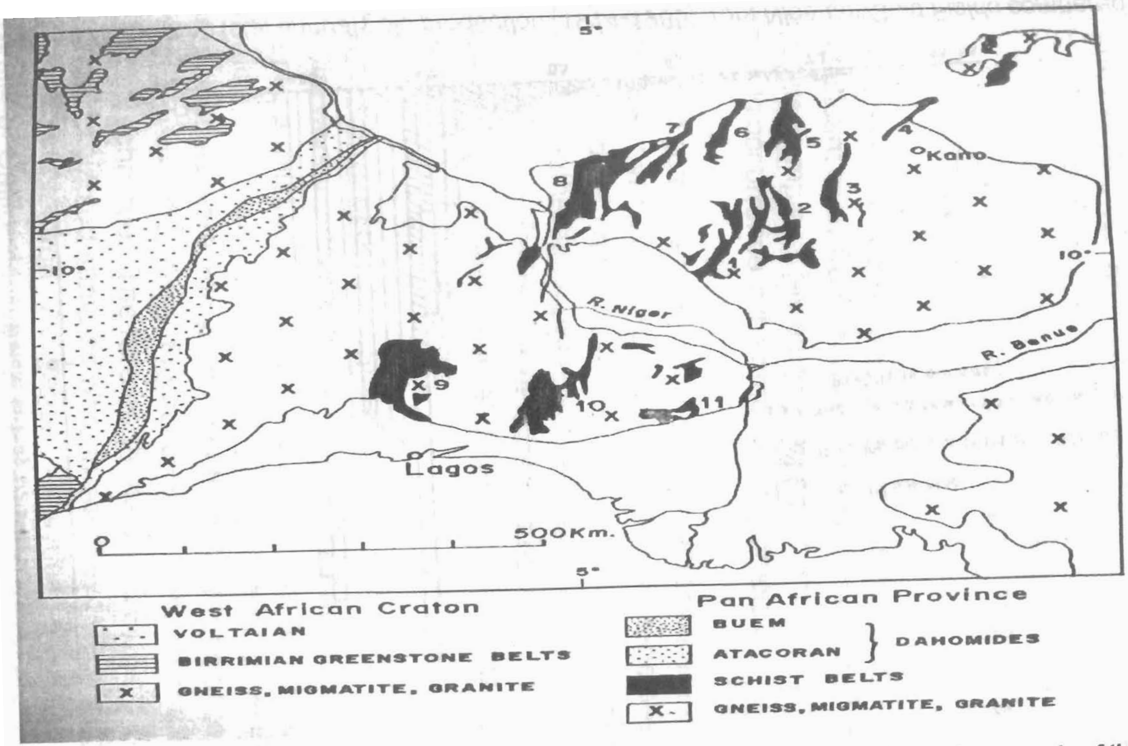

Figure 16: Location of the Nigerian schist belts in relation to the Dahomide belt on the western margin of the Pan-African Province. The schist belts are: 1, Zungeru-Birnin Gwari, 2. Kushaka, 3. Karaukarau, 4. Kazaure, 5. Wonaka, 6. Maru, 7. Anka, 8. Zuru, 9. Iseyin-Oyan, 10. Ilesha and 11. Igarra (after Turner, 1983)

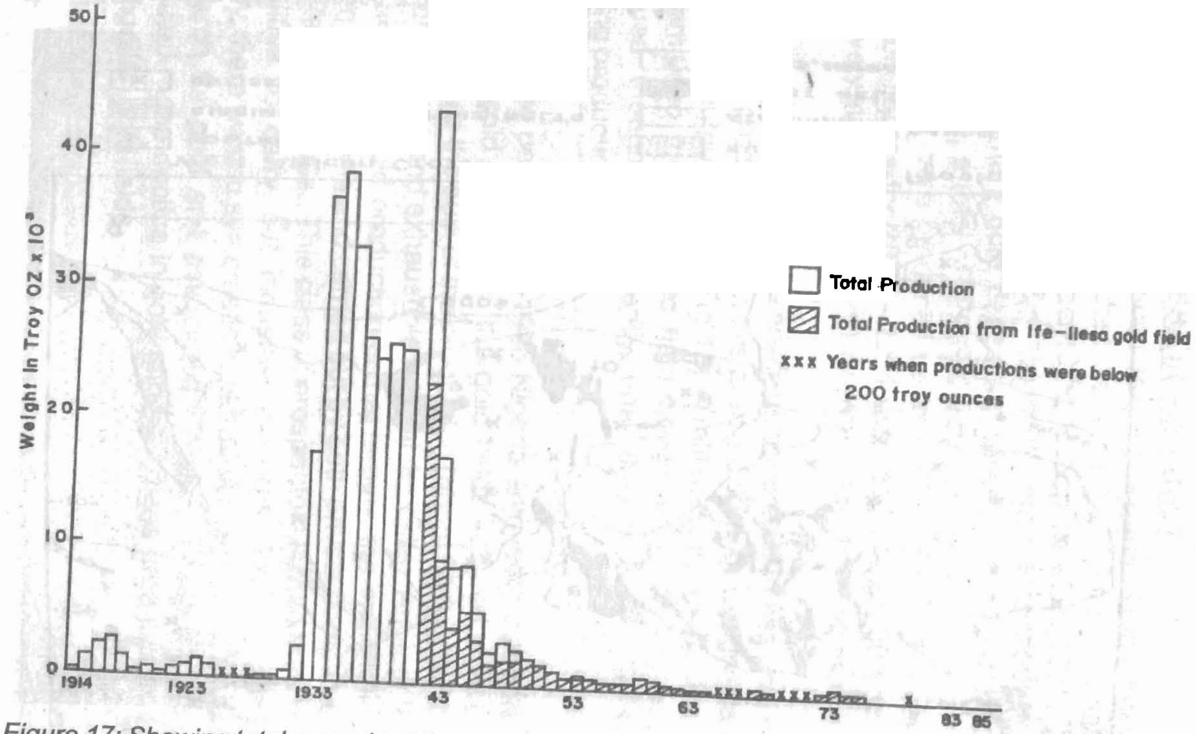

Figure 17: Showing total annual gold production (1914-1985) from Nigerian Gold Fields compared with production from Ife-Ilesha area (Ajayi, 1988). Socurce Federal Ministry of Mines and Power.

In the Ife-Ilesa area, two types of gold mineralization have long been recognized (de Swardt, 1953). These are;

(i) Primary gold-bearing quartzs veins which occur in feldspathic gneiss in the Iperindo area, and.

(ii) Alluvial gold which occurs in the area largely underlain by the amphibolites complex with notable locations at Ilesa, Itagunmodi, Ibodi, Osu, Igun, Iregun, Yemogun, Eyinta and surroundings areas.

Records show that the production from primary quartz veins is less significant than from the alluvial gold associated with the amphibolite complex. My study focused on the more important area of gold occurrence in the amphibolite complex.

In addition to gold, the occurrence of some other minerals such as nickelferous pyrrhotite and talc have been reported whilst cassiterite and columbite have been worked from ancient alluvial deposits or weathered pegmatites associated with granitic bodies and schists. The Ife-Ilesa area is thus of economic importance because of its economic mineral potential, hence the continued and renewed interest in the area.

Petrochemistry of the Amphibolites

The initial work involved the synthesis of the geology of the area from both published and unpublished studies as well as from geological observations in the field. Forty representative samples of amphibolites were analyzed for both major (10) and trace (11) elements using the X-ray Fluorescence Spectrometry (XRFS) analytical technique. The rare earth metal (REE), Sc, Hf and Th contents of selected samples were in addition determined by the Instrumental Neutron Activation Analytical (INAA) at the University of California Irvine Triga reactor. The determination of the Au content was carried out on 10 randomly selected samples (Six of MMA and four of FLA) by Radiochemical Neutron

Activation Analytical (RCNAA) techniques respectively. The main objective of this study was to determine the abundance of major and trace elements in the amphibolites source rocks with a view to providing a basis for the understanding of the primary distribution of these elements in the amphibolites. Petrochemical studies are also very important in deciphering the geotectonic setting of these rocks and thus infer their mineralization potentials (Fig. 6).

Based on the field relationships, petrography, major and trace element studies, I was able to establish that there are two textural varieties of the amphibolites derived from original suite of igneous rocks. These are the massive melanocratic amphibolites (MMA) and the foliated leucocratic amphibolites (FLA) with the former showing ocean floor theoleiitic basalt (OFB) and the latter calc-alkaline island-arc based (IAT) affinities. The latest model of a bark-arc marginal basin environment, a widely accepted model for the geotechnical setting of the Ife-Ilesha schist belt was first proposed to explain the features of the rocks and their regional association with the metasediments and the gneisses as well as the major discontinuity, the Ifewara/Iwara faults (Ajayi, 1981). Further studies based on trace and REE elements geochemistry and the geotectonic setting of the Ife-Ilesa schist belt (Rahaman, et al., 1988) confirmed the earlier results of Ajayi (1981). We further concluded that the relatively high abundances of incompatible trace elements and the higher light rare elements (LREE) were due to contamination with crustal sources. We also proposed that the presence of rocks of OFB and IAT affinities in the area, the asymmetric nature of the sedimentary facies within the schist belt and domination of the pelitic rocks require quiet depositional environment. The belt of Pan African granitic rocks to the west of the schist belt and the fold belt character of the schist belt (Burke et al., 1977) strongly suggest that active subduction process have been operative here. Hence, a tectonic model involving the Wilson cycle with ocean opening and closing was thus first proposed for the area.

The result of RNAA was used to determine if there is any spatial relation between the placer gold deposits and the amphibolites. These was on the basis of Anhaeuser (1976) proposal that gold and other metals in Achaean greenstone belts were mobilized from essentially mafic or ultramafic volcanic source rocks. The essence of determining the Au contents in the amphibolites shown to be originally mafic rocks is to provide useful information on the level of mineralization in the area, though subject to other factors that will concentrate trace into economic deposit.

Tables 7 and 8, show the results in comparison with compatible trace elements and the mean, ranges of gold in other rock types. Although the samples are few due to constraints of access, costs of analytical facilities, useful inferences are evident. Except for sample no 18 located South of Araromi village, with the highest value of 1.77 ppb (4 times the background), the results showed rather low and restricted values compared to other rock types (Table 8). The amphibolites have much lower mean Au value but higher than the mean value for dunites of Oshin (1981). However the overall mean Au value of 0.4 ± 0.1 ppb though relatively lower is comparable to the mean of 0.6 ppb for 42 OFB of Keays et al., (1981). When compared to mean values of 2.55 ppb for tholeiites, 1.82 ppb for mafic rocks and 0.92 ppb for ultramafic rocks reflect the relatively low level of Au mineralization in the area compared to typical Archean greenstone gold fields. The mean Au value is interpreted to reflect background values in the original igneous rocks related to Au in solid solution in the mineral lattices which have not been affected by post igneous processes (Oshin, 1981). This observation derives from results of studies that the intensity of alteration is not the controlling factor in Au mobilization since high Au values do not correlate with the degree of alteration (hydrothermal).

TABLE 7: ABUNDANCE OF GOLD (IN PPB), COMPATIBLE TRACE ELEMENTS, Zr (IN PPM) AND K_2O/Na_2O RATIOS OF AMPHIBOLITES FROM IFE-ILESA SCHIST BELT

Sample No.	Au	V	Cr	Ni	*Co	Cu	Zn	Pb	Zr	K_2O/Na_2O
1	0.46	---	---	---	---	---	---	---	---	---
6	0.56	289	94	71	26	14	77	5	60	0.22
8	0.43	226	163	126	60	60	78	23	16	0.33
15	0.29	133	199	86	28	13	106	18	27	0.12
18	1.7	151	286	106	33	13	87	17	59	0.30
26	0.27	139	101	23	58	8	55	21	98	0.15
29	0.44	110	225	86	58	11	108	25	221	0.20
33	0.35	---	382	204	---	6	125	35	239	0.97
35	0.50	20	185	27	36	---	224	46	172	2.26
40	0.39	34	53	20	---	---	361	115	143	2.27

LEGENDS

Nos. 1, 6, 8, 15, 18 and 26 - MMA
29, 33, 35 and 40 - FLA
*Co Partially Extractable Cobalt (Data from Alokan, 1986)

TABLE 8: MEAN AND RANGES OF GOLD IN THE AMPHIBOLITES OF IFE ILESA SCHISDT BELT COMPARED WITH THOSE OF OTHER ROCK TYPES. ALL VALUES ARE IN PPB EXCEPT OTHERWISE INDICATED

ROCK TYPES	MEAN	RANGES
Ife – Ilesa – (MMA)	0.40 ± 0.12	0.27 - 1.7
Ife – Ilesa – (FLA)	0.42 ± 0.06	0.35 - 0.40
Ife – Ilesa Amphibolites (MMA and FLA)	0.40 ± 0.10	0.27 - 1.7
Ocean Floor Basalts (42)+	0.60	---
Berberton Ultramafic Rocks (a)	---	1.55
Average Tholeiites(a)	2.55	---
Olivine Basalts(b)	2.2	
Tertiary Tholeiitic Basalts (b)	2.0	
Periodolite (b)	2.2	
Ryholite-Porphyry (c)	0.2954 (ppm)	
Average Mafic Rocks (d)	1.82	
Average Ultramafic Rocks (d)	0.92	
Cumulate Rock (e)		
• Dunite	0.27 ± 0.03	
• Dunite without Chromite Band	0.89	
• Pyroxenite	1.0	
• Cumulate-Gabbro	1.7 ± 0.92	

LEGEND

(+) Data from Keays et al., 1981
(a) Data from Anhauser (1976)
(b) Data from Vicent and Crocket (1960)
(c) Data from Champaigny and Sinclair (1982)
(d) Data from Oshin (1981)
(e) Av. Au in Cumulate Rocks (Oshin 1981)
*Value of (1.66) ppb not included in the calculation of mean for Ife Ilesa amphibolites.

The anomalous Au value of 1.77 ppb represents Au which occurs outside the mineral lattice such as mineral surfaces or along grain boundaries. This is the readily leached Au from the rock and which eventually becomes concentrated as alluvial gold.

The major conclusion from this study based on comparable Au level in OFB and low Mg tholeiitic basalts (Keays et al, 1981), is that the level of Au mineralization within the amphibolites of the Ife-Ilesa schist belt is comparable to those of younger placer deposits in the Archean, early proteozoic greenstone belts and Precambrian areas known to contain small amounts of native gold and heavy metals. In addition, the concentrations of other 'ore' elements (V, Cr, Co, Zn) in the two textural varieties generally show ranges and mean values comparable to those of basalts. However, Pb shows an enhanced mean value whilst Cu is depleted relative to average basalts. Only Ni, V and Pb show dispersion patterns that are spatially related to known areas of gold mineralization and reported disseminated nickelferous pyrrhotite.

LITHOGEOCHEMICAL STUDIES A GEOCHEMICAL EXPLORATION METHOD

A study of partially extractable metals in 121 bed rock samples (amphibolites) from the Ife-Ilesa area using aqua regia was carried out by Ajayi and Suh in 1999. The objective was to determine the level of leachable metals and assess the suitability of lithogeochemistry as an approach to exploration for gold and other metals. Partial extraction techniques unlike 'total' analysis allow for the evaluation of sulphide and oxide phases which are the easily leached to both soil and the drainage system. The results revealed generally normal background populations except for Cr, Ni and Cu which show both background and anomalous populations. Furthermore, multielement geochemical metal anomalies reflecting basic ultrabasic rocks were shown to occur in Ifewara, Itagunmodi, Araromi and Mokuro areas which correlate spatially with where alluvial gold had been worked. In addition new areas where the Nigerian Mining Cooperation (NMC) earmarked for mining and the area known for disseminated nickelferous pyrrholite sulphide occurrence were delineated. Quantitative R-mode factor analysis of the data revealed a five factor model which account for 71.8% of the total data variance with the following metal associations. Zn- Co - Cd; Ni-Cr; Fe-Mn; Cu-pb and Ag-V. The Zn-Co-Cd, Ni-Cr and Cu-Pb associations were interpreted as indicative of both lithological and mineralization effects whilst the rest reflect lithologic effect only. We thus concluded that the partial extraction technique is useful as a rapid and relatively cheap method for regional geochemical survey in the area.

Geostatistical Interpretation of Regional Geochemical Exploration Data

The continued interest in the search for potential areas of Au mineralization led to extensive exploration, mainly reconnaissance and regional geochemical surveys. The geochemical data which were qualitatively evaluated failed to identify areas of Au mineralization (Onuogu and Ferrante 1965, Metals and Minerals, 1976). For example Elueze (1977) noted that the visual examination of the distribution patterns of As, Au, Ni, Cu, and other trace elements in (300) stream sediment samples are not spatially related to known areas of gold mineralization. This feature is attributed to the continued variable background values in the various underlying rock. Garrett et al., (1980) amongst others noted that this phenomenon presents a major problem in the interpretation of reconnaissance geolochemical surveys.

The definition of a geochemical anomaly in recent times, in relation to mineralization involves more than establishing large differences in element concentration between samples. This is only applicable to near surface and large high grade mineralized areas. Chork (1978) observed that errors inherent in geochemical data plus local environmental factors have a profound effect on the migration and distribution of trace and major elements in a sampled medium. Hence, it was stressed that these errors are important where surface expressions of mineralization is subtle and contrasts weakly with the background. Thus, the approach of the traditional interpretational technique of geochemical data has been observed to be inadequate and lacks the ability to distinguish subtle features related to mineralization from the more obvious geochemical expressions of bedrock composition and surface environment. This is more so in stream sediments where metal concentrations are derived from multiple sources.

These complexities in geochemical data account for the shifting of emphasis from qualitative to quantitative interpretational techniques. Hence for an effective geochemical exploration in the search for potential areas of gold mineralization and the associated metals in the Ife-Ilesa area, there is the need for a more radical approach to the interpretation of geochemical data. This is to overcome the deficiencies of the traditional method of visual examination and simple statistics. The interpretation should not only be qualitative but quantitative. These techniques have been shown to have considerable advantage over the traditional methods (Nichol et, al, 1969; Nichol 1973; Chapman 1975; Chork 1978; Garrett et, al, 1980 and Howarth 1983). The resulting geochemical patterns are readily and more reliably explained in terms of primary geochemical features and ore-forming processes thus yielding valuable information on the area and providing an improved understanding of the geochemical dispersion processes.

In my studies, computer based statistical and mathematical techniques were applied as aids in the interpretation of integrated geochemical survey data from the Ife-Ilesa area. A total of 1104 samples consisting of 301 bedrock, 353 active stream sediments and 450 soil samples analysed for both major (10) and trace elements (11) were used for statistical and other mathematical techniques of interpretation (Fig. 18). The stream sediment and soil data were derived from the various studies arising from M.Sc. Applied Degree Programme Mineral Exploration (Option) initiated by the Department in 1974/75 (See Matheis, 1977).

Details of my study involved

(i) Frequency analysis to provide improved estimation of the basic statistics of the geochemical data.

(ii) single element plot at sample locations of the stream and soil samples based on the INPLOT programme.

(iii) Regional contouring of the observed (raw data) and computed trend surfaces and residuals based on the TREND/PLOT programme adapted from Davis (1973). This procedure deals with the spatial variation of the geochemical data for the purpose of recognizing subtle geochemical features which may be related spatially to areas of potential mineralization.

(iv) Multivariate statistical analysis to obtain inter-element correlations and element associations by R-mode factor analysis.

This study was the first detail application of mathematical geology to solving local exploration problems and providing quantitative base line geochemical data for the sampled media in the Ife-Ilesha goldfield area which falls within a tropical environment. Time will not permit detailed presentation of the results which are in Ajayi, 1981, 1988, 1994 and 1995. However, highlights of the findings are as follows.

1. The use of probability graphs proved a useful practical approach in estimating threshold and background values which are basic parameters in the evaluation of the spatial distribution patterns of sub-populations in geochemical data sets. The result revealed the presence of two or more populations, representing background, anomalous and other geochemical effects as described by Sinclair (1974, 1976). These reflect heterogeneity in the distribution of the elements in the sampled media explained in terms of the complex geology, surface processes, mineralization and probably post magmatic effects in the bedrock material.

2. The complexities inherent in these geochemical data hitherto not revealed in previous qualitative interpretation became apparent. This is very important since only some of these populations reflect the geochemical haloes being sought whilst the others mask them.

3. Multivariate R-mode factor analyses shows the strong inter-element relationships. In the soil and stream sediments, four factors with comparable element associations were identified as the most meaningful solution in terms of the known geology, surficial environment and mineralization. The stream sediments element associations are C0-Mn-Fe-Ni, Zn-Cu-Pb, Mg-K and Cr, whilst those for the soils are Co-Mn-Cu, Cd-Ni, Cr-Cu and Zn-Pb.

The factor scores distribution maps show strong lithologic control. Hence lithology is considered the most important factor accounting for element distribution in the surficial environment of the tropical rain forest region of southwestern Nigeria. Furthermore, the low proportion of the total data variability accounted for by the mineralization factors indicate the subtle and weak responses of mineralization processes in the area.

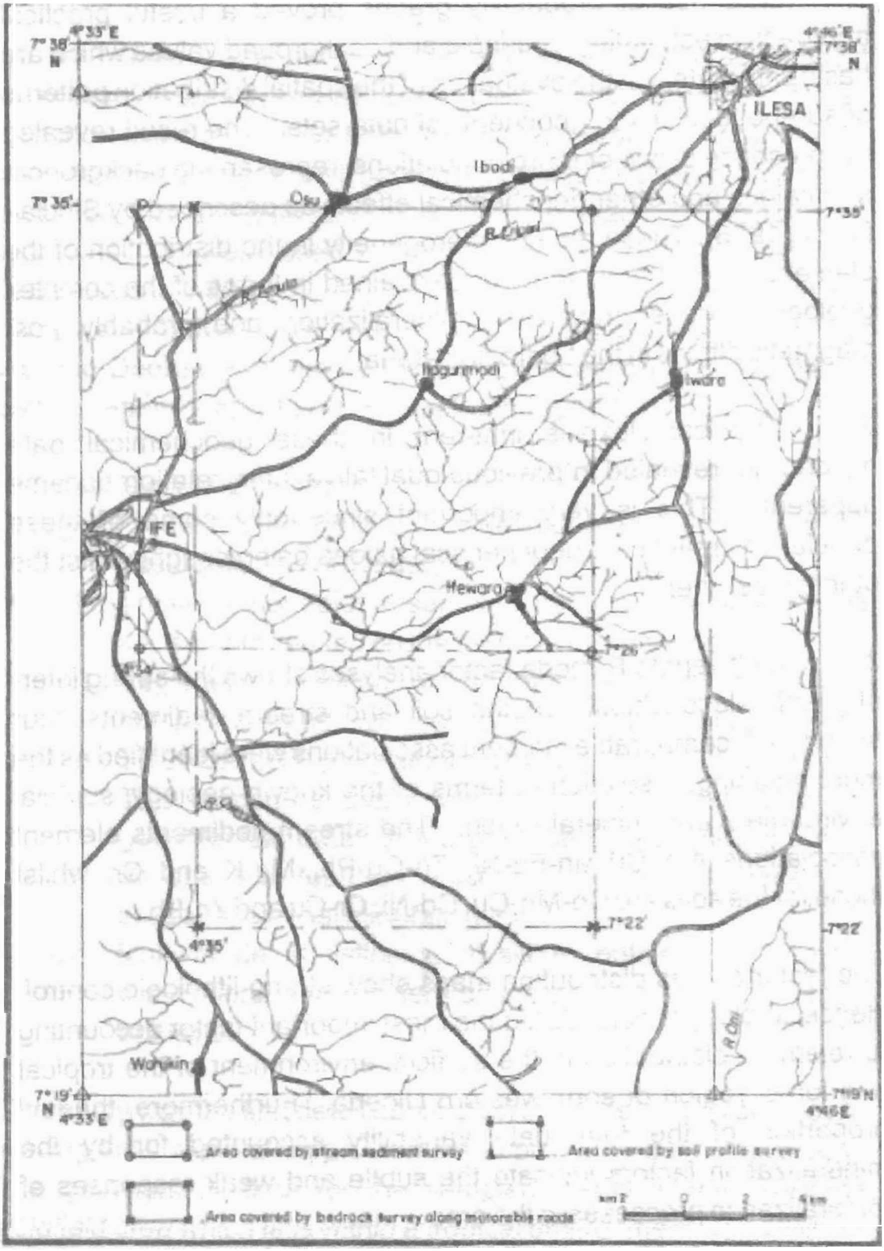

Figure 18: Location and Drainage Map of Area of Study

Although, factor analysis has been widely used and proved useful as an aid to interpretation of geochemical data, however, Nichol (1973) noted that it is not possible to determine the extent to which the data variability of individual samples is explained in the principal component because the inherent residual components in the factors cannot be assessed. As a result of this limitation, further data analysis using moving average and trend surfaced analyses were carried out to elucidate trends relating to possible areas of mineralization. These techniques have been successfully employed in the interpretation of geochemical data (Conor and Miesh, 1964; Nacwoski et al, 1967, Chork, 1978 and Chapman, 1978). Chapman (1978) and Chork (1978) concluded that the moving average procedure is a very useful technique in large scale drainage surveys since it is effective in reducing small variations in order to reveal large residual patterns which Chork (1973) asserted do serve to focus attention on anomalous samples.

The contouring and trend surface programmes used were adapted from Davis (1973), written and tested and ran at the Obafemi Awolowo University Computer Centre in the hay days of (1985 1988). The programmes were coded "INPLOT"; "PPLOT" and "TREND". The ANOVA statistical technique was used to evaluate the "goodness of fit" and the appropriateness of increasing degrees of polynomial trend surface fitted.

In the application of the smoothing technique, the random components due to sampling and analytical errors are suppressed with the anomalous zones that are of spatial significance enhanced. This has led to a refinement of both soil and stream sediment data. The results produced better, smoother and "cleaner" geochemical maps compared to the manually contoured maps of the raw data. Anomalous patterns of single elements (Figs. 19 and 20) outline broad systematic target areas spatially related to known area of Au mineralization as well as other areas whose association with Au mineralization were previously not detected around Araromi, Itagunmodi and Ejio.

The trend surface analysis of the regional geochemical data showed that low order surfaces prove more useful in revealing the main regional trends in the soil data than in the stream sediments data. All the computed trends for soil except first to fourth order for Zn; third order Cr, Pb, Cd; and the first to third order Ag show that the distribution of the data were all significantly different from random ($P < 0.05$). In the stream sediments, only the first to fourth order Co; first and second order Fe; and first order Mn trend surfaces were significantly different from random ($P < 0.05$).

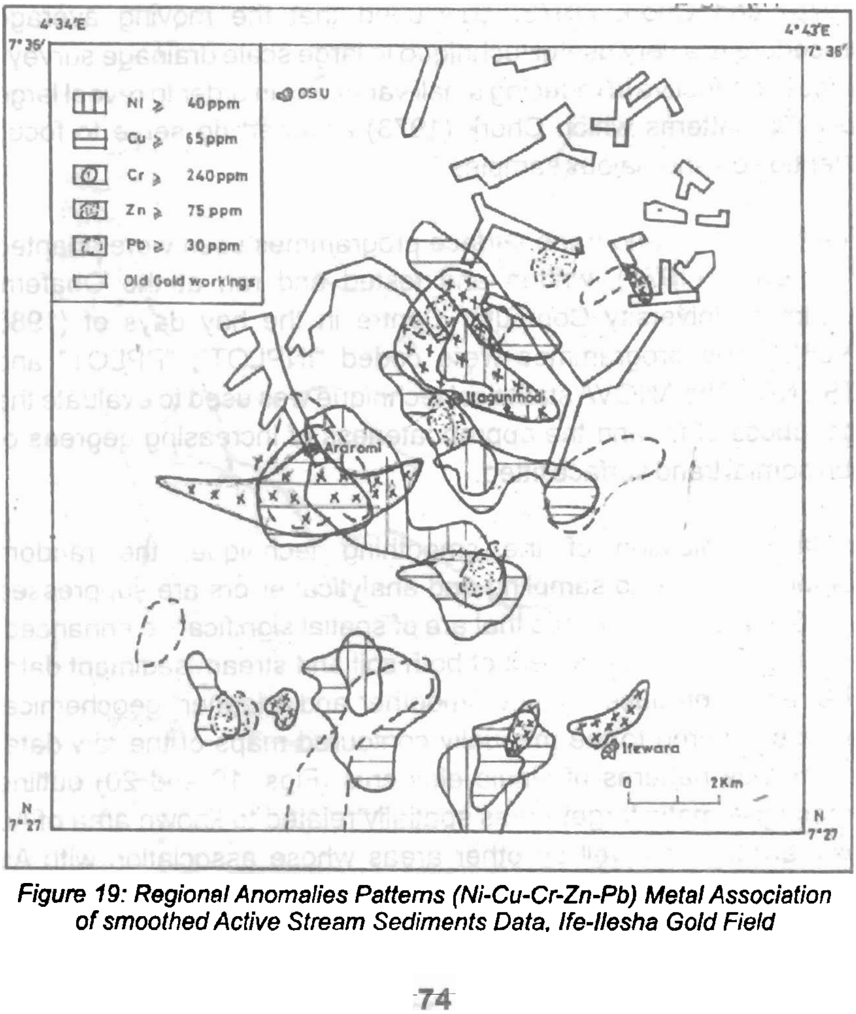

Figure 19: Regional Anomalies Patterns (Ni-Cu-Cr-Zn-Pb) Metal Association of smoothed Active Stream Sediments Data, Ife-Ilesha Gold Field

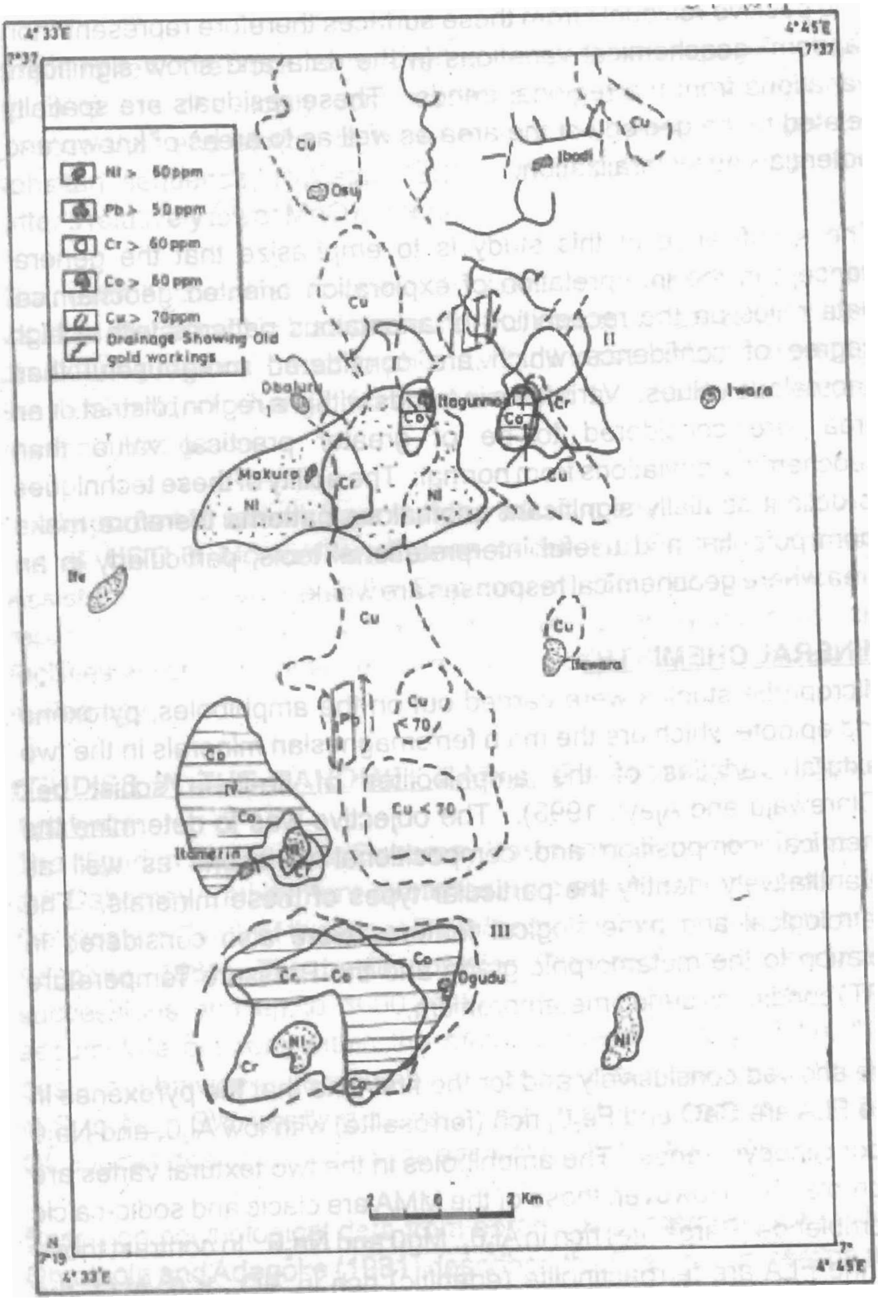

Figure 20: Regional Trace Metal Anomalies Patterns of Smoothed Soil Data, Ife-Ilesha Area, Southwestern Nigeria

The positive residuals from these surfaces therefore represent "non random" geochemical variations in the data and show significant variations from the regional trends. These residuals are spatially related to the geology of the area as well as to areas of known and potentials Au mineralization.

The significance of this study is to emphasize that the general concept in the interpretation of exploration oriented geochemical data relies on the recognition of anomalous patterns with a high degree of confidence which are considered more useful than anomalous values. Variations in trends within a region, district or an area, are considered to be of greater practical value than geochemical deviations from normal. The ability of these techniques to delimit spatially significant anomalous patterns therefore make them potential and useful interpretational tools, particularly in an area where geochemical responses are weak.

MINERAL CHEMISTRY

Microprobe studies were carried out on the amphiboles, pyroxene and epidote which are the main ferromagnesian minerals in the two textural varieties of the amphibolites of Ife-Ilesa schist belt (Olarewaju and Ajayi, 1993). The objective was to determine the chemical composition and compositional variations as well as quantitatively identify the particular types of these minerals. The petrological and mineralogical features were also considered in relation to the metamorphic grade and the Pressure Temperature (PT) conditions during metamorphism.

We showed conclusively and for the first time that the pyroxenes in the FLA are CaO and Fe_20_3 rich (ferrosalite) with low Al_20_3 and Na_20 poor clinopyroxenes. The amphiboles in the two textural varies are hornblende. However, those of the MMA are clacic and sodic-calcic hornblende (Pargasite) rich in Al_20_3, Mg0 and Na_20. In contrast those of the FLA are ferroactinolite (edenitic) rich in TiO_2, K_20, Al_2O_3 but poorer in SiO_2, MnO and Fe_2O_3. Epidote occurs commonly as accessory minerals but sometimes when they occur as major, in the amphibolites, the rock is referred to epidote amphibolite. The epidotes are chemically comparable to Fe-rich, Al-poor epidote (clinozoisite) and similar to those of stripped amphiblotie unit in kohsitan sequence, Pakistan (Bard, Optic cited) except for the latter's relatively lower MnO content.

The overall chemical features of these minerals suggest that variable metamorphic load pressure (PL) conditions prevailed in the area during regional metamorphism with clinozite (epidote) marking the threshold of change from greenschist to amphibolite facies metamorphic grade.

It is important to remark here that the microbe analysis was carried out at USTLC Montpellier, France under the French Technical Assistance Programme to the Department. This study cannot be replicated here even now because of lack of analytical research facilities which has continued to hinder fundamental basic research in Geology.

STUDIES IN THE DAHOMEY BASIN: Geochemistry in Basin Analysis

The Nigerian sector of the Dahomey Basin sometimes referred to as the Dahomey Embayment stretches from south eastern Ghana to the Western Flank of the Niger Delta/Anambra Basin (Omotsola and Adegoke, 1981). The basin contains Cretaceous and Cenozoic successions and up to 3000 metres of sediments are known to accumulate onshore within the major grabens. Along strike, the basin is subdivided into a number of horst and grabben structures by N-S to NE SW trending faults. The most important fault is the Okitipupa ridge which marks the eastern margin of the basin.

Based on polynological data from boreholes penetrating the basin, Omotsola and Adegoke (1981) described the Cretaceous section as the Abeokuta Group and subdivided it into an Ise Formation of Necomian, probable Valanginian, to Baremian age; Afowo Formation of Turronian to Maestrician age and the Araromi Formation of Campanian to late Paleocene age. The basin has prospect for hydrocarbons. Major oil discovery was made in 1966 on the narrow continental shelf and possibilities for oil in deep offshore from Cretaceous sands. Similar sands are being exploited in the Seme fields of Benin Republic.

The major mineral resource in the basin is Tar sands (bituminous sands). The Tar sands belt is about 120km E-W, straddling Ogun, Ondo and Edo State and has an average width N-S extent of about 5km. Adegoke et al., (1980) estimated that the belt holds the equivalent of over 40 billion barrels of oil in place. Other important mineral deposits being exploited include limestone, on which two major cement plants are based, phosphates and kaolinitc clays.

The research initiated within the basin is on the geochemical studies of the Cretaceous sediments in Ifon area in the eastern part of the basin (Ajayi et. al, 1989) and the Paleocene Oshoshun Formation in the Western part, (Ajayi et. al, 2006). These are the first detailed geochemical studies in basin analysis in these areas designed as multidisciplinary approach in resolving the geological problems of the source of the sediments and their environment of deposition.

In the Ifon area, the 27 representative borehole samples used were retrieved during the exploratory drilling for clay in Ifon area in 1980. The boreholes range in depth from 26m to 35m and straddles on E-W belt of 3.7 km. The main lithologies comprise the coarse to medium grained sandstone, grey and black shale, lignitic shales, clays, sandy clay, mudstones and siltstones.

The thirty samples from the western part of the basin were collected from two of the five boreholes drilled in 1987 by Geological Survey of Nigeria (GSN) during the phosphate exploratory project in Oja-Odan-Idogo areas of Ogun State. The drilled depths vary from 99.2m to 200m.

The Ifon samples were analysed for their major, trace elements at USLT, Montpellier, France. The Rare Earth Element (REE) concentrations of the Ifon samples and the major, trace and REE contents of the Oshosun Formation were determined using the Instrumental Neutron Activation Analytical (INAA) technique at the University of Texas Austin TRICIA Mark I Reactor with a Thermal neutron flux of 2×10^{12} n Cm^{-2s-1}. The latter analysis was carried out by Prof. F. I. O. Asubiojo during his visit to the Lab as part of our collaborative research.

The results showed that the Ifon sediments attained a high degree of chemical maturity and are compositionally rich in SiO_2, Al_2O_3 and TiO_2. These three major elements account for between 81wt% and 95.86% wt% of the samples. Furthermore, the absolute REE Increase in the order sandstone> sandy clay> mudstone> clays> Shales. Although the sediments show large variations in REE concentrations, they show uniform and similar REE patterns reflecting the efficiency of mechanical mixing in sedimentary process rather than chemical process (Nancy and Taylor, 1976).

The Inductively coupled Plasma Mass Spectrometer (ICP -MS) analytical technique was used to determine the major and trace elements in rock and phosphate samples obtained from shallow trenches and pits from Igbotako, Ebitibamu and Oja odan phosphate deposits. The study established that the phosphates (Pelletal and granular) are predominantly composed of CaO (16, 97- 42.59) wt% and P_20_5 (22.65 - 31.65) wt% respectively with appreciable amounts of Al_2O_3, $Fe2_03$, V, Cr and Sr (Obisesan, 2004). This suggest that the phosphates are complex calcium phosphate (Franlite apatite) hosted in a highly matured host rocks (clays, grey and black shale). On the basis of Sr/Mn variation diagram/plot of Horgath, 1989, we concluded that the phosphates dominantly plot in the granite pegmatite field thus indicating derivation from prophyritic granites in the nearby basement rocks.

In addition the similar low V/Cr ratios (0.9 - 1.1), appreciable amounts of redox sensitive trace elements (Mn, Zn, V, Cr and Cr) known to accumulate in marine sedimentary phases under poor oxygen (Thomas et al, 1993, Henderson, 1982) confirm the reducing environment of deposition of the phosphate and host rock (See, Gross, 1974;Landergreen and Manheim, 1963).

In consideration of the similar major trace and REE elements patterns for the sediments of the Dahomey Basin from the west to the east, coupled with the horst and grabben structural framework, the restricted oxygen poor shallow marine environment of depostion is proposed for the sediments of the Dahomey basin. This is consistent with the horst and grabben structural frame work proposed for the basin by Omatsola and Adegoke, (1980).

STUDIES IN ENVIRONMENTAL AND HEALTH GEOCHEMISTRY

Vice Chancellor Sir, recently, studies on the natural radioactivity of the Tar Sands and the phosphates in collaboration with colleagues at Centre for Energy Research and Development (CERD) and Physics Department Prof. Mr. Balogun, F. A., Drs. Fasasi, M. K; and Tochokossa, P and Mokobia, C. E.) was initiated by me. Two M.Sc. theses (Oyawale, 2003; and Obisesan, 2004) emanated from this collaborative research. In particular, Mr. Oyawale's thesis on the "Radioactivity of Bituminous Sands of Ondo State S. W. Nigeria" won the NMGS/AGIP 1st Prize in 2003. I wish to modestly add that the M.Sc. thesis of Suh, C. E., in 1993 titled "Primary Metal dispersion Patterns for gold Exploration in the Amphibolites Complex of Ife-Ilesa schist belt SW Nigeria" supervised by me was the first to win the maiden NMGS/NIOMCO prize in 1994. These prizes were instituted for the best M.Sc. thesis in the area of Economic Geology and Mining.

In these studies, the presence and the level of radioactivity of radionuclides in the minerals and the host rocks were determined. The purpose was to provide baseline data and the environmental impact in the exploitation of these mineral resources. These are relevant in the area of environmental and health geochemistry. The fundamental basis of the study is that natural radioactivity is associated with natural sources such as uranium deposits, oil and gas, and it is also a major component of phosphate particularly those of sedimentary origin. Boyle (1982) and Khrater et al; (2001)

showed that the radioactivity of phosphate deposits mainly come from their uranium content. Based on the activity concentrations of the radio nuclides the absorbed doze rates were estimated to determine the levels of health hazards the workers (miners) might be exposed.

The results for the Tar Sands area (Oyawale et.al; 2004) revealed that the radionuclides identified with reliable regularity belong to the decay series of U-238 and Th-232 whilst the non-decay series of K-40 were below the detection limit. In the overburden (lateritic soils) the average specific activity concentration for 214B$_{1,}$ ^{208}Tl, and ^{226}Ra were 165.64 ± 2.91 BqKg^{-1}; 150 ± 2.91 BqKg^{-1} and 60.97 ± 2.27 BqKg^{-1} respectively. These values though are relatively higher compared to the Tarsands, are within the range of normal soils. The specific activity concentrations in the bituminous sands are very low with values ranging between (18.2 ± 3.5 to 36.13 ± 3.15 BqKg^{-1}; (17.17 ± 0.4 Bq - 31.01 + 0.84) Bq Kg^{-1} for Ra-226 and Pb 214 respectively. The calculated equivalent doze rates of (0.17 to 0.78) msv/yr^{1} in the overburden and (0.07 1.35) msr/yr^{-1} in the bituminous sands are very low.

In the phosphates, the measured specific activity concentration due to U-238 vary between 48.49 Bq Kg^{-1} and 192.83 BqKg^{-1} for the granular phosphates from Ebiti Bamu. The pelletal phosphates of Igbotoko contain values which range between 298 BqKg^{-1} and 424.84 BqKg^{-1}. Similar variations occur in those of the host rocks. The specific activity concentration due to Th-232 series range between 1.70 BqKg^{-1} and 10.89 BqKg^{-1} in the pelletal phosphate whilst in the granular phosphate values vary between 9.75 BqKg^{-1} and 30.96 BqKg^{1}. The equivalent absorbed doze rate were (1.23 to 1.63) MSv/yr^{-1} and (0.33 to 0.79) MSv/yr^{-1} in the granular pelletal phosphates respectively. These values for both the Tar sands and the phosphates are below the normal background of 2MSv/yr^{-1} limit set for humans and much lower than the 20 MSv/yr^{-1} for radiation workers in most environments as recommended by the International Commission on Radiological Protection (ICRP). Hence, there is no health hazard threat to the miners of both tar sands and phosphate.

ORGANIC AND IN ORGANIC GEOCHEMISTY OF OIL AND SOURCE ROCKS OF THE NIGER DELTA

The Niger Delta basin has been producing and exporting oil since 1958 with a production of 5,100 bbl of crude oil per day to the present daily producing capacity of over 2.5 million bbl. The national reserve base is over 30 billions barrels of oil. Nigeria has greater potential of gas than oil with the current revenue estimate of over 165 trillion Standard Cubit Feet (SCF) which is far in excess of the proven oil reserve.

Exploration and production activities of oil (upstream) is predominantly (90%) on joint partnership between the NNPC and the International Oil Companies (IOCs) under Joint Operating Production (JOAs) or Production Shearing Contracts (PSCs). The remaining 10% of the upstream activities is undertaken by indigenous companies which operate in partnership with IOCs under sole risk or as independents. The operations are in the on-shore Niger Delta, coastal offshore areas and the deep >200m and ultra deep (2,500m) waters.

Nigeria's Petroleum Industry is well grounded in successful exploration activities. Various studies had been carried out on the geochemistry of both oil and source rocks. In addition trace metal distribution especially transition metals in oils had been used amongst other applications in exploration for oil-oil and oil-source rock correlation, classification, maturity of oils, migration pathways and depositional environments of organic matter (see for example Barwise, 1990; Nwachukwu et al; 1995; Udo et al; 1992) amongst others.

The Ph.D. research thesis of Dr. A. Akinlua co-supervised with Prof. B. B, Adeleke at the University of Ibadan was based on the organic and inorganic geochemistry of oil and source-rocks from an oil field in N.W Niger Delta Area. Subsequent Post Doctoral Fellowship awards facilitated his visits to the Department of Chemistry, University of Botswana twice to work in Dr. N. Torto's laboratory where more detailed studies were carried out with the state of the art analytical facilities (viz- GCMS; ICPMS, AAS). We cannot but acknowledge the invaluable support of Dan Jarvie, President Humble Geochemical Services, Humble Texas, USA who came to our rescue at the critical stage of the Ph.D. work. All the analyses carried out in his laboratory were free of charge. Between 2004 and January 2007, we have published seven papers, all in reputable International Journals.

In our studies on the re-appraisal of rock and pyrolysis to source rock studies (Akinlua et al; 2005), we demonstrated that for proper source rock Kerogen characterization, it is essential that source rock samples should be extracted prior to TOC and Rock Eval pyrolysis to remove the effect of oil-based mud contamination. Furthermore Gas Chromatographic (GC) data was utilized to evaluate vertical and lateral reservoir continuity, compartmentalization and tubing string communications in the oil field (Akinlua, et. al. 2005). The results revealed a degree of vertical heterogeneity in the field whilst vertical reservoir continuity exist between the oils, which are from a well with dual completion. In addition, it was established that lateral reservoir compartmentalization exist in the field whilst lateral continuity indicated that communicating fault also exist in the field. These results have implications in future oil exploration and production.

Akinlua et. al; (2006) based on the light hydrocarbons of the oils concluded that there are two oil types, normal and degraded thus establishing the application in oil typing as well as post accumulation alterations (biodegradation). The aromatic hydrocarbon content and infrared (IR) characterization of the oils revealed that the distribution pattern were influenced by thermal maturity and biodegradation (Akinlua et al; 2007).

The trace metal concentrations of the kerogen from the Agbada Formation were determined using graphite furnace Atomic Absorption Spectrometric Technique (Akinlua et. al; In Press). The results showed that the kerogens are of terrestrial origin with higher concentrations of As, Cd, Cr, Co, Cu, Fe, Pb compared to the oil. However, the V and Ni values were comparable.

Another highly significant aspect of our study is the application of REE in the fingerprinting of the Niger Delta Oils. This is the first innovative contribution to the petroleum geochemistry of the Niger Delta Oils. The preliminary results were presented by me at the Association of Afro-Asian Petroleum Geochemists (AAAPG) Conference in China in 2004. (Courtesy NAPIMS and Pan Ocean Oil Corporation Limited). The four Light REE (LREE) La, Ce, Nd and Pr detected show very wide variation. The values varied from (0.01 0.49) ppb, (0.06 - 1.58) ppb, (0.01- 0.47) ppb and (0.0 0.18) ppb respectively. Furthermore all LREE showed significant and positive inter element correlation ('r' = 0.75 - 0.95, $P = <0.05$) and with aromacity index (T/n C_7). Jarvie (2001) concluded that the higher the aromaticity index, the less the distance the oil migrated. Thus, we suggested that the significant and positive relationship between the LREE and aromaticity index could be used as migration indicator. Based on cluster analysis, two oil groups were obtained. This is consistent with the migration characteristics revealed by organic geochemical data.

Finally, the strong similarity in the LREE distribution pattern and bulk plankton showed that the LREE in crude oil had biogenous input. With these results, we were able to demonstrate that LREE contents of oil provide alternative technique on oil-to-oil correlation, migration characteristics and origin which constitute major areas of application of geochemistry in oil exploration.

CONTRIBUTION OF RADON STUDIES IN THE BASEMENT COMPLEX TERRAINS

Ours was the first effort to quantify the geogenic radon soil-gas potential and appraise the application of the technique as a geological and structural mapping tool in the crystalline basement terrain of Ile-Ife Nigeria. Ajayi and Adepelumi (2002) used the soil-gas radon techniques to map both lithologic and tectonic contacts in the basement complex terrain of Ile-Ife (using the EDA RD-200 Radon Detector 7.5.21) (Fig. 21). The results obtained show a high radon concentration on the axis of the faults (See Fig. 22). The presence of a suspected strike-slip fault hitherto undetected, and a known fault earlier delineated by Olorunfemi et al, (1986) using Integrated Geophysical Methods were confirmed. Generally, the observed radon concentration in the soil exhibits a strong dependence on the local geology.

Furthermore, Adepelumi et. al; (2005) carried out a more detailed study in a selected area within the Obafemi Awolowo University Campus (Fig. 23). Ten long traverses at closely spaced sampling intervals of 50m were established perpendicular to the regional strike of the lithologic rock units. The lengths of the traverses are 1,000m long with a traverse-traverse separation of 100m. A total of 200 radon soil-gas measurements were made.

The results clearly indicate that the soil-gas radon concentrations found in the regolith soils overlying the crystalline bedrock reflects the geochemistry of the underlying bedrock, as these are residual soils. Also, the pattern of radon soil-gas within the regolith soil was found to have strong correlation with the underlying various geologic rock types.

The rock units are classified into three categories: granite gneiss (unit A); grey gneiss (unit B); and mica schist (unit C), based on the concentration of radon levels measured in soils overlying each rock group. The soils overlying zone A with radon level greater than 1,000 pCi/l are classified as high radon potential. Areas with values of 400-1,000 pCi/l are classified as zone B (moderate potential zone), while zone C (low potential areas are characterized by less than 400 PCi/l. The high to moderate radon values occur especially in areas underlain by granites and gneissic basement rocks of Precambrian age (Figs. 24a, b). It is envisioned that houses built in zone A probably will have relatively high indoor radon level compared to areas B and C. This will require follow-up indoor radon studies.

Thus, through these studies, we were able to confirm the usefulness of radon soil-gas technique as a good geological mapping tool in the tropical regions known for poor bedrock exposure. We thus concluded that information obtained from radon studies can be used to compliment other geophysical methods for both local and regional geologic mapping.

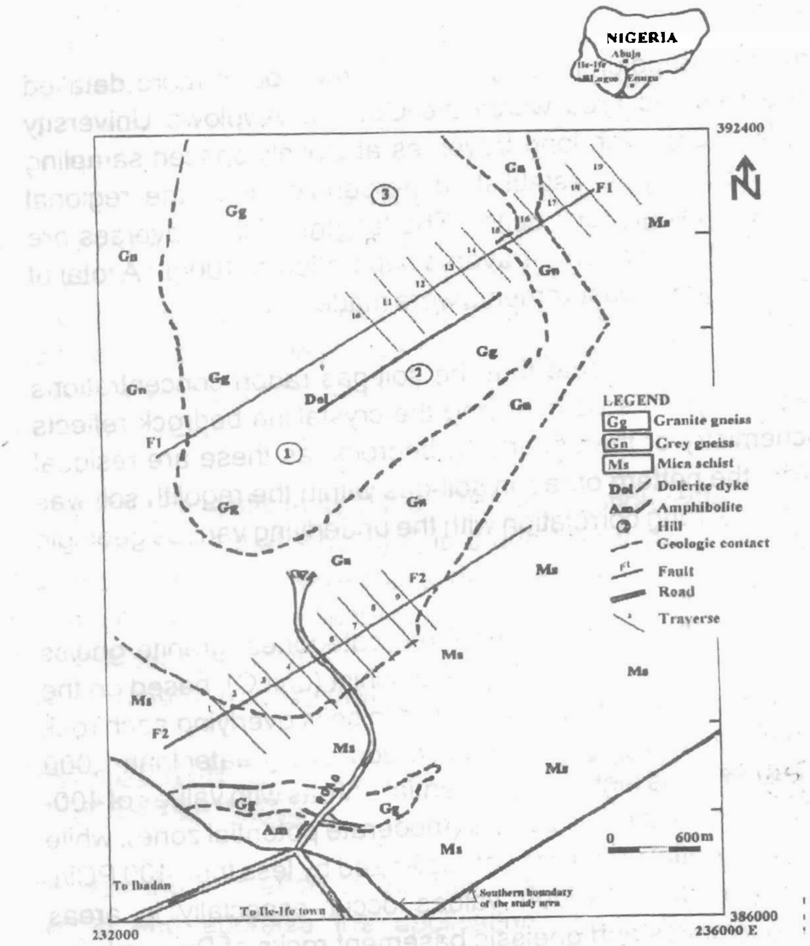

Figure 21: Geologic Map of Ile-Ife Basement Complex Showing the location of the study area.

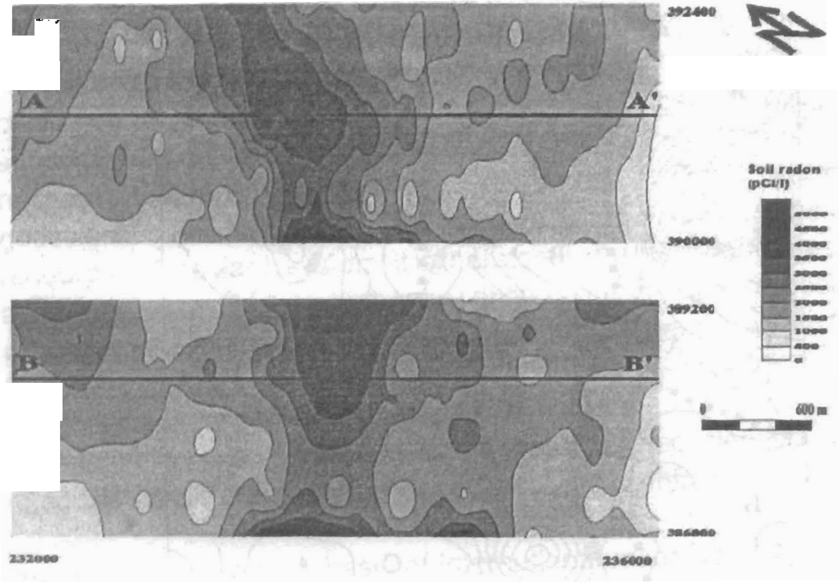

Figure 22: Soil-gas radon radioactivity map for the study area. Note that high radon concentrations depict the fault zone

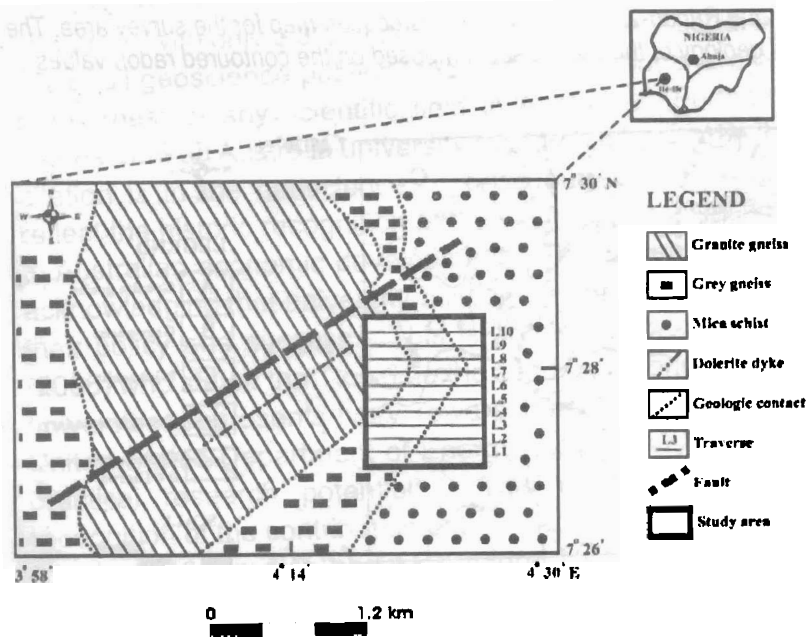

Figure 23: Geologic map showing the location of the radon sampling points

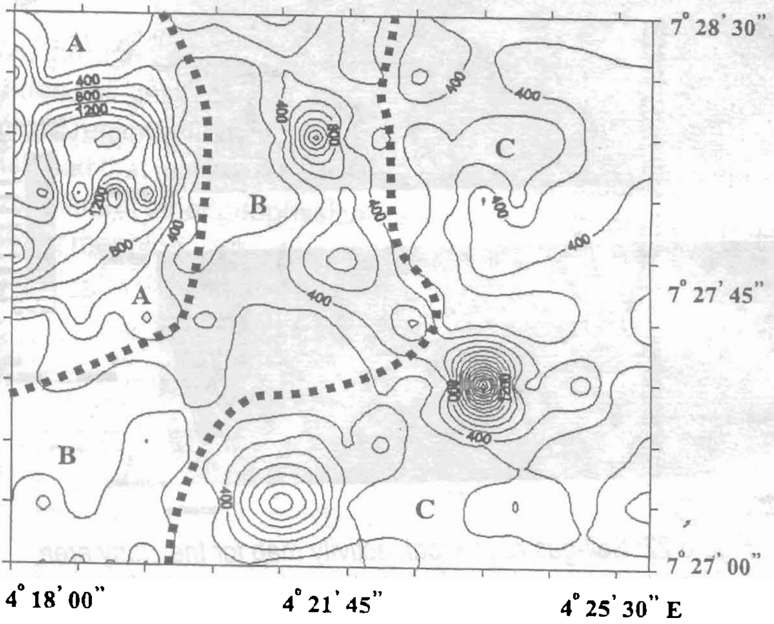

Figure 24a: Radon-222 concentration distribution map for the survey area. The local geology of the area is superimposed on the contoured radon values

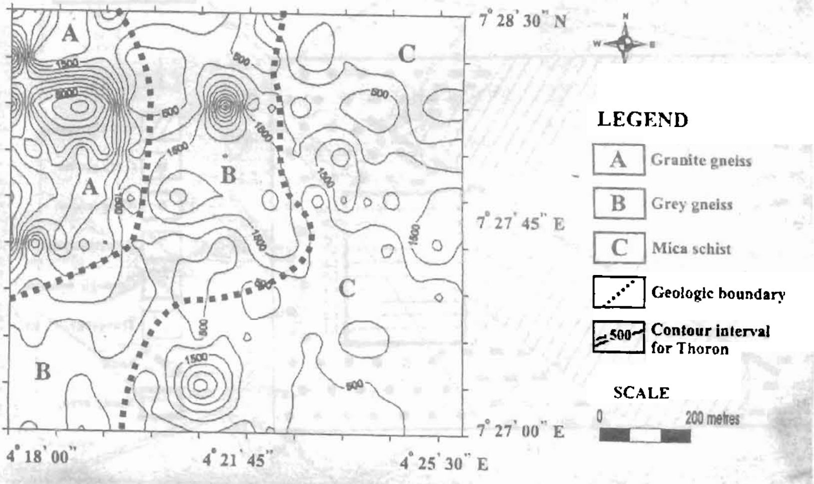

Figure 24b: Radon-220 concentration distribution map for the survey area. The local geology of the area is superimposed on the contoured thoron values.

GEOSCIENCE EDUCATION IN NATIONAL DEVELOPMENT AND SUSTAINBAILITY

Permit me sir to start this with relevant quotation from the 2003 policy paper on National Committee for Earth Sciences (NCES), a subcommittee of the Australian Academy of Science as part of their national Research Priorities on Geosciences (NRPs). "Without geoscientific knowledge, it is not possible to rationally manage the resources of the earth system. it is therefore in the national interest to build this knowledge which can only come from an effective geoscience community". The above statement underscores the fact that the potentials of geoscience knowledge's contribution to the national good are enormous. In order to realize these potentials, it is necessary to have enough highly capable geoscientists with specialists skills and a strong national geoscience infrastructure.

As an example, on the basis of international measure of research performances, Australia has enviable international reputation for their ability to generate innovative and valuable geoscience knowledge. Australia is recognized as a world leader in geoscience research. With only 0.3% of the world population, Australia provides 5% of all geoscience publications and equivalent share of citation, the highest of any scientific field in Australia. Furthermore the highest ranked Australia university research programme in terms of citation is in the geoscience. These outstanding achievements reflect the historic recognition of the value of geoscientific research to Australian economic development. This is due to the extent of acknowledging that university based research has been the core of their policy and success. This is amply demonstrated by Milam (2006) who stated that "to some the academic world of colleges and universities represents Ivory Towers, detached from reality. To the United States Department of Energy, they represent a crucial and practical research potential". This statement was made in recognition of the contribution of the academia whereby 13 projects (costing $10.7 million and $5.6 added by industry and academic partners) designed to improve efforts to develop large unconventional gas sand oil. This resulted in the estimated 700 Trillion Cubic Feet (TCF) of an convectional gas and oil resources compared to an industry estimate of 190 TCF in conventional natural gas reserves.

Even with the enviable track of records and success of Australia, the recent survey shows a serious decline in geoscience capacity within the university sector. This is a global feature which (we all know it is more apparent in Nigeria) has been acknowledged will jeopardize the overall capacity of the geosciences to continue to perform well and continue to contribute to the national good. It is the strong belief of NCEs that "recovery is possible if remedial action is taken now" to reverse this trend.

David and Wright (1997) in their paper on "Increasing Returns and Genesis of American Resource Abundance" noted that the abundance of American mineral resources should not be seen as merely a fortunate natural endowment, but is more appropriately understood, as a form of collective learning, a return on large scale investment in exploration, transportation, geological (geoscience) knowledge and the technologies of mineral extraction refining and utilization. This was the basis of United States of America's development of her mineral resource endowment well ahead of countries on other continents. The minerals sector thus constituted a leading edge of the knowledge economy in US history. They therefore identified the following elements in the use of the American Minerals Economy.

An accommodating legal environment
- Investment in the infrastructure of public knowledge
- Education in mining, minerals and metallurgy.

The trend is also true of other countries such as Canada, Australia, Latin America and Brazil amongst others endowed with vast mineral resources. It has been shown that return on investments in country specific mineral knowledge have remained high in recent decades, so that production and reserve levels have continue to grow in a well-managed resource based economies. It is also known that many other resource based economies have performed poorly not because they have over emphasized minerals, but because they have failed to develop their mineral potential through appropriate policies.

Mr. Vice Chancellor Sir, it will be very instructive to cite few examples of countries that have developed national policies in both mineral development policies and investment in geoscience education.

In Norway, the first commercial discovery of oil occurred only in 1969 (13 years after Nigeria first discovery in 1956 at Oloibiri). Today, as a new comer in many ways, the Norwegian experience and expertise parallels that of California. Virtually from the start, negotiations with International Oil Companies emphasized the transfer of competence and control to Norway (Anderson, 1993). With the establishment of a state-owned company (Statoil) in 1973, an investment in training of Petroleum engineers, in the Norwegian Technical University and Rogaland Region College, "recipient competence" was transformed into "participant competence", making it possible to speak of an independent Norwegian Oil Industry.

A distinctive approach to exploration developed at the University of Oslo's Department of Geology, focusing on the properties of different types of sandstone as reservoir rock and the flow of water and oil in sediment basis, has become to be known as the "Norwegian School of thought" regarding oil exploration. Indeed, these advances in Technology and in the infrastructure of knowledge have extended the quantity of Norway's petroleum reserves. Today, Statoil is a major player in the Nigerian Oil Industry.

The Nigerian Oil Industry is over forty (40) years old. Do we have a truly Independent National Oil Company as an Exploration and Production (E & P) comparable to Statoil of Norway, Peterobras of Brazil, Petronas of Malaysia and CNOAC of China? The situation in the Nigeria oil industry was effectively captured by Afolabi, (2007). He asserted that the Nigeria Petroleum and Development Company (NPDC) a subsidiary of NNPC was established as a truly E & P Company and it existed on paper. All her funds come from NNPC while all her incomes are in the Federation Account (CBN). To add salt to her wounds, all NPDC choice acreages were withdrawn from her and awarded to new comers. In essence, Nigeria is just interested in JVC and in collecting royalties!! The issue is not that Nigeria does not have very brilliant men and women who have excelled in the minerals and energy industries, but that we lack patriotic national policies on sustainability.

The recent success stories in Latin America started with turn around in the 1990s was anchored on not only reform encouraging foreign investment in mining and increasing security of mining investments, but also with strong roles for the State geological agencies. Latin America is now world's fastest growing mining region, well ahead of Australia, Canada, Africa and the US in the share of spending on exploration.

The leaders in this burgeoning new minerals growth are Chile, Peru and Brazil. For example, Brazil is the leading industrial nation of the region, though her share of the mining sector is low compared to her neighbours. However, following an intensive government investment programme in prospecting, exploration and basic geologic research, mineral production grew at more than 10% per year in the 1980s. Mineral exploration activities expanded rapidly in the 1990's, increasing both production and Brazil's reserves in most minerals. Currently, Brazil produces more than 60 mineral commodities and is the world's largest exporter of iron-ore.

The case of Australia demonstrates that expansion of a country's minerals base can go hand in hand with economic growth and technological progress. The Australia's mineral sector is knowledge intensive. In the past ten years, income from Australia's intellectual property in mining has grown from $40 million to $1.9 billion per year. Also R & D expenditures by the mining sector accounted for about 20% of R & D expenditure by all industries in 1995 - 1996. In 2003, Strategic Leaders Group for Mineral Exploration Agenda proposed a $20 million per year funding with a total funding of $140 million over a seven year period on research and development areas on Deep Ore

Discovery Programme (Table 9). This commitment to R and D underpins future growth in mineral exploration. Australia has emerged as one of the world's leaders in mineral exploration and development of technology. Also Australia's unique geology calls for unique science. World Geoscience, an Australian company is a leader in the development of airborne geophysical survey techniques. Also the industry leaders have put up an ambitious technological vision known as "Glass Earth Project" a complex of six new technologies that would allow analysts to peer into top few kilometers of the Earth's Crust to locate valuable mineral resources.

TABLE 9: PROPOSED SEVEN YEAR FUNDING OF DEEP ORE DISCOVERY PROGRAMME RESEARCH AND DEVELOPMENT IN AUSTRALIA (WILIAMS, 2003).

DEEP ORE DISCOVERY PROGRAMME				
S/N	RESEARCH AND DEVELOPMENT AREAS	FUNDING ($M/YEAR)	TOTAL FUNDING OVER 7 YEARS ($M)	PERCENTAGE OF FUNDING
1.	Geophysical tools to characterize subsurface features	7.50	52.50	38
2.	Geochemical exploration Methodologies for areas of deep cover, and drilling technologies	6.75	47.25	34
3.	Exploration models for effective targeting of buried mineralization	2.25	15.75	11
4.	Data processing, integration, interpretation and visualization methods (including Geoscience Portal and Earth Science Grid)	3.50	24.50	17
	Total	20	140	100

Source: Recommendations prepared by the Strategic leaders Group for the Mineral Exploration Action Agenda

In recognition of the role of geoscience education, the Australian National Committee for Earth Sciences has proposed a five year strategic plan coded "Geoscience Unearthing the Future" with the following goals.

- **Education**: a sustainable and wealthier Australia through more effective geoscience education.

- **Research**: a vibrant world leading geoscience research community.
- **Sustainability**: a sustainable Australian society through understanding of Earth's life support system

- **Wealth**: a wealthier Australia through discovery of new clean energy and mineral resources that fuel national and regional economies.

These are ideal goals for our nation Nigeria that has similar geological environment for the effective development of her geoscience community.

Mr. Vice Chancellor Sir, the key challenges for geoscience with respect to mineral resources in relation to sustainability are

- ability to maintain a sustainable society requires solutions that arise in geosciences i.e. continue to maintain the energy, mineral and water resources that fuel the economy, and remediating effects of withdrawing these assets from the earth system requires the expertise of a vital and viral group of geoscientists who will continuously address the complex and changing problems that these challenges present.

- that for countries that are enriched or endowed with natural resources, the major mineral deposits and oil provinces that remain to be discovered are hidden beneath thick cover or either deep within the crust or beneath deep waters offshore. Thus maintaining the strong economy requires continued innovation in geoscience to create new technologies to detect and develop these hidden treasures.

CONCLUSION

Vice-Chancellor Sir, in the course of this lecture, I have incorporated and built-in recommendations as against the pattern of submitting a list of recommendation at inaugural lectures. The kernel of my lecture is that exploration is the lifeblood of the mineral industry, the pillar of our complex modern society and the driving force of human existence. It has been shown that there is a strong and significant correlation between investment in exploration for particular mineral commodities and the magnitude of additional resources discovered in the ensuring years. Furthermore, competitive geoscientific exploration data provided by government will lead to increased levels and intensity of private exploration activities participation in the areas covered. Exploration needs to be aided by the latest technology and a sound and improved geoscientific knowledge base to meet the demands of searching for hidden treasures. Exploration is the key to "seeing where people can't go".

For our nation Nigeria, I commend the simple biblical injuction that having seen the benefits accruable to other nations on their intensive investment in exploration, geoscientific education and technology coupled with patriotic national policies on mineral resources development, Nigeria must "go and do likewise".

ACKNOWLEDGEMENTS

My Vice-Chancellor Sir, gratitude or appreciation or thankfulness is in the heart of man. Psalm 111:1 says "*I will thank the Lord with all my heart as I meet with His godly people*". I will therefore not endeavour to particularize on this occasion in a accordance with the rule. Even if one is tempted to break the rule, which is not in my character, the list will indeed be endless.

Therefore, to all the Godly people I have met in my journey of life thus far, and God used in no small measure to do great things in my life, on behalf of myself and family (nuclear and extended), accept my hearty thanks and appreciation. Above all, the honour, glory and adoration belong to God for He has done great things.

My Vice-Chancellor Sir, ladies and gentlemen, I thank you for your attention and God Bless you ALL Amen.

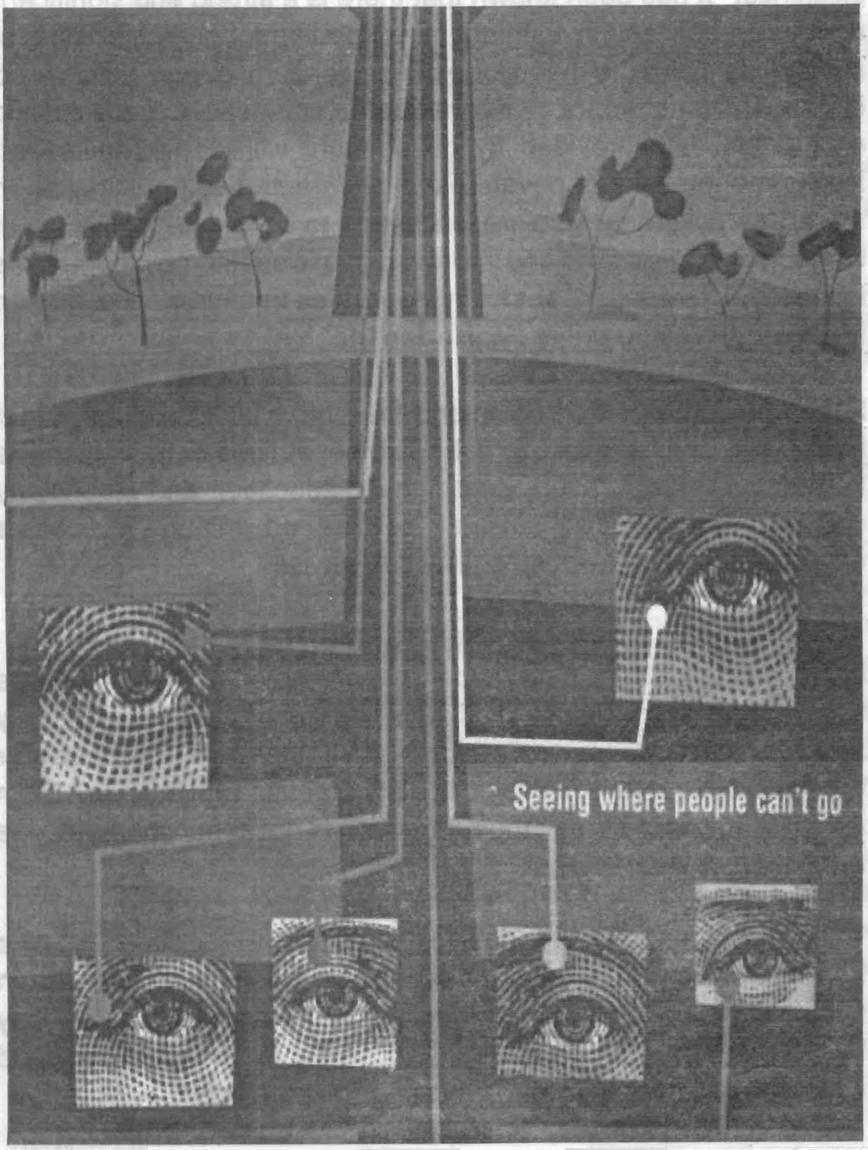

Figure 25: Seeing where people can't go
(After, EarthMatters, CISRO, 2003)

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