

A STUDY OF NATURAL RADIATION LEVELS AND  
DISTRIBUTION OF DOSE RATES WITHIN THE  
YOUNGER GRANITE PROVINCE OF NIGERIA

ABIYE OLATUNJI SOLOMON

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GRANITE PROVINCE OF NIGERIA**

**ABIYE OLATUNJI SOLOMON  
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**A THESIS SUBMITTED TO THE SCHOOL OF  
POSTGRADUATE STUDIES, UNIVERSITY OF JOS, IN  
PARTIAL FULFILMENT OF THE REQUIREMENTS FOR  
THE AWARD OF THE DEGREE OF DOCTOR OF  
PHILOSOPHY IN UNIVERSITY OF JOS**

## **DECLARATION**

I hereby declare that this thesis titled ‘A study of Natural Radiation Levels and Distribution of Dose Rates within the Younger Granite Province of Nigeria’ is a record of my original work and to the best of my knowledge, no part of it has been presented to any other institution for the award of any higher degree.

---

**A. O. Solomon**

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-v-

## **DEDICATION**

This work is dedicated to my kids:

Fayowa, Kunle and Lekan Solomon.

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## ABSTRACT

A study of natural radiation levels and distribution of dose rates in parts of the Younger Granite Province of Nigeria constitutes this work. It has established the extent and distribution of various parameters of ionizing radiation across the area. By using a combined solid scintillation and gas filled radiation detection techniques, gross gamma as well as gross alpha/beta radiations were detected and measured within the different rock units, the result of which show that radiation levels are high within the younger granites and in parts of the basement areas but low within the basalts. Radiation maps prepared for this area show a good correlation with existing geological maps of the area signifying that natural terrestrial radiation signatures can be used as a tool for regional geological mappings especially in poorly exposed plains. The maps indicate that absorbed dose rates in air range from 0.030-0.431  $\mu\text{Gyh}^{-1}$ , while dose equivalents and effective dose rates are well in excess of 1mSv/yr maximum permissible limits in some areas, suggesting a reasonably good chance of radiation hazards in those places. Highest values were found within the Ririwai Sheet 126, attributable to high concentration of radionuclides within both the peralkaline and non-peralkaline granites that constitute the complex. People living in areas identified with high background radiation levels in this study should therefore be made aware of the potential radiation related health problems, while government should also do more to stop the common practice of using mine wastes for foundation fillings and block construction because of the radiological implications.



## **CHAPTER ONE**

### **GENERAL INTRODUCTION**

#### **1.1 INTRODUCTION**

Beyond the ultraviolet are higher energy radiations which we all get in low doses from space, air, and from the earth. Collectively, these radiations are referred to as ionizing radiation. Ionizing radiation is that class of radiation which is able to produce ions that is capable of disrupting life processes. Non ionizing radiations are not able to create ions, although they may adversely affect human health in other ways.

At the formation of the earth about four billion years ago, the materials with which it was made contained many radioactive isotopes some with short and others with very long half-life. Natural radioactive materials are found in rocks, soil, air, food and drinking water. The natural environment therefore is a major source of radiation, to which man is exposed. Ionizing radiation from natural sources that we are all exposed to at all times is called natural background radiation.

According to United Nations Scientific Committee on Effect of Atomic Radiation (1988), each inhabitant of the earth is exposed to an average of about 2.4 mSv radiation dose per year both from cosmic sources and earth's crust. Other sources of radiation are artificial, resulting from medical applications, nuclear industry and nuclear bomb explosion.

Radiation can be defined as the emission and propagation of energy in the form of rays or waves from the atoms and molecules of a radioactive

substance as a result of nuclear decay. It can be classified into two main types namely ionizing and non-ionizing. Ionizing radiation is the type of radiation capable of ionizing an atom, and ionization usually occurs when one of the orbital electrons of an atom has been completely removed from it. The resultant effect of this is that the residual atom becomes positively charged (positive ion or cation), and the freed electron becomes negatively charged (negative ion or anion). To be able to do this, the energy propagated must be sufficient to overcome the binding force of the atom as explained by the quantum theory:

$$E = hc/\lambda$$

where: E = the energy in electron volts

h = the Plank's constant

c = the velocity of light

$\lambda$  = the wavelength

The effects of radiation may be divided generally into four types. They include acute somatic effects, developmental effects, genetic effects, and late somatic effects (Noz and Maguire, 1979; UNSCEAR, 1972, 1977, 1982). Acute somatic effects occur in individuals within days or weeks of their exposure. It include injuries to the brain which causes delirium and convulsions; damages to the eye lens resulting in cataracts; gastrointestinal tract injury resulting into nausea and vomiting; sterility if ovaries or testes are damaged; and damages to the bone marrow which affects the body's ability to fight infection. Depending up on the degree of irradiation however, certain tissues such as the bone marrow, the intestinal lining, or the skin, may be able to replace cells killed by

radiation within a few days. Some damages are however permanent above a certain dose level.

Developmental effects normally occur in unborn children of mothers exposed to radiation. A common consequence is brain damage or mental retardation, particularly if exposure occurs between the 8th and 15th week of gestation, when rapid development of fetal brain tissues do occur (Arena, 1971). Radiation exposure may also cause genetic mutations in adults which are carried through to children or later descendants. Victims and descendants of the 1945 Hiroshima and Nagasaki (Japan) atomic bomb blasts are known examples.

Late somatic effects are injuries produced in an individual many years after exposure to radiation. The major late somatic effect is the development of various forms of cancer. Of recent, the use of depleted uranium to destroy targets during war has generated a lot of international outcry because of its late somatic effects on the victims.

Naturally occurring radionuclides in rocks produce external exposure to radiation and natural radioactivity in rocks is caused principally by  $^{238}\text{U}$ ,  $^{235}\text{U}$ ,  $^{232}\text{Th}$ , and to a lesser extent by  $^{40}\text{K}$  and  $^{87}\text{Rb}$ . Radiation from these sources are generally of low doses but could pose health problems. A 1977 study by Advisory Committee on Biological Effects of Ionizing Radiation as well as the United Nations Scientific Committee on the Effects of Atomic Radiation report of 1977 have all shown that even low doses of radiation pose a human cancer risk three to four times higher than previously estimated. The

estimated cancer risks for children exposed are also about twice as large as those for adults.

Radionuclides in natural environment may be acquired into the body unintentionally through inhalation, ingestion or absorption (IAEA, 1989). Subsequently, they are deposited at various sites in the body. The human body cannot sense exposure to radiation directly except at levels that are invariably lethal and therefore, it can not provide defense against it. Because of the severity of this problem therefore, acceptable (safe) levels of radiation exposure and consequently radiation doses (maximum permissible doses - MPD) have been set by various bodies based on research findings in this field. These bodies include the National Academy of Science/National Research Council Advisory Committee on Biological Effect of Ionizing Radiation (BEIR), International Commission on Radiological Protection (ICRP), National Council on Radiation Protection and Measurement (NCRP), International Commission on Radiation Units and Measurements (ICRU), United Nations Scientific Committee on Effect of Atomic Radiation (UNSCEAR), International Atomic Energy Agency (IAEA) as well as World Health Organization (WHO).

Maximum permissible dose (MPD) for non occupationally exposed individual is put at 1mSv/yr. At high doses, ionizing radiation is dangerous. It is therefore necessary to know the level of radiation within our living environment because of the health implications.

## 1.2 THE STUDY PROBLEM

The Younger Granite province in north central Nigeria is made up of non-orogenic granites of the Mesozoic Era (MacLeod et al, 1971), and forms a distinct metallogenic province consisting essentially of biotite granite, riebeckite biotite granite, hornblende fayalite granite, hornblende biotite granite, rhyolite, syenite, gabbro, dolerites and basalts, with varying amount of natural concentration of thorium, uranium and potassium as indicated generally in Table 1. Some of these rocks are also associated with alluvial deposits of cassiterite (tin oxide,  $\text{SnO}_2$ ) and columbite (oxide of tantalum-niobium, iron and manganese,  $(\text{Fe,Mn})(\text{Ta,Nb})_2\text{O}_6$ ), as well as radioactive mineral residues such as thorite ( $\text{ThSiO}_4$ ), zircon ( $\text{ZrSiO}_4$ ) and monazite ( $(\text{Ce,La,Yt})\text{PO}_4$ ). Rocks in this area therefore constitute a major source of external exposure to radiation for the inhabitants of the area.

While much is known to have been published on the geology, structures and mineralization in this province, only very little is known about the extent and distribution of various parameters of natural radiations in the area. The present work studied this problem. It measured radiation levels from both gamma radiation as well as from alpha/beta radiation sources from major classes of rocks *in situ* across the area. The work also identified and delineated zones of possible radiation hazards within the study area.

### **1.3 OBJECTIVES OF THE STUDY**

In line with the study problems stated above, this study is aimed at the following:

- 1). To measure the levels of ionization in count rates from both gamma and alpha/beta radiation sources for the major classes of rocks across the area
- 2). To calculate radiation dose equivalents from the measured count rates for these classes of rocks
- 3). To establish correlation and mathematical relationships between the various measured and calculated radiation parameters for each classes of rocks
- 4). To combine data of field radiation measurements with information on existing airborne radiometric map of the area in regression plot, to generate grid data for the preparation of map of distribution of absorbed dose rates in air, map of distribution of dose equivalents as well as map of distribution of effective dose rates for the area
- 5). To prepare map of radiation hazard for the study area using the ICRP 1mSv/yr maximum permissible dose limit for the general public as basis.

### **1.4 USEFULNESS OF THE STUDY**

The present study will contribute immensely to the understanding of the characteristics of natural terrestrial radiation in this region in many ways:

1) It will provide background information on the levels and distribution of radiation doses in the study area. This can be used to confirm, and to plan decisions regarding possible radiation related health problems in the area. It could also be used to raise public awareness on the subject so as to help promote an understanding of the essential linkages between environment and development.

2) Ionization from rocks depend on the concentration of primordial radionuclides such as  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  in the rocks. Data obtained in this study therefore could be useful for future radio-geochemical investigations in the area especially the search for rare earth elements and location of potassium alterations.

3) The work will provide scientific data on the levels of ionizing radiation in the area. The data will therefore form a reference baseline in situation of atmospheric fallouts resulting from accident and emergency situations from nuclear power plants or other nuclear sources.

## **1.5 LOCATION, EXTENT AND ACCESSIBILITY**

The study area (Figure 1) is located within Latitude  $9^{\circ} 30' \text{ N}$ , and  $11^{\circ} 00' \text{ N}$ , and Longitude  $8^{\circ} 00' \text{ E}$  and  $9^{\circ} 30' \text{ E}$ , covering the Forum, Ganawuri, Kagoro, Kigom, Ropp, and Sara-Fier complexes in the lower part, as well as the Amo, Buji, Jarawa, Jere-Sanga, Jos-Bukuru, Junguru, Kofai, Kwandonkaya, Miango, Saiya Shokobo, Shere, Sutumi and Tongolo complexes in the central

part. The upper part of the study area consists of the Banke, Dutsen Wai, Gamawa, Kudaru, Ririwai, and Zuku complexes. They are all located on topographical sheets 125, 126, 147, 148, 168 and 169 published by the Federal Survey Department on a scale of 1:100000. The study area covers a total of about 18,000.00 square kilometers. The complexes of interest have been chosen to cut across the general geologic ages within the ring complexes, for possible correlation between radiation levels and geologic ages. According to Bowden et al (1976), Buchanan et al, (1971) and Kinnaird et al (1981), the average age of the complexes listed in the lower part above is 152 Ma, while those in the middle and upper parts are 162 Ma and 172 Ma respectively.

The area is accessible by a network of roads, footpaths and farm tracks. Major roads here include Jos - Pambegua, Pambegua - Zaria, Pambegua - Dutsen Wai - Anchau, Pambegua - Kauru, Saminaka - Dadinkowa - Ririwai, Jos - Bauchi, Magama - Gumau, Jos - Ryom, Ryom - Ganawuri,, Jos - Barkinladi - Mangu, and Jos - Miango roads among others. They provided a reasonably good access and were used to traverse the area during fieldwork.

## **1.6 CLIMATE AND VEGETATION**

To a very large extent, the climate of the north central Nigeria is determined by the movement of the Inter-Tropical Convergence Zone and heights above mean sea level. It has one of the highest altitudes in Nigeria and



this explains why temperatures are generally low around the area compared to most other parts of the country.

The north central areas of Nigeria is characterized by two seasons: wet and dry. The wet season comes between April and October, with August having the highest value while the dry season comes between November and March periods of every year. A chart of distribution of monthly rainfall around Jos to the south of the study area is shown in Figure 2. The mean annual surface temperature here varies from about 25°C to 35°C. Temperatures generally fall in July and August periods of the year corresponding to the peak of rainy season, as well as in December and January periods corresponding to the peak of harmattan in the area as illustrated in Figure 3. Vegetation here is that of Sudan Savannah characterized by grasses, shrubs, thorns, and scattered trees but relatively thick areas can also be found.

## **1.7 RELIEF AND DRAINAGE**

The area of study consists of two major relief features which are distinguishable from one another i.e. the highland and the lowland areas. The highlands generally consist of the Younger Granite complexes some of which are shown in Plates I-IV. Average elevation here is about 1000 meters above mean sea level. The lowlands are composed essentially of poorly exposed plains, and made up of rocks of the basement complex consisting of gneisses, migmatites and older granites (Plates V,VI &VII), with newer basalts

Plate VIII) found in some places. Average elevation here is about 550 meters above mean sea level.

Both the lowland and the highland areas have been affected by weathering and erosion with laterites covering most parts of the lowlands. The drainage pattern in the area is generally a dendritic type characterized by irregular branches, but few ones appeared to be structurally controlled. Most of the rivers are seasonal but some flow all year round.

### **1.8 SETTLEMENT AND LAND USE.**

Settlement within the study area is typical of that found in most parts of Nigeria. Highly populated areas are confined to major towns such as Jos, Barkinladi, Miango, Toro, Saminaka, Pambegua and Rirawai. Outside the towns, settlement is essentially sparse. The major occupation of the people in the area is farming. Dark soils can be found in most areas especially those resulting from the weathering of the basalt, and are fertile, supporting various forms of crops.

Mining and mineral processing activities are also common in this area (Plate IX & X). While the streams are used mainly for washing, drinking water in this area is mainly obtained from hand dug wells (Plate XI) and in few cases from shallow boreholes fitted with handpump (Plate XII).

## **1.9 RADIOACTIVITY**

Radioactivity is the spontaneous emission of energy in the form of particles or waves (electromagnetic radiation), or both, from the atomic nucleus of certain elements. It was discovered in 1896 by Henri Becquerel (a French Physicist) who observed that uranium emitted penetrating rays continuously and without initiation. This pioneering work was followed by Pierre and Marie Curie shortly afterwards. They proved that the radioactivity of uranium was an atomic property and not a chemical one.

The pioneering work above led to the discovery that radioactive atoms emit three different kinds of radiation namely alpha particle, beta particle and gamma rays (gamma rays are similar to, but more energetic than, the X-rays, an energetic form of electromagnetic radiation discovered by the German Physicist Wilhelm Conrad Roentgen in 1895).

Building on the research of Marie Curie and others, it was soon realized that if atoms emitted such things, they could not be indivisible and unchangeable. Atoms are made up of smaller particles, and these could be rearranged. In 1900 Ernest Rutherford found that the radioactivity of the “emanation” (as he called it) from thorium diminished with time. This decay of radioactivity was a vital clue. Rutherford, working in Canada with the Chemist Frederick Soddy, developed a revolutionary hypothesis to explain the process. They realized that radioactive elements can spontaneously change into other elements, and as they do so, they emit radiation of one type or another. The spontaneous decay process continues in a chain of emissions until a stable atom

is formed. They recognized that the ceaseless emissions pointed to a vast store of energy within atoms.

The understanding of how the atom is built is of great importance in understanding what happens when radioactive atoms emit radiation. As Rutherford first explained in 1911, each atom is made of a small, massive nucleus, surrounded by a swarm of light electrons. It is from the nucleus that the radioactivity, the alpha or beta or gamma rays, shoot out. By 1932 Rutherford's colleagues had found that the nucleus is built of smaller particles, the positively charged protons and the electrically neutral neutrons. A proton or a neutron each has about the mass of one hydrogen atom. All atoms of a given element have a given number of protons in their nuclei, called the atomic number. To balance this charge they have an equal number of electrons swarming around the nucleus. It is these shells of electrons that give the element its chemical properties.

Atoms of a given element can have different numbers of neutrons, and thus different atomic mass. Soddy named the forms of an element with different atomic masses the isotopes of the element. For example, the lightest element, hydrogen, has the atomic number 1. Its nucleus normally is made of one proton and no neutrons, and thus its atomic mass is also 1. Hydrogen on the other hand has isotopes with different atomic masses. "Heavy" hydrogen, called deuterium, has one proton and one neutron in its nucleus, and thus its atomic mass is 2. Hydrogen also has a radioactive isotope, tritium. Tritium has one proton and two

neutrons, and thus its atomic mass is 3. The three forms of hydrogen each have one electron, and thus the same chemical properties.

Rutherford and Soddy also discovered that every radioactive isotope has a specific half-life. Half the nuclei in a given quantity of a radioactive isotope will decay in a specific period of time. The half-life of uranium-238 for instance is 4.5 billion years, which means that over that immense period of time half the nuclei in a sample of uranium-238 will decay (in the next 4.5 billion years, half of what is left will decay, leaving one quarter of the original, and so forth). The isotopes produced by the decay of uranium themselves promptly decay in a long chain of radiations. Radium and polonium are links in this chain.

The early work of Marie and Pierre Curie led almost immediately to the use of radioactive materials in medicine. In many circumstances isotopes are more effective and safer than surgery or chemicals for attacking cancers and certain other diseases. Over the years, many other uses have been found for radioactivity. Until electrical particle accelerators were invented in the 1930s, scientists used radiation from isotopes to bombard atoms, uncovering many of the secrets of atomic structure. To this day radioactive isotopes are still being used as "tracers" to track chemical changes and the processes of life by biologists and physiologists.

Isotopes are crucial even for geology and archeology. As soon as radioactive decay was understood, Pierre Curie realized that it could be used to date materials. Soon the age of the earth was established by uranium decay at several billion years, far more than scientists had supposed, and since the 1950s

radioactive carbon has been used to determine the age of plant and animal remains, for example in ancient burials back to 50,000 years ago.

### **1.9.1 Alpha Particles**

An alpha particle is made up of positively charged helium ion and owing to the charge and relatively large particle size, they have limited power of penetration, but are highly ionized and could cause serious internal damage to sensitive parts of the body if radionuclides that emits alpha particles are ingested. The alpha particle is a stable combination of two protons and two neutrons, and the only natural source of alpha particles is nuclear decay. Alpha particles are emitted from the nuclei of many heavy radioactive atomic nuclei during decay.

Alpha particle emission occur only in elements of high atomic weight. It contains two neutrons and two protons, and because of this, it has a mass of four units, which makes it an extremely heavy particle. This indicate that emission of an alpha particle from a radioisotope results in the formation of another element four mass units lighter and two atomic numbers lower. An examples of this type of radioactive decay is the transformation of  $^{226}\text{Radium}$  to  $^{222}\text{Radon}$ .

Alpha particle has a low penetrating power. For instance, an alpha particle with an energy as high as 5 MeV has a range (the maximum distance that is necessary to stop it) in tissue of less than 0.04 millimeter. However, alpha particle is highly interactive in the vicinity where it is produced because of its

large mass and its hefty charge. When they travel through a material, they lose energy by collision.

### **1.9.2 Beta Particles**

Beta particles are electrons with greater penetrating power than alpha particles but owing to a lesser ability to ionize, they are not as damaging to living cells as are alpha particles. Beta particles are of two types namely negatrons (electrons) and positrons.

Beta decay is a spontaneous nuclear process that transforms some unstable radioactive atomic nuclei into others, and the stability of a nucleus is determined by the number of neutrons and protons contained in the nucleus. A nucleus that has too many neutrons decays by the emission of an electron for it to be stable. In this process a force known as weak interaction force changes a neutron into a proton inside the nucleus, thereby increasing the charge or the number of protons by one. Similarly, a nucleus with an excess number of protons decays by the emission of a positron by changing a proton into a neutron. The total number of neutrons and protons in the nucleus does not change in the beta decay process.

Some beta emitters occur in nature, mostly among the heavy elements of the uranium, thorium, and actinium groups, commonly found in association with crystalline rocks. Thorium for instance is a principal constituent of some minerals, notably thorite and monazite (a mixed rare-earth and thorium

phosphate). The actinide elements are the fourteen chemical elements that follow actinium in group IIIB of the periodic table, all of which are radioactive, because their nuclei are so large that they are unstable and release great amounts of energy when they undergo spontaneous fission. Generally, the heavy elements of the uranium, thorium, and actinium groups have an excess of neutrons and hence decay by the emission of electrons.

### **1.9.3 Gamma Radiation**

Gamma radiation is a form of electromagnetic radiation, first detected as emissions from natural radioactive substances such as uranium, radium, and thorium. Gamma radiation does not carry any electric charge or mass but it is a penetrating radiation. Its properties are similar to x-rays but only differs in origin i.e. while the sources of gamma rays are nuclear processes, those of X rays are atomic.

There are several different sources of gamma radiation. After the emission of an alpha or beta particle from a parent nucleus, the daughter nucleus formed may have more energy than it would have in its normal state.

The nucleus then de-excites by the emission of gamma rays carrying the excitation energy. Gamma radiation is also produced in a nuclear reaction such as the combination of a neutron with a proton to form a deuteron. When a particle like an electron combines with its antiparticle, in this case a positron, they give rise to gamma radiation.



Gamma radiation undergoes many diverse interactions with matter at different energy ranges. Low-energy gamma radiation may be totally absorbed by an atomic electron that is then emitted. The ejected electron is known as a photoelectron, and the process is known as the photoelectric effect. Gamma radiation can also interact with an atomic electron, sharing its energy and giving rise to the Compton effect, in which the original gamma radiation is scattered away with reduced energy and the electron is ejected. This electron is known as a Compton electron. Gamma radiation of sufficiently high energy can also interact with the electric field of the positively charged nucleus producing an electron and a positron. This phenomenon is known as pair production.

When a beam of gamma radiation passes through matter, its intensity after emergence has diminished, principally as a result of the above three processes. Very high energy gamma radiation can also cause nuclear disintegration and can eject a nuclear particle such as a neutron or a proton. Various types of mesons can also be produced by gamma radiation of extremely high energy in its interaction with atomic nuclei. Gamma radiation is emitted as photons, or discrete quanta of energy.

## **1.10 SOURCES OF RADIATION**

Radioactivity and exposure to ionizing radiation may occur naturally or produced artificially as shown in Figure 4. While radiation may come from naturally occurring radionuclides, the usual method for artificially produced

radioisotope is by the bombardment of stable nuclei with charged or uncharged particles. This can be achieved by the use of nuclear reactors (the primary source of radioisotopes for biological purposes), by particle accelerators, or by other neutron sources such as a neutron generator.

### **1.10.1 Natural Sources of Radiation**

The largest natural source of radiation exposure to humans is radon gas. While radon gas has always been in the environment, its contribution to human radiation exposure has increased in recent years. Radon's primary pathway is from the earth, through the basements of houses and other buildings, and into inside air that people breathe. Radon exposures can vary depending on the soil and rock structure beneath buildings.

Other terrestrial sources of radiation include naturally occurring radioactive materials that exist in rocks and soil. The main contributors are the radioactive isotope of potassium and the isotopes that are products of the decay of uranium and thorium. These radioisotopes are shown in Tables 2, 3, and 4.

As the earth moves through space it is also bombarded by high energy particles and gamma rays. These particles and rays add to the background radiation. The earth's atmosphere acts as a shield, absorbing much of the energy from cosmic radiation. People who live close to sea level are protected by a thicker blanket of atmosphere than those who live at high elevations, and thus

have a lower exposure to cosmic radiation. The dose rate from cosmic radiation vary with altitude and latitude.

Internal radiation comes from radioactive materials that occur naturally in the human body. Potassium and carbon are the primary sources of internal radiation exposures. The <sup>40</sup>Potassium isotope (0.01 percent of all potassium) is naturally radioactive. It enters the human body through the food chain. Carbon makes up about 23 percent, by weight, of the human body. Carbon can also enter the body through the food chain and by breathing.

### **1.10.2 Man Made Sources**

Man made sources of radiation include medical exposures such as diagnostic x-rays, as well as from nuclear medicine involving diagnostic procedures such as the use of nuclear tracers. Very small amounts of radioactive materials, called tracers, are put into the blood stream, and their progress through the body is monitored with a radiation detector. With this, blocked or restricted blood vessels can be identified. Nuclear medicine also includes treatment of disease. Some examples are cobalt irradiation for the treatment of cancers, or the injection of radioactive iodine which concentrates in the thyroid for treatment of Graves' disease.

Radiation is used in the manufacturing of many consumer products. It is used to sterilize products such as cosmetics and medical supplies. Radioactive materials are also used in other consumer products such as smoke detectors,

while other consumer products that could expose people to radiation include smoking of cigarettes, burning gas lanterns, using natural gas for heating and cooking, using phosphate fertilizers, radiation from color television, as well as the use of cell phones. The dose rates from these sources are small and vary considerably.

Other man made sources includes radiation exposures from fallout during international nuclear weapons testing programs and nuclear power plant accidents. For instance, high levels of radiation were created in the atmosphere after the Chernobyl accident in the then Soviet Union (April, 1986). Very recently radiation problems arising from the use of depleted uranium in war have been reported and investigations into the health and environmental consequences of this is continuing (United States Army Environmental Policy Institute-,USAEPI 1994; United State Army Material Command -USAMC, 2000; United State Defence Department -USDD, 2000).

## **1.11 RADIOACTIVITY PATHWAYS**

Radionuclides travel through the environment along the same pathways as other materials. They travel through the air, in water (both groundwater and surface water), and through the food chain. Radionuclides may enter the human body by ingestion (eating or drinking), by inhalation, or through the skin. Radionuclides can also be released into the air by human activities or created in

the atmosphere by natural processes such as the interaction of cosmic radiation with nitrogen to produce radioactive  $^{14}\text{C}$ Carbon. Radionuclides in the air can settle out of the atmosphere if air currents cannot keep them suspended, and rain or snow can remove them. When these particles are removed from the atmosphere, they may land in water, on soil, or on the surfaces of living and non-living things.

### **1.12 RADIATION SURVEYS**

Radiation survey involves the measurement of natural radiation levels, detection of radiation contamination, monitoring the effectiveness of shielding arrangements, as well as estimating radiation exposure to personnel. There are two main categories of radiation monitoring devices. They include gas filled detectors and scintillation detectors.

Gas detection instruments are based on the principle that ions are produced when radiation passes through a gas-filled chamber. Electrons liberated in the chamber are attracted to the center electrode (anode) by a positive voltage potential, while positive ions are attracted towards the walls (cathode) of the chamber. This produces an electrical pulse or current which can then be detected and recorded by a scaler or ratemeter (Handloser, 1959; Price, 1964; Fenyves and Haiman, 1969; Ouseph, 1975). Gas filled detectors are of three types, namely ionization chambers, proportional counters, and Geiger-Mueller detectors. The primary difference between these detectors is the voltage

applied to the chamber, and the kind of detector to be used depends on the intensity and the type of radiation field encountered.

### **1.12.1 Ionization Chambers**

Ionization chambers operate at very low applied voltage. At very low voltages, ion pairs created by radiation passing through the chamber may recombine before they are collected and counted. As the voltage of a gas filled detector is increased, virtually every ion pair produced by the incident radiation will be captured. The current flowing through the meter is therefore directly proportional to the activity of the source. This feature makes ionization detectors very useful as radiation monitoring devices. Survey instruments operating at this voltage are called ionization chambers. Because almost all ion pairs are collected, this instrument is used when it is necessary to accurately determine exposures. Ionization chambers however, are relatively ineffective for measuring rates less than 1 mR/hr, and are slow to respond to changing fields. For this reason, ion chambers are not useful for detecting contamination. They are primarily used to determine exposures in areas of high radiation intensity.

### **1.12.2 Proportional Counters**

As the voltage of the tube is increased, electrons are accelerated faster and achieve sufficient energy to create secondary ionizations in the gas. This

amplification is termed an avalanche and dramatically increases the size of the electrical pulse at the central anode. Gas multiplication can create millions of ion pairs per ionizing event, in contrast to the ionization chamber which creates one ion pair. Although an avalanche has occurred, gas amplification is proportional to the energy of the initiating event in this voltage region. Radiation monitoring devices operating in this region are therefore called proportional counters. With sufficiently thin windows, alpha particles which produce a large number of ions in the gas, can be distinguished from beta particles. In addition, the counter can be used to measure the energies of incoming gamma rays.

### **1.12.3 Geiger-Mueller (GM) Counters**

The Geiger-Mueller counter is the most widely used area survey instrument for the detection of low-level radioactive contamination and exposure. It is very sensitive, relatively inexpensive, and rugged. Radiation passing into a Geiger-Mueller tube (typically containing helium, neon, or argon) creates ions that are accelerated by a high voltage potential of approximately 1200 volts. Secondary ionizations are created from collisions with the accelerated ions. These ions are also accelerated and achieve sufficient energy to form additional ions. This process eventually produces an avalanche of billions of ion pairs from the initial ionization and creates a large electrical pulse at the anode. The magnitude of the output pulse is independent of the nature of the

particle or its energy because gas amplification has reached its maximum potential.

A major disadvantage of Geiger-Mueller counters is their limitation to low radiation fields, typically below 200 mR/hr. This is however within the expected values for radioactivity from natural sources. Once ionizations have been initiated in a Geiger-Mueller tube, it becomes insensitive for a short time, called the dead time, and will not respond to further ionizing events. As a result, the number of counts recorded will be less than the true count rate. This error is relatively very small at low radiation intensities.

#### **1.12.4 Scintillation Detectors**

Scintillation detectors operate on the principle that certain materials scintillate or give off light when exposed to radiation. Scintillation detectors use a crystal that releases light when exposed to x-rays or gamma rays. There are two types of scintillation detectors namely solid and liquid. Most solid scintillation crystals are composed of sodium iodide with a small amount of thallium added as an "activator". The crystal is coupled to a photomultiplier tube that converts the light flashes to amplified electrical pulses and amplification factors of a million or more are achieved. The number of pulses are directly proportional to the intensity, and the size of the pulse is directly proportional to the energy of the incident radiation. These pulses can then be analyzed by a counter, spectrometer, oscilloscope, or computer.



Because scintillation crystals are solid, rather than gaseous, their higher density and atomic number makes them very efficient and sensitive instruments for the measurement of x-rays and gamma rays. The crystal in a solid scintillation detector can be thin or thick. The thin crystal has an energy range of approximately 10-60 KeV, while the thick crystal has a range from about 50 KeV to 1 MeV. Scintillation detectors, however, are not as rugged as Geiger counters because the crystal is hygroscopic and can absorb water from the atmosphere.

Liquid scintillation detectors use organic compounds that give off light when radioactive materials are added to a liquid scintillation cocktail (LSC). Material from a swipe is dissolved or suspended in the solution, and almost all of the emitted radiation passes through some portion of the scintillator. The light is detected by photomultiplier tubes, analyzed and counted in a manner similar to solid scintillation detectors.

### **1.13 UNITS AND STANDARDS**

The rates of emission of radiation for different radioisotopes vary considerably. The decay constant is defined as the given fraction of atoms disintegrating in a specific unit of time. Another way of expressing the decay constant is the half-life, i.e. the time it takes a radioisotope for its radioactivity to decrease by one-half. This may vary from fractions of seconds to billions of years.

### **1.13.1 Count Rates**

The standard unit of radioactivity is the Curie, which is defined as the number of disintegrations occurring in one gram of radium per second. Radium was chosen because it was available in pure form and has a long half-life, 1,600 years. The Curie is equivalent to  $3.7 \times 10^{10}$  disintegrations per second (dps). The Curie is a large unit, so several fractions of this unit are also used. These include the millicurie (mC), that is one-thousandth of a Curie, or  $3.7 \times 10^7$  dps, and the microcurie, that is one-millionth of a Curie, or  $3.7 \times 10^4$  dps.

The usual state of a radioisotope is as a mixture with a large amount of the stable isotopes of the same element. Specific activity therefore, is defined as the amount of radioactivity per given weight or weight equivalent of a sample. It expresses the relative abundance of a radioisotope in a sample. Specific activity is often expressed as dps or dpm, counting rates (counts per minute, cpm), or curies, mC, or micro C per unit weight.

### **1.13.2 Exposure - The Roentgen**

The radiation intensity at a given place is termed its exposure. This exposure is measured by the ability of the radiation to produce ionization at that place. The unit of exposure is Roentgen and one Roentgen is defined as the quantity of X or gamma radiation that produces one electrostatic unit of charge of either sign in 1mL of air at standard temperature and pressure.

### **1.13.3 Absorbed Dose - The Rad**

The Roentgen defines a radiation field in air but does not provide a measure of absorbed dose in ordinary matter or tissue. When radiation passes through an object, part of the energy will be transferred to the material. This is referred to as the absorbed dose. Because of the limitation of the roentgen, a unit of radiation which applies to any form of radiation was adopted in 1956. This unit is known as the rad. It is the unit of absorbed energy or dose imparted by ionizing radiation to 1 gram of any material at the particular point of interest.

In contrast to the roentgen, the rad is used to express the radiation dose absorbed in any medium from any type of radiation. One rad is equal to the amount of radiation that results in the absorption of 100 ergs per gram in any material. It is approximately equal to the absorbed dose delivered to soft tissue by one roentgen of X or gamma radiation. The absorbed dose rate in air in grays per hour (Gy/h) units is used to express gamma ray intensity in the air from radioactive materials in the earth and in the atmosphere.

### **1.13.4 Dose Equivalent -The Rem or Sievert**

The effects of radiation in biological tissues differs with types of radiation. Because of this reason, in comparing the effects of radiation on living systems, a unit known as roentgen equivalent man (rem) is used. One rem therefore, is the dose from any radiation that produces biological effects in man

equivalent to one rad of x-rays. The dose in rems is the product of the dose in rad and a factor called the quality factor. According to International Commission on Radiation Protection and Measurement (1977), gamma rays, X-rays and beta radiation all have a quality factor of 1, neutrons 10, protons 10, alpha particle 20, and heavy ions 20. This quality factor depends on the relative biological effectiveness (RBE) of the type of radiation under consideration.

The RBE is the ratio of the absorbed dose of photons of specific energy to the absorbed dose of any other ionizing radiation required to produce the same biologic effect (Noz and Maguire, 1979). It is a function of energy of the radiation, type and degree of biologic damage and nature of the tissue or organism under consideration. Therefore,

$$D.E.(rems) = Q \times N \times \text{rads}$$

where Q = quality factor

and N = product of any other modifying factor now assigned

a value of 1 by ICRP.

Generally,

$$D.E (rem) = RBE \times \text{rads.}$$

Recently, effective dose as against dose equivalent became a central concept in the modern radiation protection. It is a measure of the health risk to human beings due to radiation exposure accounting for different effects of different radiation types and different sensitivity of different organs. Effective

dose is calculated by multiplying actual organ doses by "risk weighting factors" which give each organ's relative radiosensitivity to developing cancer, and adding up the total of all the number. The sum of the products is the "effective whole-body dose" or just "effective dose." These weighting factors are designed so that this "effective dose" supposedly represents the dose that the total body could receive (uniformly) that would give the same cancer risk as various organs getting different doses. For instance, if 2mSv is received by lungs (with a weighting factor of 0.12) and the thyroid receives 1 mSv (with a weighting factor of 0.05), the effective dose is  $(2 \times 0.12) + (1 \times 0.05) = 0.29$  mSv. This model says that the cancer risk from the whole body getting 0.29 mSv uniformly is the same as the lungs getting 2 mSv and the thyroid getting 1 mSv (and no other organ getting a significant dose).

For radiation protection purposes one usually would like to have a total risk factor. If the exposure to radiation is uniform then in fact a single overall risk factor can be used and the equivalent dose throughout the whole body is a measure of that risk. However, if the different tissues are exposed to different amounts of radiation, as is the case if radioactivity has been ingested or inhaled and deposited in the body, then a different quantity is needed to represent the total risk.

The tissue weighting factor is shown in Table 5. It takes into account the relative detriment to each organ and tissue including the different mortality and morbidity risks from cancer, the risk of severe hereditary effects for all generations, and the length of life lost due to these effects.

### **1.13.5 Unit Conversion**

In recent years, the SI (System International) units used in radiation protection are the Gray (Gy) and the Sievert (Sv). The Gray is the unit of absorbed dose corresponding to the rad and is the energy imparted by ionizing radiation to material corresponding to one joule/kg, while the Sievert is the unit of dose equivalent corresponding to the rem.

$$1\text{Gy} = 100 \text{ rad} = 1\text{J/kg and}$$

$$1\text{Sv} = 100 \text{ rems, or}$$

$$1 \text{ Sv} = \text{RBE} \times \text{Gy or } Q \times N \times \text{Gy}$$

### **1.14 MAXIMUM PERMISSIBLE DOSE**

Over the years, research work in the field of radiation safety have shown that ionizing radiation is not only dangerous but could be lethal. For this reason, several international bodies have worked on standards in relation to radiation hazards and this has led to the establishment of maximum permissible dose (MPL). Notably among these regulatory bodies are the National Academy of Science, National Research Council Advisory Committee on Biological Effect of Ionizing Radiation (BEIR), International Commission on Radiological Protection (ICRP), National Council on Radiation Protection and Measurement (NCRP), International Commission on Radiation Units and Measurements (ICRU), United Nations Scientific Committee on Effect of Atomic Radiation

(UNSCEAR), International Atomic Energy Agency (IAEA) as well as World Health Organization (WHO).

In making the maximum permissible dose recommendations, both NCRP and ICRP divide the population into two groups namely members of the general public, and "radiation workers" who are exposed to radiation through their occupation. Government standards establish limits for occupational exposure that are greater than those established for the general public. The rationale is that "radiation workers" presumably accept the increased risk by informed consent as a trade-off in exchange for the benefits of employment. The maximum permissible dose for the general public is set at 1mSv/yr by NCRP as well as ICRP.

## CHAPTER TWO

### GEOLOGY

#### 2.1 GENERAL GEOLOGICAL SETTING

The end of the Kibaran orogeny of  $1100 \pm 200$  Ma saw the division of the African continent into three main stable blocks namely, the Kalahari Craton, the Congo Craton and the West African Craton. Each of these cratons has an Archean region of Basement rocks consisting mainly of gneisses, granites and migmatites, traversed by irregular Pre-Cambrian greenstone made up of slightly metamorphosed supracrustal rocks and schists, as well as Pre-Cambrian mobile belt consisting of high-grade metamorphosed, folded and faulted rocks.

Nigeria is located within the mobile belt which separates the West African Craton to the west from the Gabon Craton to the southeast. According to Ajibade and Fitches, (1988), Ajibade *et al* (1988) and Rahaman, (1988). This mobile belt was affected extensively by the widespread Pan-African thermotectonic event of  $600 \pm 150$  Ma but relics of older rocks dating to Archean (3500 Ma) as well as Lower Proterozoic (2000 Ma) can still be found in the Nigerian Basement Complex. Crystalline rocks of the Basement Complex can be found in many places in Nigeria covering about 50% of the entire area (Figure 1b) and are generally separated by sedimentary basins of Mesozoic (230 Ma) and Cenozoic ages ( $\sim 2$  Ma). Rocks within the Basement Complex include migmatites, gneisses, schists, quartzite, amphibolite, charnockite, aplite, calc-silicates and diorites, most of which have been affected by several deformation



episodes the last of which is reflected in the general N-S trending folds formed by E-W compression (Annor, 1986; Solomon, 1986). The rocks are also associated with intrusive phases of orogenic granite, aplite, pegmatite and charnockite in several places (MacLeod et al 1971; Turner, 1983; Ogezi, 1988).

Structural trends in the Basement Complex are dominantly ENE-WSW with significant NW-SE and N-S trends especially in the central parts of Nigeria (Oluyide, 1988). These regional trends represent lineaments which are active intermittently since at least Late PreCambrian (~2000 Ma). They also represent zones of hot spot magmatism, ring faulting and cauldron subsidence during the Mesozoic times (230-65Ma) when granitic intrusions forming the ring complex were emplaced. A culmination of the geologic events along these lineaments were essential elements responsible for the opening of the South Atlantic in part during Early Cretaceous time (~140 Ma) along an ENE-WSW active fracture zones represented by an RRR triple junction that was situated below the Niger Delta miogeosyncline. The Cretaceous separation was accompanied by the development of the Benue valley which evolved as a deep trough formed from rifting.

Cretaceous sediments were deposited along both the middle Niger Basin and the Benue Trough. In addition to the Benue Trough sediments, Cretaceous and Tertiary sediments were also represented in the Illumedun (Sokoto) Basin to the northwest and the Chad Basin to the northeast.

## 2.2 THE BASEMENT COMPLEX

The evolution of the rocks of the Basement Complex of Nigeria took place over at least four orogenic episodes. They include the Liberian Orogeny (2800 ±200 Ma), Eburnean Orogeny (2000 ±200 Ma) which formed the Eburnean granites and metamorphic rocks with associated Proterozoic supracrustal low grade metasedimentary and metavolcanic rocks, the Kibaran Orogeny (1100 ±200 Ma) and the Pan African Orogeny (600 ±150 Ma). According to McCurry (1989), the Pan African Orogeny was responsible for an extensive modification of the original rocks through metamorphism, migmatization and granitization. Significant manifestation of the Pan African Orogeny is the widespread repetition of lithology within the basement complex. The gneisses and migmatites here can be found cutting across all the geologic ages above. Various forms of mineralization have also been reported within the basement rocks in Nigeria (Wright *et al.*, 1985).

Basement rocks are found within the study area, intruded by rocks of the Younger Granites in most places. These basement rocks generally form a low relief and consist essentially of gneisses, migmatites and Older Granites as shown earlier in Plates V-VII.

### **2.2.1 Gneisses**

Gneiss is a term applied to banded rocks formed during high-grade regional metamorphism. Gneisses are mostly of igneous origin, coarse and relatively even-grained. They are foliated but do not readily split along the plane of foliation. The different varieties of gneiss are named after the type of rock from which they have been formed (as granite gneiss and diorite gneiss) or after a mineral in which the rock is unusually rich (as biotite gneiss and hornblende gneiss).

Gneisses found in the area of study are generally medium to coarse grained with a gray to light brown colour. They are foliated and dip generally at less than 40°. The major minerals in the rock are mostly k-feldspar, plagioclase, quartz, microcline and biotite (Plates XIII & XIV). The quartz and feldspars could occur singly or in clusters. Quartz can equally be seen forming 'buckshot' in microcline.

While fresh crystals of plagioclase feldspars can be seen in some parts of the rock slide (Plate XV), this mineral can be seen altering to clay minerals in some other parts (Plate XVI), a term generally referred to as sericitization. In most cases, the quartz found in the gneiss show fractured features with the formation of subgrains of quartz (Plate XVII). This could indicate solid state deformation. Accessory minerals here generally include sphene, allanite and zircon (Plate XVIII).

Gneisses are found extensively in areas surrounding the Ropp Complex, in the Jengre - Saminaka areas surrounding the Jere-Sanga Complex, the Guskie and Badiko areas close to the Kwandonkaya Complex and around the Pambegua areas to the north.

Structural trends within this rock vary slightly from place to place but with a general NE-SW trend and gentle to average dips. Figure 5 is a rose plot for foliation in gneisses around Saminaka within the central part of the study area. The major trend here is N15E, while the average trend shown on equal area pole to foliation plot (Figure 6) is N32E with a gentle dip of about  $31.7^\circ$  to the north west.

### **2.2.2 Migmatites**

Migmatites are formed by the injection of granitic material in the form of a magma, a hydrothermal solution or a rather indefinite diffusion of materials through a pre-existing rock. In all migmatites therefore, there is clearly a reaction between the host rock and the invading materials and this often lead to the destruction of the original fabrics and the formation of new structure.

Owing to its origin therefore, migmatites are high-grade, pervasively heterogeneous rocks, that are partly metamorphic and partly igneous-like in appearance. The igneous-like part is most commonly granitic and the metamorphic part is generally a biotite schist or gneiss.

Migmatites occur extensively within the Basement Complex of Nigeria, and within the study area, they vary widely in texture, ranging from coarsely mixed to a more diffuse-textured type and in some cases, they could be porphyroblastic. The rock is characterized by a rough banding and with varied appearance displaying an alternation of felsic (leucocratic) minerals and mafic (melanocratic) minerals (Plate VI). Some parts of the rock do not even reveal the alternation of bands but rather mesocratic features.

Hand specimen observation revealed that the migmatites here consist of quartz, feldspars, biotite, muscovite and other mafic minerals. Quartz in this rock form round shapes and mostly in clusters, while muscovite and biotite appear in flakes and constitute the main mafic mineral. Stains of garnet are also common in some places. Around the western part of Ganawuri Complex, the migmatite is medium grained. It is well foliated with alternation of mica rich layers and quartzo-feldspathic minerals. In thin section, the minerals found in the rock are mostly plagioclase feldspar, quartz, and biotite as the dominant mineral (Plate XIX). The quartz appear to be evenly distributed. They also show subgrains, with subgrains of quartz beginning to form in most places (Plate XX). This is usually an evidence of solid state deformation.

In the Gumau area west of the Kwadonkaya Complex and east of Jere-Sanga Complex, they are generally weathered but show definite, alternate layering of leucocratic and melanocratic bands. The thickness of the leucocratic bands ranges between 1mm - 4mm, and the thickness of the melanocratic bands vary between 4mm – 6mm. The migmatite is medium grained in texture with

biotite and quartz as the main minerals. Minor folds as well as several boudinage structures can be found on the rock.

In the Pambegua area close to the Kudaru and Dutsen Wai complexes, the migmatites show textural variations from fine to medium and coarse grained types. Characteristic minerals here include quartz, biotite, and plagioclase (Plate XXI), with sphene and zircon as accessories (Plate XXII). Here the quartz grains are fractured resulting in the formation of subgrains, while the biotites appeared a ligned. This is also similar to the migmatites around the Kurra area.

Major foliation trends in the migmatites in this area varies from NW-SE to NNE-SSW. Around Pambegua area, major trend of foliation in migmatites is N55E (Figure 7), while the average foliation value is N58E, dipping averagely to the NW at  $57.4^{\circ}$  as shown in a pole to foliation plot (Figure 8). Around the Ganawuri area to the south western part, the major trend of foliation is N25W (Figure 9) while average foliation trend is N21.5W, dipping averagely to the NE at  $64^{\circ}$  as shown in a pole to foliation plot (Figure 10). In the Toro area towards the eastern part, the major foliation trend is N35W (Figure 11), with average value of N36W, and a gentle average dip of about  $21^{\circ}$  to the SW as shown in a pole to foliation plot (Figure 12). Apart from structural features such as foliation and joints, migmatites in this region are also commonly associated with microfolds (Plate XXIII).

### **2.2.3 Older Granites**

Older Granites varies in texture, structure and mineralogy. They occur north of Kwadonkaya Complex (the Solli Hill granite), north of Ganawuri Complex and west of Rukuba Complex (the Zagun Granite), west and south of the Ropp Complex (the Sho Granite), south of Kudaru Complex (the Rahama Granite) and southwest of Dutsen Wai Complex (the Pambegua Granite).

Minerals in the rock include quartz, feldspars, biotite, muscovite, hornblende and microcline (Plate XXIV). The microcline occur usually in irregular shape, with low birefringence under cross polars, while the biotite occur as a brownish mineral of various shapes. In most cases, the feldspars are deformed, gradually weathering to clay minerals. Accessory minerals here include zircon, magnetite, apatite and some opaque minerals.

Structural features on the rock include veins, minor folds, lineation, boudinage, xenolithic inclusions, foliation, joints and microfaults. These structural features are tectonic in origin and indicates the extent of deformation to which the rocks have been subjected during the various deformation episodes. Major foliation trends in older granites in this area varies generally from N-S to NNE-SSW. In the Pambegua area, major trend of foliation in the older granite is N35E (Figure 13), while the average foliation value is N47E, dipping averagely to the NW at 39° as shown in a pole to foliation plot (Figure 14). In the Sho area to the southern part, the major foliation trend is N5E (Figure 15) while average

foliation trend is about N24E, dipping averagely to the NW at 57.3° as shown in a pole to foliation plot (Figure 16).

#### **2.2.4 Intermediate Rocks, Calc-Silicates and Amphibolites**

Intermediate rocks are igneous rocks with about 52-63% SiO<sub>2</sub>. Intermediate rocks are found in the Toro, Sho and Saminaka parts of the study area. In the Toro area, hypersthene diorite can be seen outcropping in many places, elongated generally in the N-S direction. The rock is dark, massive, fine to medium grained, and consisting of hypersthene, plagioclase, biotite, microcline and quartz as the main minerals. Hypersthene diorite also occur around the Saminaka area located on Lere Sheet 147. The diorite here is dark, coarse grained and forms an abrupt contact with the porphyritic granite of the area. Around the Sho area south east of Jos, the diorite is essentially a quartz diorite type with considerable variation in texture and mineralogy. Here the rock is foliated and having the same structural trend of NW-SE as that of the surrounding migmatite. The mineralogy is essentially quartz, hornblende, plagioclase and biotite.

Impure marble and calc silicate rocks occur around the Kurra Fall area, forming bands and lenses within the migmatites and migmatitic gneisses of the area. The common minerals in the rock are diopside, tremolite, quartz with some calcite, plagioclase and garnet. Amphibolites can also be found around Naraguta



West (MacLeod et al 1971). They are fine to medium grained rock and consist essentially of hornblende and calcic plagioclase.

### **2.3 THE YOUNGER GRANITE**

Large numbers of Younger Granite ring complexes have been recognized and mapped in Nigeria. They were first defined by Falconer (1911) as cross cutting alkaline granites containing riebeckite or biotite, characterized by chilled margins with the country rocks. In Nigeria, a good number (about 50) separate Younger Granite complexes have been recognized, trending in a N-S belt with the ages of the complexes decreasing southwards. Rahaman et al (1984) confirmed a general southerly age trend and indicated that the major local magmatic activity were concentrated along at least two ENE and WSW zones. The age patterns according to the report suggests that the parent magma may have been locally derived from several simultaneous high level magma chambers connected to a common deeper source. The emplacement of these ring complexes are believed to have been controlled by fracture systems in the basement.

Four major petrographic groups can be recognized within the younger granites. They include:

a). Hornblende pyroxene fayalite granite. This is greenish, porphyritic with phenocrysts of quartz and feldspar.

b). Hornblende biotite granite. This is characterized by the presence of mafic minerals and needles of apatite. This granular rock outcrops considerably in all the complexes.

c). Biotite granites. Biotite granite is very abundant within the younger granites. Quartz, biotite and feldspars are common minerals in the rock. The quartz are sometimes formed into rounded crystal aggregates.

d). Riebeckite granite. This is a less well represented rock within the younger granites. They are found in association with basalts in some case.

From the decrease in ages of the complexes southwards, it is believed that the main phase of acid magmatism in Nigeria's Younger Granite province commenced during Triassic (225 to 195 Ma) times and continued to migrate in a general southerly direction until at least to the close of the Jurassic. This is supported by Bowden *et al* (1976) in a study of age trends for some ring complexes in Niger and Nigeria. The cessation of magmatism therefore may have been synchronous with the initiation of the opening of the South Atlantic

Turner (1976) proposed three stages in the development of the Nigeria ring complexes.

1). Early volcanic stage: This is the first stage of a large rhyolite volcano. Before the end of this stage, large amounts of magma have accumulated in the subvolcanic reservoir about 5km beneath the surface.

2). Caldera and Ring dyke stage: When the centre of the volcanic structure within a ring fault collapsed, magma rose along this fault and crystallized as granite porphyry which was extruded into the caldera rocks of this stage.

3). Intrusive Stage: This is the warming phase of igneous activity when smaller granite intrusives were emplaced at increasingly deep levels. The magma in this stage evolved and crystallized at lower temperatures and as lower assemblages. The rocks are composed of biotite granite.

### **2.3.1 Lithological Summary**

As shown in Figure 1(a), about twenty seven (27) Younger Granite complexes are located within the study area and vary in extent and in lithological characteristics. They include the Amo, Banke, Buji, Dutse Wai, Forum, Gamawa, Ganawuri, Jarawa, Jere - Sanga and Jos - Bukuru complexes. Others are Junguru, Kagoro, Kigom, Kofai, Kudara, Kwandonkaya, Miango, Ririwai, Ropp, Rukuba, Saiya-Shokobo, Sara-Fier, Shere, Sutumi, Tongolo and Zuku complexes. They are all located within Topographical Sheets 125, 126, 147, 148, 168 and 169.

The Amo Complex is located north of Rukuba Complex and found on Lere Sheet 147. The succession of ring-intrusions in the complex include riebeckite microgranite, granite porphyry, riebeckite biotite granite, early hornblende biotite granite, biotite granite, Teria biotite granite, Tega porphyritic granite, Amo peak biotite granite, Rough range biotite granite, late hornblende biotite granite, Amo albite riebeckite granite and biotite microgranite with late felsites. The complex host varying amount of cassiterite.

The Banke Complex is located north of Kudara Complex and east of Dutsen wai Complex. It is made up of predominantly pre-caldera ash fall tuffs and crystal poor ignimbrites, basaltic lava, crystal-rich intra-caldera ignimbrites, vertically banded crystal-rich ignimbrites, granite porphyry and biotite granites.

The Buji Complex is located east of Amo Complex and covers about 78 sq. Km. It is composed of two superimposed ring complexes which include the eastern ring complex made up entirely of volcanic rocks, and the western ring complex made up of granitic rocks. The cycle of magmatic activities here include the volcanic as well as the granitic cycles. The volcanic cycle consists of early rhyolites, tuffs and agglomerates, late intrusive rhyolites, quartz hedenbergite porphyry as well as quartz feldspar porphyry, while the granitic cycle consists of aegirine microgranite, Buji biotite granite and Gurum albite riebeckite granite.

The Dutsen Wai complex is located at about 20 km north east of Pambegua town off Pambegua - Zaria road. The complex form a distinct topographic features and is generally brownish in colour. Lithological units within this complex include biotite granite, biotite microgranite and arfvedsonite albite granite. The rock is generally medium to coarse grained but fine grained portions can equally be seen. Minerals in the rock as can be seen in hand specimen include feldspars, quartz and biotite. In thin section, radioactive halos can be seen around zircon within the biotite flakes.

The Forum Complex is located about 25 Km southeast of Jos. It is one of the smallest of the complexes and is made up essentially of one lithological unit, the biotite granite.

The Gamawa Complex is found northeast of Ririwai Complex. It is made up of agglomerates, tuffs and breccias, arfvedsonite granite porphyry, fayalite hedenbegite syenite, as well as aegirine arfvedsonite granite. It is about 60 sq km in size.

The Ganawuri Complex is located south-west of Jos and covers an area of approximately 100 sq.km. In contrast with other complexes, intrusion within this region commenced with the emplacement of granite plutons rather than ring dyke. There are two defined cycles of intrusion within this region namely the Ganawuri cycle and the Kigom cycle. The continuity of rocks from both cycles can be attributed to the final intrusive phase of the Daw biotite granites which cross-cuts earlier intrusions of both cycles (Buchanan et al, 1971). The Ganawuri cycle emplaced several granite intrusions. They include the Daw biotite granite, fayalite biotite granite, hornblende fayalite granite, Ganawuri biotite granite, fine grained biotite granite, porphyritic biotite granite and hornblende biotite granite. The Kigom cycle include aegirine microgranite, riebeckite aegirine granite, riebeckite biotite granite and arfvedsonite granite.

The Ganawuri Complex is well exposed. Texturally, the rock is medium to coarse grained and leucocratic in colour. The main mineral composition as seen in hand specimen are biotite, quartz and feldspars. The Daw biotite granite has the highest cassiterite and columbite values within the complex.

The Jarawa Complex is located east of Shere Complex on Maijuju Sheet 169. It consists essentially of hornblende biotite granite, biotite granite and biotite microgranites. The rock varies in grain size but is generally medium grained.

The Jere - Sanga Complex is located about 40 km north of Jos. The complex displays the conventional sequence of younger granite magmatic activity which can be summarised as follows: Fiskan Mata riebeckite-biotite-granite, Dutsen Sanga riebeckite-biotite-granite, Dutsen Jere riebeckite-granite, and Limoro syenite and syenite-porphry. These constitute the plutonic cycle. The volcanic cycle includes the quartz-fayalite-porphry, the late intrusive rhyolites and the early rhyolites, tuffs and breccias. Joints can be seen extensively on this rock generally taking various trends.

Tin mineralization in this complex is limited to western part, as well as south of Jengere. Columbite is also found in this part in good quantity compared to the other parts of the complex.

The Jos-Bukuru Complex is located within the central part of the Nigerian Ring Complex. It can be seen extensively around the Jos and Bukuru areas and shows textural variations attributable to the closeness of the complex to the roof of the batholith (Falconer, 1921). The sequence of magmatic events can be classified into three namely the early granite cycle, the central granite cycle, and the volcanic cycle. The early granite cycle includes the Delimi biotite granite, Rayfield-Gona biotite granite, Kuru stock biotite granite, N'gell biotite granite, Jos biotite granite, Naraguta quartz pyroxene fayalite porphry, Vom

hornblende biotite granite and the Neil's Valley granite porphyry. The central granite cycle consists of the north Vom microgranite, Sabongida biotite granite, Bukuru biotite granite and Shen hornblende fayalite granite. The volcanic cycle is made up of rhyolites and pyroclastics of the Neil's Valley as well as felsite dykes. Major mineral in the rock include biotite, quartz, plagioclase and hornblende with various accessory minerals. The Jos-Bukuru Complex represent the richest and most extensive alluvial deposit of tin and columbite in the younger granite province and concentrates mainly within the numerous greisens. Zircon, monazite and xenotime have also been recovered as impurities within the cassiterite. These minerals are radioactive.

The Junguru Complex is found around Lame in the north central part of Toro Sheet 148. It is a small complex, occupying less than 10 sq Km. It is made up of two main lithological units mainly arfvedsonite granite and biotite granite.

The Kagoro Complex is located southwest of Ganawuri Complex. The complex consists of two overlapping ring structures, and made up essentially of hornblende biotite granite, fayalite hornblende granite as well as biotite microgranite.

The Kigom Complex is located close to Ganawuri Complex and found on Naraguta Sheet 168. Principal lithological units here include ferrorichterite granite, riebeckite annite-granite, arfvedsonite aegirine-granite and aegirine microgranite.

The Kofai Complex is shared in part by Toro Sheet 148 and the adjoining Maijuju Sheet 169. It is generally less than 10 sq km, and made up of

gabbro, dolerite and basic assemblages, granite porphyry, biotite granite as well as biotite microgranite.

The Kударu Complex is located along Saminaka - Pambegua road. Lithological units within this complex include quartz porphyry and microgranites, quartz porphyry, fayalite-hedenbergite granites, arfvedsonite granite, as well as biotite granite. The major minerals characteristic of the rocks of this complex include quartz, biotite, muscovite, feldspar and pyroxene while garnet, magnetite, zircon, hematite and some opaque minerals occur as accessories.

The Kwandonkaya Complex is situated about 45 km north-east of Jos, occurring on the Toro topographical sheet 148. The rocks here are well exposed and generally medium in grain size. It is entirely granitic in composition with no evidence of any earlier volcanic activity preserved. According to Buchanan (1971), the cycle of intrusion in the complex may be summarized as follows: Panshanu diorite microgranite, porphyritic biotite granite, medium grained biotite granite, Panshanu biotite granite, hornblende biotite granite, hornblende fayalite granite as well as early quartz-feldspar-porphyry dykes. In most places, the granite is generally cream coloured with feldspar, microperthite, quartz, biotite and microcline as the main minerals while zircon, magnetite and other opaque minerals occur as accessories in the rock.

The Miango Complex is located west of Jos-Bukuru Complex. It is a simple intrusion, and made up of two main lithological units namely granite



porphyry and biotite granite. The form of intrusion here suggests emplacement by cauldron subsidence.

The Ririwai Complex is located off Saminaka - Kano road north east of the Kudaru Complex. The complex forms a concentric circle and is made up of pre-caldera agglomerates, ash fall tuffs, crystal-poor ignimbrites and minor comenditic ignimbrites, basalts, quartz porphyry, granite porphyry, aegirine arfvedsonite granite and porphyry, biotite granite, biotite microgranite, as well as arfvedsonite albite granite. Rocks here are generally purple to brownish in colour with feldspars, quartz and biotites clearly seen. The texture vary from fine to medium, but coarse in some areas.

The Ropp Complex is situated in the Ropp area of the Jos Plateau, covering roughly about 350 sq.km. Within this complex, both granitic and volcanic cycles of rocks are recognizable. According to Buchanan *et al* (1971), the cycle of granitic intrusion was initiated by a coarse grained granite porphyry similar to that of the Jos-Bukuru Complex, and followed by a succession of biotite and riebeckite granites. The granitic cycle include late dolerites, Mongor granite porphyry, Kaskara biotite granite, Yelwa pyroxene granite and granite porphyry, Ruku riebeckite biotite granite porphyry, Durowa albite riebeckite granite, Butra riebeckite-biotite granite, Kassa biotite granite, Buka Bakwai biotite granite, Gana biotite granite, Kwop biotite granite, Sho granite porphyry and hornblende biotite granite. The volcanic cycle include the quartz porphyries, the rhyolite and explosion breccias as well as the early basic dykes.

In hand specimen, the mineral constituents of the rock include biotite, quartz and feldspars, while in thin section other minerals like microcline as well as accessory minerals can be seen. In terms of its economic potentials, the Ropp Complex is the second largest tin producer in the Nigerian Younger Granite province. The cassiterite here is also associated with columbite, as well as radioactive zircon, thorite, monazite and trace amount of xenotime.

The Rukuba Complex occur close to the Jos Bukuru Complex and is one of the simpler types of Younger Granite structure, consisting of two overlapping plutons of biotite granite, and covered by large basalt flow at the central part. The sequence of granite intrusion include the northern pluton and the southern pluton (Macleod et al, 1971). The northern pluton include Timber Creek biotite granite while the southern plutons consists of Dutse Kura biotite granite, Rukuba biotite granite and hornblende biotite granite. The rock is medium to coarse grained, but in some places it is porphyritic in texture. The mineralogy is essentially quartz, biotite and feldspars. The complex is also rich in columbite with valuable deposits of alluvial tin.

The Saiya-Shokobo Complex is found north of Jere Sanga Complex on Lere Sheet 147. Lithological units here include dolerites and gabbro, alkali-feldspar syenite, pre-caldera agglomerates and ignimbrites, basalts, quartz porphyry, arfvedsonite granite porphyry, crystal rich ignimbrites, arfvedsonite granite porphyry, arfvedsonite granite and biotite granite.

The Sara-Fier Complex is located at the south eastern edge of Maijuju Sheet 147. It is composed of almost entirely of intrusive rocks with only little

remnant of volcanics preserved in some places. The granitic rocks here forms five major ring structures linked into a N-S chain. Major lithological units here include pre-caldera and intra-caldera agglomerates, ignimbrites and basaltic lavas, granite porphyry, hornblende biotite granite, biotite granite, hedenbergite hornblende granite, arfvedsonite granite, syenite and quartz syenite.

The Shere Complex is located next to the Jos-Bukuru Complex. It is made up of monzogabbro, fayalite granite, biotite granite, arfvedsonite aegirine granite, riebeckite annite granite, arfvedsonite albite granite and granite porphyry.

The Sutumi Complex is a very small complex found east of Kwandonkaya Complex. It is about 2.6 sq Km in size. The complex is essentially a modified acid volcanic plug in which the volcanic materials have been displaced by later granite intrusion. Lithological units here include pre-caldera agglomerates, ash fall tuffs, ignimbrites and breccia, hornblende biotite granite and biotite granite

The Tongolo Complex is located at the north eastern edge of Toro Sheet 148. It is fairly extensive and predominantly granitic. The order of intrusion in the complex include early rhyolites and agglomerates, quartz-feldspar-porphyry and intrusion breccia, quartz-pyroxene-porphyry, Dagga Allah porphyry, granite porphyry, riebeckite-aegirine-granite, medium grained biotite granite, Kulfana biotite granite, porphyritic biotite granite, Sororo biotite granite, biotite granite, riebeckite granite and riebeckite biotite porphyry.

The Zuku Complex is located south east of Ririwai Complex on Ririwai Sheet 126. It consists of pre-caldera agglomerates, ash fall tuffs and commenditic ignimbrites, ferroaugite syenite porphyry, arfvedsonite granite and aegirine granite.

In general, rock forming minerals found within the younger granite complex are quartz, feldspars and biotite. A typical thin section photomicrograph of the younger granites is shown in Plates XXV and XXVI. Here, radioactive halos can be seen around the zircons within the biotite flakes. Structures within the younger granites are mostly are mostly cooling joints.

## **2.4 BASALTIC ROCKS**

Basalts occur extensively within the study area. They are mostly found around the Ryom district southwest of Jos as well as around Heipang areas to the south of Jos. They are believed to be products of volcanic activities which took place intermittently from Tertiary (65 Ma) to Recent time (~1 Ma). The basalts in this region can be subdivided into three groups namely lateritized Older Basalt, Older Basalt and Newer Basalt. Macleod *et al* (1971) noted that the lateritized basalts represents lavas now decomposed to clay usually overlain by a thick cap of lateritic ironstone. Together with underlying river sediments they were termed the Fluvio-volcanic Series in the initial survey of the Plateau by Falconer in 1921. Later extension of the survey into the southern plateau suggests that fresh basalts also belong to this lateritized series. In a resurvey of

the plateau tin field (Mackay et al., 1949), these unaltered basalts were grouped with the Newer Basalts and the term Fluvio-volcanic Series was restricted to the completely decomposed basalts and their accompanying sediments. These rocks appear to be confined to the plateau, occurring as remnants and are generally protected from erosion by a capping of hard lateritic ironstone. Their distribution is similar to that of the Older Basalts and Newer Basalts.

The Older Basalts are generally small, eroded and partly decomposed. It is restricted to areas in which the lateritized basalts are abundant and in some cases are underlain by lateritized basalts. Older Basalts here include a variety of petrographic types namely thoolitic basalts (thooliites), alkali olivine basalts and high alumina basalts.

The Newer Basalts (Plate VIII) also cover a considerable area here. It is believed to have erupted after the plateau had achieved its present day topography and have not been affected much by erosion. Major minerals in the rock include olivine and plagioclase as shown in Plate XXVII.

## CHAPTER THREE

### LITERATURE REVIEW

#### 3.1 NATURAL RADIOACTIVITY

All living species are each day, exposed to certain amount of natural radiation in the form of particles and rays either from cosmic sources or background radiation from materials on the earth. Such radiation vary largely, depending on elevation above sea level and most importantly the geology of the area. Most of the natural radioactivity in rocks is caused by  $^{238}\text{U}$ ,  $^{235}\text{U}$ ,  $^{232}\text{Th}$ , and to a lesser extent by  $^{40}\text{K}$  and  $^{87}\text{Rb}$ . Radioelement concentrations of different classes of rocks are given in Table 1 (Killeen, 1979).

Radiation absorbed dose rates vary from country to country and from place to place. It is a function of the local and regional geology, altitude above mean sea level, the level of mining and processing of radioactive mineral, as well as the disposal methods for mine wastes. Measurements of natural background radiation have been performed in many parts of the world using a variety of techniques. These techniques have involved the use of ionization chambers as well as portable and airborne scintillation counters. Laboratory analyses of the radioactive elements in soil and rock samples have also been used to estimate the average radiation exposure in several different countries.

The distribution of uranium and thorium in soils and rocks were studied by Hensen and Stout in 1968 using both radiochemical separation and alpha spectrometric techniques. The study observed that weathering and soil formation is the principal factor in the accumulation of uranium and thorium, and that

higher concentrations of these radionuclides are found in soils compared with the underlying rocks. Determination of the activity of natural radionuclides in soils and the resultant absorbed dose rates in air have also been carried out in countries including India, Indonesia, Iran and Ireland using gamma spectrometry method. In the monazite rich areas of India, the absorbed dose rates in air from the natural environment has been found to be  $300 \times 10^{-8}$  Gy/hr, while in normal areas the value is  $4.2 \times 10^{-8}$  Gy/hr (Chhabra, 1966). Mishra and Sadasioan (1970) studied both the non volcanic and volcanic areas of Indonesia. In the volcanic areas, the average absorbed dose rates in air is  $250 \times 10^{-8}$  Gy/hr while in the non volcanic areas, the value is  $90 \times 10^{-8}$  Gy/hr. Iran has a high background value of about  $5540 \times 10^{-8}$  Gy/hr (Khademi et al 1980), while the average value for Ireland (AcAulay and Colgan, 1980) is  $4.2 \times 10^{-8}$  Gy/hr.

Using different radiation survey equipments, estimates of the mean absorbed dose rates in air 1 m above the ground level in different countries indicates a value of  $4.3 \times 10^{-8}$  Gy/hr for Austria (Tschirf, 1980),  $8.2 \times 10^{-8}$  Gy/hr for Scotland (Spiers et al, 1964),  $7.4 \times 10^{-8}$  Gy/hr for Tailand (Rativanich et al, 1961) and  $5.4 \times 10^{-8}$  Gy/hr for Taiwan (Yu Ming et al 1987). Malanca et al, (1996) studied absorbed dose rates in air in Brazil extensively. In the monazite (radioactive mineral) rich areas around Guarapari the average dose rates is  $150 \times 10^{-8}$  Gy/hr, while in Guarapari beach area, the value is  $2000 \times 10^{-8}$  Gy/hr. Within the volcanic areas around Mono do Ferro, Araxa, and Tapira, the values are  $3200 \times 10^{-8}$  Gy/hr,  $324 \times 10^{-8}$  Gy/hr and  $200 \times 10^{-8}$  Gy/hr respectively. In normal areas especially around Rio Grande do Norte, the value is  $5.5 \times 10^{-8}$  Gy/hr.

Molla et al (1975) reported a mean absorbed dose of  $530 \times 10^{-8}$  Gy/hr for Bangladesh while in Italy (Abe et al, 1980), the value is  $5.7 \times 10^{-8}$  Gy/hr. Daling et al, (1990) working in the Yangjiang and Guangdong areas of China reported a value of  $18.2 \times 10^{-8}$  Gy/hr and  $6.6 \times 10^{-8}$  Gy/hr respectively. In Denmark (Nie et al, 1980) the average dose rate is  $3.8 \times 10^{-8}$  Gy/hr, while according to Ohlsen (1971), the value for the Democratic Republic and the Federal Republic of Germany is  $9.4 \times 10^{-8}$  Gy/hr and  $5.3 \times 10^{-8}$  Gy/hr respectively.

According to Eisenbud (1973), the mean annual total body absorbed dose rate received by man is  $10^{-3}$  Sv/yr, while the United Nations Scientific Committee on Effects of Atomic Radiation (1977) estimated the worldwide absorbed dose to be 32 mrad/yr (320  $\mu$ Gy/yr). The United Nations Scientific Committee on Effects of Atomic Radiation (1972) and the National Council on Radiation Protection and Measurement (1976) also gave the average dose equivalent from cosmic radiation at sea level to be 28 mrem/yr (280  $\mu$ Sv/yr).

Radiation levels from natural sources are low in some countries but could be very high in others. According to Oakley (1972), average dose equivalent from natural radionuclides is about 26 mrem/yr for the United States, while studies on distribution of absorbed dose rates in air carried out in Norway (Strander, 1977) and Romania (Toader, 1979) have shown a value of  $7.3 \times 10^{-8}$  Gy/hr and  $8.1 \times 10^{-8}$  Gy/hr respectively. Except for Bangladesh, Brazil, India, Indonesia, Iran and Malaysia, the mean absorbed dose rates in air from the other countries above compare well with the World average of  $5.0 \times 10^{-8}$  Gy/hr.



Studies on natural background radiation levels in Canada (Grasty et al, 1984) have shown that highest levels of radioactivity are found in the northern parts made up of granitic rocks, while lowest levels were recorded within the Athabasca sandstone. The weighted average summer outdoor exposure rates is  $3.7 \pm 2.3$   $\mu\text{R/hr}$  of which 48% comes from the potassium, 43% from the thorium and 9% from the uranium series. A study of the concentration of  $^{238}\text{U}$  in soils in Hong Kong (Yu, 1994) have shown highest values also within the granites while similar studies in soils from Vulcano Island (Mediterranean Sea) indicated low concentrations within the basalts as against the rhyolitic rocks with the highest values (Brai et al, 1995).

Activity refers to the number of nuclear transformations occurring in a given quantity of material per unit time and it depends not only on the parent rock or the soil type, but also on the type of local geological works around. In areas with mine tailings containing minerals such as monazite, the activity levels are usually high. Activity concentration in soils due to  $^{40}\text{K}$ ,  $^{238}\text{U}$  and  $^{232}\text{Th}$  have been reported for different countries. In Rio Grande do Norte Brazil, activity concentration for  $^{40}\text{K}$ ,  $^{238}\text{U}$  and  $^{232}\text{Th}$  radionuclides are 704.0, 29.2 and 47.8 Bq/Kg, while in Santana do Matos areas, the values are 1332.5, 43.7 and 116.7 respectively (Malanca, 1996). According to Bou-Rabee and Bem (1996), activity values from  $^{40}\text{K}$ ,  $^{238}\text{U}$  and  $^{232}\text{Th}$  for Kuwait are 829.0, 11.8 and 10.0 Bq/Kg respectively. In Spain, the values are 653.0, 38.3 and 41.0 Bq/Kg respectively (Baeza et al, 1994) while in Lusaka Zambia, soil activity concentration due to  $^{40}\text{K}$  is 714.0 Bq/kg,  $^{238}\text{U}$  is 25.0 Bq/kg and  $^{232}\text{Th}$  is 26.0

Bq/kg (Hayumbu et al 1995). According to the United Nations Scientific Committee on the Effects of Atomic Radiation (1982), the world average activity concentration for  $^{40}\text{K}$  is 370.0 Bq/kg,  $^{238}\text{U}$  is 25.0 Bq/kg while  $^{232}\text{Th}$  is 25.0 Bq/kg.

Radionuclides in natural environment may be acquired into the body unintentionally through inhalation, ingestion or absorption. Subsequently, they are deposited at various sites in the body. Accumulation of radionuclides in broad-leaved plants as well as radionuclides absorption by roots of plants have also been reported (Ibrahim and Whicker, 1988; Linsalata et al, 1985). According to Mitchell (1974), environmental pathway represents a major source of transfer of radionuclide to man. Average annual internal beta and gamma doses have been calculated in tissues from internally deposited naturally occurring radionuclides such as  $^3\text{H}$ ,  $^{14}\text{C}$ ,  $^{40}\text{K}$ ,  $^{87}\text{Rb}$ . The values are 20 mrem/yr for soft tissues, 7.2 mrem/yr for osteocytes, 7.2 mrem/yr for haversian canals, 16.4 mrem/yr for cells close to surfaces of bone trabeculae and 6.4 mrem/yr for marrows (National Council on Radiation Protection and Measurement, 1976). For annual alpha dose equivalent from naturally occurring radionuclides such as  $^{238-234}\text{U}$ ,  $^{236}\text{Ra}$ ,  $^{228}\text{Ra}$ ,  $^{223}\text{Rn}$ ,  $^{220}\text{Rn}$ ,  $^{210}\text{Po}$ , the values are 8 mrem/yr for soft tissues, 110 mrem/yr for osteocytes, 65 mrem/yr for haversian canals, 44 mrem/yr for cells close to surfaces of bone trabeculae and 8.5 mrem/yr for marrows.

Available information on ionizing radiation in Nigeria include airborne gamma ray survey carried out over most parts of the country between 1974 and

1975 by the Geological Survey Division, Federal Ministry of Mines and Power. The primary aim of the survey was to seek for uranium and thorium mineralization principally because of their application in nuclear energy production. The total counts for gamma-rays of energy in the range of 0.9 - 3.0 MeV were compiled in the form of contour maps and presented on a scale of 1: 100000, representing the trends of ionization in the areas covered. Uwah (1993) also carried out analyses and interpretation of the air-borne gamma-ray survey data for the Ugep area, south east Nigeria, for radioactive mineral recovery and concluded that the concentrations of uranium and potassium are generally low in the area except for the few locations where uranium concentration are a little above the average values for sedimentary and metamorphic rocks.

Alluvial deposits of cassiterite and columbite have been mined in the Jos Plateau area of Nigeria since around the 1920's. These minerals are associated with residues such as thorite, zircon, monazite and xenotime which are radioactive. Accumulated radioactive wastes from mining and processing of cassiterite and columbite can now be seen in most part of the plateau. According to Funtua (1997), laboratory measurement of  $^{232}\text{Th}$  in zircon, monazite and xenotime samples collected from two mines around Jos area gave an average values of 3,600, 650,000 and 188,000 Bq/kg of activity respectively. This is quite high considering the fact that substances are traditionally considered radioactive above the range of a few hundred Bq kg<sup>-1</sup>. Babalola (1984) has also reported high activity concentrations from cassiterites collected from the tin mining and processing camps around the Jos Plateau. In a study on zircon and

monazite sands from the Jos Plateau, Umar (1995) has reported activity concentrations of 732-244 00 Bqkg<sup>-1</sup> and 412-123600 Bqkg<sup>-1</sup> respectively. Work on measurement of radiation levels in mining processing plants in Jos Metropolis (Azu, 1995), as well as monitoring of alpha and beta particles in mine sites in Jos and environs (Ike et al, 2002a) have all shown values several times above that of the non mining areas. Values well in excess of 0.034 rems/wk have also been reported. An assessment of radiological impacts of tin mining activities in Jos and its environs carried out by Ibeanu (1999), revealed a mean activity concentration of 1251, 3867 and 8301 Bqkg<sup>-1</sup> for <sup>40</sup>K, <sup>226</sup>Ra and <sup>232</sup>Th respectively in soil samples collected from old tailing dumps.

Radiation levels of cassiterite tailings in Jos carried out by Adiuku-Brown and Ogezi (2001), revealed that there is enhanced radioactivity wherever tailings are heaped compared to the background. The values obtained from there report ranged from 0.002rems/wk to 0.04rems/wk around such tailings compared with background values of between 0.0001rems/wk to 0.0006rems/wk.

Farai and Jibiri (2000) carried out a study on outdoor gamma radiation exposure dose rates due to radioactivity concentration of <sup>40</sup>K, <sup>238</sup>U and <sup>232</sup>Th in the soil in eighteen (18) cities across different environments in Nigeria. The report gave 0.102±0.032 µGy.h<sup>-1</sup> for the northern part, 0.089±0.014 µGy.h<sup>-1</sup> for the western part, and 0.040 ± 0.006 µGy.h<sup>-1</sup> for the eastern part of the country. Ajayi and Ajayi (1999) working on estimation of absorbed dose rate and collective effective dose equivalents due to gamma radiation from selected

radionuclides in soil in Ondo and Ekiti States, south western Nigeria, reported a mean absorbed dose rate, annual effective dose equivalent and collective effective dose equivalent in these states to be  $0.015 \pm 0.008 \mu\text{Gy}\cdot\text{h}^{-1}$ ,  $18.4\mu\text{Sv}\cdot\text{yr}^{-1}$  and  $73.6 \text{ man}\cdot\text{Sv}\cdot\text{y}^{-1}$  respectively. In his work on evaluation of absorbed dose rate and annual effective dose equivalent due to terrestrial gamma radiation in rocks in a part of south western Nigeria, Ajayi (2002) also reported that the average absorbed dose rate and average annual effective dose equivalent are  $8.33 \pm 2.76 \text{ nGy}\cdot\text{h}^{-1}$  and  $8.7 \pm 2.9 \mu\text{Sv}\cdot\text{yr}^{-1}$  respectively.

Published work as part of the ongoing study on distribution of radiation dose rates in part of the Jos Plateau include the work of Ike et al (2002b) where the distribution of natural gamma radiation dose rates within the Toro Sheet 148, North Central Nigeria are shown. Solomon et al (2002) also presented the natural background radiation characteristics of basalts on the Jos Plateau and the radiological implication of the use of the rock for house construction. The report show that the gamma radiation dose rates vary from 0.3225 - 0.5805 mSv/yr while dose rates due to alpha/beta radiation are from 1.575 - 3.15 mSv/yr, making buildings constructed with the basalts radiologically safe for dwellers since external exposure to radiation is essentially from gamma rays.

The present work therefore intends to study comprehensively, the distribution pattern of natural radiation doses across a major part of the Younger Granite province of Nigeria because of radiation safety concerns.

## **CHAPTER FOUR**

### **METHOD OF INVESTIGATION**

#### **4.1 INTRODUCTION**

Measurements of natural background radiation have been carried out in many parts of the world using a variety of techniques, involving the use of gas filled detectors, scintillometers, spectrometers (Lovborg *et al*, 1979), as well as laboratory analyses of radioactive element concentrations in soil and rock samples from which estimates of the average radiation exposures are obtained. In geological environments with strong heterogeneity in lithology and mineralogical composition, variability in radioactivity of rocks from place to place could make representative sampling for laboratory analyses difficult to achieve on a regional scale. Estimation of radiation exposure on a regional scale based on results of laboratory analyses of limited soils and rock samples therefore may not show the general radiation status of the region under investigation. Field measurements (in situ) will however enable more data points to be established, and more data to be generated. A good distribution of data points will in turn help to present a better radiation pattern for such region. This is a frequently used approach for large area survey and hence used in this investigation.

Radiation surveys carried out in this study involved the measurement of radiation levels from different lithologies using a solid scintillation counter

shown in Plate XXVIII (Saphymo-Stel Model SPP2-NF), for detecting and measuring gross gamma radiation as well as a Geiger Muller tube shown in Plate XXIX (PUG-7A from Technical Associates), for detecting and measuring gross alpha and beta radiations.

#### **4.2 GROSS GAMMA RADIATION MEASUREMENT**

Solid scintillation technique was used to detect and measure gamma radiation in the field. A scintillation equipment operates on the principle that flashes of light are emitted by atom of a material after being ionized by radiation. The magnitude of the light produced is proportional to the energy lost by the particles in traversing the scintillator. Scintillation counters usually contain transparent crystalline materials, protected by plastic and placed in an optical contact with the face of a photomultiplier tube that greatly amplifies the weak light pulses, converts them to an electric signal and feed them into an electronic counter. This is especially suitable for the detection and measurement of gamma radiation.

The SPP2-NF scintillometer used for this study basically comprises a scintillator (NaI.Tl) photomultiplier assembly used as a detector, an impedance matcher, an electronic flip flop, a direct-reading integrator, a stabilized transistor power supply, and a pulse-generating circuit for the sound alarm. The accuracy under normal condition of measurement i.e. normal 'field' temperature as well as with energy above 30keV is  $\pm 10\%$ . The sensitivity of the equipment can be

altered by changing the position of the switch lever. The sensitivity in real hit per second is from 0 - 15,000, and in a scale of 0 - 150 slow, 0 - 150 fast, 0 - 500, 0 - 1500, 0 - 5000 and 0 - 15000. Any of these positions may be used depending on the strength of the radiation to be measured. The scintillometer is in a form of a duralinox box and this assembly supports a pistol-shaped block fitted with a grip. This box consists of five sub assemblies and made up of electronic parts and general cabling, while the pistol body (the probe that detects the gamma rays) comprises essentially of the photomultiplier - scintillator coupling with dynode power supply as well as a measuring device. The position of the crystal in the probe is marked on the outside by a red circle and ring.

Before field measurements began, the scintillation counter was calibrated using a  $^{137}\text{Cs}$  source (Plate XXX) with a specific count rate of 277 counts per second that comes with the equipment to make sure the count levels reflect the actual hit per second of gamma rays coming from the rock materials. This was followed by a check up on the power supply to be sure that the right operating voltage of 4 - 4.5 VDC is attained. Measurements were taken at some point slightly above the samples.

Measurements of gross gamma were made with the 15,000 c/s position and the piston positioned above the point where measurement was to be taken for a few second for the needle pointer to stabilize. It indicates the average number of real hit per second detected by the scintillator crystal. Where the deviation of the needle was less than 1/3 of the scale, the knob was switched to



the next lower scale and so on until the needle was in the last 2/3 position of the scale. This enabled good accuracy and also helped protect the equipment.

The data obtained in counts per second for gross gamma counts were converted to exposure in roentgen/hour. With this equipment, 2000c/s correspond to 0.85 milliRoentgen/hr (mR/h). The values obtained represents the level of ionization i.e. exposure rates at a given place in roentgen unit (R). The exposure rates were again converted to absorbed dose rate in rad/hour using the relation between absorbed dose rate (Da) and exposure (E) as given by Grasty et al (1984) i. e.

$$Da \text{ (rad/h)} = a(\text{rad/R}).E(\text{R/h})\dots\dots\dots\text{Eq (1)}$$

where a has the value of 0.869 rad/R.

The effects of radiation in biological tissues differs with types of radiation (Noz and Maguire, 1979). For this reason therefore, in comparing the effects of radiation on living systems, a unit known as roentgen equivalent man (rem) was used as explained in Section 1.13.4. Therefore,

$$D.E(\text{rems}) = RBE \times \text{rads [RBE = Relative Biological Effectiveness]}. \text{ For gamma rays, RBE} = 1$$

Values obtained in rad were therefore converted to their rems equivalent, as well as the Sievert (Sv) unit which is the SI (System International) unit used in radiation protection.

$$1\text{Gy} = 100\text{rad} = 1\text{J/kg}, \text{ and } 1\text{Sv} = 100\text{rems}.$$

Since 2000 c/s correspond to 0.85 milliRoentgen/hr (mR/h),

$$1\text{c/s} = 4.25 \times 10^{-4} \text{ mR/h} \dots\dots\dots\text{Eq. (2)}$$

For low energy photons, the instrumental multiplication factor (K) is 0.2.

Therefore,

$$\begin{aligned} 1\text{c/s} &= 4.25 \times 10^{-4} \times 0.2 \text{ (mR/h)} \dots\dots\dots\text{Eq. (3)} \\ &= 8.5 \times 10^{-5} \text{ mR/h or } 8.5 \times 10^{-8} \text{ R/h} \end{aligned}$$

Using the relation  $\text{Da (rad/h)} = a(\text{rad/R}).\text{E(R/h)}$ ,

$$\begin{aligned} 1\text{c/s} &= 8.5 \times 10^{-8} \text{ R/h} \times 0.869 \text{ rad/R} \dots\dots\dots\text{Eq. (4)} \\ &= 7.39 \times 10^{-8} \text{ rad/h or } 1.24 \times 10^{-5} \text{ rad/week} \end{aligned}$$

To convert from rad to rem unit, the values obtained in rad were multiply by the value of Relative Biological Effectiveness (REB) for gamma rays. This is 1 as explained in section 1.13.4.

Dose equivalent in rem = Relative biological effectiveness x rad.

$$\begin{aligned} 1 \text{ c/s} &= 1.24 \times 10^{-5} \text{ rem/week.} \\ &= 6.45 \times 10^{-4} \text{ rem/yr} \\ &= 6.45 \times 10^{-6} \text{ Sv/yr.} \dots\dots\dots\text{Eq (5)} \end{aligned}$$

Therefore, 1c/s of gamma radiation measured using the Saphymo-Stel scintillation counter (Model SPP2-NF) corresponds to  $6.45 \times 10^{-3}$  mSv/yr.

### 4.3 GROSS ALPHA/BETA RADIATION

Gross alpha and beta radiations were detected and measured in the field using gas filled radiation detector (Geiger Muller counter). It is the most widely used survey instrument for the detection of low-level radiation exposure. This equipment (PUG-7A Radiation Meter) utilizes a continuously adjustable,

regulated high voltage supply of 200-1500V to operate the GM detector delivering a pulse of 5 millivolt or above. Features on the instrument include H.V. display indicating on the meter the voltage generated and applied to the detector, a range switch which consists essentially of four (4) multiplier positions (X1K, X100, X10 and X1) which are used to multiply the scale readings depending on which one is used, a time constant control switch for low and high count rates, a discrimination potentiometer for pulse control and a display meter with two scales (0-500 CPM and 0-1 mRem/h).

Readings were taken directly in mRem/h. Measurements of gross alpha and beta radiations in the field started in each case with the last scale position (X1K), and the probe positioned above the point where measurement was to be taken until the pointer stabilized. As in the case of the scintillometer, full scale deflections were avoided by using the appropriate switched scale. The instrument was also calibrated before use.

Since the detector used (P-6LB) sees less than 1% of the gammas that penetrates the window, what is measured is essentially alpha and beta radiations combined. Discrimination between alpha and beta radiation were made only in few cases with strong radiation such as in cassiterite mining sites. This was done by conducting two measurements in such location, one with a paper filter and the other with no filter since the range of alpha radiation in solid material is such that 2 sheets of ordinary printing paper will stop them. The first count therefore is alpha and beta combined while the second is beta only. The difference in count therefore is the alpha.

Using PUG-7A Geiger counter with P-6LB detector for gross alpha/beta radiation count, 500 counts/minute correspond to 0.6 mRem/h in dose rate implying that :

$$\begin{aligned} 1 \text{ count/ minute} &= 1.2 \times 10^{-3} \text{ mRem/h.} \\ &= 2.02 \times 10^{-1} \text{ mRem/week or } 2.02 \times 10^{-4} \text{ Rem/week} \\ &= 1.05 \times 10^{-2} \text{ Rem/y or } 10.5 \text{ mRems/y} \\ &= 1.05 \times 10^{-4} \text{ Sv/year .....Eq (6)} \\ &\text{or } 1.05 \times 10^{-1} \text{ mSv/year since } 1 \text{ rem} = 0.01 \text{ Sv.} \end{aligned}$$

Using the conversions given above, field radiation measurement for gamma radiation as well as alpha/beta radiation for each location were then converted to the corresponding dose rates.

#### 4.4 STATISTICAL ANALYSIS

Regression analyses and tests were carried out for radiation parameters obtained in Section 4.2 and 4.3, for each of the major classes of rocks in the area (the Younger Granites, the Basement Complex and the basalts). The aim is to see if statistical correlations and mathematical relationships exist between radiation parameters investigated in this study. If good correlations and mathematical relationships are obtained, it will help in understanding the characteristics of natural radiations in the area. It will also be useful in the preparation of the map of radiation dose rates for the region by combining field measurements with air-borne spectrometric data for the area.

Relationships between radiation parameters obtained are generally not linear, therefore, polynomial regression was used to model the dependent variables with one independent variable. Mathematically, a polynomial of the order  $k$  in  $x$  is an expression of the form  $y=c_0+c_1x+c_2x^2+c_3x^3+\dots+c_kx^k$ , where the  $c$ 's and  $k$  which must be non-negative whole numbers are constants.

#### **4.4.1 Coefficient of Determination**

In all the plots made, the coefficient of determination  $R^2$  which is a criterion for model quality, were checked to assess the quality of the regression models. The coefficient of determination is the proportion of the dependent variable's variability that is explained by the independent variable. It has a maximum value of 1.  $R^2$  is important in measuring the relationship between two variables. Generally, unless the absolute value of the correlation is greater than 0.5, the relationship between variables is not statistically significant.

#### **4.4.2 The t-Test**

The t-test was used to assess the adequacy of each independent radiation variable in the model. It tests the hypothesis that there is no linear relationship between the dependent variable and the independent variable. The paired t-test compares two samples and determines the likelihood of the observed difference occurring by chance. The chance is recorded as the p-value. A small p-value say

0.001 means it is unlikely (only a one chance in 1000 chance) that such a mean difference would occur by chance under the assumption that the mean difference were zero. In such a case it can be said that there is a statistically significant difference between the two groups.

#### **4.4.3 The z-Test**

The z-test was used to compare two radiation variables at a time. It tests the hypothesis that the correlation coefficient is equal to a hypothesized value, usually set at zero. An hypothesized correlation coefficient of zero is equivalent to the hypothesis that there is no correlation between variables. The z-test compares the two groups and determines the likelihood of the observed correlation occurring by chance. The chance is reported as the p-value. A small p-value say 0.001 means it is unlikely (only a one chance in 1000 chance) that such a correlation would occur by chance, and in such a case, it is said that there is a statistically significant difference between the two groups.

#### **4.4.4 The F-Test**

The F-test for variances in this study shows whether the variance of one radiation group is smaller, larger or equal to the variance of the other group. It is used to determine whether or not all of the k independent variables taken

together significantly contribute to the prediction of the dependent variable. This test statistic has the form:

$$F = \text{MS regression} / \text{MS residual} \quad (\text{MS} = \text{Mean Square})$$

The F-test depends on the degree of freedom (the number of observation in the group minus one) for each of the two groups. The F-test is formed as a ratio of the two variances, and the parameters of F-test are usually referred to as numerator degrees of freedom and denominator degrees of freedom.

In testing for significance, the level of significance reported as the p-value is compared with the probability of significance used in the program i.e. 0.05. If the p-value is much less than 0.05, we reject the null ( $H_0$ ) hypothesis and conclude that there is significant difference. If  $p\text{-value} > 0.05$ , we do not reject the null hypothesis and conclude that there is no significant difference.

The null hypothesis is the statement one evaluates through one's analysis of the data. It usually provides a basis for hypothesizing a p-value from the known distribution for a test statistic. Typically, statistical analyses compare a test statistic calculated from the data to that of the null hypothesis to see if the null hypothesis can be rejected. If the calculated value is sufficiently different from that postulated by the null hypothesis, the null hypothesis can be rejected in favor of some alternative, usually a statement which is the negation of the null hypothesis. For example, the null hypothesis for an unpaired t-test is that the difference between the means of two groups of continuous measurements is zero. So, rejection of the null hypothesis entails that the means of the two groups

are different, because the difference between the means is sufficiently different from zero.

#### **4.4.5 The Z-Score Histogram for Distribution of Dose Rates**

For the purpose of finding the probability of occurrence of any of the radiation parameters calculated (absorbed dose rates in air, dose equivalents, effective dose rates as well as alpha/beta radiation dose equivalents), Z-score histograms were plotted for each of the six topographical sheets (Dutsen Wai Sheet 125, Ririwai Sheet 126, Lere Sheet 147, Toro Sheet 148, Naraguta Sheet 168 and Maijuju Sheet 169) studied.

A Z-score histogram converts the values so that the mean is zero and the standard deviation is one. This is usually known as unit normal or standard normal distribution. If the data are normally distributed, fewer than 1 out of 100 points will be higher than 3 or lower than  $-3$ , and only 5% of the points will be larger than 2 or smaller than  $-2$ .

An important characteristic of the normal distribution is the fact that it is a family of distributions in which one member is distinguished from one another on the basis of the values of the mean ( $\mu$ ) and the standard deviation ( $\sigma$ ). With  $\mu = 0$  and  $\sigma = 1$ , the random variable that results,  $(X - \mu) / \sigma$ , is usually designated by a letter  $z$ . The probability that  $z$  takes on a value between any two points on the  $z$ -axis, say  $z_0$  and  $z_1$  can therefore be obtained by simply finding the area bounded by perpendiculars erected at these points, the curve and the horizontal axis. This



area can simply be read from Appendix B. For instance, in Figure 56b representing the Z-scores for distribution of gamma radiation dose equivalents (mSv/yr) within Dutsen Wai Sheet 125 with a mean ( $\mu$ ) = 0.905 and a standard deviation ( $\sigma$ ) = 0.221, the probability of receiving a dose equivalent of 1mSv/yr and above within this sheet can be computed as follows:

$$\begin{aligned} z &= (X-\mu)/\sigma \dots\dots\dots\text{Eq. (7)} \\ &= (1-0.905) / 0.221 \\ &= 0.43 \end{aligned}$$

$$p(X \geq 1) = p(z \geq [1-0.905] / 0.221) = p(z \geq 0.43) = .3336 \text{ i.e. } 33.36\%.$$

It can be said therefore that there is only a 33.36% chance that anyone can be exposed to 1mSv/yr and above of dose equivalent from gross gamma radiation on this map. The Z-score histogram is especially important for health related issues such as hazard assessment (Daniel, 1983; Kleinbaum and Kupper, 1978).

#### **4.5 MAP OF DISTRIBUTION OF RADIATION DOSE RATES**

Radiometric maps on a scale of 1:100000 containing exposure rates in  $\mu\text{R/h}$  in the form of contours were obtained for the study area. They were produced from airborne gamma ray survey carried out over most parts of the country between 1974 and 1975 by Fairy Surveys Ltd and Hunting Geological and Geophysics Ltd England, on behalf of the Geological Survey Division, Federal Ministry of Mines and Power. The primary aim of the survey was to

search for possible areas of uranium and thorium mineralization because of their application in nuclear energy production.

By using a Global Positioning System (Plate XXXI), the coordinates (longitude and latitude) of points where radiation measurements were made in the field were obtained. These points were then located on the spectrometric maps. In all, 601 field measurement points were located on the six (6) airborne spectrometric maps covering the areas of interest.

To prepare maps of distribution of radiation dose rates, data of field gamma radiation measurements were first converted to various dose units such as absorbed dose rates in air ( $\mu\text{Gy/h}$ ), dose equivalents ( $\text{mSv/yr}$ ), and effective dose rates ( $\text{mSv/yr}$ ). The difference between the different units is as explained in Section 1.13. In particular, effective dose rates were obtained by multiplying the values of dose equivalents by the weighting factors for 12 body organs and tissues and summing up the weighted doses as explained in Section 1.13.4.

By combining in regression plots, values of each dose type (absorbed dose rates in air in  $\mu\text{Gy/h}$ , dose equivalents in  $\text{mSv/yr}$  and effective dose rates in  $\text{mSv/yr}$ ) with the corresponding value of exposure rates ( $\mu\text{R/h}$ ) obtained from the radiometric maps for the said 601 data points, quantitative equations (Eq. 23, 24 and 25) were obtained along with other statistical parameters described in Section 4.4. The equations best describe the strength of relationship between the two sets of data (variables).

The radiometric maps on a scale of 1:100000 were later divided into grids of  $3^\circ$  by  $3^\circ$  each from which about 121 data points were obtained for every

sheet. Exposure values at these points were then substituted into the appropriate empirical equations (Eq. 23, 24 and 25) to obtain ground values for the various dose rates. With this approach, ground radiation values and their distribution pattern can be obtained from all parts of the map including the inaccessible areas.

For alpha/beta radiation, direct regression were not made with the corresponding value of exposure rates ( $\mu\text{R/h}$ ) from same point on the radiometric maps for those 601 data points because the limit of alpha and beta radiations in air is very small, and therefore the approach above could introduce errors into the equation. Rather, alpha/beta radiation dose equivalents calculated from field data were first combined in regression plot with those of gamma radiation to obtain Equation 26. The gamma dose equivalents for different grid points obtained using Equation 23 were then substituted in Equation 26 to obtain the corresponding data for alpha/beta radiation dose equivalents for those grid points.

Radiation values obtained were later contoured on a background of the geology of each of the six sheets ( Dutsen Wai Sheet 125, Ririwai Sheet 126, Lere Sheet 147, Toro Sheet 148, Naraguta Sheet 168 and Maijuju Sheet 169). The maps thus produced include the maps of distribution of air absorbed dose rates in air ( $\mu\text{Gy/h}$ ), the maps of distribution of gamma radiation dose equivalents ( $\text{mSv/yr}$ ), the maps of distribution of effective dose rates ( $\text{mSv/yr}$ ) as well as maps of distribution of alpha/beta radiation dose equivalents for the area of study. Also radiation hazard maps were produced for each of the above

topographical sheets based on a reference dose of 1mSv/yr maximum permissible dose limit set for the general public by the International Commission on Radiological Protection (ICRP). The maps are intended to show where and how much of radiation dose equivalent is received in any part of the study area.

## CHAPTER FIVE

### RESULTS

#### 5.1 INTRODUCTION

Owing to the differences in lithology, structure and mineralogical composition of rocks, their radiation levels differ significantly from rock to rock and from one place to another (Chong, 1985; Chong *et al*, 1985). It has been observed also that where such rocks are enriched in tin mineralization, they are often associated with thorium (Suleiman, 1995; Ghazali and Hashim, 1989). Thorite ( $\text{ThSiO}_4$ ) and Zircon ( $\text{ZrSiO}_4$ ) are radioactive and usually occur as accessory minerals in biotite granites and riebeckite granite that constitutes a large percentage of the lithologies within the younger granite province of Nigeria. They have been recovered as bi-product in cassiterite and columbite mining (Babalola, 1984; Umar, 1995) on the Jos Plateau.

Radiation levels calculated from the data of field radiation measurements were plotted into line graphs as well as contour maps of distribution of dose rates for the study area. The line graphs were plotted to show whether or not the radiation pattern from the rocks are related to the geologic ages of the major classes of rocks (the Basement Complex, the Younger Granites and the Basalts) found in the area, while the contour maps will indicate the pattern of distribution of radiation parameters in relation to the geology of the area. The radiation parameters plotted include adsorbed dose rates in air ( $\mu\text{Gyh}^{-1}$ ), dose equivalents (mSv/yr) as well as effective dose rates (mSv/yr) all from gamma radiation

sources, and dose equivalents (mSv/yr) from alpha/beta radiation in the area. Others include maps of radiation hazards based on gamma radiation values since alpha/beta radiation is low penetrating and therefore do not pose radiation problems except ingested through food or water. Radiation data used in the preparation of the maps are based on results of statistical analysis and regression plots as explained in Sections 4.4 & 4.5.

## **5.2 LINE GRAPHS**

Line graphs for the distribution of gamma radiation count rates are shown in Figure 17 for the Younger Granites, Figure 18 for the Basement Complex and in Figure 19 for the basalts. The values range from 80-1340 c/s with a mean of  $228 \pm 102.0$  for the Younger Granites, 50-400 c/s and a mean of  $160 \pm 68.0$  for the Basement Complex, as well as 50- 90 c/s with a mean of  $60 \pm 9.0$  for the Basalts. Highest frequency of count rates obtained falls between 206-336 c/s within the Younger Granites, 120-155c/s for the Basement Complex and 58-62 c/s for the Basalts.

Radiation dose equivalents calculated for gamma radiation for these classes of rocks indicate values between 0.516-8.643 mSv/yr with a mean of  $1.468 \pm 0.660$  for the Younger Granites (Figure 20), 0.323-2.580 mSv/yr and a mean of  $1.035 \pm 0.438$  for the Basement Complex (Figure 21) and 0.323-0.581 mSv/yr with a mean of  $0.387 \pm 0.057$  for the Basalts (Figure 22). Highest frequency of dose equivalents obtained falls between 1.329-2.141 mSv/yr within

the Younger Granites, 0.774-1.000 mSv/yr for the Basement Complex and 0.037-0.040 mSv/yr for the Basalts.

It can therefore be seen that emission of gamma radiation is generally higher within the Younger Granites compared to the other two classes of rocks. From the profile of gamma radiation for the Younger Granites (Figure 20), dose equivalents are mostly higher within the Ganawuri, Jere-Sanga, Kwandonkaya and Ririwai complexes where values in excess of 1mSv/yr were obtained, and lower within the Kudara Complex and part of Dutsen-Wai Complex.

Within the basement rocks studied, the undifferentiated migmatites around the Bishichi area south east of Jos and the porphyritic granites around Miango area west of Jos (Figure 21), record the highest values, while values from other rocks within this class are essentially lower than 1mSv/yr.

Values obtained for the basaltic rocks such as lateritized basalts, older basalts and the newer basalts are typically low (Figure 22), reflecting low concentration of primordial radionuclides in the rocks (Solomon *et al*, 2002).

Line graphs for the distribution of alpha/beta radiation count rates are shown in Figure 23 for the Younger Granites, Figure 24 for the Basement Complex and in Figure 25 for the basalts. The values range from 5-215 c/m with a mean of  $39.052 \pm 18.892$  for the Younger Granites, 15-105 c/m and a mean of  $41.890 \pm 17.374$  for the Basement Complex, and 15-30 c/m and a mean of  $21.739 \pm 3.790$  for the Basalts. Highest frequency of alpha/beta count rates falls between 26-47 c/m within the Younger Granites, 24-33 c/m for the Basement Complex and 19.5-21.0 c/m for the Basalts.

Radiation dose equivalents calculated for alpha/beta radiation for these classes of rocks indicate values of between 0.525-22.575 mSv/yr with a mean of  $4.077 \pm 1.883$  for the Younger Granites (Figure 26), 1.575-11.025 mSv/yr with a mean of  $4.398 \pm 1.824$  for the Basement Complex (Figure 27) and 1.575-3.150 mSv/yr with a mean of  $2.283 \pm 0.398$  for the Basalts (Figure 28). Most of the dose equivalents obtained fall between 2.730-4.935 mSv/yr within the Younger Granites, 2.520-3.465 mSv/yr within the Basement Complex and 2.047-2.205 mSv/yr for the Basalts.

For comparison, both gamma and alpha/beta radiations for each of the major classes of rocks were presented in combined plots as shown in Figures 29, 30 & 31. As can be seen in Figure 20, radiation levels here do not correlate well with either increase or decrease in geologic age of the rocks shown in Figure 1. Similar observation was also made in a study of relation between radiation exposure rates and ages of geological formations in Taiwan (Hsu *et al.*, 1994).

### **5.2.1 Rock Radiation Parameters & Regression Characteristics**

Result of regression analysis for various parameters of natural radiation from the Younger Granites is as shown in Appendices A-1 to A-5. An  $R^2$  value of 0.729 (Figure 32) was obtained for gamma radiation count rates (c/s) versus alpha/beta radiation count rates (c/m), 0.682 (Figure 33) for alpha/beta radiation count rates (c/m) versus gamma radiation count rates (c/s), and 0.729 (Figure 34) for gamma radiation dose equivalents (mSv/yr) versus alpha/beta radiation count



rates (c/m). An  $R^2$  value of 0.575 (Figure 35) was equally obtained for alpha/beta radiation dose equivalents (mSv/yr) versus gamma radiation count rates (c/s), and 0.589 for gamma radiation dose equivalent (mSv/yr) versus alpha/beta radiation dose equivalents (mSv/yr) as can be seen in (Figure 36). The values are all statistically significant.

An  $R^2$  value of between 0.575 and 0.729 means that 57.5 to 72.9% of the dependent variables in each respective case is explained by (or dictated by) the independent variable. The  $R^2$  is a good criterion for modeling regression quality (Goodman, 1970; Kleinbaum and Kupper, 1978, Daniel, 1983). The values above indicate therefore that there is a strong correlation between the radiation variables within the Younger Granites in this area. It also follows therefore that from the knowledge of the value of one variable, others can be computed using appropriate empirical relationships given in equations 8-12.

The p-values for F-test obtained in the analysis of variance in Appendices A-1 to A5 (b) are low, generally  $<.0001$ . It indicates only a one in 10000 chance meaning that it is unlikely that the observed difference between the means of the two radiation variables compared in each case, will occur by chance if the two groups had the same mean. It implies therefore that there is a statistically significant difference between the two means.

The p-values for t-test obtained in Appendices A-1 to A5 (c) vary from plot to plot but generally  $<.0001$ . The t-test assesses the adequacy of each independent variable in the model. It tests the hypothesis that there is no linear relationship between the dependent variable and the independent variable. A

small p-value, say 0.0001, means it is unlikely (only a one chance in 10000 chance) that such a mean difference would occur by chance under the assumption that the mean difference were zero. In such a case it can be said that there is a statistically significant difference between the two groups. In testing for significance generally, low p-values much less than 0.05 leads to the rejection of the null hypothesis and the conclusion that the observed correlation does not occur by chance.

Result of regression analysis for various parameters of natural radiation from the Basement Complex is as shown in Appendices A-6 to A-10(a-c). A coefficient of determination ( $R^2$  value) of 0.917 was obtained for gamma radiation count rates (c/s) versus alpha/beta radiation count rates (c/m) as shown in Figure 37, 0.92 in Figure 38 for alpha/beta radiation count rates (c/m) versus gamma radiation count rates (c/s), and 0.917 in Figure 39 for gamma radiation dose equivalents (mSv/yr) versus alpha/beta radiation count rates (c/m).  $R^2$  value of 0.92 (Figure 40) was obtained for alpha/beta radiation dose equivalent (mSv/yr) versus gamma radiation count rates (c/s), while that of gamma radiation dose equivalents (mSv/yr) versus alpha/beta radiation dose equivalents (mSv/yr) shown in Figure 41 is 0.917. These values are all statistically significant.

An  $R^2$  value of between 0.917 and 0.920 means that 91.7 to 92.0% of the dependent variables in each respective case is explained by the independent variable. The  $R^2$  values obtained here are quite high, indicating that there is a very strong correlation between the radiation variables from the Basement Complex

rocks in this area. Empirical equations 13 - 17 can therefore be used to obtain any of the variables indicated with a knowledge of one.

The p-values for f-test obtained in the analysis of variance in Appendices A-6 to A-10 are low, generally  $<.0001$ . It indicates only a one in 10000 chance meaning that it is unlikely that the observed relationships between the variables occur by chance.

Within the Basalts, the situation is much different. Result of regression analysis for various parameters of natural radiation here is as shown in Appendices A-11 to A-15 (a-c). An  $R^2$  value of 0.351 was obtained for gamma radiation count rates (c/s) versus alpha/beta radiation count rates (c/m) as shown in Figure 42, 0.350 for alpha/beta radiation count rates (c/m) versus gamma radiation count rates (c/s) as shown in Figure 43, and 0.351 (Figure 44) for gamma radiation dose equivalents (mSv/yr) versus alpha/beta radiation count rates (c/m). Figure 45 shows the regression plot for alpha/beta radiation dose equivalents (mSv/yr) versus gamma radiation count rates (c/s) which gave a  $R^2$  value of 0.35, and 0.351 (Figure 46) for gamma radiation dose equivalent (mSv/yr) versus alpha/beta radiation dose equivalents (mSv/yr). They yielded Equations 18 – 22.

The  $R^2$  values obtained within the basalts are all statistically insignificant. An  $R^2$  value of between 0.350 and 0.351 means that only 35 to 35.1% of the dependent variables in each respective case is controlled by the independent variable. As explained in Section 4.4, unless the absolute value of the correlation ( $R^2$ ) is greater than 0.5, the relationship between variables is considered not

important. It can be said therefore that unlike the Basement Complex and Younger Granites, there is no significant relationship between radiation parameters within the Basalts in the study area. This can be explained on the fact that basic extrusive rocks such as basalts have very low concentration of potassium, uranium and thorium (Table 1) which are largely responsible for natural radiation in rocks. Occurrence of basalts in the study area is limited, accounting for less than 5% of the rocks. They are mainly found around the Hoss, Ganawuri, and Hiepang areas of Plateau State.

### **5.3 MAPS OF DISTRIBUTION OF RADIATION DOSE RATES**

Statistical interpretation in the form of regression analysis, polynomial plots and Z-score histogram were carried out for radiation parameters in the study area for possible correlation and mathematical relationships governing natural terrestrial radiation in this area, as well as to know the probability of exposure to 1mSv/yr (maximum permissible dose) and above.

As explained in Section 4.5, preparation of maps of distribution of radiation dose rates were based on extent and strength of association as well as quantitative regression equations that best describe the relationship between radiation measurements obtained from the field and airborne exposure rates for corresponding points obtained from radiometric maps for the area. Result of regression analysis of gamma radiation dose equivalents (mSv/yr) versus airborne gamma exposure rates ( $\mu\text{R/h}$ ) gave a coefficient of determination ( $R^2$  value) of

0.835 as shown in Figure 47, and yielded Equation 23, while that of absorbed dose in air ( $\mu\text{Gy/h}$ ) versus airborne gamma exposure rates ( $\mu\text{R/h}$ ) shown in Figure 48, as well as that of effective dose rates ( $\text{mSv/yr}$ ) versus airborne gamma exposure rates ( $\mu\text{R/h}$ ) presented in Figure 49 gave a coefficient of determination ( $R^2$  value) of 0.835 each, and yielded Equations 24 and 25 respectively. Equation 26 with  $R^2$  value of 0.546 shown in Figure 50 was also obtained for alpha/beta radiation. The p-value for both f-tests and t-tests for the regression are all statistically significant as can be seen in Appendices A-16 to A-19. On the basis of the regression results summarized in Equations 23, 24, 25 and 26 along with values of airborne gamma exposure rates obtained from a  $3^\circ$  by  $3^\circ$  grid made on each of the airborne radiometric maps, corresponding ground data were generated and plotted into maps of natural terrestrial radiation covering Dutsen Wai Sheet 125, Ririwai Sheet 126, Lere Sheet 147, Toro Sheet 148, Naraguta Sheet 168 and Maijuju Sheet 169 that constitute the study area.

### **5.3.1 Dutsen Wai Sheet 125**

Maps of distribution of gamma absorbed dose rates in air (Figure 51), dose equivalents (Figure 52) and effective dose rates (Figure 53) within Dutsen Wai Sheet 125 show values of 0.078 - 0.236 with a mean of  $0.104 \pm 0.025 \mu\text{Gyh}^{-1}$ , 0.682 - 2.058 with a mean of  $0.905 \pm 0.221 \text{ mSv/yr}$  and 0.648 - 1.955 with a mean of  $0.860 \pm 0.210 \text{ mSv/yr}$  respectively. Highest values tend to concentrate around the Dutsen Wai Complex in the north central part, the Banke Complex in the north eastern part, as well as the Kудару Complex towards the

south eastern part. In these areas, values of between  $0.115 - 0.22 \mu\text{Gyh}^{-1}$ ,  $0.90 - 1.8 \text{ mSv/yr}$  and  $0.85 - 1.75 \text{ mSv/yr}$  can be received respectively. Within these Younger Granite complexes found in this sheet, the Banke and Dutsen Wai Complexes have the highest values while the values around the Kudaru Complex are lower.

Within the basement complex rocks towards the western part essentially made up of migmatites and gneisses, values are generally lower than  $0.095 \mu\text{Gyh}^{-1}$  for absorbed dose rates in air,  $0.90 \text{ mSv/yr}$  for dose equivalents and  $0.85 \text{ mSv/yr}$  for effective dose rates. Around the Pambegua, area underlain by older granites, values are however generally higher.

The map of distribution of alpha/beta radiation dose equivalents for this sheet (Figure 54) show a value of  $2.965 - 11.373$  with a mean of  $4.434 \pm 1.380 \text{ mSv/yr}$ , with highest values recorded also around the complexes mentioned above. Although the values are high compared to that of gamma radiation, they do not pose radiation problems because of their low penetration power.

Within the Dutsen Wai topographical sheet, the highest frequency of gamma absorbed dose rates in air, dose equivalents and effective dose rates occur between  $0.094 - 0.110 \mu\text{Gyh}^{-1}$  (Figure 55a),  $0.819 - 0.957 \text{ mSv/yr}$  (Figure 56a) and  $0.778 - 0.909 \text{ mSv/yr}$  (Figure 57a) respectively. The highest frequency for alpha/beta dose equivalent is found between  $3.806 - 4.647 \text{ mSv/yr}$  (Figure 58a).

The Z-Scores for absorbed dose rates in air (Figure 55b), radiation dose equivalents (Figure 56b) and effective dose (Figure 57b) all show a normal

distribution type of curve. Using the curves, the probability of exposure to  $0.11457 \mu\text{Gyh}^{-1}$  and above (corresponding to  $1\text{mSv/yr}$  and above) was calculated for absorbed dose rate in air, as well as  $1\text{mSv/yr}$  and above for radiation dose equivalents and effective doses within this topographical sheet. The probability of exposure to absorbed dose rates in air in excess of  $0.11457 \mu\text{Gyh}^{-1}$  gave a value of 0.3372 (33.72%), while that of radiation dose equivalents and effective dose rates are 0.3336 (33.36%) and 0.2514 (25.14) respectively. In most areas on this topographical sheet therefore, natural radiation levels can be said to fall within permissible limit of  $1\text{mSv/yr}$ . The Z-Scores for distribution of alpha/beta radiation here (Figure 58b) also show a normal distribution type of curve.

### **5.3.2 Ririwai Sheet 126**

The distribution of radiation absorbed dose rates in air (Figure 59), dose equivalents (Figure 60) and effective dose rates (Figure 61) within Ririwai Sheet 125 show a value of  $0.088 - 0.431$  with a mean of  $0.120 \pm 0.035 \mu\text{Gyh}^{-1}$ ,  $0.768 - 3.764$  with a mean of  $1.047 \pm 0.307 \text{mSv/yr}$  and  $0.730 - 3.576$  with a mean of  $0.995 \pm 0.292 \text{mSv/yr}$  respectively. High values are concentrated especially around the Ririwai Complex itself located in the central part of the map. Here, dose equivalents and effective dose rates vary between  $1.25 - 3.7 \text{mSv/yr}$  and  $1.2 - 3.6 \text{mSv/yr}$  respectively. High radiation values within this complex may be attributed to zircon – thorite mineralization (Pointer *et al* 1988) and high concentration of rare earth elements within the complex (Iyer, *et al*, 1983, 1988, Kinnaird *et al*, 1985, Imeopkaria and Chalokwu, 1990, Chalokwu and

Imeopkaria, 1989. Radioactive disintegration may also be the source of high heat flow (Verheijen and Ajakaiye, 1979) reported here.

Values of radiation parameters are generally much lower around other complexes on this map such as Gamawa, Guraka and Zuku, as well as part of Banke and Tibchi complexes. Radiation values from these complexes are however well above that of the surrounding basement rocks.

A map of distribution of alpha/beta radiation dose equivalents also plotted for this sheet (Figure 62) shows a value of 3.549 – 19.093 with a mean of  $5.338 \pm 1.726$  mSv/yr, with highest values found around complexes.

Within the Ririwai Sheet 126, highest frequencies of absorbed dose rates in air, dose equivalents and effective dose rates are between 0.88 – 0.122  $\mu\text{Gyh}^{-1}$  (Figure 63a), 0.768 – 1.068 mSv/yr (Figure 64a) and 0.730 – 1.014 mSv/yr (Figure 65a) respectively. For alpha/beta radiation, it is between 5.103 – 6.658 (mSv/yr) as shown in Figure 66a.

The Z-Scores for probability plot for absorbed dose rates in air (Figure 63b), radiation dose equivalents (Figure 64b) and effective dose rates (Figure 65b) all show a normal distribution type of curve. With the curves, the probability of exposure to an absorbed dose rate in air of 0.11457  $\mu\text{Gyh}^{-1}$  and above (equivalent to 1mSv/yr and above) is calculated to be 0.5636 (56.36%). The probability of exposure to a dose equivalent or effective dose of 1mSv/yr here were also calculated to be 0.5596 (55.96%) and 0.4920 (49.20%) respectively. The result show therefore that while the highest radiation dose values are found in this area, the chances of exposure to a dose equivalent or



effective dose of 1mSv/yr and above is less than 56%. The Z-Scores for distribution of alpha/beta radiation here (Figure 66b) also show a normal distribution type of curve.

### **5.3.3 Lere Sheet 147**

Distribution of absorbed dose rates in air (Figure 67), dose equivalents (Figure 68) and effective dose rates (Figure 69) within Lere Sheet 147 show a value of 0.078 - 0.236 with a mean of  $0.117 \pm 0.027 \mu\text{Gyh}^{-1}$ , 0.682 – 2.058 with a mean of  $1.024 \pm 0.232 \text{ mSv/yr}$  and 0.648 – 1.955 with a mean of  $0.973 \pm 0.220 \text{ mSv/yr}$  respectively. High values are concentrated especially around the Shaiya Shokobo, Jere Sanga and Amo complexes. The Buji Complex show low radiation levels with values similar to the surrounding basement rocks. Within the basement rocks west of Jengere and around Saminaka area, values are generally low and less than  $0.12 \mu\text{Gyh}^{-1}$  for absorbed dose rates in air, as well as 1mSv/yr for dose equivalents and effective dose rates. Around Garum Kurama to the south western part of the map however, the basement rocks show higher radiation values.

A map of distribution of alpha/beta radiation dose equivalents for this sheet (Figure 70) show a value of 2.965 – 11.373 with a mean of  $5.208 \pm 1.448 \text{ mSv/yr}$ . Just like on other maps, highest values were found around the biotite granites

Within the Lere Sheet 147, highest frequencies of absorbed dose rates in air (Figure 71a), dose equivalents (Figure 72a) and effective dose rates (Figure 73a) are between 0.110 – 0.125  $\mu\text{Gyh}^{-1}$ , 0.992 – 1.095 mSv/yr, and 0.909 – 1.040 mSv/yr respectively. For alpha/beta radiation dose equivalents (Figure 74a) the value is 4.647 – 5.487 mSv/yr.

The Z-Scores for probability plot for absorbed dose rates in air (Figure 71b), radiation dose equivalents (Figure 72b) and effective doses (Figure 73b) all show a normal distribution type of curve. Using the curves, the probability of exposure to a reference levels of 0.11457  $\mu\text{Gyh}^{-1}$  and above for absorbed dose rates in air, and 1mSv/yr for dose equivalents and effective doses gave a value of 0.5359 (53.59%), 0.5396 (53.96%) and 0.4522 (45.22%) respectively. The results show generally that for absorbed dose rates in air and dose equivalents, the chances are equally likely, but less likely for effective dose rates. The Z-Scores for distribution of alpha/beta radiation here (Figure 74b) also show a normal distribution type of curve.

### **5.3.4 Toro Sheet 148**

Distribution of absorbed dose rates in air (Figure 75), dose equivalents (Figure 76) and effective dose rates (Figure 77) plotted for Toro Sheet 148, show a value of 0.078 - 0.255 with a mean of  $0.141 \pm 0.043 \mu\text{Gyh}^{-1}$ , 0.682 – 2.229 with a mean of  $1.234 \pm 0.379$  mSv/yr and 0.648 – 2.118 with a mean of  $1.173 \pm 0.360$  mSv/yr respectively. Here, radiation values appear to be uniformly

high in the areas surrounding the Kwandonkaya and Tongolo complexes recording higher dose values compared with the Junguru, Dagga Allah, Kunkur, Sutumi and Kofai complexes.

Within the basement complex rocks generally made up of migmatites and gneisses, absorbed dose rates in air are generally between 0.09- 0.14  $\mu\text{Gyh}^{-1}$  while those of dose equivalents and effective dose are between 0.8 and 1.3 mSv/yr. Around the south eastern corner of the map however the basement rocks records higher doses of radiation.

The map of distribution of alpha/beta radiation dose equivalents plotted for this sheet (Figure 78) show a value of 2.965 – 12.285 with a mean of  $6.544 \pm 1.380$  mSv/yr, with highest values generally found around the Kwandonkaya and Tongolo complexes. Alpha and Beta radiations are weakly penetrating and do not pose problems except ingested through food or drinks.

Within the Toro Sheet 148 topographical sheet, highest frequencies of absorbed dose rates in air, dose equivalents and effective dose rates are 0.114 – 0.131  $\mu\text{Gyh}^{-1}$  (Figure 79a), 0.991 – 1.146 mSv/yr (Figure 80) and 0.942 – 1.089 mSv/yr (Figure 81a) respectively. For alpha/beta radiation, it is 5.103 – 6.658 mSv/yr (Figure 82a).

The Z-Scores for distribution of absorbed dose rates in air (Figure 79b), radiation dose equivalents (Figure 80b) and effective dose rates (Figure 81b) all show a normal distribution type of curve. With the curves, the probability of exposure to 0.11457  $\mu\text{Gyh}^{-1}$  or more of absorbed dose rates in air is 0.7291 (72.91%), while the probability of exposure to 1mSv/yr of more of dose

equivalents and effective dose rates are 0.7324 (73.24%) and 0.7018 (70.18%) respectively. These values are generally high despite the fact that highest radiation dose values within the study area were obtained from Ririwai Sheet 126. The Z-Scores for distribution of alpha/beta radiation here (Figure 82b) is a normal distribution curve type.

### **5.3.5 Naraguta Sheet 168**

Radiation values plotted for Naraguta Sheet 168 show a value of 0.030 - 0.236 with a mean of  $0.104 \pm 0.045 \mu\text{Gyh}^{-1}$ , 0.258 – 2.058 with a mean of  $0.910 \pm 0.395 \text{ mSv/yr}$  and 0.245 – 1.955 with a mean of  $0.864 \pm 0.375 \text{ mSv/yr}$  for absorbed dose rates in air (Figure 83), dose equivalents (Figure 84) and effective dose rates (Figure 85) respectively. Highest radiation levels were recorded around Ganawuri, Forum, Kigum, Ropp and Jos-Bukuru complexes with values generally in excess of  $0.11 \mu\text{Gyh}^{-1}$ , 1.10mSv/yr and 1.02 mSv/yr for absorbed dose rates in air, dose equivalents and effective dose rates respectively. It can also be noted here that highest range of values (from minimum to maximum) for all radiation parameters were recorded on this sheet out of the six sheets studied. This is because basalts (which are generally very low in natural radiation levels) are found extensively on this topographical sheet along with biotite granites (which are typically high in natural radiation levels). The basalts are located around the western parts as well as in the southern and south eastern parts. According to Solomon *et al* (2002), radiation levels are generally low in basalts

since basalts are made essentially of calcic plagioclase, pyroxene and olivine which are non radioactive.

The map of distribution of alpha/beta radiation dose equivalents also plotted for this sheet (Figure 86) show a value of 2.965 – 11.373 with a mean of  $5.036 \pm 1.925$  mSv/yr, with highest values also found around the Ganawuri, Forum, Kigum, Ropp and Jos-Bukuru complexes made up essentially of biotite granites

Within the Naraguta Sheet 168, highest frequency of absorbed dose rates in air, dose equivalents and effective dose rates are between 0.112 – 0.133  $\mu\text{Gyh}^{-1}$  (Figure 87a), 0.978 – 1.158 mSv/yr (Figure 88a) and 0.929 – 1.100 mSv/yr (Figure 89a) respectively. For alpha/beta radiation, highest count is between 3.806 – 4.647 mSv/yr as shown in Figure 90a.

The Z-Scores for distribution of absorbed dose rates in air (Figure 87b), radiation dose equivalents (Figure 88b) and effective dose rates (Figure 89b) all show a normal distribution type of curve, and a probability value of 0.5910 (59.10%) for exposure to absorbed dose rates in air of  $0.11457 \mu\text{Gyh}^{-1}$  or more, as well as 0.4129 (41.29%) and 0.3594 (35.94%) for exposure to 1mSv/yr or more of dose equivalents and effective dose rates respectively. The Z-Scores for distribution of alpha/beta radiation (Figure 90b) equally show a normal distribution type of curve.

### **5.3.6 Maijuju Sheet 169**

Map of distribution of absorbed dose rates in air (Figure 91), dose equivalents (Figure 92) and effective dose rates (Figure 93) plotted for Maijuju Sheet 168 show a value of 0.078 - 0.196 with a mean of  $0.117 \pm 0.023 \mu\text{Gyh}^{-1}$ , 0.682 – 1.715 with a mean of  $1.024 \pm 0.204 \text{ mSv/yr}$  and 0.648-1.629 with a mean of  $0.973 \pm 0.194 \text{ mSv/yr}$  respectively. Highest radiation levels on this map were recorded around Shere, Jarawa and Sara-Fier complexes with values generally in excess of  $0.12 \mu\text{Gyh}^{-1}$ , 1.30 mSv/yr and 1.20 mSv/yr for absorbed dose rates in air, dose equivalents and effective dose rates respectively. Within the Basement Complex, radiation levels are generally lower with an average value of about 1mSv/yr.

The map of distribution of alpha/beta radiation dose equivalent also plotted for this sheet (Figure 94) show a value of 2.965 – 9.457 with a mean of  $5.213 \pm 1.285 \text{ mSv/yr}$ , with highest values found around the Jarawa and Sara-Fier complexes.

Within the Maijuju Sheet 169, highest frequency of absorbed dose rates in air, dose equivalents and effective dose rates are between 0.114 – 0.125  $\mu\text{Gyh}^{-1}$  (Figure 95a), 0.992 – 1.095 mSv/yr (Figure 96a) and 0.942 – 1.040 mSv/yr (Figure 97a) respectively.

The Z-Scores for distribution of absorbed dose rates in air (Figure 95b), radiation dose equivalents (Figure 96b) and effective dose rates (Figure 97b) all show a normal distribution type of curve, and a probability value of 0.5438

(54.38%) for exposure to absorbed dose rate in air of  $0.11457 \mu\text{Gyh}^{-1}$  or more, as well as 0.5478 (54.78%) and 0.4443 (44.43%) for exposure to 1mSv/yr or more of dose equivalents and effective dose rates respectively. The Z-Scores for distribution of alpha/beta radiation (Figure 98b) equally show a normal distribution type of curve.

#### **5.4 RADIATION HAZARD MAPS**

Based on a reference dose of 1mSv/yr maximum permissible dose limit for the general public as set by International Commission on Radiological Protection (ICRP), as well as other related organizations, radiation hazard maps were prepared for each of the six topographical sheet in the study area. The maps show where and how much of radiation dose equivalent is received in any area.

Radiation hazard maps produced are shown in Figure 99-104. The areas in graded pink colour represent areas with radiation dose equivalent of 1mSv/yr and above. Information contained in these maps could be used as a baseline, to confirm and to plan decisions regarding possible radiation related health problems in the area. This may help raise public awareness on the subject as well as to help promote understanding of the essential linkages between environment and development.

## CHAPTER SIX

### DISCUSSIONS, CONCLUSION AND RECOMMENDATION

#### 6.1 RESEARCH SUMMARY

A study of natural radiation levels and distribution of dose rates in parts of the Younger Granite province of Nigeria has just been completed and the key findings include the followings:

i). Radiation dose equivalent from gamma sources in this area is 0.516-8.643 mSv/yr for the Younger Granites, 0.323-2.580 mSv/yr for the basement complex and 0.323-0.581 mSv/yr for the basalts, while those from alpha/beta sources from these rocks are 0.525-22.575 mSv/yr, 1.575-11.025 mSv/yr and 1.575-3.150 mSv/yr respectively.

ii). Result of regression analyses for various parameters of natural terrestrial radiation from the area are statistically significant for both the Younger Granites and the basement rocks but not for the basalts. The coefficient of determination ( $R^2$ ) of 0.575 – 0.729 were obtained for the Younger Granites, 0.917-0.920 for the basement rocks and 0.35 – 0.351 for the basalts.

iii). Distribution of absorbed dose rates in air, dose equivalents, and effective dose rates are 0.078-0.236  $\mu\text{Gyh}^{-1}$ , 0.682–2.058 mSv/yr and 0.648–1.955 mSv/yr respectively for Dutsen wai Sheet 125; 0.088-0.431  $\mu\text{Gyh}^{-1}$ , 0.768–3.764 mSv/yr and 0.730–3.576 mSv/yr for Ririwai Sheet 126; 0.078-0.236  $\mu\text{Gyh}^{-1}$ , 0.682–2.058 mSv/yr and 0.648–1.955 mSv/yr for Lere Sheet 147. Within Toro Sheet 148, these radiation parameters gave 0.078-0.255  $\mu\text{Gyh}^{-1}$ , 0.682–2.229 mSv/yr and 0.648–2.118 mSv/yr respectively while for Naraguta



Sheet 168, the values are 0.030-0.236  $\mu\text{Gyh}^{-1}$ , 0.258–2.058 mSv/yr and 0.245–1.955 mSv/yr. Within Maijuju Sheet 169, the values are 0.078-0.196  $\mu\text{Gyh}^{-1}$ , 0.682–1.715 mSv/yr, and 0.648–1.629 mSv/yr respectively.

iv). Using the ICRP (1990) dose limit of 1mSv/yr as hazard reference, the probability of exposure to a dose equivalent of 1mSv/yr and above is 0.3336 for Dutsen Wai Sheet 125; 0.5596 for Ririwai Sheet 126; 0.5396 for Lere Sheet 147; 0.7324 for Toro Sheet 148; 0.4129 for Naraguta Sheet 168 and 0.5478 for Maijuju Sheet 169. It can be seen therefore that while high radiation values were obtained in some areas especially within Ririwai Sheet 126, such values may not be widely distributed. High radiation values and extensive distribution determine its hazard potential.

## **6.2 DISCUSSION**

Within the study area, terrestrial radiation values are moderately low except in some areas identified on the radiation maps where higher values exists. In some places, it has also been noticed around the weathered rock materials that radiation values appear to be higher than from the fresh parts. This may be explained by the origin of the radionuclides as well as by the weathering of the parent rocks. The original sources of uranium-series, thorium-series, actinium-series, potassium and rubidium radioactivity in the terrestrial environment are the earth's crust and mantle. As molten magma cools, silicate minerals are formed (magmatic differentiation). In the early stages of the cooling, the

silicates tend to be mafic (those that are predominately iron and magnesium rich), and deficient in aluminum, silicon, sodium, and potassium. The mafic rocks are dark in color. As cooling and differentiation progress, the balance tends to reverse, the sialic (containing mostly silicon-aluminum) igneous rocks as formed. They are generally lighter in color or speckled. Radionuclides are present in these rocks in such small quantities as to have little tendency to form mineral in which they would be essential components. Their crystal structures are also not compatible with that of major silicates. As a result of these factors, the remainder of the magma cools to form miscellaneous and varied minor mineral which contain the uranium, thorium and other minor and trace elements.

Mechanical (physical) and chemical processes break rock down into soil. Weathering plays a key role in this process. Where mechanical processes dominate the breakdown, the separation usually occurs along mineral boundaries that leads to a separation of the major silicates from the minor ones containing the thorium and uranium. These minor minerals include zircon and monazite. They are resistant to chemical decay and are often found as small individual grains. Where chemical (or biological) action predominates, the thorium and uranium bearing minor minerals can give up their radionuclides to layers of cations in clay minerals. When the host rocks erode, the radionuclides tend to be separated from the major minerals and can form a localized concentration thereby giving higher radiation counts.

Radiation values are particularly high within Ririwai Sheet 126 especially around the Ririwai Complex where absorbed dose rates in air, dose

equivalents, and effective dose rates have shown values of  $0.088-0.431 \pm 0.035 \mu\text{Gyh}^{-1}$ ,  $0.768-3.764 \pm 0.307 \text{ mSv/yr}$  and  $0.730-3.576 \pm 0.92 \text{ mSv/yr}$  respectively. High radiation values in this area may be attributed to enrichment of radioactive elements within both the peralkaline and non-peralkaline granites that essentially constitute this complex.

The Ririwai complex contains several distinctive lithologies derived from post-metasomatism of granite by a clear sequence of alterations. According to Bowen *et al.*, (1974, 1976), high concentrations of radionuclides occur within the different rock types in this complex. The radionuclides include cesium (Cs), hafnium (Hf), thorium (Th), scandium (Sc), rubidium (Rb), zirconium (Zr), strontium (Sr), yttrium (Y), uranium (U), lanthanum (La), neodymium (Nd), samarium (Sm), europium (Eu), gadolinium (Gd), thulium (Tm), ytterbium (Yb), and lutetium (Lu) among others. They mostly belong to the lanthanide and actinide series, and occur in coarse-grained discrete crystals associated with magmatic quartz or as aggregates of small crystals, which are often aligned along the cleavage of micas, or form complex intergrowths outside the micas.

In this complex for instance, zirconium (Zr) concentration of between 680–3,075 ppm have been reported within the riebeckite granite and albite-riebeckite granite as against an average value of only 235 and 175 ppm within the Jos-Bukuru Complex and the Pankshin Complex respectively (Bowden and Turner, 1974).

The ratio of concentration of the radionuclides found within the Ririwai Complex compared to other complexes such as Jos-Bukuru and Pankshin

complexes as calculated from the result of earlier geochemical analysis by (Bowden and Turner, 1974; Bowden et al, 1976), reveal a value of between 2.8 and 26.75. These factors therefore explain why radiation dose rates are higher within the Ririwai Complex compared to other Nigerian Younger Granite complexes.

Indiscriminate disposal of radioactive mine wastes into the environment also constitutes another radiation problem in the area of study generally. These mine wastes are rich in zircon, monazite and xenotime, and activity concentration of between 3600 to 18,8000 Bqkg<sup>-1</sup> is now known to exist in some places within this area. Mean activity concentration of <sup>40</sup>K, <sup>226</sup>Ra and <sup>232</sup>Th have also been given to be 1251.7 ± 478.3 Bqkg<sup>-1</sup>, 3867.7± 1282.7 Bqkg<sup>-1</sup> and 8301.9±2862 Bqkg<sup>-1</sup> respectively as against a value of 447.0±68.0 Bqkg<sup>-1</sup>, 37.4±7.4 Bqkg<sup>-1</sup> and 115.4±16.7 Bqkg<sup>-1</sup> for normal (non mineral processing) areas for the same radionuclides (Ibeanu, 1999). It can be seen therefore that radiation values from mining and mineral processing sites are quite high.

Mine wastes now find their way into the streams within the area where sands are packed to make blocks for building. Gradually, people are beginning to live in houses with elevated radiation levels and the long term effects could be dangerous. Elevated concentrations of <sup>40</sup>K, <sup>226</sup>Ra and <sup>232</sup>Th in leafy and root vegetables have also been reported around Jos. According to Ibeanu, (1999), daily intake from these plants now stands at 4.42±0.71 Bq for <sup>40</sup>K, 0.46±0.04 Bq for <sup>226</sup>Ra and 0.43±0.04 Bq for <sup>232</sup>Th.

There is the need therefore to protect the environment for adequate health and well being of the people, as well as to conserve and use sustainably the environment and natural resources for the benefit of present and future generations.

### 6.3 CONCLUSIONS AND RECCOMENDATION

Based on the findings from this work, the following conclusions can be drawn as regards the characteristics of natural radiation levels in this area.

i). Radiation levels above permissible limits exists in some places within the study area. High background radiation levels were recorded around the Younger Granite complexes, with highest values obtained within Ririwai Sheet 126 around the Ririwai Complex. Within this topographical sheet, absorbed dose rates in air, dose equivalents and effective dose rates show a value of 0.088 - 0.431  $\mu\text{Gyh}^{-1}$ , 0.768 – 3.764 mSv/yr and 0.730 – 3.576 mSv/yr respectively. These values are much higher than mean absorbed dose rate of  $0.102 \pm 0.032 \mu\text{Gyh}^{-1}$  and average annual outdoor effective dose equivalent of  $130 \pm 41 \mu\text{Sv.y}^{-1}$  estimated for northern Nigeria from radioactivity concentration of  $^{40}\text{K}$ ,  $^{238}\text{Uranium}$  and  $^{232}\text{Th}$  in soils (Farai and Jibiri, 2000). High radiation values within this complex can be attributed to zircon – thorite mineralization and high concentration of rare earth elements within the complex.

ii). While the radiation levels are significantly high within the granites, the basalts found in the study area have low radiation levels and can therefore be used for building construction with little likelihood of radiological hazards.

iii) Evidence of indiscriminate dumping of mine wastes have been seen in most places suggesting lack of proper planning of disposal of such waste. These heaps of radioactive mine wastes are being spread into the environment by agents of erosion such as wind and running water. This will have a long-term impact on the environment as radionuclides may gradually enter the food chain. The following recommendations have arisen from this investigation.

i). Government should do more to raise public awareness on the effects of ionizing radiation so as to help promote understanding of essential linkages between environment and development. Mines wastes as well as rocks with high levels of radiation should not be used for foundation fillings or for any form of building construction.

ii). As much as possible, settlements should be avoided within the areas identified with radiation levels significantly above permissible levels because of the long term effects of ionizing radiation on their health.

iii). Where the use of fresh rock materials for building is inevitable, efforts must be made to ventilate such houses properly to minimize additional radioactivity through the accumulation of radon in such building.

iv). The block industries in major towns in this area should be monitored constantly to ensure that the sands and gravel they use and subsequently the finished blocks maintain low radiation levels.

v). Drinking water and food items should be periodically checked for their radiation levels since they form a pathway through which radioactive materials are ingested into the body.

vi) Government should take steps to stop indiscriminate dumping of mine wastes in the environment. Government should also make effort to take inventories of all existing mine and mineral processing dumps within and around the towns in this area with a view to determining the best way to properly dispose them.

#### **6.4 CONTRIBUTION TO KNOWLEDGE**

From the results presented in this work, the following contributions have been made to the understanding of the nature of natural terrestrial radiation in this region, as well as to knowledge in general.

i). Radiation dose rates are generally high within the Younger Granite province of Nigeria, and the risk of exposure to a dose equivalent of 1mSv/yr and above is high, ranging from 33% to 73%. People living within and around the complexes should therefore limit their outdoor exposures as much as reasonably achievable.

ii). The work has shown that mean absorbed dose rates in air in the study area is  $0.044 \pm 0.007 \mu\text{Gyh}^{-1}$  within the basalts,  $0.119 \pm 0.050 \mu\text{Gyh}^{-1}$  for the basement rocks, and  $0.168 \pm 0.003 \mu\text{Gyh}^{-1}$  within the Younger Granites. This

give an average value of  $0.106 \pm 0.002 \mu\text{Gy h}^{-1}$  corresponding to 0.929 mGy/yr.

This value is higher than the world average of 0.5 mGy/yr.

iii). Geologically, the basaltic parts of this area are the safest in terms of exposure to ionizing radiation from natural terrestrial sources as dose rates are generally about 50% lower than the maximum permissible dose limit. Basaltic rocks in this area can therefore be said to be radiologically safe for use in building.

iv). The radiation maps produced appear to correlate well with distribution of major outcrops shown on the geological map of the area. This observed correlation between radiation maps produced and geological maps of the area of study suggests that natural terrestrial radiation signatures can be used as a tool for mapping regional geological boundaries especially in poorly exposed plains.

v). The work has provided scientific data on levels of natural radiation in the area which could be used by the health authorities to confirm and to plan decisions regarding possible radiation hazards in the area.



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