

**GEOCHEMISTRY OF ROCKS AND SOILS FROM GARATU AREA OF BIDA  
SHEET 184NE IN RELATION TO GOLD MINERALISATION**

**BY**

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## **ABSTRACT**

Geochemistry of rocks and soils in relation to gold mineralization was carried out to study aim to evaluate the geochemistry of the rocks and soils in the Garatu area of Bida Sheet 184NE in relation to gold mineralization. The study area occupies the central portion of the Nigerian basement complex. The geological mapping involved determination of the various rock types and lithology and a systematic grid regional soil sampling points on a scale 1:25,000, while the geochemical study involved determination of bulk chemistry to identify major and trace elements and also the REEs to quantify the gold potentials and other economic minerals in the rock and soil samples. This analyses was carried out at Actlab, Canada. The result of the geological mapping revealed that the area mapped is predominantly of granite intruding the Schist from the north to the south. A total number of 10 soil and 5 fresh representatives of rock samples were carefully collected for geochemical and petrographic analysis. The result of the mineralization potential of the rock and soil samples reveal gold enrichment of 72% and 90.86% respectively. This result indicates significant gold enrichment in the study area. The enrichment however is more viable in the soils which geologically means significant amount of gold have migrated from their primary environment of rock to the secondary environment as in soil.

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## ABBREVIATIONS

E	Easting
N	Northing
EEF	Element Enrichment Factor
GPS	Global Positioning System
KM	Kilometer
PPM	Part per million
PPB	Part per billion
S/N	Serial Number
W	West
INAA	Instrumental Neutron Activation Analysis
ICP-MS	Induced Coupled Plasma-Mass Spectrometry
TD-MS	Total Digestion Mass Spectrometry

**CHAPTER ONE**

### 1.0 INTRODUCTION

#### 1.1 Background of the Study

In nature, gold most frequently appears in its pure form (that is, uncombined). Native gold often contains eight to ten percent silver, but when mixed with silver that is over twenty percent, the result is stibnite ( $\text{AuSb}_2$ ) when associated with antimony, tellurite ( $\text{AuTe}_2$ ) when combined with telluride, and electrum ( $\text{AuTe}_2$ ). Compared to other metals, gold has a lower average concentration in the world, at 0.005 g/t. Primary rocks have low concentrations of gold, thus upgrading is required by a factor of 3000–4000. To obtain commercial concentrations, this is typically the average requirement for ore formation procedures. Using organic gravity concentration techniques or gold leaching using host rock fluids may make this practicable. As a result, by redepositing in a more concentrated form after severely oxidizing, acidic, and complexing (chloride) solutions. Gold tends to

concentrate more in leftover hydrothermal fluids and metallic or sulphidic in the aftermath phases due to its siderophile properties (weak affinities for metals like iron and oxygen, high affinities for metals like iron). Instead of silicates, which represent the early stages of a cooling magma's development the greatest places to look for gold are rocks that contain a lot of clay and little carbonate. Reprecipitation happens when hydrothermal solutions come into contact with a reducing environment, like a place where there is a lot of carbonate, carbon, or reducing sulphide (Wong and Arun, 2009).

All of the halogens tend to react with gold, but bromine reacts with gold powder exothermically at normal temperature to form  $Au_2Br_6$ . Gold has captivated humans in various ways for a large portion of human history. Almost all civilizations have valued, reckoned, and valued this unique metal. Over time, many methods for obtaining this precious metal have changed. The earth occasionally gives clues as to where she might be keeping some gold. Look at the foliage, stream, sediment, and of course the rocks to show some of these natural indicators.

Orogenic gold deposits, which are found in nearby metamorphic terranes, make up the vast bulk of gold deposits in the globe (Babatunde *et al.*, 2020). Only orogenic terranes that formed during compressional to transpressional deformation episodes include these deposits. They have excellent structural control and are frequently found in lithologies ranging from lower amphibolite facies to greenschist facies (Groves, 1998, Goldfarb, 2001, Pirajno, 2009). The ore-bearing fluids, which are typically of low salinity, are produced by the interaction of many processes, including metamorphism, deformation, crustal thickening, de-volatilization of sedimentary wedge during subduction, and circulation of meteoric water. Additionally, syn-orogenic magmatism may have contributed, especially in areas where gold mining is spatially connected to the granitoids

(Groves, 1998, Robb, 2005, Babatunde, 2020). However, ore deposition and In ductile, brittle-ductile to brittle regimes associated with the ore deposit, which often take place at the height of metamorphism and also extend to post metamorphism, carbonate-sulfide-sericite-chlorite alteration occurs (Pirajno, 2009).

### **1.1.1 Gold and rock geochemistry**

This is a crucial resource for mineral exploration. It becomes crucial mostly in places where the primary mineralization is unknown. This work is specifically focused on the geochemical investigation of gold concentration in the soil and rock of the research area utilizing field mapping and gravity concentration. Unlike silver, which is chalcophile, gold has a significant siderophile geochemical feature (Stefan, 2009). As a result, the average amount of gold in iron meteorites is 1ppm, but only 0.004ppm of it is found in the Earth's crust (range 0.001–0.005 ppm). However, fractionation of felsic melt may result in economically viable gold concentrations. Gold concentrations in magmatic rocks show positive correlations with Fe and S. A number of minerals, such as sulfides, biotite, pyroxene, magnetite, and hornblende, host trace gold in magmatic rocks. Gold is liberated from source rocks under the direction of these minerals' dissolution behavior; Sulphides presumably dissolve first in flowing fluids. Gold is concentrated in sediments like sandstones and conglomerates containing 0.03 ppm of Au on average, coal ashes 0.1 ppm, and black shale 2 ppm. Arsenian iron sulphides in the mid-oceanic ridges concentrate gold and silver (28–140 ppm Au, 800–2400 ppm Ag). The grades of Cyprus Type deposits are coming very close to 8 ppm Au. Gold and silver can substitute for one another in many minerals due to similar ionic radius and charge, and the crustal gold/silver ratio is 1:20. Unlike silver, which forms sulfides, gold enters a variety of uncommon sulphosalts with metals including antimony, selenium, and bismuth.

### **1.1.2 Gold and soil geochemistry**

According to researches, alluvial and eluvial deposits, which were produced by primary gold mineralization in the basement rocks of the schist belts, account for 90% of all of Nigeria's gold production (Wanduku, *et al.*, 2021). Gneisses have also been found to have a few gold-quartz veins (Hawkes and Bafor, 1983). The distribution of gold in Nigeria is not random; instead, it is governed by the geological conditions, which are outlined by various orogenic cycles and tectono-structural boundaries, (Kankara, 2017) reported that pyrite, magnetite, quartz, tourmaline, and chlorite are linked to gold mineralization in the Maru schist belt. It is claimed that the host rocks, which include quartzite, mica-schist, phyllites, and contact aureoles of tonalities, are connected to subordinate fault systems via sub-parallel shear zones that are definitely along anticlinal axes. In terms of geochemistry, gold is widely known for being a relatively immobile element in the surface environment. Because of this, it might be difficult to evaluate the geochemical surface signal of gold occurrence. However, given specific physical and chemical circumstances, epigenetic gold may become mobile and disperse from the surface, leading to geochemical gold anomalies at the surface. The highly flexible, robust particles that make up gold frequently result in poor sample representations and inconsistent analytical results.

In order to purify their local surroundings, some bacteria (including *Ralstoniametallidurans*) decrease and gold from a soil solution, either intracellularly or extracellularly. From placers and weathered Au deposits, bacterioform Au particles have been identified. Chemical and nanoparticulate mobilization and reprecipitation as bacterioform Au particles are made easier by the stimulation of secondary Au formation and development by bacterial biofilms. When compared to primary gold, secondary gold frequently has less contaminants because Ag, Cu, and Hg are more soluble in solution. Placers that contain transported gold include identifiable submicroscopic opaque mineral

inclusions that can be linked to particular genetic types and even ore areas. By the way, this is one of the defenses used against dissolved mobile gold's ability to form nuggets. It was already determined that the most popular variety of Gold is referred to as "black sand." Recent studies have shown, however, that black sand does not completely confirm the existence of gold; rather, it merely shows that the soil contains numerous minerals and heavy metals, with gold being the most significant of all of them. Gold is one of the heaviest materials known to man; it weighs nearly 19 times as much as water, therefore any gold transported in a stream will fall first. Black sand weighs heavier than most other materials even though it is not as heavy as gold, which is more than three times as heavy as the iron that makes up the majority of it. One of the rarest elements is gold, along with platinum and rhenium. Surprisingly, there are numerous, geographically widespread gold resources. Clearly, mobilizing, transporting, and concentrating gold may be accomplished by very common crustal fluids. Metamorphic and magmatic fluid systems are responsible for the formation of many primary gold deposits. Examples of this include numerous gold deposits that formed in orogenic belts from considerable volumes of crustal rocks with a characteristic geochemical background. All significant gold deposits belong to a type known as "orogenic gold deposits," which are intimately tied to magmatic activity and single districts that originated in brief intervals of 5–20 My (Sillitoe 2008). Weathering and soil formation create secondary gold deposits.

The proportion of gold grains in the mineral fractions or the two basic techniques for gold prospecting in soil are the concentration of both major and trace (Pathfinder) elements in the sample.

## **1.2 Statement of the Problem**

The previous works that had been done in the study area by previous authors have mainly focused on petrology of the rocks, with no mention of the gold mineralization potential of the area. This research is aimed at identifying the gold mineralization and its associated elements using soils and rocks.

Artisan miners waste too much resources, energy and time and end up getting little. However, their presence at the area indicates the presence of gold. As the world's population grows, so does the demand for gold, which has prompted more corporate entities and private investors to invest in the gold mining industry. However, compared to the enormous expenditures of expeditions, the material collected at each end is frequently negligible. Many mining sites in Nigeria have been abandoned as a result of this phenomena, and in many cases they have been turned over to artisanal miners who, in the absence of baseline data to act as guidelines, resort to their standard trial-and-error mining method while operating "blind."

## **1.3 Justification for the Research**

The eventual development of the deposit will be a pointer and similarly focus the area's gold deposit hunt. The acquired data from this study will help maximize the resources, time and energy for both professionals and artisan miners in evaluating the gold viability of the study area.

Hereon is an illuminating analysis of the Garatu area's gold mineralization potential in such a manner that will benefit academics, policy makers, practitioners and even the layman. There are now little records that outline the thorough baseline exploration data on the country's gold mineralization, despite the immense interest that many people have in investing in the mining industry.

## **1.4 Scopes of the Study**

This study is on the Gold mineralization potential of the Garatu area of Bosso Local Government Area of Niger State using soils and rocks of the area with field geological mapping of the study area on a scale of 1:12,500 utilizing the sampling of the soils and rocks of the area. Soil samples were taken from horizon B, which is 50–60 cm beneath the surface (Fe-rich layer). Sledge hammer was used to take fresh representation of rock samples, and permanent marker was used to label the samples. Each sample location's coordinates was recorded using the Global Positioning System (GPS). Studies on the potential for gold mineralization using minerals and elements. Mineral contents of the rock was determined using thin section petrographic examinations.

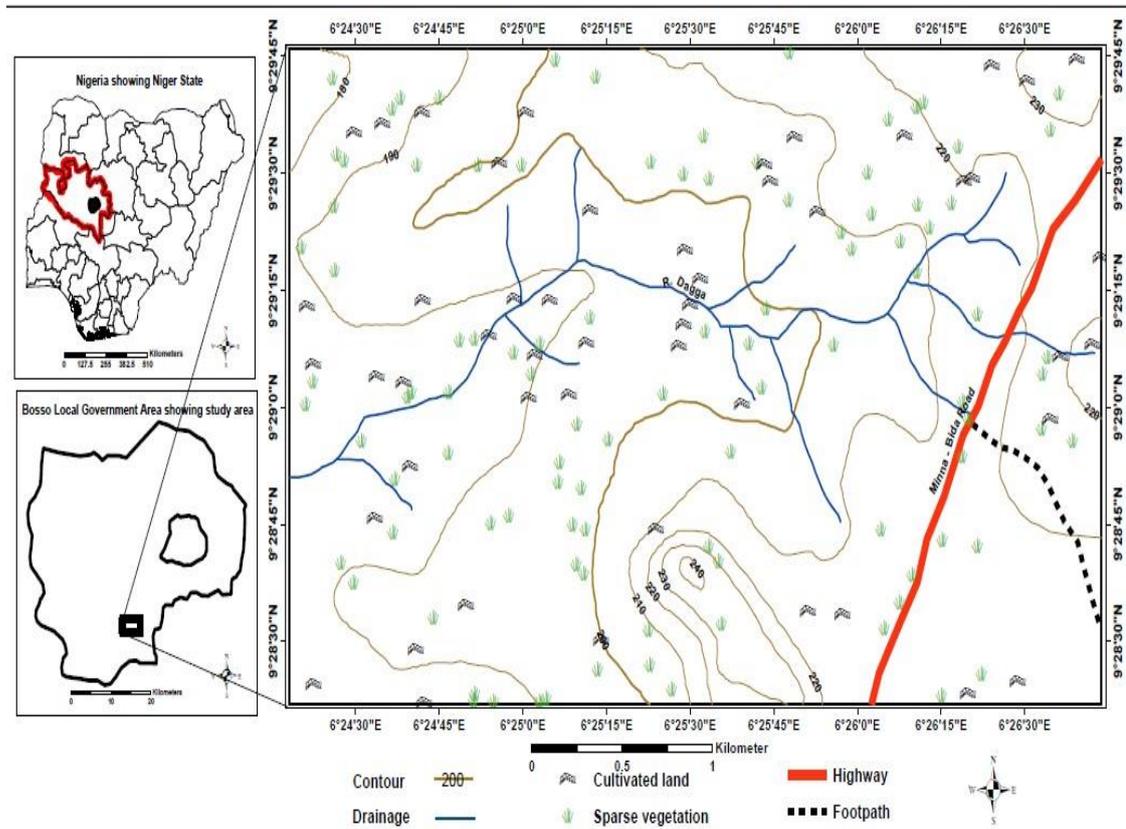
## **1.5 The Study Area**

### **1.5.1 Location, area extent and accessibility**

The study area lies within Garatu area of Bosso Local Government Area of Niger State, it is part of the Bida sheet 184NE. The study area is located between latitude

09<sup>0</sup>28'30.00"N and 09<sup>0</sup>29'45.00"N and longitude 006<sup>0</sup>24'30.00"E and 006<sup>0</sup>26'30.00"E

(Figure 1.1) It takes up the majority of the space in the Nigerian basement complex. The Minna-Bida trunk A road provides access to the area. The outcrops' placement is improved by the road.



**Figure 1.1 Topographic map of the study**

### 1.5.2 Climate and vegetation

The dry and wet seasons are two separate seasons that are experienced in Niger State. From roughly 1,600mm in the south to 1,200mm in the north, Rainfall fluctuates throughout the year. The rainy season lasts between 150 and 210days or more from the north to the south.

The average maximum temperature is consistently high throughout the year, but in particular in March and June it is about 32°C. But the state normally has the lowest minimum temperatures during December and January, when the majority of the state is impacted by the tropical continental air mass that blows from the north. In Niger State, the dry season starts in October.

The state's whole landscape is covered in southern guinea savannah vegetation. Woodlands and tall grasses mixed with tall, dense flora are its defining features, same like other states with similar vegetation. The Niger trough and flood plains, however, have taller trees and a few oil palm trees. Rain forest species can still be seen in some places.

### **1.5.3 Relief and drainage**

The research region is mostly level, has few rocky outcrops, and is on average 192 meters over sea level. In the north and east region, seasonal stream systems drain the land. The extensively weathered granite and metasediment rocks that make up the outcrops must have originated as a result of the weathering of granite into sediment and subsequent metamorphosis to schist. They must have spent a considerable portion of geologic time hidden beneath the earth's surface due to weathering and erosion. The numerous seasonal stream channels in the mapped area serve as evidence that water is the primary cause of weathering and erosion. The current state of the rocks and their surroundings is a result of the rocks having been exposed to varied temperature conditions as well as numerous mechanical, chemical, and biological surface processes. Seasonal streams and rivers that drain the area well serve as suitable avenues for the exposed rocks along their paths. Clayey to sandy clay is the most common type of soil in the area.

### **1.5.4 Settlement and land use**

Most of the residents of this area are small-scale farmers. During the rainy season, they typically plant food crops such yams, guinea-corn, maize, millet, melon, and vegetables.

The artisans also mine for gold using the resources found on the property.

## **1.6 Aim and Objectives of the Study**

This study aim to evaluate the geochemistry of the rocks and soils in the Garatu area of

Bida Sheet 184NE in relation to gold mineralization.

This aim was achieved using the following objectives

- i. Field mapping at a scale of 1:12,500 and collection of soil and rock samples
- ii. Carry out Thin Section Petrography.
- iii. Analysis of the soil and rock samples for bulk chemistry.
- iv. Assess of the gold mineralization potential and other economic minerals on the environment.
- v. Production of a map of the study area's geology.

## **CHAPTER TWO**

### **2.0 LITERATURE REVIEW**

#### **2.1 General Geology of Nigeria**

The Basement Complex, Younger granite, and Sedimentary basins are the three main lithological components that make up Nigeria's overall geology. The Nigeria Basement Complex is a prominent feature of the Pan-African mobile belt, which extends south of the Tuareg Shield and between the West African and Congo cratons. the calc-alkaline Mesozoic The basement Complex is invaded by younger granites from the Jos Plateau and is unevenly covered with Cretaceous and more recent rocks. The Nigeria Basement is located in the region that was recently energized as a result of the plate collision between the inactive continental margins of the west African cratons and the pharusian continental

margin. It was impacted by the 600Ma Pan-African orogeny (Obaje, 2009). The Liberian (2,00 Ma), Eburnean (2,000 Ma), Kibaran (1,100 Ma), and Pan-Africa cycles, which are believed to have created the basement rocks are deformation, metamorphism, and remobilization, which account for the four main orogeny cycles (600Ma).

The first three cycles, according to explanation, created syntectonic granite and homogenous gneiss as a result of substantial granitization and gneissification, as well as strong deformation and isoclinal folding (Obaje, 2013). Granite and granodiorites were tectonically positioned late during this last deformation, along with contact metamorphism. The orogeny's end was marked by faulting and cracks (Obaje, 2013). Four significant petro-lithological units can be distinguished within Nigeria's Basement Complex, namely;

i. Migmatite Gneiss complex (Migmatite, Gneisses, Granite-Gneissess); ii. Schist Belts (Metasediment and Metavolcanic rocks); Phillites, schists, pelites, Quartzite, Marbles, Amphiboles; iii. Older Granites (Pan-Africa, Granitoids) Granites, Granodiorites, Syenites,

Monzonites, Gabbro, Charnokites; and iv. While the undeformed Acid and Basic Dykes include Muscovites,

tourmaline and Beryl-bearing Pegmitites, Aplites and Syenitesdykes; basaltic and Lampropyric dykes.

According to (Adeoti and Okonkwo, 2016), the evaluation of the geological and structural evolution on the Basement complex of Iwaraja area of South-Western Nigeria revealed that basement rocks are composed of granitic rocks that have undergone two periods of

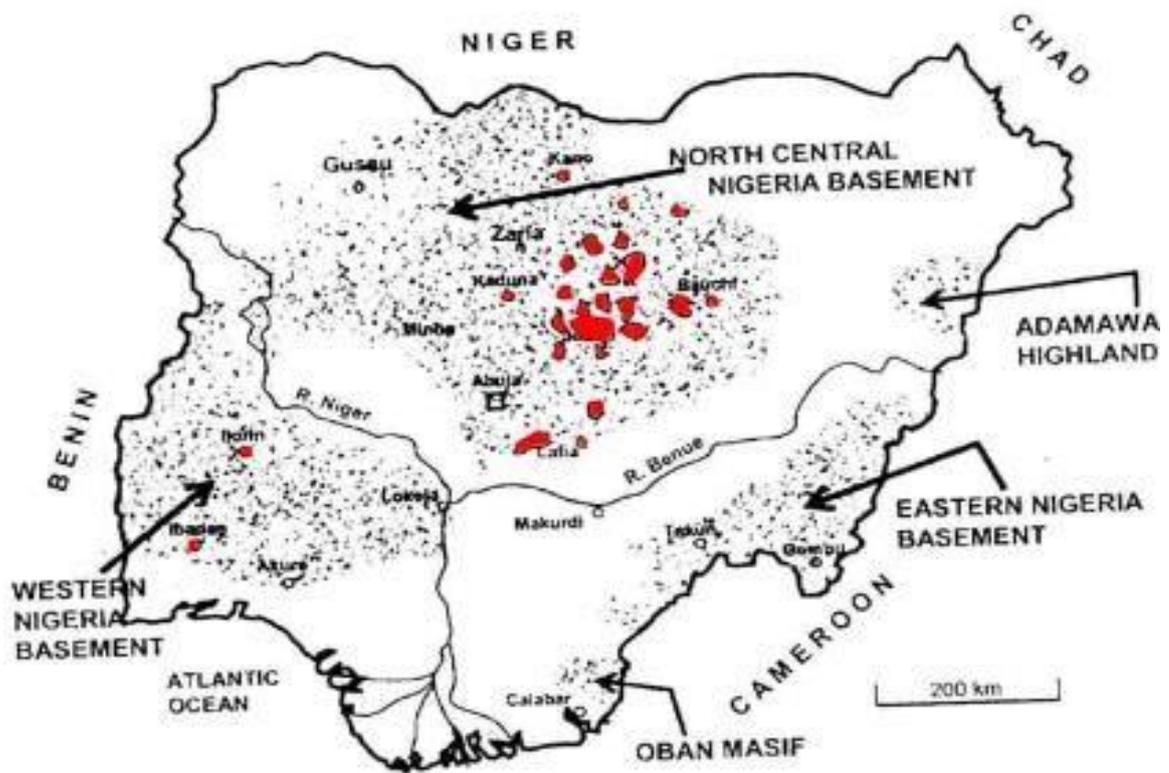
deformation, including late and post-tectonic rocks like prigmatites. These rocks include quartzites and quartzschists of the Effen Psammite Formation, quartzmica schists, biotite schists. According to certain theories, the first phase largely a fabricforming deformation with a small amount of mineral lineation that was sinking. Minor fold has almost no traces. The Iwaraja (ductile) shear zone developed as a result of the second phase deformation.

## **2.2 The Basement Complex**

Nigeria's geology is composed of three main litho-petrological components. (Figure 2.1). The Pan-African Mobile Belt includes the Nigerian Basement Complex, which is south of the Tuareg Shield and positioned halfway between the Congo and West African Cratons (Black, 1980). It is unconformably covered by Cretaceous and Younger sediments, which are intruded by the Mesozoic calc-alkaline ring complexes (Younger Granites) of the Jos Plateau (Figure 2.2). The 600 Ma Pan-African orogeny had an impact on the Nigerian Basement, which is located in the reactivated zone created by plate collision between the West African craton's passive continental margin and the active Pharusian continental margin (Obaje, 2009).

At least four main Orogenic cycles of deformation, metamorphism, and remobilization—the Liberian (2,700 Ma), Eburnean (2,000 Ma), Kibaran (1,100 Ma), and Pan-African cycles—are thought to have produced Basement rocks (600 Ma). Intensive deformation, isoclinal folding, regional metamorphism, and significant migmatization are claimed to be characteristics of the first three cycles. The Pan-African deformation that created syntectonic granites and homogenous gneisses was accompanied by regional metamorphism, migmatization, broad granitization, and gneissification (Abaa, 1983). The latter stages of this last deformation were accompanied by contact metamorphism and the

late tectonic emplacement of granites and granodiorites. Faulting and fracture indicated the end of the Orogeny (Obaje, 2009).



**Figure 2.1: Basement Geology of Nigeria (After Obaje, 2009)**

Nigeria's basement complex contains four significant petro-lithological units.

1. The Migmatite – Gneiss Complex
2. The Schist Belt (Metasedimentary and Metavolcanic rocks)
3. The Older Granites (Pan African granitoids)
4. Undeformed Acid and Basic Dykes.
2. The Schist Belt (Metasedimentary and Metavolcanic rocks)
3. The Older Granites (Pan African granitoids)

#### 4. Undeformed Acid and Basic Dykes.

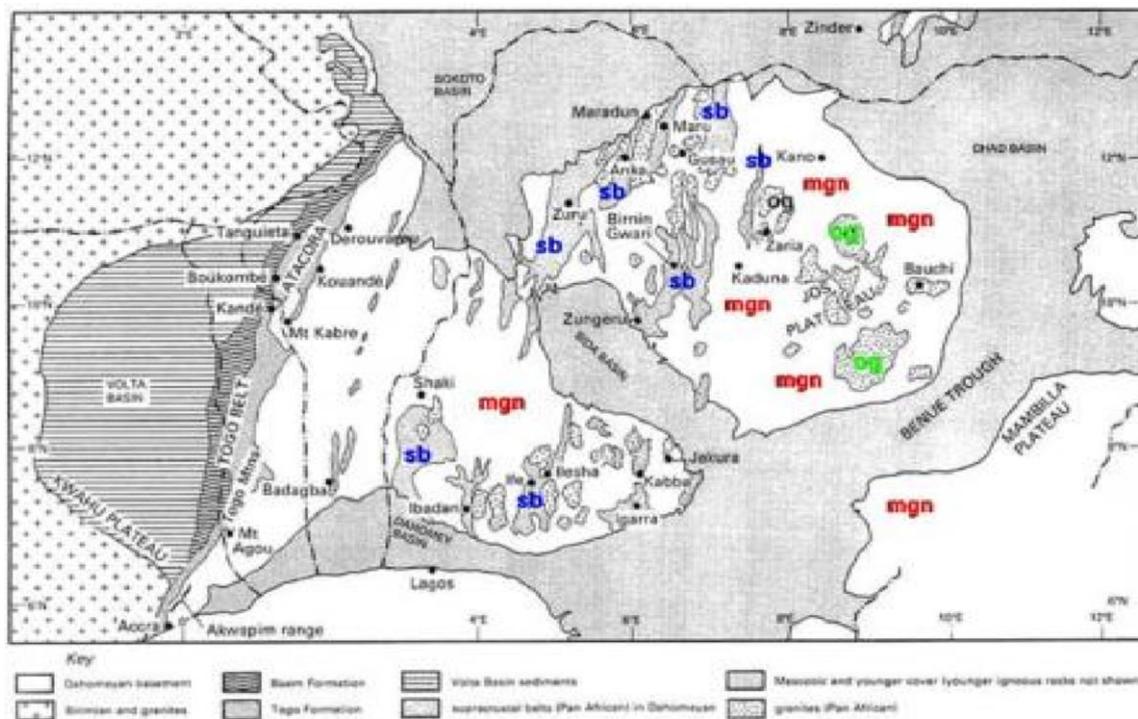
##### **2.2.1 The migmatite-gneiss complex**

According to Obaje (2009), the Migmatite-Gneiss Complex is the most prevalent of the component units in the Nigerian Basement and is typically referred to as the basement complex *sensu stricto* (Figure 2.3). The lithology of the complex, which includes migmatites, orthogneisses, paragneisses, and basic and ultrabasic metamorphosed rocks, is heterogeneous. The migmatite gneiss complex was thought to have undergone considerable petrographic removal, which caused the majority of its constituent minerals to recrystallize. The partial melting of the pre-existing rocks may be the source of this. For this complex, a Pan-African to Eburnean age was determined.

It may be referred to as the "Migmatite-Gneiss-Quartzite Complex" by a couple of writers. It occupies about 60% of the floor space in the Nigerian basement. (Obaje, 2016). The earliest important geologic event, which took place at 2,500 Ma, involved the start of activities that would create crust (e.g. the mantle-derived banded Ibadan grey gneiss) ages between 900 and The Pan-African event left its mark at 450 Ma, which is evident on structural overprint and reset numerous geochronological clocks in older rocks, but also gave birth to the granite gneisses, migmatites, and other similar lithological units. The Eburnean, which is 2,000–200 Ma old, is characterized by the

Ibadan type Granite Gneisses. It is interesting how closely the Birrimian of the West African Craton formation resembles it in terms of time. Rocks in Nigeria of the same age are, however, only extremely sparingly, if at all, mineralized, despite the fact that manganese, gold, and iron mineral concentrations are linked to Birrimian rocks.

Comparatively little is known about the quantity of Eburnean and older rocks in Nigeria. The existence of these rocks in the area south of latitude 9°N is indisputable from geochemical analysis. However, it has been demonstrated lithologically, particularly in Nigeria's northeast and southeast, that identical rocks only represent PanAfrican ages (Obaje, 2009).



**Figure 2.2: Basement Geology of Nigeria: The Migmatite-Gneiss Complex (mgn), the Schist Belts (sb) and the Older Granites (og) (Modified after Wright, 1985).**

### 2.2.2 The schist belt

The majority of the Nigerian Schist Belts are low grade, N-S trending belts with a predominance of metasediments, which are most developed in Nigeria's western region. Since these belts have been folded into the migmatite-gneiss-quartzite complex, they are regarded as Upper Proterozoic supracrustal rocks. The lithologies present in the schist belts include phyllites, peliticschists, banded iron formation, carbonate rocks (marbles/dolomitic marbles), and mafic metavolcanics (amphibolites). Ocean floor debris from minor back-arc basins are most likely among them. According to (Obaje,

2016), the Schist Belts were thought to be remnants of a single supracrustal cover, but (Obaje, 2016) suggests that there were many deposition basins. Another study also suggested that the Schist Belts are fault-controlled rift-like formations. According on structural and lithological associations, different ages of sediments have been hypothesized. Some publications, however, challenged these claims by presenting evidence to the opposite, demonstrating that both series featured the same deformational histories. It was accurate to say that the conformable metamorphic fronts served as the structural links between the Schist Belts and the Basement. The rocks of the Schist Belt are typically regarded as Upper Proterozoic. Even so, there have been some serious disagreements regarding the geochemistry of the amphibolite complexes found in the Schist Belts. According to some, the Ilesha belt might be a greenstone belt from the Archaean period. While others supported the idea that the evolution of the Schist Belts was predominately ensialic. The distribution of primary gold occurrences in some belts but their notable absence in others may suggest that they do not represent a single supracrustal sequence, and the apparent lack of subduction-related mineral deposits may be suggestive of a limited role for ensimatic processes, are some metallogenic characteristics of the Schist Belts that are relevant to these issues. Most of the Nigerian

Schist Belts are located in the country's western region. west of 8E longitude, with infrequent but substantial occurrences in the eastern portion. Only a 300 km wide, NEtrending zone has schists. The gneisses and migmatites that make up the Dahomeyan predominate in the area to the west of this zone. comparable to the west, there are no known schist belts to the east for 700 km, with the exception of Cameroun, where the Pan-African granite-migmatite terrain to the north of the Congo Craton has a number of schist belts estimated to be Upper Proterozoic in age. The schist belts in Nigeria that have been extensively examined and mapped include those in the following locations: Anka, Maru, Zuru, Kazaure, Kuseriki, Kushaka, Zungeru, Iwo, IsheyinOyan, and Ilesha (Figure 2.4), where it is revealed that they are typically linked to gold mineralization. The Kushaka Schist Belt is where the research region is located, thus that is where most of the focus will be.

#### ***2.2.2.1 The Kuseriki Schist Group***

Several works by various authors were conducted in the northern Nigerian district of Kuseriki in an effort to further divide the Nigerian schist belts. Somewhere in Zungeru.

**There are four formations in the Kuseriki Schist Group:**

1. The Kuseriki Psammite Formation at the base of the succession;
2. The Kushaka Schist Formation;
3. The Zungeru Granulite Formation and;
4. The BirninGwari Schist Formation at the top.

Lithologically, the Zungeru-BirninGwari Schist Belt refers to the area where the Zungeru-Granulites Formation and the BirninGwari Schist Formation meet to create a single structural unit. It is a straightforward N-S syncline that is between 150 and 200 km long, with the northern portion being deviated extraordinarily by a NE-SW trans current fault. On both of the Schist Belt's sides, outcrops of the Zungeru Granulite Formation may be seen. It is primarily composed of amphibolites and some quartzites interbedded with fine- to medium-grained quartzo-feldspathic rocks.

The Birnin Gwari Schist Formation is located along the Schist Belt's synclinal axis. Finely banded phyllites, which predominate in the lower section of the west, towards the east are followed by higher grade biotite-muscovite schists. The Durimi pebbly schist, a conglomerate of metamorphosed mudstone with some impure quartzite or metagreywacke strata, lies on top of them. Numerous curved Schist Belts are created by the Kushaka Schist Formation and are divided by Gneiss domes and anticlines. In terms of lithology, structure, and igneous connections, they diverge from the Zungeru-BirninGwari belt. Semi-pelitic biotite-muscovite schist is the most common form of rock, with garnet and staurolite

present in some areas. Phyllites, metasilstones, and graphitic schists are examples of other rocks. The Schists are interbedded with several substantial units of banded garnet grunerite iron deposit. Numerous amphibolites, amphibole, epidote, chlorite, and talc-bearing Schists are related to tholeiitic basalt at least in part. Amphibolites are extremely thick in some places, indicating significant volcanic accumulations. The straight Zungeru-BirninGwari Belt contrasts with the curved Kushaka Schist Belt. It was proposed that the Kushaka Schist Formation's lower scale features reveal its more extensive and intricate past. The link between the ZungeruBirninGwari and Kushaka Schist Formations and Pan-African granite plutons is another significant distinction between the two schist formations. Granites indeed intrude both the Zungeru and BirninGwari Formations, but they only reach the outermost portion of the BirninGwari Schist Belt; there is no granite intrusion in the middle. In contrast, granite, granodiorite, and syenite plutons abundantly invade the Kushaka Schist Belts, frequently penetrating the Belts' axial zone. According to estimates, the Kuseriki Schist Group dates to the Kibaran period (1,159 70 Ma).

### **2.2.3 The older granites (pan african granitoids)**

In order to identify the deep-seated, frequently concordant or semi-concordant granites of the Basement Complex from the high-level, very discordant tin-bearing granites of Northern Nigeria, Falconer coined the term "Older Granite" in 1911. The migmatitegneiss-quartzite complex and the schist belts are both cut by the Older Granites, which are thought to represent pre-, syn-, and post-tectonic rocks. Both their age (750-450 Ma) and composition show extensive merging. They depict the Pan-African orogeny's diversified and extensive (750–450 Ma) magmatic cycle. This suite of rocks includes tonalites, diorites, granodiorites, genuine granites, and syenites, with a variety of compositions in between. An significant rock group that was deposited during this time is the Charnockites. They typically include high-level invasions, and anataxis has been

crucial (Kankara, 2017). Although the thermal effects may have contributed to the remobilization of mineralizing fluids, the Older Granites suite is notable for the general lack of accompanying mineralization.

Orogeny and add a considerable amount of materials to the crust, up to 70% in some locations (Olusiji, 2013). The attempt to categorize the Older Granites according to timing during an orogenic event was only applicable for close-proximity events. The

Older Granites suite's contact characteristics point to the coexistence of many magmas. On the AFM diagram, granites are classified as calc-alkaline rocks by composition and, while having a substantial amount of alkalis, are frequently slightly corundum normative. In addition to their age, which was not known when they were given the name Older Granites, it was suggested that the word "Pan African Granitoids" be used for the Older Granites because it encompasses several significant petrologic groups that were produced at the same time. (Olusiji, 2013) discarded the previous classification of members of the Older Granites suite on the basis of their texture, mineralogical composition, and the relative timing of their emplacement. Biotite granites, biotite muscovite granites, syenites, chnockites, serpentinites, and anorthosites are the granitoids that outcrop with the schist belts, primarily in northwestern and southwestern Nigeria. Members of the Older Granite suite were instead categorized as follows, primarily based on a textural characteristic:

1. Migmatitic granite;
2. Granite gneiss;
3. Early pegmatites and fine-grained granite;
4. Homogeneous to coarse porphyritic granite;

5. Slightly deformed pegmatite aplites and vein quartz; and

6. Undeformed pegmatites, two-mica granites and vein quartz.

Particularly in the eastern section of northern Nigeria, Pan-African granites are beginning to develop in greater abundance. While Pan-African Granites are isolated intrusions in the area west of Zaria, intrusive granites and associated rocks cover migmatite relics in the area between Rahama and the Mesozoic and Cenozoic periods. Elongate batholithic sheets that are partly concordant and foliated made composed the earliest "syntectonic" group. The second type, referred to as "late tectonic," consists of poorly foliated discordant masses that are abundant in mafic xenoliths and have a smaller percentage of potash feldspar.

The Pan-African orogeny's broad mobilization and reactivation of older Basement Rocks is thought to have produced the late granites. The Migmatite-Gneiss Complex and the Schist Belts, into which they normally intruded, are closely linked by this Older Granites. Therefore, older Granite rocks can be found in most areas where Migmatite-Gneiss Complex or Schist Belt rocks are present. However, the Wusasa (Zaria), Abuja,

Bauchi, Akwanga, Ado-Ekiti, and Obudu regions are notable for their older granites. The majority of older granite rocks are found in Bauchi area and some areas of southwestern Nigeria as dark, greenish-gray granites with substantial amounts of olivine (fayalite) and pyroxene coexisting with quartz, feldspars, and micas. It is thought that the late granites are the results of extensive The Older Granites in these regions are known as Oyawoyite (after Professor Oyawoye who first mapped them) and Bauchite (in the Bauchi area) for its unique composition. The charnockitic rocks (Charnockites) of the Basement Complex are made up of the Bauchites and Oyawoyites.

### **2.3 Geology of Niger state**

The geology of Niger State, where the study area is located, is a part of the overall geology of Nigeria, which is made up of crystalline basement rocks in the west that are relatively older than 2.2 billion years and ancient igneous and metamorphic rocks that were formed in the Precambrian's late Archean and Proterozoic eons, which cover about 75% of the northeast and 25% of the southwest, respectively (Schluter, 2006). The parent rocks are identical to those that have been characterized in other regions of the nation that are mostly underlain by the Basement Complex rocks. The crystalline rocks in the Niger state Basement Complex, which range in composition and structure, include migmatite, quartz, and gneisses. Intruded into the metamorphic terrain of Birnin-Gwari, Kesheriki, Ushama, and the Kushaka in the area's northern half are metasedimentary and meta-volcanic rocks, including diverse schistone rocks and earlier granite suites (Mahmud, 2017). Gold mineralization has been recognized as being related to the schist Belts (Obaje, 2009).

### **2.4 Previous Geology Work**

Ajibade and Woakes (1987) conducted a thorough investigation on the Proterozoic crustal development in Nigeria's Pan African Regime, which encompasses the research area. It stated that magmatic injection into low-grade schist had caused the migmatite to form along the Minna. Which can both be equally described by the two types and generations of pegmatite: the one created by anatexis and likely developed earlier during the Eburnean, and the Pan Africa Migmatite formed by magmatic injection into low-grade schist belt during the emplacement of Pan Africa granites. The Federal University of Technology, Minna's Geology Department faculty and students have conducted several field studies in the area throughout the years, resulting in additional and ongoing geological information. The authors carried out 1: 100,000 scale geological mapping of some areas in the state, particularly the geological contact zones. These studies were utilized to reinterpret parts of the lithology and rectify the geological boundaries (Idris *et al.*, 2015).

## **2.5 Gold Mineralization**

According to geology, saltwater and minerals with a gold content of up to 85% are the principal geological sources of elemental gold. A significant amount of gold in solution is found in the oceans, but estimates vary depending on the geological perspective and, of course, the location of the samples. Gold content in samples has been found to range from as little as 0.1 to as much as 2.0 ppb by weight. (Ibrahim, *et al.*, 2019) The Atlantis 2 Deep has gold concentrations of between 5 and 10 ppm in the top 10 meters of sediment. Sadly, due to the vast amounts of water involved and past failures, attempts to extract gold from seawater on a commercial scale have been unsuccessful. Ion exchange, however, seems to provide the research's best current path. The oceans must be considered as a major potential gold supply because salt, bromine, and magnesia are frequently extracted from seawater. On the basis of their affinities for metals, sulfides, silicates, or gas phases, element relationships are broadly categorized.

## **2.6 Host Rocks for Gold**

Metamorphic and magmatic fluid systems are the most frequent sources of primary gold deposits, which are confirmed by several geological illustrations. This assertion has been supported over time by thousands of gold deposits that developed in orogenic belts from significant quantities of crustal rocks with a typical geochemical background. Orogenic gold deposits are referred to as this group and are thought to be the end result of a crustal-scale massive flow of aqueous-carbonic metamorphic fluids as well as of more localized magmatic-hydrothermal fluids during orogeny. The majority of main gold resources were formed in collision and subduction zones. Since the American Cordilleras are made up of isolated districts that originated over relatively brief periods of time (5–20 My), practically all significant gold deposits are tied to magmatic activity there. Placer deposits of gold are

produced as a result of erosion, transport, and sedimentation, as well as weathering and soil formation. The following are the more prevalent genetic categories of gold deposits:

1. IOCG deposits, copper-gold porphyries, polymetallic skarn, part of shale- or turbidite-hosted gold deposits, magmatic-hydrothermal (Quartz veins, Stockwork orebodies, Breccia pipes and brecciabodies, Carlin type deposits),
2. Metamorphic local redistribution, concentration and recrystallization of gold;
3. Ortho-magmatic by-product gold in sulphide ores formed from segregated sulphide liquid;
4. By-product gold in submarine exhalative deposits (VMS and Sedex);
5. Volcanogenic epithermal and hot springs deposits;
6. Including orogenic deposits (apart from the magmatic-hydrothermal portion of the category) and shale, or deposits hosted by turbidite; Metamorphic hydrothermal quartz veins, vein stockworks, replacement, and disseminated orebodies;

## **2.7 Gold Prospection Methods**

The development of Nigeria's mineral resources has benefited greatly from prospectors. The necessity for copper for utensils, lead for bullets, and iron for tools and weaponry has led to a quest for the sources of these metals since the first settlements. Much of the expansion in the West between 1850 and 1910 was spurred on by the allure of gold and silver. Later, when the nation's industrial needs for metals grew to include zinc, molybdenum, tungsten, chromium, vanadium, and many others, prospectors began looking for and discovering these as well. It is incorrect to assume that rocky, uninhabited mountains or barren deserts have never been prospected; they most likely have.

### **2.7.1 Geochemical prospecting**

The foundation of geochemical prospecting is the systematic determination of the chemical composition of rocks, soils, glacier debris, stream sediment, water, and plants. The concentration of a crucial trace element is the chemical property that is most frequently tested. The prospector may be led to the elements in the rocks or soils that create a geochemical anomaly by zones in the soils or rocks with relatively high, or anomalous, concentrations of specific elements (different from normal). If the concentration of the sample is high in comparison to the concentration of the surrounding area, the actual amount of the crucial element in the sample may be extremely small but still constitute an anomaly. When the majority of soil samples are discovered to have silver concentrations of less than 0.00001 percent (0.1 parts per million, or ppm), but a few of them have concentrations of up to 0.0001 percent (1 ppm), these few "high" concentrations are actually geological anomalies. Maps with plots of analytical results may show areas that need more investigation.

Anomalies in geochemistry are categorized as primary or secondary. Primary anomalies are caused by the elements' dispersion outside of mineral-forming solutions. High metal concentrations surround the deposit, and metals may be distributed laterally or vertically via cracks or faults, creating a "halo" around the deposit. Because they can be hundreds of times larger than the deposit they surround and are therefore simple to find, haloes are particularly helpful in prospecting. Secondary anomalies are the result of the elements' dispersion due to weathering. Some fundamental minerals, like gold or cassiterite, are impervious to chemical weathering and are carried by streams as broken-down debris.

### **2.7.2 Wet chemistry methods**

For use in geochemical prospecting, analytical methods have been developed for a variety of elements. These range from really straightforward processes that may be carried out outdoors, to more complicated processes that can be completed in an appropriately equipped laboratory while camping.

The best place to perform more complex analyses is in a well-established laboratory, especially for those involving risky chemicals or difficult techniques. The output of laboratory methods is typically comparable to that of camping methods, but they must be carried out appropriately by a qualified chemist.

Instrumental methods. Emission spectrographs, atomic absorption spectrophotometers, and X-ray spectrographs are the instruments most frequently employed for large-scale prospecting because they enable fast identification of the majority of elements. Both U.S. Geological Survey Circular 948 (Phillips and Evans, 2004).

The employment of emission spectrographic techniques is very common, and they have the specific benefit of providing findings for at least 40 to 60 elements in each sample. The analysis is carried out by heating a sample with an electric arc or spark, which excite the atoms of the elements in the sample and cause them to emit light. This light is scattered by a prism or diffraction grating into a spectrum that has lines with distinct wavelengths that are specific to different elements.

### **2.7.3 Geophysical prospecting**

In order to help the prospector search for both mineral and energy fuel reserves, geophysical prospecting combines the geological and physics sciences. The use of

magnetic surveys to find iron deposits and scintillation counters to find radioactive uranium deposits are two well-known examples.

In mineral exploration, the five main geophysical techniques—gravimetric, geoelectric, radiometric, and seismic—are frequently used. While some of these approaches and techniques are very straightforward and affordable, others require the use of sophisticated instruments, advanced ways of data processing, and complicated methods of data interpretation.

#### **2.7.4 Magnetic prospecting methods**

The intrinsic magnetic qualities of some minerals, such as magnetite, provide the foundation of magnetic prospecting. The needle in a compass exhibits irregular behavior when it is placed next to a rock that contains magnetite because the magnetic field of the boulder distorts the Earth's magnetic field. Magnetism in rocks that contain the minerals pyrrhotite (iron sulfide) and magnetite (iron oxide) is typically strong enough to be detected by sensitive magnetic instruments.

Gamma is the most widely used unit for describing the strength of a magnetic field. The intensity of the Earth's magnetic field in the contiguous United States varies from a low of around 48,000 gammas in Texas and Florida to a high of about 60,000 gammas in Minnesota when it is not disturbed by highly magnetic rocks.

#### **2.7.5 Geoelectric prospecting methods**

The main idea behind electrical prospecting is that different minerals and rocks have varying degrees of resistance to the flow of electric current. When measured in ohmmeters, the electrical resistivity of rocks can range from a few hundred for some

igneous and metamorphic rocks to several thousand for shales and clays. Some orebodies are referred to as conductors by geophysicists because of their extremely low resistivity (conductivity is the inverse of resistivity). For instance, the majority of typical sulfide minerals, with the exception of sphalerite (zinc sulfide), have very low resistivities—a few hundredths of an ohm-meter—such as chalcopyrite (copper-iron sulfide) and galena (lead sulfide). A sulfide orebody may give an extremely low resistance to the passage of electricity compared to the nearby rocks if the individual grains inside it are in good electrical contact with one another. As a result, the orebody is referred to as a conductor. Other structures, including clay pockets, graphite schists, or brine-soaked sediments, can also act as good conductors.

Finding conductors that could be orebodies requires the application of numerous electrical techniques. Some require large field workers, highly expensive, and intricate equipment to conduct the measurements, and mathematical calculations must be performed on the data before interpretation. However, other methods make use of inexpensive to moderately expensive machinery that can be easily managed by one or two people and call for little to no mathematical knowledge. For instance, the VLF approach uses very low frequency (VLF) radio waves, electromagnetic fields that are continuously broadcast in the 15–25 kHz range by a number of strong stations throughout the world. These stations' primary fields generate electrical currents of the same frequency to flow in the Earth by penetrating it to a depth of 30–300 feet (about 10–100 meters). At the Earth's surface, secondary magnetic fields produced by this current can be seen. The primary and secondary fields at the surface are uniform and oriented in the horizontal direction in regions where the electrical resistivity of the Earth is uniform. The currents, however, tend to concentrate along low resistance routes, such as those that may be offered by orebodies, where the Earth's resistivity is not uniform. The secondary fields at the surface are disturbed as a

result, and these disturbances can be monitored and utilized to forecast the presence and location of ore bodies.

## **CHAPTER THREE**

### **3.0 MATERIALS AND METHODS**

#### **3.1 Material**

Materials used for this study include Rocks and Soil.

#### **3.2 Methods**

##### **3.2.1 Desk and reconnaissance studies**

The desk study phase of this project involved extensive research on the general topic and careful evaluation of the literature related to the search for gold using rocks and soils. Using ArcGIS software, a topographical map of the research area was also produced. During the field mapping visit to the research region, this served as a guide for the collection of rock and soil samples as well as the marking of paths and river channels. To corroborate the first field findings that were made macroscopically on the field samples

acquired during geological prospection and structural mapping across the entire study region, all of these were correlated and then followed by traversing on the ground.

### **3.2.2 Field work**

After gathering secondary data from various sources, a thorough field investigation was conducted in the subject area. The field research includes soil and rock geochemical sampling, geological and structural mapping. The samples were examined and described using hand specimens based on their color, hardness, texture, mineralogy, transparency, and structural components.

Field procedures include:

1. Digger was used to collect samples from the horizon B on the depth of 50cm-60 cm into the surface, where the greatest amount of leaching have taken place.
2. Sample bags were used bag about 100-150g of the sample needed for preparation and additional analysis were collected using sample bags.
3. GPS: The locations of the outcrops were quantitatively determined using the Global Positioning System (GPS).
4. Notebooks were used to record measurements, observations, and descriptions of the rocks.
5. Hammer for the breaking and collection of rock samples respectively.

### **3.2.3 Geological mapping**

Mapping on 1: 12,500 scale was completed with the help of a base map, compass inclinometer, and GPS. On the field diary and base map, the terrain was carefully examined and noted. Two different rock types, granite and schist, were mapped. They

were both noted in the field notebook and their related structural data was later analyzed and plotted on the base map. For additional geochemical and petrographical research, fresh representative samples of rocks were obtained, labeled properly, and stored in the sample bags.

The study area's geological boundaries, vegetation, footpaths, sample location map (Figure 3.1), and geological map (Figure 3.2) were all produced after the fieldwork was completed. All observed geological and structural features and coordinate readings from the fieldwork were then captured and digitized into ArcGIS software for geological and structural interpretation.

#### **3.2.4 Soil sampling**

An organized grid-based regional soil geochemical investigation was done. Ten soil samples in all were taken from the study region. The sampling locations were spaced 8 to 9 meters apart and perpendicular to the stream channel's meandering point. The general North-South orientation of the research region was perpendicular to the sample route, which ran East-West.

Using a digger, soil samples were taken from depths ranging from 50 to 60 cm (Plate 1). To prevent soil contamination, the digger was frequently cleansed with an unconsolidated rag after each digging. The Fe-rich layer, which is thought to be horizon B, was the focus of the sample. The samples were taken from a depth of 70 cm when a Fe-rich layer was not found at an average depth of 60 cm (which is typical of locations with thick depositional cover). In the field, soil samples weighing between 100 and 150g were taken, bagged in the sample bag, and labelled with sample point numbers (Plate 2).



**Plate I: Taking soil sample at the depth of 50-60cm.**



**Plate II: 100-150g of soil samples packed inside the fabric sample bag**

### **3.2.5 Rock sampling**

Schist dominates the area that was mapped, and trending towards the south eastern region of the study area is granite. The grain sizes range from medium to coarse and phoppyroblastic outcrops are rare. The majority of the mapped rocks have weathered.

Which made their identification very challenging. Although it wasn't a complete obstacle to the investigation because the intended sample was little reduced to soil. Samples of granite and schist rocks were also collected.

The southern part is where the study's granite observations well located. They resemble rocks with medium-fine grained textures. While the northern region is often dominated by schist. The large laterites in the area, however, suggest that granite has continuously underlain the rest of the area and has been covered by extremely light overburden. The granite rocks typically appear as flat-lying outcrops along stream channels, but they can also occasionally be exposed in relatively high-rising positions. These exposures have a light to dark color, a texture that ranges from medium to fine, and they are heavily worn.

### **3.3 Sample Preparation**

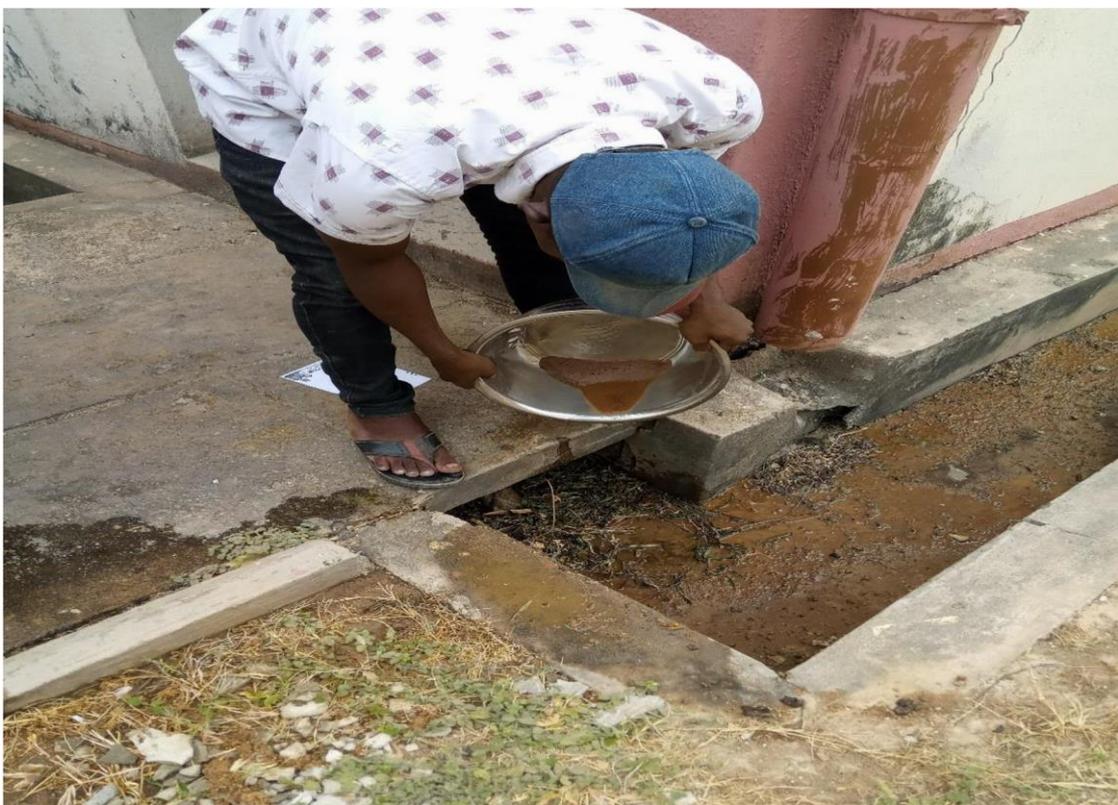
#### **3.3.1 Soil preparation**

Gravity concentration method as one of the oldest practise was employed to increase the concentration of gold in the soil samples and prepare them for additional geochemical analyses. Where milled material has relatively reduced to uniform grain size and most of the particles become similar in sizes, concentration work is most effective. This approach is known as the gravity method (Panning).

The samples were ground to release the gold particles from the soil and to reduce the size of the grains. The soil samples were then progressively placed in a large, curved pan with water. causing the pan to move in a sequence of movements that are intended to discharge lighter sediment. Lighter objects and water are ejected from the pan while gold remains at the bottom due to its density (Plate 3). After several successful repetitions, particles thought to contain gold were removed, dried out in the sun (Plate 4), and then put back in

bags for additional mineralogical and chemical investigation to evaluate their maximal viability.

Within a medium-sized pan, panning employs water to separate heavy gold particles from other lighter particles. As a result, this technique was determined to be successful since it lowers the possibility of bulk material contamination.



**Plate III: Process of panning the concentrate.**



**Plate IV: Soil samples undergoing air dry.**

### **3.3.2 Rock petrographic study**

Rock samples were typically prepared as separate grab samples or core samples for petrographic investigation using a Polarizing Light Microscope. The samples had a polished surface for examinations with an electron microscope and were sliced into thin sizes that allowed light to travel through them in a light microscope. The procedure for creating a thin section petrographic slide is described below.

### **3.3.3 Rock sample preparation and geochemical analysis**

The fresh representative samples were broken into smaller particulates, and then repacked into a sample bottle and ready for further geochemical analysis (Plate 5).



**Plate V: Rock samples milled and filled into sample bottles**

### **3.4 Laboratory Work**

This phase entails sample preparation and geochemical analyses of the field-collected samples of soil and rock. In order to quantify the gold potentials and other economic minerals in the rock and soil samples, the bulk chemical analyses was used to detect major and trace elements as well as REEs. The thin section preparation and petrographic analyses were completed at Vineyard Lab, Gidan Matasa, Bosso Estate, Minna, and the Geology Department, Federal University of Technology, Minna, whereas this analyses was completed at Actlab, Canada.

#### **3.4.1 Laboratory Analyses**

Inductively Coupled Plasma (ICP), Thermal Desorption Mass Spectrometry, Instrumental Neutron Activation Analysis (INAA), and other analytical techniques were used in the soil geochemical investigations (TD-MS).

**3.4.1.1 Instrumental neutron activation analysis (INAA) method-procedures** The main application of instrumental neutron activation analysis (INAA) is to identify various elements in soils at low concentrations. In this type of examination, the samples go through the following steps to get analyzed:

Polyethylene-wrapped samples were exposed to radiation in the reactor core. Irradiation was possible at two separate reactor sites thanks to pneumatic tubes. Elemental nuclei capture neutrons during irradiation to create radioactive nuclei. Single neutron capture reactions predominated because of how strongly thermalized the neutron flow is. The nuclides of interest were identified by gamma ray spectroscopy employing a high-resolution germanium detector along with the required signal analyser and electronics after a proper decay period following irradiation.

Comparing the elements' quantities to standards that are typically irradiated with the samples allowed for element quantification. Anticoincidence or coincidence counting methods were used to raise the signal to noise ratio, which raised detection limits.

Elements including Au, As, Ba, Br, Co, Cr, Cs, Fe, Hf, Hg, Ir, Na, Rb, Sb, Sc, Se, Ta, Th, U, W, La, Ce, Nd, Sm, Eu, Tb, Yb, and Lu were analyzed using this method.

**3.4.1.2 Induced Coupled Plasma-Mass Spectrometry (ICP-MS) Method-Procedures**

#### **Sample Preparation**

In order to destroy soil samples, 1% nitric acid was used. After that, samples were acidified with 5% HNO<sub>3</sub> to keep metals dissolved. The provided acidified soil samples came in 12 to 15 ml tubes. Salt concentrations in samples were kept to a minimum of 0.2% (2g/l). The trace elements and REEs are among the substances examined using this technique.

## **Method Procedures**

A peristaltic pump was used to pump the sample solution into the apparatus. A spray chamber inside the pump nebulized the sample. At a temperature of 6000–8000K, the resultant aerosol was fed into an argon plasma. Following the removal of the solution, atomization and ionization took place. The ions created in the plasma only partially reach the mass-spectrometer component.

### ***3.4.1.2 Total Digestion Mass Spectrometry (TD-MS) Method***

5 mm 90 mm stainless steel tubes were employed for sampling, and the TD-GC/MS technique was used for analysis. These parts were added to the sampling tubes after being properly folded. Thermal cleaning was used to condition the packed sampling tubes for 30 minutes at a helium flow rate of 350°C. The column temperature was programmed as follows: initial temperature 100°C for 3 min, ramp of 10°C until 250°C, ramp of 5°C until 320°C, and lastly temperature held at 320°C for 10 min. The helium gas carrier pressure used in the GC/MS system was 145kPa. Each sample's analysis took 42 minutes in total.

While the source temperature was 250°C, the temperature of the transfer lines (from TD to GC and from GC to MS) was maintained at 280°C. The different elements contained in the soil sample were identified and quantified using simultaneous full scan and selective ion monitoring (SIM) modes. The elements Ga, In, Re, Li, Nb, Sn, Sr, Tl, and Bi were all examined using the TD-MS technique.

## **CHAPTER FOUR**

### **4.0 RESULTS AND DISCUSSION**

#### **4.1 Results**

##### **4.1.1 Geology and field relation**

The result from the field mapping revealed that two main lithological units were dominated the study area namely: Schist and granitic rocks. Schist makes up around 80% of the research area, while the remaining 20% is made up of medium-coarse granitic rocks that tend to be near the study area's south-eastern corner. The majority of the mapped rocks have weathered. This made it challenging to identify them.

#### ***4.1.1.1 Granite***

Granitic rocks cover southernmost region of the research area, which is 20% of the entire study area. Medium-fine grained Granitic Rock often appears as flat-lying outcrops exposed along stream channels. These exposures have a medium to finegrained texture, a light to dark color, and are heavily worn (Plate 6). It is assumed that mica, feldspar, and quartz must be present in the exposure. Pyroxenes and hornblend are two additional minor elements that were found.



**Plate VI: Sample of the granitic rocks collected from the study area**

#### ***4.1.1.2 Schist***

Schist, which makes up about 80% of the study area have undergone moderate to high grades weathering (Plate 7). Its texture ranges from fine to medium grained, and in some locations, outcrops have turned into boulders as a result of jointing systems caused by mechanical and biological weathering.



Plate VII: Schist outcrops at the study area

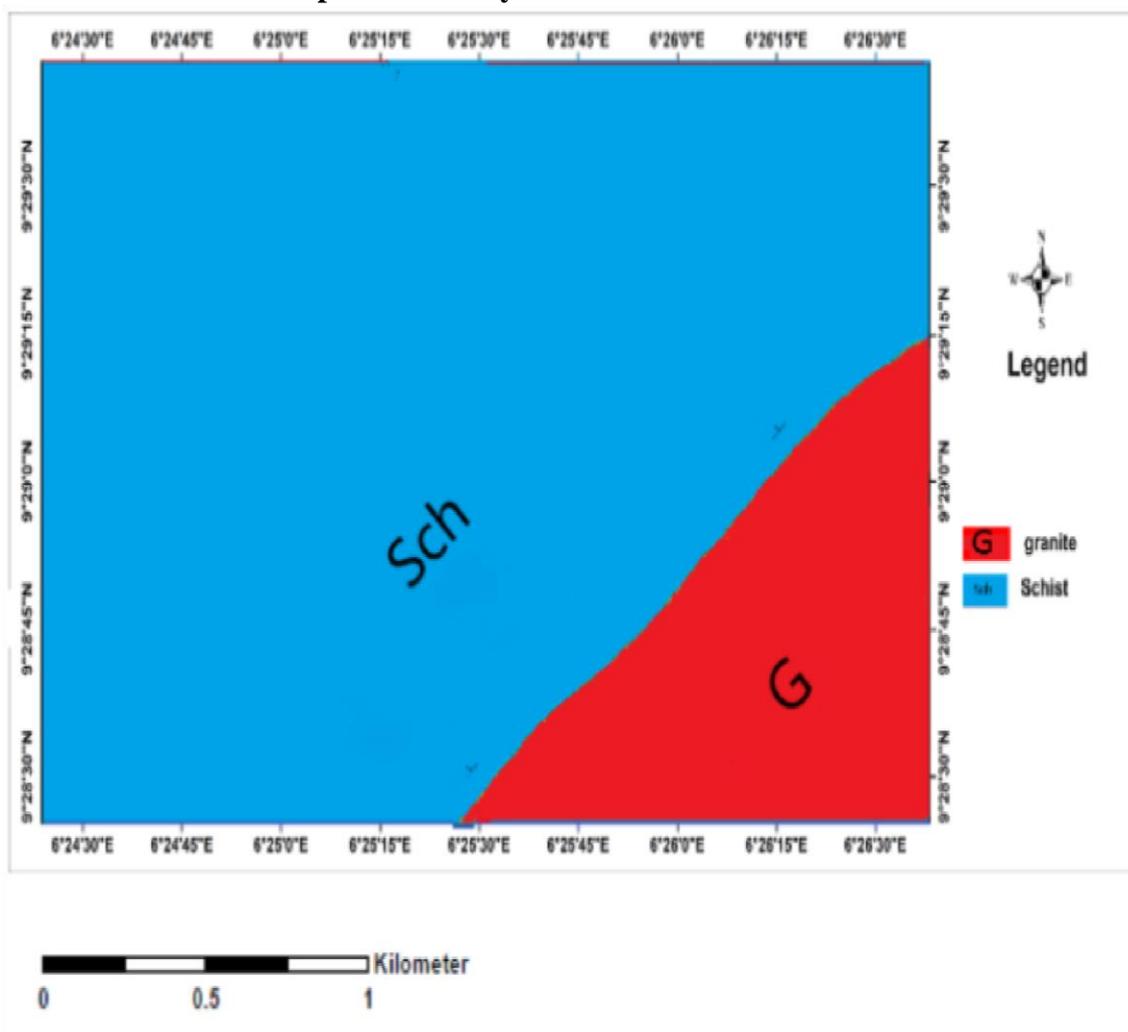


Figure 4.1 Geological map of the study area

## 4.2 Petrography of Rocks

### 4.2.1 Photo micrograph of the rocks from the study area

#### Granite

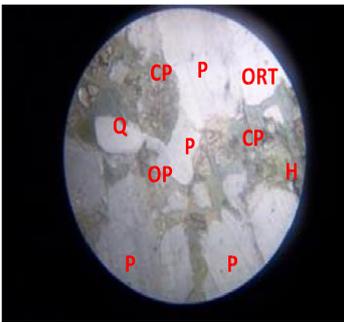


PLATE 8A: Observation under PPL Mag: X10

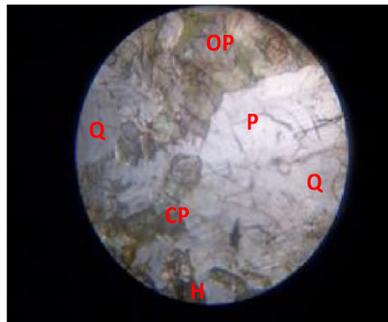


PLATE 9A: Observation under PPL Mag X10

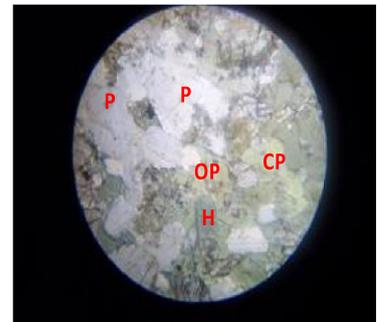


PLATE 10A: Observation under PPL Mag X10

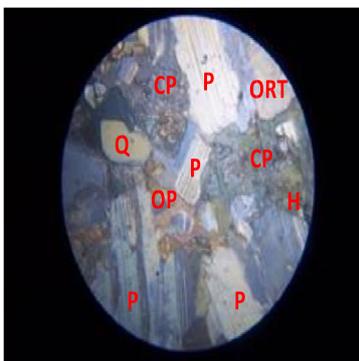


PLATE 8B: Observation

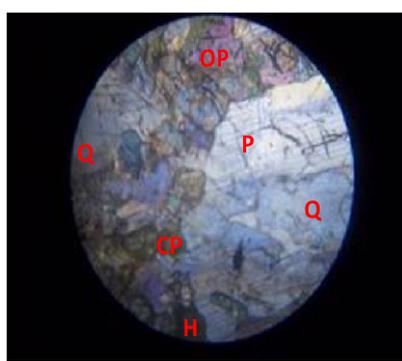


PLATE 9B: Observation under XPL Mag: X10

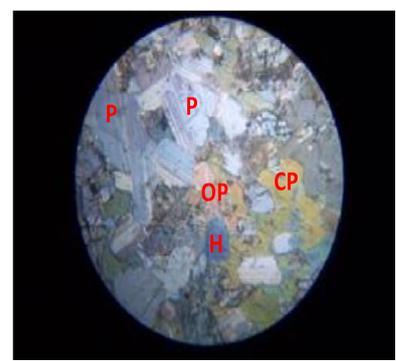


PLATE 10B: Observation under XPL Mag: X10

#### KEY

Q= Quartz

P= Plagioclase

OP= Ortho pyroxene  
ORT= Orthoclase  
H= Hornblende  
CP= Clinopyroxene

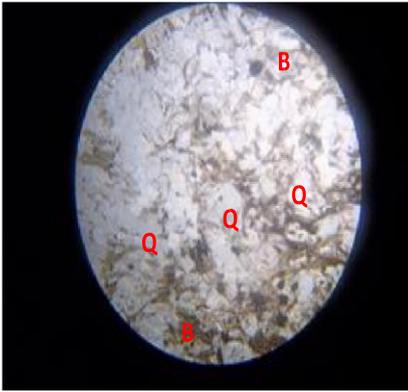
#### 4.2.2 Photo Micrograph interpretation

**Table 4.1 Petrographic study of the thin sections under transmitted light microscope for sample KS1-KS3**

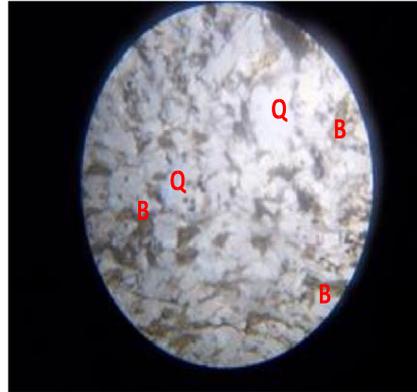
Mineral	Colour in PPL	Colour in XPL	Extinction angle	Diagnostic feature	Crystal form	Twining	% in thin section
Quartz	colourless	Blue to milky	As at 0-90° Quartz is fully visible. Revealing 0 extinction angle	Moderate to low relief, low pleochroic and no cleavage presence	Anhedral crystals	None	25
Orthoclase	Colourless	Blue to milky color	33°	Perfect interference but low relief and pleochroism	Anhedral crystals	Carlsbad	10
Plagioclase	Colourless	Blue	66°	Moderate relief, no cleavage and high pleochroism	Anhedral crystal	Albite	30
Hornblende	Brown	Green to brownish	18°	Moderate relief, unlike biotite, it shows scattered cleavage directions and interference presence	Anhedral crystal	None	20
Pyroxene	Green	Green to red	35°	Moderate relief and high pleochroism	Elongated, tabular anhedral to euhedral crystal form	None	15



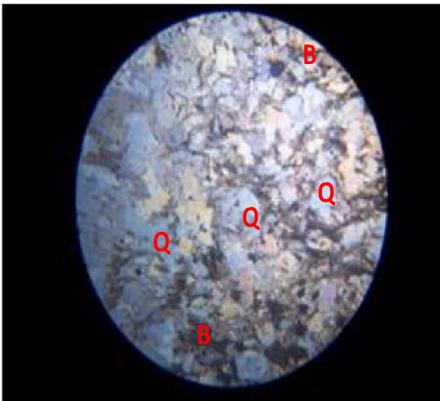
**Schist**



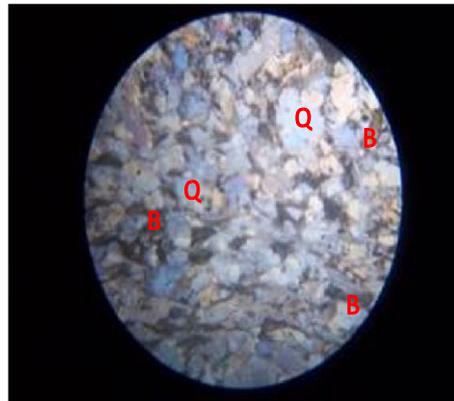
**PLATE 11A: Observation under PPL  
Mag: X10**



**PLATE 12A: Observation under PPL  
Mag X10**



**PLATE 11B: Observation under  
XPL Mag: X10**



**PLATE 12B: Observation under XPL  
Mag: X10**

**KEY**

Q= Quartz

B= Biotite

**Table 4.2 Petrographic study of the thin sections under transmitted light microscope for sample KS4-KS5**

<b>Mineral</b>	<b>Colour in PPL</b>	<b>Colour in XPL</b>	<b>Extinction angle</b>	<b>Diagnostic feature</b>	<b>Crystal form</b>	<b>Twining</b>	<b>% in thin section</b>
Quartz	colourless	Blue to pale brown	0°	Moderate to Low relief, low pleochroic and no cleavage presence	Anhedral crystal	None	64
Biotite	Dark	Dark brown	25°	Low relief perfect cleavage and pleochroism halos	Entirely euhedral observed, crystal	None	36



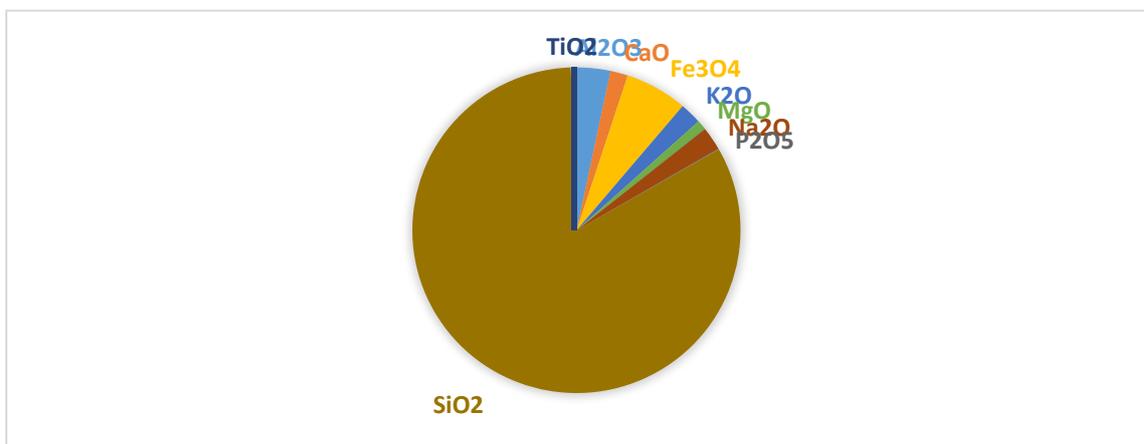
### **4.3 Geochemistry of the analyzed rock concentrates**

#### **4.3.1 Major oxides**

The results are shown in Table 2.  $\text{SiO}_2$  is the highest major oxide, with a mean value of 80.228, and it is successfully followed in decreasing order by  $\text{Fe}_2\text{O}_3$ ,  $\text{CaO}$ ,  $\text{Al}_2\text{O}_3$ , and  $\text{MgO}$ , while the remaining major oxides are all below 1 weight percent. The weathering of felsic protolithic rock is indicated by the high  $\text{SiO}_2$  and  $\text{Fe}_2\text{O}_3$  levels.

**Table 4.3 Concentration of Major Oxides (Wt%) in the Rock Samples**

S/N	Al <sub>2</sub> O <sub>3</sub>	CaO	Cr <sub>2</sub> O <sub>3</sub>	Fe <sub>3</sub> O <sub>4</sub>	K <sub>2</sub> O	MgO	MnO	Na <sub>2</sub> O	P <sub>2</sub> O <sub>5</sub>	SiO <sub>2</sub>	TiO <sub>2</sub>
KS1	0.17	1.3	0.01	6.43	0.77	1.66	0.05	0.445	0.21	80.11	0.12
KS2	4	0.83	0.01	5.26	1.2	0.531	0.04	1.335	0.14	85.44	0.4
KS3	6.1	4.2	0.005	4.002	1.21	1.28	0.03	2.7	0.01	73.82	0.4
KS4	1.66	1.4	0.001	5.15	2.41	0.93	0.03	2.7	0.02	74.44	1
KS5	4.23	0.6	0.0006	9.01	4.82	0.18	0.01	4.04	0.011	87.33	0.73
<b>Min</b>	<b>0.17</b>	<b>0.6</b>	<b>0.001</b>	<b>4.002</b>	<b>0.77</b>	<b>0.18</b>	<b>0.01</b>	<b>0.445</b>	<b>0.01</b>	<b>73.82</b>	<b>0.12</b>
<b>Max</b>	<b>6.1</b>	<b>4.2</b>	<b>0.01</b>	<b>9.01</b>	<b>4.82</b>	<b>1.66</b>	<b>0.05</b>	<b>4.04</b>	<b>0.21</b>	<b>87.33</b>	<b>1</b>
<b>Mean</b>	<b>3.232</b>	<b>1.666</b>	<b>0.0065</b>	<b>5.9704</b>	<b>2.082</b>	<b>0.9162</b>	<b>0.032</b>	<b>2.244</b>	<b>0.0782</b>	<b>80.228</b>	<b>0.53</b>



**Figure 4.2: Pie chart representation of mean Concentration of Major Oxides in rock sample**

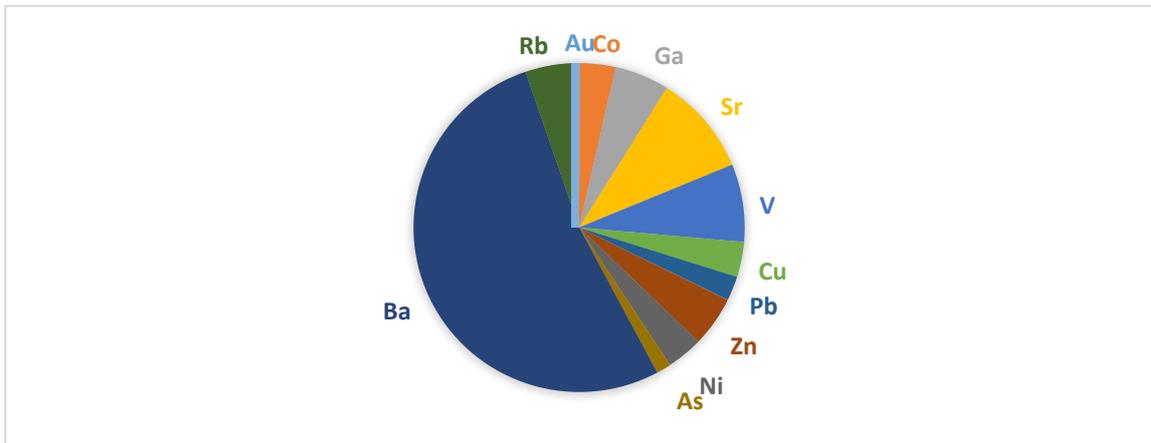
### 4.3.2 Trace elements

The result of the trace elements from analyzed in the rock samples (Table) shows that Ba with mean value of 242.4 is the highest followed successfully in decreasing order by

Sr, V, Ga, Zn, Rb, Ni, Co, Cu, Pb, As, Th, and Au ppm

**Table 4.4: Concentration of Trace Elements (Ppm) In The Rock Samples**

S/N	Au	Co	Ga	Sr	V	Cu	Pb	Zn	Ni	As	Ba	Rb	Th
KS1	0.7	11	26	55	30	11	7	40	15	5	300	< 15	4.3
KS2	0.35	7	33	16	56	7	8	32	12	5	210	18	7.2
KS3	0.25	23	30	46	34	23	11	12	20	8	200	25	0.9
KS4	0.1	21	12	88	44	21	23	22	22	3	102	21	2.3
KS5	0.4	18	22	23	12	18	6	8	13	12	400	20	1.4
Min	0.1	7	12	16	12	7	6	8	12	3	102	18	0.9
Max	0.7	23	33	88	56	23	23	40	22	12	400	25	7.2
Mean	0.36	16	24.6	45.6	35.2	16	11	22.8	16.4	6.6	242.4	21	3.22



**Figure 4.3: Pie chart representation of mean Concentration of Trace elements in the rock samples**

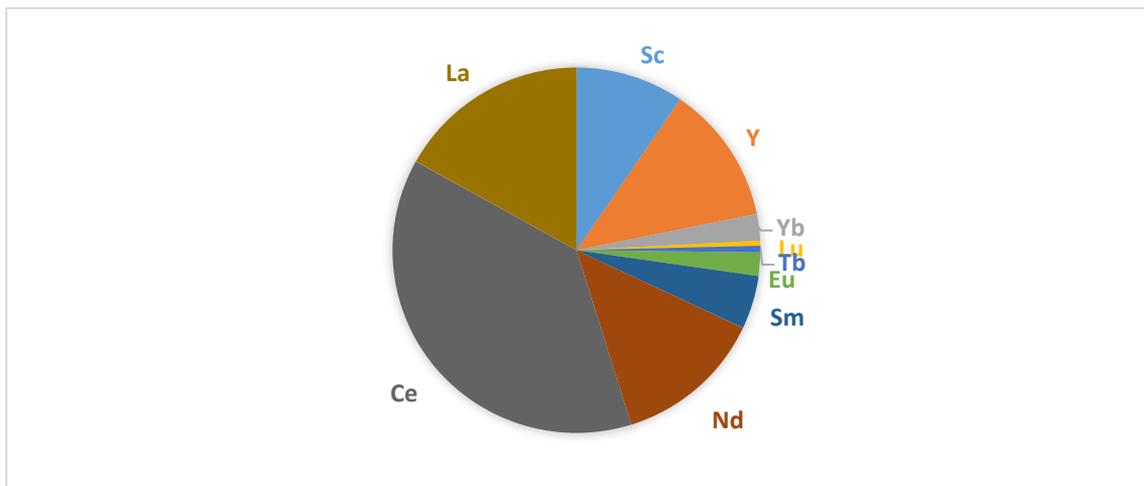
### 4.3.3 Rare earth elements

The result of the Rare Earth Elements (REEs) analyzed in rock samples as shown in

(Table 8), reveals that the mean concentrations of the REEs in decreasing order are Ce, La, Nd, Y, Sc, Sm, Yb, Eu, Tb, and Lu ppm

**Table 4.5: Concentration of Rare Earth Elements (ppm) In The Rock Samples**

S/N	Sc	Y	Yb	Lu	Tb	Eu	Sm	Nd	Ce	La
KS1	15	33	5.2	0.91	0.6	2.4	7.2	45	60	30.2
KS2	9	17	3.3	0.77	< 0.5	3	4.1	5	70	16.3
KS3	6	3	3.4	0.34	0.7	5	2.9	9	43	15.7
KS4	10	3	0.6	0.44	0.6	0.3	5.3	6	22	18.1
KS5	12	11	0.4	0.07	< 0.5	0.6	6.3	7	12	12
<b>Min</b>	<b>6</b>	<b>3</b>	<b>0.4</b>	<b>0.07</b>	<b>0.6</b>	<b>0.3</b>	<b>2.9</b>	<b>5</b>	<b>12</b>	<b>12</b>
<b>Max</b>	<b>15</b>	<b>33</b>	<b>5.2</b>	<b>0.91</b>	<b>0.6</b>	<b>5</b>	<b>7.2</b>	<b>45</b>	<b>70</b>	<b>30.2</b>
<b>Mean</b>	<b>10.4</b>	<b>13.4</b>	<b>2.58</b>	<b>0.506</b>	<b>0.633333</b>	<b>2.26</b>	<b>5.16</b>	<b>14.4</b>	<b>41.4</b>	<b>18.46</b>



**Figure 4.4: Pie chart representation of mean Concentration of Rare Erath elements in the rock samples**

## 4.4 Geochemistry of the Analyzed Soil Concentrates

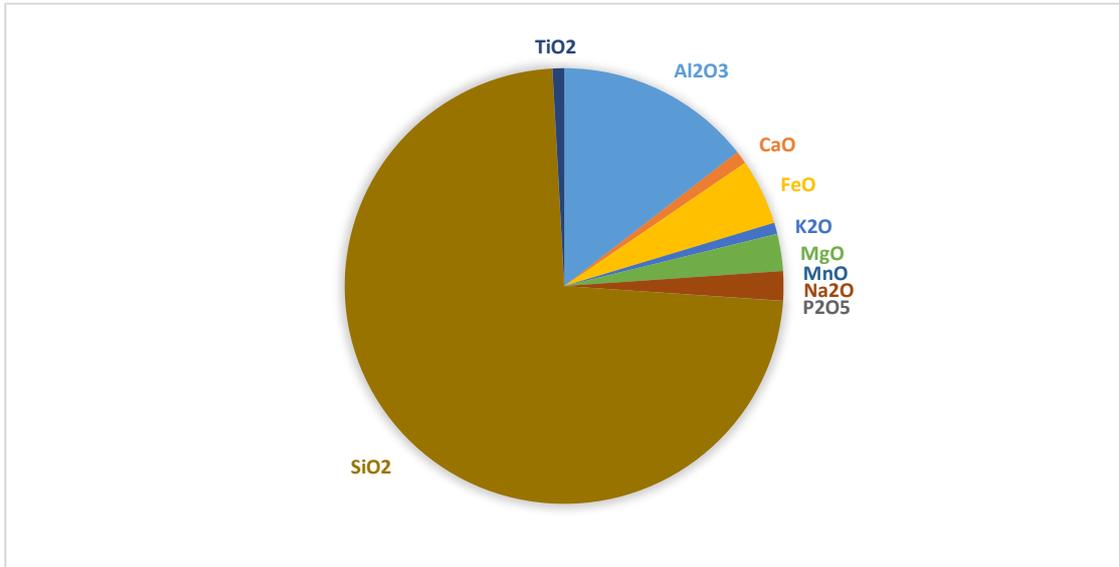
### 4.4.1 Major oxides

The result of the major oxides analyzed in the soil sample (Table 4) shows that the highest major oxide is SiO<sub>2</sub> with the mean value of 66.13 followed successfully in decreasing order by Al<sub>2</sub>O<sub>3</sub>, MgO, Fe<sub>2</sub>O<sub>3</sub>, CaO, and Na<sub>2</sub>O while in continuous decreasing format the rest of CaO, TiO<sub>2</sub>, K<sub>2</sub>O, MnO, P<sub>2</sub>O<sub>5</sub>, and Cr<sub>2</sub>O<sub>3</sub> are all below the value 1 wt

%

**Table 4.6: Concentration of Major Oxides (Wt%) in the Soil Samples**

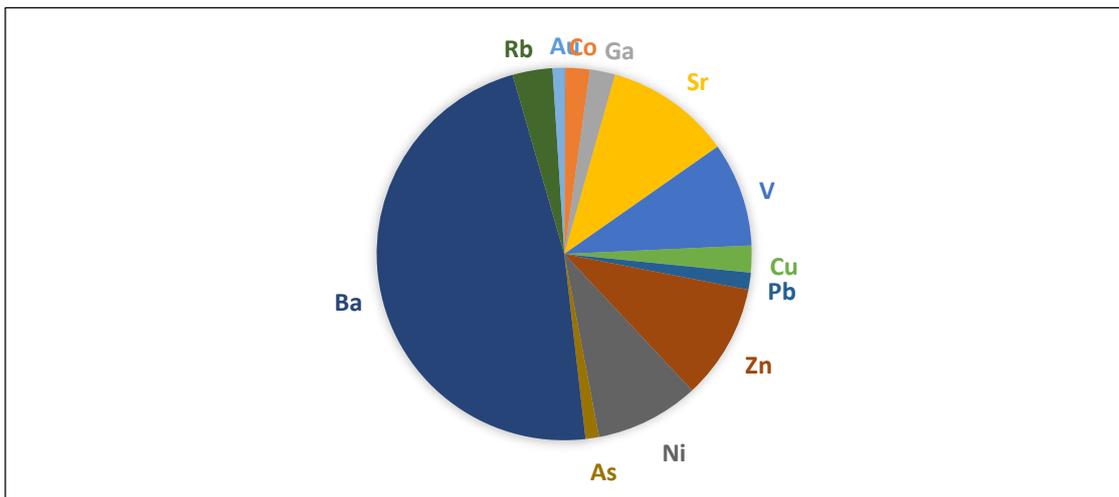
S/N	Al <sub>2</sub> O <sub>3</sub>	CaO	Cr <sub>2</sub> O <sub>3</sub>	Fe <sub>3</sub> O <sub>4</sub>	K <sub>2</sub> O	MgO	MnO	Na <sub>2</sub> O	P <sub>2</sub> O <sub>5</sub>	SiO <sub>2</sub>	TiO <sub>2</sub>
KS1	14.93	1.41	0.003	5.15	0.53	0.73	0.012	3	0.001	69.45	0.083
KS2	13.21	0.46	0.0012	6.6	0.8	1.43	0.01	5.12	0.01	66.72	0.37
KS3	6.5	0.6	0.003	7.9	0.41	2.02	0.02	0.74	0.01	65.07	0.9
KS4	13.83	0.53	0.004	5.4	1.1	1.62	0.01	1.32	0.02	62.43	2.39
KS5	19.33	1.12	0.001	2.84	0.93	3.5	0.01	2.24	0.01	67.81	2.22
KS6	9.47	0.31	0.006	2.41	1.5	2.22	0.003	1.64	0.021	67.67	0.15
KS7	16.99	0.48	0.001	2.42	1.61	5.34	0.01	1.32	0.001	63.05	0.53
KS8	7.97	0.13	0.004	2.3	0.13	0.75	0.03	2.84	0.01	65.42	0.18
KS9	11.3	0.8	0.01	2.72	0.39	3.18	0.003	0.46	0.02	69.08	0.35
KS10	17.42	2.81	0.015	6.6	0.11	3.9	0.03	1.04	0.01	64.6	0.55
Min	6.5	0.6	0.001	2.3	0.11	0.73	0.003	0.46	0.001	62.43	0.083
Max	19.33	2.81	0.015	7.9	1.61	5.34	0.03	5.12	0.021	69.45	2.39
Mean	13.095	0.865	0.0048	4.434	0.751	2.469	0.0138	1.972	0.0113	66.13	0.7723



**Figure 4.5: Pie chart representation of mean Concentration of Major Oxides in soil sample**

#### 4.4.2 Trace elements

The result of the trace elements from analyzed in the soil samples (Table 7) shows that Ba with mean value of 261.25 is the highest followed successfully in decreasing order by Sr, Zn, V, Ni, Rb, Cu, Ga, Co, Pb, As, Th, and Au in ppm.



**Figure 4.6: Pie chart representation of mean Concentration of Trace Elements in**

**Table 4.7: Concentration of Trace Elements (Wt%) in the Soil Samples**

S/N	Au	Co	Ga	Sr	V	Cu	Pb	Zn	Ni	As	Ba	Rb	Th
KS1	0.2	7	11.9	50	12	10	4	21	14	5.2	110	<15	2.3
KS2	0.034	21	10.3	23	10	4	9	33	22	3.7	420	<15	3.6
KS3	0.244	5	9.4	40	44	34	12	46	17	4.6	420	16	7.2
KS4	0.101	9	16.4	77	34	12	6	34	18	4.3	<50	<15	10.2
KS5	0.3	11	16.3	43	20	8	7	70	21	8.3	390	18	5.4
KS6	0.123	4	3.8	16	32	9	3	23	6	4.1	330	<15	3.8
KS7	1.2	22	15.8	88	102	3	3	120	122	3.8	100	<15	1.9
KS8	0.321	6	12.7	23	106	10	15	44	45	10.4	200	<15	5.8
KS9	0.9	12	5.3	92	44	3	10	77	100	12.1	120	<15	5.1
KS10	1.12	10	18.1	109	32	6	7	9	33	1.9	<50	23	10
Min	0.034	5	3.8	23	10	3	3	9	6	1.9	100	16	1.9
Max	1.2	22	18.1	109	106	34	15	120	122	12.1	420	23	10.2
Mean	0.4543	38	38	08	15	15	46	85	62	46	261.25	19	5.53

soil sample

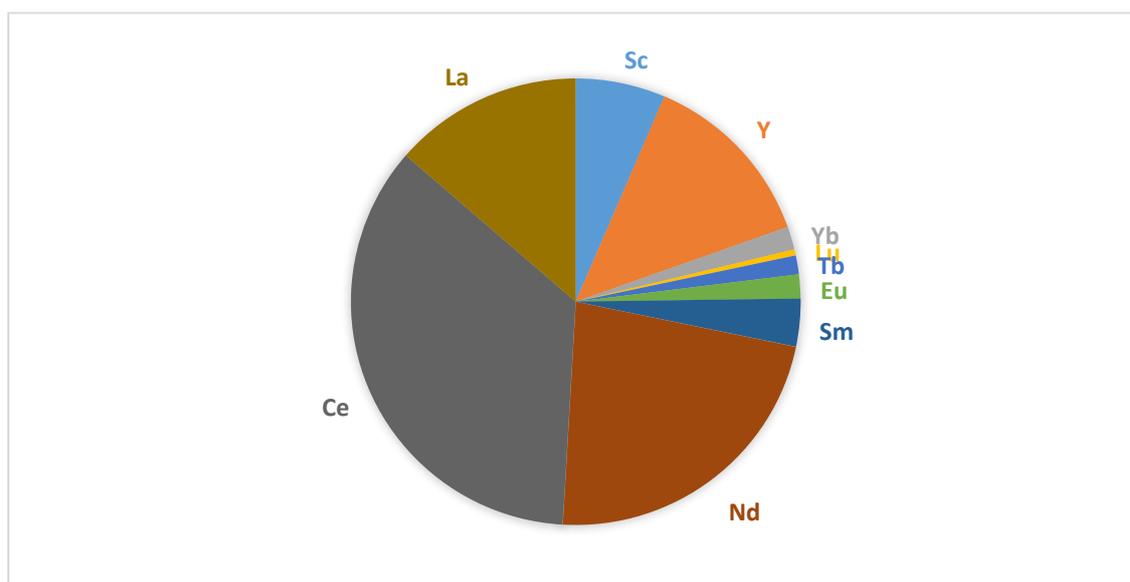
#### 4.4.3 Rare earth elements

The result of the Rare Earth Elements (REEs) analyzed in soil samples as shown in (Table 9), reveals that the mean concentrations of the REEs in decreasing order are Ce, Nd, La, Y, Sc, Sm, Eu, Yb, Tb, and Lu ppm.

**Table 4.8: Concentration of Rare Earth Element in The Soil Samples**

S/N	Sc	Y	Yb	Lu	Tb	Eu	Sm	Nd	Ce	La
KS1	9.6	22	2	1	< 0.5	0.5	2	44	44	12
KS2	7.3	13	1.7	0.07	0.8	3	2.8	65	43	18
KS3	6.4	44	1	0.44	0.6	3	1.8	8	24	23
KS4	10.2	32	3.8	0.65	0.8	7	1.4	23	87	9
KS5	8.9	13	4.1	0.77	< 0.5	0.7	7.4	9	32	6
KS6	6.3	8	5	0.81	< 0.5	0.3	6	35	12	21
KS7	12.6	4	0.3	0.32	2	0.5	5	21	11	7
KS8	7.5	9	0.4	0.11	1.4	1	2.1	9	56	15

KS9	11.2	23	1.8	1.09	1.5	1.9	8	20	77	43
KS10	8.5	12	2.7	0.66	6	6	11	77	100	33
<b>Min</b>	<b>6.3</b>	<b>4</b>	<b>0.3</b>	<b>0.07</b>	<b>0.6</b>	<b>0.3</b>	<b>1.4</b>	<b>8</b>	<b>11</b>	<b>6</b>
<b>Max</b>	<b>11.2</b>	<b>44</b>	<b>4.1</b>	<b>1.09</b>	<b>6</b>	<b>7</b>	<b>11</b>	<b>77</b>	<b>100</b>	<b>43</b>
<b>Mean</b>	<b>8.85</b>	<b>18</b>	<b>2.28</b>	<b>0.592</b>	<b>1.871429</b>	<b>2.39</b>	<b>4.75</b>	<b>31.1</b>	<b>48.6</b>	<b>18.7</b>



**Figure 4.7: Pie chart representation of mean Concentration of Rare Erath elements in the soil samples**

#### 4.5 Geochemical Association

The degree of association or coherence of gold with other elements found in the rock and soil samples was assessed using Pearson correlation. Positive correlation indicates that both elements correlate with one another in the sense that there is a linear relationship between the elements. Positive and negative correlations are generally noticed when interpreting correlation. Both elements grow when one does. When two elements are negatively correlated, one element's abundance rises while the other falls. Based on the values between the two variables, this correlation was divided into three categories: weak

correlation (values between 0.1 and 0.30), intermediate correlation (values between 0.31 and 0.50), and strong correlation (values between 0.51 and 1).

#### **4.5.1 Correlation coefficients of Au with major oxides in rock samples**

The correlation coefficient of Au against the major oxides of the rock shows that Au has a positively medium correlation with  $\text{Fe}_2\text{O}_3$ ,  $\text{MgO}$  and  $\text{SiO}_2$  all designated with a yellow color. Au correlated positively strongly with  $\text{Cr}_2\text{O}_3$  and  $\text{P}_2\text{O}_5$  while Au correlates negatively with the remaining major oxides of the rock sample. Correlation basically entails the concentration alloy of the said mineral with the Au content.

**Table 4.9: Correlation coefficient of Au with Major oxides in rocks samples**

	Al2O3	CaO	Cr2O3	Fe2O3	K2O	MgO	MnO	Na2O	P2O5	SiO2	TiO2	Au
Al2O3	1											
CaO	0.509174	1										
Cr2O3	-0.40016	-0.02238	1									
Fe2O3	-0.15108	-0.69429	-0.30772	1								
K2O	0.230232	-0.42187	-0.82522	0.779805	1							
MgO	-0.44017	0.508552	0.582705	-0.5241	-0.76531	1						
MnO	-0.57983	0.042308	0.942822	-0.44014	-0.89125	0.753221	1					
Na2O	0.580841	0.069395	-0.96417	0.371638	0.852547	-0.65517	-0.99004	1				
P2O5	-0.6188	-0.34856	0.932415	0.001466	-0.60726	0.451222	0.877915	-0.92362	1			
SiO2	0.059235	-0.74285	0.068047	0.749738	0.459217	-0.67157	-0.20022	0.07253	0.275857	1		
TiO2	0.457222	-0.22644	-0.92985	0.477586	0.914333	-0.83855	-0.97367	0.943365	-0.81646	0.277852	1	
Au	-0.38339	-0.27468	0.660988	0.42739	-0.20564	0.33154	0.519115	-0.55096	0.776578	0.458149	-0.55654	1

Medium correlation



Strong correlation



#### **4.5.2 Correlation coefficients of Au with major oxides in soil samples**

The correlation coefficient of Au against the major oxides of the rock shows that Au has a positively strongly correlation with  $\text{Fe}_2\text{O}_3$ , and  $\text{MgO}$  all designated with a blue color. Au correlated positively medium correlation with  $\text{Al}_2\text{O}_3$  and  $\text{CaO}$  while Au correlates positively poorly with  $\text{MnO}$  and negatively the remaining major oxides of the soil sample.

**Table**

**4.10: Correlation coefficient of Au with Trace elements and Rare Earth elements in the rock sample.**

As	Ba	Cu	Co	Ga	Ni	Pb	Rb	Sr	Th	V	Zn	Ce	Eu	La	Lu	Nd	Sc	Sm	Tb	Y	Yb	Au		
As	1																							
Ba	0.795636	1																						
Cu	0.262754	-0.2226	1																					
Co	-0.49632	-0.56737	-0.38823	1																				
Ga	0.202343	0.255027	-0.50963	0.625639	1																			
Ni	-0.39267	-0.71401	0.780307	-0.02928	-0.56537	1																		
Pb	-0.6039	-0.83082	0.513407	0.025976	-0.74228	0.841643	1																	
Rb	0.282748	-0.32845	0.598471	0.167717	-0.09555	0.353202	0.36151	1																
Sr	-0.60254	-0.62334	0.50125	-0.21332	-0.75791	0.860979	0.844555	-0.0758	1															
Th	-0.49418	-0.10862	-0.94003	0.616206	0.459966	-0.58182	-0.2536	-0.41962	-0.36115	1														
V	-0.79767	-0.78681	-0.38641	0.870773	0.205818	0.137347	0.393826	0.102088	0.123789	0.674724	1													
Zn	-0.71568	-0.1774	-0.76549	0.377177	0.209304	-0.24486	-0.08581	-0.80065	0.121169	0.782325	0.513573	1												
Ce	-0.47132	-0.16588	-0.74377	0.779692	0.742893	-0.35909	-0.35998	-0.46141	-0.2954	0.797319	0.625842	0.773766	1											
Eu	0.019354	-0.1374	-0.02502	0.667898	0.802073	0.03209	-0.33739	0.100067	-0.29697	0.079246	0.25968	0.056167	0.611817	1										
La	-0.54309	-0.03343	-0.39001	0.004178	0.02084	0.0253	-0.06477	-0.9072	0.383402	0.316209	0.096864	0.829649	0.513511	0.073711	1									
Lu	-0.72247	-0.24815	-0.73887	0.5295	0.349382	-0.20452	-0.10858	-0.72399	0.077018	0.784524	0.592968	0.978853	0.873261	0.251672	0.799473	1								
Nd	-0.2209	0.29669	-0.37211	-0.18828	0.122437	-0.15764	-0.33921	-0.94599	0.177064	0.189887	-0.20533	0.683524	0.419164	0.092089	0.938532	0.64489	1							
Sc	-0.02545	0.531821	-0.43861	-0.58239	-0.2566	-0.4029	-0.28833	-0.85288	0.077475	0.203807	-0.4007	0.502227	-0.00243	-0.55607	0.633165	0.341377	0.732435	1						
Sm	0.038326	0.528975	-0.29081	-0.71254	-0.41079	-0.31328	-0.18881	-0.74827	0.152302	0.058072	-0.49118	0.357544	-0.19189	-0.67573	0.528544	0.17901	0.633859	0.981384	1					
Tb	-0.43674	-0.50446	0.517103	0.018415	-0.25747	0.82113	0.493322	-0.13386	0.784657	-0.42452	0.057583	0.121906	0.018673	0.308692	0.505839	0.183798	0.384797	-0.11924	-0.11461	1				
Y	-0.15584	0.452405	-0.77028	-0.03296	0.341237	-0.59825	-0.58282	-0.95312	-0.22	0.573734	-0.06172	0.790135	0.592362	0.013429	0.783934	0.73453	0.861846	0.78424	0.651487	0.10125	1			
Yb	-0.30814	0.029574	-0.5065	0.47493	0.669499	-0.21037	-0.44763	-0.64973	-0.13265	0.454693	0.249755	0.700263	0.862818	0.679547	0.736495	0.795185	0.735155	0.17238	-0.00243	0.3353	0.699981	1		

## Table

Au 0.193172 0.697656 -0.59421 -0.18248 0.449669 -0.64302 -0.78761 -0.85032 -0.37994 0.319759 -0.36002 0.520359 0.449954 0.140367 0.639456 0.485357 0.833705 0.716376 0.600988 -0.1172 0.925046 0.673674 1

**4.5.3 Correlation coefficients of Au with other elements in the soil samples** The correlation coefficient of Au against the major oxides of the samples shows that Au has a positively weakly with only MnO designated with red color. Has positively medium correlation with Al<sub>2</sub>O<sub>3</sub> and CaOall designated with a yellow color. Au correlated positively strongly with Cr<sub>2</sub>O<sub>3</sub> and MgO. While Au correlates negatively with the remaining major oxides of the rock sample.

**4.11 Correlation Coefficient of Au with Major Oxides in the Soil Samples Table 4.12: Correlation coefficient of Au with Trace elements and Rare Earth elements in the soil sample.**

	Al2O3	CaO	Cr2O3	FeO	K2O	MgO	MnO	Na2O	P2O5	SiO2	TiO2	Au
Al2O3	1											
CaO	0.563609	1										
Cr2O3	0.020925	0.668398	1									
FeO	-0.09361	0.376781	0.116512	1								
K2O	0.24115	-0.43699	-0.48326	-0.37883	1							
MgO	0.549237	0.303468	0.214277	-0.25352	0.357875	1						
MnO	-0.10796	0.393119	0.30577	0.335318	-0.68057	-0.12983	1					
Na2O	0.083811	-0.20634	-0.48722	0.1097	-0.00554	-0.50292	0.011158	1				
P2O5	-0.37045	-0.22818	0.368424	-0.13061	0.068987	-0.14855	-0.33911	-0.31819	1			
SiO2	-0.05355	0.070999	0.043378	-0.21651	-0.21373	-0.28284	-0.37824	0.241062	0.046578	1		
TiO2	0.378436	0.008395	-0.23895	0.097983	0.2234	0.136341	-0.12267	-0.19928	0.24723	-0.37766	1	
Au	0.385112	0.459013	0.514023	-0.21015	-0.0737	0.817257	0.186264	-0.52783	-0.24942	-0.23298	-0.21148	1

Poor correlation 

Medium correlation 

Strong correlation 

**Table**

	Co	Ga	Sr	V	Cu	Pb	Zn	Ni	As	Ba	Rb	Th	Sc	Y	Yb	Lu	Tb	Eu	Sm	Nd	Ce	La	Au
Co	1																						
Ga	0.267696	1																					
Sr	0.284274	0.446404	1																				
V	0.120899	0.136977	0.106232	1																			
Cu	-0.553	-0.12142	-0.28526	-0.04148	1																		
Pb	-0.21229	-0.10091	-0.23314	0.29233	0.366108	1																	
Zn	0.565689	0.076261	0.256945	0.563358	-0.20704	-0.06488	1																
Ni	0.581356	0.03709	0.557074	0.63942	-0.43203	-0.01559	0.825355	1															
As	-0.16816	-0.31669	-0.10181	0.280669	-0.13797	0.541139	0.348288	0.333297	1														
Ba	-0.0236	-0.42719	-0.77809	-0.23591	0.375051	0.267528	0.014568	-0.36844	0.071235	1													
Rb	-0.19393	0.432147	0.260809	-0.24052	0.34475	0.138037	-0.18588	-0.26012	-0.23918	0.12959	1												
Th	-0.36761	0.396095	0.374582	-0.11481	0.312821	0.309715	-0.42053	-0.30739	-0.14055	-0.33139	0.523858	1											
Sc	0.530705	0.346504	0.722961	0.288049	-0.50706	-0.37247	0.665568	0.768342	0.172808	-0.64788	-0.26565	-0.17334	1										
Y	-0.39939	-0.12411	0.053078	-0.30632	0.78461	0.302593	-0.19964	-0.30518	0.005183	0.075497	0.180993	0.444292	-0.15272	1									
Yb	-0.36009	-0.09341	-0.11718	-0.61424	-0.11569	-0.48778	-0.4124	-0.56059	-0.18557	0.067932	0.163603	0.260227	-0.23893	-0.03828	1								
Lu	-0.39235	-0.24974	0.347245	-0.46084	-0.0993	-0.42033	-0.10655	-0.0411	0.213881	-0.3038	0.079413	0.02782	0.27438	0.211969	0.521245	1							
Tb	0.171433	0.458388	0.696145	0.185053	-0.24786	0.057354	-0.1367	0.278146	-0.29539	-0.55248	0.486254	0.484194	0.16195	-0.23303	-0.18743	-0.09352	1						
Eu	-0.01878	0.429358	0.482143	-0.24616	0.143265	0.101775	-0.41352	-0.22504	-0.39805	-0.43426	0.310167	0.869549	-0.00034	0.427958	0.167134	-0.0644	0.513236	1					
Sm	0.109267	0.091665	0.531109	-0.11562	-0.45736	-0.21039	0.064111	0.270558	0.02286	-0.20806	0.524174	0.169985	0.172691	-0.41557	0.305099	0.401681	0.629849	0.054623	1				
Nd	0.263075	0.131963	0.219557	-0.47633	-0.39186	-0.30736	-0.56198	-0.21948	-0.60308	-0.22334	0.142246	0.084881	-0.1296	-0.27971	0.145742	-0.01949	0.553002	0.375182	0.347023	1			
Ce	-0.10546	0.337516	0.58482	-0.16342	-0.21852	0.256042	-0.39542	-0.01828	0.103131	-0.65324	0.187916	0.725344	0.185519	0.18825	0.074295	0.208398	0.596986	0.754381	0.286731	0.369938	1		

La	-0.15387	-0.47837	0.35253	-0.12886	-0.0355	0.309746	-0.19786	0.200766	0.23546	-0.13448	0.169449	0.250768	-0.09389	0.170954	-0.0607	0.339117	0.460639	0.2101	0.525487	0.28893	0.458441	1	
Au	0.391749	0.290111	0.808276	0.449321	-0.37805	-0.1376	0.49143	0.789196	0.007788	-0.54044	0.246847	0.023111	0.620284	-0.33027	-0.36127	0.112003	0.735045	0.040011	0.663421	0.138855	0.224074	0.377308	1

#### 4.6 Elemental Enrichment Factor (EEF)

On the basis of the geochemical data samples from the study region, the enrichment factors of the elements in rocks and soil samples were calculated. (Table 13 and 14). It is essential in other to investigate the level of enrichment of these elements in sediments and rocks; relative to their crustal abundance in this study, the published crustal concentrations of these elements by Reedman,1979 were used as baseline or background values while the enrichment factors (EF) were calculated using the equation below.

$$EF=C_n/B_n$$

Where: -  $C_n$ = concentration of the element measured in sediments/rocks

$B_n$ = Baseline concentration given by Reedman,1979

From table 13 which is the rock sample, the result shows that elements such as Fe, Mg, Na, Ba, Co, Ni, Sr, V, Zn are all depleted in relation to their background value while Au having enrichment of 70. While table 14 which is the soil sample, elements such as Fe, Ce, La, Nd, Sc, Sm, Y, Ba, Co, Sr, V and Zn are depleted to their background value while Au having enrichment of 90.86, compared with baseline value for Reedman,1979, the higher enrichment of the element indicate presence of gold mineralization and associated trace elements.

The gold comparatively is more enriched and consequently more mineralized in soil (Table 13) than the rock (Table 14). This result reveal that the gold is less mineralized in the rocks which is it primary environment while those in soil and in their secondary form are more mineralized. Meaning that the rock has been weathered; releasing the primary gold which were now moved by weathering and concentrated in an area within the soil, hence given rise to higher concentration in the soil sample.

**Table 4.13: Gold and Other Mineralisation Potentials of Rock in the Study Area**

S/N	ELEMENTS	AVERAGE BACKGROUND ANALYSED CONCENTRATION VALUE (ppm)	COMPUTED ENRICHMENT (Clark's Values, ppm) Reedman, 1979	MINERALISATION FACTORS (Efs)%	MINERALISATION STATUS
1	Ce	41.4	46	0.9	Depleted
2	La	18.46	18	1.03	Depleted
3	Au	0.35	0.005	70	Significantly enriched
4	Sc	10.4	5	2.08	Depleted
5	Y	13.4	40	0.34	Depleted
6	Nd	14.4	24	0.6	Depleted
7	Ba	242.4	400	0.61	Depleted
8	Fe	4.955	4.11	1.21	Depleted
9	Na	1.545	2.33	0.6631	Depleted
10	Al	1.711	7.34	0.23311	Depleted
11	V	35.2	135	0.3	Depleted
12	Zn	22.8	65	0.351	Depleted
13	Sr	45.6	450	0.1013	Depleted
14	Sm	5.16	7	0.74	Depleted
15	Co	16	23	0.70	Depleted
16	K	4.955	2.23	2.222	Depleted
17	Ni	16.4	80	0.21	Depleted

With respect to Clark's value to assess the mineralization potential of the element, only Au revealed high enrichment in the rock sample with the computed value of 72%, others elements are depleted in enrichment.

**Table 4.14: Gold and Other Mineralisation Potentials of Soil in the Study Area**

S/N	ELEMENTS	AVERAGE ANALYSED VALUE (ppm)	BACKGROUND CONCENTRATION (Clark's Values, ppm) Reedman, 1979	COMPUTED ENRICHMENT FACTORS (Efs)%	MINERALISATION STATUS
1	Ce	48.6	46	1.1	Depleted
2	La	18.7	18	1.04	Depleted
3	Au	0.4543	0.005	90.86	Significantly Enriched
4	Sc	8.85	5	1.77	Depleted
5	Y	18	40	0.45	Depleted
6	Nd	31.1	24	1.30	Depleted
7	Ba	261.25	400	0.653	Depleted
8	Fe	4.434	4.11	1.1	Depleted
9	Mg	2.469	2.28	1.1	Depleted
10	Na	1.463	2.33	0.63	Depleted
11	Al	6.93224	7.34	0.944	Depleted
12	V	49.84615	135	0.37	Depleted
13	Zn	55.15385	65	0.85	Depleted
14	Sr	59.92308	450	0.133	Depleted
15	Ni	49.38462	80	0.62	Depleted

With respect to Clark's value to assess the mineralization potential of the element, only Au revealed high enrichment in the soil sample with the computed value of 90.86%, others elements are depleted in enrichment.

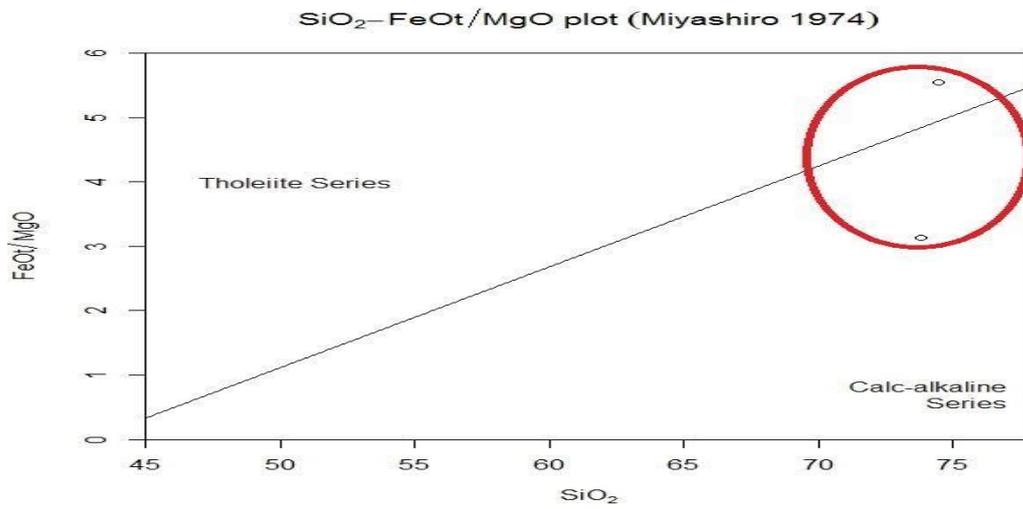
**Table 4.15 Gold Assessment from the Analyzed Soil Samples**

<b>Sample location</b>	<b>Easting</b>	<b>Northing</b>	<b>Gold Assessment (ppm)</b>
KS 1	06°24'53.70"	09°29'10.60"	0.2
KS 2	06°24'53.50"	09°29'09.60"	0.034
KS 3	06°24'51.80"	09°29'08.20"	0.244
KS 4	06°24'50.90"	09°29'11.20"	0.101
KS 5	06°24'57.10"	09°29'12.20"	0.3
KS 6	06°24'59.10"	09°29'08.30"	0.123
KS 7	06°25'01.80"	09°29'06.20"	1.2
KS 8	06°25'04.10"	09°29'04.00"	0.321
KS 9	06°25'55.30"	09°28'56.70"	0.9
KS 10	06°24'53.20"	09°29'20.70"	1.12

**Table 4.16: Gold Assessment from the Analyzed Rock Samples**

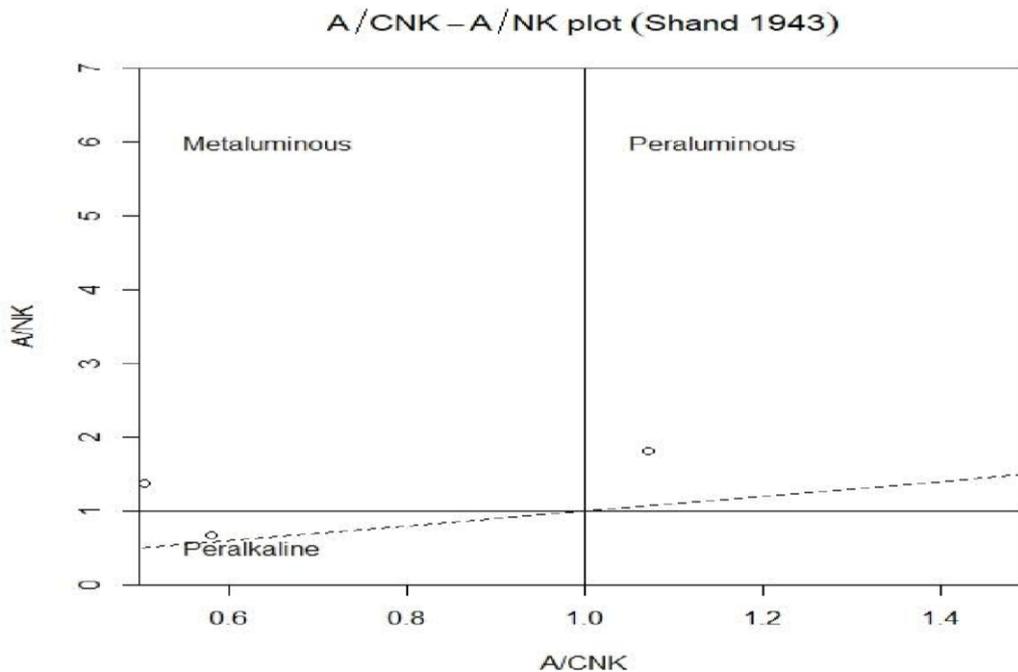
<b>Sample location</b>	<b>Easting</b>	<b>Northing</b>	<b>Gold Assessment (ppm)</b>
KS 1	06°25'08.00"	09°29'02.50"	0.7
KS 2	06°25'09.20"	09°29'01.10"	0.345
KS 3	06°25'10.40"	09°29'00.00"	0.246
KS 4	06°25'02.40"	09°28'56.20"	0.055
KS 5	06°25'53.20"	09°28'17.70"	0.401

#### 4.7 Provenance/Geotectonic Evolution Studies of the Rocks



**Figure 4.8: Protolith rock classification in the study at Garatu SiO<sup>2</sup>-FeOt/MgO (Modified after Miyashiro, 1974)**

Rocks of the study plot within the Tholeiite Series and Calc-Alkaline series.



**Figure 4.9 Protolith rock classification in the study at Garatu A/CNK-A/NK (Modified after Shand, 1943). Rocks of the study plot within the Metaluminous and Peraluminous.**

## CHAPTER FIVE

### 5.0 CONCLUSIONS AND RECOMMENDATIONS

#### 5.1 Conclusion

This study emphasizes on the geochemical characteristics and provenance of the gold resources of Garatu area of Bosso local government Niger state utilizing rocks and soil as the two main materials for the study. It was revealed that the area is basically underlain by Schist ranging to about 80% and granite which trend towards the south eastern part occupies the space of 20%. This was achieved as after a geological mapping and thin section petrography of the rock samples taken from the study area.

The result of the mineralization potential of the rock samples reveal gold enrichment of 72%, and in decreasing order are the enrichment factors of other elements, Sc 2.08%, Fe 1.21%, La 1.03%, Ce 0.9%, Sm 0.74%, Co 0.70%, Nd 0.6%, Ba 0.61%, Na 0.66%, V 0.3%, Zn 0.351%, Y 0.34%, Al 0.233%, Ni 0.21% and Sr 0.1013%. From the results above, only Gold has shown significant enrichment factor within the study area.

The result of the mineralization potential of the rock samples reveal soil sample enrichment of 90.86%, and in decreasing order are the enrichment factors of other elements, Sc 1.77%, Nd 1.30%, Fe 1.1%, Mg 1.1%. Ce 1.1%, La 1.04%, Al 0.944%, Zn 0.85%, Ba 0.653%, Na 0.62%, Ni 0.62%, Y 0.45%, V 0.37%, and Sr 0.133%. Like in rock sample, only Gold have shown significant enrichment factor within the study area. However, gold seems to have migrated from its primary environment and more concentrated the second environment.

The correlation matrix, gold in the rock sample seems to correlate weakly, moderately and positively with the following element of Ba, Ga, Th, Zn, Ce, Eu, la, Lu, Nd, Sc, Sm,

Y and Yb. In the soil sample, it correlates with As, Ga, Pb, Sr, Zn, Ce, La, and Sc. The results of the provenance studies indicate Tholeiite Series and Calc-Alkaline series origin from the SiO<sub>2</sub>-FeO<sub>t</sub>/MgO diagram and Metaluminous and Peraluminous origin from the A/CNK-A/NK Diagram.

## **5.2 Recommendations**

In order to avert blind mining and land degradation as a result of indiscriminate pitting and trenching – data acquired from this study can be used to not only manage the land use but also maximize profit for the both artisanal miners and the private investors.

As it is being practised in other sister African nations like Tanzania and South Africa, public loan program should be initiated for artisanal and small scale miners to create constant flow of credit.

Since its been established that there is more concentrate of gold in the soil than it is in the rocks of the study area, more energy should be channelled towards exploring the soil both for further research and exploration work.

## **5.3 Contribution to Knowledge**

This study emphasizes on the geochemical characteristics and provenance of the gold resources of Garatu area of Bosso local government Niger state utilizing rocks and soil as the two main materials for the study. It was revealed that the area is basically underlain by Schist ranging to about 80% and granite which trend towards the south eastern part occupies the space of 20%.

The result reveal that the gold is less mineralized in the rocks which is it primary environment while those in soil and in their secondary form are more mineralized. Meaning

that the rock has been weathered; releasing the primary gold which were now moved by weathering and concentrated in an area within the soil, hence given rise to higher concentration in the soil sample.

The correlation matrix, gold in the rock sample seems to correlate weakly, moderately and positively with the following element of Ba, Ga, Th, Zn, Ce, Eu, La, Lu, Nd, Sc, Sm, Y and Yb. In the soil sample, it correlates with As, Ga, Pb, Sr, Zn, Ce, La, and Sc.

The results of the provenance studies indicate Tholeiite Series and Calc-Alkaline series origin from the  $\text{SiO}_2\text{-FeOt/MgO}$  diagram and Metaluminous and Peraluminous origin from the A/CNK-A/NK Diagram.

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