GEOSCIENTIFIC PROSPECTION OF ORE DEPOSITS IN KATAEREGI, NORTH-CENTRAL NIGERIA

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OCTOBER 2023.

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A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL,
FEDERAL UNIVERSITY OF TECHNOLOGY MINNA, IN PARTIAL
FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTERS OF
TECHNOLOGY (MTECH) IN GEOLOGY (MINERAL EXPLORATION)

OCTOBER, 2023

DECLARATION

I hereby declare that this thesis **“Geoscientific Prospection of Ore Deposits in Kataeregi, North-Central Nigeria”** is a collection of my original research work and it has not been presented for any other qualification anywhere. Information from other sources (published or unpublished) has been duly acknowledged.

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Signature & Date

CERTIFICATION

The thesis titled “Geoscientific Prospection of Ore Deposits in Kataeregi, North-Central Nigeria” by KONYE, Finbarr Ugochukwu (MTech/SPS/2018/8584) meets the regulations governing the award of degree of Tech Geology of the Federal University of Technology, Minna and it is approved for its contribution to scientific knowledge and literary presentation.

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ACKNOWLEDGEMENTS

Thanks to God who made it possible for me to have come this far in my academic pursuit..I am grateful to my supervisor, Dr C.I Unuevho. I appreciate the effort of the Head of Department, Dr. (Mrs.) S. H. Waziri and all the lecturers in the department. I appreciate the effort of my family members, friends and well-wishers and everyone for standing by me.

ABSTRACT

This study is focused on delineating primary gold deposit and prospecting for cobalt (Co), manganese, nickel (Ni), copper (Cu) and zinc (Zn) by integrated surface geological mapping and elemental compositional analysis of samples of rock outcrops. Energy Dispersive X-ray Fluorescence Spectrometer was used to carry out elemental compositional analysis. The outcropping lithologic units are banded gneiss, augen gneiss, massive amphibolite, banded amphibolite and Older Granite. The metamorphic lithologic units generally trend NE – SW and dip eastwards in the area. Gold concentration is between 0.011 to 0.2 % within the south eastern and south western parts of the studied area. This gold concentration in these parts of the area far exceeds the economic threshold value of 0.00092 for gold. The gold is associated with 0.18 – 0.24 % Co in the south eastern part. This means that Co enrichment is above 100% in south eastern part. Similar, Co enrichment exists in the north eastern part, though unassociated with primary gold. Manganese, Cu, Zn and Ni concentration exist below their respective economic threshold value within the area. The gold and Co are found in the gneiss and amphibolite in the neighbourhood of granitic intrusions in the area. Subsistence level gold mining is common within Kataeregi and its environs. Many of the mines were not established on the basis of geosciences data. Consequently they become abandoned after a short period of operation, and are hardly reactivated. The economic value of the mines will be enhanced if some technological and economic critical metals are found within the area.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Ore is a natural material with a high concentration of economically valuable minerals that can be mined for a profit. An ore deposit is a natural body of rock that bears economic concentration of one or more metals (Unuevho *et al*., 2018). Ore deposit can also be defined as an occurrence of minerals or metals in sufficiently high concentration to be profitable to mine and process using current technology and under current economic conditions (Harraz *et al*., 2016). Ore deposits may be considered as: Commercial mineral deposits (Ore: suitable for mining in the present times) or non-commercial ore deposits (Protore: problems in mining, transportation, prices). Ore grade is the concentration of economic mineral or metal in an ore deposit.

There are several types of ore deposits: Magmatic, Hydrothermal, Sedimentary, and Residual (Harraz *et al*., 2016). Among numerous studies on the distribution of ore bodies in space through geological time, according to Goldfarb *et al*. (2010), and Maier and Groves, (2011) to mention but few their variations reflect tectonic setting, evolving atmosphere and oceans, and decreasing heat production in the Earth. However, Camwood and Hawkesworth (2013) caution that the spatial and temporal distribution of ore deposits is likely to be biased in terms of preservation. This is because preservation of different deposits can be affected to greater or lesser extents depending on their tectonic setting. High-grade iron ore bodies formed in Banded Iron Formation (BIF) are the largest single metal concentrations in the Earth’s crust. Angerer *et al*. (2014) identified the critical elements of a mineral system that are required to form these deposits in the Archaean and

Palaeoproterozoic of Western Australia. On a global scale, the well-recognized secular variation in the formation of Banded Iron Formation (BIF) with time (Cawood and Hawkesworth, 2013) is attributed to both the increase in oxygenation of the ocean–atmosphere system and the prevalence of large igneous provinces that reflect mantle plume breakout events and an increased hydrothermal flux to the oceans (Bekker *et al*., 2010). Angerer *et al*. (2014) show that, on a regional scale, the formation of a suitable primary host BIF is a function of the stratigraphic and geodynamic setting to consequent uncertainty in genetic models and thus exploration models derived from them (Mole *et al*., 2014). Nowhere is this better exemplified than in the long running debate regarding orogenic gold deposits, which account for more than 75 percentage of cumulative gold production (Phillips and Powell, 2010). These hydrothermal quartz vein-related deposits form in metamorphic terranes during the late stages of orogeny and typically post-date regional metamorphism of the host rocks (Goldfarb *et al*., 2005; Tomkins, 2013).

A metamorphogenic origin is most commonly advocated for the fluids Craw *et al*. 2010; Phillips and Powell, 2010). However, late orogenic magmatism is also a widespread feature in many orogenic belts, and many gold deposits show a spatial association with intrusions, as well as a broad temporal relationship (Goldfarb *et al*. 2005). This combined sedimentological and geochemical approach may ultimately lead to better prospectivity assessments of Phanerozoic sediment packages worldwide. Moles *et al*., (2014) and Hill *et al*., (2013) provided complimentary sulphur isotope studies on the Neoproterozoic–early Palaeozoic but recent research shows that microorganisms are involved in the biogeochemical cycling of gold, including its dissolution and re-precipitation at the surface and deep underground (Lengke and Southam, 2006; Reith and McPhail, 2006; Johnston *et* *al*., 2013). Thus the microbiology of gold has implications for its dispersion from ore deposits in the weathering environment and the design of geochemical exploration programmes to locate them. Shuster *et al*., (2013) contribute to this rapidly expanding field of research by demonstrating that sulphate-reducing bacteria can immobilize gold from saline and hypersaline solutions where chloride occurs in excess. Whilst the academic study of ore deposit genesis contributes to our understanding of Earth processes through geological time, the continued evolution of genetic models for ore deposits also enhances our ability to predict where new deposits may occur, and hence how to conduct exploration for new resources most efficiently and effectively. Lusty and Gunn (2014) outlined the challenges for future global resource security and the potential options for future supply.

The Federal Government of Nigeria has emphasized that resurgence of the mining industry is a key to reviving Nigerian economy (Unuevho *et al.*, 2016). There are massive ores and disseminated ones. The massive ore deposit to be a single mass with over 50 percentage of mineral component and a minimum cross sectional area of 100 m^2. Pardo *et al.,* (2012) remarked that ore bodies of disseminated minerals contain less than 20 percentage of mineral content, which is fine grained and occurs as specks and veinlets throughout the host rock body. Au occurs in quartz veins in sizes that are invisible to naked eyes to sizes that are visible large aggregates (Ralph *et al.*, 2016). The natural process of ore formation is known as metallogenesis.

Metallogenesis is driven by igneous activity, irrespective of whether the ore metals are deposited in hydrothermal veins, in pegmatites or concentrated in minerals that separated during magmatic crystallization Grainger *et al.,* (2008). Effective exploration and exploitation of ore mineral resources hinge upon integrated application of geological, geochemical and geophysical data. These data acquired within a known mine constitutes geoscientific characterization of the ore deposit at the mine. New mines can be revealed in other areas by analogous geoscientific data. The search for ore mineral resources begins with area selection using regional geological knowledge, followed by careful geological mapping, geochemical sampling, and geophysics and drilling.

1.2 Statement of the Research Problem

A lot of illegal and informal gold activities go on along the stretch of land between Minna and Bida in North-Central Nigeria. All these mines were established by trial and error approach. Many of these mines become inactive after short period of operation and are hardly replaced. Besides, the miners are unaware of other economic metals that commonly associate with the gold. One of such mining towns in this stretch of land is Kataeregi. Locating new mines within Kataeregi and immediate environs requires geoscientific characterization of the ore deposits in active mines and delineating areas with analogous geoscientific character, as well as ascertaining other economic metals associated with the gold ore. Such geoscientific characterization and determination of economic metals associated with within Kataeregi is yet to be conducted.

1.3 Justification for the Study

i. The knowledge of the economic metals associated with the gold ore will enhance the economic potential of the known gold deposits.

ii. The geoscientific characterization of the existing ore deposits at active mines in Kataeregi will help to reveal ore deposits that are yet to be discovered within Kataeregi and immediate environs.

1.4 Aim and Objectives of the Study

It is the aim of this research to ascertain other economic metals associated with gold ore, as well as delineate ore deposits that are yet unknown within Kataeregi and immediate environs.

The specific objectives are to:

i. Produce the geological map of Kataeregi environment on 1:15,000 scale
ii. Establish the lithologic unit that host gold ore within Kataeregi and immediate environs.
iii. Determine the concentration of gold associated metals in the metamorphic rocks.
iv. Determine the geo-electrical attributes (electrical resistivity, induced polarization and spontaneous potentials) of ore deposits within active mines.

1.5 Scope of the Research Work

This research work shall comprise geological mapping and production of geological map on the scale of 1:15,000, elemental concentration analysis using Energy Dispersive Fluorimeter (EDXRF) equipment.

1.6 Study Area

1.6.1 Geographical location

The study area (Kataeregi) is located 39 km along Minna – Bida road, in Katcha Local Government Area of Niger State, North-central Nigeria. The area is part of Bida Sheet 184

NE. It is located within Longitude $6^{o}17^{'}0^{''}$ E to $6^{o}23^{'}0^{''}$E and Latitude $9^{o}20^{'}$ $30^{''}$N to $9^{o}25^{'}$ $30^{''}$N on the scale of 1:15,000 covering a total area of about 68 km^{2} (Figure 1.1). It lies between the geographical co-ordinates of Northing's 811400 – 813200 m N and Easting's 732200 – 733400 m E in the Universal Traverse Mercator (UTM) Minna Zone 31. The topographic elevation around the site ranges from 335.0 to 365.0 m above mean sea level and generally slopes gently from the north towards the southern part. The area has a climate characterized by two seasons; the wet season and the dry season. The wet season starts from around mid-April and ends in October with an average rainfall of 1500 mm to 2000 mm while the dry season starts around November and ends in March with an average maximum temperature of about 33°C.

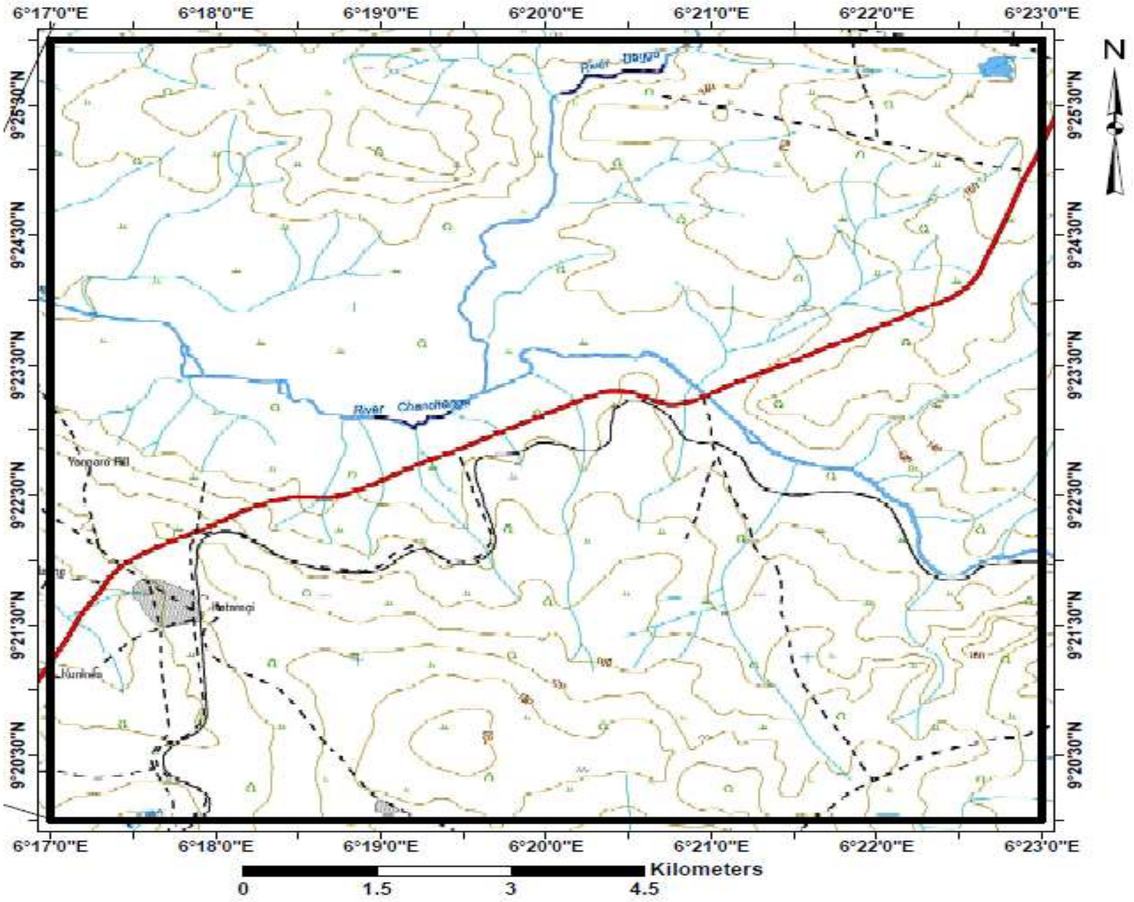


Figure 1.1: Topographic Map of Kataeregi

1.6.2 Regional geological setting

Kataeregi and immediate environs lie within Minna regional geological unit (Ajibade *et al*., 2008). Precambrian to Lower Paleozoic rocks outcrop in this region. They comprise of three main lithostratigraphic units: gneiss-migmatite complex in high-grade (amphobolite) metamorphicfacies; supracrustal Younger metasediments and metaigneous rocks in low-grade (green schist to lower amphibolite) metamorphic facies; granitic through granodoiritic to dioritic and gabbrointrusives and their extrusive equivalents. These rocks are an integral part of the Nigerian cratonic basement called northern Nigerian Massif. Kataeregi town is situated between Km 42 and Km 48, along Minna - Bida Road. It lies between latitude 9°20' N to 9°25' N of the Equator and longitude 6°15' E to 6°20' E of Greenwich Meridian.

The area is underlain by crystalline rocks of the basement complex of Nigeria. The area lies in south-western part of North central Nigeria basement complex. The gneiss is intruded by granites rocks of older granites suites. The structural pattern in the area show brittle-ductile deformation as represent by folding. The area lies entirely within the Nigerian Basement Complex which forms a part of the Pan-African mobile belt between the west craton to the west and the congo craton to the south east. The dominant rock type in the area is granite-gneiss complex among others. The whole part (north to south) is occupied by granite group of rock. In the eastern part banded gneiss variety is found.

1.6.2 Drainage pattern, vegetation and climate of the area

The area is drained by River Dagga and its tributaries (Rivers Weminafia and Kwakodna) flowing in NNE-SSW direction in accordance with one of the fracture patterns in the area.

The area falls within the Guinea savannah vegetation comprising grasses, shrubs and trees with greater concentration of the trees found along river channels.

The climate alternates between rainy season (April to October) and dry season (November to March) with the highest amount of rainfall (1525 mm) recorded in August/September (Grant *et al*., 1978). The dry season is marked by the influence of harmattan which is as a result of north-east trade wind that blows across the Sahara and is often laden with dust lasting from December to February. During this period, the area is reduced to bare land due to bush burning resulting from dryness of the soil and grasses.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Geology of Nigeria

The geology of Nigeria is made up of three lithostratigraphic units: basement complex, younger granites and sedimentary basins, which are roughly in equal proportions (Figure 2.1). Other minor formations are the volcanic plateau and the river alluvium (Adelena, 2012). The basement complex terrain comprises of rock types such as migmatitic and granitic gneisses, quartzites, slightly migmatised to unmigmatized meta- sedimentary schists and diorite rocks and various igneous intrusions. These rocks which range from the Precambrian through the Jurassic younger granites to the Tertiary to Recent volcanic rocks overlying the basement complex (in the south, north-east and north-west) consist of arkosic, gravely, poorly and cross-bedded sandstone, shales and limestone (Adelena, 2012).

The crystalline basement complex rocks are hard, with low permeability and generally not water bearing. Most of the areas of the country underlain by this rock type fall within the semi-arid parts where surface water is either, seasonal or non –existent, and groundwater would then be the only source of water (Jimoh *et al*., 2019). Despite the poor hydrological characteristics, basement complex rocks are still important in groundwater development of Nigeria, because groundwater occurs in the weathered and fractured zones within the rock formation and provides a lot of water need of the rural population in over 50 percent of the country. The crystalline basement of Nigeria generally represents the deeper, fractured aquifer and is noted as a poor source of groundwater. Streams and rivers rise quickly during and after precipitation events, thus indicating a rather low storage capacity of the soil and underlying rocks. Generally basement complex aquifers have low to moderate yields (0.083 to 3 litres per second) (Ge and Garven 2013).

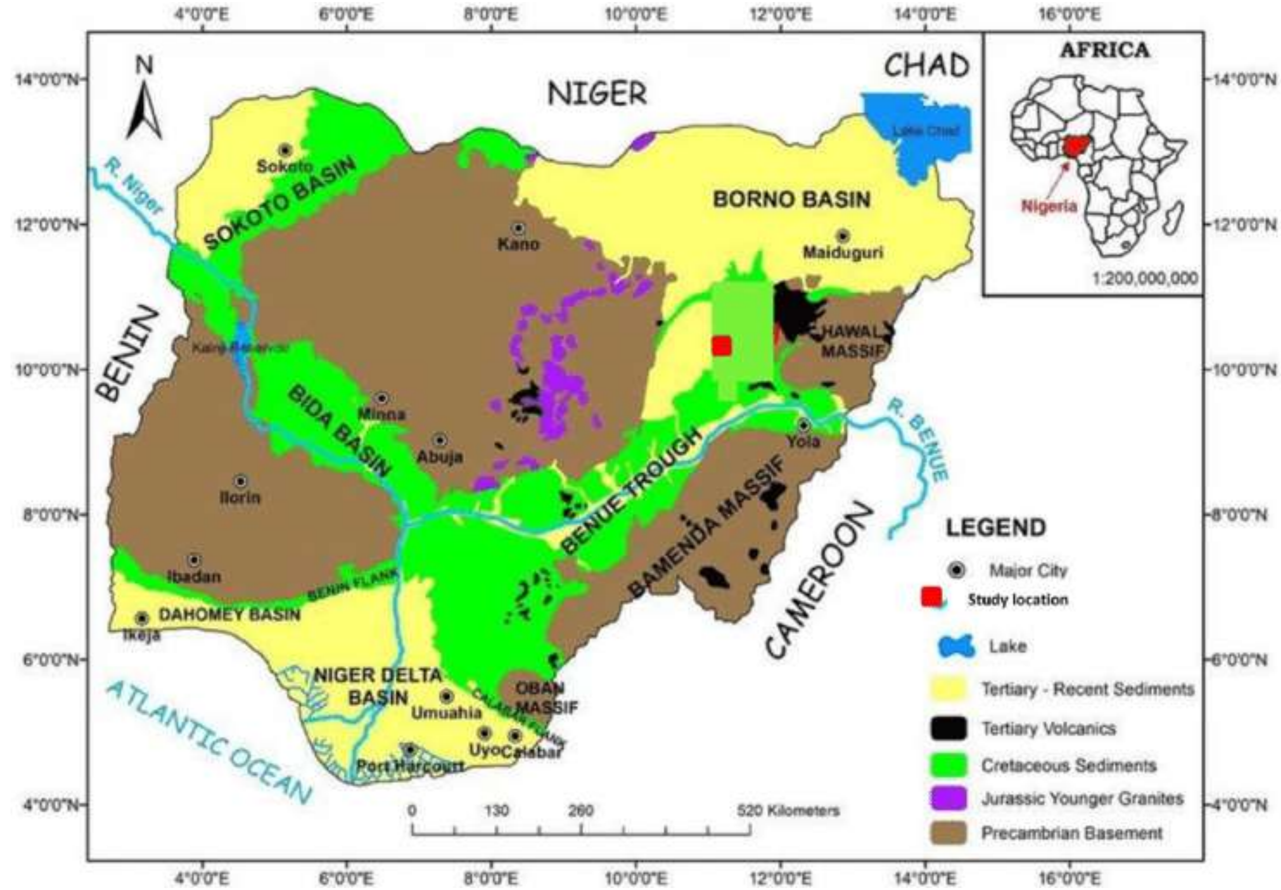


Fig. 2.1: Geological map of Nigeria (Jimoh *et al.*, 2019).

Nigeria is underlain by seven major sedimentary basins which are Calabar Flank, Dahomey Basin and Niger Delta Basin which are along the coast, and more interior Benue Trough, Chad Basin, Nupe Basin and the south eastern sector of the Illumededen Basin (Mali-Niger-Benin-Nigeria) known locally as the Sokoto Basin. These sedimentary basins have higher groundwater potential than the basement complex rocks. However, shales, mudstones, and siltstones are very poor aquifers, and in most cases are aquicludes.

The volcanic plateau is found around Jos and Bauchi states of Nigeria, with rock types mainly olivine basalts, Cretaceous lavas and tuffs. These rocks form aquifers with low to moderate yields (usually below 3 litres per second) which are typically unconfined with water table of less than 5m and borehole and borehole depth of 15 to 50 m. Alluvial deposits cover the valleys of major rivers and streams ranging from the thin discontinuous sands occurring in the smallest streams to the thick alluvial deposits of rivers Niger and Benue and are largely unconfined with shallow water tables. The rock types around Kaduna comprise, undifferentiated basement complex, mainly gneiss meta-sediments (phyllite and schists), quartzite, older granite, younger granite and newer basalt.

2.2 Basement Complex

The discussion on the Precambrian geodynamic evolution usually generates controversy due to the rarity of naturally verifiable data on the physico-chemical conditions of the Earth from that era (Kohanpour *et al*., 2017). As pointed out by Hubbard *et al.* (1975), many of the studies on the evolution of the Nigerian Basement Complex (NBC) have been largely generalized and subjected to individual biases. Such subjective dispositions have largely resulted from the paucity of reliable data on the basement rocks. Although there is a general agreement that the entire basement in Nigeria was affected by the Pan-African orogenic event, the extent and impact of that event remains an issue for debate. Whereas some researchers (Harper *et al*., 1973; Cahen *et al*., 1984) hold the view that the Pan-African orogeny was widespread, overprinted and obliterated all traces of older tectono-metamorphic events, others (Ajibade *et al*., 2008; Fitches *et al*., 1985;) argue that imprints of older events remain isotopically preserved within the Nigerian Basement Complex.

More so, considering the ubiquity of the Pan-African reactivation across the Nigerian basement, the protolith of the age within the basement remains debatable (Ferre *et al.*, 1996). Even though studies on the evolution of the basement rocks in Nigeria commenced well over 4 decades ago, most of such studies are largely skewed in favour of age dating the complex using radiometric data without paying adequate attention to other aspects.

Two areas where the basement suffers from apparent neglect relative to isotope geology and geochemistry are the structural geology and numerical modelling. According to Anor and Freeth (1985), due to the paucity of structural data, most of the thermo-tectonic and orogenic events postulated for the basement complex are inferred from the correlation of available isotopic data with various dated events from different parts of Africa. Also, Odeyemi (1981) has attributed the seemingly poor understanding and classification of the Nigerian Basement Complex to be as a result of the over-reliance on isotopic data without a corresponding integration of other aspects of geosciences. Although some workers have attempted integrating structural and isotopic data for the better understanding of the evolution of the basement complex (Ferre *et al.*, 1996), more comprehensive data and studies are needed in this direction. The NBC is part of the southern end of the Trans-Sahara Pan-African mobile belt situated between the Archean Paleoproterozoic blocks of the West African and Congo cratons. The basement complex is considered to be part of the reactivated Pan-African belt that resulted from the collision of the passive continental margin of the West African Craton and the active margin of the Tuareg Shield.

This Trans-Saharan-Pan-African orogenesis led to the development of various high grade metamorphism, massive granite plutonism and late orogeny-parallel tectonics (Ominigbo *et* *al*., 2020; Okonkwo and Ganev, 2012). Although there remains a debate as to the extent and effects of the Pan-African orogenic event, there is seemingly an agreement amongst researchers that the entire basement was affected by the 650 Ma ±150 thermo-tectonic events (Ferre *et al.,* 1996; Anor and Freeth, 1985). And, whereas some early researchers (Pidgeon and Pankhurst, 1976) considered the Nigerian basement as a singular Archean block, later studies (Ferre *et al*., 1996; Ekwueme, 1990) have demonstrated that the basement complex in Nigeria consists of at least 2 geochronologically distinct units: an Archean province in the western part of the country and Eburnean block to the east. Based on geochronology, stratigraphy and composition, the rocks of the NBC fall into 2 broad groups: the pre- Pan-African crystalline rocks (2.8 – 1.3 Ga) comprising migmatite gneisses and ancient granites; and the Pan African crystalline rocks (1.1 – 0.5 Ga), consisting of the Older Granites and metavolcano-sedimentary series.

Typically, the Pan-African lie unconformably on the pre-Pan-African basement (Ekwueme, 1990). The complex is underlain by different lithological units: the migmatite-gneiss-quartzite complex, the Older Granite and the Younger Granites otherwise regarded as the Schilt Belts and the undeformed charnockites, gabbroic and dioritic rocks (Ominigbo *et al*., 2020; Odeyemi, 1981). In many places, the Older Granites intrude both the migmatite gneisses and the schists. Chronologically, the Migmatite Gneisses are the oldest rocks in the basement complex and are thought to be reworked older crust by orogenic events, with the undeformed acid and basic dykes being of later- to post-Pan-African orogeny (Haruna, 2017). The NBC is considered to be characterized by contrasted accreted terrains (typical of the south of the Pan-African belt of West Africa) which can be grouped into 2 provinces: western Nigeria and eastern Nigeria. The western group consists of tonalite-trodnhjemite granodiorite (TTG) type orthogneisses, amphibolites facies and greenstone facies metasediments. On the other hand, the rocks in the eastern province are predominantly made up of synformal schist belts ranging from greenstone to amphibolite facies. Whereas the petrological units in western Nigeria are Archean, their counterparts in the eastern province are typically Eburnean. More so, the general absence of gold mineralization and banded iron formations in significant amounts in eastern Nigeria support the inference that unlike western Nigeria, the east lacks.

2.3 Younger Granite

Younger Granite Ring Complexes (YGRC) constitutes a major subdivision within the Basement Complex rocks of Nigeria. There is sufficient information which indicates that the YGRC province has some of the best examples of granitic ring complexes in the world. The occurrence of these ring complexes was possible through a process of intense volcanism which was characterized by the formation of rhyolites ignimbrites, basalts and trachyte, and the emplacement of ring faulting through a process commonly referred to as cauldron subsidence.

Volcanic episodes were characterized by elliptical and crescent shaped intrusions such as per alkaline and non per alkaline granites, and minor amounts of syenites, anorthosites, porphyries, gabbro, hybrid rocks and equally ring dykes and cone sheets. Even though the younger granites intrusions overlap each other, it is found that its emplacement follows a north-south trending order over a 1,300 kilometre distance along Nigeria-Niger, and a NNE-SSW trending order over a 1,000 kilometre distance stretching into the Cameroun province Sedimentary basins: Over the years, serious focus has been on the petroliferous sedimentary basins and the highly mineralized schist belts and the Younger Granites in Nigeria with the gneisses and Older Granites suffering relative neglect. This is in large part due to the mineral and hydrocarbons exploration activities in those schist belts and sedimentary basins respectively (Gok *et al*., 2010). As a result, the structural attributes of the Nigerian basement rocks particularly the gneisses remain poorly understood. This situation has contributed to the current fairly poor understanding of the evolution of the basement complex, particularly the extent and episodicity of the Pan-African event due to paucity of comprehensive and reliable scientific data.

2.4 Sedimentary Basin

Sedimentary basins are places where subsidence of Earth's crust has allowed sediment to accumulate on top of a basement of igneous and metamorphic rocks. Over geologic time these sediments and associated fluids are chemically and mechanically transformed through the compaction and heating associated with basin subsidence. The buried materials constitute the sedimentary stratigraphic record and contain both unique natural resources and information regarding the history of tectonic, biologic, oceanographic, and climatic events during Earth's evolution.

Sedimentary basins and sedimentary materials cover most of Earth's surface. Understanding the evolution of sedimentary basins, and the reasons for their existence in particular places at specific times, can provide fundamental insights into a wide range of earth processes. The imprint of geologic events left on the materials of sedimentary basins is the most detailed record of the history of earth's outer shell, the lithosphere. Basins come in many shapes and sizes and form in response to a variety of processes that influence the elevation of earth's surface. Some are filled with strata deposited entirely in terrestrial environments, others with strata deposited below sea level in marine environments; many basins include both kinds of sediment. Sedimentary basins also develop in many different geodynamic settings, and their geohistories are diverse. To define the nature of basin-forming events, it is essential to understand how and where sedimentary strata have been deposited and preserved during earth’s history.

2.5 The impact of Artisanal Miners

The impact of the activities of artisanal and small-scale gold mining on the environment and health of the workers and inhabitants of an area can never be over emphasized. The artisanal and small-scale gold mining simply implies the mining of gold by individuals or at most small groups of people employing basic implements with or without valid permits from government. Series of scientific work have been documented revealing various impacts of Artisanal revealing various impacts of artisanal and Small-scale Mining (ASM) ranging from environmental, fluvial and soil contamination, health challenges and mitigations (Appleton *et al*., 2001; Jung, 2001; Hilson, 2002; Lottermoser and Pratt, 2007; Mallo, 2012).

The high and increasing gold price among other metals in the world market today has triggered the attentions of world populace, marginalized communities and developing countries into adopting this informal method of mining. Since the activity require modest investment and minimal technical skills to complement their source of livelihood. Gold as one of the most valuable precious metals, constitute more than half of all the minerals mined worldwide, with an estimate of about 6 to 9 million artisanal miners involved

(Tieguhong *et al*., 2009). Mining is an essential economic activity that has the potential of contributing to rapid socioeconomic development of a country blessed with the resource. It can also be source of doom to mankind if not properly executed, leading to environmental and health challenges to plants and animals. Particularly within the North-western Schist Belt and some other parts of Nigeria, gold mining and other associated sulphide minerals by artisans have been on the increase. This activity might have introduced toxic trace elements into the soils, stream sediments and even the water draining the area. This work therefore focuses on the geochemical investigation and physical impact assessment of Kataeregi artisanal gold mining, North-central Nigeria.

2.6 Geology of the Area

An accurate interpretation of resistivity data of an area may not be obtained without a good knowledge of the local geology of that area, thereby necessitating a detailed geological mapping of the area. About half of the landmass of Niger State is underlain by the Basement Complex rocks while the remaining half is occupied by the Cretaceous Sedimentary rocks of the Bida-Basin. It lies within the north-central portion of the Nigerian Basement complex rock which is characterized by three lithofacies: the migmatite-gneiss complex, the low grade schist belt and the older granites (Olasehinde and Amadi, 2010). The geological mapping revealed that the area is underlain by granite and gneiss which in most locations are undifferentiated granite-gneiss-complex

2.7 Previous Work

Geoscientific research has emphasized on the stratigraphy, sedimentary structures, petrology, paleocurrent pattern and economic geology of the area. Garba (2002) remarked that gold mineralisation and rare metals (Ta, Nb) bearing pegmatites around Zungeru region area ligned along regional lineaments created during the Pan African orogeny. Ajibade *et al.* (2008) reported that some gold mineralisation is hosted within the Ushama Schist Formation**.** Ralph *et al.* (2016) reported that Au occurs in quartz veins in sizes that are invisible to naked eyes to sizes that are visible large aggregates. Ajibade *et al.* (2008) reported some Au mineralisation hosted within Ushama Schist and Kushaka Schist in north central Nigeria basement complex.

Bahiru and Woldai (2016) employed surface geological mapping to build relationships between lithology and structure to assess controls on gold mineralization in Buhweju area of Uganda. They established a cluster of gold occurrences associated with high lineament density at Kitata mine site. However, geochemical indications should be validated by geophysical investigations. Ore mineral exploration is now preferably conducted using integrated surface geological, geochemical and geophysical methods (Unuevho *et al*., 2018). Some researchers employ geoelectrical methods to prospect for ore mineral resources because many ore minerals are electrically conductive, unlike their generally resistive host rocks (Kearey *et al*., 2002; Salmirine and Turunen, 2007; Musset and Khan, 2009; Pardo *et al*., 2012).

Electrical resistivity and spontaneous potential methods were first successfully employed to prospect for ore minerals in the 1900’s by Schlumberger brothers. From that time, the methods have detected numerous ore bodies such as Kimheden ore body at Skellefte in northern Sweeden, copper ore at Chalkidili in northern Greece and sulphide ore body at Sariyer in Turkey (Reynolds, 2011). Unuevho *et al.* (2016) combined digital elevation model with surface geological mapping and geoelectrical data to prospect for ore minerals in Kundu, north central Nigeria basement complex. They interpreted spontaneous potential values between +20 and +40 mv to indicate possible ore mineral bearing quartz veins and pegmatite bodies, when associated with IP values greater than 10 ms. They also interpreted SP values in the neighbourhood of -100 mv to indicate possible subsurface massive ore minerals, when characterized by resistivity values lower than 150 Ωm. Their interpretation is in conformity with geoelectrical characterization of massive ore minerals, and ore minerals disseminated in pegmatite dikes and quartz veins.

Kearey *et al.* (2002), Salmirine and Turunen (2007), Musset and Khan (2009) and Pardo *et al.* (2012) employed geoelectrical methods to prospect for ore mineral resources because many ore minerals are electrically conductive, unlike their generally resistive host rocks. Electrical resistivity and spontaneous potential methods were first successfully employed to prospect for ore minerals in the 1900's by Schlumberger brothers. From that time, the methods have detected numerous ore bodies such as Kimheden ore body at Skellefte in northern Sweeden, copper ore at Chalkidili in northern Greece and sulphide ore body at Sariyer in Turkey (Reynolds, 2011). Some of the successes in induced polarisation prospecting are Kalgoorlie ore field in western Australia (Telford *et al*., 2001), Gortdrum copper-silver deposit in Ireland, copper-gold ore body within Malmfalten ore district in Sweden (Malmquist and Parasnis,1972; Rezvani, 2015) and copper mountain deposit in Quebec in Canada (Hallof and Engelmann, 1996).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

The materials used for the study comprises of some geologic materials according to the different methods used in the studies. In geological methods, Geologic hammer was used to collect some rock samples, sledge hammer were also used to collect hard samples of rocks use for geochemical analyses, hand held global positioning system (GPS) were adopted to determine the coordinates i.e. the longitude and latitudes in different locations, the compass clinometer was also employed to determine the dip and strike of the rock structures. Samples of rocks were picked at random using the sledge hammer to break the rocks, geologic hammer were also used in some cases. The strike and dip of some of the rock structure were measured using the compass clinometer and recorded in the field notebook. The topographic map of the study area was also used to traverse along the area. Total of 14 rock samples were collected on the field (Figure 3.1), from different rock samples for geochemical analyses and thin section analyses. The rocks were packed in nylon bags for easy carriage.

3.2 Methods of Study

3.2.1 Geological mapping

Surface geological mapping was conducted on 1:15,000 scale on the topographical map of Kataeregi, part of Bida Basin Sheet 185 NW. This was done with the aid of a global positioning system (GPS), compass clinometers, hammer, markers, measuring tape sampling bags, sledge hammer and a digital camera. Representative rock samples were studied and collected with the aid of a geological hammer and sledge hammer from all the available rock exposures on the surface. Each outcrop was observed and described according to its mode of occurrence, macroscopic characteristics (colour, mineralogy and texture), structural elements, presence of any weathered surfaces and field relationship with adjacent rocks; whether they have been intruded by or they have intruded other rocks were carefully observed and recorded.

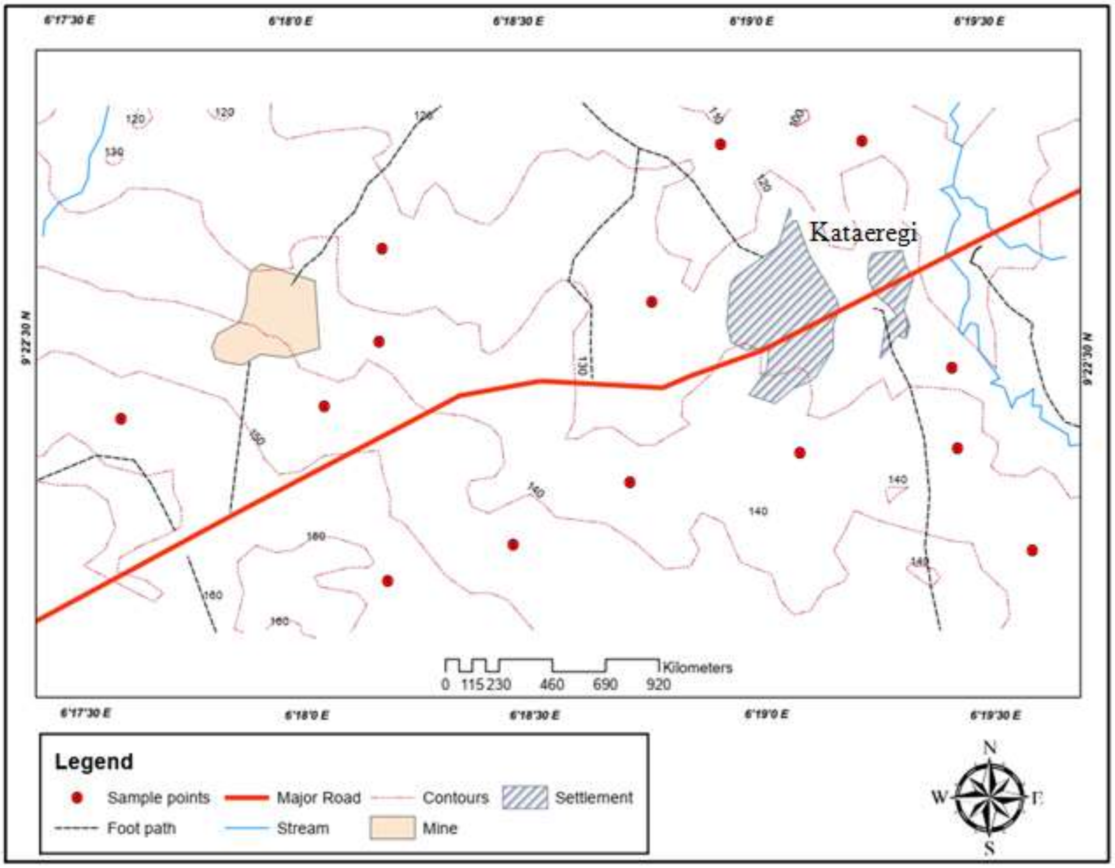


Figure 3.1: Sample location map of the study area.

Lithological boundaries were carefully identified or inferred by careful observation of changes in rock types, nature of soil and topography. Strike and dip values of rock units were measured using a compass clinometer. Field photographs and sketches to support observations made in the field were taken with a digital camera. The samples collected in the field were labelled using a marker and points were plotted on the base map at the exact locations where the samples were observed, described and collected. This was made possible with the aid of a GPS and geographical coordinates of the base map. All the labelled samples were carefully stored using sampling bags.

The base map for the geological mapping was produced on a scale of 1:1500 from Bida Sheet 184 NW. Fresh rock samples were taken from rock outcrops on the field, and the outcrop locations indicated on the base map using GPS. Textures of the fresh rock were observed, and strike and dip of metamorphic rocks were taken.

3.2.2 Sample Collection for Laboratory Analyses

Rock samples were collected in the field. Some of the samples were selected for thin section analysis. Clean polyethylene bags were used in storing them. The sample bags were carefully labelled with permanent markers to avoid mix up. The other rock samples were further selected for geochemical analysis.

Thin sections of representative samples were made from the fresh rock samples. Petrographic analysis of the thin sections was done using a petrographic microscope. Identified minerals under thin sections were combined with rock textures to name the rocks. Plane polar and cross polar properties of the rocks were obtained and the optical properties of the rocks were identified. The named rocks were plotted on the base map, and geological map was then produced on 1:15000 scales.

3.2.3 Elemental composition analysis of rock samples

Representation of rock samples were selected from twelve different locations, in the vicinity of granite bodies. The samples were crushed using a pestle and mortar. The crushed samples were homogenized. The homogenized samples were placed in an EDX 3600B Energy Dispersion X-ray Fluorescence Spectrometer. Percentage elemental content of Au, Mn, Co, Ni, and Zn were given.

3.2.4 Analytical Method

Twelve stream sediments samples were subjected to geochemical analysis using X-ray fluorescence spectroscopy (XRF) to determine trace and major elements concentration in the samples. The XRF analyses were carried out at the National Agency for Science and Engineering Infrastructure (NASENI) centre of excellence in Nanotechnology and Advanced material in Akure, Ondo State.

3.2.5 Ascertaining ore status of the rock bodies

The percentage concentration of the metals was divided by their average crustal abundance to obtain their enrichment factor. The determined enrichment factor was compared with the economic enrichment factor and threshold values.

3.2.6 Data Processing

The data were processed using the following software: Surfer 13

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Field Geology

The study area lies within the Basement Complex. The major lithology encountered on the Basement Complex includes: Granite, Migmatite, Gnesis and Amphibolite Schist as indicated in the geological map of the study area (Figure 4.1).

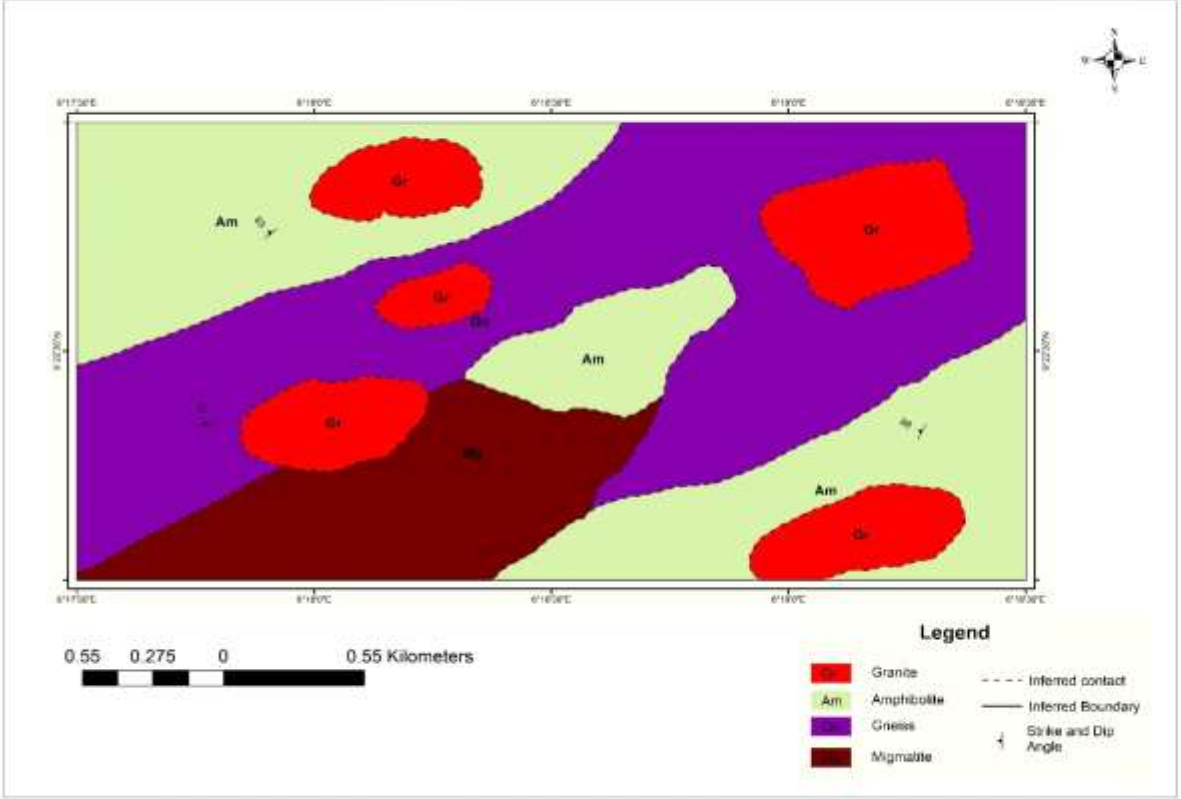


Figure 4.1: Geological map of Kataeregi

4.2 Description of Outcrops

In plate I, the granite consists of quartz, orthoclase and biotite. It has a foliation of NE-SW direction with quartz vein cutting across it. The granite is porphyritic or apheneritic in texture and most of it occurred adjacent. The rocks appear in most places in the field. It is pale to light colour, fine grained texture and some phaneritic texture. The crystals are equal with distinct outline. The individual crystal may be about 0.2 to 0.6 mm in size. In some locations, the rock looks like gneiss structure with few biotite minerals.

Augen-gneiss consists of white and dark spots (Plate II). It occurs in some parts of study area. It trends NW-SW direction. Its dark spotted colour makes it distinguished in the field. It is mostly found in the southern part of the study area. In plate III, there is an intrusion of amphibolite into granite rock that is amphibolite was seen in line with granite, this structure were seen in the eastern part of the study area.

Plate I: Granite; Longitude 9°22′1″N Latitude 6°18′20″ (Kataeregi)

Plate II: Augen gneiss; Longitude: 9°22′23″N Latitude: 6°18′36″E (Kataeregi)

Plate III: Ganite intruded into amphibolite: Longitude 9°23′04″ N Latitude 6°18′09″ E (Kataeregi)

Plate IV shows a migmatite rock sample. Its structure and shape makes it a unique sample as seen in the field. Magmatite was seen in the western part of the study area.

Plate IV: Migmatite: Longitude 9°22′23″ N Latitude 6°18′01″E (Kataeregi)

Samples of gold were detected around stream sediments (Plate V). The corresponding features around those places are massive amphibolite, running waters and sandy soils.

Plate V: Gold Sample: Longitude 9°22′16″ N Latitude 6°18′29″ E (Kataeregi)

Plate VI shows a pond area, where artisan mining takes place. Gold is sometimes seen with the local miners in a porcelain plate as shown above. The local miners have to dig millions of feet inside the ground level to get the gold sample.

Plate VI: Pond Area; Latitude 9°22′17″ N, Longitude 6°18′30″ N (Kataeregi)

4.3 Structural Geology

Structures mapped on the Basement Complex in the study area include: joints, faults, micro-folds and veins. The joint ranges from open joints (average opening of about 2.5cm) or healed joints (filled with quartz vein or feldspar). The lithology and structures in the study area have a general trending pattern of NE-SW.

4.4 Petrography

The microscopic study of some selected rock samples in thin section revealed the major mineral component of the different rock types mapped in the study area. The photomicrographs of the observed optical properties of these essential mineral and their textural relationships in plane polarized light (PPL) and cross polarized right (XPL) are presented in plates VII, VIII, IX, X and XI. The optical properties are presented in Tables 4.1, 4.2, 4.3, 4.4, and 4.5. The mineral compositions of rock samples from the area of study are quartz, Amphibolite, biotite, Muscovite and orthoclase.

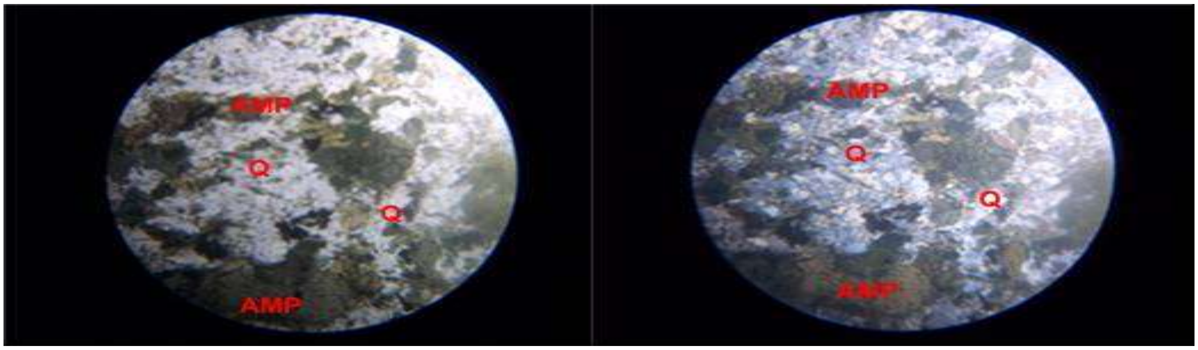


Plate VII: Thin section photomicrograph of sample L1; XPL and PPL X4(Geo-Solution laboratory centre-Bosso Minna)

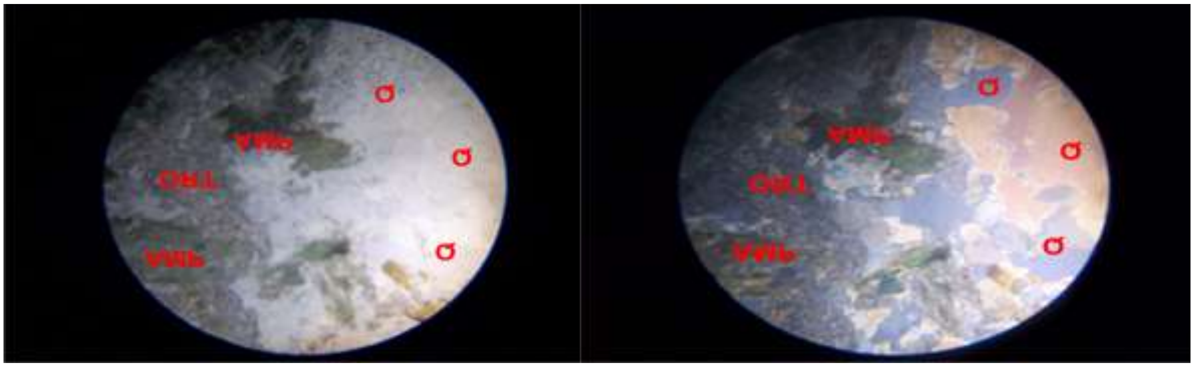


Plate VIII: Thin section photomicrograph of sample L2, XPL and PPL x40 (Geo-Solution laboratory centre-Bosso Minna)

Table 4.1: Description of thin section analyses of sample L1

MINERALS	OPTICAL PROPERTIES	(XPL)	(PPL)	ASSUMED ROCK NAME
QUARTZ	Color	Bluish to light blue	Colourless	AMPHIBOLITE SCHIST
	Relief:	Low relief	Low relief	
	Form/size	Anhedral to euhendral	Anhedral to euhendral	
	Inclusion	Absent	Absent	
	Cleavage	Absent	Absent	
	Extinction	present	Absent	
	Interference	Present	Absent	
	Pleochroism	Low pleochroic	Low pleochroic	
	Twinning	Absent	Absent	
AMPHIBOLITE	Color	Greenish to brown	Greenish	
	Relief:	Low relief	Absent	
	Form/size	Euhendral to euhendral	Euhendral to anhendral	
	Inclusion	Absent	Absent	
	Cleavage	Two cleavage direction	Two cleavage direction	
	Extinction	Absent	Absent	
	interference	Absent	Absent	
	pleochroism	Absent	Absent	
	Twinning	Absent	Absent	

Thin Section Analysis in Geo-solution laboratory centre Bosso Minna

Table 4.2: Description of thin section analyses of sample L2

MINERALS	OPTICAL PROPERTIES	(XPL)	(PPL)	ASSUMED ROCK NAME
QUARTZ	Color	Bluish to light blue	Colourless	Amphibolite schist with quartz vein
	Relief:	Low relief	Low relief	
	Form/size	Anhedral to euhendral	Anhedral to euhendral	
	Inclusion	Absent	Absent	
	Cleavage	Absent	Absent	
	Extinction	present	Absent	
	interference	Present	Absent	
	pleochroism	Low pleochroic	Low pleochroic	
	Twinning	Absent	Absent	
ORTHOCLASE	Color	Blueish to milky	Colourless	
	Relief:	Low relief	Low relief	
	Form/size	Anhedral to	Anhedral to	
	Inclusion	euhendral	euhendral	
	Cleavage	Absent	Absent	
	Extinction	Absent	Absent	
	interference	Present	Absent	
	pleochroism	Present	Absent	
	Twinning	Low pleochroic Carlsbad (turbid texture)	Low pleochroic Absent	
AMPHIBOLITE	Color	Greenish to brown	Greenish Absent	
	Relief:	Low relief	Euhendral to anhendral	
	Form/size	Euhendral to euhendral		
	Inclusion	Absent	Absent	
	Cleavage	Two cleavage direction	Two cleavage direction	
	Extinction	Absent	Absent	
	interference	Absent	Absent	
	pleochroism	Absent	Absent	
	Twinning	Absent	Absent	

Thin Section Analysis in Geo-solution laboratory centre Bosso Minna

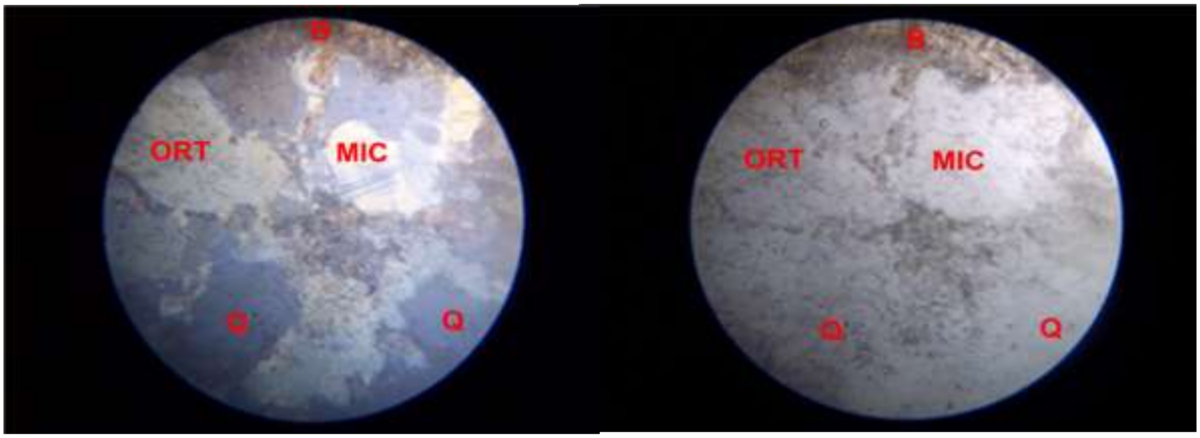


Plate IX: Thin section photomicrograph of sample M18, XPL and PPL x40 Geo-solution laboratory centre Bosso Minna

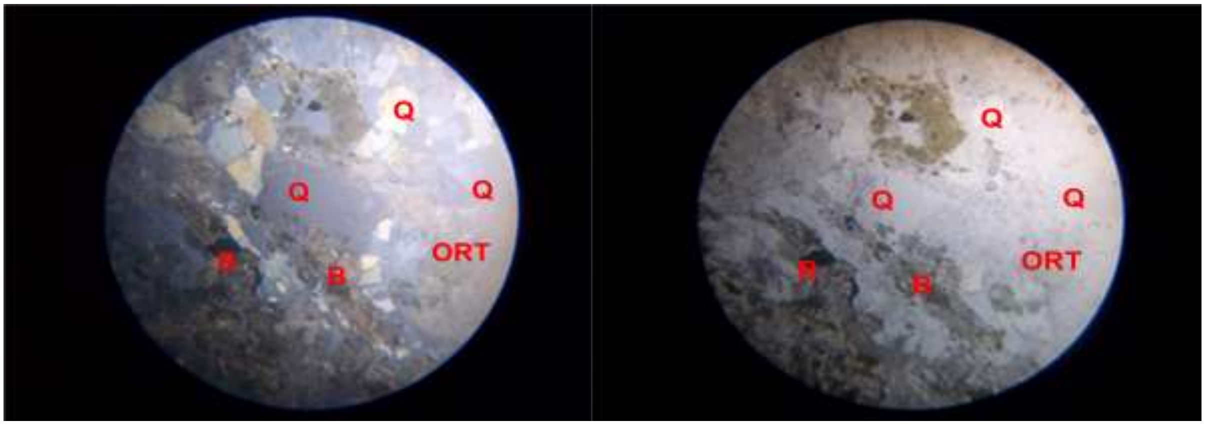


Plate X: Thin section photomicrograph of sample M16, XPL and PPL x40 Geo-solution laboratory centre Bosso Minna

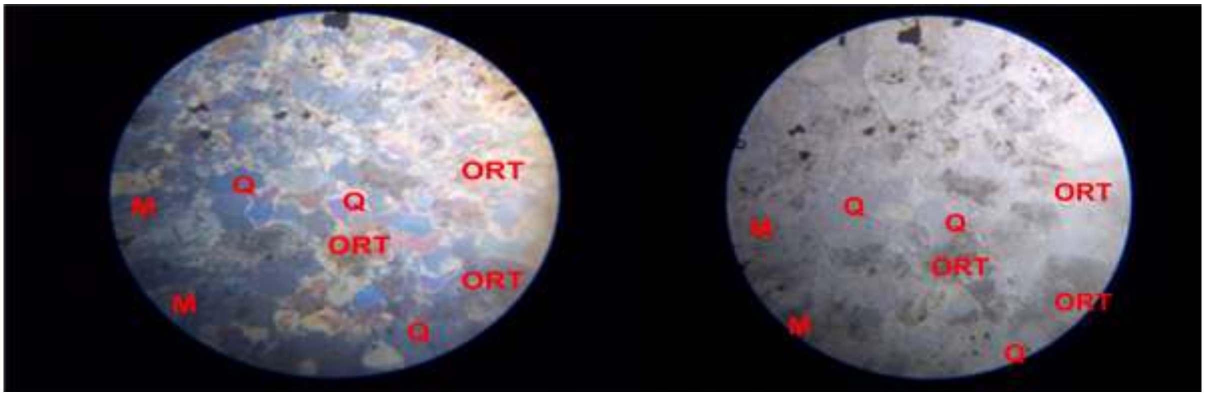


Plate XI: Thin section photomicrograph of sample S8, XPL and PPL x40 Geo-solution laboratory centre Bosso Minna

Table 4.3: Description of thin section analyses of sample M18

MINERALS	OPTICAL PROPERTIES	(XPL)	(PPL)	ASSUMED ROCK NAME
QUARTZ	Color	Bluish to light blue	Colourless	GRANITE
	Relief:	high relief	Low relief	
	Form/size	Anhedral	Anhedral	
	Inclusion	Absent	Absent	
	Cleavage	Absent	Absent	
	Extinction	present	Absent	
	interference	Present	Absent	
	pleochroism	Low pleochroic	Low pleochroic	
	Twinning	Absent	Absent	
ORTHOCLASE	Color	Blueish to milky	Colourless	
	Relief:	Moderate relief	Low relief	
	Form/size	Anhedral	Anhedral	
	Inclusion	Absent	Absent	
	Cleavage	Absent	Absent	
	Extinction	Present	Absent	
	interference	Present	Absent	
	pleochroism	Low pleochroic	Low pleochroic	
	Twinning	Carlsbad (turbid texture)	Absent	
BIOTITE	Color	Dark brown	Dark	
	Relief:	Low relief	Absent	
	Form/size	Euhendral	Euhendral	
	Inclusion	Absent	Absent	
	Cleavage	Two cleavage direction	Two cleavage direction	
	Extinction	Absent	Absent	
	interference	Absent	Absent	
	pleochroism	Absent	Absent	
	Twinning	Absent	Absent	
MICROCLINE	Color	Bluish colouration	Colourless	
	Relief:	Moderate relief	Absent	
	Form/size	Euhendral	Euhendral	
	Inclusion	Absent	Absent	
	Cleavage	Absent	Absent	
	Extinction	Absent	Absent	
	interference	Absent	Absent	
	pleochroism	Absent	Absent	
	Twinning	Crossed hatch	Absent	

Thin Section Analysis in Geo-solution laboratory centre Bosso Minna

Table 4.4: Description of thin section analyses of sample M6

MINERALS	OPTICAL PROPERTIES	(XPL)	(PPL)	ASSUMED ROCK NAME
QUARTZ	Color	Bluish to light blue	colourless	SCHIST
	Relief:	Low relief	Low relief	
	Form/size	Anhedral	Anhedral	
	Inclusion	Absent	Absent	
	Cleavage	Absent	Absent	
	Extinction	present	Absent	
	interference	Present	Absent	
	pleochroism	Low pleochroic	Low pleochroic	
	Twinning	Absent	Absent	
ORTHOCLASE	Color	Blueish to milky	colourless	
	Relief:	Low relief	Low relief	
	Form/size	Anhedral	Anhedral	
	Inclusion	Absent	Absent	
	Cleavage	Absent	Absent	
	Extinction	Present	Absent	
	interference	Present	Absent	
	pleochroism	Low pleochroic	Low pleochroic	
	Twinning	Carlsbad (turbid texture)	Absent	
BIOTITE	Color	Dark brown	Dark	
	Relief:	Low relief	Absent	
	Form/size	Euhendral	Euhendral	
	Inclusion	Absent	Absent	
	Cleavage	Two cleavage direction	Two cleavage direction	
	Extinction	Absent	Absent	
	interference	Absent	Absent	
	pleochroism	Absent	Absent	
	Twinning	Absent	Absent	
		Absent	Absent	

Thin Section Analysis in Geo-solution laboratory centre Bosso Minna

Table 4.5: Description of thin section analyses of sample S8

MINERAL	OPTICAL PROPERTIES	(XPL)	(PPL)	ASSUMED ROCK NAME
QUARTZ	Color	Bluish to light blue	Colourless	MUSCOVITE SCHIST
	Relief:	Moderate relief	Low relief	
	Form/size	Anhedral to euhendral	Anhedral to euhendral	
	Inclusion	Absent	Absent	
	Cleavage	Absent	Absent	
	Extinction	present	Absent	
	interference	Present	Absent	
	pleochroism	Low pleochroic	Low pleochroic	
	Twinning	Absent	Absent	
ORTHOCLASE	Color	Blueish to milky	Colourless	
	Relief:	Low relief	Low relief	
	Form/size	Anhedral to euhendral	Anhedral to euhendral	
	Inclusion	Absent	Absent	
	Cleavage	Absent	Absent	
	Extinction	Present	Absent	
	interference	Present	Absent	
	pleochroism	Low pleochroic	Low pleochroic	
	Twinning	Carlsbad (turbid texture)	Absent	
BIOTITE	Color	Dark brown	Dark	
	Relief:	Low relief	Absent	
	Form/size	Euhendral	Euhendral	
	Inclusion	Absent	Absent	
	Cleavage	Two cleavage direction	Two cleavage direction	
	Extinction	Absent	Absent	
	interference	Absent	Absent	
	pleochroism	Absent	Absent	
	Twinning	Absent	Absent	
MUSCOVITE	Color	Pinkish	Colourless	
	Relief:	Low relief	Absent	
	Form/size	Euhendral	Euhendral	
	Inclusion	Absent	Absent	
	Cleavage	Two cleavage direction	Two cleavage direction	
	Extinction	Absent	Absent	
	interference	Absent	Absent	
	pleochroism	Absent	Absent	
	Twinning	Absent	Absent	

Thin Section Analysis in Geo-solution laboratory centre Bosso Minna

4.5 Geochemical Analysis of the Samples

Twelve (12) representative sediment samples were prepared for geochemical analyses, each sample was analysed for major elements as well as trace elements. The major oxides analysed which are expressed in weight percentages are: SiO_2, Al_2O_3, Fe_2O_3, CaO_2, K_2O_3, MgO, P_2O_5, Na_2O_3 TiO_2, and Mno. The trace elements analysed which are expressed include: Vanadium (V), Chromium (Cr), Nickel (Ni), Cobalt (Co), Rubidium (Rb), Copper (Cu), Lead (Pb), Zinc (Zn), Zirconium (Zr), Cadmium (Cd), Silver (Ag), Molybdenite (Mo), Tin (Sn), Niobium (Nb), Gold (Au) and Silver (Ag) ppb (Table 4.6).

4.6 Major Oxides (weight percentage)

The results of the concentrations of major oxide composition of elements for the analysed rock samples from the study area, Kataeregi, North-central Nigeria are presented in tables 4.7 and 4.8. Alumina (Al_2O_3) ranged between 15.76 -14.13 with a mean concentration value of 13.69 weight percentage which is low when compared with the published crustal abundances of 15.40 weight percentage by Rudnick *et al.*, (2021) (Table 4.9). The presence of alumina in the sample is as a result of chemical weathering of aluminosilicate minerals (residual clay Minerals) compositions in the surrounding basement rocks such as feldspars and micas. Iron (Fe_2O_3) ranges between 8.49 - 10.74 weight percentages with low average concentration of 9.962 weight percentage when compared with published crustal abundances. Silica (SiO_2) content ranged between 50.78 and 54.2 weight percentages and has an average concentration value of 55.25 weight percentage which is slightly low compared to Rudnick *et al.*, (2021) (Table 4.9).

Table 4.6: Elemental Percentage compositions of some rock samples

LOCATION	LONGITUDE	LATITUDE	ROCK TYPE	METAL	PERCENTAGE COMPOSITION
L1	9°22′22.6″	6°18′002.1″	Migmatite	Au,	0.0000
				Co,	0.1855
				Mn	0.0588
				Ni,	0.0241
				Cu,	0.0186
				Zn	0.565
L2	9°22′24.4″	6°17′05.6″	Gneiss	Au	0.198
				Co	0.179
				Mn	0.0464
				Ni	0.0315
				Cu	0.0160
				Zn	0.04
L6	9°22′04.4″	6°18′09″	Amphibolite	Au	0.0134
				Co	0.1225
				Mn	0.0455
				Ni	0.0330
				Cu	0.0174
				Zn	0.0544
M6	9°22′22″	6°18′20″	Amphibolite	Au	0.0000
				Co	0.2103
				Mn	0.0769
				Ni	0.0228
				Cu	0.0196
				Zn	0.0535
M18	9°22′16″	6°18′29″	Amphibolite	Au	0.0053
				Co	0.0187
				Mn	0.0223
				Ni	0.0235
				Cu	0.0171
				Zn	0.0390
S4	9°22″22.6	6°18′02.1″	Amphibolite	Au	0.0000
				Co	0.2319
				Mn	0.0974
				Ni	0.0319
				Cu	0.0235
				Zn	0.0455
S8	9°22′20″	6°18′30″	Amphibolite	Au	0.0000
				Co	0.0486
				Mn	0.0486
				Ni	0.0308
				Cu	0.0232
				Zn	0.0567

Elemental composition from National Agency for science and Engineering infrastructure (Naseni)

Table 4.7: Concentration of Major oxides

Elements	M1	M6	M21	M18	S8	S4	L14	L12	L2	L1	L6	L11	Average
MgO	11.15	9.04	8.67	11.52	7.85	9.31	8.96	8.28	10.63	9.15	11.11	9.53	9.6
Al_3O_2	15.762	14.586	11.391	12.781	14.721	13.368	11.31	13.815	15.705	12.841	13.92	14.135	13.69
SiO_2	50.799	57.243	56.371	50.066	60.857	54.984	59.279	54.918	55.056	54.067	55.168	54.205	55.25
P_2O_5	0.475	0.522	0.497	0.647	0.273	0.606	0.877	0.696	0.491	0.478	0.371	0.47	0.53
K_2O	0.079	1.238	1.197	2.987	1.249	0.131	1.41	0	1.058	2	1.018	1.738	1.18
CaO	10.994	6.19	10.695	10.908	6.838	9.586	7.359	8.903	6.31	10.326	8.935	7.836	8.74
MnO	0.076	0.01	0.023	0.029	0.063	0.125	0.001	0.059	0.06	0.076	0.059	0.09	0.06
TiO_2	1.1	0.138	0	0	0	1.131	0	1.165	0.358	0	0	0.008	0.33
Fe_3O_2	8.498	10.391	9.201	9.935	5.055	10.387	9.513	10.246	9.349	9.012	6.704	10.736	9.09
NaO_2	1.54	1.24	1.14	1.32	2.24	1	1	1.43	1.57	2.01	2.22	1.05	1.48
TOTAL	100.473	100.598	99.185	100.193	99.146	100.628	99.709	99.512	100.587	99.958	99.505	99.798	99.95

The Chart of major Oxides from National Agency for Science and Engineering Infrastructure (Naseni)

The SiO_2 concentrations in the samples indicate granitic composition of the surrounding rocks. Potassium oxide (K_2O) ranged between 0.079 and 1.74 weight percentages in the sediment samples with a mean value of 1.18 weight percentages (Table 4.7), this value is low when compared to Rudnick et al., (2021). The presence of K_2O in the rock samples showed that clay minerals are present due to the weathering of feldspar in the country rock. MgO ranged between 11.5 - 9.53 weight percentages with 9.6 weight percentages Na_2O ranged between 1.54 - 1.05 weight percentages with average of 1.48 weight percentages the lest oxide was TiO_2 which ranged between 1.1 - 0.008 weight percentages with an average value of 0.33 weight percentages. The highest is alumina (Al_2O_3) ranged between 15.76 - 14.13 with a mean concentration value of 13.69 weight percentages. MnO ranged from 11.5 - 9.53 with average of 9.6 weight percentages. In the concentration of major oxides (Table 4.8), MgO shows a moderately low concentration of 9.6 percentages. Al_2O_3 also show moderately low concentration of 12.69 percentages. P_2O_5, K_2O, MnO, TiO_2 and Na_2O are in low concentrations of 0.50 percentages, 1.48 percentages, 06 percentages, 0.33 percentages and I.48 percentages respectively. TiO_2 has the least concentration with 0.33 percentages while SiO_2 is the highest in concentration with 55.25 percentages (Figure 4.2).

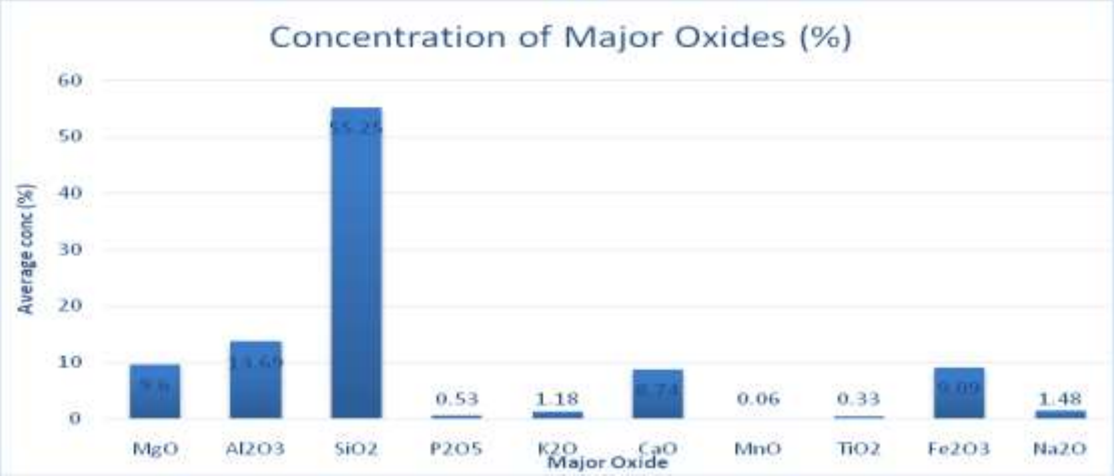


Figure 4.2: Concentration of major oxide

Table 4.8: Correlation of major oxides with Ag

	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	MnO	TiO_2	Fe_2O_3	Na_2O	AG
Al_2O_3	1									
SiO_2	-0.18388	1								
P_2O_5	-0.53774	-0737.7	1							
K_2O	-0.36127	-0.13454	-0.008214	1						
CaO	-0.33486	-0.68135	0.071498	0.05019	1					
MnO	0.397116	-0.28627	-0.35487	-0.38386	0.218011	1				
TiO_2	0.36446	-0.3228	0.220425	-0.8078	0.243156	0.512283	1			
Fe_2O_3	-0.21598	-0.39526	0.647276	0.035579	0.092669	-0.01297	-0.269355	1		
Na_2O	0.362458	0.12606	-0.68782	0.045057	-0.03409	0.140433	--0.21711	-0.83463	1	
AG	-0.4419	-0.1331	-0.18126	0.457271	0.373023	-0.22264	-0.47459	-0.00507	-0.1761	1

The table 4.8 shows that Al_2O_3 has a high concentration with MnO (0.397116), TiO_2 (0.362446) and Na_2O (0.362458) with low concentration to SiO_2 (-0.18388), (-0.53774), K_2O (0.36127) SiO_2 shows a high concentration to Na_2O (0.12606),with low concentration to P_2O_5 (-0.13454), CaO (-0.68135), (-0.28827), Fe_2O_3 (-0.39526), $P2O_5$ shows high concentration to K_2O (0.003214), CaO (0.071498), F_2O_3 (0.6477276), TiO_2 (0.2204) with low concentration to MnO (-0.35407), Na_2O (-0.63752), K_2O shows high concentration to CaO (0.05019), Fe_2O_3 (0.035579), Na_2O (0.0450537) with low concentration to MnO (0.35386), and TiO_2 (-0.8078), MnO (0.218011), TiO_2 (0.243556), Fe_2O_3 (0.092669) with low concentration of Na_2O (0.03489), MnO shows high concentration of Na_2O (-0.83463

4.7 Trace Elements

The trace element analysis results of rock sample from the study area are summarized with their comparison with published concentrations by Rudnick *et al*. (2021). The concentration of trace element in the sediment sample analysed are presented in bar chart (Figure 4.3).

Most of the trace elements show low concentrations (Table 4.9). Vanadium has a low concentration between 0.041 and 0.43 ppm, chromium shows a low concentration from 0.30 to 0.33 ppm, copper shows a concentration of 0.17 to 0.19 ppm. Nickel shows a concentration of 0.26 to o.27 ppm. Cupper shows a concentration of 0.001 to 0.03 ppm. Zinc shows a concentration of 0.004 to 0 0.06 ppm. Lead shows a concentration of 0.003 to 0.005 ppm. Argon shows a concentration of 0.02 to 0.14 ppm. Wollasonite shows a high concentration between 107.88 and 108.89 ppm. Wollasonite is a pathfinder element for finding gold and other ore minerals.

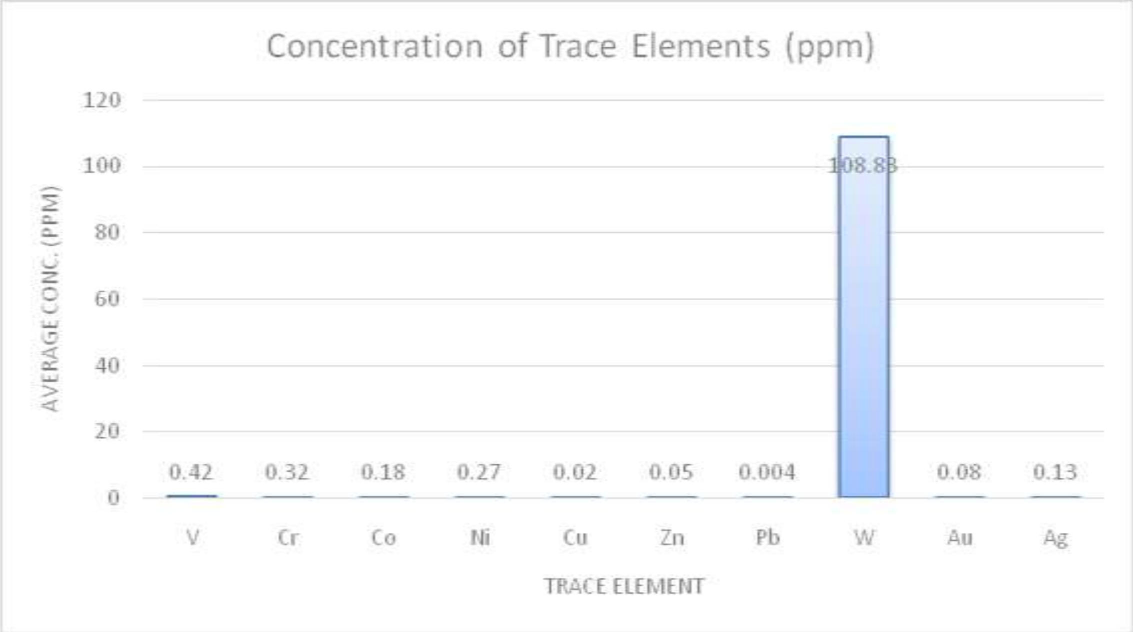


Figure 4.3: Concentration of trace elements (ppm)

The ternary plot of trace element concentration (Figure 4.4) shows that mineral are concentrated more on Fe_2O_3 than in K_2O and P_2O_5.

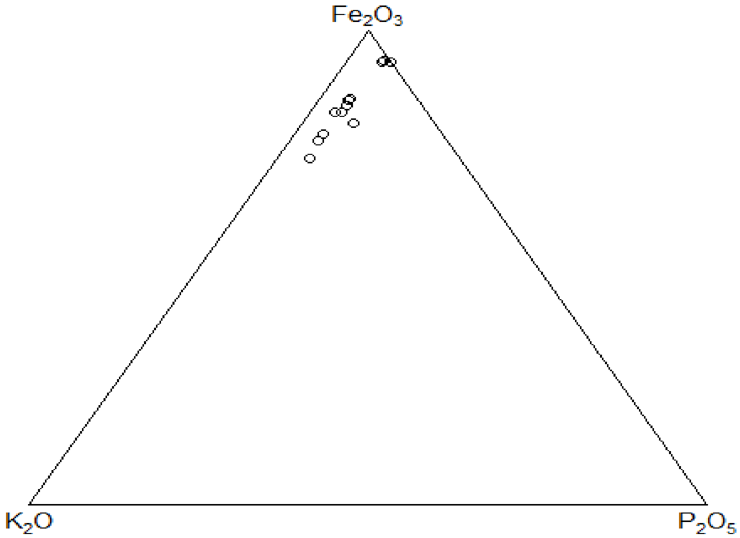
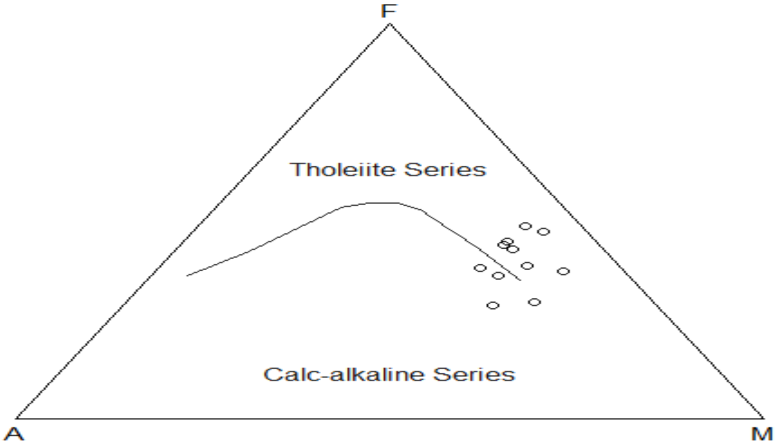


Figure 4.4: Concentration of trace elements

Figure 4.6 is the concentration of rocks in the ternary diagram. It shows that some rocks are of theolite origin while some are of alkaline origin. The curve at the middle of the diagram separates the rocks of theolite origin from the rocks of the calc-alkaline origin (Green and Ringwood, 1968).



Fig; 4.6: Concentration of minerals in rocks.

4.8 Enrichment Ratios

In an attempt to deduce the enrichment and or depletion of some trace elements in relation to their average crustal abundances in sediment samples from the study area, enrichment ratios were calculated. The enrichment ratio (ER) was computed using the following equation:

$ER=Cn/Bn$

Where: Cn = Average concentration of an clement measured in the sediment sample
Bn = Relative concentration of the element in the background according to Rudnick *et al.*, (2021)

The enrichment ratios of the trace elements are summarized in Table 4.9. The assessment of these elements was done in accordance to the work of Rudnick *et al*., (2021) who interpreted enrichment ratios (ER) as follows:

ER< 2 - Depletion to minimal enrichment

ER 2<5 - Moderate enrichment

ER 5< 20 - Significant enrichment

ER 20<40 - Very high enrichment

ER > 40 - Extremely high enrichment

Table 4.9: Background value and enrichment factor of sample analysed (modified after Rudnick *et al*., 2021)

Elements	Average concentration (Cn)	Background Concentration (Bn) (Rudnick *et al*., 2021)	ER= Cn/Bn	Status
Ni	0.27	65.00	0.004	Depleted
Cr	0.32	92.00	0.0035	Depleted
Zn	0.05	67.00	0.00075	Depleted
W	108.88	1.00	108.88	Significant enrichment
Co	0.18	24.00	0.008	Depleted
Pb	0.04	50.00	0.0008	Depleted
V	0.42	28.00	0.015	Depleted
Au	0.08	5.00	0.016	Depleted
Ag	0.13	1.00	0.13	Depleted

Some elements from National Agency for Science and Engineering Infrastructure(Naseni)

4.9 Distribution of trace elements in the analysed samples

Some traced elements as detected on the study area show high content value while some show low content value.

4.91 Nickel – Ni

Nickel was detected in all samples and showed relatively low concentrations with a mean value of 0.27 ppm (Table 4.9). The abundance of Nickel is very low in the study area when compared with the average abundance in the earth's crust which is 65 ppm (Rudnick *et al.,* 2021).

4.92 Zinc – Zn

Zinc is widely distributed in the area with an average value of 0.05 ppm (Table 4.9). Comparing the average value of zinc in the study area with the average abundance of zinc in earth's crust (67 ppm), the abundance of zinc in the study area is relatively low.

4.93 Lead – Pb

Lead was not detected in all samples and showed relatively moderate concentrations with a mean value of 0.004 ppm (Table 4.9). The abundance of lead is low in the study area when compared with the average abundance in the earth’s crust which is 17 ppm (Rudnick *et al.*, 2021).

4.94 Chromium – Cr

Chromium was detected in the samples and showed concentrations with a mean value of 0.32 ppm (Table 4.9). When compared with the average abundance of the element in the earth’s crust which is 92 ppm (Rudnick *et al.*, 2021), the abundance of chromium is relatively low. Chromium mineralization is very unlikely in this area.

4.95 Cobalt – Co

Cobalt was detected in all the samples analyzed and showed concentrations with a mean value of 0.18 ppm (Table 4.9). When compared with the average abundance of the element in the earth’s crust which is 24 ppm (Rudnick *et al.*, 2021), the abundance of cobalt is low in the study area

4.96 Copper – Cu

Copper was detected in all samples analyzed with a mean value of 0.02 ppm (Table 4.9). A comparison of the background value (28 ppm) to its average abundance in earth’s crust shows moderate abundance of copper in the study area. The anomalous and relatively high values occur dominantly in areas underlain by mafic or ultramafic rocks. Most ferromagnesian minerals will house copper (showing a greater affinity for mafic than for felsic igneous rocks.

4.97 Vanadium – V

Vanadium was detected in all samples and showed relatively wide concentrations with a mean value of 0.42 ppm. The abundance of vanadium is low in the study area when compared with the average abundance in the earth's crust which is 28 ppm (Rudnick *et al.*, 2021). In the study area the schists and amphibolite are dark coloured which indicate the possible occurrence of ferromagnesian minerals and thus the source of vanadium which is found in mafic rocks.

4.98 Wollasonite - W

Wollasonite was detected in all the samples and shows a good abundant with a mean value of 108.80 (Table 4.9). The abundant of wollasonite in the earth's crust is 1.00 ppm (Rudnick *et al.*, 2021). This shows that wollasonite is abundant in the study area.

The comparism of these elements with published crustal abundances (Rudnick *et al.*, 2021) show that they fall below the range of the background value, except wollasonite. This indicates that wollasonite is a pathfinder element in detecting gold and other ore minerals in the study area.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Geologic field mapping reveals that area lies in the Basement Complex. The lithology encountered includes: Granite, Migmatite, Gnesis and Amphibolite Schist as indicated in the produced geological map of the studied area. Structures found in the field are joints, faults, micro-folds and veins. The joint ranges from open joints (average opening of about 2.5 cm) or healed joints (filled with quartz vein or feldspar). The lithology and structures in the study area have a general trending pattern of NE-SW.

The results obtained from geochemical analyses show presence/abundance of some metals like cobalt (Co), manganese, nickel (Ni), copper (Cu), lead (Pb), Chromium (Cr) and zinc (Zn) .Cobalt is abundant in the area. Gold is less abundant. Gold concentration is between 0.011 to 0.2 percentages within the south eastern and south western parts of the area. This gold concentration in these parts of the area far exceeds the economic threshold value of 0.00092 for gold. The gold is associated with 0.18 – 0.24 percentages Co in the south eastern part. This amounts to 100 percentages copper enrichment factor in south eastern part. Similar Co enrichment exists in the north eastern part, though unassociated with primary gold. Manganese, Cu, Zn and Ni concentration exist below their respective economic threshold value within the area. The gold and Co are found in the gneiss and amphibolite in the neighbourhood of granitic intrusions in the area. Most of the trace elements show low concentrations. Wollasonite shows a high concentration between 107. 88 - 108.89, while other trace elements show low concentrations, between 0.33 - 0.42. Wollasonite is a pathfinder element for finding gold and other ore minerals.

5.2 Recommendation

Subsistence level of gold mining is common within Kataeregi and its environs. Many of the mines were not established on the basis of geosciences data. Consequently they become abandoned after a short period of operation, and the land are hardly reclaimed.

It is recommended that since the studied area is minimally rich in gold, cobalt and very rich in wollasonite, advanced mining technology should be employed for the mining of these minerals instead of the use of local mining technique.

5.3 Contribution to Knowledge

The research established that Kataeregi and its environs have minimal enrichment in some metals like cobalt, gold, copper, zinc, manganese, nickel. Other elements found are vanadium, chromium, wollasonite, argon.

The thesis further established that wollasonite - a pathfinder element for finding gold has high concentration with a mean value of 108.89 in the studied area. Gold concentration is between 0.011 to 0.2 percentages within the south eastern and south western parts of the area. This gold concentration in these parts of the area far exceeds the economic threshold value of 0.00092 for gold. The gold is also associated with 0.18 – 0.24 percentages Co in the south eastern part of the studied area.

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