THE GEOLOGY, GEOCHEMISTRY AHD POSSIBLE ORIGIN OF GOLD MINERALIZATION AT DUKKI OLD MINE, MARU ZAMFARA STATE, NIGERIA.

BY

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A THESIS SUBMITTED TO THE POSTGRAUDATE SCHOOL, AHMADU BELLO UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF GEOLOGY
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JULY, 2000

DECLARATION

I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any other University or Institution Information derived from published or unpublished work of others has been acknowledged in the text.

10 JULY 2000

SIDIKAT LAMI SALAU

CERTIFICATION

This thesis entitled "The Geology, Geochemistry and Possible Origin of Gold Mineralization at Dukki Old Mine, Maru Zamfara State, Nigeria" by Sidikat L. Salau meets the regulations governing the award of the degree of master of science of Ahmadu Bello University and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

To my Auntie,Late Alhaja Seliat Alakẹ Salawu

and

her Son, Late Alh. Tiamiyu Salawu

May your soul rest in peace Amen.

ACKNOWLEDGMENT

I am indeed very grateful to the Almighty Allah for giving me wisdom, guidance and strength to complete this course successfully.

I wish to express my sincere gratitude to Dr. I. Garba for the field supervision, general counseling and provision of all the necessary materials used in the execution of this project.

I am indebted to the Director, Geological Survey of Nigeria Abuja for nominating and sponsoring me for this course.

It is with pleasure that I recall the friendship that existed between the staff of NMC Jos, CERT. Zaria and myself during the data acquisition stage of this project. Mr. T. O. Jimoh and Mr. Akingbade are remembered for knowledge sharing and help rendered during the field work.

I owe immense gratitude to Dr. Umar, Dr. I. I. Funtua, P. O. Ogunleye, Dr. Gimba and other staff of CERT. Zaria for allowing the use of their XRF equipment and computer for interpretation.

My profound gratitude to Messr. P. O. Oluyide, A Afolabi, L. O.I Abu, A. N. Oyeka, J. W. Nalaya O. O. Badejo Alh. Ali Maru, P. D. Iyaji, Chief E. A. Fabunmi to mention but few and other staff of Geological Survey Dept. Kaduna.

Grateful acknowledgment is offered to the many individuals and colleagues whose generosity and assistance in the preparation of the manuscript has been possible. In particular, I am grateful to the entire staff and colleagues of Geology Dept. A. B. U., Zaria for their encouragement, moral and in some cases financial assistance in making this project successful. These include the H.O.D Dr. I. Garba, Prof. E. C. Ike, Prof. K.Schoneick, Prof. S. Abba, Dr. N. J.kI kponkonte, Dr. U. Dambatta, Mr. E. A. Bala, Dr. Omada, Mr. S. A. Alagbe, Mr.

E.O. Obiosio, Mr. T. Najime, Mallam H. Hamza, Mrs. Grace Bukar, Sefinat M. Sanni, Mrs. O. Adeoye and others.

I am also immensely grateful, to the following people who saw me through my financial predicament Mrs. Wossy M. Shittu, Mr. I. Rotimi of Edges Nig. Limited Abuja, Dr. J. A. Jaiyeoba, Mallam Aliyu Salau and Mrs. T. A. Adedare.

My mother is very much remembered for her love, help encouragement understanding, and motherly care to my children and me during the period of this course.

Finally, I wish to thank my immediate family for their patience and understanding throughout the duration of this programme.

Should any other such acknowledgment be missing I hope that this will be regarded as due to accidental omission rather than intentional.

ABSTACT

The Dukki Old gold mine is situated within the Precambrian to Lower Paleozoic Maru schist belt of NW Nigeria. The belt consists of metasediments, metaigneous rocks (schist belt lithologies) and granitic intrusions. The metasediments and metaigneous rocks have been deposited on older basement gneisses and migmatites and both units were deformed together and intruded by the Pan-African granitoids. The gold mineralization comprises series of N-S auriferous veins hosted in the sheared zone within series of silicified schists/phyllites and quartzites. Geophysical survey using the EM/VLF method was carried out at Dukki mine area, which defined the auriferous veins and revealed concealed mineralized zone. The mineralized zones discovered correspond with the limits of the old workings. Free gold occurs in quartz. Other vein constituents are sericite, magnetite, limonite, limonite and pyrite in minute quantities. Wallrock alteration processes include; silicification, sencitization and haematization. Based on petrography, structural and geochemical characteristics, the Dukki gold mineralization is inferred to have been an epigenetic type, controlled by late tectonic faults that developed along regional anticlinal axis during the closing stages of the Pan-African event. The mineralizing fluids were possibly sourced from within the crustal metasedimentary rocks of the schist belt, probably along original transcurrent fracture systems that developed during the waning stages of the Pan-African events.

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CHAPTER ONE

1.1. Introduction

Gold mining in Nigeria has so far never been significant on a world scale. Production started in 1913 and by 1970 a total production of 12 tonnes has been recorded (Woakes et. al., 1987). The actual production must have been far more than the figure because of the informal nature of the sector. The occurrences of gold in Nigeria are confined to the western half of the country mostly related to the schist belts (fig. 1.1.). One of the most notable of such occurrence's in northwestern Nigeria is the Dukki old mine situated within the Maru Schist Belt. This thesis reports the research work carried out on the Dukki Mine.

1.2. Location and Accessibility

The area of study lies between Latitude 12°15'N and 12°25'N and Longitude 6°15'E and 6°30'E, while the Dukki Old Mine is located within Latitude 12°21'10"N and 12°23'50"N and Longitude 6°15'35"E and 6°15'50"E . The area is in Maru district in Maru Local Government Area of Zamfara State, Nigeria. It covers about 152Km^2 (fig. 1.2.) while the Dukki Old Mine covers about 6Km^2.

Accessibility in the area is good. The Sokoto-Gusau Trunk A road cuts across the Maru belt. The Dukki mine is about 1Km off this trunk A road along a well established minor road leading to Dukki



Fig. 1.1. Some locations of Gold Mineralization in Nigeria (After Garba, 1998)

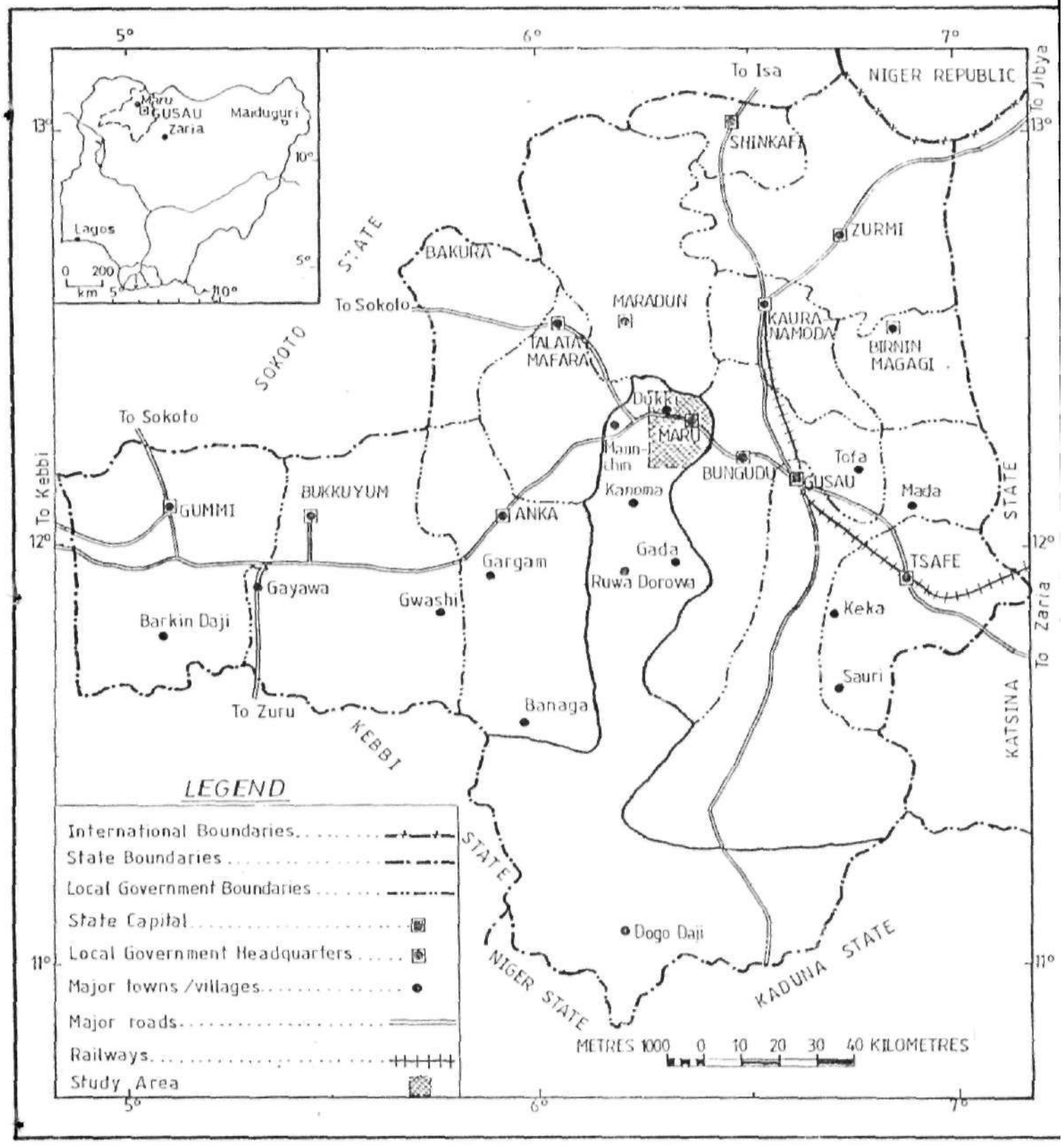


Fig. 1.3. Map of Maru L.G. showing the study area. (Fig. 1.2. Insert; Nigeria ma showing Zamfara state).

village to the north. This minor road branches off the main road at about 1.5Km west of Kadauli village. A network of footpaths criss-crossing the entire study area has also enhanced accessibility. The major villages in the area include, Farin Buwa, Maiinchi-Kadauki as depicted on the map (Fig. 1.3).

1.3. Physiography and Drainage

The study area being in northwestern Nigeria has distinct dry and wet seasons characteristics of that part of the country. The rainy season lasts from May to October and dry season from November-April. Rainfall ranges between 805mm-1023mm with annual mean of 700mm. The average temperature of 31°C with highest and lowest temperature of 44°C and 15°C respectively recorded in March and December.

Vegetation is rather sparse; typically of sudan-sahel savannah consists of shrubs, thorny bushes and grasses. Few trees are found mainly close to river and stream channels.

The topography of the area is characterised by a rugged terrain with prominent hill ranges (ridges) of metasediments mainly trending in the N-S and NNE and SSW direction. Prominent among these hills is the Baraba (Maraba) hill of 1809m height above sea level or 409 above the surrounding plains (Egbuniwe 1982), the highest in the area mapped.

Drainage pattern is generally dendritic type. This is controlled by the main river in the area, River Sokoto that flows through WNW-ESE

and into which all other tributaries drain. Most of the tributaries flow parallel to the regional trend of rocks in the study area. The major tributaries include Farin Ruwa, Kadauli and Gebe Ture. All the rivers and streams are seasonal.

1.4. Settlement and Human Activities

The area is sparsely populated. Maiinchi and Maru are the major settlements, while Kadauli and Farin Ruwa are small linear settlements along the Sokoto-Gusau trunk road.

The most important environmental factor influencing the distribution of population in this area is availability of water during the critical dry season for domestic activities and animal rearing, as well as mining activities. During this period, villagers travel for long distances with their animals in search of water.

The inhabitants are predominantly Hausa and Fulani speaking groups and are mainly farmers and cattle rearers. Farming is dominated by the cultivation of grains such as millet, maize and guinea corn, which are the main staple food, while cash crops include cotton and groundnuts. The animals reared include cattle, goats, sheep, donkeys and camels. Free-range poultry farming is also practised occasionally. Camels and donkeys are used as beast of burden.

Gold mining from stream courses and from quartz bodies is an important activity particularly during the rainy season.

1.5. Review of Previous Work

The Maru area has been of interest to many researchers because of the relatively good rock exposures and the importance of the Maru schist belt in the geological evolution of the Precambrian basement of Nigeria. The earliest work was by Truswell (1902), who studied the geology of the crystalline basement of the Maru sheet 53 and part of Talata Mafara sheet 31 on a scale of 1:100,000 (Truswell and Cope, 1963). McCurry, (1976) reported on the Maru schist belt as part of the Precambrian lower Paleozoic rocks of northern Nigeria. Ajibade (1976) provisionally classified and correlated the schist belts of NW Nigeria. Ogezi (1977) undertook some geochronological studies of basement rocks in NW Nigeria, which included phyllites from the Maru schist belt. Egbuniwe (1982) carried out a detailed study of Maru schist belt from which a genetic model was proposed and correlated the belt with other schist belts of NW Nigeria. Recently, reviews were made of the schist belts of northwestern Nigeria of which the Maru belt is an important component (e.g. Ajibade et. al., 1987; Ajibade and Fitches 1988; Turner, 1983; Fitches et. al., 1985). Other field reports include those of geological survey of Nigeria, the Nigerian Mining Corporation and the geological mapping carried out by the Geology Department, Ahmadu Bello University, Zaria.

1.6. Objectives and Scope of the Research Project

The primary objectives of this research are: -

* To map the lithologies and structures in the area of Dukki Mine.

* To investigate of the nature of gold mineralization in the mine from the available rock exposures.

*To determine the occurrence of concealed mineralization and the continuity of surface exposures of mineralization at depth using electromagnetic (EM - VLF) geophysical exploration technique.

In order to achieve the above objectives, the research is limited to the following scope of work:

i. Reconnaissance geological survey of about quarter of the entire 1:50,000 sheet 53 (Maru NE) to confirm existing geological maps.

ii. Detailed geological mapping of the targeted area of Dukki mine on a scale of 1:4,000.

iii. Electromagnetic (EM), VLF (Very Low Frequency) geophysical survey.

iv. Petrographic and geochemical studies of rock samples collected from the geological mapping.

CHAPTER TWO

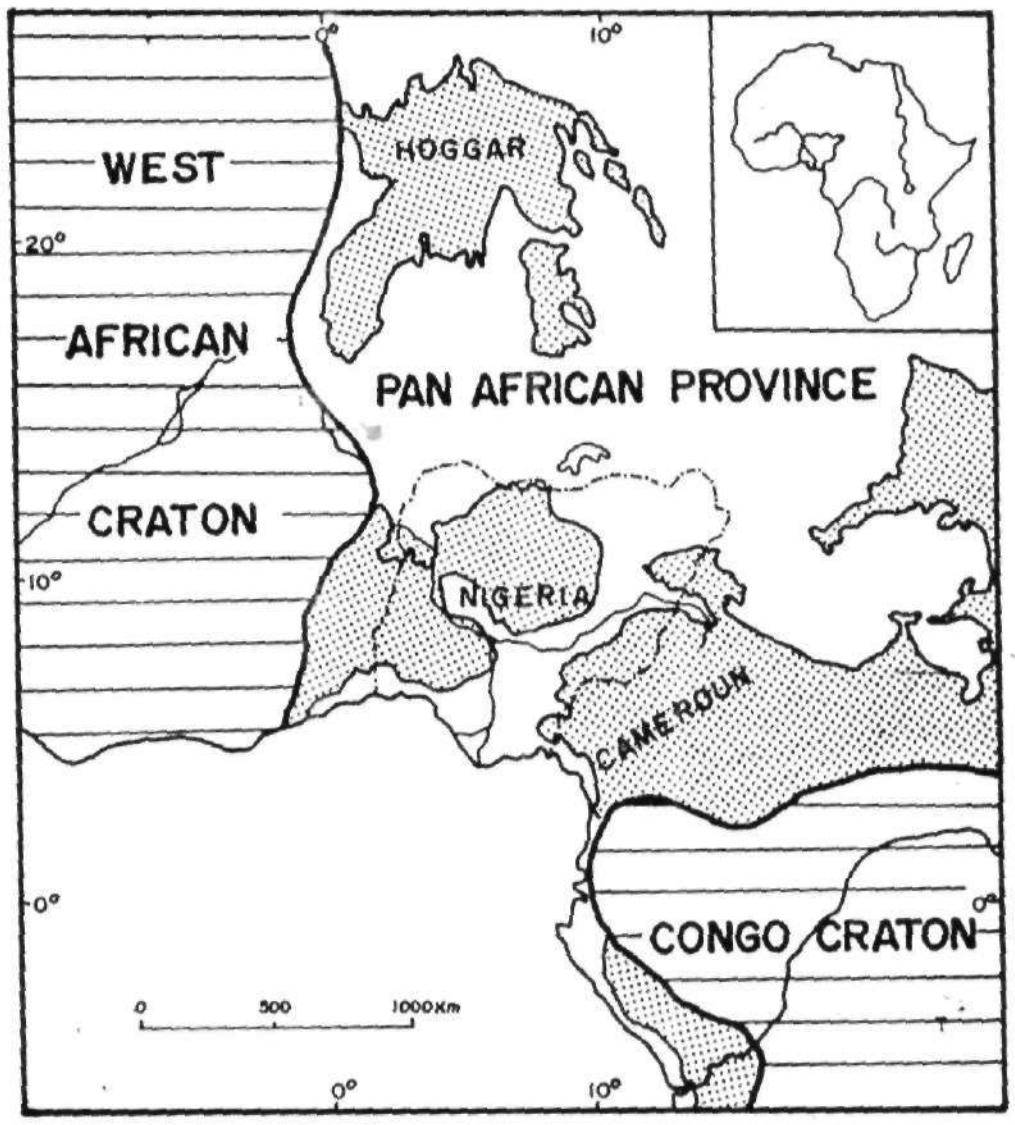
2.0. REGIONAL GEOLOGY

2.1. The Nigerian Basement

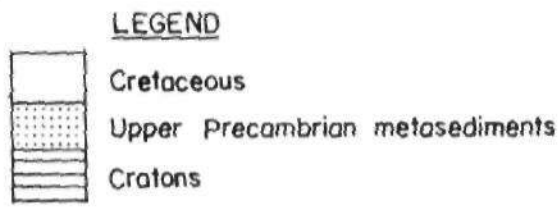
The Nigerian basement lies in the (C.600M.a) Pan-African mobile belt situated between the West African and Congo cratons (Fig. 2.1.). The crystalline basement rocks underlie more than 50% of the country (Kennedy, 1964). The basement consists of a wide variety of metamorphic and igneous rocks and has been shown to be polycyclic with isotopic ages, ranging from C.2800M.a to 450M.a. The Pan-African event (600±150M.a) was the latest reactivation that affected the whole region (Turner, 1983; Fitches et. al., 1985; Wright et. al., 1983) and it caused regional metamorphism and deformation which imposed a generally N-S foliation trend and brought about the emplacement of granitoids.

The basement is usually subdivided into three distinctive lithological units:

i). A migmatite-gneiss complex which constitutes about 70% of basement complex (Truswell and Cope 1963; McCurry, 1976; Black, 1980; Ajibade et. al., 1987; and Ajibade, 1988) is a polymetamorphic complex consisting of gneiss and migmatites with high grade supracrustal relics of basic and calcareous schists, marbles and quartzites termed "Older Metasediments" (McCurry 1976). This unit is



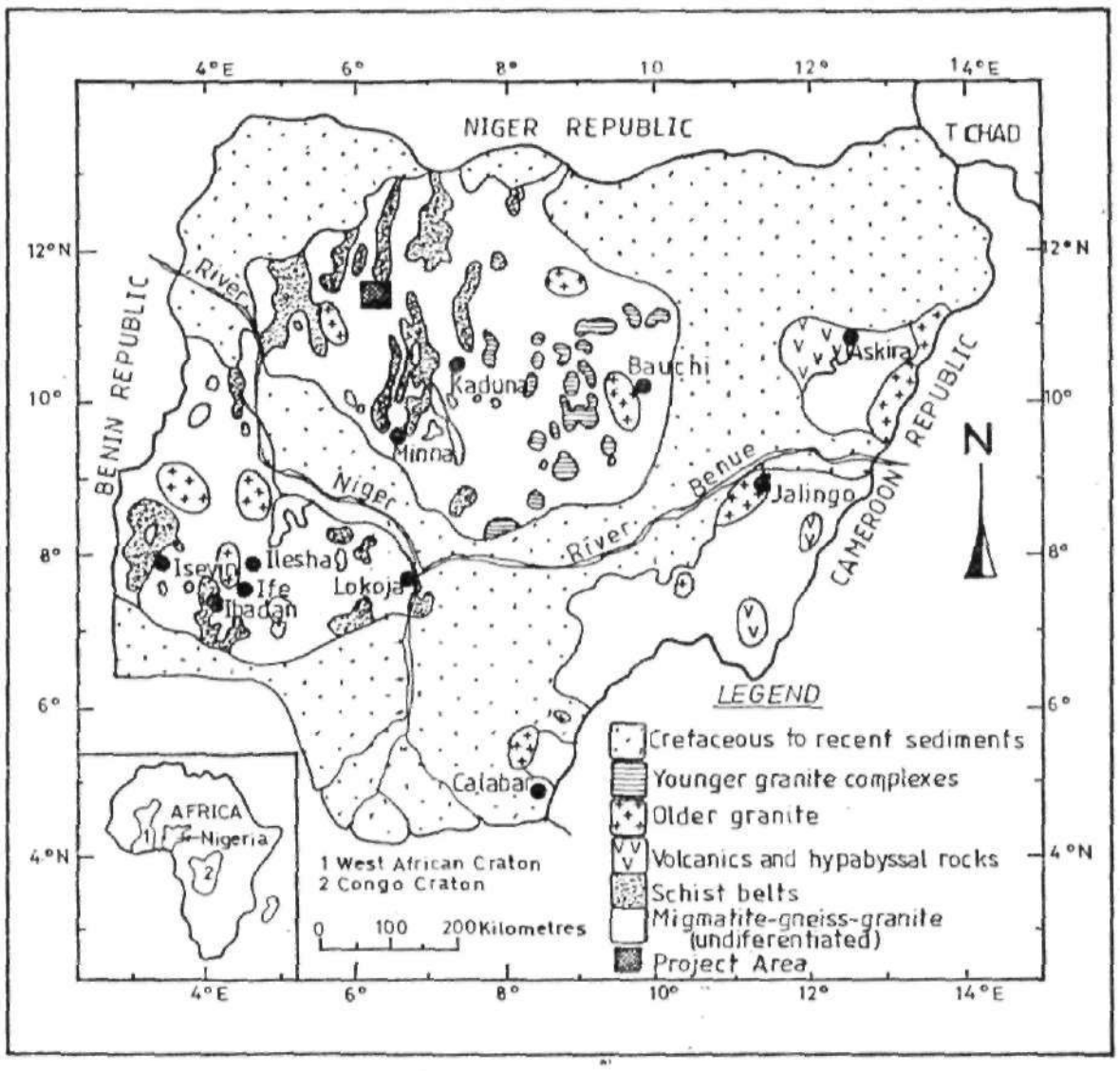
Fig·2.1. Location of the Nigeria sector of the Pan-African Province of West Africa. (After Ajibade, 1989)



generally of lower amphibolite facies grade of metamorphism (Ajibade et. al., 1977; Ogezi, 1977).

ii). Schist belts consisting of low grade (supracrustal) metasediments and metavolcanics and are confined largely to the western half of the country (fig. 2.2.), although some relics of schist bodies have been mapped around Jalingo to the north-east (Agumanu, 1975) and on the Obudu plateau in the south-east (Okeke, 1979). The age of these rocks is controversial. They are in some places demonstrately younger than the migmatite-gneiss complex, but are cut by the older granites. They are late Proterozoic to earliest Phanerozoic (Egbuniwe, 1982). These schist belts consist predominantly of pelites and semi-pelites with psammites, banded iron formation, metaconglomerate, metagreywackes and metavolcanics termed "Younger metasediments" (McCurry, 1976) and is generally of greenschist facies grade of metamorphism.

iii). Older (Pan-African) granites: This suite intrudes both gneisses and metasediments as swarms of plutons and batholiths covering a wide spectrum of rock types from tonalites through granite to diorite, syenite and charnockites. Age determinations indicate that they are Pan-African bodies with ages ranging from C.750M.a to 550M.a. The most predominant are the granodiorites. These rocks range in size from small subcircular crosscutting stocks to large elongated concordant batholithic bodies.



Figure·2.2. Simplified geological map of Nigeria.

2.2. The Northwestern Nigerian Basement

The three lithological units of the Nigerian Basement outlined above are well represented in northwestern Nigeria. The basement complex in this part is unique compare to other parts of the country because of the presence of late Pan-African calc-alkaline volcanics rocks which have close chemical affinities with subduction related magma. This has helped in relating the evolution of the complex to plate tectonic models.

2.2.1. *Migmatite-Gneiss Complex*

The geology and field relationship in various parts of the migmatite-gneiss complex of NW Nigeria have been described by many workers including Fargher, 1961; Nehikhare, 1963; 1970; Muotoh, 1973; among others. The complex comprises homogenous biotite and hornblende-gneiss as well as banded gneisses and the migmatites consist of an early foliated, fine banded gneiss, and a later neosomal granitic mafic component (Ogezi, 1977). Contacts between the gneisses and migmatites are mostly gradational, such that they are neither easily distinguished in the field nor separated on geological map. Also found within the migmatite-gneiss complex are small localised high grade metasedimentary relics of quartzites, mica-sillimanite and talc schist as well as amphibolites. This was first observed and recorded by Falconer, (1911), and was referred to as "Older Metasediments" by McCurry (1976) to distinguish them from the low grade metasediments of the schist belt which were referred to as

"Younger metasediments". However, Russ (1957) suggested that the gneissic basement evolved by sedimentation followed by phases of migmatization, granitization and igneous intrusions, and that the Older Metasediments represent relics preserved from the migmatization and gneissification process, while talc schist and amphibolites are metamorphosed basic rocks.

Few geochronological data available have revealed the rocks to be Archaean (C.3300M.a) Eburnian (C.2000M.a), Kibaran (C.1,100M.a) and Pan-African (C.600M.a) (Grant et. al., 1972; Ajibade, 1977 and Ogezi, 1977, Dada, 1989, 1996, Ekwueme and Kroner, 1992). Ogezi (1977) suggested on this basis, that the migmatite gneiss complex probably includes rocks as old as the Archaean (C.3300M.a) and following McCurry, (1976) she correlated the complex with the Liberian (C.2800M.a) and the metasediments with the Birrimian (C.2,100M.a) as cited by (Egbuniwe, 1982). Upon intensive work done by Ogezi (1977) no reliable isochron data has been obtained from migmatitie-gneiss complex of the NW Nigeria.

2.2.2. The Schist Belts

These are supracrustal assemblages of low grade metasedimentary and metavolcanic rocks that crop out in well defined belts in the NW Nigerian basement. The belts are considered to be restricted to the west of 8°E meridian (McCurry, 1976) but Ajibade, (1976) cited Turner and Webb, (1974) who recorded occurrences of quartz schists and conglomerate around the Daura younger granites

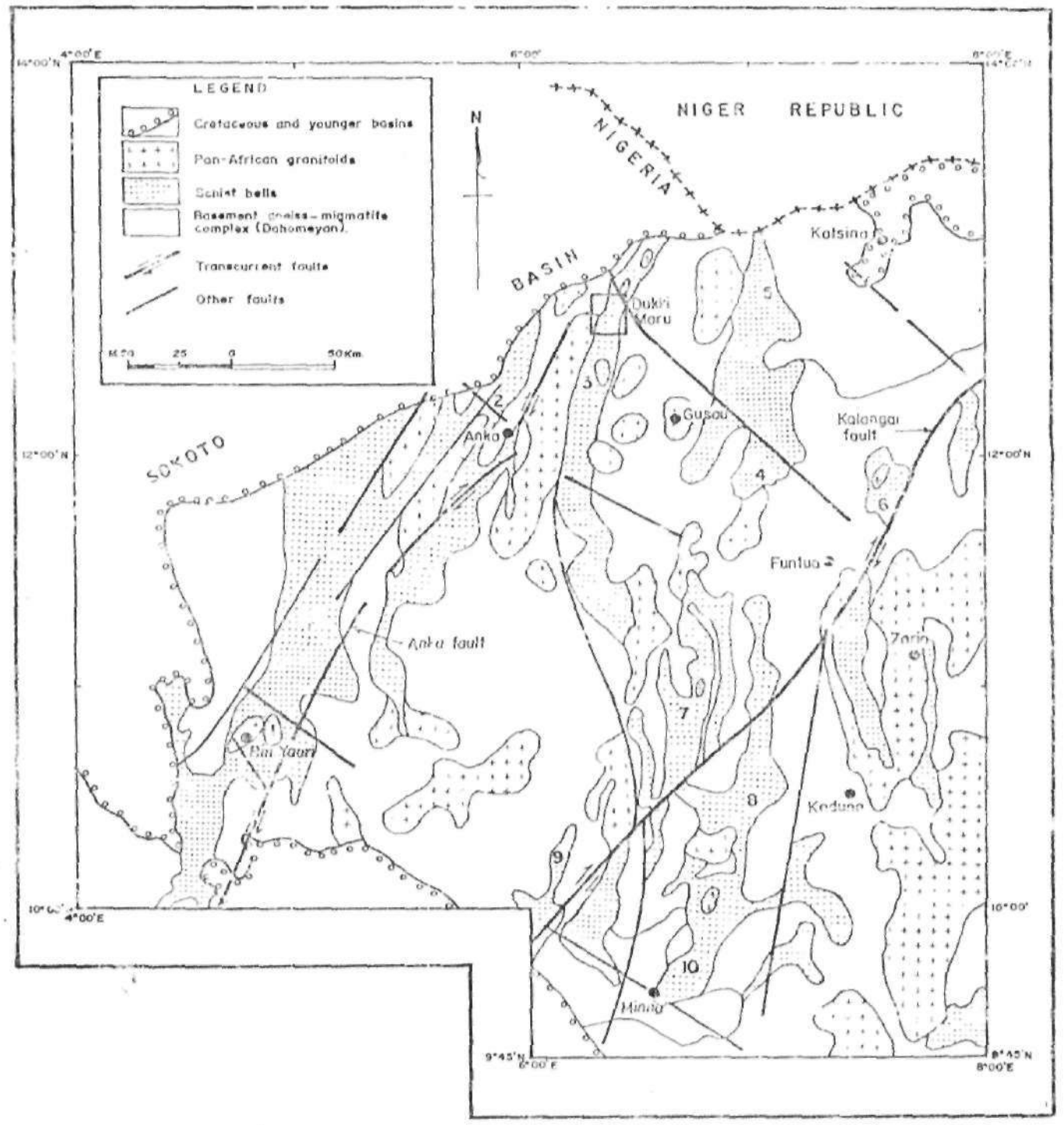


Fig. 2.3. Simplified geological Map of N.W. Nigeria showing the distribution of the schist belts and the location of the project area; 1: Zuru, 2: Anka, 3: Maru, 4: Wonaka, 5: Kazaure, 6: Malumfashi, 7: Birnin-Gwari, 8: Kushaka, 9: Ushama, 10: Toto (modified after Garba, 1998).

east of longitude 8°30'E. This probably indicates that the schist belts are more extensive than previously recognised. The 'Younger Metasediments' of the NW Nigeria are generally of greenschist facies grade. The belts trend approximately NNE-SSW (Fig. 2.3.) and consist predominantly of pelites and semipelites with psammites, banded iron formation (BIF) metaconglomerates, metagreywackes and metavolcanics and carbonaceous rocks which are low grade and thought to have been deposited during the late Proterozoic (C.1,100Ma), (McCurry, 1976 and Egbuniwe, 1982).

Turner, (1983) identified (10) ten schist belts (fig. 2.3.). They are the Zuru, Anka, Maru, Birnin-Gwari, Karau-Karau, Ushama, Wonaka, Kushaka, Kazaure and Malumfashi. Each of these belts is separated from the adjacent belts by migmatitic-gneisses or granites (Egbuniwe, 1982).

The schist belts of NW Nigeria exhibit similarities and contrasts Egbuniwe (1982) has shown that western and eastern pairs of some schist belts in NW Nigeria can be correlated, showing that spatial relationship exists between the Birnin-Gwari and Kushaka formations also between Anka and Maru belts. Egbuniwe (1982) suggests that it is possible that the western pair of the belts, the Anka and Birnin-Gwari were once continuous along strike as were the eastern pair, the Maru and Kushaka belts. It is possible that the differences and similarities between the eastern and western belts are due to different ages and evolution or lateral facies changes between pairs of belts. Very little is

known of the age and structural relationship between the various schist belts and between the schist belts and the migmatite gneiss complex. The schist belts are generally considered to be supracrustal cover on the gneissic complex (McCurry, 1976; Ajibade, 1976; Ogezi, 1977; Holt, 1982; Egbuniwe, 1982).

One of the outstanding problems that reportedly emerged from various investigations of the schist belts of NW Nigeria is the difference in their ages and tectonic settings.

2.2.3. Older (Pan-African) Granite

The older granites are suites of granitoids that intruded the basement gneisses and migmatite. Their contacts with the country rocks may be sharp and cross-cutting, concordant and transitional or even migmatitic (McCurry, 1976). They are widespread in the NW Nigeria. They vary from small sub-elliptical plutons to large batholiths and from syn-tectonic to late- and post-tectonic intrusives (fig. 2.2.).

The Pan-African granitic intrusions in NW Nigeria are grouped into three phases of emplacement (Ajibade et. al., 1987). They comprise the following: medium to coarse-grained foliated tonalites, homogeneous foliated granodiorites and, very coarse-to coarsely porphyritic granodiorites and granites devoid of foliation. The foliated varieties are considered to be syntectonic and unfoliated porphyritic to be late tectonic. Many of the granitic plutons give ages in the range of 750 - 650M.a (e.g. Ogezi, 1977; Holt, 1982).

Chemically, the plutons individually and collectively have a calc-alkaline trend and all have I-type characteristic resembling those

generated at very deep crustal level or in the upper mantle during subduction and collision process (Fitches et. al., 1985). Wright et al., (1985) and Fitches et al., (1985) attributed them to the subduction zone that emerged at the margin of the West African craton 250km to 350km to the West of the Nigerian Pan-African province.

2.2.4. Pan-African (Late) Volcanics in the Anka Area

The late volcanics are the unmetamorphosed volcanics and hypabyssal rocks (mainly dacites and rhyolites) that overlie and intrude the basement gneisses, supracrustal and granitic rocks in the Anka schist belt. Age determination of dacites revealed late Pan-African age of about 500Ma narrowly post-dating the Pan-African deformation and plutonism (McCurry and Wright, 1977). Fitches et al., (1985) considered the volcanic suite as having chemical affinities with high-K, calc-alkaline late tectonic volcanic rocks (magmatic arc type) of intra-continental collision belts.

2.2.5. Structures

2.2.5.1. Foliation, Lineation, Cleavage and Folds

Structural studies in the Pan-African province and especially in the NW Nigeria sector revealed between two to four phases of deformations which resulted in folding and cleavage development (McCurry, 1976; Grant, 1978; Ajibade, 1976, 1980; Holt, 1982; Ajibade and Wright, 1988). A well developed foliation is preserved in the schists and phyllites defined by parallel alignment of platy minerals

(micas, especially muscovite). Foliation measurement usually showed NNE-SSW trend and vertical to subvertical dips (Turner, 1983). Lineation of minerals in the rocks show NNE-SSW direction corresponding to the regional trend of the basement complex.

The dominant tectonic fabric in NW Nigeria is the steep dipping N-S phyllitic to slaty cleavage and the spaced to crenulation cleavage which are mainly axial planar to tight isoclinal folds. McCurry (1976), Grant (1978) and Egbuniwe (1982) suggest folding during two successive phases of deformation resulting in isoclinical folds with axes trending ENE-WSW and N-S respectively. Ajibade and Wright, (1988) and Oluyide and Udoh, (1988) identified four phases of folding ranging from the two earliest tight to isoclinal folds, followed by the third consisting of minor open folds, to the latest typified by E-W kink bands.

2.2.5.2. Fault Systems

Two major regional fault systems have been recognised in the NW Nigerian basement, they are the NE-SW and NNE-SSW trending fracture zones (fig. 2.4.) within the basement rocks which cross-cut and off set the more N-S grains defined by the common foliation direction. The pattern of these fracture systems was probably developed during the Pan-African orogeny, but may also represent lineament of much greater age (Wright, 1976). Airphoto and satellite imagery interpretation (Holt et. al., 1979; Oluyide, 1988; Udoh, 1988) revealed two obvious directions of major faults and shear zones in NW Nigeria.

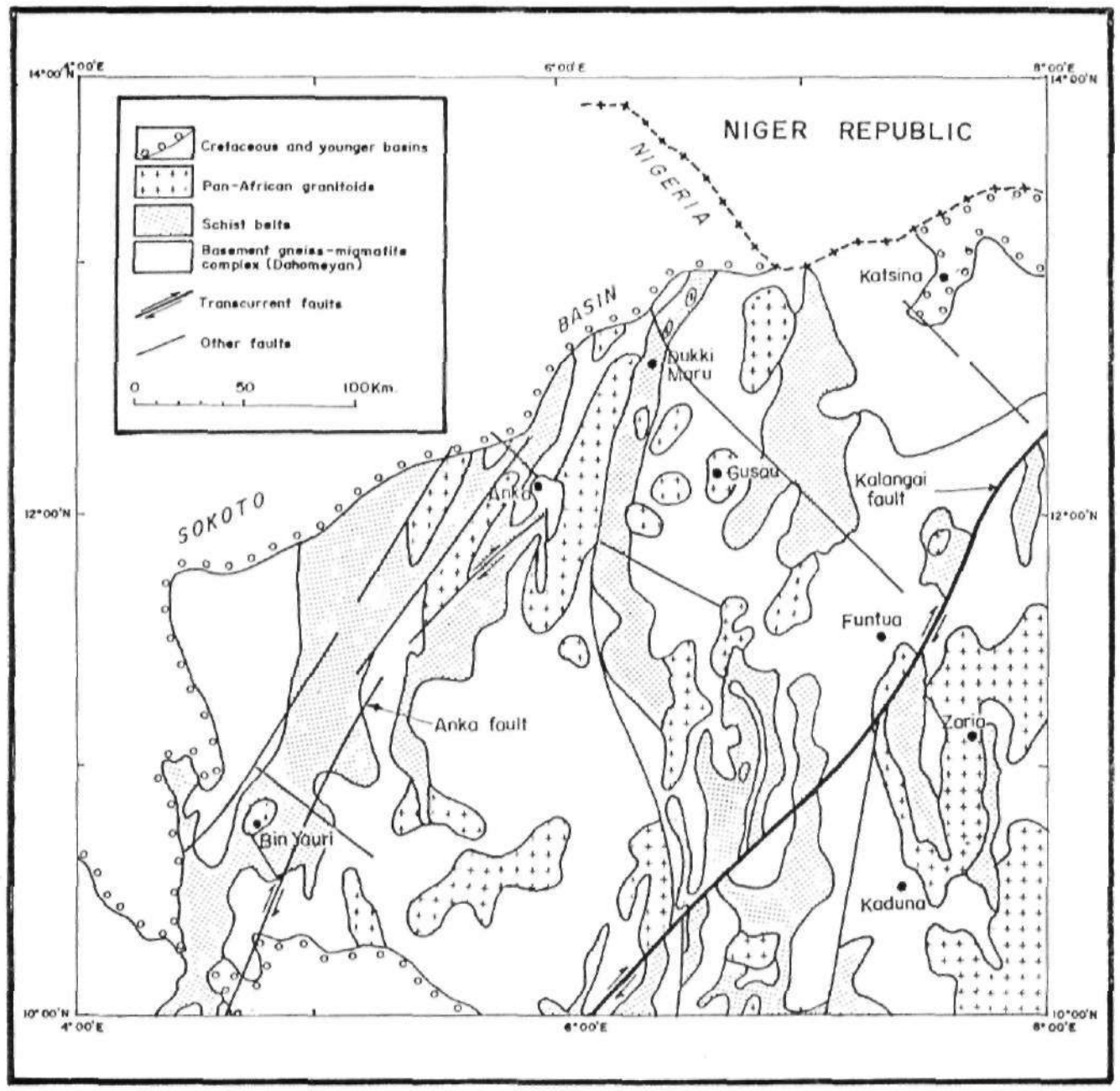


Fig: 2.4 The geology structural map of the N.W. Nigeria Pan-Africa Terrain. (modified after Garba 1998)

These comprise early steeply-dipping N-S trending zones of shearing, silicification and mylonitization cut and displaced by NE-SW dextral wrench fault and locally developed conjugate sinistral faults. The trend of the schist belts and some mylonite zones parallel to their boundaries have been ascribed to early Pan-African (Ajibade et. al., 1979).

2.2.6. Metamorphism

The NW Nigerian basement complex generally experienced regional metamorphism but locally thermal metamorphism occurred as a result of plutonic intrusions within some of the schist belts resulting in the formation of contact aureoles. Texturally, muscovite (or sericite) probably of regional metamorphism origin are lath-like and aligned in the schistosity, while the larger ones are tabular and overgrew the schistosity during contact metamorphism (Egbuniwe, 1982).

Retrograde metamorphism occurred within shear/fracture zones, with chloritization of biotite, sericitization of feldspar and conversion of hornblende to biotite as a result of reduction in temperature and pressure (Ajibade, 1978; Egbuniwe, 1982; Garba, 1992).

Metamorphism in the NW Nigerian basement complex reached greenschist to middle amphibolite facies in the 'Younger Metasediments' and upper amphibolite facies conditions in the crystalline rocks (McCurry, 1976; Ogezi, 1977; Ajibade, 1971 and Egbuniwe, 1982).

Grade of metamorphism varies from one place to another. In Zungeru area for example, Ajibade, (1978) recognised a Barrovian type of metamophism with metamorphic grade ranging from greenschist facies to almandine amphibolite facies (staurolite-almandine-muscovite sub-facies). Thermal metamorphism is recognised in the Anka and Maru belts, which resulted from the emplacement of older granites. This has formed narrow contact aureoles. In the Maru area mineral assemblages of quartz, muscovite, biotite, chlorite opaque (magnetite and pyrite) in the pelitic and semi pelitic schists and psammites are indicative of greenschist metamorphism (Egbuniwe, 1982). In the staurolite-garnet biotite bearing pelites, the presence of staurolite suggests lower amphibolite facies conditions (Winkle, 1974), while the first appearance of biotite and almadine garnet are respectively indicative of middle-upper greenschist facies metamorphism (Miyashiro, 1973). These minerals are also stable under amphibolite facies conditions.

Four periods of metamorphism have been recognised in NW Nigeria and these are correlated with deformation episodes (Table 1, after Egbuniwe, 1982).

2.2.7. Geochronology

Correlation of the basement complex rocks of Nigeria with other basement rocks in some West African countries have been attempted by Jones and Hockey 1954, Truswell and Cope 1963, Oyawoye, 1964 and Dada, 1996). Other workers on the geochronology of rocks in NW

Table 1.: ***Summary of sedimentary and igneous, structure, metamorphism and ages of events in the better known schist belts of northwestern Nigeria (After Egbuniwe, 1982)***

	Maru Belt	Anka Belt	Maikwonaga-Sado	Dimin Gwari Schist Formation	Ushama Schist Formation	Kushaka Schist Formation
Sediments	Pelites Psammites Graphitic schists B.I.F Grunerite schist?	Pelites Psammites including greywakes Volcaniclastics Conglomerates	Pelites Psammites	Pelites Graphitic schists Greywackes Pebbly schist	Pelites Psammites	Pelites Psammites Graphitic schists B.I.F Garnet-grunerite Schist
Igneous Rocks	Low-K pillow Basalts Amphibolites Chlorite schist	Dacites Rhyodacites Rhyolites Tuffs Agglomerates Subvolcanic Microtonalite	Pillow basalts Serpentinites Gabbros	Rhyolite, dacite	Amphibolites	Amphibolite Chlorite schist Talc and Green schist
Structure	D_1 : Flat-lying fold with N-S axes. Flat S1 slaty cleavage D_2: Upright folds with N-S axial planes and N-S axes. Spaces to crenulation cleavage. D_3: Steep open to isoclinical chevron folds. Axial plane crenulation cleavage and lineations. D_4: Steeply dipping *E-W kink bands.*	D_1: Upright folds with NNE-SSW axial planes and axes D_2: Steeply dipping E-W kink bands.	Unknown	D_1: Upright open to isoclinical folds with NE-SW trending *axial planes. Axial* plane slaty cleavage. D_2: Upright open to isoclinical folds. NNE-SSW axial planes. Axes plung NE. D_3: Open, concentric folds. Axial planes trend NE-SW and dip NW. D_4:Conjugate sets of *angular folds* and kink bands. Axial planes strike E-W and N-S steep dips	D1 same as B.G.S.F? D2: Upright folds; NNE-SSW trending axial planes with westerly dips.	D1: Small-scale folds with E-W axial planes. D2: Upright tight to isoclinical folds with steepto vertical axes. D3: Open folds with NNE-SSW axial planes and N-S axes. D4: *Rare folds and* local strain-slip cleavage.
Metamorphism	Predominantly greenschist with local lower amphibolite facies. Peak post D1, pre-D2.	Greenschist facies	Greenschist facies	Greenschist to lower amphibolite facies. Peak syn-D1.	Greenschist to lower amphibolite facies.	Greenschist to upper amphibolite facies.
Ages of Events	Sedimentation and volcanism >1068m.y D1 deformation c.1068m.y D2 Deformation 680-580m.y D3-D4 <580m.y	Sedimentation and volcanism c.760m.y (on microtonalite) D1 deformation <760m.y post orogenic volcanism 500m.y *(K/Ar on dacite)*	Volcanism c.825m.y Molasse sedimentation c.495m.y	Post-tectonic 566my granite plutonism masking earlier events	Unknown	Sedimentation and D1-D2 deformation >730m.y D3 deformation 730-650m.y
Sources	This work	Fargher, 1961; McCurry & Wright, 1977; Holt (in prep.)	Ogezi, 1977	Truswell & Cope, 1963; Ajibade, 1980	Ajibade, 1980	Truswell & Cope, 1963; Grant, 1978.

Nigeria include McCurry (1976; 1977), Ogezi (1977), Ajibade (1976) Holt et al. (1978), Egbuniwe (1982), Ajibade and Wright (1988). The Basement Complex contains rocks of Archaean age, which have been deformed and modified several times prior to the Pan-African Orogeny (Ajibade et. al., 1977). However, it is widely accepted that the oldest rocks are some of the migmatite-gneisses complex rocks (the 'Older Metasediments'). The early Proterozoic (Eburnean)event was probably accompanied by sedimentation, deformation, metamorphism and syntectonic igneous activity, (Ajibade et. al., 1987). The Eburnean orogeny was considered to be a granite forming event approximately 2,200 ± 200Ma (Grant, 1970). Ogezi, (1977) dated the Gusau-migmatite as 1158 ± 30Ma using Rb/Sr isochron method and interpreted the age as the time of Kibaran amphibolite facies metamorphism. Evidence for the Kibaran orogeny comes from Rb/Sr isochron age of 1064 ± 64Ma from phyllites of the Maru schist belt (Ogezi, 1977). This was interpreted as dating the time of metamorphism of the belt. Ogezi, (1977) concluded that there was a major Kibaran tectonics event in NW Nigeria. This was further confirmed by Ajibade, (1980) who however, argued that the schist belts are all of the same age and that their 1,100Ma age obtained from Birnin-Gwari schist formation must represent a later date of rehomogenization from the mild heating during the emplacement of Pan-African granites. The age of Pan-African magmatism and metamorphism is in the range of 750 ± 450Ma Ogezi, (1977), and the main deposition of the supracrustal rocks must have ended before this period.

In summary therefore, the Nigerian basement complex comprises rocks of the Archaean (C.3300M.a) Liberian 2,700 ± 200Ma Eburnean 2000 ± 200Ma and Pan-African 600 ± 150Ma ages (Ajibade et. al., 1987).

2.3. The Maru Schist Belt

This belt is one of the prominent schist belts in NW Nigeria. It is also referred to as the Maru formation (Truswell, 1963). This belt is about 200Km long and 12 - 19Km wide, bounded to the east by a migmatite-gneiss complex and to the west by the Maiinchi granodiorite (Fig.2.5.). The belt extends northward towards the Nigeria-Niger border, where the Cretaceous sediments of Gundumi formation to the north and the Kushaka formation to the south overlie it. The rocks are poorly exposed with extensive tracts covered by gravels, laterite and other superficial deposits (plate I). Strong deformation, tectonic transposition of beds and metamorphic differentiation mask bedding in many places as reported by Egbuniwe, (1982). The Maru formation comprises low grade metamorphic derivations of mudstones, siltstones, carbonaceous shales and sandstones with Banded Iron Formation (BIF) and basic volcanics.

Lack of marker horizons and extremely rare presence of sedimentary structures (excluding bedding) have made it impossible to establish a stratigraphic sequence, stratigraphic inter-relations, thickness and younging directions (Egbuniwe, 1982).

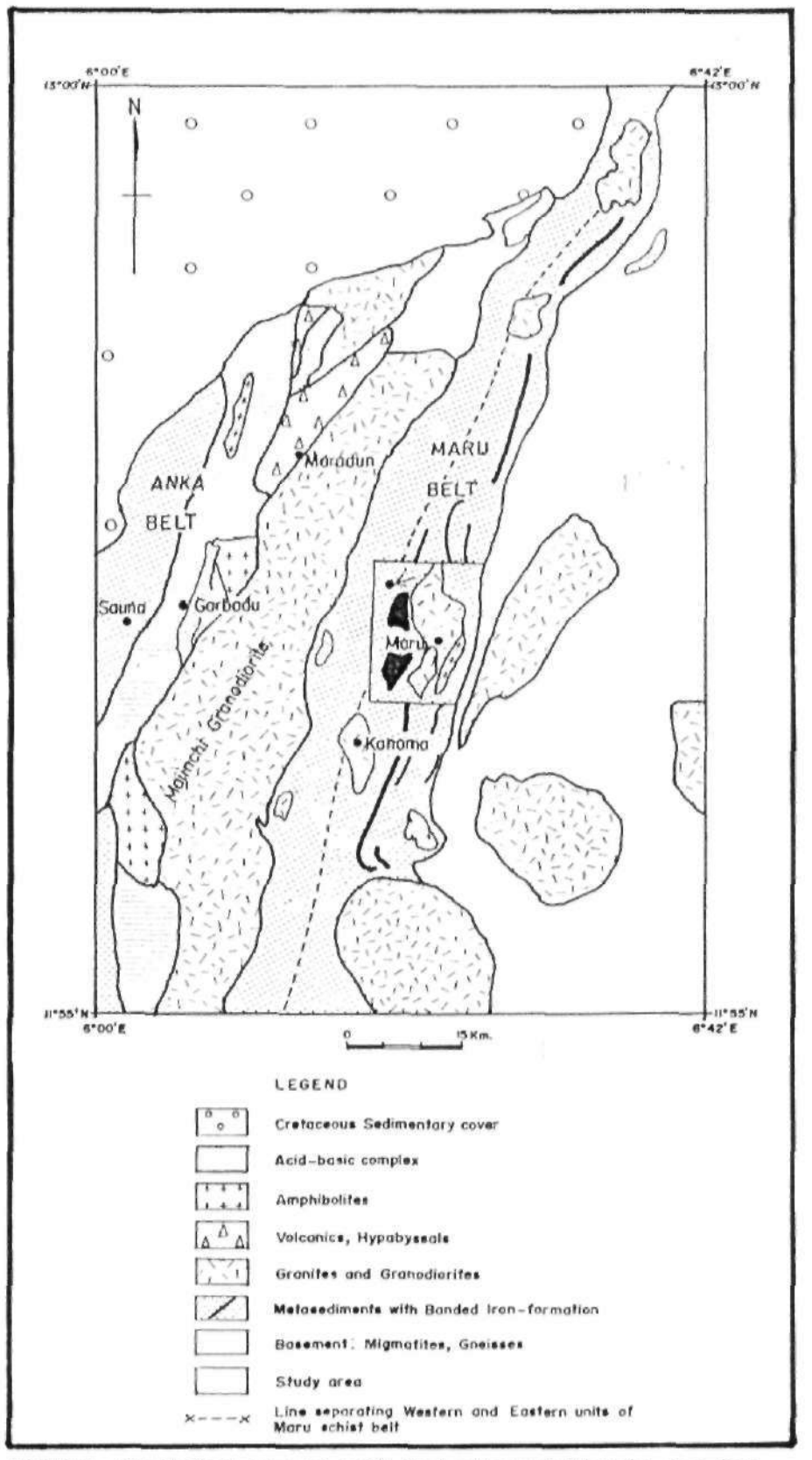


Fig:2.5 Geological map of part of Northwest Nigeria showing the Maru Schist Belt (after Holt et al., 1978).

2.3.1. Geology

The three basic lithological units of the Nigerian basement rocks are also represented in this belt. These are the migmatite-gneiss complex, the schist (supra-crustal) and the Older granites, (Fig. 2.6.).

a). ***The migmatite-gneiss*** -This bound the schist belt to the east of the map (Fig. 2.6.) and consists of high grade gneisses and basic sheets (paleosome with neosome of leuco-gneiss, aplites and pegmatites). The complex comprises homogenous biotite and hornblende gneisses as well as banded gnesses and migmatite. Egbuniwe (1982) reported these rocks to consist of early foliated, fine banded gneiss, which have undergone several phases of deformation, metamorphism and migmatisation. They show high metamorphic grade and more complex structures and are the oldest unit in the belt. Mineralogical, the rocks consist of common minerals such as quartz 15-35%, plagioclase 40-55%, microcline 0-3%, biotite 5-10% and some accessories minerals - appetite, limonite and opaque (Egbuniwe, 1982).

b). ***The schist (supracrustal) lithologies*** - These constitute more than 50% of the belt. Holt et al., (1978) have differentiated the entire Maru schists into eastern and western units.

The eastern units consist of pelites with locally dominant quartzites and Banded Iron Formation (BIF), while the western unit is almost entirely made up of pelites and in both units the pelites locally grade into semipelites (Adekoya, 1998). The pelites and semipelites are mainly represented by phyllites with minor weakly developed slates



Plate 1 - Gravels, laterite rubbes & other superficial deposits

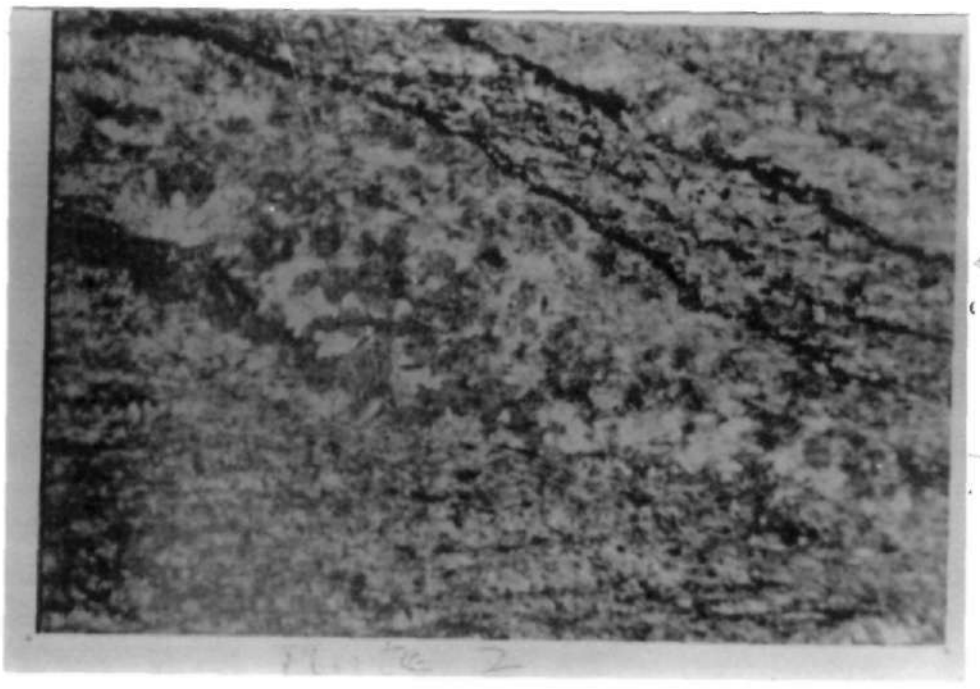


Plate 2 - Thin section of phyllite at x 25mm

and schists. These rocks are locally banded or laminated and are also rich in quartz and phyllosilicates (Egbuniwe, 1982), thus resembling interlaminated siltstones and shales. Fitches, et. al., (1985) attributed much of the lamination to tectonic pressure solution stripping, and suggested that the initial sediments were more homogeneous, poorly bedded or unbedded mudstones or shales.

Mineralogical, the phyllites consist predominantly of muscovite with little chlorite and quartz. Accessories such as biotite, magnetite pyrite and finely dispersed carbonaceous matter are observed, (plate 2).

The psammites commonly occur as thin bands or lenticles (<1-10m thick) of fine grained orthoquartzites flaggy micaceous quartzites and ferruginous quartzites. These probably represent pure sandstones with shale partings and ferruginous sandstones or chert respectively with no sedimentary structures (Egbuniwe, 1982).

The amphibolites are metamorphosed basic volcanic rocks and are two types, the massive and weakly foliated and are locally migmatised. However, both are texturally and minerallogically similiar and also may belong to the same basic suite (Egbuniwe, 1982).

Mineralogical, they consist mainly of hornblende 36-60%, plagioclase 25-38%, quartz 5-8%, and epidote 10-16% with accessory minerals like biotite, sphene, opaque, sericite and appetite (Egbuniwe, 1982).

c). ***The granitic plutons*** **-** These are the Older granite suite and comprises about 30% of the belt. They intruded both the migmatite-

gneiss complex and the schists. These plutons flank the Maru belt on its eastern and western margins and thus separate the belt from the migmatites.

Texturally, they range from fine-medium through coarse grained to porphyritic. Minerallogically, they consist of quartz 45-55%, K-feldspar 15-35% and plagioclase 10-25% in some biotite, hornblende 8-10%. Accessories include epidote, zircon, sphene (Egbuniwe, 1982). The intrusion of these plutons is accompanied by contact metamorphism in some places.

2.3.2. Structures in Maru Schist Belt

The structures of the Maru schist belt, like that of other Nigerian schist belts are complex due to polyphase deformation. In this deformation, in this belt at least three or four deformation episodes (D_1, D_2 and D_3, D_4) (Egbuniwe, 1982) have been recognised, the D_2 being the major deformation phase. The Maru metasediments, including the Banded Iron Formation (BIF), are regionally folded producing D_2 antiforms and synforms with a N-S trend (Adekoya, 1998). The Baraba antiform is observed with F_2 fold, with its axis running through the BIF (Fig. 2.6b). The F_2 folds are upright commonly tight to isoclinal but sometimes are more open structures with steep to vertical plunges. These open folds usually have smoothly rounded hinges (Egbuniwe, 1982). D_1 and D_3 structures are generally less common but the relics are preserved in pelitic and semipelitic metasediments. The earliest D_1 structures represented the first generation fold (F_1) and these have

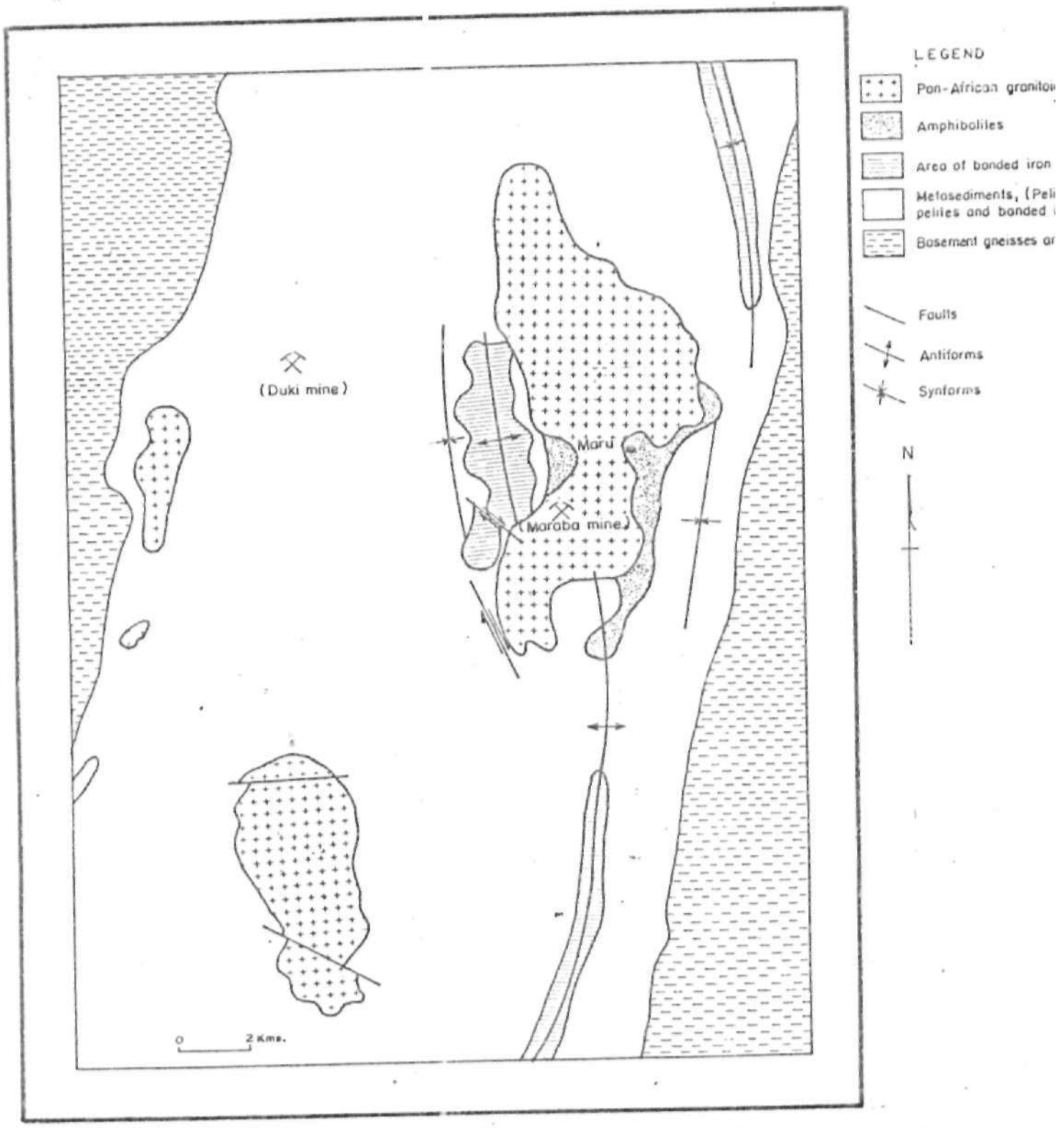


Fig. 2.6b Geology and structures of the Maru belt(after Garba 1999

Deformation Event (D)	Metamorphic Event (M)
D_4	M_4 No recrystallization.
D_3	M_3 Greenschist facies metamorphism. Local recrystallization And rotation of muscovite, chlorite, actinolite and tremolite Parallel to S_3 and L_3.
D_2	M_2 Greenschist facies metamorphism. Local recrystallization And rotation of phyllosilicate minerals parallel to S_2. Partial retrogression of staurotlite to chlorite and Sericite. Retrogression of hornblende to actinolite and Tremolite.
D_1	M_1 Greenschist to lower amphibolite facies metamorphism Outlasting D_1 deformation. Growth of metamorphic chlorite, muscovite, and magnetitie. Growth of staurolite and garnet. Retrogression of magmatic pyroxene to hornblende and calcic plagioclase to albit and epidote/clinozoisits.

Table 2: Relationship of deformation to metamorphism (After Coorey 1974)

been reduced to fold relics or contortions, while Chevron folds and other open folds are examples of the D_3 structures and D_4 are steeply dipping E – W kink bands. Egbuniwe (1982) showed that the Maru Schist belt have experienced four episodes of deformation, but with only three clearly defined.

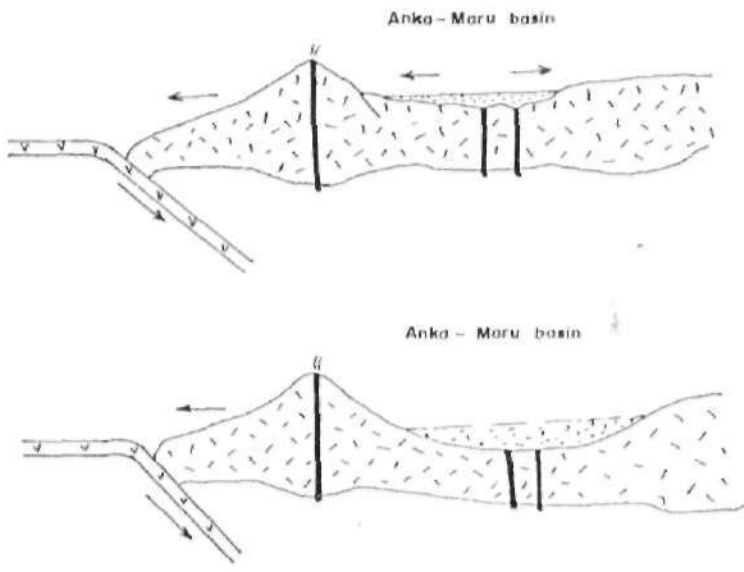
Table 2, shows relationship of deformation to metamorphism in the Maru basement complex modified by Egbuniwe (1982)

2.3.3. Evolution

Geology and geochemistry of the three basic units of the belt was used by Egbuniwe (1982) to establish some facts about the evolution of the Maru belt. It was demonstrated that pillow lavas and amphibolites are derivatives of basic igneous rocks and are interlayered with the metasediments. Hence, the geochemistry of the metavolcanics revealed that they are low K-theoleites, having chemical affinities with both island arc and mid-ocean ridge basalts but more affinities with island arc basalts.

The interlayering of metavolcanics with metasediments suggests the volcanism was contemporaneous with sedimentation, although it is impossible to determine what stratigraphic position they occupied in the sequence.

Current models on the evolution of the Maru belt was based on isotopic evidence of a Kibaran tectono-metamorphic and probably sedimentation event in the schist belts of NW Nigeria (Ajibade, 1980 and Egbuniwe, 1982). Two out of the few models stipulated by Egbuniwe (1982) would be reviewed in this study. Egbuniwe (1982) used both geological and geochemical evidences from Maru formation in constructing an evolutionary model for the Maru belt, pairing the Maru belt with the Anka belt. The total assemblages and organisation of lithologies from the Anka to Maru belt are closely similar to a magmatic arc marginal basin association. Fig. 2.7a-d briefly summarised this model.



1 2

(a) (> 800 my) (>1068 m.y) ago

Initial back-arc extension caused crustal thinning, Sedimentation and extrusion of basic/ultrabasic rocks into the basin.

(b) (> 800 m.y) (>1068 m.y) ago

Volcanics and volcanogenic sediments were deposited in the basin from island-arc B.I.F was produced as volcanic exhalates.

(c) (800-750 m.y) (1068 m.y) ago

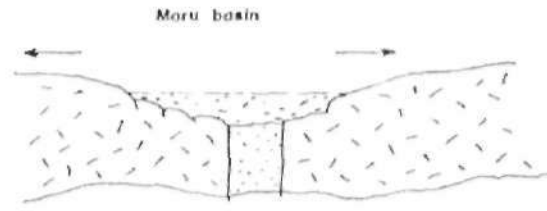
Closure of the basin to deformation and syntectonic granite plutonism, resulting in the in the seperation of the Anka-Maru basin into two belts.

(d) 750-580 m.y ago

Composite diagram of the Anka and Maru belts after the emplacement of the Mainchi batholith and Anka pegmatite complex, and uplift of the inter-belt zone.

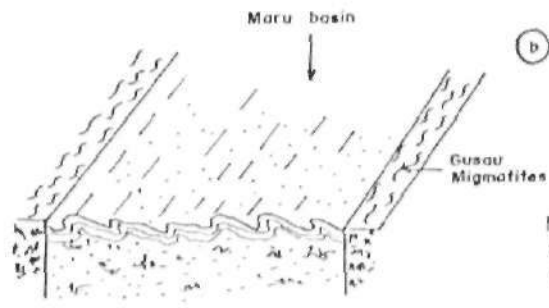
Fig. 2·7 a,b,c & d. Marginal basin model for the evolution of Maru & Anka belts in the Pan-Africa. (After Egbuniwe, 1982)

The second model of the Maru belt is paired with the Kushaka schist formation and ensialic and Kibaran events because they are lithologically similar, and so interpreted as a pre-or-early Kibaran ensialic basin. This is assumed to have formed as a result of crustal extension and vertical movements caused by mantle diapirism (Egbuniwe, 1982). Fig. 2.[illegible]a-d is further used to summarise this model.



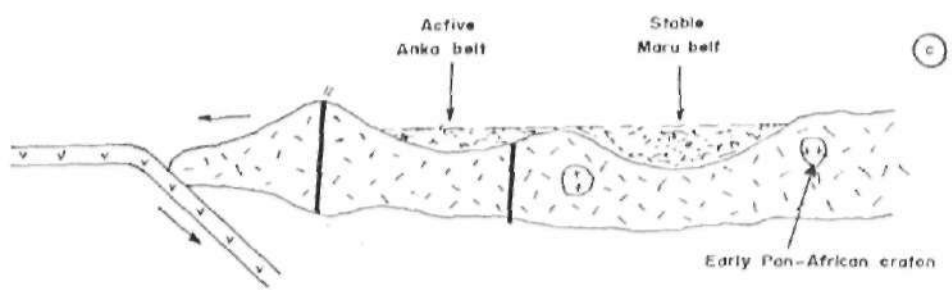
(a) > 1068 my ago

Maru basin development on thinned continental crust, sedimentation and volcanism comtemporaneous, Pre-1068 my ago



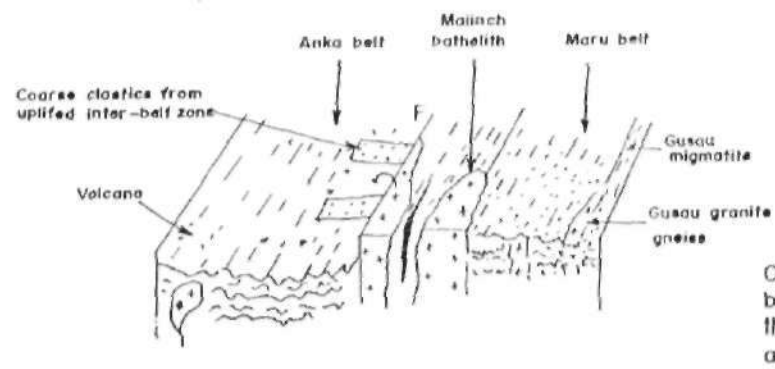
(b) 1068 my ago

Maru basin closed, 1068 Ma ago with consequent deformation and Metamorphism of the sediments and volconics.



(c) 825-650 my ago

Maru belf stable by early Pan-African times, Anka basin developed as marginal basin behind magmatic arc, in response to subduction processes at the W. African craton margin.



(d) 650-500 my ago

Composite diagram of the Maru and Anka belts after Pan-African basin closure in the Anka belt with Syn-orogenic plutonism and deformation in boths. Late-post orogenic volcanism restricted to the Anka belt.

Fig. 2·8 a,b,c & d The second model for the evolution of the Maru belt (ensialic) in the Kibaran. And early Pan-African event. (after Egbuniwe, 1982)

CHAPTER THREE

THE DUKKI OLD GOLD MINE

3.1. Introduction

Gold mineralisation in Dukki area occurs within the phyllites/schists and quartzites. At present the Dukki mine is expressed by series of pits varying in length from less than a meter to more than 160m. Although most of them have collapsed, they can be up to 30m in depth, and 0.3m - 10m in width. The mine is in a series of subvertical narrow shear zones (usually of less than 1m) and are confined to a zone of about 400m wide and runs N-S for about 5Km. In the area of study, there are four discontinuous but sub-parallel shear zones comprising non-silicified and silicified phyllites/schists and quartzites within which are the auriferous quartz veins and veinlets. In almost all places the mineralised structures and wallrocks have been completely mined out, leaving no trace of the auriferous veins. The gold bearing shear zones have been severely weathered in most places to depth of between 10-15m in some places. However, massive quartz-schist bodies are left standing whereas the soft (weathered) wallrocks extremely worked, (Plate 3.).

3.2. Geology

Detailed geolgical mapping of the Old Mine area, which covers a total area of about 5Km2, was carried out on a scale of 1:4,000 (fig. 3.1). The main rock units of the Dukki mine area are:

1). Phyllites/schists

2). Quartzites/Quartz schists



Plate 3: Massive quartz-schist body outstanding within weathered phyllite



Plate 4a: Weather phyllites/schists with a defined N-S trend

3). Quartz bodies

3.2.1. Phyllites/Schists (Metapelites)

These occupy about 85% of the area and are mostly weathered (plate 4a). They appear as schists and phyllites and are difficult to differentiate because they grade into each other in most places. Some distance away about 1.5Km NE from the mine are the graphitic schists. These rocks are typically homogeneous, have fine (2mm-2cm) laminations and are silvery-grey, bluish-grey or brownish when fresh. They are soft and fine grained, well laminated and foliated, but crumble easily along the cleavage plane (plate 4b).

In thin section, they comprise predominantly of muscovite (sericite) (65%), quartz (25%) with accessory minerals of chlorite, opaque minerals (mainly magnetite, pyrite), finely dispersed carbonaceous matter, tourmaline, staurolite, garnet and zircon (Egbuniwe, 1982).

The lamination is marked by fine (1-3mm) scale laminae of silty materials in planes enhanced by concentration of carbonaceous materials opaque ore, sericite and rare chlorite in fine seams (Plate 5). There are compositional and textural variations on a fine-scale in the rock unit. Laminations comprise alternating granoblastic quartz-rich and mica rich (sericite) unit in sharp contact with each other, which can be regarded as couplets. Egbuniwe (1982) suggests that the lamination is probably a combination of sedimentary and tectonic processes, since the lamination is parallel to and locally



Plate 4b: Outcrop of phyllite along the stream channel.



Plate 5: Fine Laminations in phyllite.

distinguishable from the S_1 schistosity. The textural description also suggests that probably this unit is derived from mudstones, shales and siltstones deposited in a quiet water environment (Egbuniwe, 1982). However, some of these phyllites/schists are found as silicified rocks, highly indurated and tough.

3.2.2. Quartzites /Quartz Schists

Quartzites occur very frequently in the area often intercalated with the phyllites/schists. They occupy about 8% of the area of study and are more resistant to weathering, they therefore stand out higher above the surrounding schists, forming some relatively low ridges (Plate 6). They are derivatives of coarse-grained clastic sediments represented by light-grey to light and dark brown homogeneous psammites, appearing as bands of orthoquartzites and flaggy micaceous quartzites highly foliated and show no ferrugenisation (Egbuniwe, 1982). They probably represent pure sandstones, with shale partings (plate 6).

In thin section they consist mainly of quartz (80-85%) and mica (muscovite and biotite) 15-20%. Primary sedimentary textures are no longer visible due to recrystallization. Quartz occurs as granoblastic grains, mostly recrystalized into a stable polygonal fabric. Haematite, magnetite, limonite and chlorite are of minor occurrence.



Plate 6: Outcrop of Quartz-Schist



Plate 7: The Milky white (drausy) quartz

3.2.3. Quartz Bodies

Quartz bodies (veins, lenses and boudins) are abundant in the area with a large proportion found in the phyllites/schists. They are two types:

a). Milky white (Drausy) quartz

b). Vuggy/Sugary quartz

3.2.3.1. The Milky White (Drausy) Quartz

These are quartz veins that form discontinuous elongated massive bodies, which may or may not be parallel to the strike direction within the phyllites/schists.

In thin section, they predominantly consist of quartz and some few muscovite flakes within cracks, which form less than 1% of the rock. They are medium to very fine-grained. These have been emplaced shortly after deposition and consolidation of the sediments and suffered the same deformation as the schists but are not associated with sulphide mineralization.

3.2.3.2. *The Sugary/Vuggy Quartz Bodies*

These are brownish in colour and conform with the foliation trend of the host rocks. The quartz bodies are coarse-grained occurring as veins, veinlets and stockworks interbedded within phyllites/schists as well as in the quartzites. Usually they show evidence of remobilization and recrystallization and are apparently undeformed. They vary in width from 0.5cm to 0.5m and may persist up to 250m along strike, but are sometimes found as pinch and swell or boudin structures. A series



Plate 8: Some of the Vuggy quartz of floats

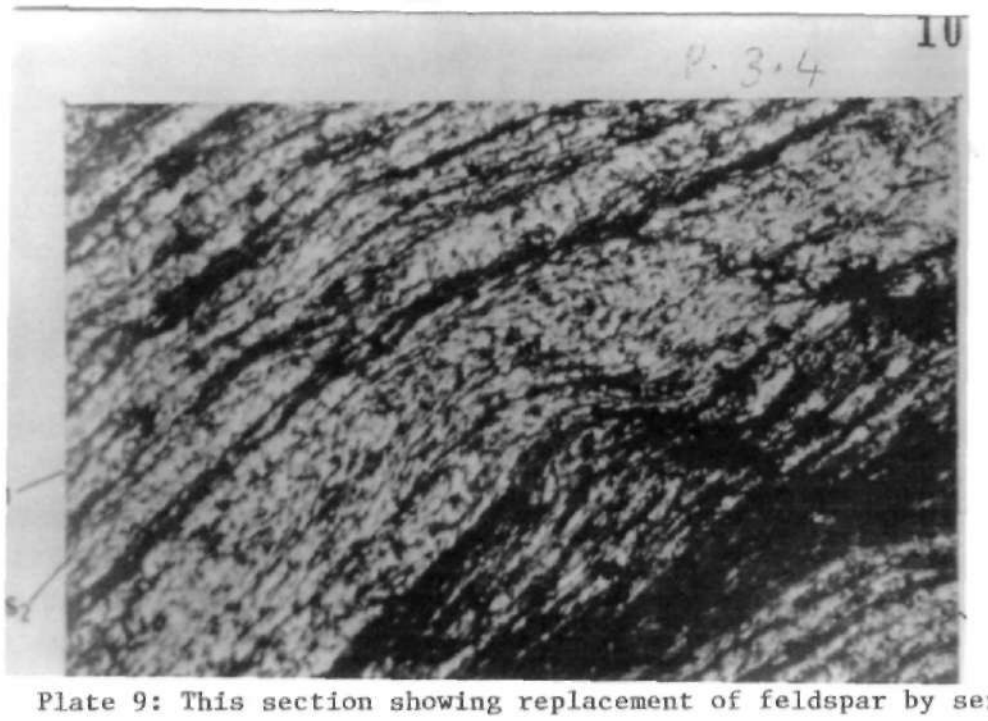


Plate 9: This section showing replacement of feldspar by sericite.

of these quartz bodies are traceable and persist for about 2km along the strike probably following slip-strike fault trends.

In thin section, they also predominantly consist of quartz (96%) little mica of about 2% and opaque minerals (mainly magnetite, limonite, haematite and scarcely observed pyrite). These quartz veins may be associated with sulphide mineralization as indicated by rusty (Fe) iron coatings in vugs, probably as a result of leaching of the sulphide/oxide minerals. These are the quartz bodies that carry the gold mineralization in both the phyllites/schists and quartzites.

3.3. Gold Mineralization and Wallrock Alteration

The gold mineralization at Dukki is a vein type as is the case for the generality of the Nigerian gold deposits. The quartz gold vein mineralization is accompanied by hydrothermal wallrock alteration.

In Dukki, the altered rocks are usually found as vertical band of soft red gritty or brick-red indurated materials within the light-grey to bluish phyllites/schists and the quartzites. These materials are themselves infiltrated by quartz veins. The clayey matter between the grains of grit may be altered feldspar and the appearance and fields relations of the bands are that of a decomposed highly siliceous dyke (Tattam, 1941). The vein mineralization is characterised by the presence of predominantly iron oxide assemblages comprising essentially of magnetite, limonite, haematite and scarcely observed disseminated pyrite. The main gangue minerals are quartz and sericite. Gold in its native form also occurs free in the quartz matrix.

The fresh rock composition is predominantly of muscovite and quartz with accessory chlorite, opaque minerals, (mainly magnetite, pyrite and finely dispersed carbonaceous matter), tourmaline and zircon.

The wallrocks of the Dukki mine have been altered to secondary (hydrothermal) assemblages (quartz, sericite, magnetite partially replaced by haematite and pyrite which is scarcely observed). The alteration is probably due to reactions caused by mineralizing fluids permeating the wallrocks at the time and place of gold mineralization.

The alteration zone consists of individual units of approximately 10m wide. These units cover an area of about 400m in width (Fig. 3.1.). The (feldspar + mica) assemblages have been replaced by sericite in the wallrocks (Plate 9) indicating some degree of shearing, and affecting most of the phyllites/schists hosting gold mineralization. Therefore, sericitization occurs in the phyllites/schists, thus the feldspar is totally replaced by sericite.

There is also increase in the quantity of quartz compared to other minerals in an altered wallrocks. This silicification is indicated in the mineralized zone by the presence of secondary quartz, which occurs as cryptocrystalline grains in the matrix. The increase in quartz may be due to alteration of the alkali feldspar to sericite or selective hydrothermal leaching of alkali/earth alkaline leaving residual silica or quartz. The source of silica may be through remobilization process resulting from shearing of the host rocks. The band of soft red, gritty or brick-red indurated area is the part of mineralized zone within the host rock . The textural, colour and chemical compositional changes are an indicative of haematization alteration process by the

mineralizing fluids permeating the rock. Here, the magnetite is replaced by haematite and very fine grain of pyrite.

From the ore microscopic study of some samples collected, (the quartz veins/veinlets) the dominant opaque ore minerals are magnetite with heamatite and finely disseminated pyrite. Therefore, unlike previously studied gold fields in NW Nigeria, where bulk of the mineralization are sulphide rich, in Dukki mine, the ore mineral assemblages are mostly Fe-oxide minerals. Both the oxide and little sulphide minerals represent less than 3% of the vein constituents.Free gold also do exist in the vein.

CHAPTER FOUR

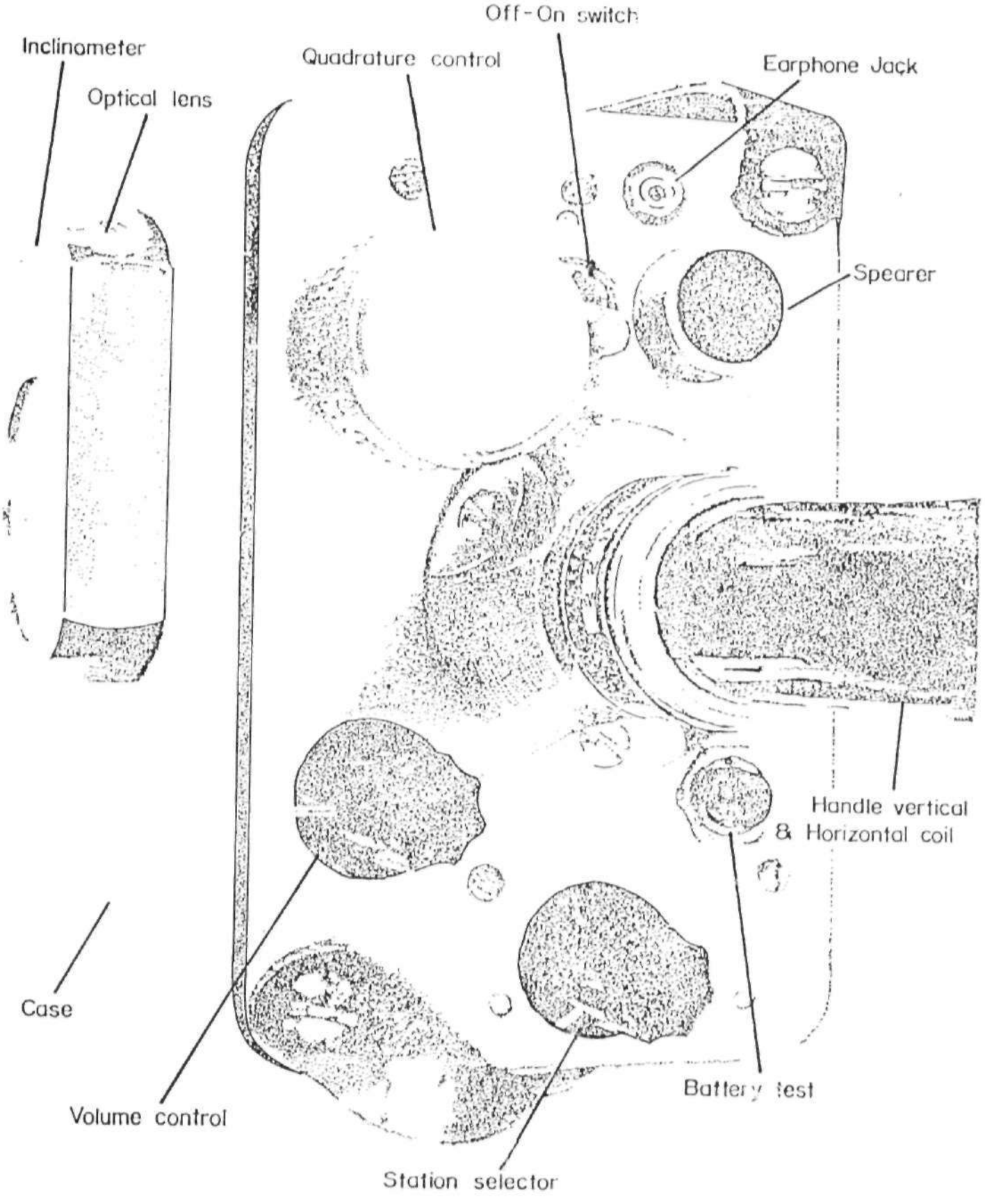
GEOPHYSICAL SURVEY

4.1. Preamble

The EM-VLF method of geophysical survey is used in search of fracture related structures for example in siting bore hole for water and also in minerals exploration. This helps to reduce uncertainty and high cost of exploration and also improve chances of success. This method has been employed in gold exploration in Niger yielding excellent and reliable results.

4.2. Electro-Magnetic Very Low Frequency (EM-VLF) Method

The EM-VLF method of geophysical investigation was employed for the first time in Nigeria for gold exploration at Dukki mine. This method is best employed in mapping near vertical contacts, geological structures (mainly fractures) and possibly to detect area of conductive sulphide and Fe-oxides mineralization through the magnitudes of anomalies recorded from the instrument. This method is an indirect way of prospecting for gold, because gold is known to be closely associated with Fe-sulphides and oxides. The structures hosting the gold are apparently fracture-controlled and are subvertical or parallel to the regional fault system.



Fig· 4.1. EM 16 Instrumentation.

4.3. EM 16 Instrumentation

The VLF (very low frequency) instrument used is the Ronka-Geonics EM 16. It consists of a housing containing the electronic circuiting to which a conventional sighting clinometer and a T-shaped handle containing coils at right angles (the reference and signal coils) are attached. Controls include a two-position station selector switch, a calibrated quadrature control and a knob, which amplifies an audio tone (see Fig. 4.1.).

Control Volume - the strength of the tone is determined by the setting of this, with the phase at zero, and by the component of VLF magnetic field parallel to the axis of the main coil.

The EM 16 energy is either lost into space or penetrates the surface. When the surface is penetrated, the energy helps in deducing fracture zones conducive for mineralization, EM 16 Specifications is as follows:

Measured Quantity - In phase and quad-phase components of vertical magnetic field as a % of horizontal primary field (i.e. tangent of the tilt angle and ellipticity).

Sensitivity - In-phase ± 150%, quad-phase ± 40%

Resolution - ± 1%

Output - Nulling by audiotune. In phase indication from mechanical inclinometer and quad-phase from a graduated dial.

Operating Frequency - VLF Radio Band - Optional. Station selection done by means of plug-in units.

Operator Controls - Made up of ON/OFF switch, battery test, push button, station selector switch, audio volume control, quadrature dial clinometer.

Power Supply - 6 disposable 'AA' cells.

4.4. Principle of Operation

An electromagnetic wave consists of coupled alternating electrical and magnetic fields directed at right angle to each other and to the power vector, which defines the direction of propagation (Fig. 4.2.).

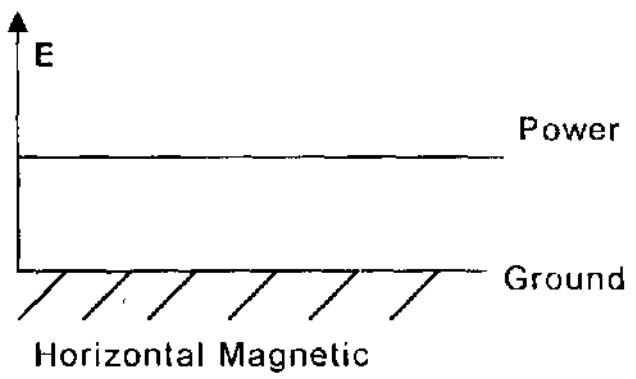


Fig. 4.2. Electromagnetic Wave Diagram.

The electric field vectors are always aligned at right angle to perfectly conductive surfaces and a wave is 'guided' by enclosing conductors.

The EM16 is a sensitive receiver covering the frequency band of the VLF transmitting stations with means of measuring the vertical field components. The VLF transmitting stations has a vertical antenna

therefore the antenna current is thus vertical, creating a concentric horizontal magnetic field around them. When these magnetic fields meet conductive bodies in the ground, there will be secondary field radiating from these bodies in the ground. This equipment measures the vertical components of these secondary fields (Fig. 4.3.). The two receiving coils earlier on mentioned have their directions as follows; the reference coil axis, which is basically horizontal and always more or less parallel to the field during measurement. And the signal coil, which is at right angle to the reference coil and its axis, is vertical.

The signal amplifier has two inputs one connected to the signal coil and the other to the reference channel. By tilting the coils the signal from the signal (vertical axis) coil is minimised and any remaining signal is reduced to zero by the quadrature control in the reference channel. The signal amplifier has zero output when both input signals are equal in amplitude and phase.

Stations, which keep the field at approximately right angles to the main strike of the ore bodies or geological structures of the area selected, are perpendicular to the transmitter but in practice ± 45° variations are tolerable. The plug-in unit inside the receiver is turned to proper transmitting station. The instrument takes two selector-units simultaneously, thus the selector switch is set to the desired plug-in.

Information on the most commonly used VLF transmitter includes - frequency transmission, geographical location and their scheduled maintenance periods. For the study area this information is tabulated below (Table 2).

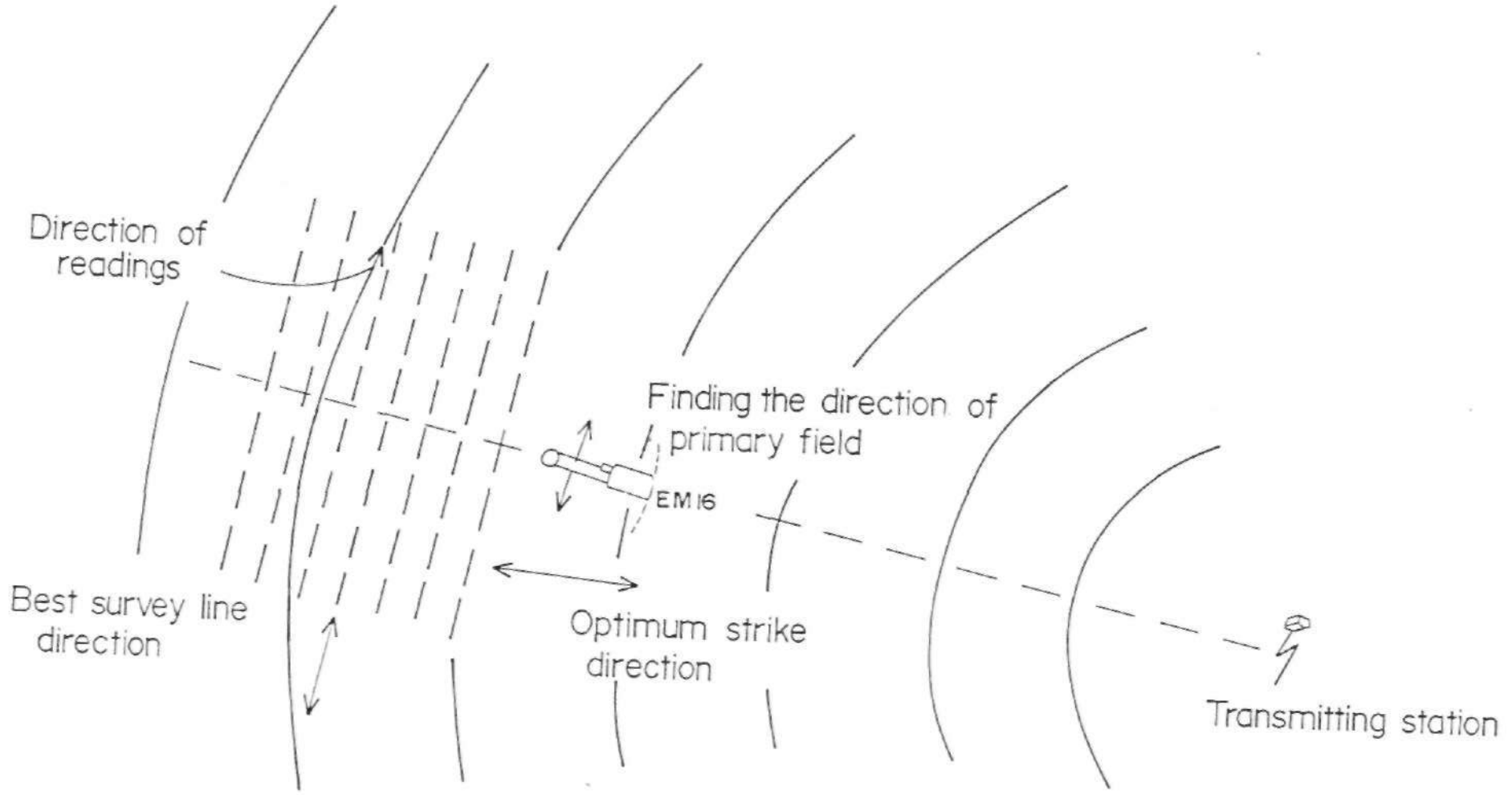


Fig. 4.3 Planning of survey

As of the time of data collection in the area of study only two transmitting stations are used due to sharp audio-tune received from these stations.

Station	Frequency	Geographical Location	Co-ordinates	KW
NAA	24.0	Culter Marine, U.S.A	67W17-44N39	1000
GRB	16.0	Rugby, England	01W11-52N22	750

Table 2: (For Frequency Transmission, Geographical Locations and scheduled maintenance periods).

4.5. Field Procedure

Survey lines are selected and drawn along the lines of the primary magnetic field and at right angle to the direction of the transmitting station. This is achieved by using compass to measure the general trend of the field of study (especially the strike) and using the **EM** 16 instrument to orient oneself. Turning the instrument sideways minimised the signal when pointing towards the station, thus indicating the magnetic field being at right angle to the receiving coil inside the handle. There is base line from which survey lines were drawn from

south to the north at 100 meters interval along the primary magnetic field (strike direction) in the area of study (Fig. 4.4.) For 1.7km and perpendicular to these lines are the other line at 20 meters interval for about 1km moving from west to east at 600m and 400m respectively. From the survey lines at 800m south and 750m north, the profiles are marked (Fig. 4.4.). Data where collected by taking readings at every 20m interval across the strike, (Appendix II). At each reading point the reference coil (lower end of the handle) was oriented along the magnetic lines. In the study area the secondary magnetic field was well established such that it gave the bearing of the transmitter.

The dials inside the inclinometer are calibrated in positive and negative percentage. As a rule, the lower end of the handle is always pointing towards the conductor. Whether a tilt angle appears positive or negative depends on direction of the conductive bodies. *If the conductor is to the front, the operator will have to lean backward and will see a positive reading on the clinometer and leaning forward indicate conductor is behind.* The readings are taken facing the same direction and in this study, readings were taken facing west throughout the period of investigation.

4.6. Presentation of Results

The readings (data - Appendix II) collected were plotted directly on the survey lines. Usually, in data presentation, two methods are employed. These are;

1). Graphical method

2). VLF map contouring method

4.6.1. Graphical Method

In this study, the graphical method was adapted since it brings out the best pictures of structural features in the area. The data collected were plotted directly on a graph sheet without filtering. This is the stacked profiles method that offers the best presentation . All the original data correctly located on the graph are displayed, and sections of profile on which there are abrupt gradients are easily recognised as a conductor/conductive bodies (Fig. 4.5.) Steeply-dipping conductors produce positive anomalies and are very obvious.

The horizontal scale chosen was 2cm to represent 100m and for the vertical scale 1cm represented 10%. The data obtained from the field were listed in Appendix I and plotted (Fig. 4.5.) to give a graphical presentation of 17 profiles at 100m intervals. They were plotted on the same sheet to enable efficient correlation of the vein fracture systems and some conductive bodies in the profiles moving from south to the north.

4.6.2. VLF Contour Maps

In this method, VLF maps are produced by filtering the results collected, since raw EM16 data were difficult to contour because the results are sometimes rather noisy. Some minor anomalies might have been caused by small local (artificial) conductors. These anomalies are removed by a process of filtering. This method could not be used

in the present study area because of these usual intricacies involved and a real extent covered.

4.7. Interpretation

The EM-VLF interpretation is done by arranging the clearly defined abrupt gradients with positive anomalies recognised as conductive bodies from the total of 17 profiles obtained from the field. These are carefully merged and correlated with geological structures.

In this study, the data collected revealed subvertical and/or subparallel narrow shear zones that are running N-S along the strike direction within the host rocks (Fig. 4.5.). Various positive abrupt gradients exhibited corresponded to abandoned workings (pits). Field observations and geophysical survey have distinguished the fresh (unaltered) rocks from the mineralised/altered rocks.

4.7.1. The Fresh (Unaltered) Rocks

These areas show relatively low positive abrupt gradients, which implies non-conductive bodies, therefore unmineralised phyllites/schists, quartzites and quartz bodies, (Fig. 4.5. profile 570m north 800m south).

The in-phase readings range from +3 to -8 and quadrature readings averaged (-4) with no significant cross-over to show distinctive lithological changes.

4.7.2. The Altered/Mineralized Zone

This unit comprises the quartz bodies, and their altered wallrocks.

4.7.2.1. The Gold-bearing Quartz Bodies

These exhibit the sharpest peaks and are thin bands of auriferous quartz veins found within the host rocks.

Profiles 500m and 300m south show in-phase amplitudes of between +5 to +20, indicating very high conductive/mineralised bodies. These of course, corresponded to field observation made from the dug pits on these profiles.

4.7.2.2. The Altered Wallrocks

These rocks exhibit broad bands, with abrupt gradients of positive anomalies, implying mineralised bodies of about 300 meters wide. The in-phase readings range from +4 to +17 (see Fig. 4.5.) profiles 450m to 750m north. The highest abrupt gradient of positive anomalies are recorded on profile 700m south, where the in-phase amplitude recorded above +20 within the quartzites. This unit may be further subdivided into: non-silicified and silicified wallrock.

The non-silicified wallrocks comprise the phyllites/schists and quartzites. They are partially indurated, gritty, highly mineralised and weathered too. Pits were extensively dug in these zones and the extent of mineralised zones was picked by the instrument as illustrated on the graph (Fig. 4.5.). These zones are widely exposed but are found buried in places.

The silicified rocks may be similar to the above but are highly indurated, tough and consist of tiny ramifying quartz veinlets of 50mm to 1cm in width. Although, these veinlets are scarcely picked by the instrument. The abrupt gradients of positive values obtained from this area (profiles 300m - 600m north) revealed this hidden zone of silicified rocks. Fewer pits were recorded in this zone, but a lot of eluvia working on the softer wallrock is presently in progress. This unit is mapped in patches but VLF readings revealed its continuity for about 400m in length along the strike. It is mineralised but the positive in-phase amplitudes are lower than those of non-silicified wallrock (Fig. 4.5.) (profile 50m - 350m north) with positive in-phase amplitude of +5 to +10.

The quartzites are found as lowlying ridges within the phyllites/schists are ironically mineralized too in some places where the auriferous quartz veins are found (profiles 700m-600m south).

CHAPTER FIVE

GEOCHEMISTRY

5.1. Introduction

Some major and trace element concentrations have been determined in the mineralized and fresh rock samples from the Dukki mine area. The distribution and association of such elements are thus discussed in this chapter in order to understand the nature of the gold mineralization process. The elements determined are dictated by the availability and capabilities of the available laboratory facilities in Ahmadu Bello University.

5.2. Field and Laboratory Methods

A total of 40 samples were collected along the grid network used for the VLF geophysical investigation. While most of the rock samples were taken from the mine pits, some were taken 500m-1km away from the mine pits.

Samples of quartz bodies (10 samples) stringers/veinlet's (9 samples) silicified (5 samples), wallrock (10 samples), and fresh rock (6 samples) were collected from the abandoned pits, shafts, trenches, stream channels and some exposed outcrops, (Appendix I1, Group A-E).

34 samples were collected from mineralised zones and 6 samples from fresh rock for background concentrations.

5.2.1. Sample Preparation

Two analytical techniques were employed for geochemical studies of the samples obtained. They are the X-Ray Fluorescence (XRF) and Atomic Absorption Spectrometry (AAS) methods.

The XRF technique was used for determination of concentrations of all the elements except for gold where the AAS technique was used. This is because effective concentration of gold could not be measured using XRF method.

Two kilograms of each of the rock samples collected was pulverized with a tungsten carbide spex mill to a fine powder form of a mean particle diameter of 50um at the laboratory of the Department of Geology A.B.U Zaria. These were thoroughly mixed using conning and quartering method . Finally, 500g of each pulverised rock samples was collected and stored in a sealed polythene bag.

5.2.2. XRF Technique

500mg of each powder samples was moistened with 5-6 drops of a binder (10% solution of PVC in toluene) thoroughly homogenised in agate mortar, and allowed to dry, transferred into a 25mm in diameter and pressed into a pellet at a pressure of 10 tons using SPECAL hydraulic pressure. This yields a specimen pellet of mass 100mgCm^2 of each of the sample.

The elemental analysis of the rock samples were done on *radioisotope x-ray analysis system* at the Centre for Energy Research and Training A.B.U. Zaria. The system consists of two interchangeable annular sources of different x-ray energies and a silicon solid state

detector (with energy resolution of 170ev at 5.9 Kev) coupled to a computer-controlled MAESTO Analog to Digital Converter (ADC) card. The spectra were collected for 3000 sec. each and evaluated using the AXIL computer program (After Espen et. al., 1996) as cited by (Ogunleye, 1987).

The excitation sources are ^{55}Fe (925 MBq) and ^{109}Cd (925 MBq). As the minimum detectable levels using one source vary greatly with atomic number, the 2 sources were used so as to maintain low minimum detectable levels over a wide atomic number range. Excitation using Ag, K X-rays (22.101, 24.928) of ^{109}Cd source allows the direct analysis of K and L-lines of elements. The elements determined in the samples using these sources are Cr, Mn, Fe, Co, Cu, Zn, Ga, Rb, Sr, Y, Zr and Nb from K lines and Pb from L-lines between 5-17 Kev. Excitation of Mn K x-rays (5.994, 6.489) of ^{55}Fe sources enables the determination of the concentrations of Al, Si, K, Ca and Ti from K-line between 1.5 and 5Kev. In order to confirm the reliability of the system calibrations, British Chemical Standard No. 395 - BAUXITE was analysed. Correction for matrix absorption was determined using thick specimen (Mo mental) technique.

A total of 16 elements (major, minor and trace) were analysed -K, Ca, Ti, Fe, Mn, Rb, Sr, Y, Cr, Co, Cu, Pb, Zn, As, Zr, and Nb, in ppm. Element below 2ppm can not be detected (Detection Limit (DTL) < 2ppm).

5.2.3. Atomic Absorption Spectrometry Technique

5g of each powdered samples was weighed into Teflon beaker and digested using combination of HCl and HNO_3 acids in the ratio of 3:1 (Aquaregia). For silicon samples, few drops of HF acid were added immediately after the addition of HNO_3 acid. The mixture was digested on the sand bath for about 3-4 hours to ensure complete dissolution. Dilute solution of cyanide in Hydrogen Peroxide was also added to the mixture and heated to dissolve all the Au. The mixture was then filtered into a 100ml volumetric flask. The determination of the Au concentration was done using Atomic Absorption Spectrometer UNICAMP 929 with the least sensitivity for Au being 0.12mg/litre. Au concentration was obtained from 29 samples and are tabulated along with results from XRF analysis (Appendix II, Group A-E).

5.3. Data Analysis

The first phase of geochemical interpretation is to condense large numerical data and extract from them, the essential information. The most objective and reliable way to do this is by statistical analysis where large sets of numbers, cumbersome and difficult to interpret may be reduced to useful form.

5.3.1. General Statistical Analysis of Data

Table 4 shows statistical data of importance (mean, standard deviation and range) obtained for 17 elements - Au, K, Ti, Mn, Ca, Fe, Rb, Sr, Y, Cr, Co, Cu, Zn, Pb, As, Zr and Nb from 40 samples collected

Table 4..: *Statistical Data for the Elemental Analysed*

Quartz Veins (n-10)

	Au	K	Ca	Ti	Mn	Fe	Rb	Sr	Y	Cr	Co	Cu	Zn	Pb	As	Zr	Nb
Mean S. Dev. Range	0.855 1.17 0.0-3.06	11,118.3 11149.19 1400-	2267.4 1237.59 0.0-	2190.3 1611.53 767-	533.6 554.72 153-	14,646 19044.43 238-	42.41 56.82 4.9-	10.36 6.99 5.3-	8.99 5.75 0.0-	304.9 252.35 0.0-	138.31 36.96 99.1-	34.45 23.14 0.0-	35.7 13.71 4.0-	27.07 7.49 17.3-	72.52 94.37 14.5-	68.86 92.80 3.7-	5.92 3.34 2.7-
		39,100	3380	5540	1820	51,300	176	27.5	19.1	891	201	80.3	51.1	42.6	316.00	257	14.2

Veinlets/Stringers (n-9)

	Au	K	Ca	Ti	Mn	Fe	Rb	Sr	Y	Cr	Co	Cu	Zn	Pb	As	Zr	Nb
Mean S. Dev. Range	1.39 1.26 0.15-	16072.22 11182.13 5390-	2521.11 10,10.04 0.0-	2487.22 1,590.97 825-	488.44 563.59 160-	17,498.89 14111.64 2230-	142.29 193.32 4.8-	26.71 26.06 4.2-	13.23 8.53 4.18-	258.78 122.46 0.0-	130.77 53.72 8.9-	38.7 17.74 0.0-	46.21 21.80 24.9-	37.89 16.61 22.9-	92.32 74.16 17-	175.39 190.95 3.35-	7.89 4.61 4.3-
	3.45	40,600	3650	5140	1890	42,600	603	78.0	25.4	396	192	61.7	82.2	52.	208	646	16.1

Silicified Rock (n-5)

	Au	K	Ca	Ti	Mn	Fe	Rb	Sr	Y	Cr	Co	Cu	Zn	Pb	As	Zr	Nb
Mean S. Dev. Range	1.22 1.52 0.0-	21,782.15 15437.13 5900-	2574.14 1446.21 0.0-	4222.25 2555.57 1060-	453.83 259.76 220-	24,540.18 18634.46 3700	62.3 62.65 7.2-	89.7 88.13 5.8-	18.88 11.85 4.9-	291.62 183.85 0.0-	159.6 25.28 136-	38.52 21.69 0.0-	53.96 29.04 28-	35.02 5.56 26.2-	107.82 64.10 14-	163.36 67.35 66.8-	11.25 6.75 3.74-
	3.75	40800	3390	6240	854	53,300	169.	150.	31.5	497	201	51.6	99.4	41.3	400.	238	17.8

Wall Rock (n-10)

	Au	K	Ca	Ti	Mn	Fe	Rb	Sr	Y	Cr	Co	Cu	Zn	Pb	As	Zr	Nb
Mean S. Dev. Range	0.47 0.83 0.0-	12,902 9,238.63 4830-	2645 991.7 0.0-	2099.8 1554.54 848-	412.8 399.2 152-	17,996 21899.69 1310-	47.09 51.63 6.0-	16.42 16.30 4.1-	35.91 87.00 3.7-	261.17 138.01 9.7-	160 96.22 0.0-	52.8 34.24 29.2-	31.81 7.79 24.4-	36.32 14.99 15.8-	53.05 61.44 3.5-	5.700 67.03 2.9-	6.92 4.69 2.9-
	2.7	28,600	3760	4920	1330	69,500.	136	50.3	248	551	285	142	47	63.4	190	146	16

Host Rock-Schists/Phyllites (n-6)

	Au	K	Ca	Ti	Mn	Fe	Rb	Sr	Y	Cr	Co	Cu	Zn	Pb	As	Zr	Nb
Mean S. Dev. Range	0.0 0.0 0.0-	30,843.3 13,123.05 7360-	3.88.33 951.22 0.0-	4873.33 1768.95 1760-	757.39 399.85 162-	44.166.67 15,941.35 13,200-	160.55 72.21 21.3-	57.98 49.02 10.3-	25.25 9.29 7.3-	38.5 94.31 0.0-	256.43 92.10 89.6-	5.33 13.06 0.0-	87.55 35.48 31-	44.4 9.05 27.4-	44.87 27.1 28.3-	162.83 79.2 24-	16.47 6.00 5.7-
	0.0	45,300	2330	6750	1230	54,500	215	144	831.8	231	324	32	128	52.9	99.6	236	22.3

from the Dukki Mine area. Their correlation coefficients were calculated (Table 6-8).

5.3.2. Inter-Element Relations and Associations

In order to estimate element distribution trend from the fresh/country rock to the mineralised zone some strongly correlated pairs of elements are considered.

The significant correlation co-efficient of above 0.80 (r = 0.80) are chosen for the 17 elements in each group (fresh country rock and mineralised zone) and are summarised as follows:

The correlation matrix of the country rock (Table 5) shows that Au does not exhibit significant correlation with other elements in this group, while the following associations are present (K-Ti-Fe-Sr-Y-Pb), (Cr-Cu). This serves as the background element associations in the non-mineralised zone.

This mineralised group consists of four units (Table 6 - 8), which are: the wallrocks, silicified rocks, stringers/veinlets and the auriferous quartz bodies.

The correlation matrix of the wallrock (Table 6) shows As to have significant correlation with Au in this unit, but the element associations include the followings (K-Rb-Sr), (K-Y), (Fe-Ti-Mn-Cu), (Pb-Zn).

In the correlation matrix of silicified rock (Table 7) Au shows almost perfect correlation with other elements in the unit except Ca, Cu and Co. This may be as a result of insufficient quantity of these elements compared to other elements in the hydrothermal fluids. Although during hydrothermal alteration process element like Ca is

Table 5 : FRESH ROCK (6 Samples)

	Au	K	Ca	Ti	Mn	Fe	Rb	Sr	Y	Cr	Co	Cu	Zn	Pb	As	Zr	Nb
Au	1.00	0.54	0.20	0.50	0.12	0.52	0.67	-0.86	-0.35	0.20	0.21	0.20	0.01	-0.26	-0.99	-0.37	-0.29
	K	1.00	-0.88	0.87	0.51	0.75	0.26	0.80	0.90	-0.88	0.14	-0.88	0.78	0.86	0.46	0.35	0.94
		Ca	1.00	-0.87	-0.73	-0.95	-0.57	-0.48	-0.95	1.00	-0.26	1.00	-0.78	-0.92	-0.10	-0.27	-0.88
			Ti	1.00	0.63	0.88	0.55	0.58	0.92	-0.87	0.52	-0.87	0.85	0.93	0.93	-0.10	0.88
				Mn	1.00	0.76	0.55	0.26	0.55	-0.73	0.63	-0.73	0.39	0.39	-0.24	-0.34	0.45
					Fe	1.00	0.79	0.26	0.88	-0.95	0.38	-0.95	-0.84	-0.89	-0.18	0.12	0.84
						Rb	1.00	-0.30	0.43	-0.57	0.36	-0.57	0.70	0.50	-0.72	-0.10	0.50
							Sr	1.00	0.57	-0.48	0.13	-0.48	0.34	0.49	0.82	-0.15	0.59
								Y	-1.00	-0.95	0.28	-0.95	0.79	0.99	0.28	0.29	0.89
									Cr	1.00	-0.26	1.00	-0.78	-0.92	-0.10	-0.27	-0.88
										Co	1.00	-0.26	0.13	0.30	-0.22	-0.84	0.83
											Cu	1.00	-0.78	-0.92	-0.10	-0.27	0.88
												Zn	1.00	0.83	-0.05	0.32	0.94
													Pb	1.00	0.20	0.28	0.89
														As	1.00	0.35	0.22
															Zr	1.00	0.41
																Nb	1.00

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Table 6 .: WALLROCK (10 SAMPLES)

	Au	K	Ca	Ti	Mn	Fe	Rb	Sr	Y	Cr	Co	Cu	Zn	Pb	As	Zr	Nb
Au	1.00	0.71	-0.37	0.61	0.24	0.68	0.45	0.65	0.77	-0.33	0.18	0.58	-0.20	-0.23	0.89	0.19	0.54
	K	1.00	-0.55	0.4	0.65	0.72	0.94	0.85	0.97	0.04	-0.31	0.68	-0.32	-0.33	0.82	0.42	0.72
		Ca	1.00	-0.66	0.18	0.06	-0.46	-0.70	-0.67	0.60	0.64	0.22	0.10	-0.12	-0.72	0.20	0.12
			Ti	1.00	0.90	0.91	0.83	0.50	0.72	0.42	0.08	0.92	-0.16	0.14	0.53	0.65	0.74
				Mn	1.00	0.81	0.76	0.29	0.47	0.71	0.10	0.85	-0.17	-0.15	0.15	0.76	0.93
					Fe	1.00	0.65	0.48	0.64	0.27	0.30	0.91	-0.21	-0.22	0.46	0.80	0.95
						Rb	1.00	0.76	0.86	0.25	-0.42	0.65	-0.26	-0.27	0.61	0.57	0.72
							Sr	1.00	0.92	-0.37	-0.45	0.39	-0.25	-0.34	0.81	0.26	0.37
								Y	1.00	-0.19	-0.38	0.57	-0.33	-0.37	0.90	0.36	0.59
									Cr	1.00	0.19	0.47	-0.12	-0.05	-0.43	0.41	0.52
										Co	1.00	0.21	0.22	0.25	-0.26	0.85	0.24
											Cu	1.00	-0.28	-0.29	0.39	0.66	0.94
												Zn	1.00	0.98	-0.27	-0.23	-0.25
													Pb	1.00	-0.29	-0.26	-0.24
														As	1.00	0.02	0.37
															Zr	1.00	0.78
																Nb	1.00

Table 7 .: SILICIFIED ROCK (5 SAMPLES)

	Au	K	Ca	Ti	Mn	Fe	Rb	Sr	Y	Cr	Co	Cu	Zn	Pb	As	Zr	Nb
Au	1.00	0.92	0.54	0.88	1.00	0.85	0.86	0.87	0.90	0.90	-0.44	-0.52	0.92	-0.85	-0.80	0.62	0.95
	K	1.00	0.18	1.00	0.90	0.99	0.99	0.99	0.99	1.00	-0.05	0.81	1.00	0.58	-0.97	0.87	1.00
		Ca	1.00	0.09	0.59	0.03	0.04	0.06	0.13	0.12	-0.99	-0.43	0.18	0.91	0.08	-0.33	0.26
			Ti	1.00	0.86	1.00	1.00	1.00	1.00	1.00	0.44	0.86	1.00	0.50	-0.99	0.91	0.99
				Mn	1.00	0.82	0.83	0.84	0.88	0.87	-0.49	-0.47	0.90	0.88	-0.76	0.57	0.93
					Fe	1.00	1.00	1.00	1.00	1.00	0.10	0.89	0.99	0.45	-0.99	0.94	0.97
						Rb	1.00	1.00	1.00	1.00	0.09	0.89	0.99	0.46	-0.99	0.93	0.98
							Sr	1.00	1.00	1.00	0.06	0.87	0.99	0.48	-0.99	0.92	0.98
								Y	1.00	1.00	-0.01	0.84	1.00	0.54	-0.98	0.90	0.99
									Cr	1.00	0.01	0.85	1.00	0.53	-0.98	0.90	0.99
										Co	1.00	0.54	-0.06	-0.85	-0.20	0.44	0.13
											Cu	1.00	0.81	-0.01	-0.93	0.99	0.76
												Zn	1.00	0.58	-0.97	0.87	1.00
													Pb	1.00	-0.35	0.11	0.64
														As	1.00	-0.97	-0.94
															Zr	1.00	0.83
																Nb	1.00

Table 8 .: VEINLETS/STRINGERS (19 SAMPLES)

	Au	K	Ca	Ti	Mn	Fe	Rb	Sr	Y	Cr	Co	Cu	Zn	Pb	As	Zr	Nb
Au	1.00	0.58	-0.24	0.67	0.11	0.52	0.32	0.29	0.13	-0.10	0.34	0.05	0.50	-0.12	0.94	0.79	0.59
	K	1.00	0.02	0.90	0.85	0.77	0.25	0.45	0.80	0.57	0.09	0.66	0.42	0.57	0.14	0.35	0.83
		Ca	1.00	-0.08	0.29	-0.02	-0.28	-0.24	0.02	0.43	-0.04	0.08	-0.25	0.34	-0.39	0.08	-0.09
			Ti	1.00	0.76	0.71	0.23	0.26	0.87	0.41	0.38	0.65	0.59	0.45	0.43	0.65	0.77
				Mn	1.00	0.11	0.31	-0.00	0.53	0.56	0.18	0.77	0.32	0.74	-0.17	0.39	0.45
					Fe	1.00	0.46	0.26	0.49	0.31	0.34	0.79	0.48	0.63	-0.02	0.16	0.45
						Rb	1.00	0.02	-0.01	-0.49	-0.19	0.12	-0.07	0.73	0.13	-0.04	0.11
							Sr	1.00	0.51	-0.06	-0.26	-0.01	0.27	-0.02	0.33	-0.08	0.65
								Y	1.00	0.30	0.21	0.37	0.55	0.19	0.61	0.70	0.85
									Cr	1.00	0.26	0.51	0.11	0.08	-0.39	0.05	0.33
										Co	1.00	0.62	0.73	-0.17	0.21	0.55	-0.13
											Cu	1.00	0.71	0.42	-0.21	0.38	0.19
												Zn	1.00	-0.07	0.36	0.68	0.20
													Pb	1.00	-0.21	0.06	0.27
														As	1.00	0.61	0.45
															Zr	1.00	0.25
																Nb	1.00

Table 9 : QUARTZ VEINS (10 SAMPLES)

	Au	K	Ca	Ti	Mn	Fe	Rb	Sr	Y	Cr	Co	Cu	Zn	Pb	As	Zr	Nb
Au	1.00	0.52	-0.26	-0.53	-0.62	-0.44	-0.24	-0.22	-0.52	-0.49	-0.53	0.28	-0.87	-0.15	0.58	-0.31	-0.22
	K	1.00	0.05	0.69	0.72	0.48	0.93	0.98	0.51	0.03	-0.02	-0.13	0.52	-0.30	0.70	0.89	0.95
		Ca	1.00	-0.07	0.50	0.89	-0.22	-0.04	-0.39	0.97	0.38	0.98	0.41	0.91	-0.41	0.50	0.35
			Ti	1.00	0.77	0.36	0.83	0.79	0.83	0.09	-0.52	-0.16	0.85	-0.35	0.93	0.63	0.64
				Mn	1.00	-0.4	0.62	0.75	0.33	0.60	-0.30	0.38	0.93	0.13	0.53	0.90	0.87
					Fe	1.00	0.25	0.42	-0.03	0.90	0.17	0.80	0.72	-0.64	0.04	0.83	0.72
						Rb	1.00	0.96	0.78	-0.18	-0.18	-0.37	0.53	-0.51	0.90	0.72	0.79
							Sr	1.00	-0.61	-0.02	-0.19	-0.21	0.60	-0.40	0.80	0.85	0.91
								Y	1.00	-0.28	-0.26	-0.44	0.49	-0.48	0.91	0.32	0.32
									Cr	1.00	0.15	0.96	0.58	0.86	-0.28	0.50	0.34
										Co	1.00	0.38	-0.45	0.54	-0.50	0.07	-0.01
											Cu	1.00	0.34	0.96	-0.51	0.34	0.18
												Zn	1.00	0.12	0.60	0.72	0.65
													Pb	1.00	-0.64	0.14	-0.03
														As	1.00	0.47	0.53
															Zr	1.00	0.98
																Nb	1.00

expected to have been leached out. It is uniquely observed that this unit exhibits near perfect correlation with higher number of elements than any other in the group. This may be as a result of complete interaction of mineralizing fluids with the wallrocks leading to re-equilibration of the fluids with the host rocks.

The correlation matrix of the veinlets/stringers (Table 8) Shows Au to have significant correlation with As as formerly observed in the wallrock. The following element associations are present (K-Ti-Y-Mn), (Au-As). It is important to note that (Fe-Cu-Zn-Pb) element associations play no significant role in this unit. This may also be due to their insufficient quantity in the mineralization process.

The correlation matrix of the quartz veins (Table 9) shows none of the elements to have significant correlation with Au. Though it exhibits other element associations such as (K-Rb-Sr), (Cu-Cr-Fe-Mn-Zn), (Cu-Pb), it is of paramount importance to note the absence of (Fe-Ti), (Pb-Zn) and (Au-As) element associations in this unit.

Summary

The elemental associations in the fresh/country rock, altered wallrocks and quartz vein/veinlets do not show much discrepancy. Though, the country rock seems to contain no gold from the analysis carried out (at 2ppm detection limit), the altered wallrock, silicified and quartz veins show almost constant element associations. Though no significant correlation value exists between Au and As in the silicified rocks and quartz veins, the veinlets with the highest average concentration value of Au has near perfect correlation with As, but with

few element associations when compared with other units in the mineralised zone and the fresh/country rock. (Fe-Ti) element association appears consistently throughout altered (silicified) wallrock, but not in the quartz veins or veinlets. The absence of (Fe-Ti) element association in this area may confirm the limitation of alteration process in the wallrock. Table 4, revealed higher concentration value of K within the altered wallrocks relative to the quartz vein/veinlets, the evidence confirmed the process of sericitization in the units.

(Pb-Zn) and (Cu-Fe) element associations show no significant correlation in the groups. This may be due to insufficient quantity of these elements in the mineralising fluid to allow for the formation of their main mineral e.g. galena, sphalerite, chalcophyrite etc. It is important also to note the consistency of (K-Rb) element association in the altered wallrock and the quartz vein showing almost perfect correlation.

5.3.3. Major Features of Element Association and their Ratios

From the geochemical data on 17 elements analysed, Appendix I (Table 10), it becomes necessary to select some prominent major and trace elements to depict the geochemical changes associated with distribution patterns that are related to known gold mineralization, and the possible source of mineralising fluid for gold mineralization at Dukki Mine. A preliminary examination revealed that these elements - As, Au, K, Rb, Sr, Ti, and Fe have distribution patterns related to gold mineralization at Dukki Mine. These were further reappraised using variation diagrams.

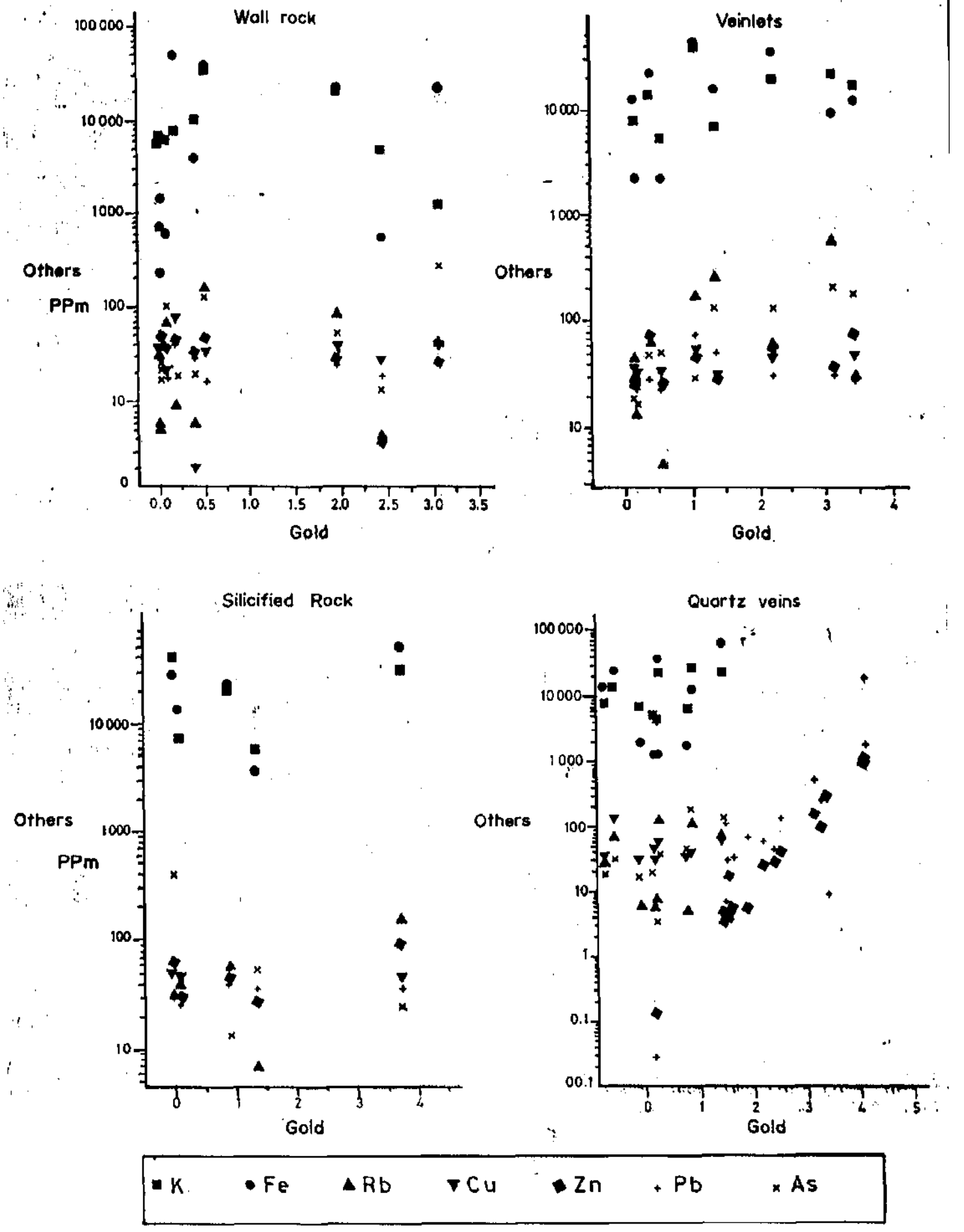


Figure 5.1. Variation diagram of Gold Vs, K, Fe, Rb, Cu, Zn, Pb and As.

The variation diagrams were constructed by plotting mean concentration values of each variable one against the other in each group (A-E) for the 40 samples collected (Fig 5.1). These variation diagrams of Au versus K, Fe, Cu, Zn, Pb and As show no regular pattern, these may imply incoherent association behaviour between Au and other elements during the process of Au mineralization. These elements were further grouped into 2 parts as follows:

a). Fe, Cu As, Ti and K group - These are major and trace elements used to depict the geochemical changing patterns associated with alteration process of the gold mineralization at Dukki.

b). K-Rb-Sr group - These are used as possible indicators of source(s) of the gold mineralizing fluids.

5.3.3.1a. Fe-Cu-As-Ti-K Association

The (Fe-Cu-As) co-enrichment exists in the altered wallrock and may be related to gold mineralization. But from variation diagrams plotted for other elements (Fe-Cu-As) versus Au no specific trend could be obtained from the four units in the mineralised group (Fig. 5.1.). The low concentration values of Cu and As relative to Fe may hinder minerals such as chalcopyrite and arsenopyrite from being formed. However, presence of Fe-Ti and Au association implies enrichment of magnetite and/or limonite in the altered wallrock as was documented in the petrographic data (Chapter 3).

The higher average concentration value of K observed in the altered wallrock relative to quartz veins may be due to enrichment of K in the altered wallrocks. This may imply K-metasomatism by mineralizing fluids. The concentration of K in potassic alteration domain

of vein-gold mineralization has been used as tracers for the ore shoot at Bin Yauri (Garba, 1992).

5.3.3.1b. K-Rb-Sr Association

(K-Rb) element association do co-enriched in nature. Concentration value of each of the elements becomes important when tracing the source of the mineralizing fluids. It is of paramount importance to note the enrichment of K relative to Rb in the quartz veins and the altered wallrock. The (Rb-Sr) element association also exist. On the other hand, the element association ratios indicate some trends that are useful for geochemical data interpretation (Table 10).

Iron-Titanium Ratio (Fe-Ti)

Table 10 reveals enrichment of Fe/Ti ratio in the altered wallrock and its depletion in the quartz veins. There is general depletion of Fe/Ti ratio from fresh rock to the quartz veins relative to the average crustal ratio. Fig. 5.2. A-E shows variation patterns from fresh rock to quartz veins. The plot exhibits linear relationship between Fe/Ti. This implies that Fe/Ti co-exists as magnetite/magnetite in nature in this study. The depletion of Fe/Ti ratio in the quartz veins may imply its limitation to the altered wallrock. The presence of magnetite/magnetite ratio within the altered wallrock confirms the process of haematization in Dukki gold mineralization. The average crustal ratio of Fe/Ti (11.4) relative to the country rock with (r=9.1) confirms alteration process.

The diagrams plotted are similar to that of El-Nafaty (1989) where he used limonite/ magnetite ratio relative to gold, thereby exhibiting a

Table 10.: ELEMENT ASSOCIATION RATIOS

Elemental Ratios	Crustal Ratios	Country Rocks	Wallrock	Silicified Rock	Veinlets/ Stringers	Auriferous Quartz veins
Fe/Ti	11.4	9.06	8.57	5.81	7.04	6.7
K/Rb	288	192	274	351	113	262
Rb/Sr	0.24	2.8	2.9	0.70	5.33	4.09

(Based on Clarke Concentration value in ppm). B. Mason 1964).

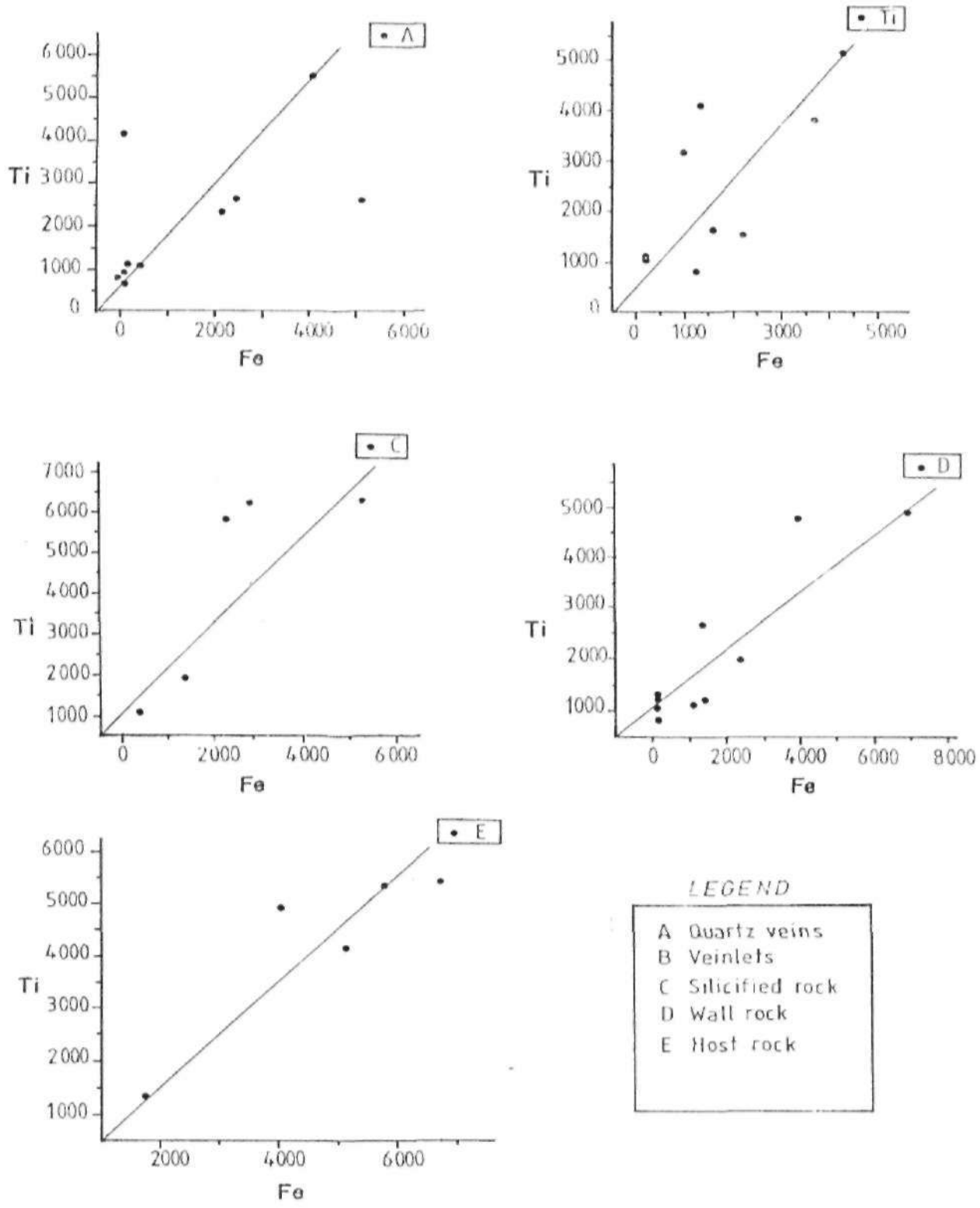


Figure 5.2: Graghs of Fe against Ti in each group

linear relationship in his study at Kuba gold mine. He employed this method as an exploration means in search for gold.

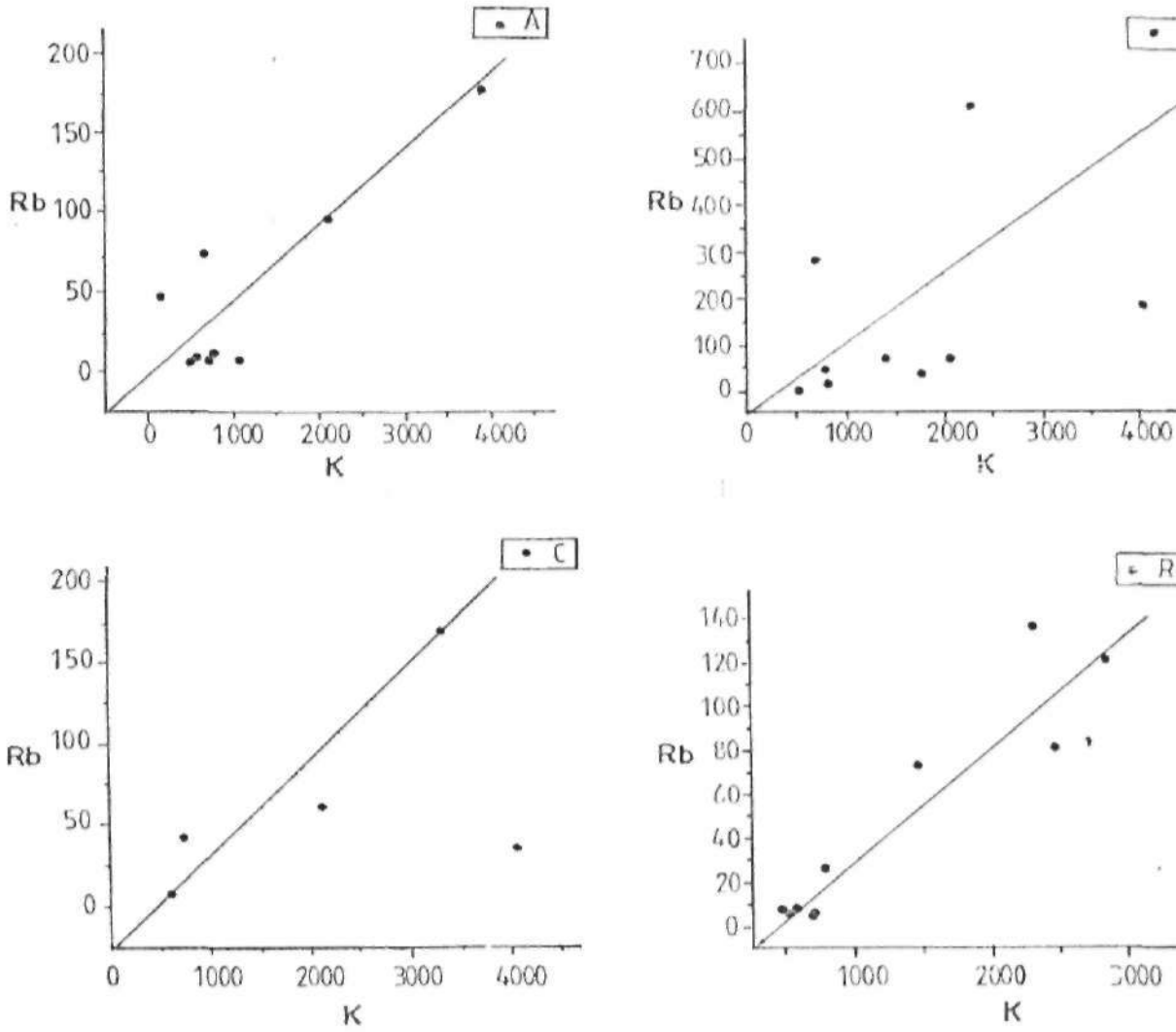
Potassium-Rubidium Ratio (K/Rb)

The K/Rb ratio (fig. 5.6. A-E) indicates a coherent behaviour of K and Rb in the variation diagrams plotted. The trend in the mineralised group shows enrichment of K relative to Rb. This is similar to Garba (1992) where such trend of K/Rb ratio were plotted on different rock types (phyllites, hornfels etc) of the Bin Yauri gold deposit, where the source of the fluid was suggested to be of non-magmatic origin.

Table 10. reveals importance of K/Rb ratio values in the quartz veins and wallrock compared with the fresh/country rock. In the former, the ratios are approximately the same as the mean crustal ratios 262ppm, 274ppm and 288ppm respectively, as it is usually the case with other NW Nigerian gold mineralization. This approximation implies the source of the fluid to be of crustal origin (Garba 1992, 1996, 1998). The latter are depleted probably due to leaching of Rb relative to K during weathering.

Rubidium-Strontium Ratio (Rb/Sr)

Fig. 5.4. A-E shows incoherent behaviour of Rb and Sr in the variation diagram. In nature, Sr does not systematically co-enrich or deplete with Rb, therefore scattered diagram may be expected as the case with Bin Yauri gold (Garba, 1992).



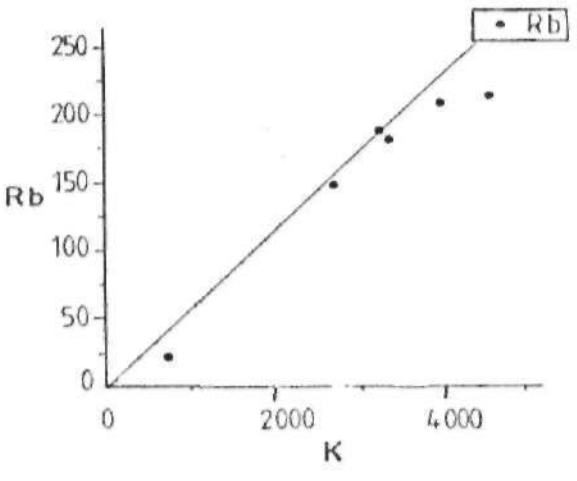




Figure 5.3: Graphs of K vs Rb for each group .

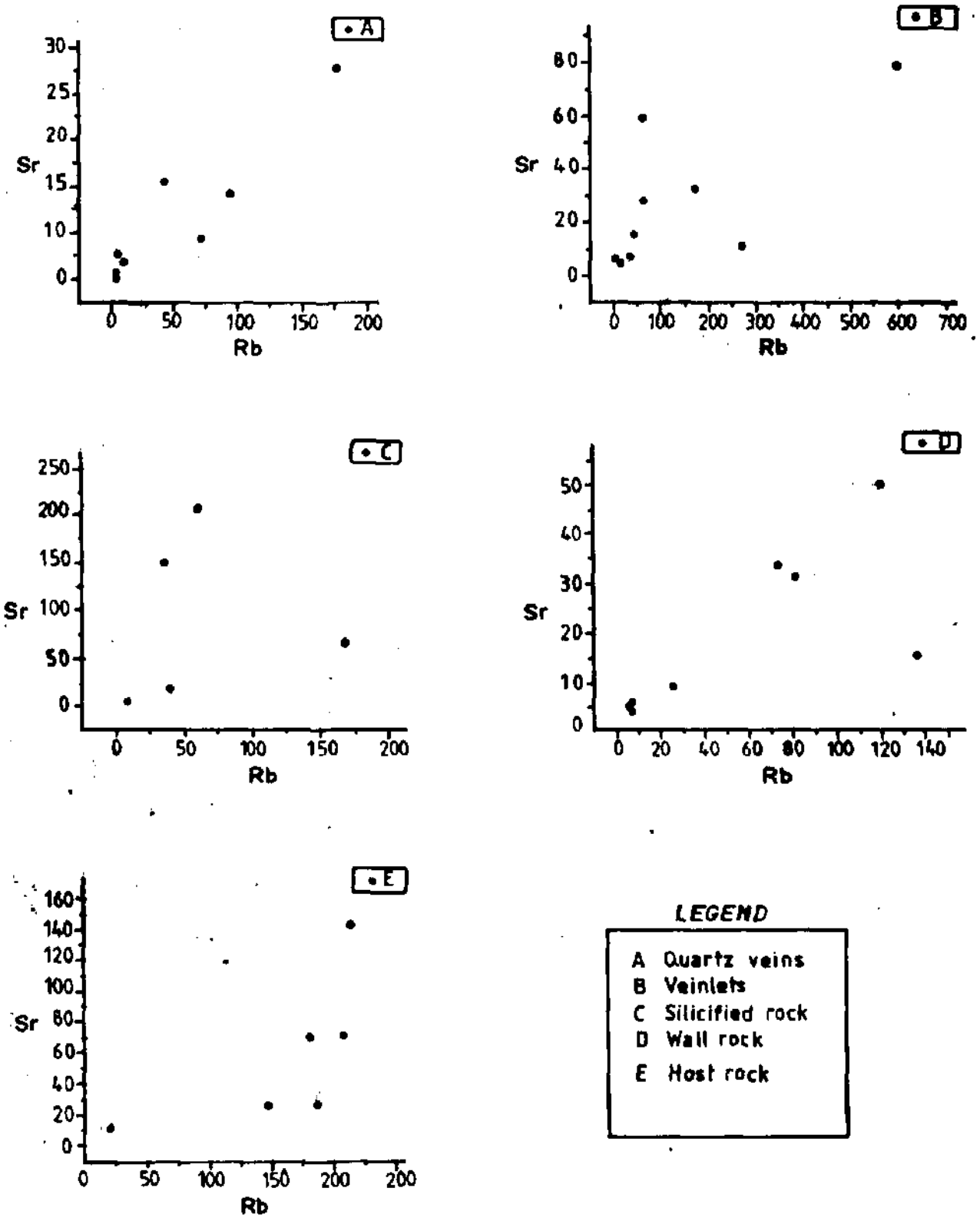


Figure 5.4: Graphs of Rb vs Sr for each group

CHAPTER SIX

CONTROLS AND POSSIBLE ORIGIN OF THE DUKKI GOLD MINERALIZATION

Controls and origin of gold mineralization in Dukki area may depend on many factors, important among them are geology, structures, geotectonic evolution of the Maru Schist Belt, physico-chemical conditions of the mineralising fluids and the petrographic and chemical character of the host rocks into which they permeate.

The geology of Dukki area is made up of rock units that are derivations of mudstones, siltstones, carbonaceous shales and sandstones deposited under quiet water environment. They are now represented by phyllites, schists (carbonaceous) and quartzites, which are deformed and metamorphosed in the greenschist facies grade together with the basement migmatite-gneiss complex during the Pan-African event (Egbuniwe, 1982). The geology of Dukki area though of later age, possibly Late Pan African, in many respects resembles that of Archaean greenstone and younger volcano-sedimentary basins, from which the largest gold deposits in the world have been reported. The resemblance is especially with respect to their size, synclinal structures, low metamorphic grade and the presence of volcanic and clastic rocks and their associated banded iron formation and gold mineralization.

Owing to scarcity of outcrops near Dukki mine it is impossible to discern detailed structural relationship, but the geophysical data collected indicate numerous subparallel fractures/faults. More generally, there is circumstantial similarity to many other gold locations where mineralization is mainly found in minor fault systems in the vicinity of a major crustal 'break' for example at Val'd or in Quebec Canada and at Iperindo mine (Oyinloye & Steed, 1996).

The Dukki mine appears to be localised by shear/fault zone that lies subparallel to a sub regional N-S anticlinal structure. The veins occupying the shear zones are conformable to regional foliation of the host rocks. The axis of the antiform runs N-S (Fig. 2.6b) and, possibly, intersects the NE-SW trending Kalangai fault system (KFS) to the south. This fault system is considered to be a deep strike-slip lineament possibly defining a Pan-African crustal suture (Wright, 1976; Ajibade & Wright 1989; Garba, 1992). This setting is comparable to the setting of the Birnin Gwari gold deposit, where gold mineralization exploited the anticlinal fold axis running N-S and disrupted by the Kalangai fault, (Garba 1998, 1999).

Geotectonic ally, the previous stipulated models in chapter 2 conveniently revealed the time framework of the gold mineralization to be of late Pan-African event. The D_1 deformation in Maru belt is recorded to be 1068m.y (Kibaran) and Ogezi (1977) confirmed the host rocks (phyllites/schists) to have been older than Pan-African. This evidence of Kibaran event is suggested to have been overprinted by the Pan-African events in the area of study. The post Pan-African

events are mainly uplifting and brittle deformation from where subsidiary conjugate fracture system developed. These served as the conduits to gold mineralizing fluids.

Like the Anka fault system, the Kalangai fault system is envisaged to be a great length of a regional lineament (>100Km) in NW Nigeria (McCurry & Wright, 1976, Ajibade & Wright, 1989). The kalangai fault association with magmatic bodies have been suggested to indicate the transcrustal structures extension into lower crust/mantle areas (Ajibade & Wright, 1989} and cited by Garba (1992, 1996). Therefore (Ajibade, 1982; Egbuniwe, 1982; Ajibade & Wright, 1989) offered support to the concept of the Kalangai fault system as possible Pan-African crustal suture.

It may be possible to relate the origin of the fluids responsible for the Dukki gold mineralisation to metamorphic devolatilization and dehydration of subducted materials along collisional suture zone proposed to be an important control and origin of mesothermal gold deposits irrespective of their age (Kerrich, 1989a-c, Garba, 1992, 1996).

Petrographically, some of the primary minerals of the phyllites/schists mainly plagioclase, biotite and magnetite have been replaced by secondary mineral assemblages of sericite, magnetite, haematite, limonite, limonite with fine disseminated pyrite, signifying hydrothermal alteration process. The wallrocks of Dukki mine have been altered, the alteration is possibly due to reactions caused by mineralizing fluids that infiltrated the wallrocks at the time and place of

gold mineralization. The hydrothermal alteration of wallrocks appear to be a common phenomenon and universal to all gold localities in Nigeria (Woakes & Bafor, 1982; Akande et. al., 1988; Garba, 1992, 1996, 1998; Oyinloye & Steed, 1996). The source of the mineralizing fluid is suggested to be epigenetic. This is deduced from the mineralised quartz veins cross- cutting the foliation of the host rocks. This signifies that Au mineralization post-dated regional (metamorphic) structural development. The structures are likely to be of late Pan-African (late tectonic) event. Therefore, the mineralization is thus not related to the main regional metamorphism, rather it is a post peak-metamorphic event.

From geochemical point of view, the similarity in chemical composition in the quartz veins, wallrock and host rocks may imply re-equilibration of the fluid with the source rocks under hydrothermal metamorphic conditions. This is indicated by the K/Rb ratio (Table 10) where the average crustal ratio of K/Rb is in approximation with that of the quartz veins and the altered wallrocks. This possibly implies the fluid to be of crustal origin as proposed by (Garba, 1992, 1996, 1998) for the Birnin Gwari and Bin Yauri gold fields. The increase in the K/Rb co-enrichment in the Dukki mine just as in the Bin Yauri gold mineralisation (Garba, 1992) is also an important evidence for the source of mineralizing fluids to have been generated within crustal metasedimentary rocks.

CHAPTER SEVEN

SUMMARY AND CONCLUSION

7.1. Geology of Dukki Area

The Dukki primary gold mineralization is localised within the Maru schist belt of Precambrian to lower Paleozoic. The belt consists of phyllites/schists, quartzites, and amphibolites, which represent suite of sedimentary, and volcanics that are infolded into the Nigerian Basement Complex. Both units were intruded by granitic rocks of the Older Granites series. This schist belt is metamorphosed together with the basement gneiss-migmatite complex during the Pan-African event of which generally N-S foliation trend is imposed on these rock units. The geology of Dukki area is mainly of phyllites/schists (carbonaceous) and quartzites into which the auriferous veins intruded occupying the brittle structure either as parallel or subparallel to the subsidiary conjugate fault, which intersected one of the major crustal sutures - the Kalangai fault system.

7.2. Mineralization And Geophysics

At Dukki mine, the auriferous veins are hosted in the shear zones within the phyllites/schists and quartzites. The vein contacts are generally sharp and commonly contain stockworks, veinlets and discordant stringers adjacent to the wallrocks. The trends of veins are conformable with the foliation trend of the host rocks with axis of the antiform running N-S and possibly intersecting the NE-SW trending

Kalangai fault system (KFS). The gold mineralization has been uncovered for a strike length of 2.5 km where gold occurs mostly free devoid of sulphide minerals association in quartzites and quartz bodies within phyllites/schists. The main veins constituents are (predominantly) quartz and sericite while the minor minerals are opaque, consisting mainly of Fe-oxide minerals such as magnetite, haematite limonite, limonite with very fine disseminated pyrite. Evidence of hydrothermal alteration within the mineralised zone/altered wallrocks revealed process of silicification, sericitisation and haeamatization.

Auriferous quartz veins within mineralised zone are generally shown by sharp or abrupt gradients from EM/VLF geophysical data (chapter 4). This geophysical survey method located the fracture zones and revealed concealed (hidden) mineralization below the surface workings.

7.3. Controls And Origin of Dukki Gold Mineralization

It may be logical to propose Dukki gold mineralizing fluids to have been generated from crustal reservoir along the major Kalangai fault system cutting the metasedimentary sequences as proposed by Garba (1992, 1996). The possible Pan-African crustal sutures are suggested to be probably the main plumbing system (primary 1°conduit) from which gold mineralising fluids were subsequently focused into subsidiary conjugate structure (minor faults/fractures) along the N-S anticlinal structures of the Maru belt. Such fluids were capable of

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equilibrating with metasedimentary host rocks, which may acquire physico-chemical characteristics, such as the pH, pressure, temperature, and Eh of the host rocks. The interaction of the fluids with suitable wallrocks or structure(s) caused gold deposition.

It is also possible to suggest that the mineralizing fluids are of hydrothermal (post) metamorphic origin. Chapter 5 indicates the dominant role of hydrothermal reservoir of gold mineralization to have generated within crustal sedimentary rocks.

The epigenetic nature of Dukki gold mineralization can also be used to suggest the age of gold deposition to be late Pan-African (C.500m.a).

However, the possible origin of gold bearing fluids is still a subject of controversy, and there have been various proposal about other source(s) including - mantle/lower crustal degassing (Cameron 1989a-b). Metamorphic dewatering (Eisenlohr et. al., 1989; Powell et. al., 1991) proposed that fluids that evolved at deeper levels after the shallower levels have passed their metamorphic peak, and may well have been responsible for the gold mineralization.

CONCLUSION

Though, the origin of gold mineralization can be controversial, for Dukki mine, the gold mineralizing fluids are proposed to have been generated within crustal metasedimentary rocks. These fluids were then channeled through the post-Pan-African transcurrent fault system (KFS) into subsidiary conjugate faults to depositional sites within the

shear zones. This is an epigenetic type of gold mineralization and is of Late Pan-African age (500-450m.y). The epigenetic nature of Au mineralization at Dukki is thus proposed to be of Late Pan African age (450 - 500 m.y). Evidence from wallrock alteration implies hydrothermal fluids involvement in the mineralization process.

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APPENDICES

Appendix I - Geophysical data obtained from survey lines at 800m South and 750m North at interval of 20m across the strike.

Appendix II - Concentration in PPM of 17 elements obtained from 40 samples collected using XRF and AAS methods.

APPENDIX 1: Geophysical Data Obtained From Survey Lines At 850m South And 750m North At Intervals Of 20m Across The Strike.

Station	Distance (m)	In-phase	Quad.	**Profile:** 850m N **Station:** GBR Facing West **Remarks**
1	400	-1	-2	F a r m l a n d
2	380	-4	-1	
3	360	-4	-2	
4	320	-5	-6	"
5	300	-3	-5	
6	280	-1	-5	
7	260	+5	-4	
8	240	+3	-4	
9	200	+1	-3	"
10	180	-3	-2	
11	140	-2	-4	
12	100	-1	-3	
13	80	+2	-2	
14	60	+3	-1	"
15	40	+2	-2	
16	0	-1	+2	
17	40	-2	+2	
18	60	-1	+3	
19	80	+1	-2	
20	100	-1	0	
21	140	-2	+1	
22	180	+4	-2	"
23	200	+2	-1	Small Quartzites with quartz veins
24	260	+8	-2	
25	300	+9	-1	"
26	340	+10	+1	F a r m l a n d
27	360	-2	+1	
28	380	-3	+2	"
29	400	-2	-2	
30	440	-1	-1	"
31	480	-2	0	
32	520	+1	-2	
33	560	+2	-1	
34	600	+1	+1	"

Appendix I contd.

Station	Distance (m)	In-Phase	Quad.	**Profile:** 750m N **Station:** GBR Facing West **Remarks**
1	400	+1	+1	Ridge
2	340	+2	+1	"
3	320	+2	-2	"
4	300	+1	-1	"
5	260	+1	-2	"
6	220	+2	-1	"
7	200	-1	+2	Farmland
8	180	-3	-1	"
9	140	-4	-2	"
10	100	+3	-1	"
11	60	+2	-2	"
12	40	-1	-1	Farmland
13	0	-2	-1	"
14	20	+2	-1	"
15	60	-1	+1	"
16	100	+1	-1	"
17	140	+3	-1	Auriferous veins
18	180	+6	-3	
19	200	+9	-2	"
20	240	+12	-3	"
21	280	+14	-2	"
22	300	+10	-1	
23	340	+4	+1	"
24	380	-2	-1	"
25	400	+2	-2	Quartz Floats
26	440	+1	-2	
27	480	-2	-1	
28	500	-1	-1	"
29	520	-2	+1	Farmland
30	560	-2	+1	
31	580	+1	+2	
32	600	-2	+1	

Appendix I contd.

Station	Distance (m)	In-Phase	Quad.	**Profile:** 650m N **Station:** GBR Facing West **Remarks**
1	400	+1	-1	d
2	360	+1	0	n
3	320	+2	-2	a
4	300	+2	-1	m l
5	260	-1	-1	r
6	220	-2	-2	a
7	200	-1	+1	F
8	160	-3	+1	
9	120	-2	-1	
10	80	+1	-1	
11	40	+2	-2	Quartz floats
12	0	+1	-1	
13	20	-2	-2	
14	60	-1	+1	
15	100	+1	-1	
16	140	+1	+1	"
17	200	-1	-1	
18	240	+2	-2	
19	280	+3	-1	D
20	300	-2	+2	N
21	320	-2	+1	A
22	360	+1	-1	L
23	400	+2	-1	
24	420	-2	+1	
25	460	-2	-1	
26	480	-1	+1	
27	520	+1	-1	T
28	560	-2	-1	A
29	580	-2	-2	L
30	600	+1	-1	F

Appendix I contd.

Station	Distance	In-Phase	Quad.	**Profile:** 550m N **Station:** GBR Facing West **Remarks**
1	400	-1	+1	
2	360	-1	0	
3	320	+2	-1	
4	300	+1	-2	
5	280	+1	-1	Flat land
6	240	+3	+1	
7	220	-1	+1	
8	180	-2	+1	
9	140	-3	+2	
10	120	+8	+1	
11	100	+16	0	
12	80	+17	-2	Ridge-Quartz veins (floats)
13	60	+12	-2	
14	40	+10	-1	
15	20	+6	-2	
16	0	+4	-2	
17	20	+2	+1	d
18	60	-2	-2	n
19	100	-3	-1	a
20	120	+2	-2	L
21	160	-2	-1	m
22	200	+2	-1	r
23	240	+2	+1	a
24	260	+2	+2	F
25	300	+1	+1	
26	320	-1	-1	
27	360	-2	+1	
28	400	-2	+2	
29	440	+2	-1	
30	480	+2	+1	Quartz floats
31	520	+3	+1	
32	560	-2	+1	
33	600	-1	+1	

Appendix I contd.

Station	Distance	In-Phase	Quad.	**Profile:** 450m N **Station:** GBR Facing West **Remarks**
1	400	+3	+1	Quartz boudins
2	360	+2	+1	Schist/phyllite exposure
3	320	-2	+2	by the stream channel
4	300	-1	+1	
5	280	-3	+2	
6	240	-2	+1	
7	200	+4	-1	Old working pits
8	180	+6	-2	where some sample are taken. Not deep
9	160	+10	-2	
10	140	+9	+1	
11	120	+3	-2	
12	100	+2	+1	
13	80	+6	+1	
14	40	+1	+1	
15	20	-9	+2	
16	0	-5	+2	Floats of quartz
17	20	-1	+2	
18	60	+2	+1	
19	100	-2	-1	
20	120	+4	-1	Dukki tracks to the stream
21	160	+7	-2	
22	180	+16	+1	Pits main working
23	200	+14	-2	
24	220	+6	+1	
25	260	+4	-1	Road to Dukki village
26	300	+3	-1	
27	340	+2	0	
28	380	-3	+1	
29	400	-2	-1	
30	440	-6	-4	
31	480	-2	-2	Quartz floats
32	520	-4	-2	Small quartzites ridges
33	560	-6	-1	
34	600	-7	+2	

Appendix I contd.

Station	Distance	In-Phase	Quad.	**Profile:** 350m N **Station:** NAA Facing West **Remarks**
1	400	+3	-1	Phyllite exposures
2	360	+1	+1	with quartz veins
3	320	+3	-2	
4	280	-2	-1	
5	260	-3	+2	
6	220	-1	+1	
7	200	+4	-1	Heaps of quartz floats
8	180	+10	+3	
9	160	+8	+2	
10	140	+7	+4	Small ridges
11	120	+9	+2	with pits (old working)
12	100	+4	-2	
13	80	-2	+1	
14	60	+2	-1	Flat land
15	40	-2	-2	
16	0	-3	+2	
17	40	+2	+1	
18	80	+4	+4	
19	100	+8	+3	Dukki main working
20	140	+16	-2	
21	160	+14	+3	Mid of the ridge
22	200	+8	-1	
23	240	+3	+2	
24	280	+1	-2	
25	300	-1	+1	
26	340	+1	+1	
27	380	+2	+1	Quartz floats
28	420	-5	-3	
29	440	-6	-1	Schist/phyllite exposure
30	480	-4	+1	"
31	520	-2	+2	"
32	560	+2	+1	"
33	600	-2	+2	

Appendix I contd.

Station	Distance	In-Phase	Quad.	**Profile:** 250m N **Station:** NAA Facing West **Remark**
1	400	+4	-1	Flat land with weathered
2	360	+2	-2	materials-quartz floats
3	340	-1	+3	
4	300	+1	-1	
5	280	+1	-3	"
6	240	-2	+2	
7	200	+4	-2	
8	180	+10	+4	
9	160	+7	+5	Small ridge of quartzites
10	140	+4	+2	Quartz floats & Quartz veins – mineralized
11	120	+1	+2	
12	100	-5	+2	
13	80	-3	+1	
14	60	+2	+7	
15	20	-2	+5	Land with washed rubbles of
16	0	-6	+3	previous works. Heaps of
17	20	-9	+4	weathered altered wall rock
18	40	-1	+2	
19	80	+5	-2	
20	100	+13	+3	The main Dukki mine
21	120	+10	-2	middle way
22	140	+17	-9	
23	160	+12	-4	
24	200	+7	-2	
25	220	+3	-3	
26	260	-3	-1	
27	280	+1	+2	
28	300	-2	+3	
29	340	-6	-3	
30	380	+2	-4	Quartz + Quartzites rubbles
31	400	-4	-1	milk quartz. No evidence of
32	440	-9	-2	previous workings.
33	480	-3	-1	
34	520	-1	-1	
35	560	-2	-2	

Appendix I contd.

Station	Distance	In-Phase	Qua d.	**Profile:** 150m N **Station:** NAA Facing West **Remarks**
1	400	-2	+2	Flat land
2	360	-5	+4	
3	320	-4	+3	
4	300	-2	+1	"
5	260	+3	+6	
6	220	-2	+5	
7	180	+1	+4	Quartz floats
8	140	+5	+5	
9	100	+1	+4	Low lying hill of quartzites
10	80	-3	+2	
11	40	-6	-2	
12	0	-8	+2	
13	40	+4	+4	Pits dug round the area. No
14	80	+13	-4	major once but samples are taken
15	100	+15	-5	from these pits.
16	140	+7	-2	
17	180	+2	+3	
18	200	-2	-2	
19	220	+4	-3	
20	240	+1	-1	Farm land
21	280	-2	+4	
22	320	-3	+2	"
23	360	-7	-5	
24	400	-2	-2	"
25	440	-12	-4	
26	460	-6	-3	"
27	500	-2	-3	
28	520	-3	+2	"
29	540	-2	+1	
30	560	+2	+4	
31	600	+1	-3	"

Appendix I contd.

Station	Distance	In-Phase	Quad.	**Profile:** 50m N **Station:** NAA Facing West **Remarks**
1	400	-4	-1	Pit - 1.5m deep
2	380	-6	0	Heaps of
3	340	-3	0	Quartz rubbles
4	300	+2	+2	
5	260	+3	+3	Flat land
6	240	+4	+5	
7	200	-3	+2	"
8	180	-3	-2	
9	140	+2	-3	"
10	120	+4	+2	
11	100	+2	-2	"
12	160	-1	+1	
13	40	-2	-3	
14	20	+6	+1	
15	0	+6	+1	Quartzite floats
16	40	+2	+2	
17	80	+2	+6	Flat land
18	120	-7	+6	
19	140	-5	+5	"
20	180	-2	+3	"
21	220	+2	+4	"
22	260	+1	+4	
23	300	-4	+2	"
24	320	+2	+1	
25	360	+2	-2	
26	400	-3	+1	"
27	420	-2	+3	
28	440	-1	+2	
29	480	+2	+1	"
30	520	+3	+2	
31	560	+4	-2	Small ridge
32	580	+3	+3	
33	600	+2	+1	

Appendix I contd.

Station	Distance	In-Phase	Quad.	**Profile:** 250m S **Station:** GBR Facing West **Remarks**
1	400	-4	+4	
2	360	-5	+6	
3	320	-6	+1	Quartz floats
4	300	-3	+3	
5	280	+3	+2	Heaps of rubbles from
6	240	+2	0	Dug pits 2.5m wide
7	220	+8	+4	25m long.
8	180	+9	+4	Quartz floats + wall rock altered
9	160	+4	+2	
10	120	+2	+3	
11	80	-4	0	
12	40	+3	-2	
13	0	+4	+2	
14	20	+3	-2	
15	60	-3	+2	Farm land
16	100	+2	0	
17	140	+6	+2	
18	180	+3	+1	"
19	200	+2	+2	
20	240	+2	-2	
21	280	+1	-2	"
22	320	-3	+2	
23	360	+2	-2	
24	380	+3	-3	
25	400	-2	+1	"
26	440	+2	-1	
27	480	-2	+2	"
28	500	-1	0	
29	520	+2	-1	
30	560	+3	-2	"
31	580	+2	-5	
32	60	+2	-4	

Appendix I contd.

Station	Distance	In-Phase	Quad.	**Profile:** 350m S **Station:** GBR Facing West **Remarks**
1	400	-6	+2	
2	360	-2	+1	
3	340	+5	+2	
4	300	+4	+3	Small quartzite ridge
5	260	+6	+3	exposure
6	220	+2	+1	
7	200	-1	+1	
8	180	-2	+2	Quartz
9	140	+1	-2	rubbles
10	120	+3	0	
11	100	+4	+1	
12	60	-1	+1	
13	40	-2	-2	Flat land
14	20	+3	-1	
15	0	+5	0	
16	40	-3	+3	
17	80	-7	+5	"
18	120	-4	+2	
19	160	+2	+4	Farm land
20	200	+1	+2	
21	220	-2	+1	
22	260	-4	+2	"
23	300	-2	+1	
24	340	+3	-2	
25	380	-2	-1	
26	400	-3	+1	"
27	420	-3	+2	Phyllite exposure
28	460	-1	0	
29	500	+2	-1	
30	520	+3	-2	"
31	560	+2	-2	
32	580	+2	+1	
33	600	+1	+1	"

Appendix I contd.

Station	Distance	In-Phase	Quad.	**Profile:** 450m S **Station:** GBR Facing West **Remarks**
1	400	+1	0	
2	360	-4	+1	
3	320	-2	+1	No prominent
4	300	-1	0	
5	280	+1	-1	
6	240	+2	-2	
7	200	-2	-4	features
8	180	-1	-3	
9	140	+1	-1	
10	100	+2	+2	observed
11	80	+1	+1	
12	40	-2	+2	
13	0	+1	+1	Flat land
14	20	-2	+1	
15	60	+1	-1	
16	80	-1	-1	
17	100	-2	+1	"
18	140	-2	0	
19	180	-1	+1	
20	220	+3	+1	
21	240	+1	+1	"
22	280	-3	-1	
23	300	-2	0	
24	340	-2	+1	
25	360	-1	-1	"
26	400	+2	+3	
27	420	+3	+1	
28	460	-2	-1	"
29	500	-2	+1	
30	540	-1	+4	
31	560	+1	-2	"
32	580			

Appendix I contd.

Station	Distance	In-Phase	Quad.	**Profile:** 550m S **Station:** NAA Facing West **Remarks**
1	400	-3	+2	
2	380	-2	+1	Silicified zone of
3	360	+2	-1	
4	320	+5	+1	The mapped area.
5	300	+9	+2	
6	280	+7	+2	Eluvial workings
7	260	+4	-1	
8	220	+6	+2	In the area, no reasonable
9	200	-1	0	dug pits.
10	180	-2	-1	
11	140	-1	+2	
12	100	+1	+1	
13	80	-2	-1	Farm land
14	40	+1	0	
15	0	-1	-1	
16	40	-2	+3	
17	80	+1	+2	
18	120	_2	-1	
19	160	-2	+1	
20	180	-1	-2	"
21	220	-2	-1	
22	260	+1	0	
23	300	-2	+2	
24	320	-2	+2	
25	360	-1	+1	
26	400	+2	-1	
27	420	+1	+1	"
28	460	+2	+1	
29	400	+1	-4	
30	520	+2	+3	
31	560	-2	+2	"
32	580	+1	-3	
33	600	+2	-1	

Appendix I contd.

Station	Distance	In-Phase	Quad.	**Profile:** 650m S **Station:** NAA Facing West **Remarks**
1	400	-2	+8	Heaps rubbles of
2	380	+4	+5	Wall rock + quartz veins.
3	340	+8	+2	
4	300	+14	-6	
5	280	+10	-5	Pits
6	240	+11	-2	
7	200	+6	+4	Wall rock
8	180	+2	+1	
9	140	-4	+4	
10	120	-2	+2	
11	100	+9	0	Quartz floats
12	0	+3	-7	
13	20	-4	-5	
14	0	-6	-2	
15	40	+1	0	Flat land
16	80	-2	-1	
17	120	-3__+3	-1	"
18	160	+2	+3	
19	200	+1	+7	
20	240	-2	+5	Farm land
21	280	-1	+3	
22	300	+2	+2	
23	340	-2	+2	"
24	380	-4	+1	
25	400	-1	-2	
26	440	+2	-1	"
27	460	+2	-2	
28	480	-1	-2	
29	500	-2	-1	"
30	520	+2	+4	
31	560	-2	+9	
32	580	-1	+5	
33	600		-4	"

Appendix I contd.

Station	Distance	In-Phase	Quad.	**Profile:** 750m S **Station:** NAA Facing West **Remarks**
1	400	-7	+3	Flat land
2	380	-2	+2	
3	340	+4	-1	Heaps of rubbles
4	300	+9	+1	
5	280	+4	0	Wall rock altered with quartz veins rubbles
6	240	+2	+1	
7	220	+3	+2	
8	200	+8	+5	"
9	180	+5	+3	
10	140	-4	+1	
11	100	-6	+4	"
12	80	-4	-5	
13	40	+3	-9	
14	0	+1	-3	Farm land
15	40	-2	-1	
16	60	-1	0	
17	80	+3	+1	
18	100	+2	-1	
19	140	+1	+5	"
20	180	-5	+1	
21	200	-4	+1	
22	240	+4	-2	
23	280	+2	-3	
24	300	-3	-1	
25	340	+1	+4	"
26	380	-5	0	
27	400	-3	+3	
28	440	-1	+1	
29	480	+2	-2	
30	500	-2	-1	"
31	540	+2	-2	
32	580	-2	+1	
33	600	+2	-3	

Appendix II cont'd.

Description	Location	S/No.	WALLROCK ELEMENTAL ANALYSIS (PPM)																
10 Samples			Au	K	Ca	Ti	Mn	Fe	Rb	Sr	Y	Cr	Co	Cu	Zn	Rb	As	Zr	Nb
Baked Reddish WallRock	800S/330 N	20	0.16	4830<	2750<	1300<	152<	1320<	7.6± 2.07	4.1<	3.7<	243<	202± 34.2	32.0<	24.4<	22.4<	78.8<	3.5<	2.9<
Baked Reddish WallRock	650S/220 W	21	0.62	6870± 2500	3010<	1000± 378	167<	1820± 195	5.42<	4.8<	4.8<	328<	238± 38.8	36<	27.3<	29.1<	43.5± 8.5	6.7± 1.8	4.5<
Indurated WR (Schist)	450S/020 E	22	0.08	7080<	2700<	848<	171<	1950± 154	6.04<	4.21<	4.03<	261<	185±3 4.8	33.0<	27.0<	43.7± 10.5	16.5<	6.35± 1.6	3.25<
Bleached WR (Schists)	300S/040 W	23	2.7	24,70 0±296 0	2970± 1160	4920± 539	866± 110	69,50 0±491 0	82.1± 7	31±3. 7	16±2. 8	269<	281± 61.5	71<	39.6± 17.2	36.1<	141± 15.4	146± 10.8	16±2. 3
Baked Reddish WallRock	250S/170 W	24	0.18	23,30 0±320 0	3050<	4810± 585	1330± 143	40,00 0±283 0	136± 10.7	15.3± 3.3	11.7± 2.7	551± 151	126<	62.5<	40.6<	53.4<	37.1<	138± 10.4	15±2. 4
WR/Quartzites	200S/200 E	25	0.15	5270<	3760<	1210<	1990± 418	594± 94.2	24,00 0±170 0	73.4± 6.3	34.3± 3.7	9.7<	285<	142± 44.8	31.5<	27.5<	18.8<	5.2±1 9	3.9<
WR/Schist/ Phyllite	200S/180 W	26	0.23	14,60 0±268 0	2830<	1990± 418	594± 94.2	24,00 0±170 0	73.4± 6.3	9.7<	285<	142± 44.8	250<	131± 37	63.4± 14.4	31.9<	22.5<	119± 9..3	7.05± 2
Schists weathered WR	050N/020 E	27	0.02	7900± 2190	2410	1180± 346	251± 71.6	14,40 0±103 0	26.1± 3.1	9.4± 2.7	7.4± 1.9	250<	131± 37	34.7<	28.4<	27.7<	19.1<	135± 4.8	5.5± 1.6
Indurated Schists	300N/260 E	28	-	5780± 2300	2970<	1070± 382	172<	11,96 0 ±80.7	7.2<	5.8<	283<	248± 35.6	38<	29.2<	27.3<	45.5± 6.4	29.1<	6.7<	5.5<
Quartzites (sheet quartz WallRock)	800S/330 W	29	0.76	28,60 0±380 0	-	2670± 5.3	254<	13,70 0±980	121± 9.6	50.3± 4.8	20.0<	135<	-	41.0<	25<	21<	190<	4.1<	5.6<

Appendix II cont'd.

Description	Location	S/No.	VEINLETS/STRINGERS ELEMENTAL ANALYSIS (PPM)																
9 Samples			Au	K	Ca	Ti	Mn	Fe	Rb	Sr	Y	Cr	Co	Cu	Zn	Pb	As	Zr	Nb
Veinlets within bleached WR	650S/220 W	11	2.2	20,000±2860	2670<	3810±489	359±85.6	36,800±2600	63.5±5.6	28±3.3	17.5±	331<	182±49.5	49.6±20.3	61±14.9	31.5<	134±13.6	198±14.4	11.4±2.0
Quartz stringers/ veinlets	500S/180 W	12	3.14	23,000±3420	-	3190±507	209<	9920±713	60.3±5.6	78±6.5	25.4<	-	99.1<	-	38.6<	30.6<	208±18.2	196±40.4	16.1±2.4
Veinlets + WR	285S/190 W	13	0.41	14,100±2500	2510<	1550±596	238±72.7	22,000±1560	68.5±5.2	59.1±5	9.1±2	250<	152±40.9	50.1±17	73.7±13.4	28.6±11	49.8±8.7	57.7±4.9	5±1.6
Veinlets/W R	200S/180 W	14	1.07	40,600±3970	3000<	5140±596	1890±174	42,600±3020	176±13.4	32.5±3.4	21.5±3.2	396±145	135<	61.7<	51.1±17.5	72.7±17.3	29.7<	202±15	13.7±2.3
Veinlets/ Stringers	150S/220 W	15	0.56	5390<	2890<	1070<	160<	2240±154	4.82<	6.11<	4.18<	346<	155±15.3	34.5<	25.7<	23.3<	51.7±8.3	3.35<	4.04<
Veinlets/ Stringers	100S/080 W	16	0.18	8040<	2650<	1050<	168<	2230±174	14±2.7	4.2<	5.2<	300<	104±32.7	33<	24.9<	22.9<	17±1.1	37.5±3.4	5.1<
Veinlets/ Stringers	100N/080 E	17	1.37	7150±2140	2450<	1660±351	175±65.9	16,200±941	273±22.9	10.3±1.9	5.3±1.6	126<	124<	32<	31±10	52±9.3	139.5<	120<	4.5<
Veinlets/W R	100N/040 W	18	3.45	17,900±2900	2870<	4090±524	806±106	12,900±921	31.8±3.8	7.2±2.6	22.9±2.9	290<	192±44.5	50.7<	82.2±13.5	30.4<	183±16.4	636±45	6.9±1.9
Stringers	250N/110 E	19	0.15	7970<	3650<	825<	391±80	12,600±891	46±4	15±2.5	8.0±2	290<	124±37	36.7<	27.7<	49±12	18.7<S	116±8.7	4.3<

Appendix II : Concentration In PPM Of 17 Elements Obtained From 40 Samples Collected Using XRF And AAS Methods.

Description	Location	S/No.	QUARTZ VEINS ELEMENTAL ANALYSIS (PPM)																
10 Samples			Au	K	Ca	Ti	Mn	Fe	Rb	Sr	Y	Cr	Co	Cu	Zn	Pb	As	Zr	Nb
Sugary Quartz vein within schist/phyllite	750S/320 W	1	3.06	14,000 ±2,620	2940 ±1190	2620 ±427	279± 80	24,500±1740	43.6± 26	15.4± 26	-	267<	112± 43	44.4<	29.3<	29.5<	316± 75	257± 18.5	6.6± 1.8
Quartz Boudin in schists/phyllite	450S/020 W	2	0.5	39,100 ±3970	2730 <	5540 ±598	1820 ±174	40,900±3020	176± 13.4	27.5± 3.9	11.5± 3.2	469± 145	105<	35.6<	51.1± 17.3<	17.3<	129.7 <	195± 15	14.2± 2.3
'Sheeted' Quartz vein/Quarzites	200S/200 E	3	1.96	21,300 ±3970	2750 <	2350 ±422	490± 88.6	22,000±1560	93.5± 15.60	14±2.4	9.9± 4.2	351<	201± 45.8	41.9<	30.5<	28<	56.8± 4.2	98±7.4	7.6± 1.7
'Sheeted' Quartz/Quartzite	050N/020 E	4	0.16	7910<	3380 <	2630 ±493	1230 ±140	51,300±3630	9.99<	7.1<	6.2<	891± 163	147<	80.3<	45.8<	42.6<	19.6<	105± 8.1	6.9± 2.1
Quartz vein sugary/Vuggy	200N/100 E	5	2.43	5080<	2500 <	767<	153<	590± 66	4.9<	5.6<	4.3<	246<	130± 31	30.8<	24.7<	20.6<	14.5<	3.7<	3.4<
Quartz vein (sugary)	650N/260 E	6	nd	5910	3300 <	1040 <	217<	1470 ±126	6.21<	5.6<	6.4<	293<	152± 38.9	38.8<	31.6<	30.00 <	27.5± 8.5	6.4<	4.5<
Quartz vein (within silicified schist/phyllite)	750N/300 - 320E	7	nd	5670<	2760 <	841<	165<	328± 55.2	6.3<	6.0<	4.7<	259<	197± 36.7	47.5<	39.1<	26.0<	18.0<	4.1<	3.9<
Quartz vein in massive quartzites	800S/330 W	8	0.38	10,800 <	-	1070 <	245<	4130 ±310	6.4<	7.8± 2.4	19.1<	-	103<	2.14	34.7<	29.9<	20.6<	4.9<	5.57± 2
Massive quartz vein	500S/000	9	nd	7,300<	-	925<	220<	719± 79.6	5.5<	5.3<	15.3<	-	137± 37.7	-	50.9<	29.5<	21.0<	4.0<	3.8<
Quartz vein (boudin) in graphitic schists	Outside gridlines	10	0.06	6713<	2314 <	4120 <	517± 116	613± 31.7	71.8± 21	9.3<	12.5<	243<	99.1<	23.1<	40.0<	17.3<	101.5 <	10.7± 2.5	2.7<

Appendix II cont'd.

Description	Location	S/No.	SILICIFIED ROCK ELEMENT CONCENTRATION (PPM)																
5 Samples			Au	K	Ca	Ti	Mn	Fe	Rb	Sr	Y	Cr	Co	Cu	Zn	Pb	As	Zr	Nb
Silicified Schists/ Phyllite + veinlet	550N/290 E	30	1.36	5900<	3390<	1060<	474± 85.8	3700± 275	7.2<	5.8<	4.9<	278<	133<	44.5<	28<	35.7<	54± 9.6	66.8<	4.2<
Silicified WR of schist/phylite + veinlets	700N/260 E	31	3.75	33,300 ± 3410	3270<	6240 ± 615	854± 108	53,300 ±3760	169± 12.8	66.3 ±5.7	31.5 ±3.5	497<	161± 53	49.1<	99.4 ±17.2	37.4<	25.7<	216± 15.2	16± 2.3
Silicified Wallrock	750N/320 E	32	0.09	7410 ±243	2990<	1830± 405	224<	14,000±994	39.8 ±3.9	16.4 ±2.4	7.7± 1.9	304<	201± 41.8	47.4<	31.6<	26.2± 11.3	45.3± 6.71	146± 10.7	3.74<
Fresh Silicified Wallrock	650N/240 E	33	0.91	21,500±3910	-	5790± 686	497± 119	23,300±1650	61± 6.5	210± 15.8	23.8<	-	136<	-	47.3<	41.3<	740± 55	150± 11.4	14.5± 2.9
Silicified Weathered Rock	550N/180 E	34	nd	40,800±4150	3220<	6190± 673	220<	28,400±2010	34.5<	150± 11.4	26.5± 3.0	379<	157<	51.6<	63.5± 16.8	34.5<	400± 31.0	238± 17.3	17.8± 2.5

Description	Location	S/No.	ELEMENT CONCENTRATION (PPM) FRESH COUNTRY ROCK																
6 Samples			Au	K	Ca	Ti	Mn	Fe	Rb	Sr	Y	Cr	Co	Cu	Zn	Pb	As	Zr	Nb
Schist/Phyllite	150N/240 W	35	nd	7360± 2140	2330 <	1760 ±351	162± 65.9	13,200±941	21.3± 2.6	10.3± 1.9	7.3± 1.6	231<	89.6<	32<	31±10	27.4± 9.3	39.5± 7.2	119± 8.8	5.7± 1.3
Schist/Phyllite	By the stream outside gridlines	36	nd	33,300±4570	-	6750 ±724	1230 ±152	54,500±3850	182± 14.1	69.8± 6.6	29.6± 11.2	-	3240 ±71.0	-	93.6± 23.3	49.0<	33.4<	24± 17.7	16.9± 3.0
Schist/Phyllite (Dukki mine)	320S/220 W	37	nd	45,300±5020	-	5110 ±702	65.7± 13.7	41,300±2930	215± 16.6	144± 11.6	31.8<	-	223± 71	-	87±24	49.1<	99.6± 16.6	223± 17	20±3
Schist/Phyllite	L.38	38	nd	27,100±3900	-	4,040 ±582	1090 ±140	49,100±3480	149± 11.8	25.6± 4.1	24.5<	-	336± 68.5	-	66.7± 20.5	42.5<	28.3<	186± 13.8	14± 2.8
Graphitic Schistss	750N/E	39	nd	32,300±4130	-	5780 ±681	484± 122	53,400±3780	188± 14.6	26.8± 7.4	32.0<	-	259± 69.9	-	119± 24.5	52.9<	36.8<	236± 17.4	19.9± 31
Graphitic Schists	150N/240 W	40	nd	39,700±3210	-	5800 ±682	919± 136	53,500±3790	209± 16.0	71.4± 7	26.3<	-	307± 69.6	-	128± 24.2	45.5<	31.6<	189± 14.1	22.3± 3.2