GEOLOGY AND STRUCTURAL EVOLUTION OF THE AREA WEST OF MAHUTA PART OF ZURU SCHIST BELT, SHANGA SHEET 73SE NORTHWESTERN NIGERIA

BY

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P13SCGL8033

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

DEPARTMENT OF GEOLOGY
FACULTY OF PHYSICAL SCIENCES
AHMADU BELLO UNIVESITY,
ZARIA, NIGERIA

NOVEMBER, 2017

DECLARATION

I declare that the work in this dissertation entitled "GEOLOGY AND STRUCTURAL EVOLUTION OF THE AREA WEST OF MAHUTA PART OF ZURU SCHIST BELT, SHANGA SHEET 73 SE NORTHWESTERN NIGERIA"carried out by me in the Department of Geology. The information derived from the literature has been properlyacknowledged in the text and list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other institution.

KITHA MBITSA		
Name of student	Signature	Date

CERTIFICATION

This dissertationentitled “GEOLOGY AND STRUCTURAL EVOLUTION OF THE AREA WEST OF MAHUTAPART OF ZURU SCHIST BELT, SHANGA SHEET 73 SE NORTHWESTERN NIGERIA” byMBITSA KITHA meets the regulations governing the award of the Degree of Master of Science (Structural Geology) of theAhmadu Bello University Zaria, and is approved for its contribution to knowledge and literacy presentation.

Student Signature	Date	
Chairman, Supervisory Committee	Signature	Date
Member, Supervisory Committee	Signature	Date
Head of Department Signature	Date	
Dean, School of Postgraduate Studies	Signature	Date

DEDICATION

I dedicate this work to almighty God, the omnipotent who has given me the will and wisdom to write, the strength to endure and the courage to face all challenges and to my parents MallamYohannaKitha Z. and Late MallamaTaniKitha.

ACKNOWLEDGEMENT

In the name of God, the most merciful, the praise worthy, all thanks be to him, the Lord of the heaven and the universe, who made everything possible and easy for me,

My profound gratitude goes to my parents, MallamKitha and Late MallamaTani for their guidance, love, encouragement, prayers and support towards the achievement of this academic programme.

My sincere gratitude goes to my supervisors Prof. U.A. Danbatta and Dr. Aliyu Abdu Ibrahim who devoted their time from the beginning to the end of this research, may God reward them abundantly.

I also acknowledge all academic and non-academic staff of the Department of Geology, UsmanuDanfodiyo UniversitySokoto for their support and good advice towards my academic programme especially Dr. I. Hamidu and Dr. M. YarimaKwaya

My gratitude also goes toDaudaKitha, DogaraKitha, AyubaKitha, Kulkwa Emmanuel Kitha, Elizabeth K. Dauda, Naomi Kitha, WagraKithaPhilimon, Mary Kitha Musa and MarthaKithaDavid for their prayers and encouragement throught out my programme. Finally I appreciate my colleagues and friends who assisted me, especially LukmanAdamu, Tevo Musa K., Umar Aliyu O. Haruna M. Grema, Dr. Zakaria B. Ashalva, and Dr. Lawrence Dare.

ABSTRACT

The study area is located within the northwestern part of Zuru Schist Belt, which is the largest schist belt in northwestern Nigeria. This research involved a detailed analysisof mesoscopic structures and petrographic descriptionof the majorlithological units. The major rocks in the study area are quartz-mica schist, medium grained granite and quartzitewhile the minor rocks arethe mica-schist, quartz veins, pegmatites and aplite dykes that have a dominant NE-SW trend. Both ductile and brittle structures were identified in the study area, with folds,lineations and foliations constituting the ductile structures while the brittle structures are joints and faults. The structures were analyzed through geometric, kinematic and dynamic analysis.These are orientatedin E-W, NW-SE, NE-SW and N-S directions. Rose diagram of lineaments revealed major NW-SE and NNE-SSW trends. The main type of jointthat dominated the study area is an orthogonal joint with a dihedron angle of 90°; and a local stress rotation model is suggested for their formation. Dynamic analysis of normal faults revealed the orientation of the three principal stress asσ1 (87/087), σ2 (02/222) and σ3 (02/312) while their kinematic axes are P-axis (compressional =87/087), T-axis (tensional=02/312) and B-axis (transitional=02/222). The study area was subjected to polyphase deformation. The phases of tectonic deformations have been recognized from the structuresand classified as D1, D2 and D3.The first phase (D1) was associated with the deformationof anS0bedding and development of S1schistosity foliation and low-lying and obliterated minor F1 folds which occurred during the Eburnean. The second phase (D2) involved heterogeneous deformation which gave rise to an S2 crenulation foliation of the earlier S1 cleavage and F2 major tight to isoclinal folds occurred during the early stage of the Pan-African orogeny while the third deformation phase (D3) is associated with the formation of F3 folds and brittle structures such as dextral faults, normal faults and joints which occurred at the late stage of the Pan-African orogeny. Strain analysis confirmed that the study area was affected by heterogeneous deformation as evident from the varying orientations of fry haloes andwide range (1.22-2.90) of average axial ratio.

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CHAPTER ONE

GENERAL INTRODUCTION

1.1 Background of the Study

The Nigerian Basement Complex is characterized by different episodes of metarmophism, orogenies and structural modifications (Odeyemi, 1981; Rahaman *etal*., 1983; Caby, 1989) which is reflected in its complex petrological and structural composition. The polycyclic nature of the basement rocks indicates that earlier episodes of metamorphism, magmatism, orogenies and tectonism would have been overprinted, reworked and modified by younger events (De Swardt, 1947; Oyawoye, 1972; Woakes *etal*., 1987; Ajibade *etal*., 1987; Omosanya *et al*., 2010, 2011, 2012).

The Precambrian rocks of Nigeria are well exposed in northwestern part of the country, therefore this area is considered important for a good understanding of the geology of the Nigerian Basement Complex (Ajibade *et al., 1987*).The Zuru Schist Belt (ZSB) is the most westerly schist belt in the Nigerian basement. It is the broadest and largest schist belt in the country with a length of about 280km and a maximum width of 40km. Its geology is little known and the main rock types are quartzites and quartz-muscovite schist (McCurrry, 1976). Structures within the Zuru Schist Belt are very complex varying widely in dip and strike. Little research has been carried regarding this schist belt, although it has complex structures that could be correlated with the Kushaka Schist Belt and other schist belts (Danbatta 1991).

This research work contributed in understanding the geologyand structural evolution of the area west of Mahuta andits surrounding.

1.2 Location, Extent and Accessibility of the Study Area

The study areais located within the Zuru Schist Belt (ZSB) andlies between latitudes 11º30'00"N and 11º 45' 00"N and longitudes 4º 45' 00"E and 5º 0' 00"E, it is part of Shanga sheet 73 SEand covers an area of about 770km². The study area is located west of Mahuta town in Kebbi state and is accessible through Abuja the Federal Capital Territory, via Minna – Kontagora – Zuru–Mahuta or through the main road from Sokoto- Dakin biu down to Mahuta (Fig. 1.1). The study area is also fairly accessible through an intricate network of dry stream and river channel,foot path and cattle tracks.

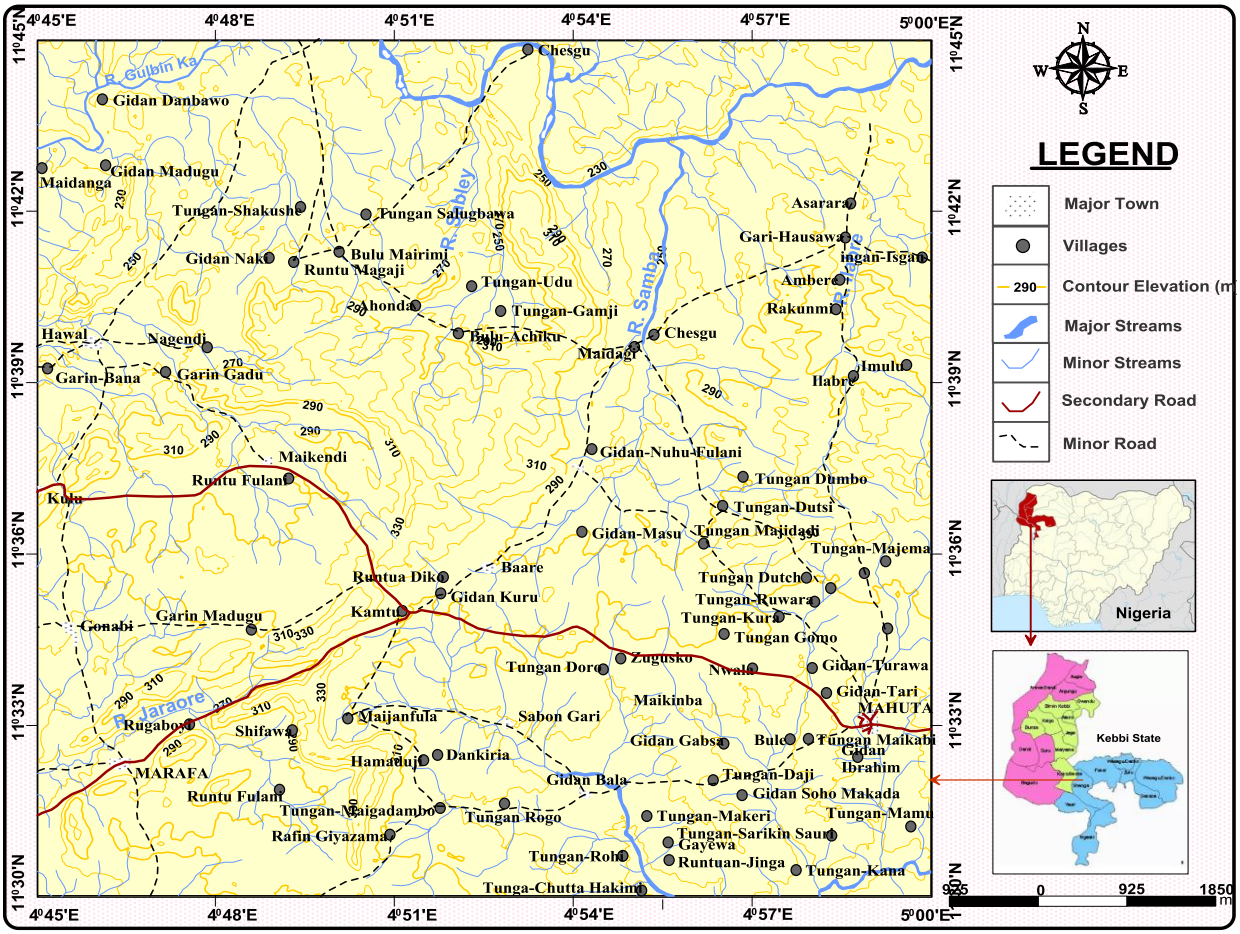


Figure 1.1: Location map of the study area

1.3 Climate and Vegetation

The study area is characterized by Tropical Continental type of climate, with two distinct seasons: wet and dry. The rainy season usually starts from June and ends October, with mean annual rainfall of about 800 to 1000mm. Temperature is generally high with mean annual temperature of about 26 ^{0}C. Relative humidity is generally low (40 percent) for most of the year except during the wet season when it reaches an average of eighty percent. The climate is dominated by the NE trend (harmattan) winds blowing from Sahara desert from November to March.

The study area is characterized by Sudan Savannah vegetation type, which is characterized by thick thorny shrubs and grass with scattered trees such as *Parkia Clappertoniana, Porassus* and dum palms. The natural vegetation has however been altered in many area by intensive cultivation, grazing, fuel wood harvesting and bush burning.

1.4 Relief and Drainage

1.4.1 Relief

The relief of the study area can be classified into three namely i) The high plains in the south and southeast ii) Plain landscape in the north and the riverine lowland of the Niger and iii) Lower Rima valleys. The high plains area is characterized by dissected crystalline rocks with hill ranges and domical rises (inselbergs) that are approximately 360m above sea level while the plain landscape forms part of the vast Sokoto plains (Davis, 1992). It is monotonous lowland of sedimentary origin, with an average height of about 300m above sea level. The plain surface is interrupted by isolated flat top laterite capped hills and ridges.

The riverine lowlands are mainly the flood plains of the major rivers which are very wide, up to 8km in some places. They are characterized by levees, backswamos and terraces on the natural vegetation (Davis, 1992).

The topography of the study area is undulating and generally rugged with the highest elevation of about 360 m above sea level and lowest around 200m above mean sea level as shown on the digital elevation model (DEM) of the study area (Figure1.2).

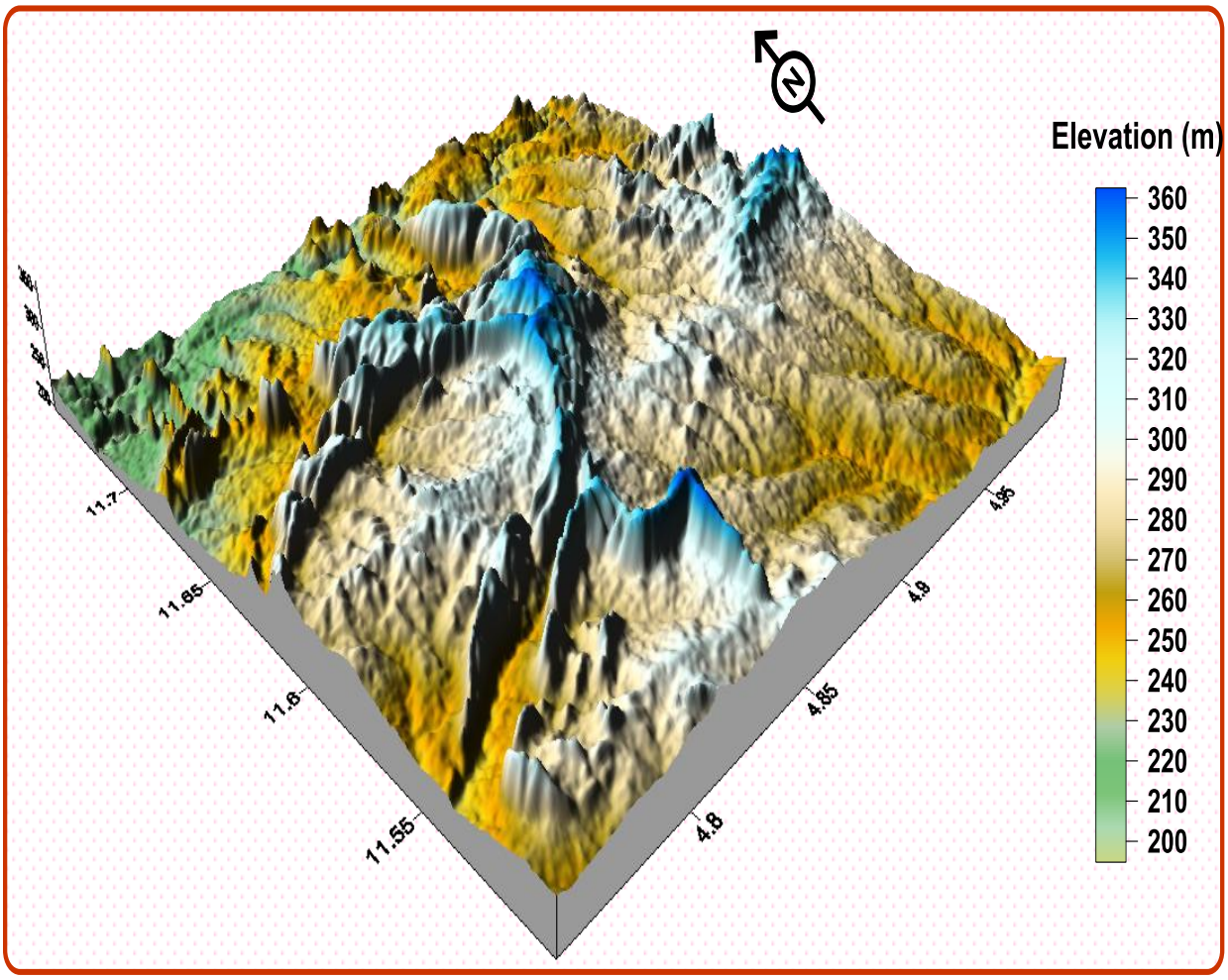


Figure 1.2: 3D Digital elevation model of the study area

1.4.2 Drainage

The drainage system in Zuru schist belt where the study area lies is dominated by River Rima system with major tributaries like Gawon, Zamfara and Gulbin Ka. These tributaries rise in the Basement Complex region of Sokoto State and flow westward to join the Rima River. However, in the southern part of the state, there are other less important rivers such as Danzaki, Soda and Kasanu, all of which flow through the study area and adjacent parts to join the River Niger to the south of the state.The rivers flowing through the Basement Complex rockshas narrow valleys with steep gradients while thoseon sedimentary formations are characterize by broad and shallow valleys.

The Rima River itself flows in a broad sweeping valley through the sedimentary area and then into the River Niger in the south west creating extensive flood plains..In terms of flow regimes, most of the rivers are storm channels maintaining bankfull discharges after individual rainstorm events only to dry out with the cessation of rainfall. This characteristic is also reflected in seasonal flow stream and drivers. The study area lies in the southeastern part of the state with a dendritic drainage pattern (Figure1.3).

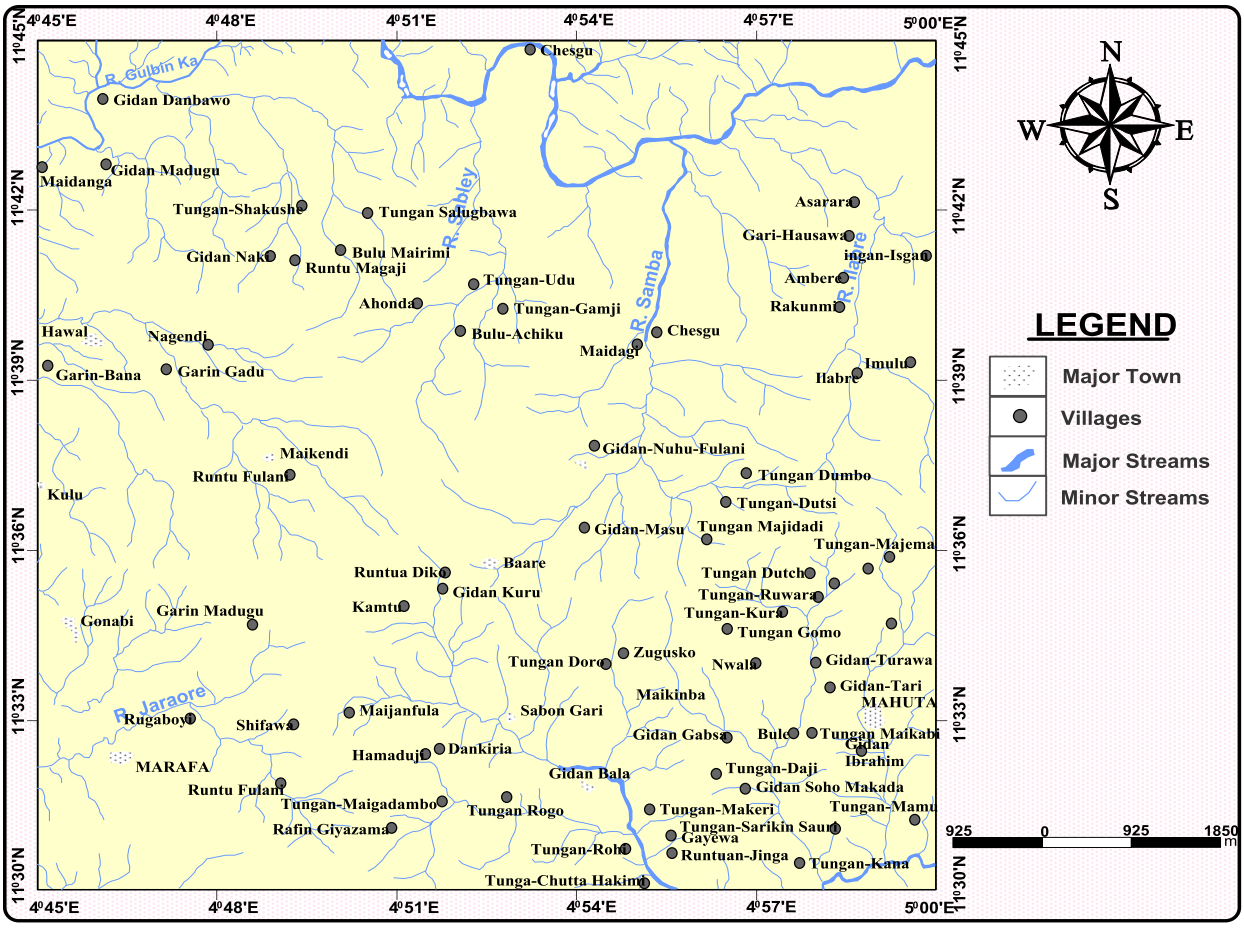


Figure 1.3: Drainage map of the study area and its adjoining parts.

1.5 Previous Work on Zuru Schist Belt

1.5.1 Rock Types

The Zuru Schist Belt (ZSB) forms an N-S trending belt in its northern part but bifurcates into a western arm and an eastern arm in its southern part. It consists of assemblages of muscovite-biotite banded gneisses, porphyroblastic gneisses, migmatites, schists, quartzites, metavolcanics (amphibolites), Older Granites and minor rock types such as gabbro, andesite, granulites and calc-silicates (Adefila, 1966; McCurry, 1978; Turner, 1983; Udoh, 1987; Danbatta, 1991).

Adefila (1966) was the first to map parts of the belt on a regional scale when he noted the occurrence of quartzites, mica schists, granulites and calc-silicates rocks. As a result of the economic potential of the area, McCurry (1978) carried out the geological investigation of the northeastern sector of the ZSB, where she identified the Yelwa and Ribah faults and produced a generalized geological map of parts of northwestern Nigeria and also recognized quartzite, schists, metavolcanics and Older Granites as the major rock units in the area (Figure 1.4). Turner (1983) described the Zuru Schist Belt on a regional scale noting low angle dips of bedding and E-W folds upon which steep N-S cleavages were superimposed.

According to Ajibade and Wright (1985), the Zuru area contains two crustal blocks that were formerly separated by an unknown distance and became welded together during the Pan-African aggregation and the boundary between these blocks is now represented by the major NE-SW shear zone that crosses the Zuru Sheet.

Danbatta (1991) carried out the geological investigations of the southwestern portion of the Zuru Schist Belt; where he noted three deformation episodes (D1, D2 and D3) that affected the belt as well as the occurrence of amphibolite, quartz schist, Zuru anticlinorium and Iri dome.

Danbatta (2005) undertook the structural analysis of the southwestern parts of the Zuru Schist Belt using aerial photographs and landsat images and recognized the existence of a number of structural elements including three major NNE-SSW to NE-SW trending lineaments (the Yelwa, Yauri and Ribah dextral faults), a NW-SE trending Gunu sinistral fault and a major N-S trending anticlinorium called the Zuru Anticlinorium in the area.

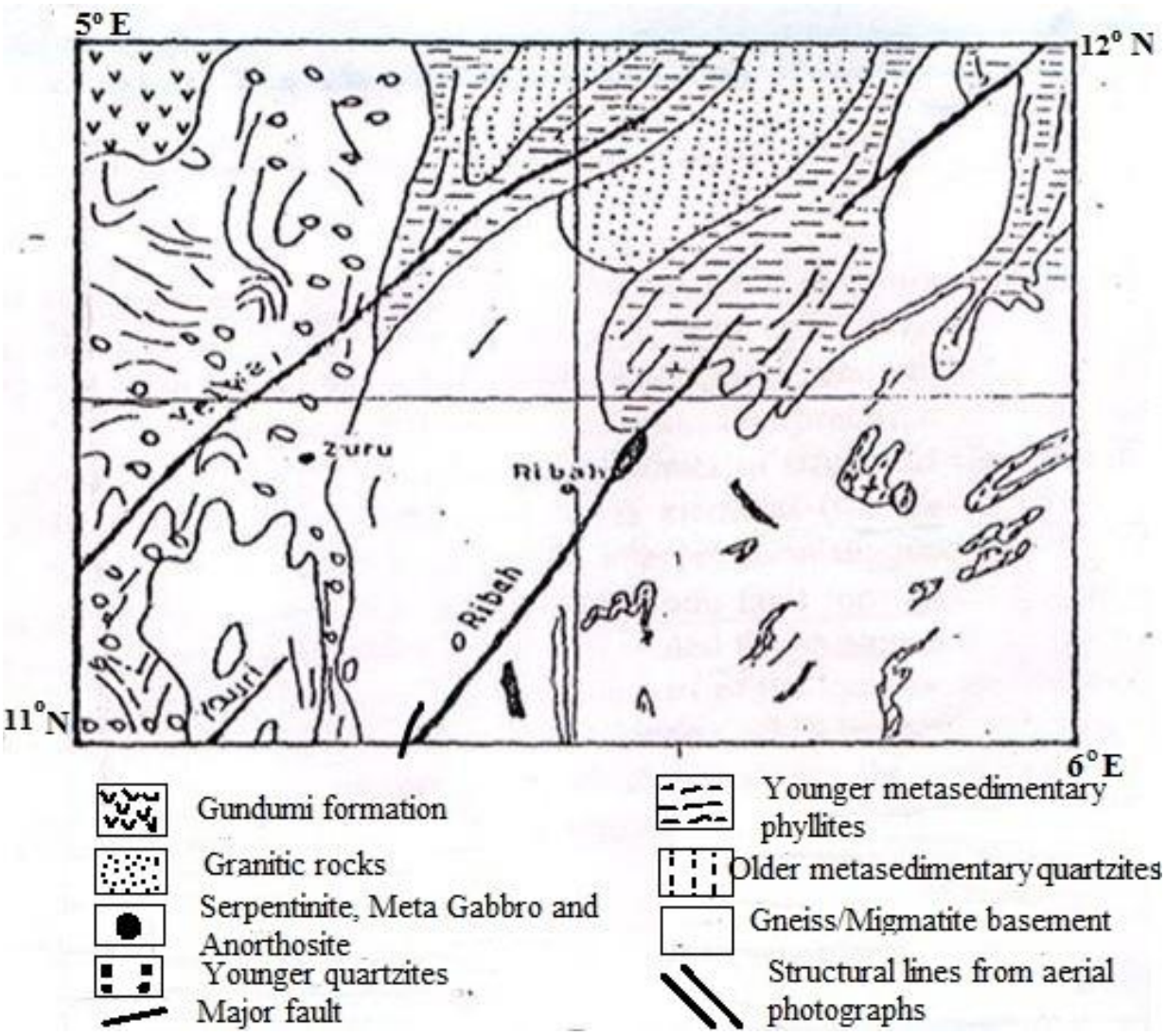


Figure 1.4: Geological map of the Zuru area (simplified and modified after McCurry, 1978).

Danbatta and Garba (2007) worked on the geochemistry and petrogenesis of Precambrian amphibolites within the southwestern part of the Zuru Schist Belt, and reported the Zuru amphibolites as having an extremely low K_2O, high AI_2O_3 and low TiO_2, Nb, Zr, Y, Ni and Cr contents that are typical of an island arc or back arc settings. The petrochemistry was used to reconstruct the nature and genesis of the region in which the amphibolite occur.

Danbatta (2008) investigated the Precambrian crustal development in the northwestern part of ZSB, and he noted that the Zuru Schist Belt is lithologically different from other schist belts of northwestern Nigeria because it is predominantly composed of quartzites with very subordinate schists and amphibolites, and no B.I.Fs (banded iron formations).

Ramadan and Abdel-Fattah (2010) worked on the characterization of gold mineralization in Garin Hawal area of Kebbi state using remote sensing techniques. They used landsat ETM+ false color composite images (bands 7, 4, 2, in R, G, and B) for regional geologic mapping and structural investigations and discovered three gold bearing shear zones.According to these authors, alteration zones and associated quartz veins were generally concordant with the main NE–SW regional structural trend of the area and are dipping to the northwest. (Fig. 1.5). Apart from the previous works in the study area by Adefila (1966), McCurry (1978), Turner (1983), Udoh (1987; 1988), Danbatta (1991), Danbatta (2005), Danbatta and Garba (2007) and Aliyu (2016). There is little or no knowledge regarding the structural evolution of other portions of the Zuru Schist Belt (ZSB) this therefore warrants the need to investigate and document the geology and structural evolution of sheet 73SE, Shanga.

1.5.2 Structural Setting of the Study Area

Structurally, the study area is located in a highly strained zone where rocks are highly deformed, foliated and affected by brittle to ductile deformation. The dominant tectonic fabric in the study area is a N–S steeply dipping phyllitic to slaty cleavage, which is mainly axial planar to tight isoclinal folds.Structures in the zuru schist belt are complex; varying widely in dip and strike with Low dipof bedding relative to open E–W folds upon which steep N–S structural trend have been superimposed.

Folding occurred during two successive phases of deformation (D2 and D3) which resulting in isoclinal folds and cleavage development. In the schist belts, crenulation cleavage and kink bands are imposed on early primary foliations, some of which are localized around plutons, and are regarded as products offorceful magmatic emplacement. Three major gold-bearing shear zones with dextral displacements have been established in the study area. They trend NE–SW displacing earlier structures by few tens of kilometers. The two gold deposits (Bin Yauri and Anka) are associated with two of these parallel shear zones which are known as the Bin Yauri-Zuru and Anka transcurrent fault systems (Garba, 2000). These NE–SW (dextral) and NW–SE (sinistral)conjugate systems are due to Late Pan-African brittle deformation that occurred after about 530 Ma on a continentalScale (Ball, 1980).The third shear zone (Garin Hawal) is parallel to the other ones and detected for the first time from Landsat. These shear zones trend sub-parallel to bedding and are characterized by the presence of abundant folded boudinaged, quartz veins, and development of a strong penetrative cleavage. Generally, the gold deposits were typically formed during compressional - transpressional tectonics,Ramadan and Abdel-Fattah (2010).

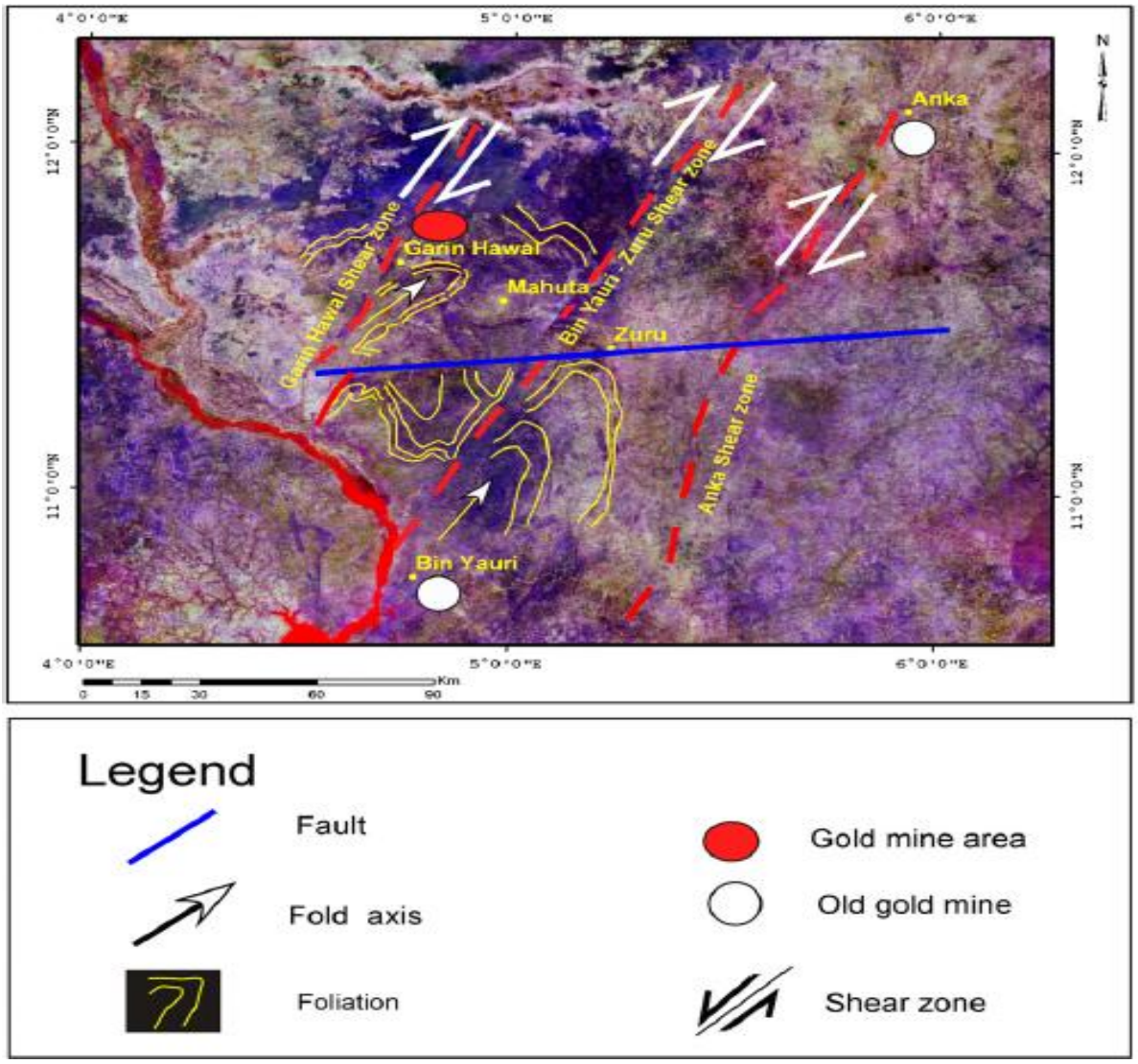


Figure 1.5: Structural map superimposed on regional Landsat ETM+ (Ramadan and Abdel-Fattah, 2010).

1.6 Aim and Objectives of the Study

The aim of the present work is to investigate and interpret the geology and structural evolution of the basement complex rocks west of Mahuta and its envrions, part of Sheet 73 SE Shanga while the specific objectives are to:

(i)Toproduce a lineament map of the study area from remotely sensed data.

(ii) Produce a geological and structural map of the study area.

(iii) Undertake the plotting of structural attitude of both mesostructures and megastructures using different softwares, such as; Orient 3.0, georose and wintensor 2.0

1.7 Scope of the Present Work

The literature review of the previous work carried out by various authors that studied the Zuru schist was done first.Prior to the field work, remote sensing interpretation of satellite data derived from ETM+ was undertaken in order to aid the field investigation as well as produce a lineament map of the study area. The field work involved reconnaissance and detailed surveys of the study area, collection of rock samples, measurement of linear and planar rock structures by taking their strikes, dips, thicknesses and coordinates. Instruments such as Global Positioning System (G.P.S), geological compass, measuring tape and topographic map of the study area were used during the field work. Laboratory analysis such as petrographic analysis, strain analysis, dynamic analysis and geometric analysis were undertaken to interpret the mesoscopic and megascopic structures in the study area. Computer softwares suchs as: Orient 3.0, win tensor 2.1, Georose and foldfault forward were used for the analysis.

1.8Statements of Research Problem and Justification

The study areas is part of the basement complex of Nigeria that consists of assemblages of muscovite-biotite, banded gneisses, porphyroblastic gneiss, migmatite, schists, quartzite, metavolcanics, Older Granites, and minor rocks such as gabbro, andesite, granulites, and calc-silicates (Adefila, 1966; McCury, 1978; Turner, 1983; Udoh, 1987; Danbatta, 1990).

The structures in the zuru schist belt are complex, varying widely in dip and strike. This schist belt is regarded as the least investigated, because few work has been done especially with regard

to the aspect of structural geology. Except for Danbatta (2005) that carried out the structural interpretation of SW part of the Zuru schist belt (N.W. Nigeria) using remote sensing data which revealed the existence of three major NNE-SSW to NE-SW trending linear elements (the Yelwa, Yauri and Ribah dextral fault) and a NW-SE trending Gunu sinistral fault. Danbatta and Garba (2007) also carried out the geochemistry and petrogenesis of Precambrian amphibolite in the Zuru schist belt, northwestern Nigeria.

National authority for remote sensing and space science (NARSS), Cairo Egypt and National resources authority, Cairo, Egypt, wrote on the characterization of gold mineralization in Garin Hawal area, Mahuta, Kebbi state, NW Nigeria. Using remote sensing (landsat ETM+ and high resolution quickbird data).

Therefore, from the existing literatures, no detail work has been done on structural evolution of the basement complex rocks in southeastern part of Shanga, and the structural style of the area remains unknown. These warrant the need to carry out this research in order to investigate and document the detailed structural evolution and established the structural style of the area west of Mahuta and its environs.

CHAPTER TWO

LITERATURE REVIEW

2.1 Preamble

The Nigerian Basement Complex forms a part of the Pan-African mobile belt and lies between the West African Craton and Congo Craton and south of the Tuareg Shield (Black, 1980; Fig 2.1). The Nigerian basement was affected by the 600 Ma Pan-African orogeny and occupies the reactivated region which resulted from plate collision between the passive continental margin of the West African Craton and the active Pharusian continental margin (Burke and Dewey, 1972; Dada, 2006).

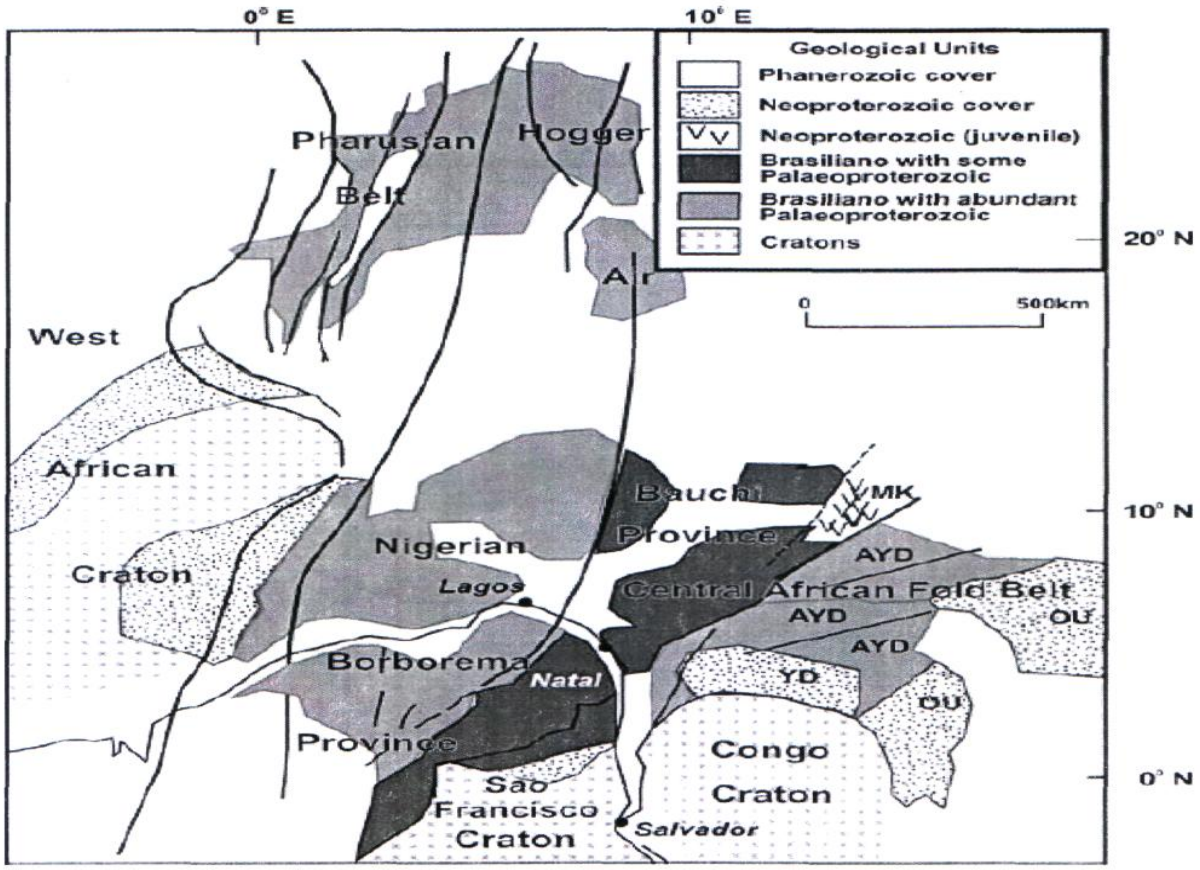


Figure 2.1: Location of the Nigerian Basement Complex between the West African Craton and Congo Craton (Dada, 2008).

The Nigerian Basement Complex is divided into three petro-lithological units namely: i) Gneisses and migmatites ii) Schist Belts (metasedimentary and metavolcanics rocks) and iii) Older Granites (Fitches *et al*., 1985; Ajibade *et al*., 1987). Intruding and truncating the Nigerian Basement are a number of Younger Granite ring complexesof Mesozoic age (Falconer, 1911; Jacobson *et al*. 1964). In addition, the structural framework of Nigerian basement is defined by both brittle deformation structures (joints, faults and shear zones) and ductile deformational structures (folds, lineations and foliations). The study area is part of NW Nigeria and it is mostly subdivided into three lithostratigraphic which are:the gneiss–migmatite complex, the supracrustal schist belts and the Pan-African granitoids.

Geochronological evidence indicates that the Nigerian Basement Complex is polycyclic and includes rocks of Archaean (2.0 – 3.0 Ga) era together with those of Eburnean (2000 ± 200 Ma) and Pan African (750 – 450Ma) event (Turner, 1983; Fitches *et al*., 1985; Ajibade *et al*., 1987; Elueze, 2000).

Lithology

2.2 Gneisses and Migmatites

The migmatite gneiss complex is the oldest basement complex rock dated as Birrimian age (about 2500 million years) and is generally considered to be the basement complex sensu stricto (Rahaman, 1988; Dada, 2006) and it is the most wide spread of the component units in the Nigerian basement, making up about 60% of the surface area of the Nigerian basement (Rahaman and Ocan, 1978). The migmatitie-gneiss complex is also termed by some workers as the migmatite-gneiss-quartzite complex. The rocks are mainly quartzites, amphibolites, calcareous rocks, biotite hornblende gneisses, quartz schist and biotite hornblende schist (Wright *et al*., 1985).The gneiss–migmatite complex is Archean – Early Proterozoic in age and

generallypossesses an amphibolite facies grade of metamorphism (Fitches *et al., 1985*). They show complex structural styles and are extensivelyinvaded by granitoid plutons of Pan-African magmatism.

2.3Metasedimentary and Metavolcanics (schist belts)

Theschist belts of Late-Proterozoic age were deposited and metamorphosedtogether with the basement gneiss–migmatite complex during the Pan-African event. These belts contain assemblages of mafic igneous rocks, pelitic sediments and banded iron formation (BIF) and show complex structural styles. The schist belts trend N–S and NNE–SSW and were deformed and metamorphosed generally in the greenschistfacies grade.

The Nigerian schist belts are best developed in the northwest zone which is about 300 km wide. The schist belts zone is flanked by migmatite-gneiss-granite terrain to the east and west, and the same terrain separates the individual belts within the zone (Turner, 1983; Ajibade *et al*., 1987). The schist belts are metasedimentary and metavolcanic deformed low grade rocks (Fitches et*al.*, 1985) and predominantly composed of metamorphosed pelitic and semi-pelitic rocks (Ekwueme,1995) but each belt differs in the amount of such lithologies as conglomerates, greywacke, quartzites, calcareous rocks and volcanic rocks.

Turner (1983) and (woakes *et* al., 1987) identified and classified eleven main schist belts in the northwestern and north-central parts of Nigeria. The eleven schist belts are the Birnin Gwari, Kushaka, Wonaka, Zuru, Anka, Maru, Malumfashi, Kazaure, Illesha, Igarra and Isenyi-Oyan schist belts as shown in Figure 2.2. These schist belts or part of them have been studied in detail e.g: Malumfashi (McCurry, 1973), Kushaka (Truswell and Cope, 1963; Grant, 1978); Birnin Gwari (Truswell and Cope, 1963; Ajibade, 1980); Anka (Fargner, 1961; Holt 1982); Maru

(Egbuniwe, 1982); and Zuru (McCurry, 1978; Danbatta, 1991; Danbatta and Garba, 2007; Ramadan and Abdel-Fattah, 2010).

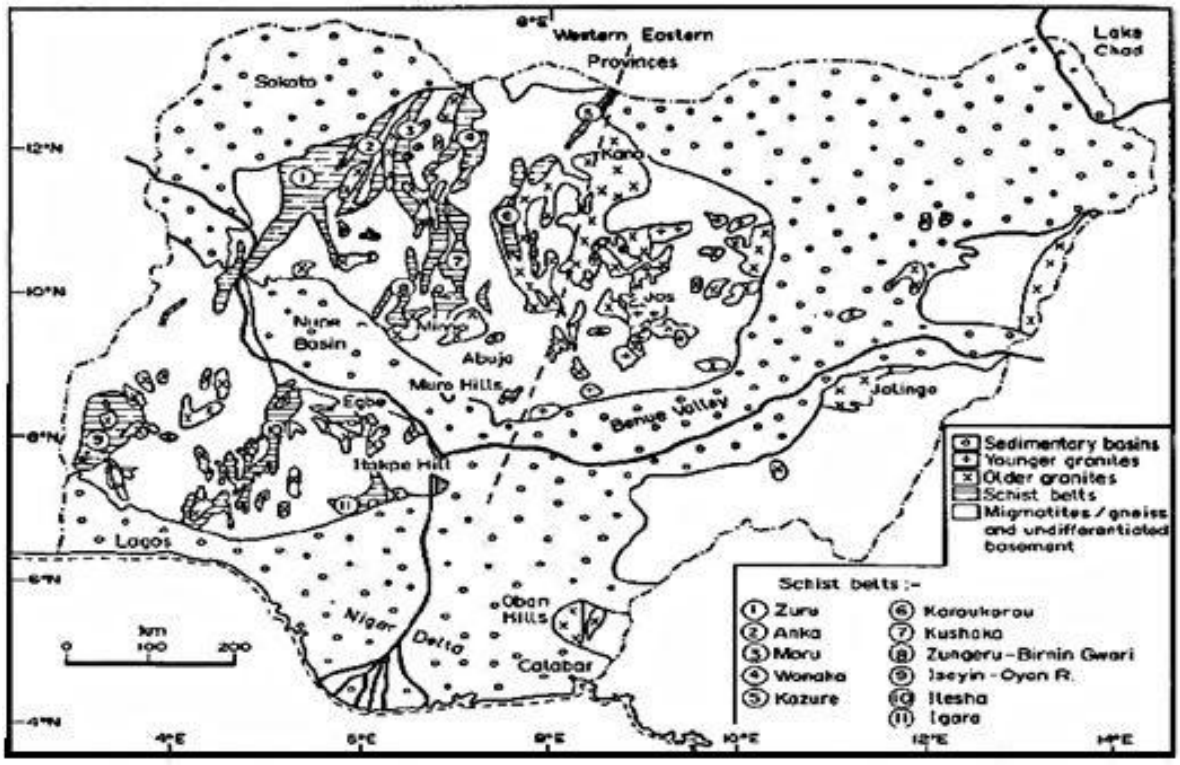


Figure 2.2: Schist belt locations within the context of the Geology of Nigeria (after Woakes*et al.*, 1987).

2.3.1 Evolutionary Models of Schist Belts

2.3.1.1 Background

The Nigerian schist belts are believed to be of two types (Danbatta, 2008): i) those composed of Older Metasediments (mainly found in southwestern Nigeria); and ii) the low-grade Younger Metasediments (mainly found in northwestern Nigeria). The closure of the ocean at the West African Cratonic margin led to the deformation and metamorphism of the sediments and underlying basement during the Pan-African orogeny (Oyawoye, 1964; 1972; McCurry, 1971;

1976; Ajibade, 1971; 1976; Chukwu-Ike, 1978; Danbatta, 1999). The existence of a major sedimentary trough is responsible for the deposition of the Nigerian schist beltsVaniman (1976).

A similar scenario was postulated by Chukwu-Ike (1978) who argued that the schist belts in NW Nigeria are fault bounded ensialic troughs. Similarly, Turner (1983) considered the Anka Maru, Birnin Gwari, Wonaka, Malunfashi and Kazaure belts as originating in one back arc basin. The Zuru and Kushaka belts were also considered to have formed in a separate basin; with the Zuru quartzite's representing basin margin deposits.The evolution of the schist belts is also considered in the context of Eburnean deformation, under extensional and compressional regimes (Danbatta, 2008a).

All the models of evolution of Nigerian Schist Belts over the years could be classified under i) ensialic ii) ensimatic and iii) ensialic - ensimatic model

2.3.1.2Ensialic Models

According to those in favour of ensialic evolution processes, crustal thinning in response to initial crustal extension and continental rifting at the cratonic margin some 1000 Ma ago, led to deposition of sediments in a graben like structure floored by continental crust. The closure of the ocean at the West African cratonic margin led to the deformation and metamorphism of the sediments and underlying basement resulting in the formation of the schist belts and reactivation of older basement during the Pan-African Orogeny (Oyawoye 1964; 1972; McCurry, 1971; 1976; Turner, 1983; Ajibade *et al.*, 1987; Danbatta, 1999). While Vaniman (1976) proposed the existence of a major sedimentary trough to be responsible for the deposition of the Nigerian schist belts while Chukwu-Ike (1978) argued that the schist belts in NW Nigeria are fault bounded ensialic troughs.

Turner (1983) also considered the Anka, Maru, Birnin Gwari, Wonaka, Malumfashi and Kazaure belts as originating in one back-arc basin. The Zuru and Kushaka belts were considered by Turner (1983) to have formed in a separate basin, with the Zuru quartzite, representing basin margin deposits. Fitches *et al.,* (1985) and Udoh (1987) envisaged complex volcano sedimentary trough deposits, with the formation in the belts being lateral facies equivalents. Corroborating this view, for the entire Nigerian Schist Belts, Ajibade *et al.,* (1987) proposed the formation of back-arc graben-like structures in Pan-African times to be responsible for the formation of the schist belts. However, recent suggestion by Olabanyi (1997) emphasized the role of Eburnean events in the formation of the Egbe-Isanlu basin due to plume induced continental drift.

Schist belts without mafic and ultramafic rocks but with documented presence of Algoma banded iron formations are considered ensialic and Eburnean in age. Banded iron formations are absent in those schist belts whose origin is ascribed to ensialic processes and Pan-African in age.

2.3.1.3 Ensimatic Models

Ensimatic models of evolution had also been reportedly proposed to explain the evolution of some of the schist belts (Ogezi, 1977; McCurry and Wright, 1977; Holt *et al*., 1978; Utke, 1987; Danbatta, 1991; Elueze, 1992). Earlier works suggested that oceanic basins closed to form schist belts of Anka, Ife-Illesha and Zuru. invoking the formation of marginal back-arc basins floored by oceanic materials that accepted sediments. The closure of these basins led to the deformation and metamorphism of the sediments and reactivation of older metasediments. Holt (1982) observed that the Anka metavolcanics have chemical characteristics of both island arcs and continental environment. He concluded that the schist belts were deposited in a retro-arc basin related to the subduction processes along the margin of the West African craton. These schist belts possibly represent additional micro continents separated from a pre-existing one

(Turner, 1983; Utke 1987; Wright and Ogezi(1977), Holt (1982), the Anka fault system in Zuru belt and Ifewara fault system have ensimatic affinities. The Anka and Zuru belts are considered as a pair of belts that evolved through ensimatic processes.

2.3.1.4Ensialic and Ensimatic Models

Danbatta (2008) proposed a new evolutionary model for the Nigerian Schist Belts suggesting that the belts evolved from both ensialic and ensimatic processes. The structures in the region are also important for the evolution of the schist belts, the huge Anka-Yauri-Iseyin (AYI) and the Kalangai-Zungeru-Ifewara (KZI) lineaments that traverse the area are considered as deep faults defining tectonic blocks. Along the AYI fault zone, Wilson cycle processes involving the opening and closing of east-west back arc oceans have operated at least locally. Closure of the basins led to the deformation of the sediments, reactivation of pre-existing rocks and the formation of the remaining schist belts and syn orogenic plutonism. Characteristic such as the presence of BIFs and close proximity to KZI fault zone,Danbatta (2008) considered the Wonaka, Kazaure, Zungeru, Birnin Gwari, Malumfashi, Igarra-Kabba-Lokoja schist belts as a group of eastern older belts. They are assumed to have been formed by similar ensialic processes in Eburnean times with some deviations in general evolutionary trend.

The proposed model by Danbatta (2008a) has also shown by implication that all the schist belts associated with the AYI fault zone including the Anka, Zuru, Maru, Kushaka, Iseyin and Ife-Illesha belts are Pan-African in age and were generated by ensimatic means. He also considered the BIF-bearing eastern schist belts to be older than the western schist belts in which BIFs are absent. On this basis and considering the concordant models of evolution earlier proposed for the different belts, the poorly known Wonaka belt is also likely to contain BIFs, as it could have truly formed through ensialic regimes. This new model rejects the previous wholly ensialic and

wholly en-simatic models. Herein,D1 (first episode of deformation) is ascribed to Eburnean compression and D2 (second episode of deformation) to oceanic subduction at 600 Ma. This last deformation is responsible for the pervasive Pan-African regional structures, major folding, thrust faults and nappes observed in this region (Caby, 1989; Affaton *et al*., 1980; Fitches *et al*., 1985; Caby and Boesses 2001).

2.4 Older Granites

The granitoids of northwestern Nigeria were first named Older Granites by Falconer (1911), who distinguished them from the Tin-bearing Younger Granites of Jurassic age which occurs in central Nigeria. The Older Granites occur as distinct plutons types (Ekwueme and Onyeagocha, 1982; Rahman, 1985) such as the Zaria granite batholith (Ike, 1988), Mainchi granite batholith (Egbuniwe, 1982) which occur in a zone generally trending N-S direction.

The Older Granites of Nigeria consist of a wide spectrum of rocks varying in composition from tonalite through granodiorite to granite, syenite and charnockitic rocks (Trustwelland Cope 1963). The granitoids have been emplaced into both the migmatite-gneiss complex and the schist belts.

The north-south linear aggregation of many large batholiths of the basement complex suggest that they may be related to deep seated pre-existing plutonic episode controlled by deep mantle structure (Ogezi, 1977). The intense regional deformation which accompanied and preceded the emplacement of the Older Granites resulted in the pronounced and wide N-S trend. The Older Granites have been dated by several authors as 500-700Ma (Van Breemen *et al.,* 1977; Rahaman *et al.,* 1983).

The granitoids are mainly syn- to late-tectonic Pan-African intrusions of granites, granodiorites and diorites with some gabbros and syenites. They range in size from small sub-circular,

crosscutting stocks to large elongate concordant batholithic bodies emplaced into both the gneiss–migmatites and supracrustal rocks during or just after the main phase of Pan-African deformation (Wright *et al., 1985*).

2.5 Metamorphism within the Nigerian Basement Complex

The Nigerian Basement Complex generally experienced regional metamorphism but local thermal metamorphism occurred as a result of plutonic intrusion within some of the schist belts resulting in the formation of contact aureoles. Metamorphism reached the greenschist to middle amphibolite facies in the younger metasediments and upper amphibolite facies conditions in the crystalline rocks (McCurry, 1976; Ogezi, 1977; Ajibade, 1971; Egbuniwe, 1982). A bimodal distribution of metamorphic facies exist between the greenschist and amphibolite metamorphic facies(McCurry, 1971). Evidence of mobility and plastic deformation in the latter indicates that metamorphic conditions in these rocks are similar to those described by Holland and Lambert (1969). The metamorphic assemblage seems to indicate a low pressure facies similar to Pyrenean and Buchan type (Hietanen, 1976; Miyashiro, 1961).

The grade of metamorphism varies from one place to another. In Zungeru area for example, Ajibade (1987) recognized a Barovian type of metamorphism with metamorphic grade ranging from greenschist facies to almandine amphibolite facies (staurolite-almadine-muscovite sub facies). There are also some indications of two periods of syntectonic metamorphism separated and followed by periods of static metamorphism (McCurry, 1971; Danbatta, 1998; 2003).

The study of microscopic domains of rocks within the Kazaure area allowed the identification of two generations of progressive metamorphism, M1 and M2 and a static one M3Danbatta (2003). The mineral assemblages showed evidence of both M1and M2 being either syn or post D1 with the earliest metamorphic event reaching lower amphibolite facies grade while the

secondmetamorphic event which is the main metamorphic event reached a low grade greenschist facie grade of metamorphism.

Thermal metamorphism is recognized in the Anka and Maru Belts which results from the emplacement of Older Granites which formed a narrow contact aureole (Fetches *et. al* 1985). The Maru area has mineral assemblages of quartz, muscovite, biotite, chlorite and opaque minerals (magnetite and pyrite).The pelitic, semi pelitic schist and psamites are indications of greenschist metamorphism (Egbuniwe, 1982). In the staurolite-garnet biotite bearing pellites, the presence of staurolite suggest lower amphibolite facies conditions (Winkler, 1974), while the first appearance of biotite and almadine garnet are respectively indications of middle-upper greenschist facies metamorphism.

2.6 Structural Framework of the Basement Complex of Nigeria

2.6.1 Faults and Shear Zones

A characteristic feature of the basement complex tectonics is the widespread occurrence of fractures, which is a general term used to describe rupture in a rock. Fractures are indicated by lineaments in silicified shear zones, which form as dykes and ridges. Also,Straight channeled streams which exploit the weak zones of the earth are also fractures. However, a fracture becomes a fault when lithologies and other linear fractures are displaced. The principal fracture directions in the basement complexes are N-S, NNE-SSW, NE-SW, NNW-SSE and NW-SE and to a lesser extent, in the E-W (Oluyide, 1988).

The N-S fractures easily identified as prominent scarp surfaces and depressions appear to have controlled the major N-S flowing streams (e.g. the lower Niger) and are also found around the Jos Plateau. They are traceable as far north as the Tuarage area of the Niger Republic (Ball,

1980). These fractures are also marked by considerable shearing and brecciation feature attributable to brittle deformation. Other structural trends include the NE-SW and NW-SE conjugate ones being characterized by a dextral sense of movement. The fault has been interpreted to result from transcurrent movements. The Benue and Niger troughs are aligned parallel to the conjugate sets; there are several other comparable sets on either side of the troughs. The NNE-SSW and NNW-SSE conjugate sets are also well developed on the basement complex Danbatta (2008). Wright (1970) discussed major NE trending faults in Nigeria, these faults are strike-slip faults which he considered are connected to the initiation of fractures in the south Atlantic (Danbatta, 2003). Present landsat studies also revealed the existence of these lineaments west of Kaduna and Zaria. These are Yelwa and Kalangai shear faults(Truswell and Cope, 1963), whose traces possibly passes beyond Katsina and Kano and are suspected to continue under sediments into Niger Republic (Danbatta, 1999).

Danbatta (2003) has reported that the Kalangai fault (K.Z.F) lineament passes through the Kazaure Schist Belt (KZSB) in a general NE-SW to NNE-SSW direction, the direction along which the belt was emplaced. He noted that the major NE-SW KFZ is parallel to a number of other faults with similar dextral displacements, which together formed an important set of faults throughout Nigeria.

The two main lineaments trends captured by Landsat ETMare: NW-SE longer lineaments and a second pair of NE-SW and NNE-SSW lineament, which appear to be widespread but spatially discontinuous and shorter(Goki *et al*. 2011a). These trends have been reported coincide with aeromagnetic study by Olaseyinde*et al*., 1990 who attributed them to the Atlantic fracture zone that extends into Nigerian Basement Complex. The north westerly trends are not apparent in the aeromagnetic map, even though they are very pronounced in the landsat ETM study. These may

be supra-crustal signatures and are not related to deep seated aeromagnetic trends of Ball (1980). In the Nigerian basement, the major trend of lineaments is NE-SW and NW-SE. But N-S and E-W directions are dominant and greater in continuity. According to Udoh (1988), the fractures which traverse the country around Yelwa, Zungeru, Bauchi and Yola constitute the most prominent of the NE-SW and NW-SE sets.

2.6.2 Folds and Foliations

The dominant foliation in the migmatite-gneiss complex is defined by alternating dark and light bands, as well as the prominent gneissosity.The foliation trend is normally north-south, with variations between NW-SE and NE-SW. The E-W trending foliations has also been recorded locally, especially in the migmatite rocks around Kishi, north of Shaki (Ayoade, 1984), Kabba region and south of Minna(Hockey *et al*., 1986). These are most probably the earliest folded structures which are now preserved as relicts, especially in the migmatites. Mullan (1978) is of the opinion that the E-W structures are probably Pan-African.

Multiple phase folding has also been recognized in the metasedimentary rocks around Okene (Hockey *et al*., 1986), Anka region (Ogezi, 1977; Egbuniwe, 1982) and Zuru region (Danbatta, 1991). On a regional scale, at least four folding phases superimposed on each other have been established especially in the more ductile metasedimentary formations (Table 2.1).

The earliest folds were first seen in small scale structures from Birnin Gwari, Zungeru areas and Abuja (Grant, 1978; Ajibade, 1998). The folds are tight to isoclinal with steep to vertical hinges and exhibiting widely varying wavelengths (Table 2.1).

Table 2.1: Deformation and structural histories established for the schist belts in the north-western Nigeria (Danbatta, 2008b).

Belt/Source of Information / Deformation events	Kazaure Belt (Danbatta, 2002)	Malumfashi Belt (McCury, 1973)	Anka Belt (Holt,1982)	SW of Zuru Belt (Danbatta,1991)	Kushaka Belt (Grant,1978)	Birnin Gwari (Ajibade,1980)	Maru Belt (Egbuniwe, 1982)
D4					Rare and relict minor folds.Local development of strain-slip cleavage	Steeply dipping folds and kinks.Axial planes strike N-S/E-W.	Steeply dipping kinks with E-W strike
D3				Open folds with smooth profiles and sleep NNE-SSW axial planes dip	Open folds with NNE-SSW axial planes.Axes plunge north and south.	Open folds NE-SW axial dip and rounded or angular crest.	Open to tight Chevron folds and tight to isoclinal folds
D2	Upright isoclinals folds with NNE-SSW axial planes. Cleavages developed	Tight to isoclinals D_L fold with N-S axial planes strike.Cleavages developed	Steeply dipping, E-w striking bands.	Tight to isoclinals folds with moderate plunging axes, N-S cleavages developed.	Tight to isoclinals disharmornic folds with steep axes.Axial planes strike N-S	Co-plnar with D1.Open to isoclinals large scale folds of S,schistocity. Axial planes strike NE-SW.	Open to isoclinals folds.Steeply dipping N-S striking cleavage.
D1	Relict recumbent isoclinals folds with N-S trending axial planes.Mostly obliterated.	Early ENE-WSW foliation mated to D_E folds.Largely obliterated.	Open to isoclinals upright folds with NNE-SSW axial planes and Axes.	Rare and obliterated minor folds with shallowly dipping E-W to ENE-WSW trends.S1 axial plane cleavage.	Rare minor folds with E-W axial planes.	Folding of cover rocks on NE-SW trending axial planes.Cataclastic deformation of basement cover contact.Cleavage well developed.	Relicts flatlying folds with N-S axes and S_1 cleavage.Folds obliterated by transposition

CHAPTER THREE

MATERIALS AND METHODS

3.1 Background

The methods adopted during this research are: literature review of previous work done in the study area,remote sensing studies,conventional field work (lithological and structural mapping), data analysis (petrographic and structural analysis), presentation and interpretation of result respectively. The desk study involves researching of books, reports and journals (both published and unpublished) to obtain relevant information about the study area.

3.2 Remote Sensing Studies

Remote sensing studies of the structural elements was undertaken so as to produce lineament map of the study area. Analysis of remotely sense data was carried out by first downloading the digital elevation model (DEM) of the study area using global mapper software V16.2. The image was then exported into Arc-GIS to extract the lineaments. The lineaments generated were further processed and analysed using rockware software to produce the rose diagram.

3.3 Field Work

The fieldwork was carried out in two phases namely: reconnaissance and detailed geologic mapping. The latter was carried out in dry season in the month of March, 2016. During this period, most of the stream /river channels have dried up making the field work safe.

The method of mapping employed was traverses based with the base map dividedinto segments. representative rock samples were collected from all available rock exposures in the study area. In the field, each outcrop was observed and described based on its mode of occurrence,

macroscopic characteristics, structural elements and field relation with adjacent outcrops. Hand specimendescription of rocks was carriedout based on the following macroscopic features: color, texture and mineralogy.The positions where the samples were collected are indicated on the base map.

Careful observation of lithological boundaries was made by observing changes in rock type, nature of soil, vegetation and topography. A compass clinometer was used to measure the attitude of structures in terms of their strike, angle of dip, dip directions, trend and plunge, length width and areal coverage.

3.4 Laboratory Analysis

3.4.1 Petrography

A total of twenty (20) fresh samples were selected for thin section preparation in the Department of Geology, Ahmadu Bello University. This rock was sliced perpendicular and parallel to the foliation plane.

A thin slice of rock is cut with the aid of a diamond saw and trimmed to fit into a glass microscope slide. The slice is glued to the slide with epoxy glue and then mounted in a holder and ground on a diamond lap until it is translucent. It is hand finished with 600 grit silicon carbide on a glass lap, when a thickness of 0.03mm is reached, the section is then complete and ready for examination under the microscope. The prepared slides were examined under the petrological microscope to identify the minerals present. The general sequence of observations carriedout under the microscope is tabulated in Table 3.1 below.

Table 3.1:General Sequence of petrographic observations under the microscope(Nyamai, 2004).

No.	Description
1.	**Form and Crystallographic properties** a. Crystal form if developed b. Cleavage, parting, or fracture: number of cleavages and angular relationships to one another, perfection of cleavage, characteristics of parting and fracture. c. Shape of grain, if distinctive (fibrous, acicular, bladed, radiating, reticulate, tabular, platy). d. Inclusions, intergrowths, alteration, association with other minerals.
2.	**Optical Properties** a. Twinning b. Opaque minerals: color by reflected light c. Transparent or translucent minerals • Color and c. Examination under crossed nicols •Isotropic or anisotropic •In anisotropic minerals, interference colors and determination of birefringence •Extinction angle. •Determination if length-slow or length fast

3.5 Structural Analysis

This part involved a detailed structural analysis of both mesoscopic and megaoscopic structures in the study area, the three major analyses adopted for structural elements observed in the study area are:

i) Descriptive geometry (Geometric analysis), ii) Kinematic Analysisand iii) Dynamic Analysis

i) Descriptive Analysis

In descriptive analysis,attitude of structures weremeasured and describe literally in terms of their physical and geometric element. Descriptive analysis regards the physical orientations and configuration of structures.

The basis of descriptive analysis is broad, ranging from direct observation of field relationship, examination of rocks deformed experimentally in the laboratory, drilling into the subsurface, geophysical monitoring and probing of the subsurface; exploring the structures of the ocean floor and studying the stratigraphy and/or petrography of the rocks in which the structures occur. Regarding this work, two components of descriptive analysis will be adopted; direct observation of field relation and study of the petrography in which the structures occur. The various software used for geometric analysis in this work are, Georose, Visible geology, Orient, and global mapper.

ii) Kinematic Analysis

This analysis deals with recognizing and describing the changes that took place during deformation brought about by movement of the body as a whole, or by internal movement within

the body. When a body or some part of a body is forced to change in location or position it undergoes deformation.Orient implements a kinematic analysis based on M-plane, or movement plane geometry (Angelier, 1979; Marshak and Mitra, 1988; Twiss and Unruh, 1998; Marrett and Allmendinger, 1990; Twiss and Moores, 2007).Although the term fault is used here, the kinematic analysis can be applied to shear zones if the displacement directions can be determined. This analysis uses structural data from fault, fold, boudinage and thin section of strained rock samples. The available softwares used for this analysis are geofry and ellipse sim.

iii) Dynamic Analysis

The aim of dynamic analysis is to interpret the stress that produce deformation, to describe the nature of the forces from which the stress are derived, and to evaluate the relationship among stress, strain, and rock strength. The data used for this analysis was collected from available mesoscopic structures encountered in the study area. The software used was Win Tensor 2.0

CHAPTER FOUR

RESULT AND INTERPRETATION

4.1 lineament analysis

Lineament digitization was done using DEM due to its high resolution and ability not to display lineament of non-geological origin. Digitization of lineament was carried out following change in tone on the digital elevation model. After digitization of lineaments, statistical analysis of lineament properties in terms of its length, density, relative abundance and orientation was carried out in the study area.

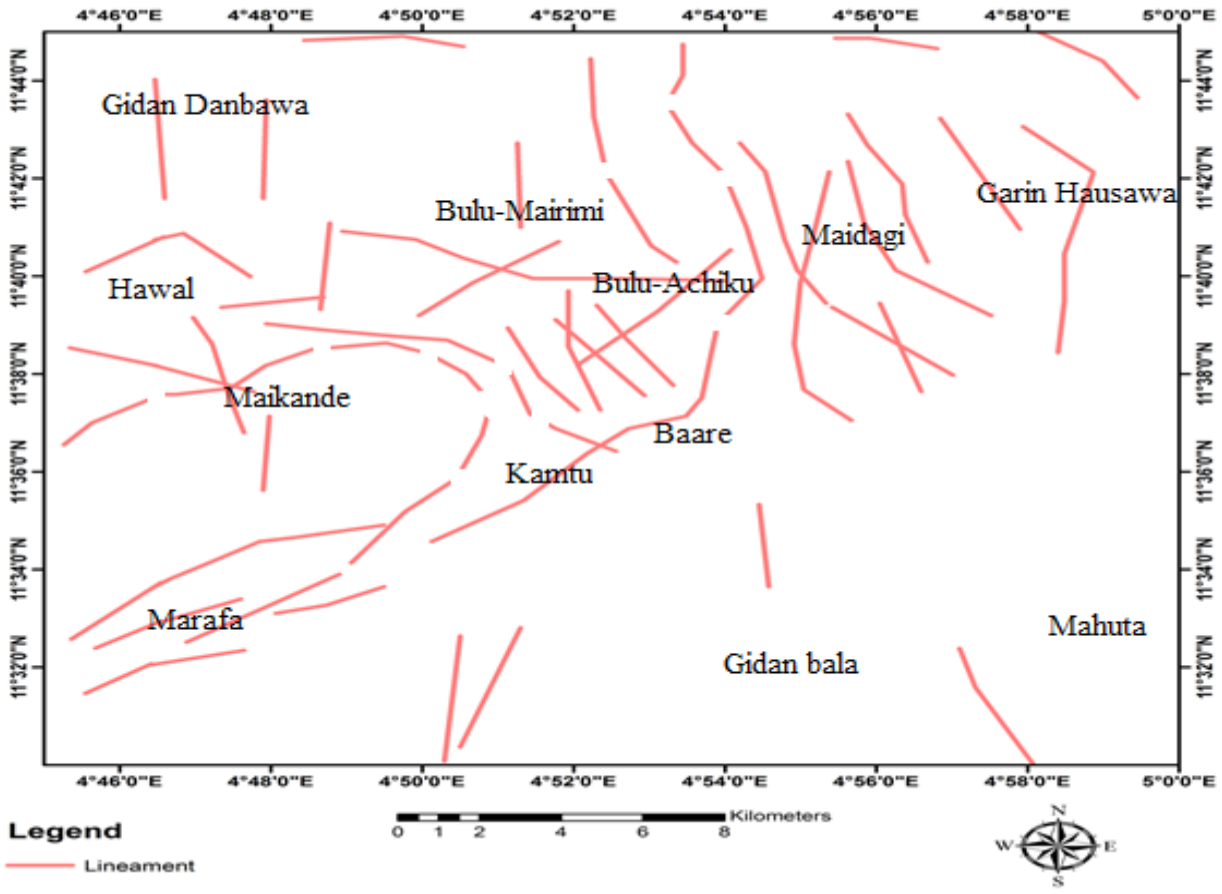


Figure 4.1: Lineament map of the study area.

4.1.1 Lineament Orientation

Analysis of lineaments was carried out and lineaments were grouped into four classes (N-S, NW-SE, NE-SW andE-W). A total of 46 lineaments were digitized, and 11 (24.5%) of these lineaments had N-S orientation,NW-SE orientation had18(39.3%), NE-SW orientation had 9 (19.2%) while E-W orientation had 8 (17%) (Table 4.1). A rose diagram generatedfrom lineaments shows a dominant NNW-SSE and NE-SW direction. (Figure 4.2).

Table 4.1: Lineament orientation properties

S/N		N-S	NW-SE	NE-SW	E-W
1	Number	11	18	9	8
2	Percentage	24.5	39.3	19.2	17

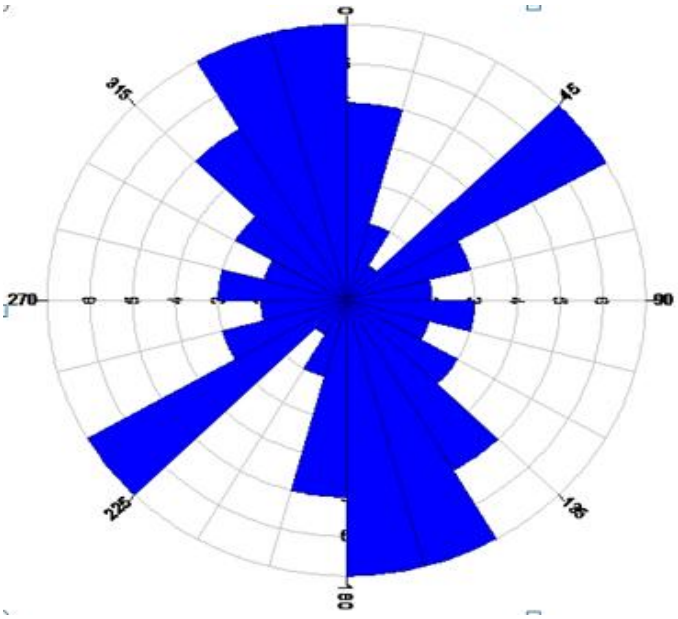


Figure 4.2: Rose diagram fromlineament within the study area with orientations in NNW-SSE and NE-SW directions.

4.1.2 Lineament Length

Digitized lineaments of the study area have a minimum length of 1.891km, a maximum length of 22.885km, a mean of 4.642km and a standard deviation of 3.8032km. Histogram plot for lineament length shows a positive skew (Figure 4.3) Positive skewness for lineaments is an indication that most lineaments in the study area are not extensive.Lineament length was divided into four classes, having their length, number, percentage and area covered summarized in (Table 4.2).

Table 4.2: Lineament Length

S/N		Very Short	Short	long	Very Long
1	Number	**15**	**17**	**12**	**3**
2	Percentage	6.364%	50.543%	42.476%	0.617%
3	Area	49Km^2	389.2Km^2	327.1Km^2	4.8Km^2

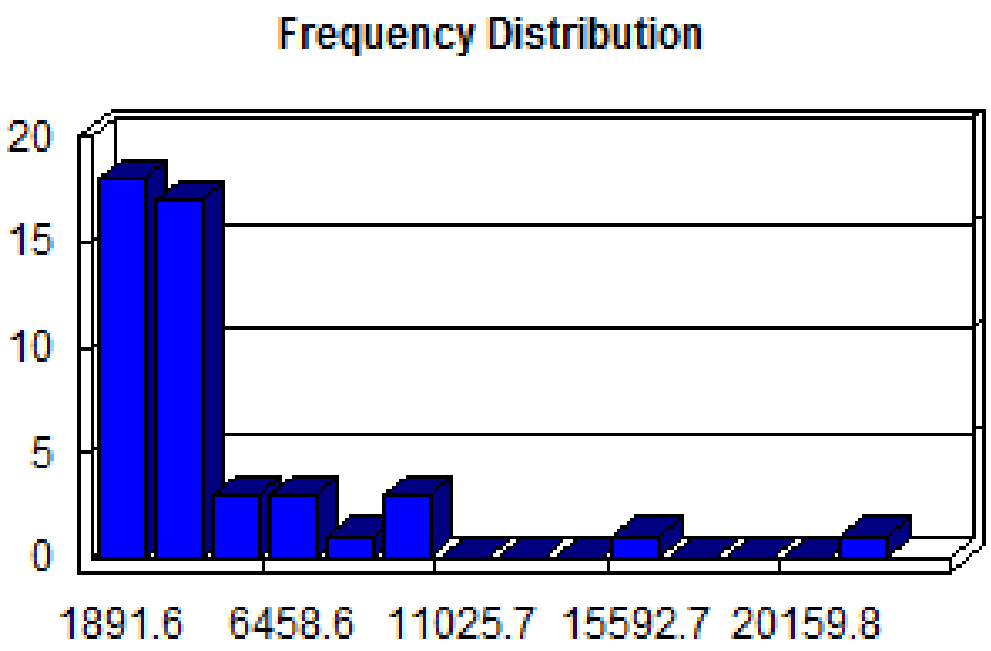


Figure 4.3: Histogram of frequency against length of lineaments.

4.1.3 Lineament Density

Lineament density was used to understand the number of lineaments per unit area. Lineament density aid in understanding the degree of shearing within the study area, Areas with high lineament density must have experience a high degree of shearing than areas of low lineament density. Lineament density for the study area ranges from 0 to 2.66 lineaments per unit area.Lineament density was classified into five classes (Figure4.4). From the lineament density map, areas of very high lineament density constitute 0.43% of the study area, occupying an area extent of 3.3 km^2 in central part of the study area around Bulu Achiku.Areas of high lineament density make up 1.02% of the study area with area extent of 7.88 Km^2 in western part, areas of medium lineament density occupy an area extent of 87.53 Km^2 and covers 11.37% of the study area in the central and southwestern part. Areas oflow lineament density have an area extent of 88.86Km^2 and constitute 11.54% of the study area while areas of very low lineament density

have area coverage of 582.42 Km^2 and constitute 75.64% of the study area, dominating southeast and northwest.

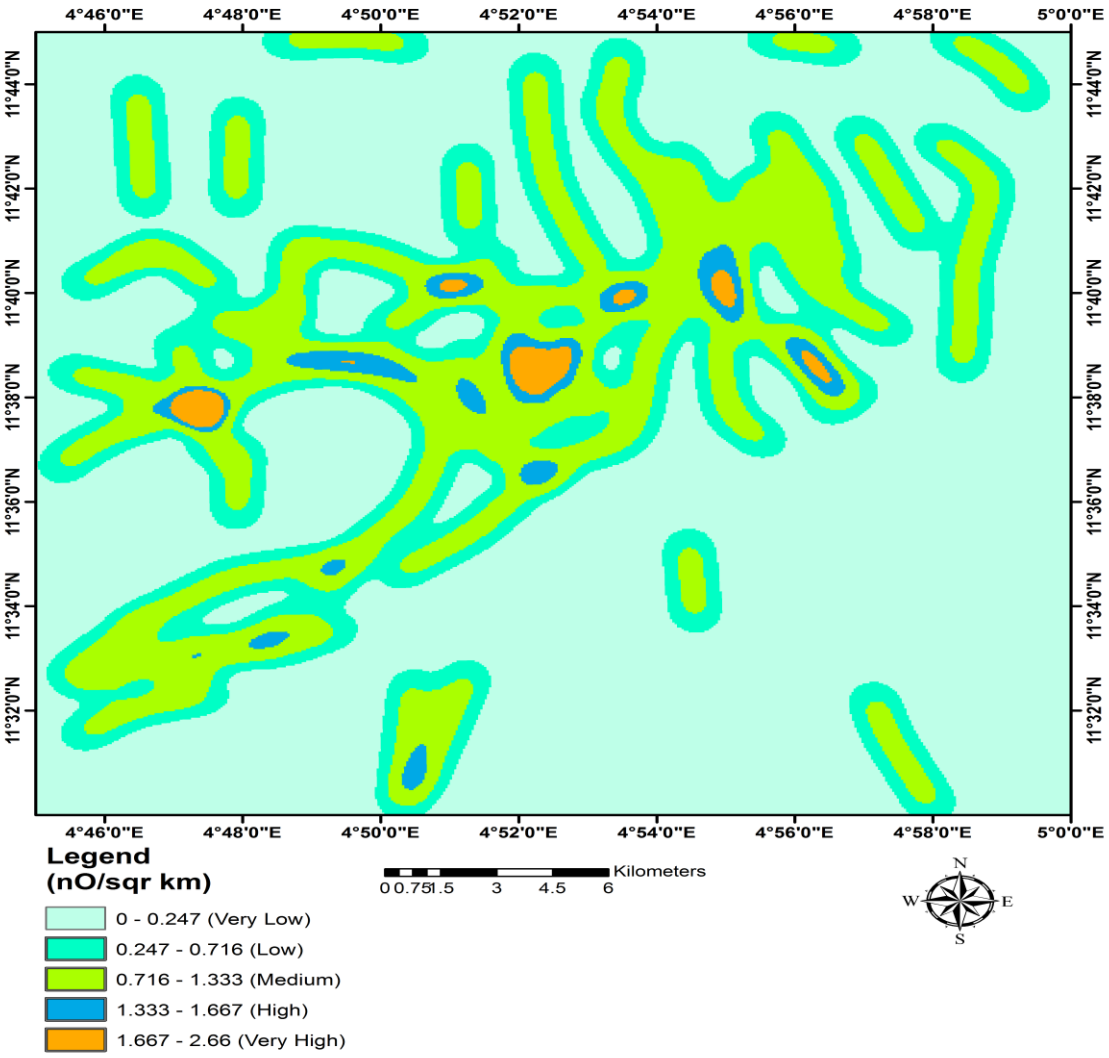


Figure 4.4: Lineament density map of the study area.

4.1.4 Lineament intersection density

Lineament intersection density ranges from 0 - 2.14, Lineament intersection densities were divided into four classes. Areas depicted as having very high lineament intersection density covers area of 0.35 Km^2representing 0.047% of the study area in western part. Areas of high

lineament intersection density represent 0.318% of the study area and have area coverage of 2.45 Km^2in central part. Areas depicted as having low lineament intersection density cover an area of 12.42Km^2 representing 1.613% of the study area. The area depicted as having very low lineament intersection density have area coverage of 754.77Km^2 representing 98.022% dominating most part of the study area. (Figure 4.5)

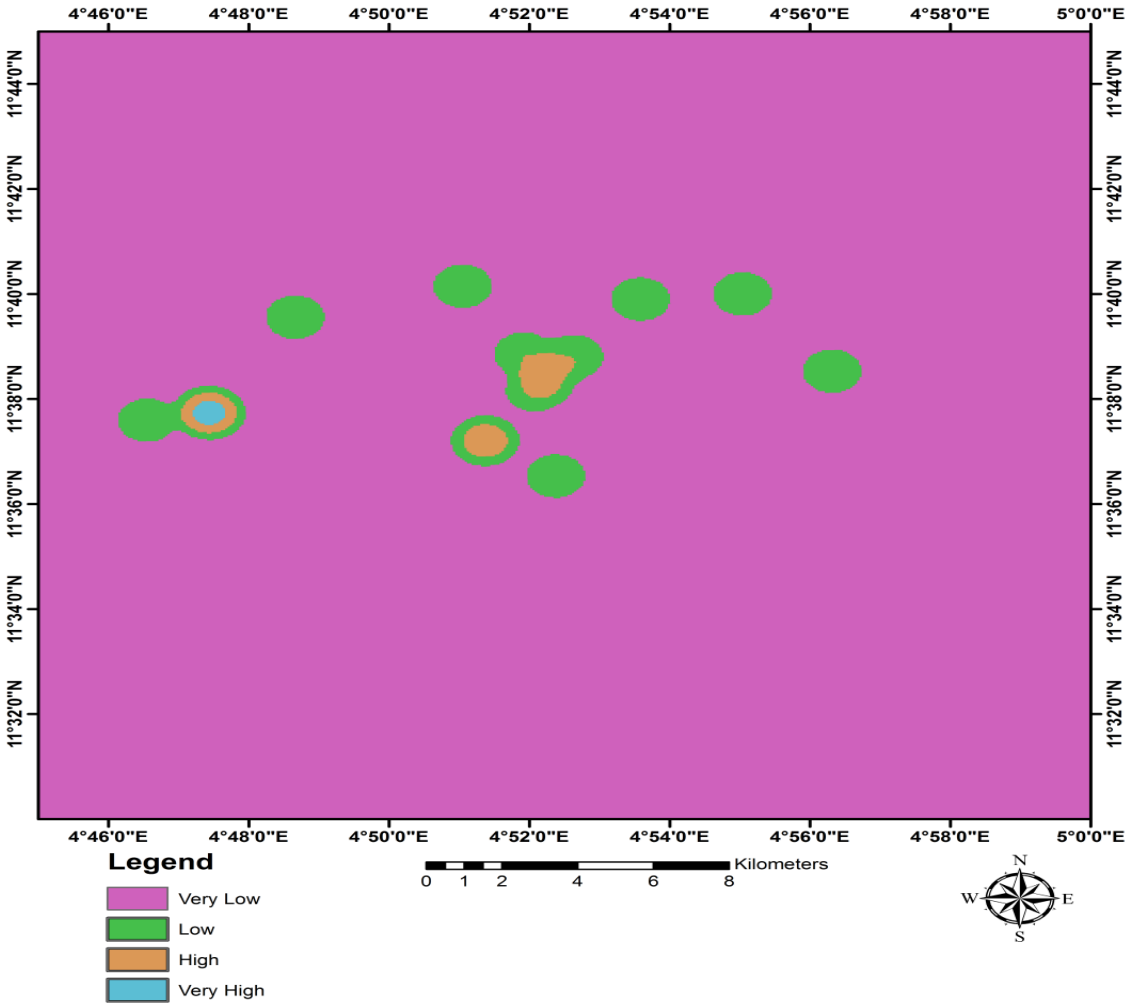


Figure 4.5: Lineament Intersection density for the study area

4.1.5 Lineament Mean Length

The mean lineament length (4.976km) was used to classify lineaments in the study area into very short (1.891 – 3.108km), short (3.108 – 4.642km), long (4.642 – 10.289km) and very long (10.289 – 22.885km) respectively (Figure 4.6). Areas with very long lineament length accounted for 0.617% of the lineaments covering a surface area of4.8Km^2 in central part, Areas with long lineament length accounted for 42.476% of the study area and covering a surface area of 327.1Km^2 in north, central and western part of the study area. Areas of short lineament length accounted for 50.543% of the study area and cover a total area of 389.2 Km^2in northwest, south and extreme northeastern part. Areas of very short lineaments account for 6.364% of the study area and cover a total area of 49 Km^2 in west and southwestern part.

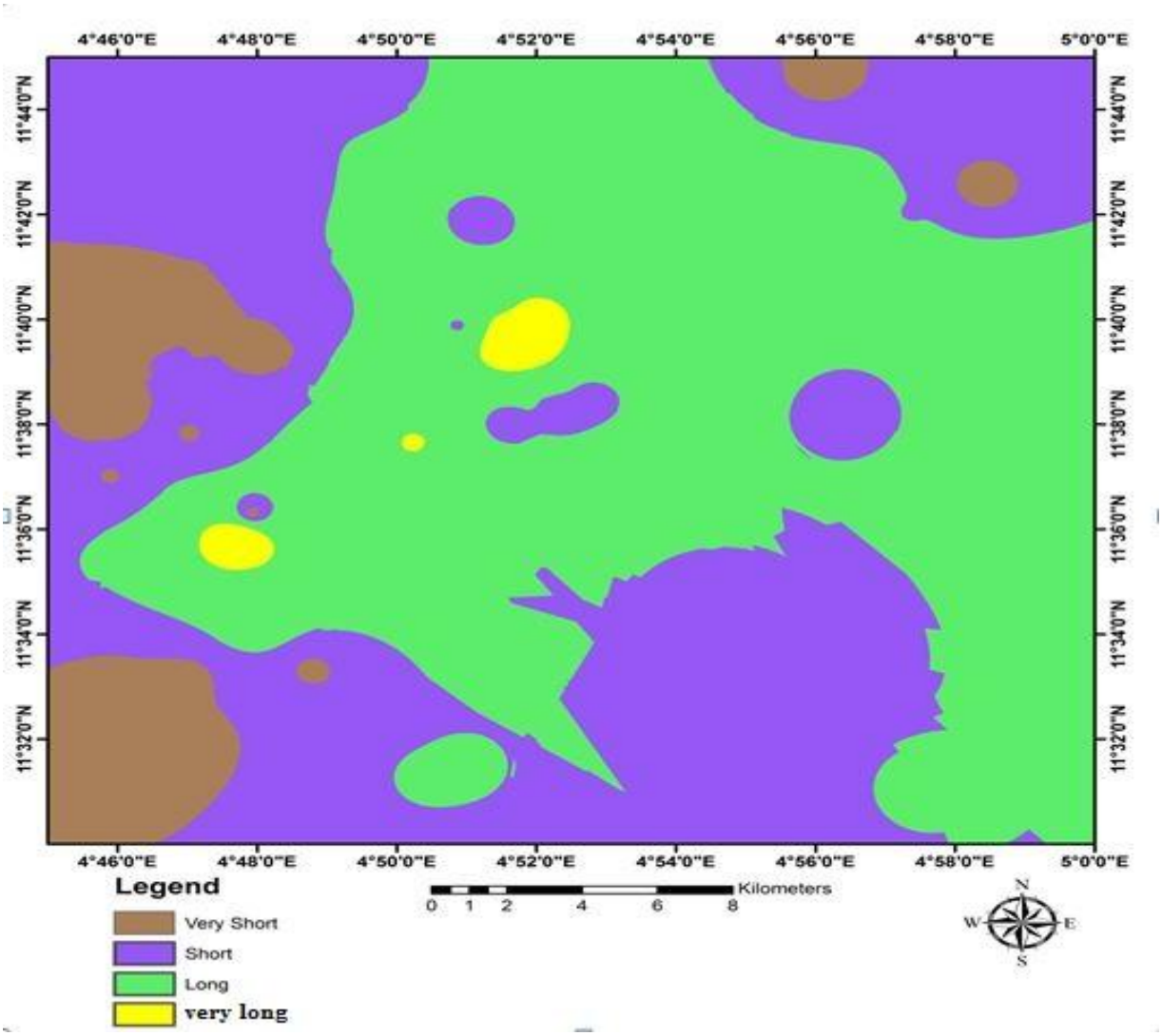


Figure 4.6: Lineament mean length map of the study area.

4.1.6 Lineament Relative Abundance

4.1.6.1 North –South Relative Abundance

A total of 18 N-S lineaments were delimited from the area. The N-S lineament relative abundance was subdivided into four classes. Areas with Very high N-S relative abundance accounted for 0.472% of the study area and have an area extent of 3.6 Km^2 in southern part, Areas with high N-S relative abundance accounted for 1.466% of the study area and have an area extent of 11.3 Km^2 distributed uniformly in central part. Areas with medium N-S relative

abundance accounted for 1.613% of the study area and have an area extent of 12.4 Km^2while areas with low N-S relative abundance accounted for 96.448% of the study area and have an area extent of 742.6 Km^2 dominating most of the study area. (Figure 4.7).

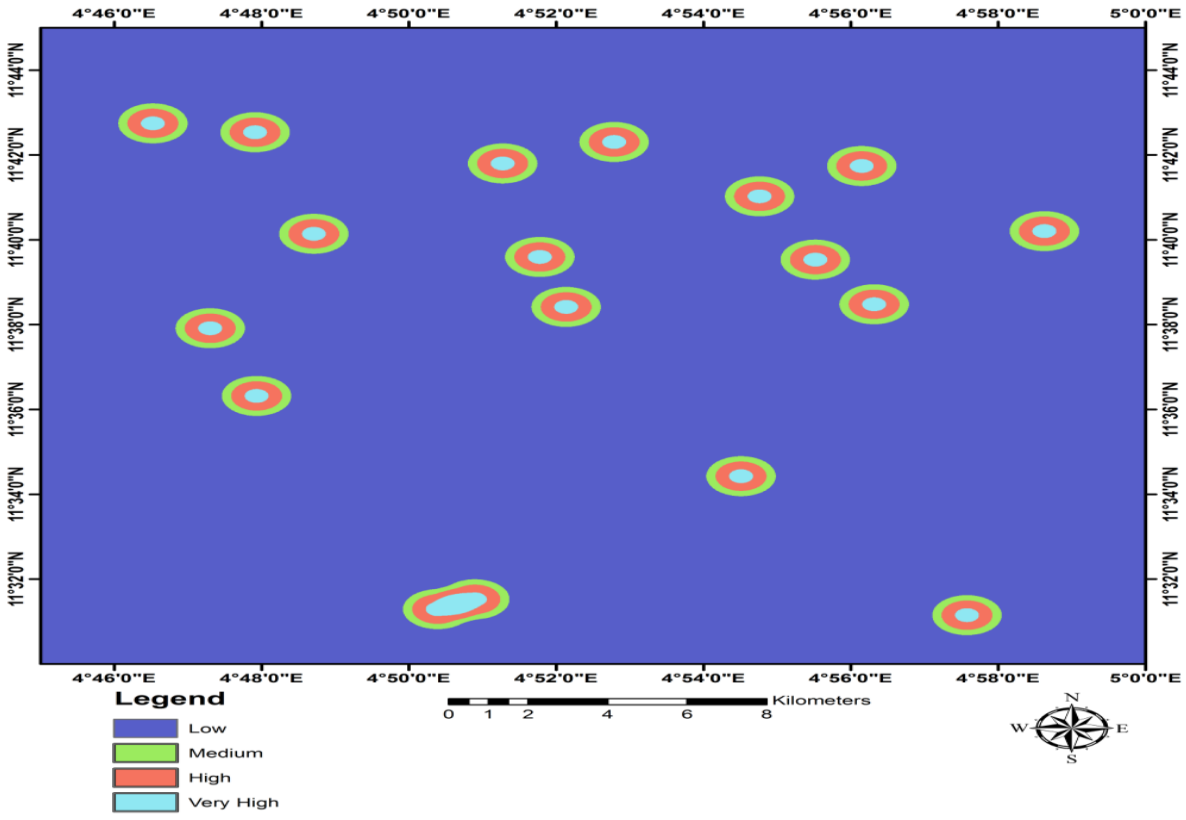


Figure 4.7: North-South lineament relative Abundance map of the study area.

4.1.6.2 East – West Relative Abundance

TheE-W lineaments in the study area total to eight and the study area is subdivided in to four classes. Areas with Very high E-W relative abundance accounted for 0.502% of the study area and have an area extent of 3.9 Km^2 in north, west and southwest. Areas with high E-W relative abundance accounted for 0.557% of the study area and have an area extent of 4.3Km^2. Areas with medium E-W relative abundance accounted for 0.707% of the study area and have an area

extent of 5.4 Km^2. Areas with low E-W relative abundance accounted for 98.235% of the study area and have an area extent of 756.4 Km^2in central, south and eastern parts of the study area. (Figure 4.8).

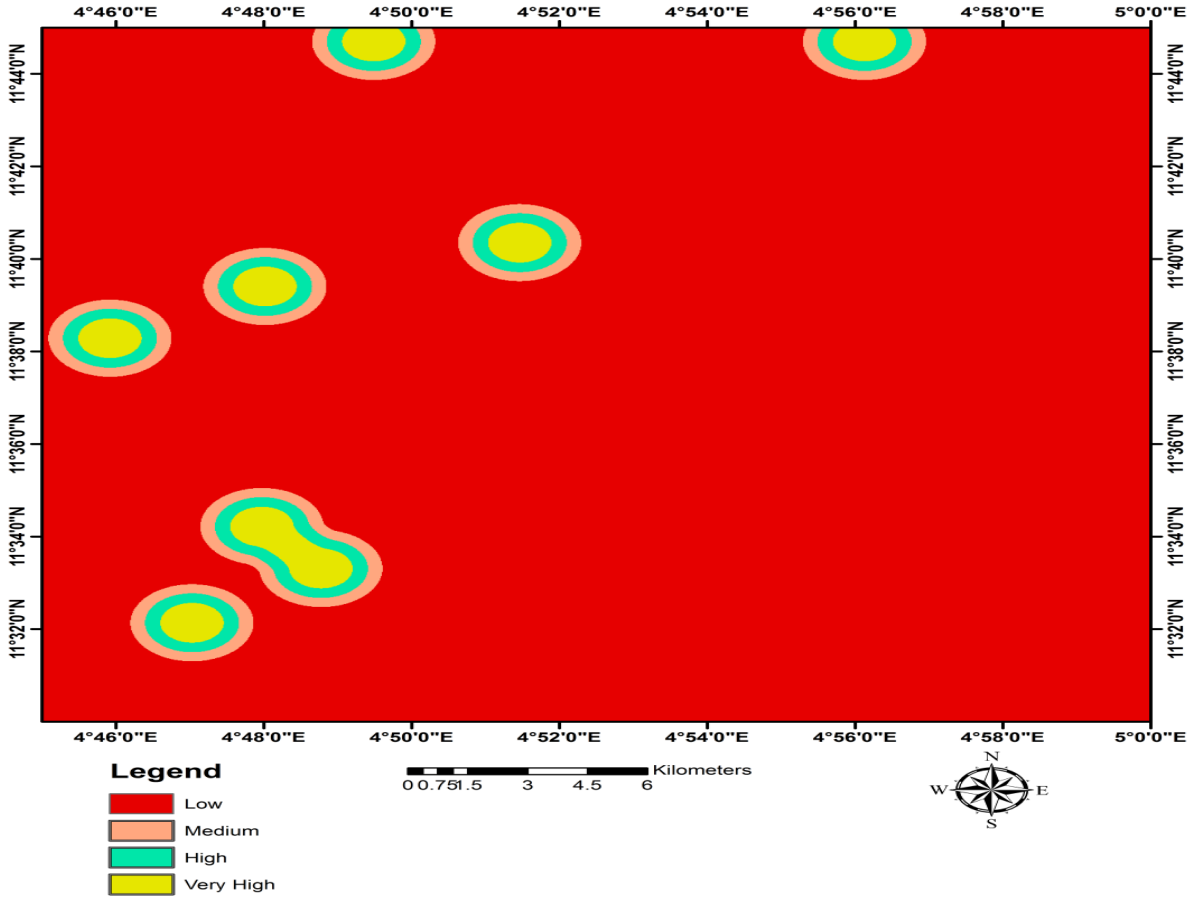


Figure 4.8: East-West lineament relative Abundance map of the study area.

4.1.6.3 Northeast – Southwest Relative Abundance

NE-SW lineament abundance has a minimum of 0, a maximum of9. NE-SW relative lineament abundance was subdivided in to four classes. Areas with Very high NE-SW relative abundance accounted for 1.641% of the study area and have an area extent of 12.6Km^2 in southwestern part, Areas with high NE-SW relative abundance accounted for 5.125% of the study area and have an area extent of 39.5Km^2 in western part, Areas with medium NE-SW relative abundance

accounted for 6.398% of the study area and have an area extent of 49.3 Km^2. Areas with low NE-SW relative abundance accounted for 86.836% of the study area and have an area extent of 668.6 Km^2 covering almost the entire study area (Figure 4.9).

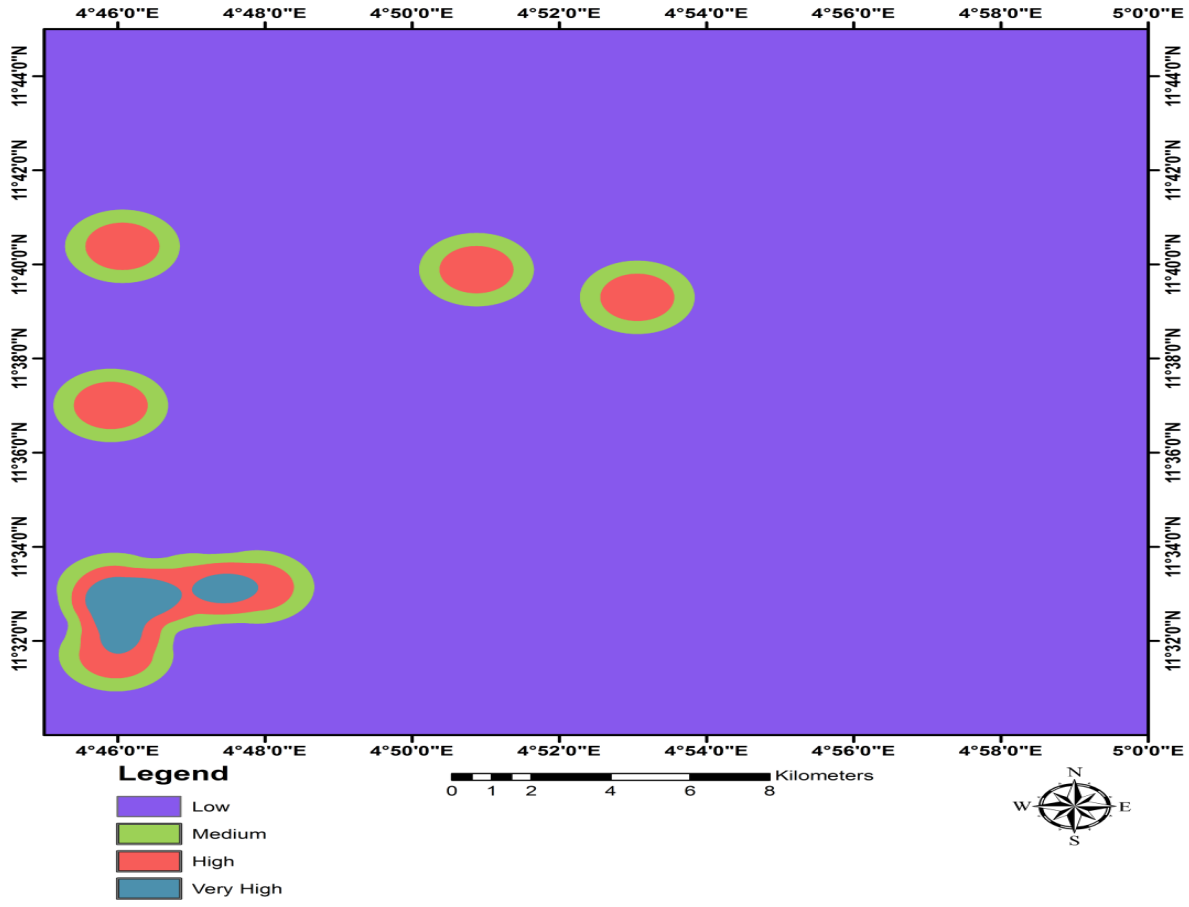


Figure 4.9: Northeast-Southwest lineament relative abundance map of the study area.

4.1.6.4 Northwest – Southeast Relative Abundance

Delineated NW-SE lineaments in the study area are eighteen. NW-SE relative lineament abundance was subdivided in to four classes. Areas with Very high NW-SE relative abundance accounted for 0.052% of the study area and have an area extent of 0.4 Km^2 in central part around Bulu Achiku, Areas with high NW-SE relative abundance accounted for 0.071% of the study

area and have an area extent of 0.5 Km^2 also in the central part, Areas with medium NE-SW relative abundance accounted for 0.538% of the study area and have an area extent of 4.1 Km^2in northeast and western part. Areas with low NW-SE relative abundance accounted for 99.3% of the study area and have an area extent of 764.9 Km^2in south and northern part of the study area (Figure 4.10).

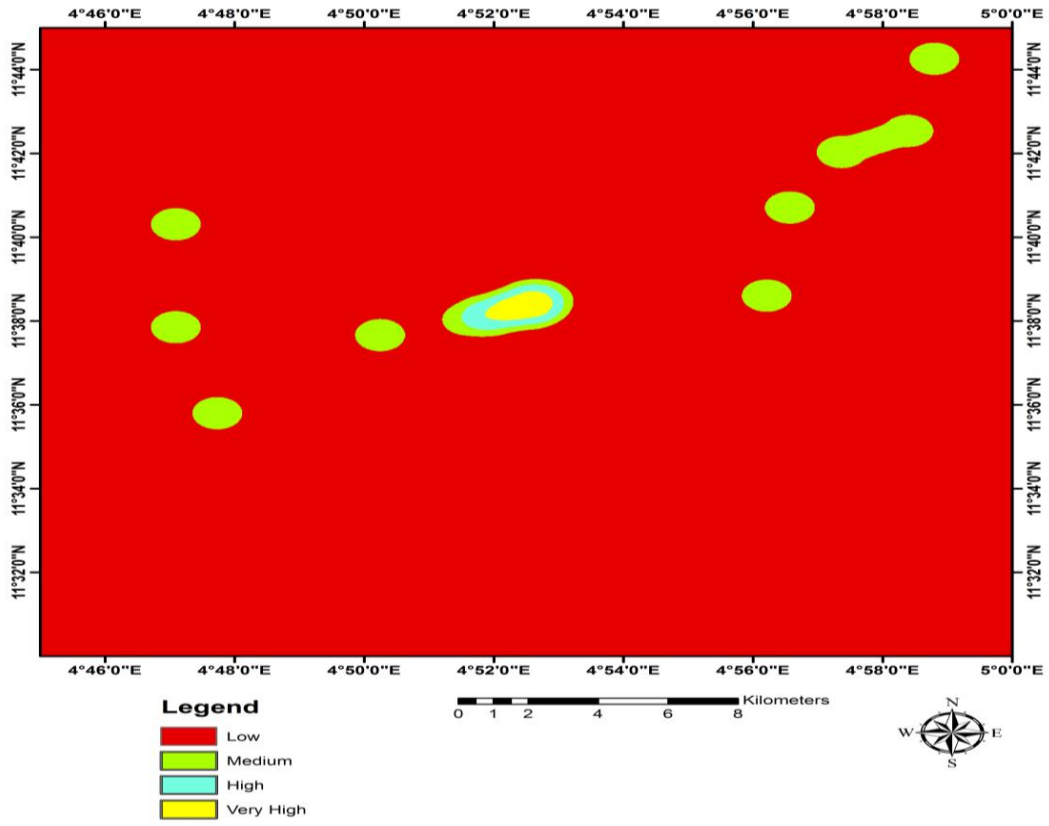


Figure 4.10: Northwest-Southeast lineament relative Abundance map of the study area.

4.1.7Relation between Lineament Length and Orientation

Relationship between mean length and azimuth was compared using tables and diagrams. Mean length for lineament orientation in N-S, NW-SE, NE-SW and E-W was used for this analysis. From this comparison it is observed that the N-S lineaments are the most abundant, and NE-SW

lineament is the least, the short lineament specie is the most abundant and very long lineament is the least. Also the E-W and NE-SW lineament species are more correlating than N-S and NW-SE lineaments (Table 4.3).

Table 4.3: Relationship between Lineament Length and Orientation.

	N-S	**NW-SE**	**E-W**	**NE-SW**	**Sum**	**Percentage**
Very Short	3	1	4	6	14	31.9%
Short	6	8	1	2	17	36.2%
Long	1	8	2	1	12	25.5%
Very Long	2	1	0	0	3	6.4%
Sum	11	18	8	9	46	
Percentage (%)	24.5%	39.3%	17%	19.2%		

4.2 Field Geology and Petrographic analysis

Field observation and relationships, hand specimen and petrographic description of rocks in the study area are discussed below. The major lithological units mapped in the study area arequart-mica schist, medium-grained granite and quartzite while the minor rocks are pegmatite, aplite dykes and quartz viens. The geological map and cross-section shows the relationship between the mapped lithologies in the study area (figure 4.11)

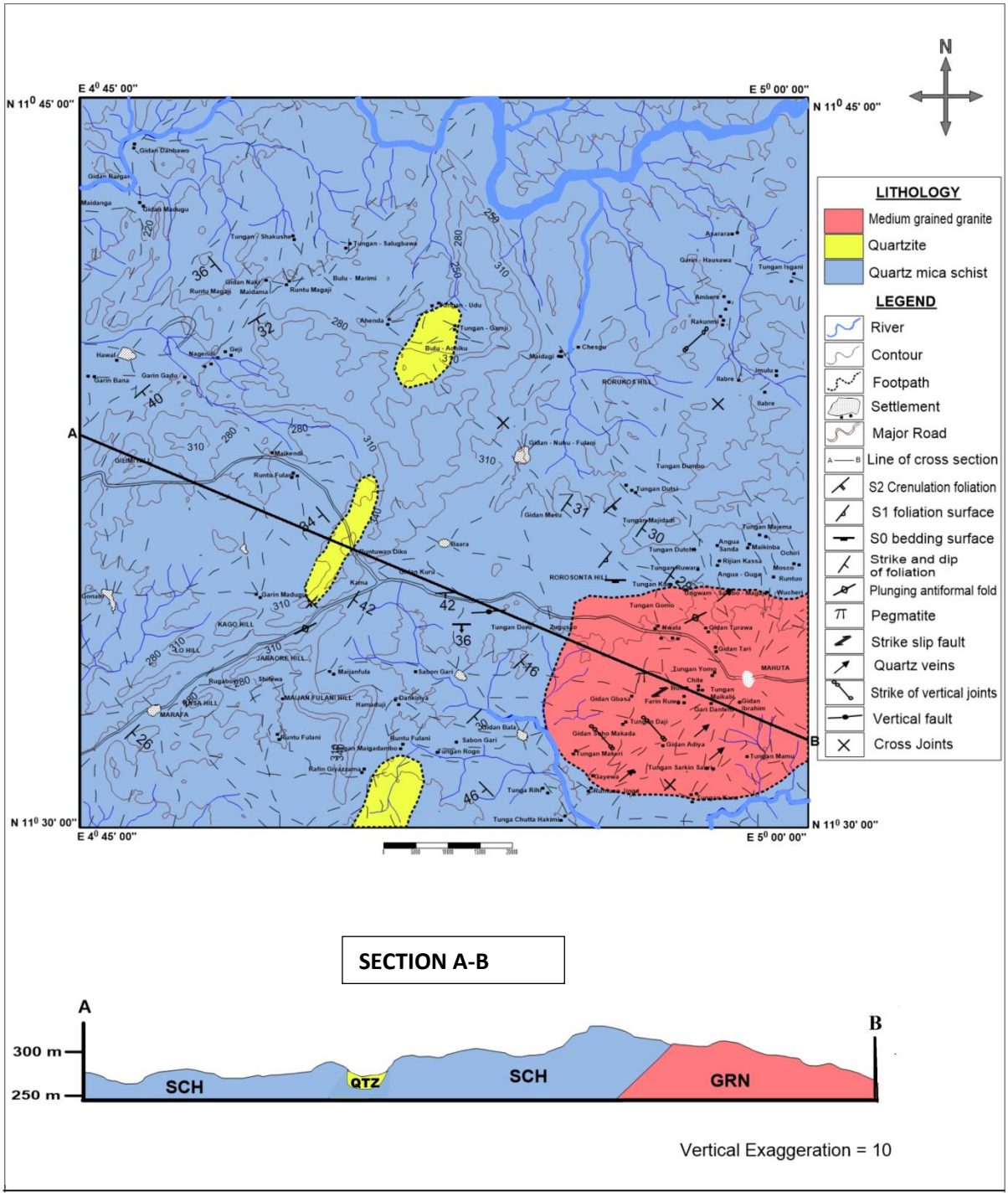


Figure 4.11: Geological map of the study area.

4.2.1 Quartz - Mica Schist (QMS)

4.2.1.1 Field Occurrence and Relationships

This is the dominant lithology in the study area covering about 70% of the map (figure 4.11). It occurs mostly as hills, poorly exposed in some areas, highly weathered, broken into pieces as slabs and boulders (Plate I). QMS vary in texture and colour from pink, light brown, reddish and dark brown. The ridges formed by quartz-mica schist dominate the study areawith an elevation of about 350m above the farmland level. The rocks are massive with prominent foliation (schistosity). The strike and dipmeasured on the quartz -mica schist varies greatly, from 006º-346º and 9º -52º. Sharp contact between the quarzt-mica schist and mica schist was encountered along Kamtu road (Plate II). The quartz- mica schist occurs with quartzite ridge along Mafara road (PlateXVI). The exposures of quartz -mica schist are jointed.



Plate I: Field occurrence of quartz-mica schist Along Garin Hausawa (11º32'25.7"N, 04º46' 55.7"E).

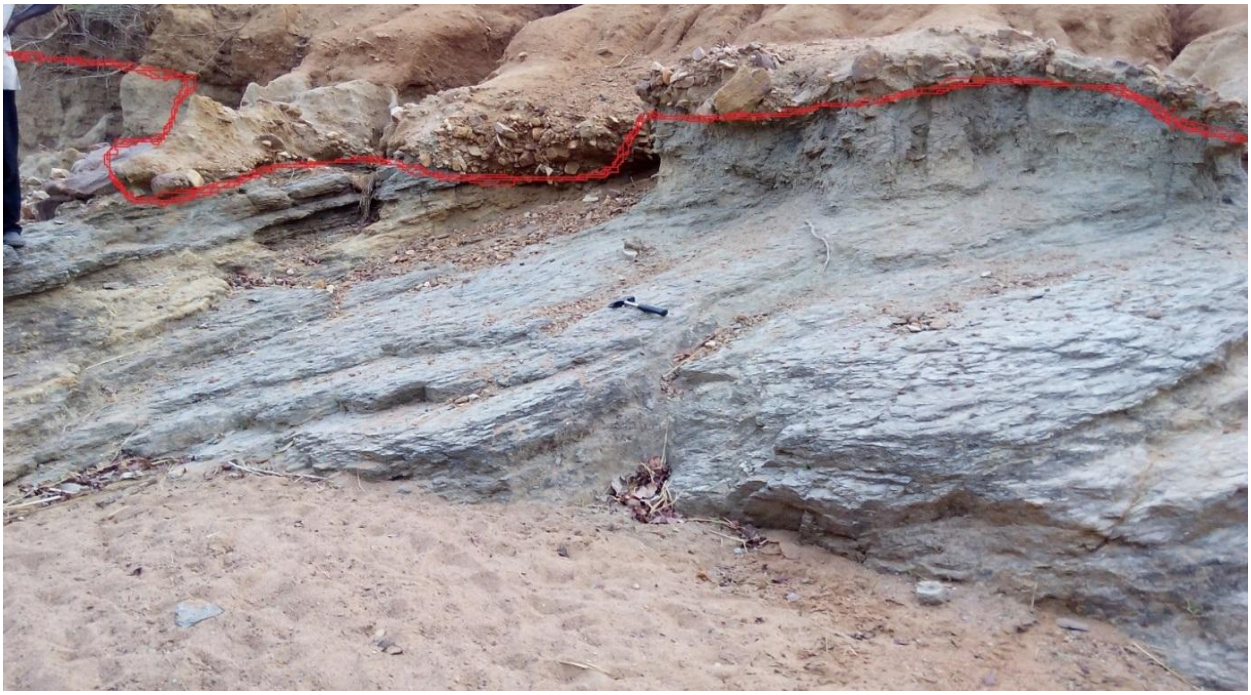


Plate II: Contact between quartz-mica schist and mica schist (11º 32' 28.9"N, 4º 46' 48.1"E).

4.2.1.2 Hand Specimen and Petrographic Description of Quartz-Mica Schist

A representative sample of quartz-mica schist obtained was described in terms of its texture, colour and possible mineral visible under hand lens. The quartz -mica schist in the study area varies in colour, but generally, a fresh sample is light in colour and medium grained in texture,foliations (Schistosity) on the quart-mica schist are defined by alignment of platy minerals (Plate III).Minerals identified using transmitted light microscopein plane polarized light (PPL) and cross polarized light (XPL) mode exhibited the following properties;quartz is colourless, non pleochroic, euhedral in shape and exhibits undulatory extinction, Muscovite is courless, non pleochroic, low relief and the interference colour changes from pink, blue to bright green and extinction is parallel.Opaque minerals appear dark in both plane polarize and cross polarized light (Plate IV and Plate V). The modal analysis of QMS is shown in table 4.5



Plate III: Hand Specimen of a quartz-mica schist (11º 36' 12.8"N, 04º 57' 40.4"E)

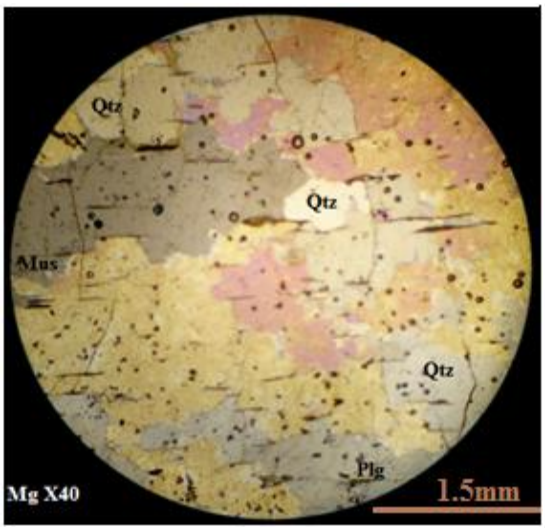


Plate IV: Photomicrograph of Quartz-mica schist in plane polarized light. Mus = Muscovite, Qtz = quartz, Plg = plagioclase (Slide MK 3).

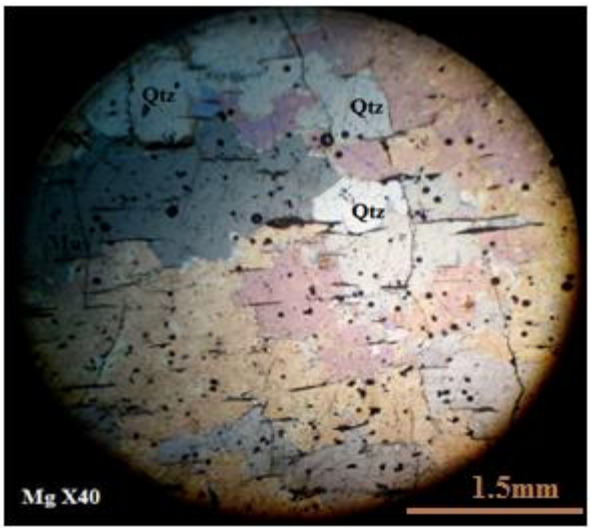


Plate V: Photomicrograph ofQuartz-mica schist in plane polarized light. Mus = Muscovite, Qtz = quartz, Plg = plagioclase (Slide MK 3).

Table 4.4: Visual estimate of minerals in Quartz-mica schist (Slide MK 3)

Minerals	**Composition (%)**
quartz	45
muscovite	30
plagioclase	20
Accessory	5

4.2.2Medium-grained Granite

4.2.2.1 Field Occurrence and Relationships

This is the second dominant lithology, covering about 15% of the study area in the southeastern portion of the map (Figure 4.11). The entire exposures occur in pockets, scattered about with an irregular outline, mostly between 1-1.2 meters above farmland level. They were encountered around Gidan tsohon makada village while few others are exposed along river channel. The granite along the river channel is highly weathered, intruded by discordant linear rock unit suspected to be an aplite dyke (XVII), the exposures along the river channels are highly jointed with the orientation of the joints parallel to the trend of the outcrop (Plate VII) while in other locations, the joint system are cross-cutting and irregular.



Plate VI: Field Occurrence of medium grained granite occurring north of Mahuta (11º 32' 09.8"N, 4º 55' 50.0"E).



Plate VII: Field occurrence of highly jointed granite along stream channel around Mahuta (11º33' 30.1" N, 4º5' 45.1"E).



Plate VIII: Relationship between rock unit (Medium-grained granite) and overburden thickness around Mahuta town (11º 32' 55.8" N, 4º 58'45.7"E)

4.2.2.2 Hand Specimen and Petrographic Description of Medium-grained Granite

Fresh sample of the granite obtained was described in terms of its texture, colour and possible minerals which were later confirmed using petrographic analysis. The granite is light in colour (Leucocratic). Feldspar formed the phynocryst with biotite and quartz constituting the groundmass. Minerals identified using transmitted light microscope in plane polarized light (PPL) and cross polarized light (XPL) mode exhibited the following properties;Quartz is colorless, euhedral in shape, undergo undulose extinction (polycrystalline). Orthoclase isanhedral to subhedral crystal, colourless with low relief in plane polarized light. It occurs as dark grey and a simple carlsbad twinning in cross polarized light.Plagioclase iscolourless, cleavage is perfect, non pleochroic, low relief and interference color (grey-white), with parallel extinction. Biotite; brown in colour, pleochroicwith perfect cleavage, moderate relief,

interference color of grey-brown- red- blue-green, Opeque mineral appeared dark under both plane polarized and cross polarized mode. Muscovite: colourless, non pleochroic, cleavage is perfect, relief is moderate-low, interference colour changes from blue, bright green and grey, extinction is parallel. (Plate IX and X). Modal analysis of medium grained granite is shown in shown table 4.6

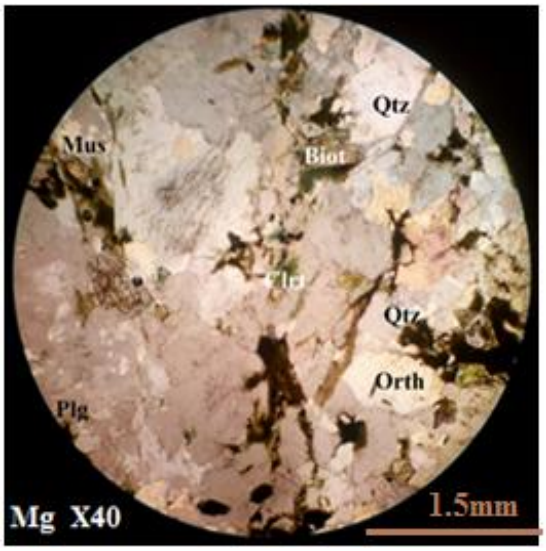


Plate IX: Photomicrograph of medium grained granite in plane polarized light. Mus=Muscovite, Qtz=quartz, Biot=Biotite, Plg=plagioclase, orth=orthoclase (Slide MK1).

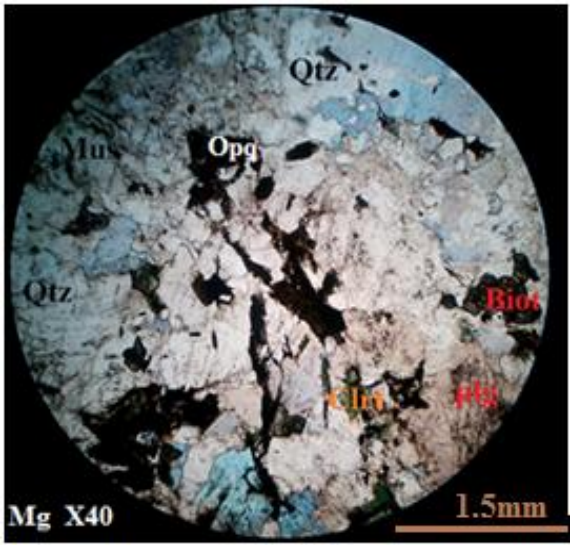


Plate X: Photomicrograph of medium grained granite in cross polarized light. Mus=muscovite, Qtz=quartz, Biot=biotite, Plg=plagioclase, Opq=Opeque (slide MK1)

Table 4.5: Visual estimate of minerals in coarse-grained granite (Slide MK1)

Minerals	**Composition (%)**
Orthoclase	35
Quartz	28

Plagioclase	24
Biotite	13

4.2.3Mica Schist (MS)

4.2.3.1 Field Occurrence of Mica Schist

The occurrence of mica schist in the study area is restricted to dug pits and river channels, it occupy less than 3% of the mapped area, directly north of granitic exposures. They lie below the quartz-mica schist with a very sharp contact between the two rock units (Plate II). From ant hills observed in the area, it is evident that the underlying rock below the quart-mica schist is Mica schist. At some locations, weathered garnet mineral appearing reddish-brown in colour with circular outline (1.5cm) occurs in the grand mass of mica schist (porphyroblastic), this is not large enough to be represented on the map (Plate XII). The exposure has an average dip of 16º-36º, striking in NW–SE direction. The surface of the mica schist is jointed, with joint direction parallel to the strike of the bed; quartz veins also intruded the mica schist at different locations with non-systematic orientation. The beds encountered are folded, having high density of joint.



Plate XI: Field occurrence of Mica schist (11º 35' 59.0" N, 4º55'38.4"E)



Plate XII: Field occurrence of Mica schist, containing weathered garnet (11º 32' 25.7"N, 04º 46' 55.7"E).

The overburden thickness around mica schist is estimated to be 3.5m.This was observed in a pit dug for local house construction around Gidan Fulani and this area is capped by a lateratized top

soil. Of all the occurrences of mica schist in the study, this area has the thickest overburden soil. (Plate XIII)

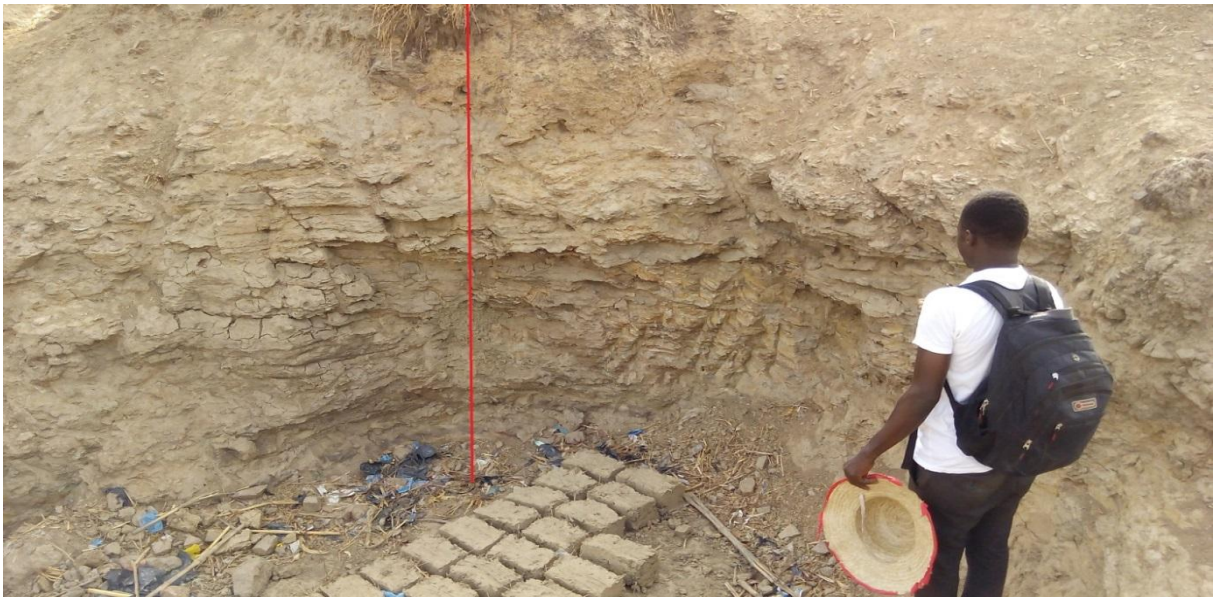


Plate XIII: Relationship between mica schist and overburdened thickness (11º 36' 17.1"N, 4º 56' 11.6"E.).

4.2.3.2 Hand Specimen and Petrographic Description of Mica Schist

A representative sample of mica schist is described in hand specimen in terms of its color, grained size, texture and visible minerals under hand lens. The rock has a tendency to split into layer parallel to the bedding plane with foliated structure (schistosity). The general appearance of the rock is light in color (Leucocratic) and fine grained. The minerals identified under a transmitted light microscope in (PPL) and (XPL) have the following properties: the general orientation of minerals in the field of view is foliated. Quartz is colourlessinPPL and XPL, non pleochroic and anhedral in shape. It has no cleavage but micro fractures occur parallel to foliation. The quartz exhibits undulatory extinction. Opaque mineral occur as dark spot. Muscovite appear colourless and non pleochroic, it has low relief with weak birefringence in XPL, but colourless under PPL. It exhibit small scale tartan twinning under the cross polarized light.biotite lacks well-developed crystals; it is anhedral to subhedral in form with perfect

cleavage. The mineral is pleochroic and has moderate relief when viewed under XPL. It shows interference colour from brown to pink, berifrengence is strong. (Plate XIV and Plate XV)

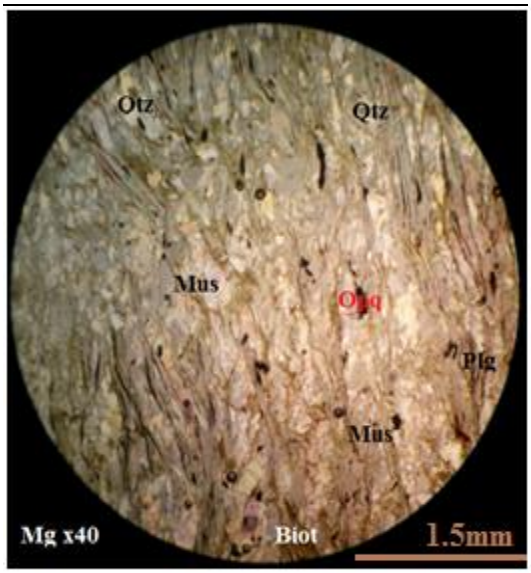


Plate XIV: Photomicrograph of a Mica schist in plane polarized light. Mus = Muscovite, Qtz = quartz, Biot = Biotite, Plg = plagioclase,Opq = Opeque (Slide MK 2).

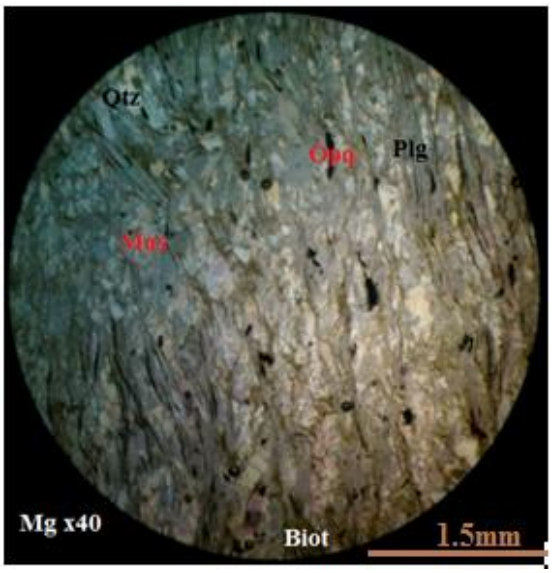


Plate XV: Photomicrograph of Mica schist in cross polarized light. Mus = Muscovite, Qtz = quartz, Biot = Biotite, Plg = plagioclase,Opq = Opeque (Slide MK 2).

ca schi

quartz	32
muscovite	27
biotite	25
plagioclase	12
Accessory	4

4.2.4Quartzite

4.2.4.1 Field Occurrence and Relationship

Quartzite in the study area occurs with quartz-mica schist. It is well exposed on ridges, having the same trend with quartz-mica schist, though the quartz-mica schist is jointed. The quartzite is highly jointed with most of the joint trending in NW-SE direction. The quartz-mica schist is weathered into slabs (Plate XVI).



Plate XVI: Field occurrence and relationship of quartzite and quartz-mica schist (11º 34'32.4" N, 04º 50' 04.5"E).

4.2.5 Minor Lithologies

Minor lithologies constitute about 2% of the study area which are; quartz veins, quartzofeldspathic pegmatite and aplitic dyke. Quartz veins occur mostly on the granite exposures and are widely distributed, with glassy texture and vary widely in length and width. The longest length recorded of quartz veins is about 20m (Plate XVII); the highest width recorded is about 5.2 cm. Measurements of orientation (trend) of the veins showed that they trend in NE-SW direction. Quartzofeldspathic pegmatite (Plate XVIII) shows large crystals of quartz and feldspars,the pegmatite range in thickness from 50 cm to 2m intruding the granites.

Aplitic dikes (Plate XVIII) intrude the granite discordantly, with an average width of 35cm.



Plate XVII: Photographs of quartz vien (a) and aplitic dyke (b) intruding the granitic rock discordantly around Mahuta town (11^0 33' 30.4"N, 004^0 58' 44.5"E).



Plate XVIII: Photograph of pegmatite around Mahuta town, with a width of about 2m, ($11^0$32' 55.8"N, and 4^0 58'45.7"E).

4.3 Structural Analysis

4.3.1Joints on Exposure of Granite

The joint sets on the exposure of medium grained granite in the study area are systematic (Plate XX), with their trends between 238º -309º, and near vertical dip of the joint surface (60º -72º), averagely 62º. The joints are widely spaced (SP3) (300mm-1m) apart, but mostly 0.5m apart; the joints are moderately to highly continuous (C3-C4) (5-10m) trace lengths. The joints are generally open i.e approximately 75% are open (O3), ranging in openness from (3-10mm), the remaining are slightly open to tight. Most joint surfaces are slightly rough (R4); the surface of the rock is moderately weathered appearing dark in colour. The readings of the joint trend in Appendix Iare recorded at different location (GR1, GR2, and GR3) on exposures of granite in the study area.



Plate XIX: Field description of joint on granitic exposure (SP3=widely spaced joint, MC=moderately continuous joint, 03=Open), (11º 31' 55.8"N, 4º 57' 14.9"E).

The plot in (Figure 4.12) below shows the trend of joint at different locations on exposure of granite at GR-1 and GR-2, the trend is dominantly NE-SW direction, while at GR-3 is NNE-SSW and NW-SE.

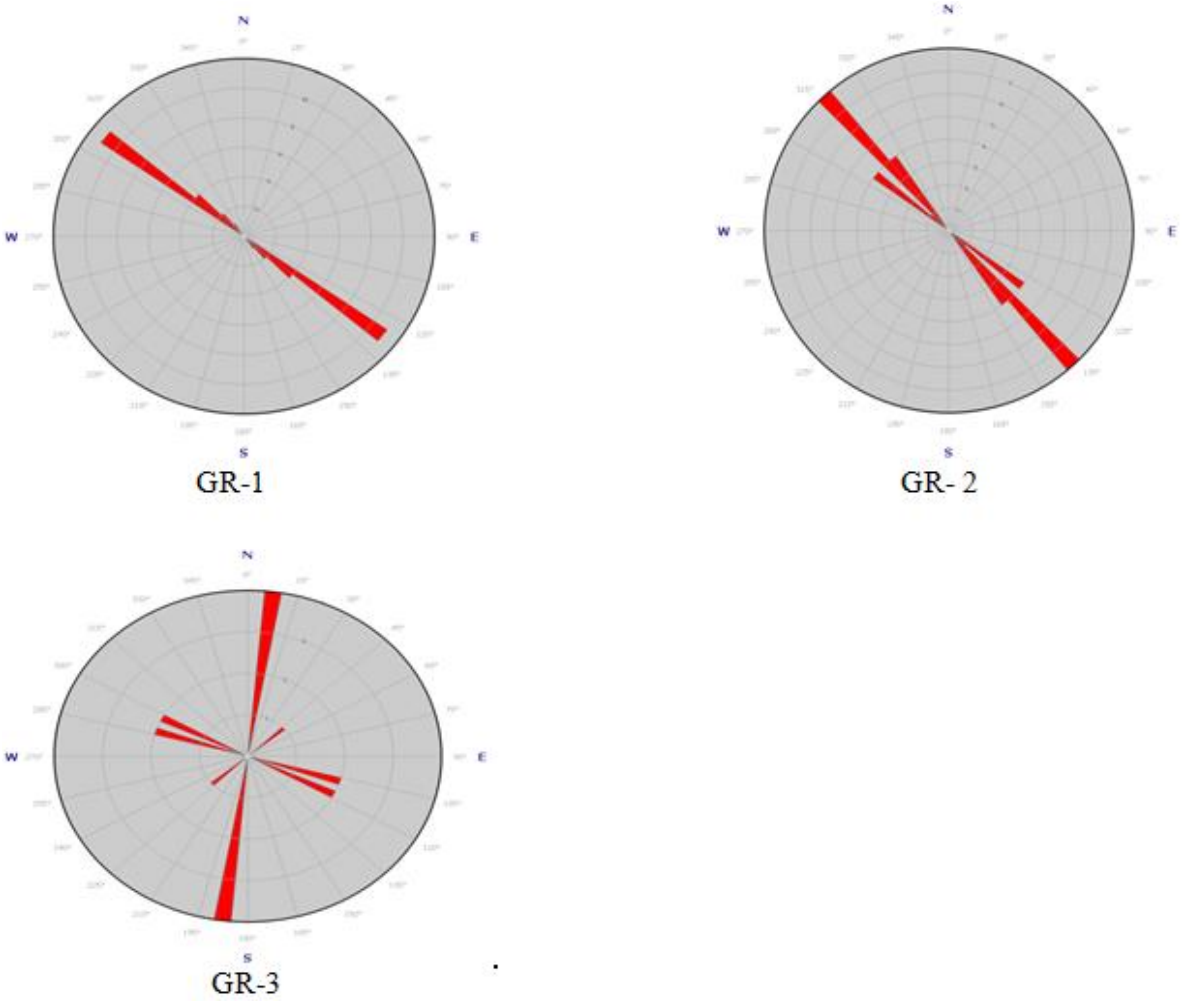


Figure 4.12: Rose diagrams of joint trends on granite exposures at location GR-1, GR-2, and GR-3).

The (Figure 4.13) show a stereographic projection of joint plane as pole, with most of the pole maintaining the same direction as the once in the rose diagram above (Figure 5.2), the poles are

clustered far away from the center of the net which indicate that the dip angle of joint plane is almost vertical.

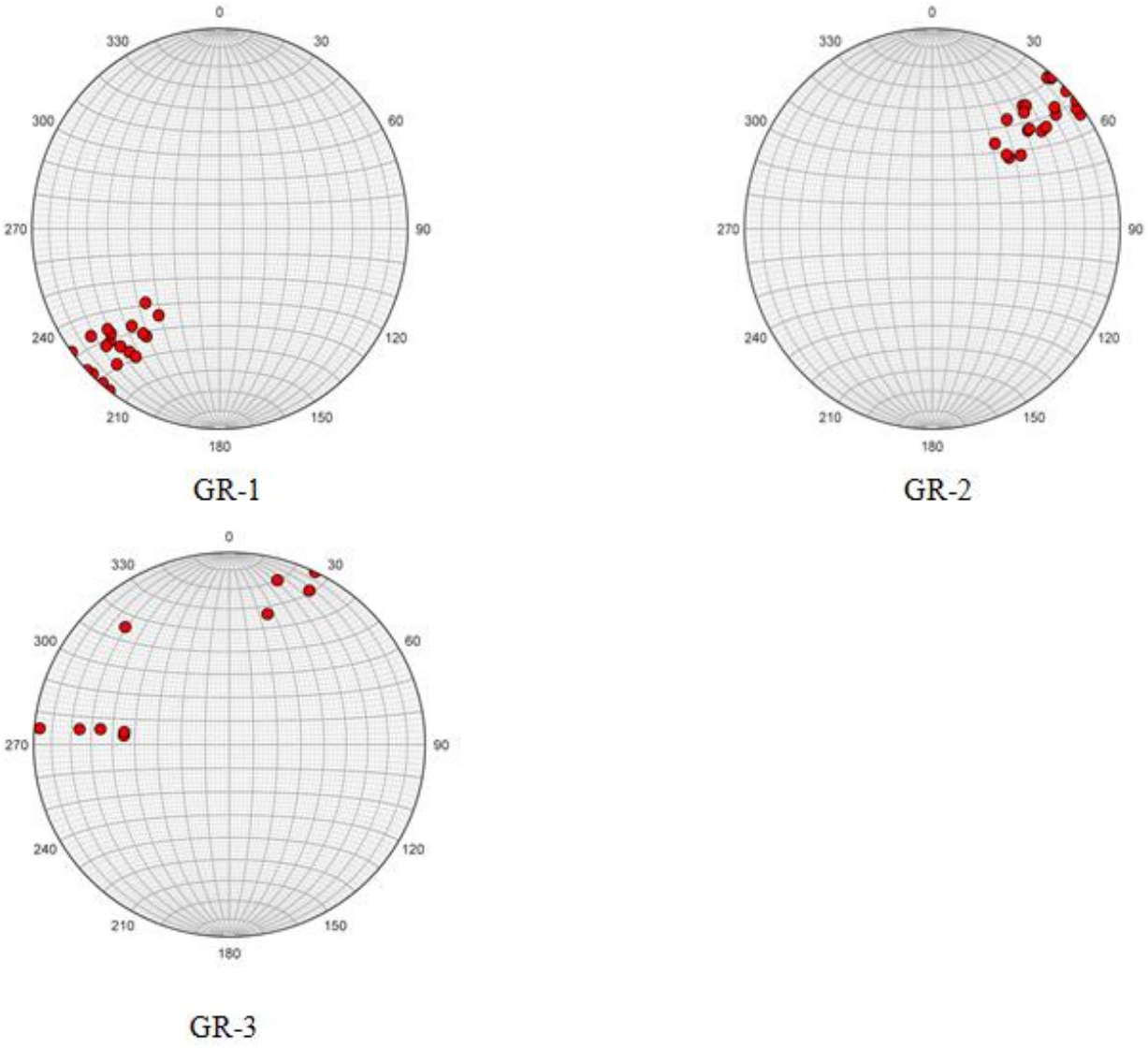


Figure 4.13: Equal-area lower hemisphere stereographic projection of joint plane as pole on granite exposure.

A total of 50 measurement of strike and dip of joints were recorded on exposures of medium grained granite during the field work exercise to get an overall orientation of the fracture on this particular lithologic unit in the study area. The pole of these planes have been plotted and

contoured (Figure 4.14 B andFigure 4.14 C) using the conventional technique (orient). The cumulative density plots show the pole of the fractures is concentrated in NE and SW sector (Figure 4.14 B), this confirms the dominant NW-SE trend of the fractures (Figure 4.14 A)while for each specific location wherethe readings were recorded, rose diagrams were plotted as shown in figure 4.12.

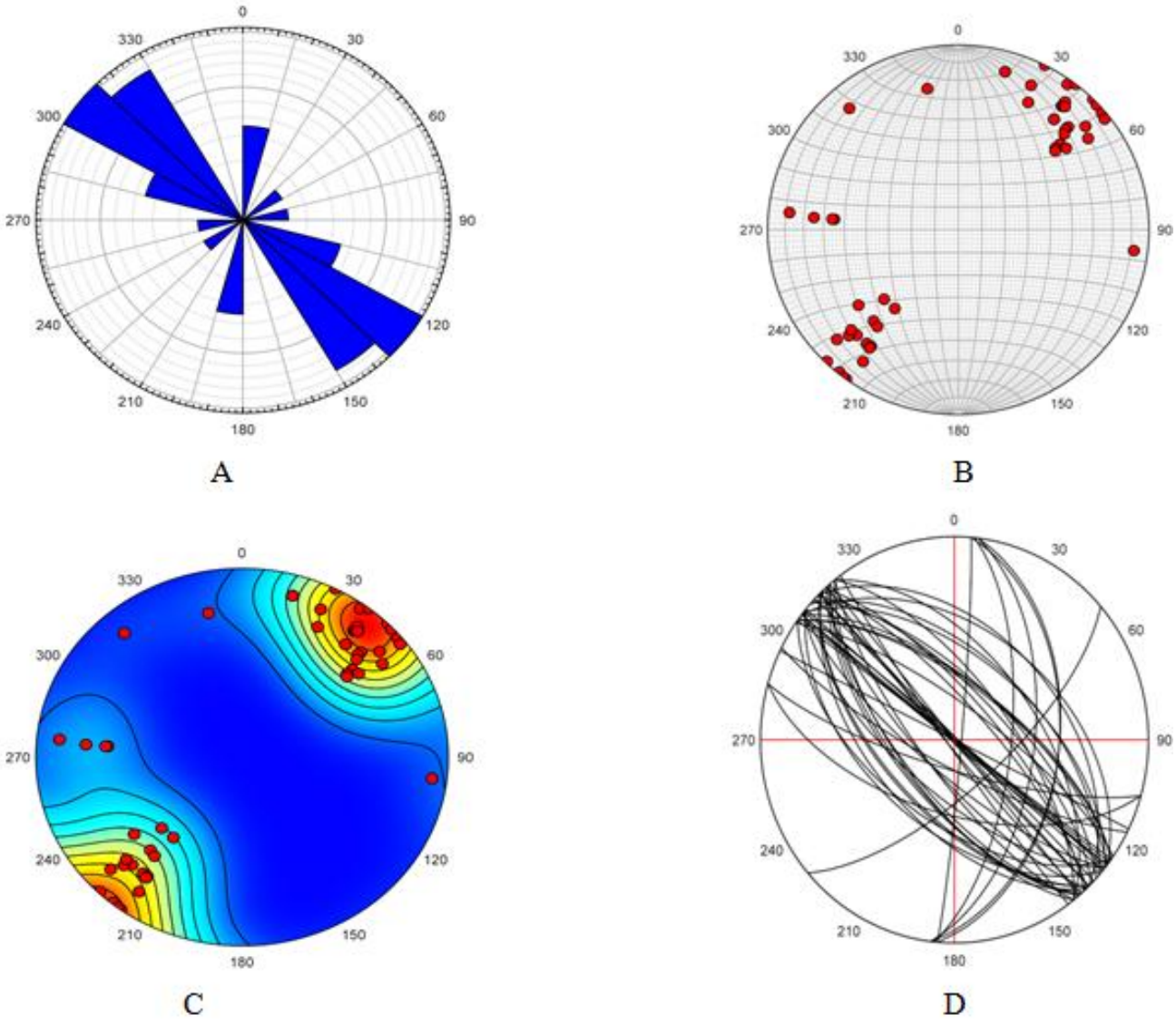


Figure 4.14: A-C)equal-area lower hemisphere stereographic projection of poles from fracture (joint) and density stereoplot (Schmidt lower hemisphere projection) for 50 point showing concentration in NE and SW portion (NW-SE trend), contours 2-4-6-8-10-12-14-16% per 1% area, maximum is 18%. **D**) Wulf net lower hemisphere stereoplots (beta-diagram) of fracture surfaces (joint)

4.3.2 Joints onQuartz-Mica Schist

This description is carried out on physical structural elements that arereal and tangible, they are known as the zone of weakness or joint. The joint set on the outcrop of quartz -mica schist in the study area are systematic; the joint type is known to be cross-strike joint, cutting perpendicular to the strike of the bed. The trend of the joint trace is between (182º -200º), with dip of the joint surface almost vertical (60º -80º), the joint is widely spaced (SP3) (1-3m) apart, but mostly 1.5m apart. The joints are continuous (C4). The joint is generally open i.e. approximately 90% are open, (O3) ranging in openness from (5-15mm), the joint surface is generally rough (R2). The outcrop is affected by physical and biological weathering. The Fractured surfaces (joints) are not healed nor cemented (Plate XX).

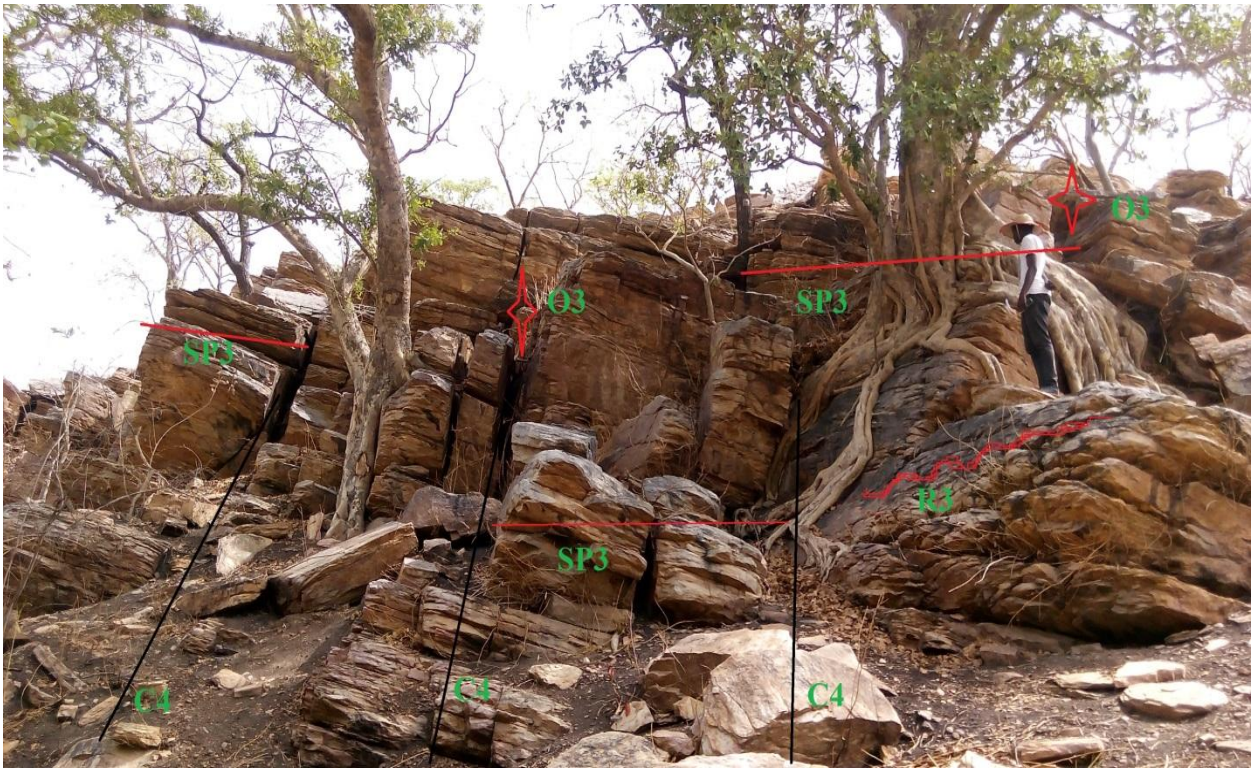


Plate XX: Field occurence of joint onoutcrop of quartz-mica schist (SP3=widely spaced joint, C4=Continuous joint, O3=Open joint, R3= rough joint surface.) (11º 39' 41.0"N, 04º 52' 7.4"E).

Table 4.7: Joint attitude recorded on exposures of quartz-mica schist.

Location ID	Joint trend	Dip of the joint plane	Joint array	Joint type
QMS-1	171º -200º	60º-70º	systematic	Cross-strike joint
QMS-2	212º -275º	50º-60º	systematic	Strike joint
QMS-3	4º -90º	60º-70º	systemati	Conjugate joint

The plot in (Figure 4.15) shows the trend of joints at different locations on exposure of quartz-mica schist in the study area,at location QMS-1 the dominant trend is NNE-SSW, at location QMS-2 the trend is dominantly NE-SW and E-W direction, while at QMC-3 is NE-SW.

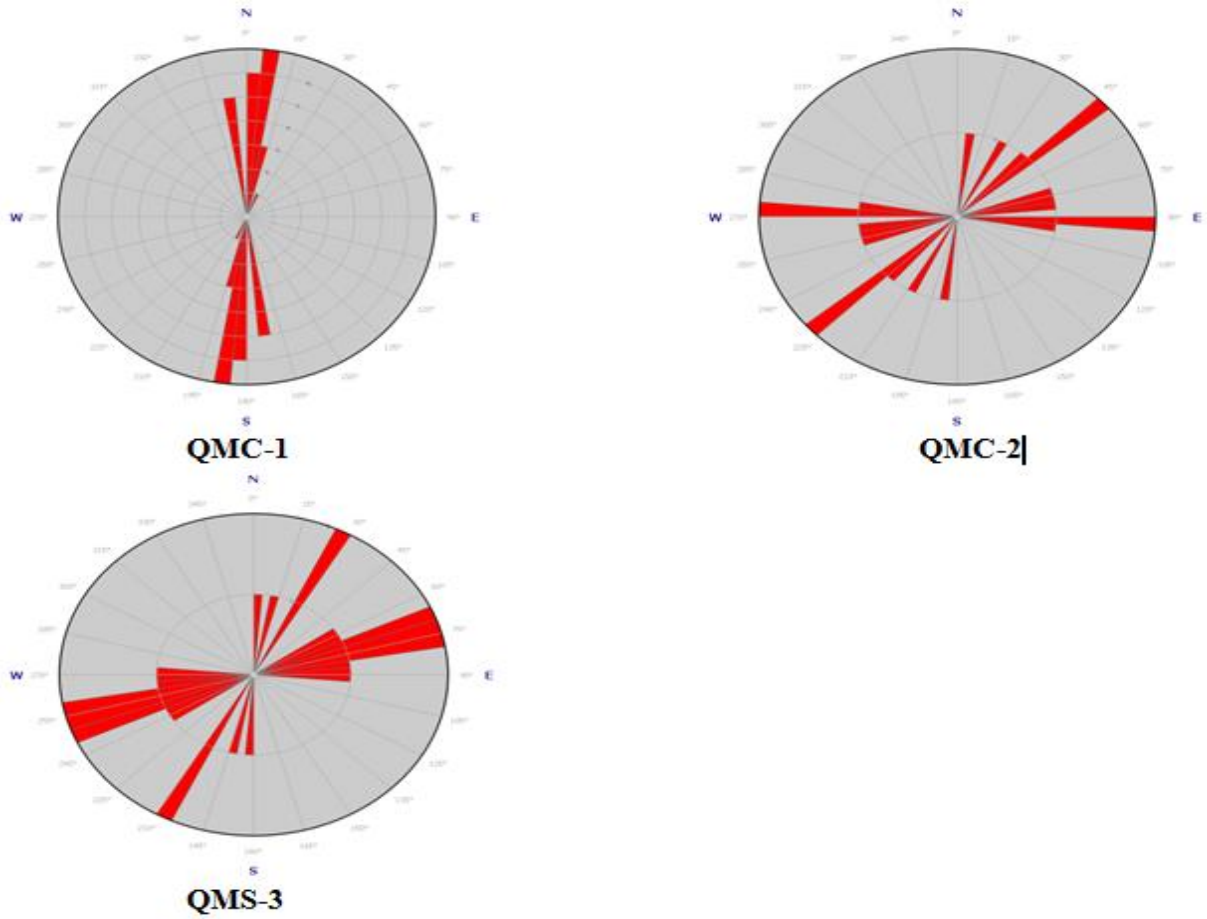


Figure 4.15: Rose diagrams of joint trends on Quartz-mica schist at three locations (QMS-1, QMS-2, and QMS-3).

Measurement of dip and strike of fracture surface (Table 4.8) was recorded during field work at three different locations QMS-1, QMS-2 and QMS-3. The pole ofthese fracture plane are plotted in figure 4.16, in QMS-1 the pole density are concentrated in eastern part, at location QMS-2 the pole concentrate in SSE while at QMS-3 the pole concentrate at NNW. The trend of the joint plane on these three plots conform to the once on the rose diagram above. (Figure 4.15)

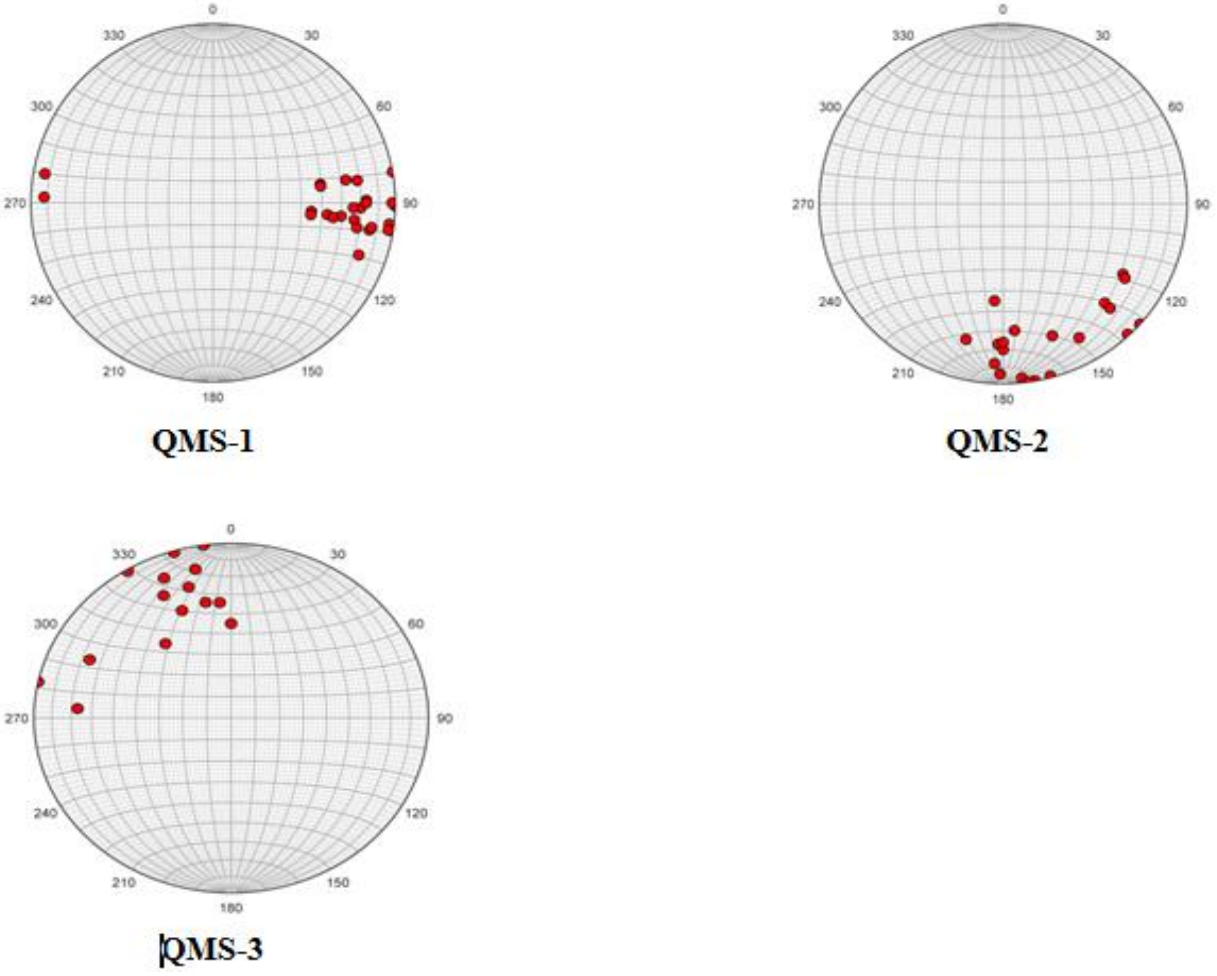
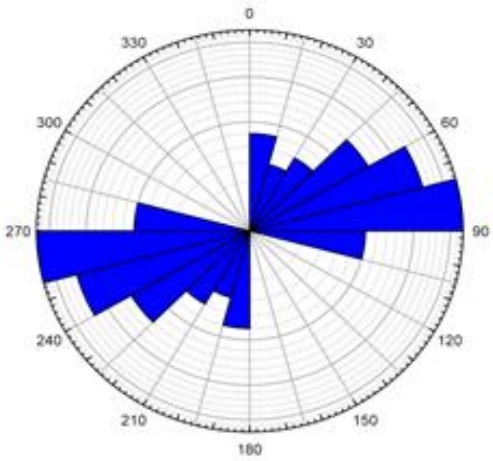
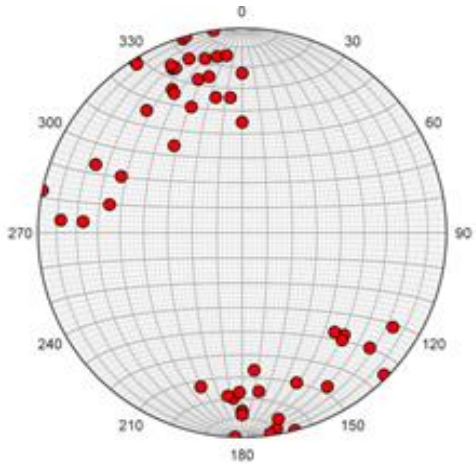


Figure 4.16: Equal-area lower hemisphere stereographic projection of joint plane as pole on quartz-mica schist

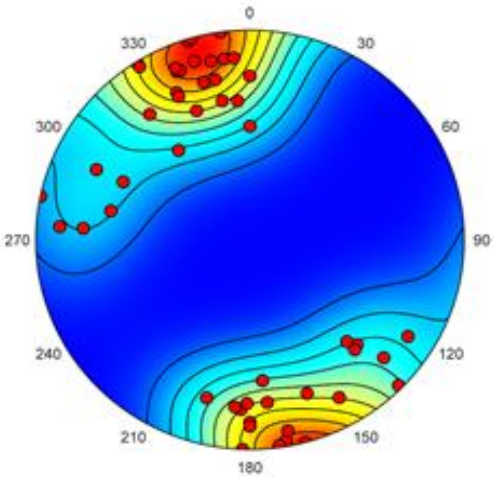
A total of 50 measurements of strike and dip of fracture plane (joints) were recorded on exposures of quartz-mica schist during the field work exercise to get an overall orientation of the fracture on this particular rock unit in the study area. The pole of these planes have been plotted and contoured (Figure 4.47) using the conventional technique (orient). The cumulative density plots shows the pole of the fractures is concentrated in NW and SE sector (Figure 4.47 B), confirming the dominant NE-SW trend of the fracture (Figure4.47 A) While for each specific location were the readings were recorded, rose diagrams are constructed as shown in figure 5.6



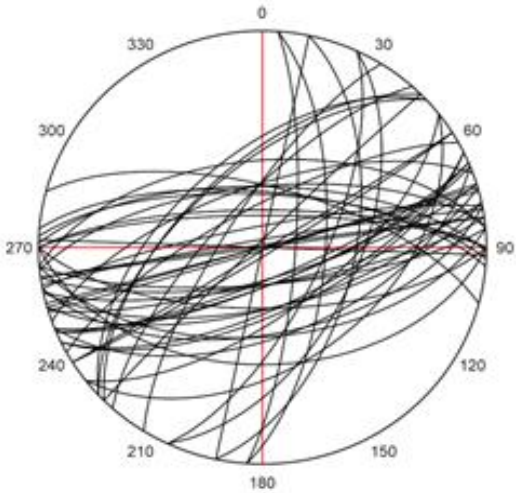
A.



B



C



D

Figure 4.17: (A-C)equal-area lower hemisphere stereographic projection of poles fracture (joint) and density stereoplot (Schmidt lower hemisphere projection) for 50 point showing concentration in NW and SE portion (NE-SW trend), contours 2-4-6-8-10-12-14-16% per 1% area, maximum is 18%. **D**) Wulf net lower hemisphere steroplots (beta- diagram) of fracture surfaces (joint).

4.3.3Faults on Exposures of Granite

The exposures of granitic rock in the study area are moderately faulted evident by the displacement of quartz veins and aplitic dykes. The faults exist at mesoscopic scale of observation. The faults encountered are strike slip fault (dextral) with a horizontal displacement of key marker elements. The fault planes are oriented in NW-SE direction, with the strike of the plane ranging between (126º -136º), the magnitude of displacement range between (11cm-70cm). The sense of displacement is to right (Dextral) hand side for the entire strike slip faults on the granitic exposures (Plate XXI and Plate XXII). The nature of the fault planes has no any evidence of reactivation parallel to its length.The faults are "tear faults" which are relatively small scale local strike slip fault subsidiary to other large scale structures such as fold, thrust fault or normal fault. In this case, the structures are suspected to be normal fault evident from linear stream channels along which the tear faults were encountered. The table 4.6 below summarized the description of fault attitude recorded on field.

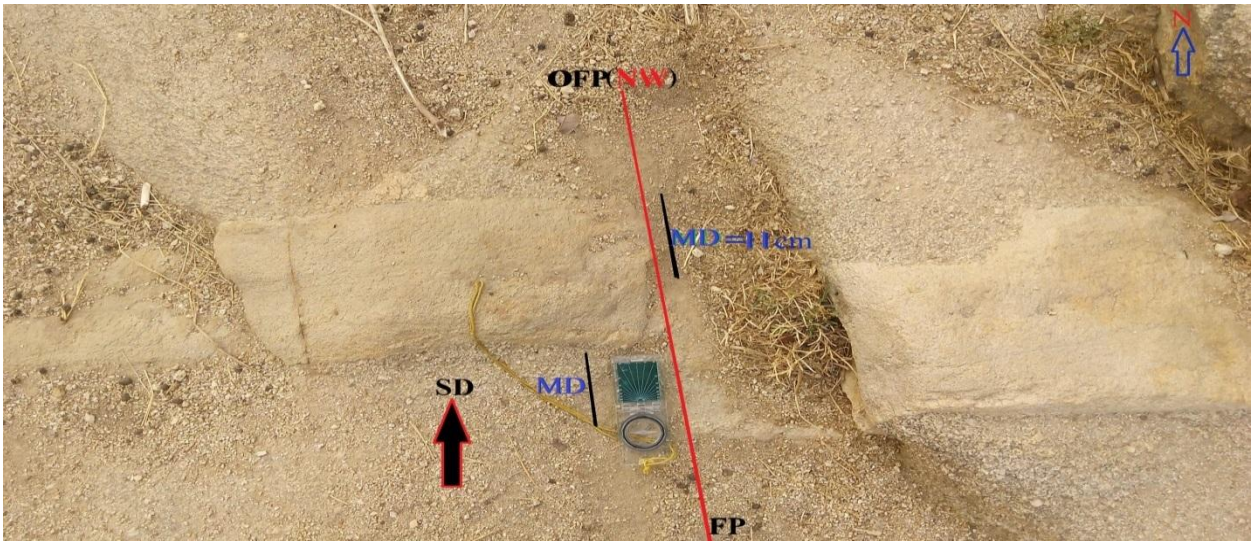


Plate XXI: Field description of dextral fault on granite (OFP=Orientation of fault plane, MD=Magnitude of displacement, FP= fault plane, SD=Sense of displacement) (11º 32'55.8"N, 4º 58' 45.7"E).

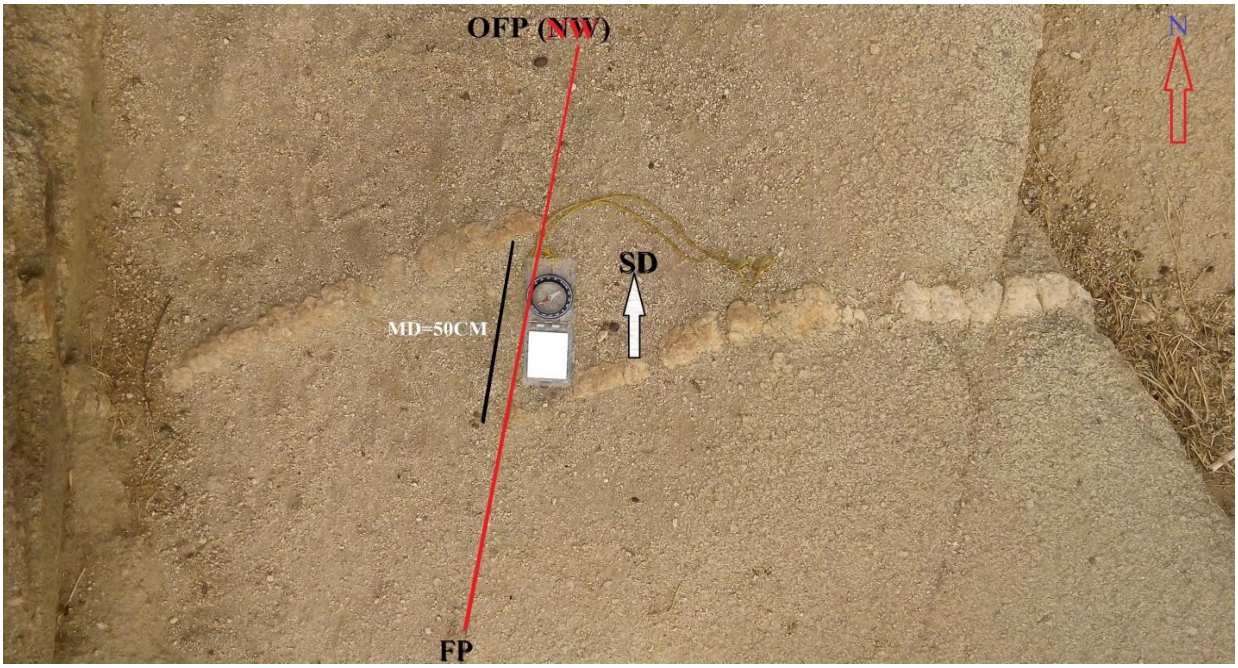


Plate XXII: Field description of dextral fault on granite (OFP=Orientation of fault plane, MD=Magnitude of displacement, FP= fault plane, SD=Sense of displacement)(11º 32' 53.8"N, 4º 58' 40.7E").

The general orientation of the fault plane along which displacement occurred has been plotted (Figure 4.18). This shows that the fault plane is generally oriented in NW-SE direction, while the red line in the middle shows the mean orientation of the fault plane. The orientation corresponds with trend of joints on granitic exposures.

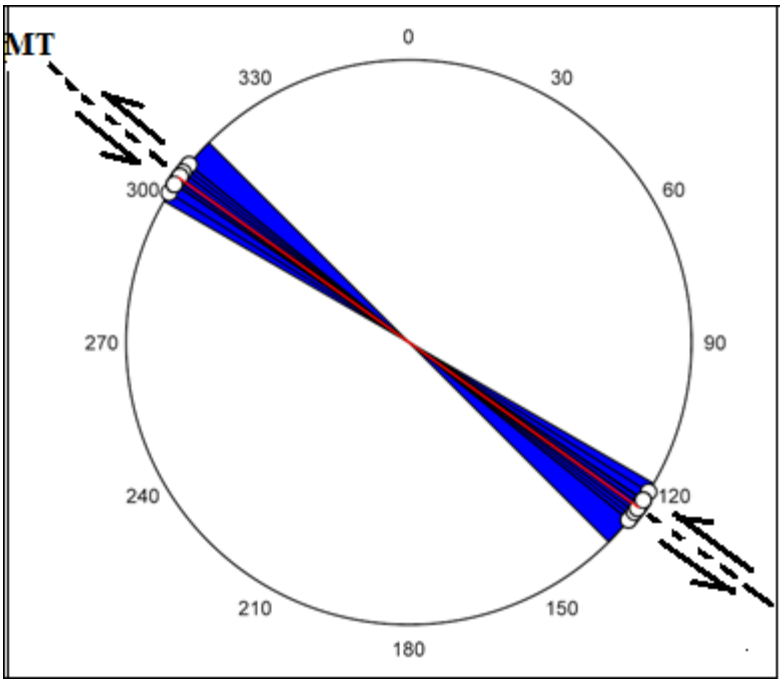


Figure 4.18: Lower hemisphere equal area projection circular plot of fault plane on granitic exposures, MT indicating the mean trend of strike-slip fault plane.

4.3.4 Faults on Exposures of Quartz-Mica Schists

The faults recognized on the exposure of quartz-mica schist are exposed by a road-cut and are mesoscopic in scale. The faults are dip-slip faults, and are described as formed by the displacement of horizontal layers of quartz- mica schists along the fault planes. The slip vector is parallel to the fault plane. The magnitude of the slip vector is 305cm. the dip of the fault plane ranges between 43º -35º, the horizontal angle formed between the off-set layer and the fault plane is averagely 135º, the fault planes are partially healed and slightly continuous in extent (Plate XXIII and Plate XXIV).

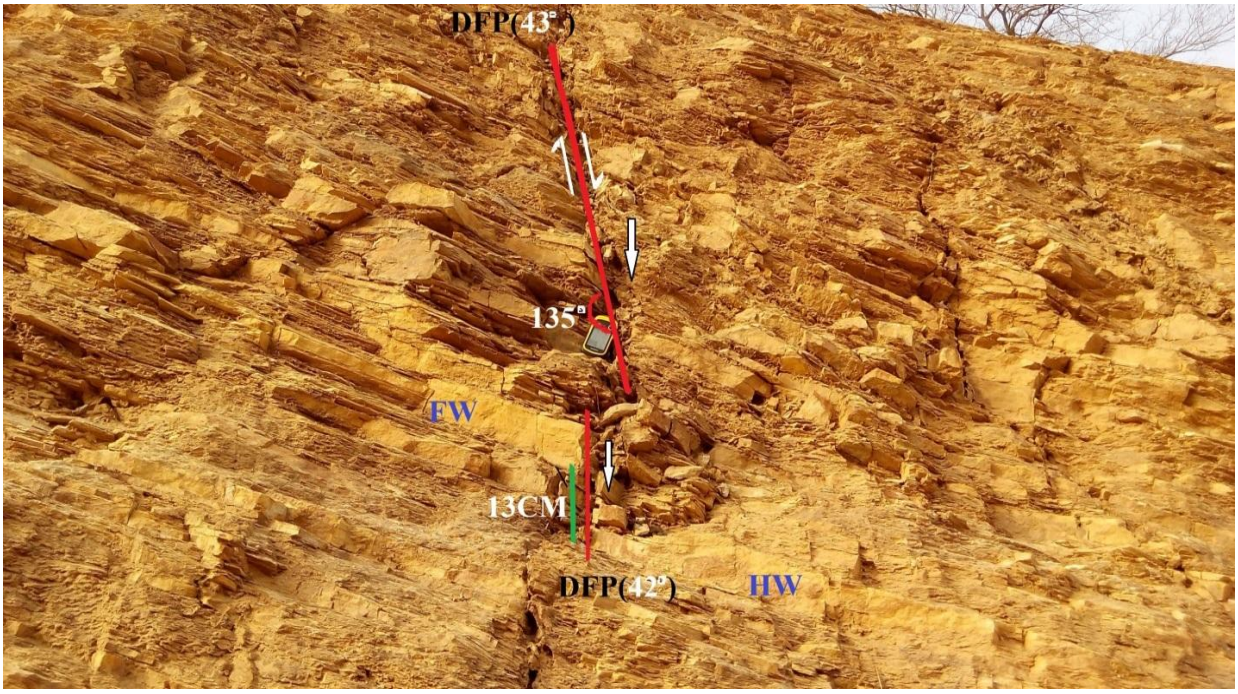


PLATE XXIII: Field occurrence of normal fault on exposure of quartz-mica schist (DPF=Dip of the fault plane, FW=footwall, HW=hanging wall) (11º32'57.3"N, E4º 58' 40.6"E)

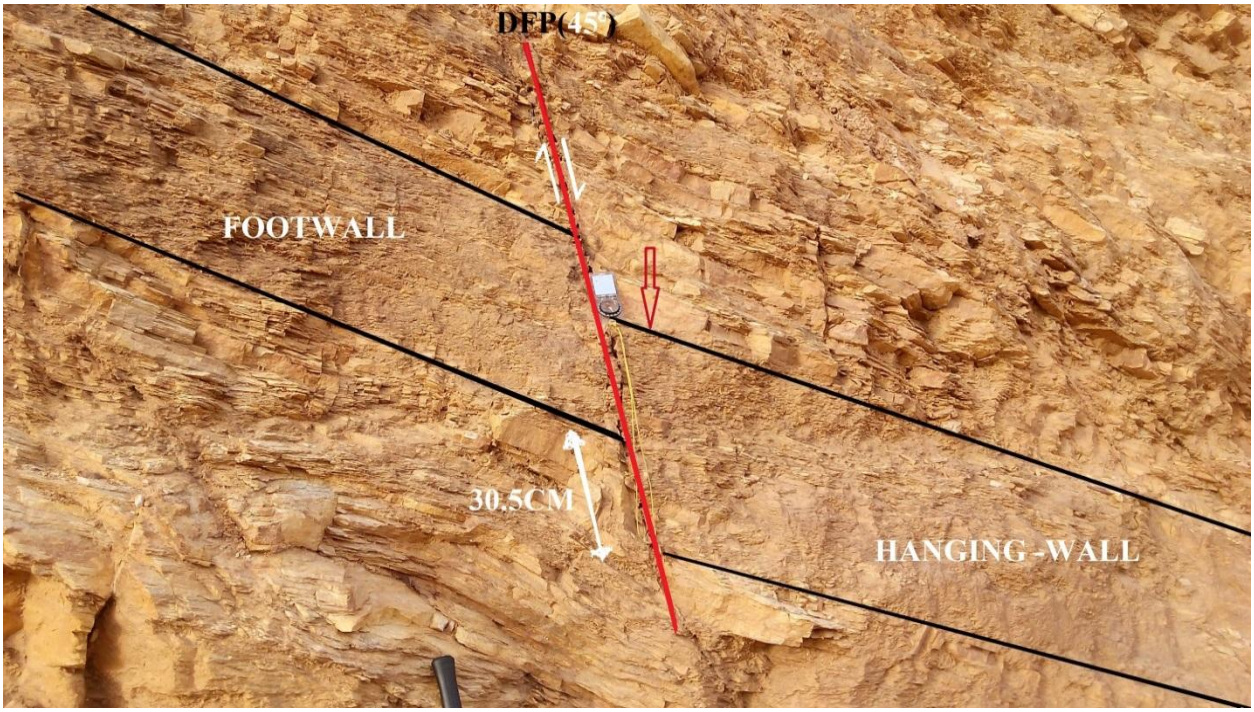


Plate XXIV: Field occurrence of normal fault on exposure of a quartz-mica schist (DPF=Dip of the fault plane, FW=footwall, HW=hanging wall) (11º32'45.1"N, 4 º 58'49.7"E).

4.3.4.1 Geometry of Coaxial Normal Fault in a Stratified Rock

4.3.4.1.1 Co-axial Normal Fault on quartz-mica schist

A number of properties can be used to describe the cross-sectional geometry of coaxial faults in stratified rocks. None are scale-dependent, but illustrations are particularly applicable to mesoscale relationships at individual outcrops. The ensuing discussion will assume a vertical fault profile plane however the same concepts apply regardless of the dip of this plane.The most common and useful two-fold subdivision ofdip-slip faults is based on their horizontal tectoniceffects. Does the fault lengthen or shorten?With reference to the fault in the study area,the fault lengthened the horizontal datum as shown in(Plate XXIII and Plate XXIV) and (Figure 4.19A).

Dip-slip faulting can have one of three stratigraphic effects: i) older over younger (repetition of section); ii) younger over older (omission of section); and iii) normal stratigraphic order (neutral section). Thethird is not always a trivial case; rather, a common type of fault is stratigraphically neutral. The fault on quartz-mica schist in the study area exhibits the stratigraphic effect in the third category (Figure 4.19).

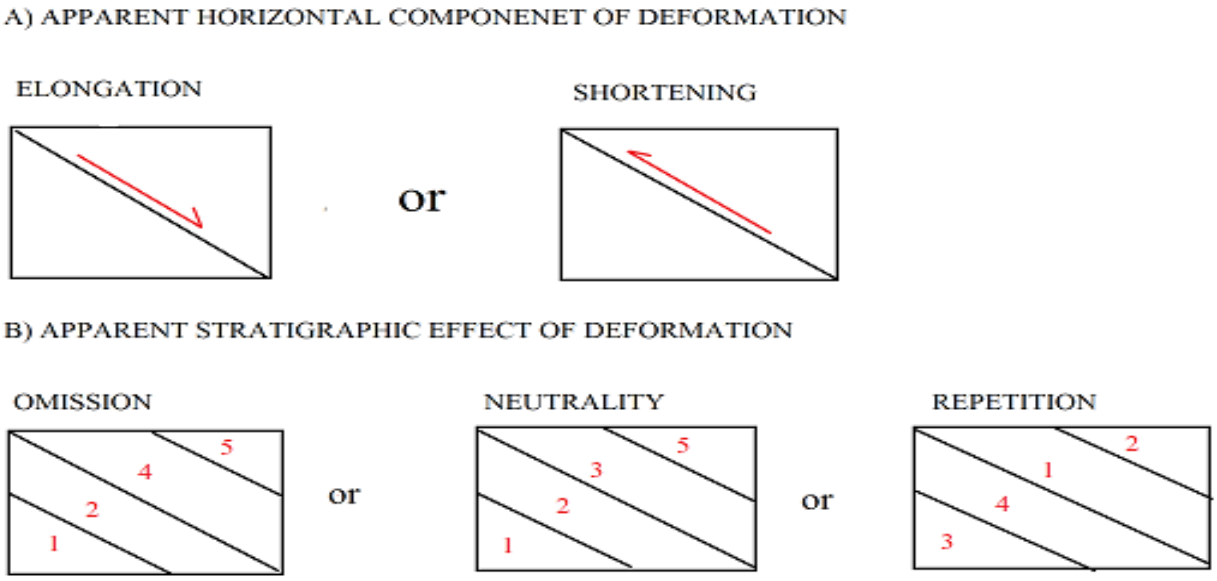


Figure 4.19: Variables used in description of dip-slip faults. 'Repetition"includes all possible variations on old-over-young at a given point onthe fault. Strata are numbered by relative age, starting with l at thebase.

4.3.4.1.2Tectonic polarity

In contractional and extensional terranes with a consistentregional tectonic transport direction, faults canbe classed as either synthetic (displacement in agreementwith the regional direction) or antithetic (displacementin the opposite direction). In the case of deformedfaults, the original polarity may be obscure. Accordingly,faults are more objectively described as rightdippingor left-dipping (Figure4.20), one of the original dip direction being synthetic, the other antithetic. The faults in Plate XXIII and Plate XXIV have right- dipping fault planes and are synthetic.

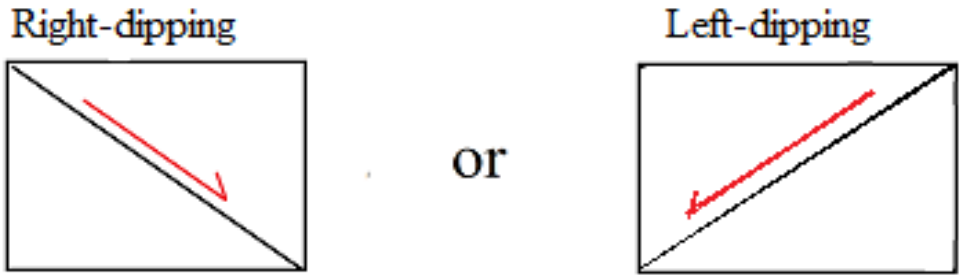


Figure 4.20: Right-dipping, left- dipping, synthetic andanthetic fault.

Hypothetically, we can describe a relationship between the foot wall block, hanging wall block, and fault plane using the stereographic projection method. This is mostly derived from modeling of normal fault in laboratory, this give a geometrical relationship between FWB, HWB and FP are arrange along E-W cross section-section of north striking coaxial fault. Figure 4.21 below show the relationship.

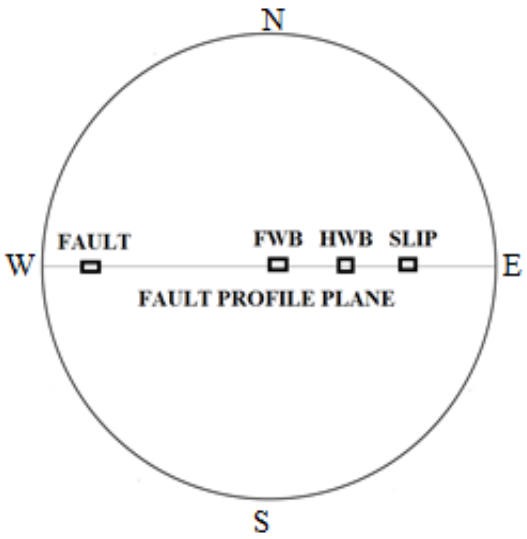


Figure 4.21: Hypothetical E-W cross-sections of N-striking coaxial faults synthetic (right-dipping), Corresponding stereographic projections show that poles to footwall block (FWB)and hangingwall block (HWB) bedding lie in the plane defined by the pole to the fault and the slip vector.

4.3.4.1.3 Stereographic Projection of Fault Plane and Bedding of Normal Fault

The attitude of fault component measure on the exposure of quartz-mica schist (PlateXXIII and Plate XXIV), show that the fault plane strike N45ºE, with a dip of 43º while the bed dip 37º, striking N320ºW. The stereographic projection of the faultcomponents shows the orientation in space and angular relationship between the fault plane and bed is 30º measured in the direction

of the slip. The rose diagrams and stereoplots (Figure 4.23) portray the various descriptions of the fault plane and assumed slip line. The dip angel of the planes is shown in figure 4.22A, strike of the fault plane is shown in figure 4.22B, stereonet of the fault plane as a line is shown in figure 4.22C, the plunge of the plane is the same as that of the line as shown figure 4.22 D, azimuth of the lines 4.22 E and the stereonet of the lines as a point is shown in figure 4.22 F respectively.

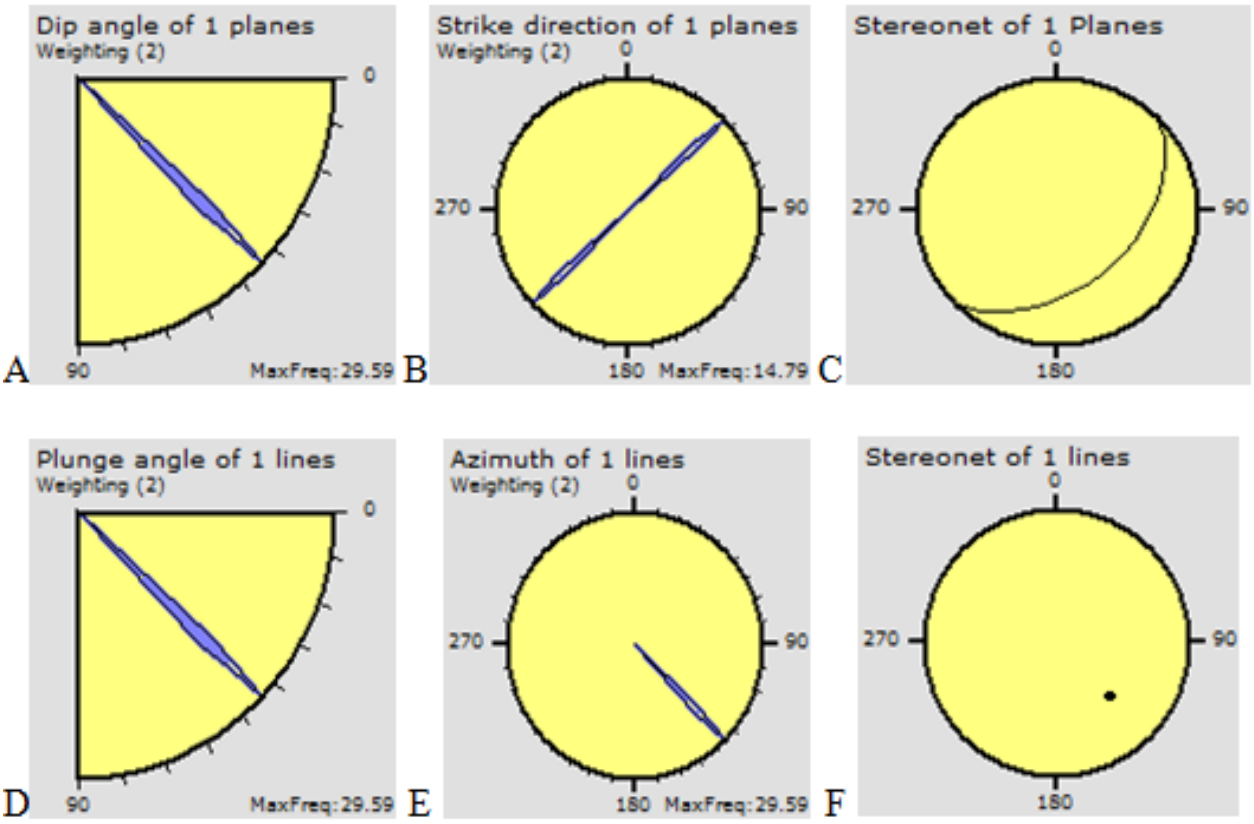


Figure 4.22 A-F: Stereographic description of fault plane and line.

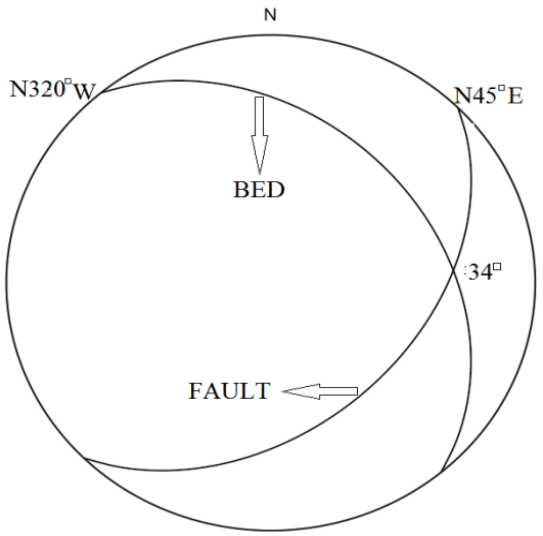


Figure 4.23: Equal-area plot of fault plane and bedding (Plate XXV) showing the relationship between bed and fault plane.

4.3.5 Dynamic Analysis of Brittle Structures

4.3.5.1 Preamble

The goals of dynamic analysis in the field of structural geology are subdivided into three, but the first two are the once determined in this research work:

i) Determine the orientation offorces that brings about deformation in rocks.

ii) Relate forces to tectonic evolution of deformedterranes

iii) Determine the mechanical factors in earthmaterials that favor/disfavor deformation.

4.3.5.2 Dynamics of Orthogonal joints on exposure of Medium-grained Granite

Joints are fractures formed as consequences of deformation of brittle rock masses in the earth's crust (Engelder, 1987; Pollar and Aydin, 1988). They are sensitive indicators of the paleo stress field and can be used to infer the orientation of the regional stress field along with its temporal

evolution (e.g Engelder and Geiser, 1988; Olson and Pollard, 1989).



Plate XXV: Orthogonal cross joint (OJ) at different length that developed in between systematic joints (SJ).(11º 31' 55.8"N, 4º 57' 14.9"E).

4.3.5.3 Models for the Formation of Orthogonal Cross Joint

The opening-mode fracture in isotropic and homogeneous materials propagate in the direction perpendicular to the local maximum tensile stress or least compressive stress if fluid drives the fracturing (Pollard and Segall, 1987; Pollard and Aydin, 1988), a local stress rotation of 90º is needed for orthogonal cross joints to form after the formation of the systematic joints. This stress rotation may be induced by either local or regional mechanisms. The proposed local mechanismsin geologicalliterature are; rock band warping (Granier and Bless, 1988), stress release under biaxial extension (Simon et al., 1988) while regional mechanisms are; Visco – elastic relaxation (Rives and Petit, 1990; Rives et al., 1994) and regional principal stress rotation (Eyal and Reches, 1983; Hancock et al., 1987; Bahat and Grossman, 1988; Dunne and North, 1990; Eyal, 1996).

The observation made on the orthogonal joint on the exposure of granite rock in the study area (Plate XXV) indicates a widely spaced and narrowly spaced systematic joint (SJ). The orthogonal jointing does not appear selectively between the pair of systematic joints, rather they intersect both the widely and narrowly spaced systematic joints. It can be concluded that a tectonic stress rotation of 90º is a possible interpretation for the formation of the orthogonal joint. (Engelder and Gross, 1993; Mollema and Antonellini 1999).

Evaluations from other mesostructures such as ptygmatic fold shows that the fold axial plane of symmetrical folds are oriented perpendicular to the systematic joint i.e having the same trend (NE-SW) with the orthogonal joints (Plate XXVI and Plate XXVII).

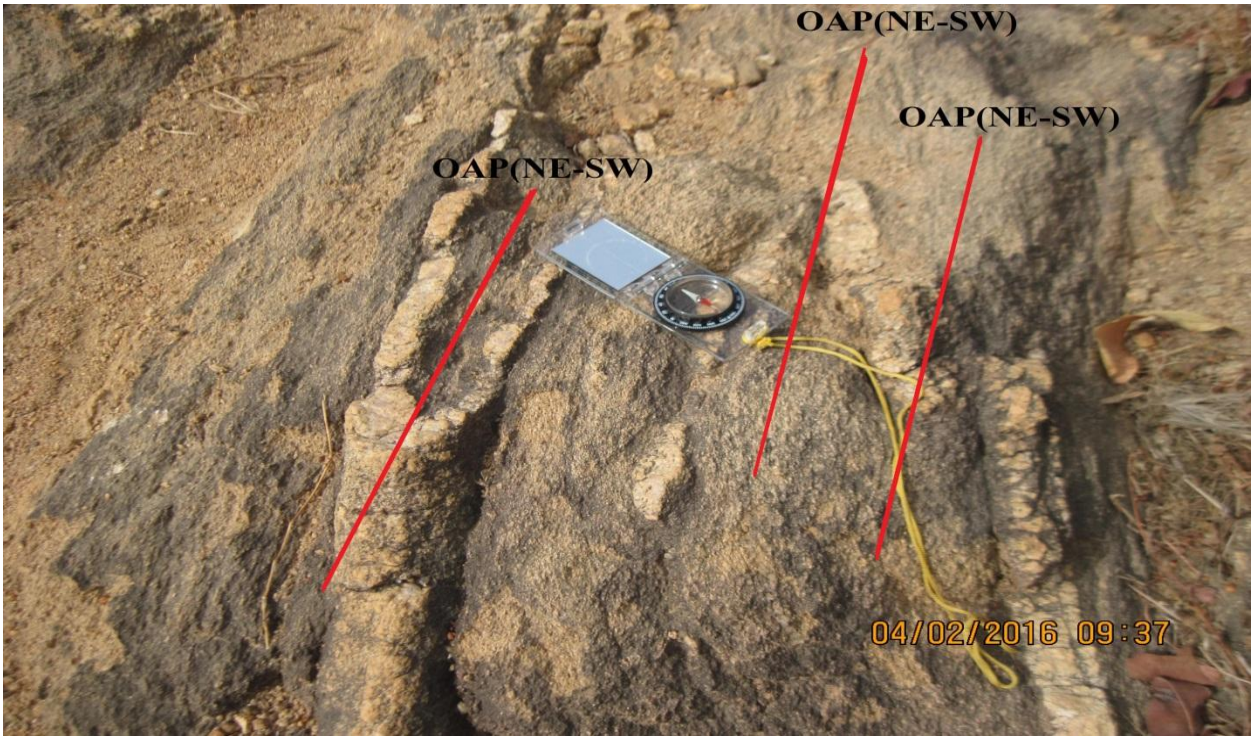


Plate XXVI: Ptygmatic fold with orientation of the axial plane (OAP) of the fold. (11° 31' 55.8"N, 4° 57' 14.7"E).

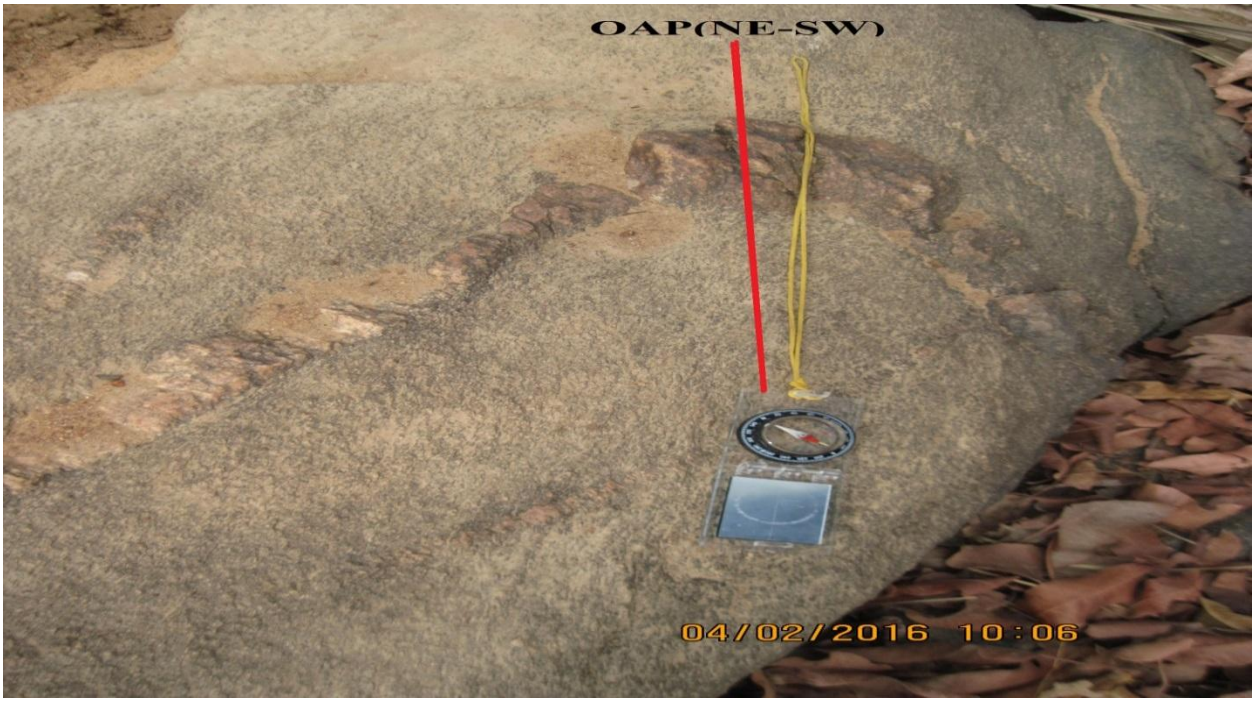


Plate XXVII: Ptygmatic fold with orientation of the axial plane (OAP) of the fold. (11°31' 50"N, 4°57' 11"E).

The conceptual model for the formation of orthogonal joints (Plate XXV) is the regional stress model, which suggests that the OJ is formed due to horizontal local stresses (σ1 and σ2) rotating through an angle of approximately 90º. Figure 5.14 below highlights the various stages in the model.

The common interpretation is that orthogonal cross joint defines the orientation of the regional stress field during their formation: least compressive stress (σ3) perpendicular to the joints. It follows that they indicate a rotation of regional principal stresses by 90º after the formation of systematic joints.

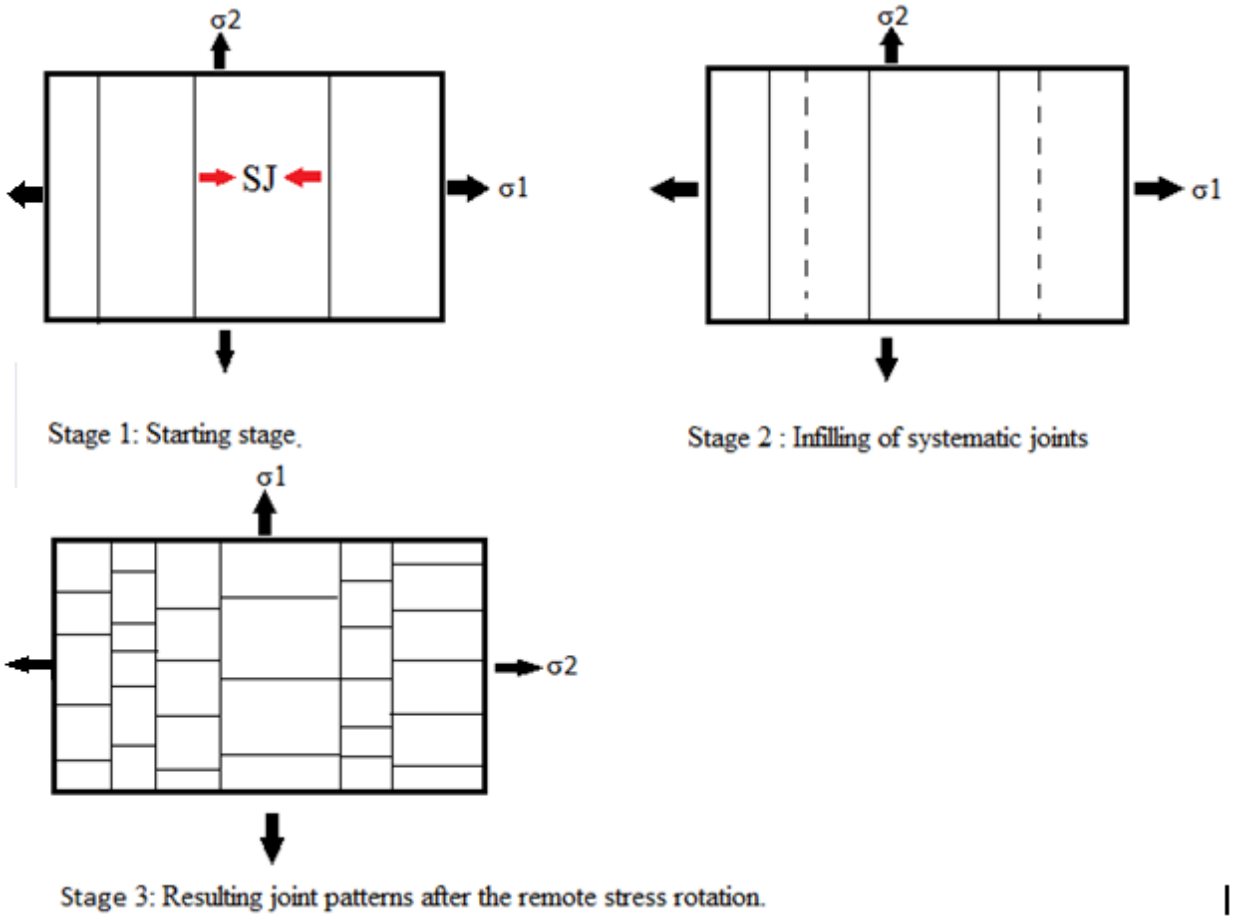


Figure 4.24: Schematic representation of model that suggests the development of orthogonal cross joints. (Stress rotational model) in the study area.

The relationship between the systematic joint (SJ), orthogonal joint (OJ) and orientation of axial plane (OAP) are shown in the cumulative rose diagram in figure 5.15. The trends of these three structures on the exposure of granite in the study area are oriented at 90º to one another this is typical characteristic of (+) joint.

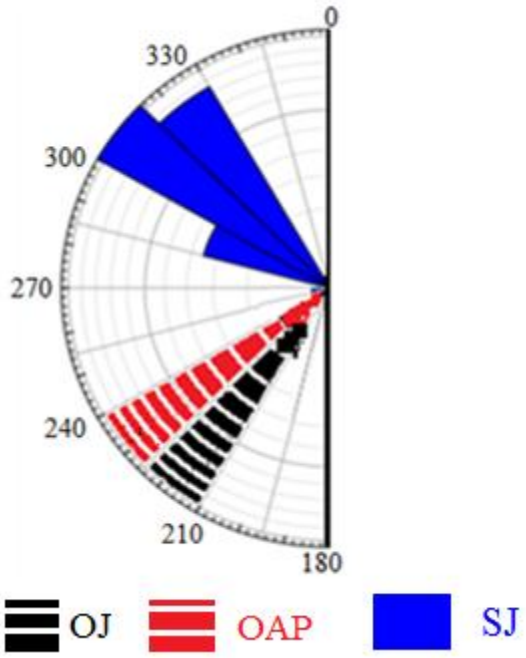


Figure 4.25: Cumulative rose diagram of major structures on granitic exposures (OJ=Orthogonal jointing, OAP=Orientation of the axial plane of ptygmatitic fold, SJ=systematic jointing.)

4.3.5.4 Dynamics of Normal Faults on Quartz-Mica Schist

To reconstruct the orientation of the stress ellipsoid from a population of faults, draw the fault plane great circles on the equal-area net along with any available data on the sense of slip and the orientation of slicken lines. One principal stress is assumed to be vertical and the other two horizontal. The line of intersection between the two fault sets gives the orientation of (σ2). The bisector of the acute angle between the fault sets is (σ1), and the bisector of the obtuse angle between the fault sets is (σ3).

The methods of determining the paleostress orientation from fault data has been used, e.g right dihedral method and graphical methods. The technique adopted in this work is the right-dihedra method, this technique was called the right-dihedra method by Angelier and Mechler (1977) and was later modified by Lisle (1987; 1988) who added an additional constraint upon the location of

σ1. The attitude of the normal faults measured on field revealed the orientation of the three principal stresses responsible for its formation, as well as their inclination. (Figure 5.17) below

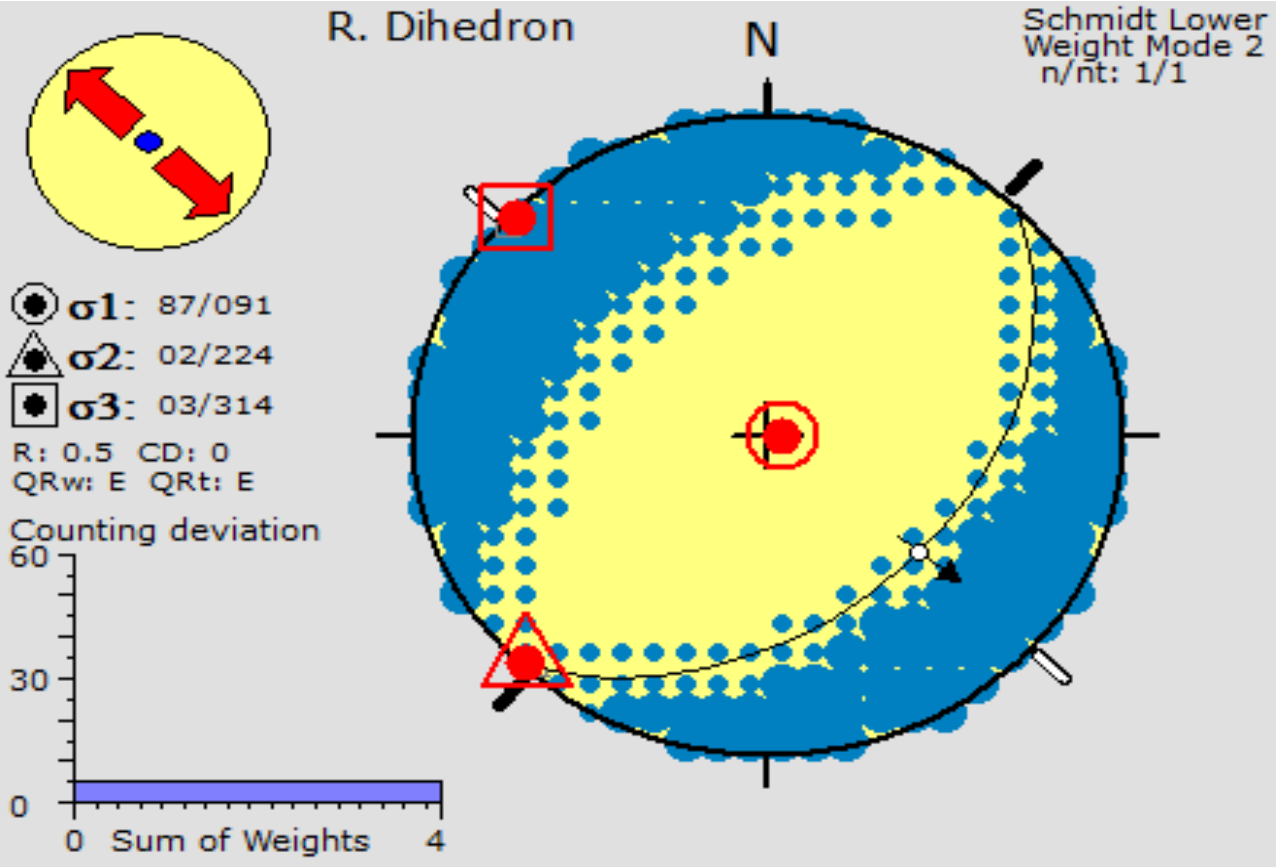


Figure 4.26: lower hemisphere stereographic projection of fault data, showing σ1, σ2 and σ3 derived using the right dihedron method Lisle's (1987).

4.3.6 KinematicAnalysis of Brittle Structures

4.3.6.1 Kinematics of joints on quartz-mica schists

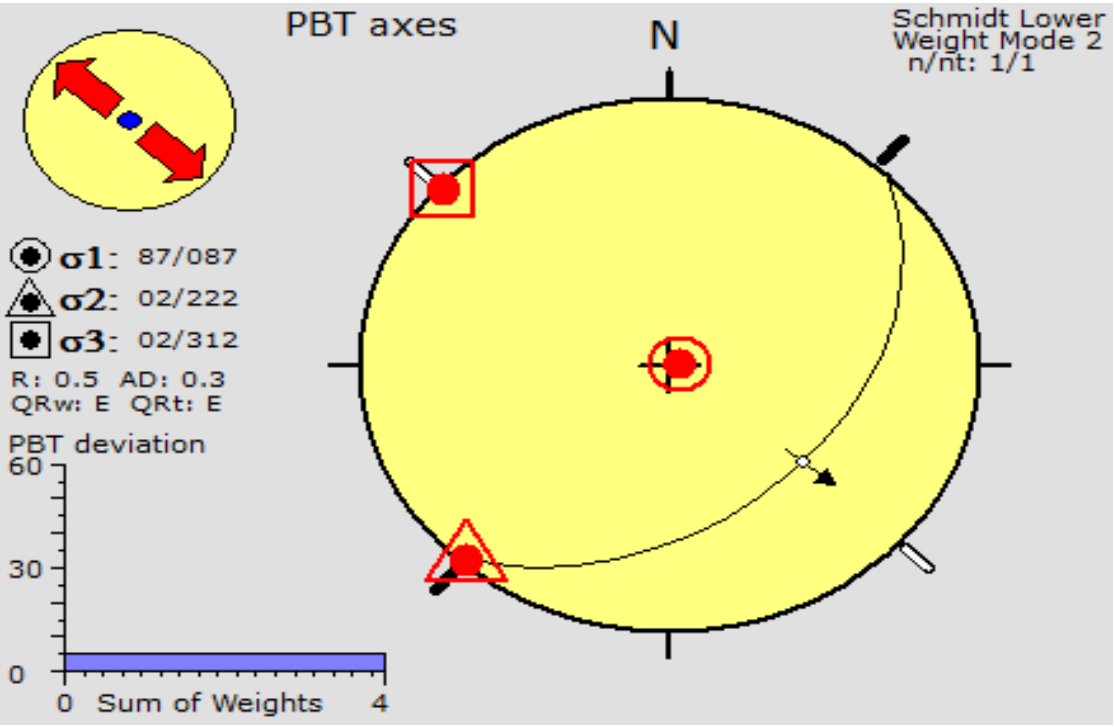
The joints observed on this exposure are dilation or extension joints with the separation ranging from 5-15cm, in a direction normal to the fracture plane, this is known as mode 1 fracture (Plate XXIX). In a relatively isotropic rock it is controlled by the remote stress field at the time of fracture propagation: joints are gaping planes parallel to the maximum compressive stress 1σ and perpendicular to the direction of the least principal stress σ3. In other words, they form in the plane containing σ1 and σ2otherwise there would be a shearing stress and a corresponding finite shear displacement on the joint plane. Triaxial experiments on brittle isotropic rocks confirmed this theoretical consideration.



Plate XXVIII: Field occurrence of tensional joint on quartz-mica schist, horizontal arrows indicates direction of movement, the blue stars indicate opening of a tensional joint.(11º 39' 41.0"N, 04º 52' 7.4"E).

4.3.6.2 Kinematics of Fault on Quartz-Mica schist

The normal faults observed and described in Plate XXIV and Plate XXV have the orientation of the fault plane represented by a great circle and the movement plane indicated by the black arrow containing the maximum principal stress σ1 and least principal stress direction σ3, more appropriately called infinitesimal shortest and the longest strain axis respectively. The line normal to slickenline, lying in the fault plane is taken as the direction of σ2. The kinematic axes which are: p-axis (compressional axis), t-axes (tensional axis), b-axis (transitional) and their various orientations/inclinations and deviation are presented (Figure5.19). The R= 0.5 represents the ration of the three principal stresses while AD=0.3 is the angle of deviation of PBT.



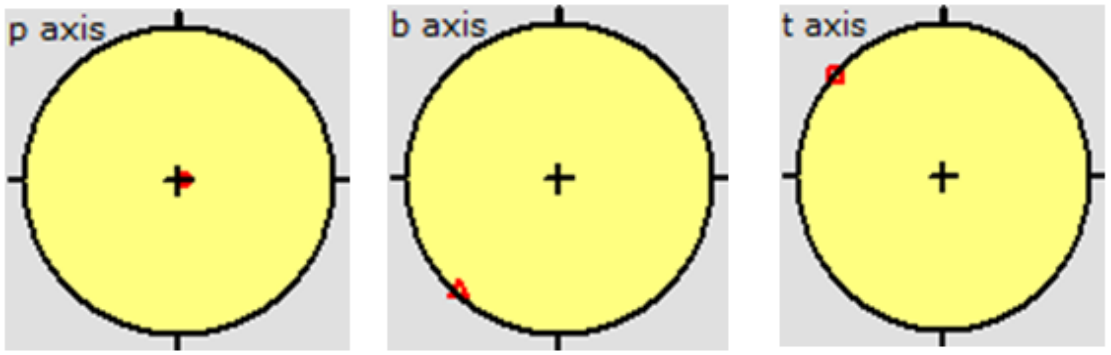


Figure 4.27: lower hemisphere projection of fault components plane with their kinematic axis.

4.3.7 Descriptive Analysis of Ductile Structures

4.3.7.1 Preamble

Ductile structures are product of deformation that responds to stress through bending, shortening or stretching. The deformation mechanisms that prevail during their formation are mechanical twining/kinking and creep mechanisms. Ductile structures have no loss of cohesion at the scale of crystal grain or larger and occur at higher temperature and pressure condition usually within the earth. The ductile structures recognized in the study area are discussed below.

4.3.7.2Fold on Mica Schist

The folds recognized on the exposure of mica schist are open folds and are cylindrical and asymmetrical in form. The hinge of the fold is flat, the inter limb angle is estimated to be 120°-70°, based on the thickness of the layers involve the fold is parallel (i.e the dip isogon is moderately convergent). The hinge area of the fold is highly jointed with trend of the joint parallel or similar to the orientation of the fold axis or hinge line (N272W°), while other joint intersect the imaginary axial plane at 90°. The limbs of the fold dip at 28° averagely. (Plate XXIX)



Plate XXIX: Field occurrence of open fold on exposure of mica schist (JT= Joint trend) (11°35'59.0"N, E4° 55' 38.4"E).

The use of beta diagram(β- diagram) can help to determine the geometric attitude of a cylindrical fold especially if the structuresare on a large-scale or not well exposed this is a typical example of what was encountered on the exposures of mica schist in the study area. Several measurements on the limbs of folds at various locations were recorded on the limbs of the folds appendix . Figure 4.28 A-D below shows the beta plot of the fold attitude, in figure 4.28 B, the trend and the plunge of the fold axis is calculated as (N302W, 15°). This implies that the fold has a gently dipping fold axis, oriented in northwestern direction

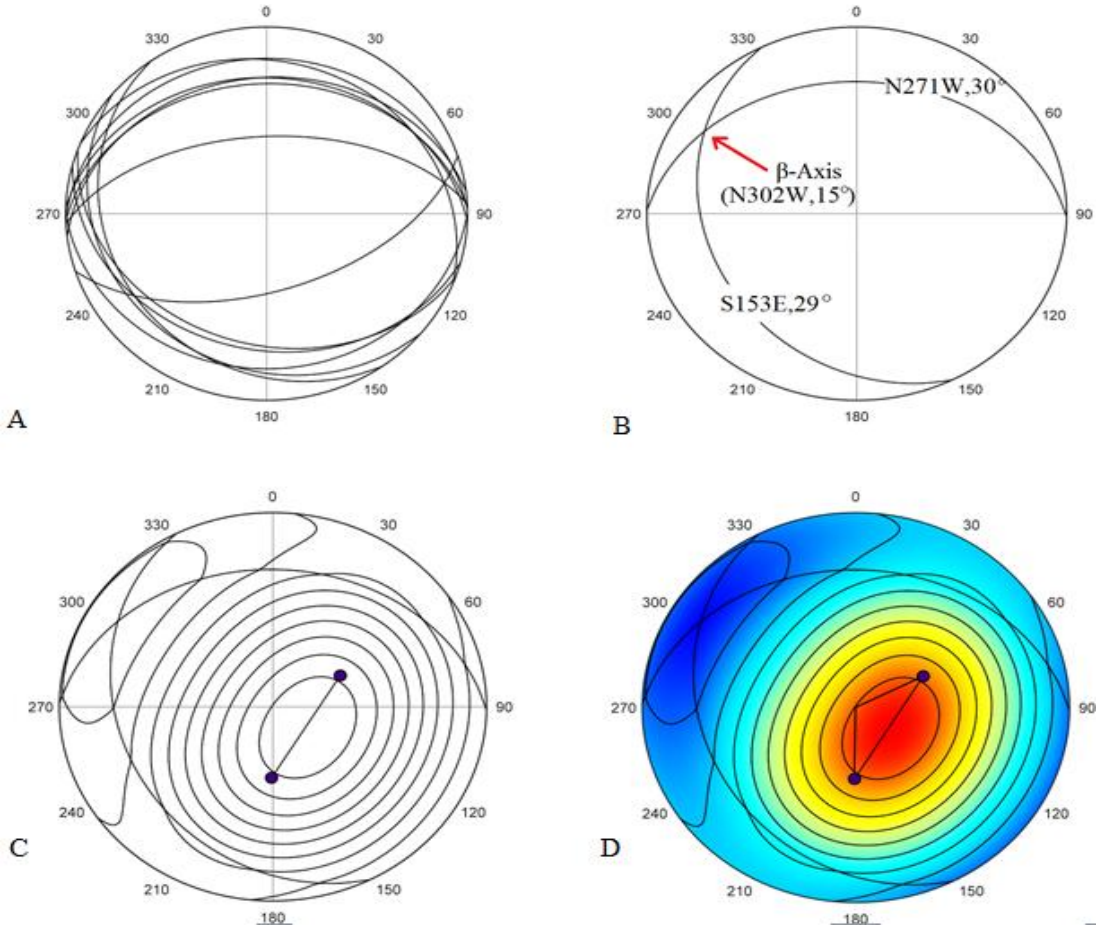


Figure 4.28: Beta plot (β –diagram) of fold limbs. A) - Plot of all the attitude of limbs at different location. B) -Plot of the average attitude of two major limbs, C) - high contour concentration showing the zone of fold hinge D)- the small triangle indicate the direction of dip of fold axis.

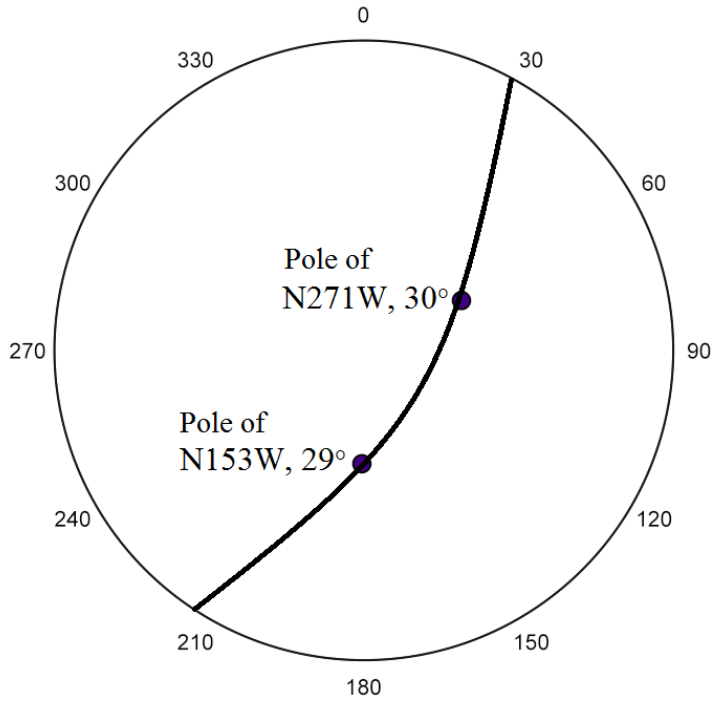


Figure 4.29: Pi-diagram. Pi circle is the great circle common to the two main pole of limbs of cylindrical fold (π-axis and π-circle).

4.3.7.3 Schistosity on Exposures of Mica Schist

Schistosity is the dominant foliation pattern that occurred on rocks in the study area, these foliations are defined by alignment of micaceous minerals (muscovite) and platy quartz, giving the rock a silky shiny lustre. The foliation (schistosity) on the exposure of mica schist is described as follows; they occur in association with fold, oriented in (strike=N292W, 25°) the surface is planar and well developed; the minerals associated with the layers are dominantly mica and little quartz(PlateXXXI).

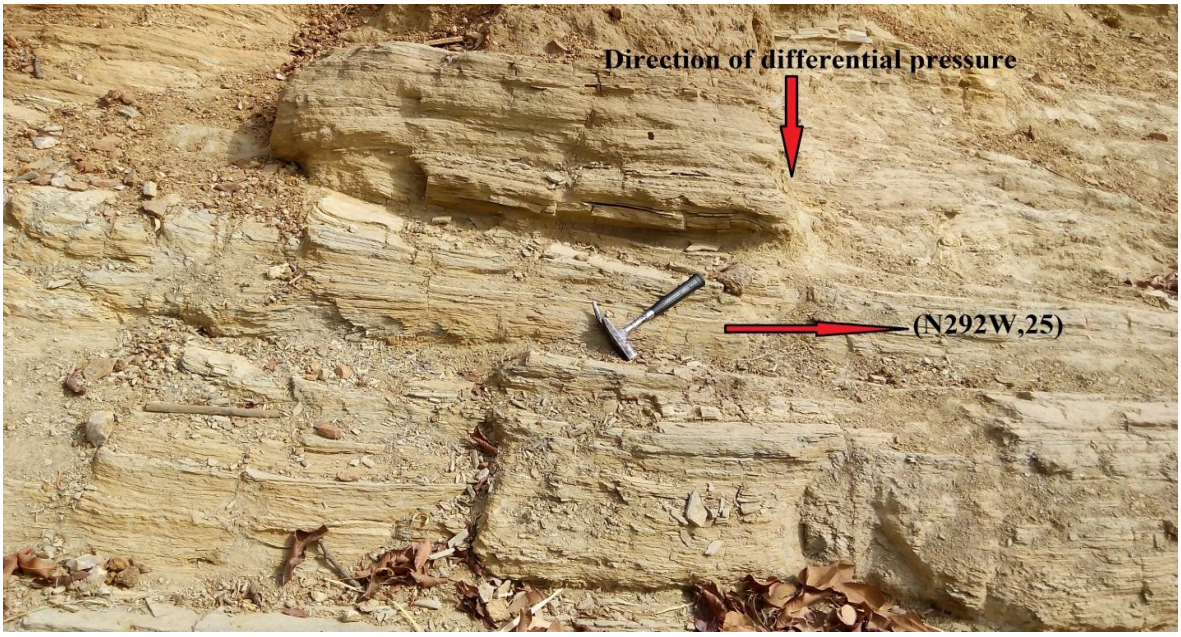


Plate XXX: Foliation (schistosity), the vertical arrow showing the differential stress, horizontal arrow indicates the orientation (11°35'59"N, 4° 55' 38.4"E).



Plate XXXI: Photograph of crenulation cleavage on a quartz-mica schist outcrop, along Kamtu road (11° 43' 33.6"N, E 4° 50' 01.8"E).

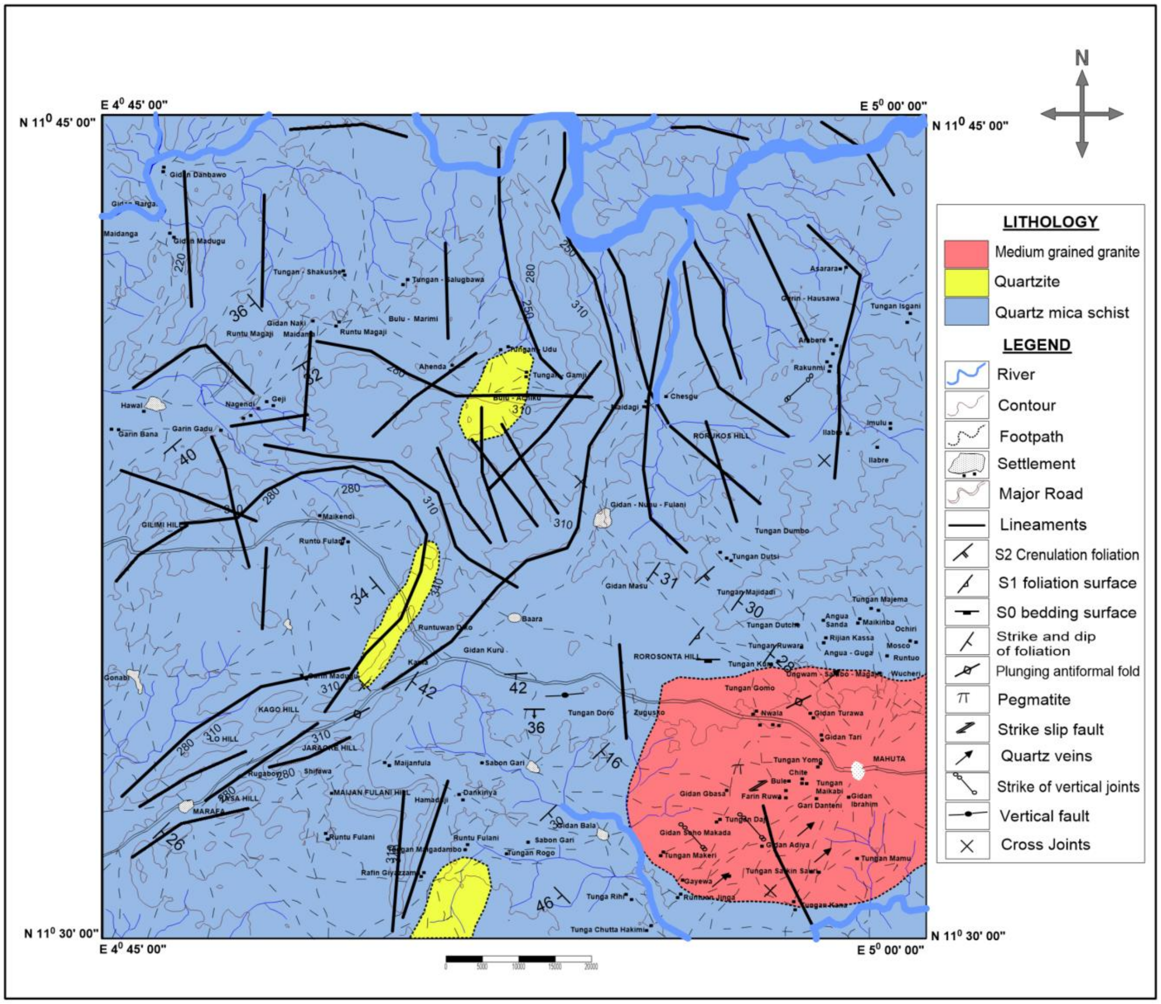


Figure 4.30: Structural map of the Study Area

4.4 Episode of Deformation

4.4.1 First phase of deformation (D1)

The first episode of deformation (D1) is not necessarily the earliest deformation affecting the area; structures that recorded D1 occur only on metamorphic rocks and are associated with the development of S1 Schistosity and an F1 folding from the S0 bedding. The earlier planar structure S1 is generally parallel to the bedding surface S0 and is defined by the preferred orientation of muscovite and platy quartz on the S0 surface (Plate XXXII). F1 fold were rarely seen as they occurred as flat lying minor fold on mica schist (Plate XXXIII) they had a NNW-

SSE trend of the axial plane. The dominant foliation S1 occurs as axial planar cleavages to this folds. This occurred along Bulu achiku road in the study area.

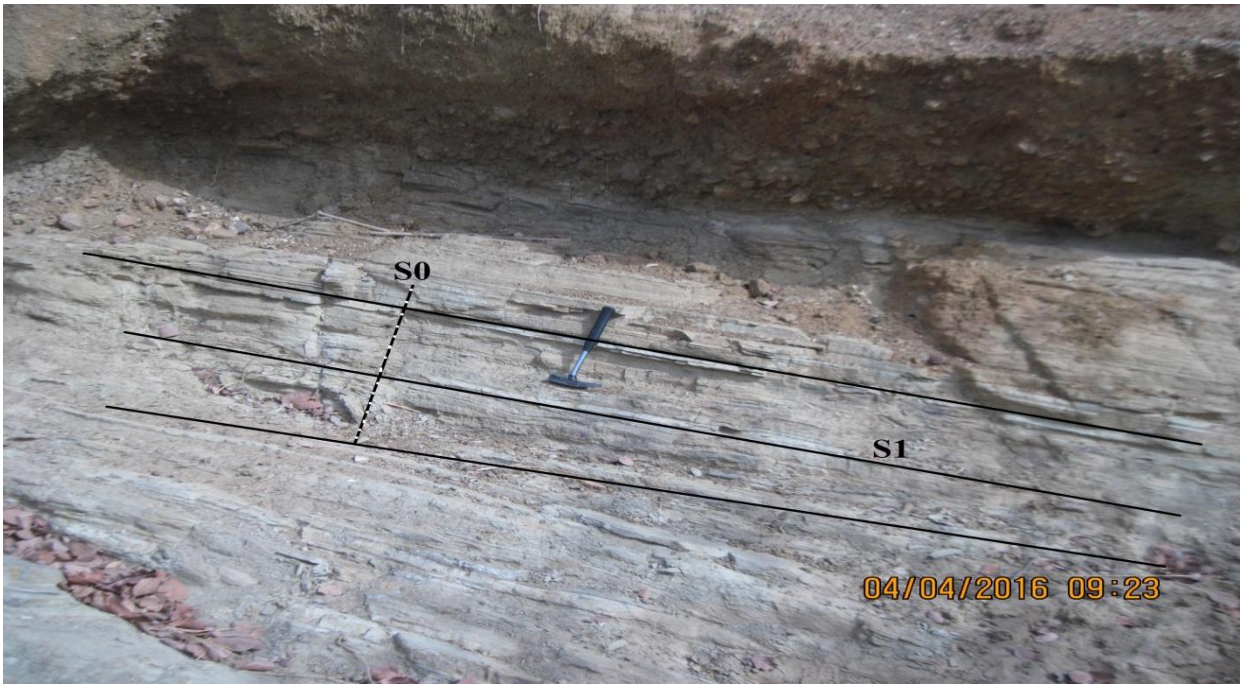


Plate XXXII: S1 schistosity on S0 surface on mica schist along Bulu Achuku road, 11° 35' 59.0"N, 4° 55' 38.4"E.

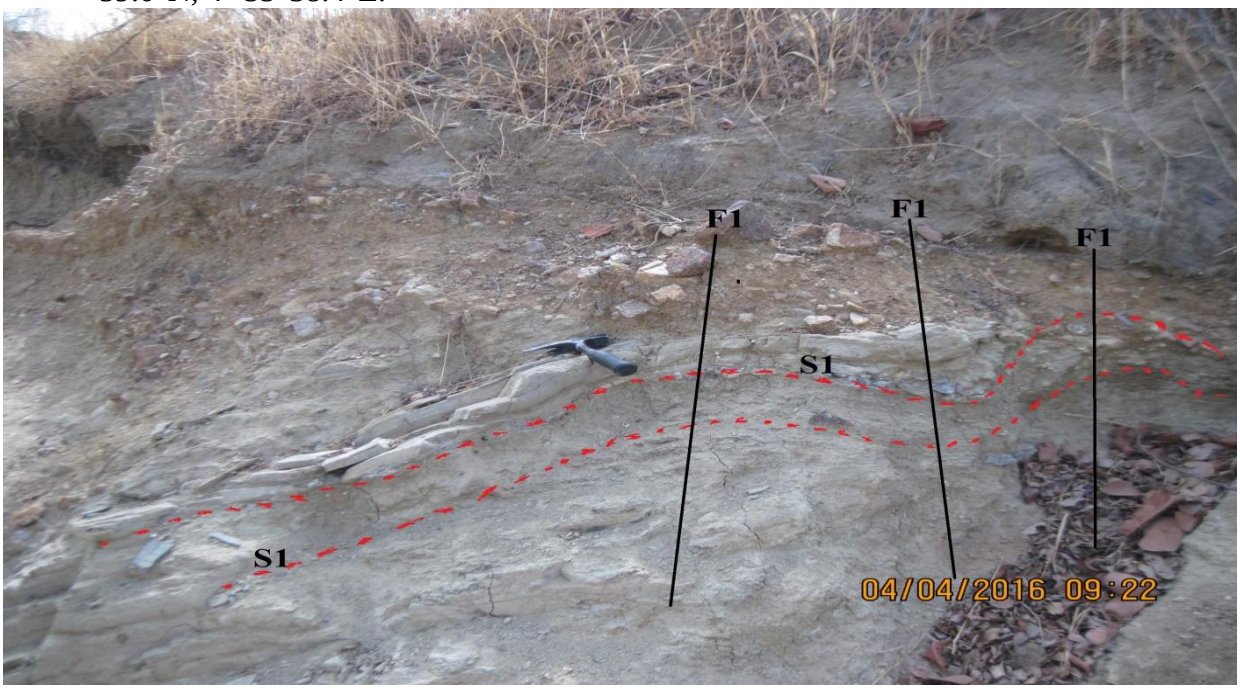


Plate XXXIII: Quartzite veinlet invading mica schist showing F1 folding and S1 schistosity along road leading to Bulu Achiku area 11° 37'50.0"N, 4° 51' 34.4"E.

4.4.2 Second phase of deformation (D2)

The D2 (second phase of deformation) is well developed on both mica schist and pocket of granite- gneiss in the study area. The D2 is characterized by heterogeneous deformation affecting the previous D1 fabric. The D2 structures have a wide spread development on mica schist and quartz-mica. The intensity of the D2 structures increases from the center of the study area toward the southwestern part on the map. This area is covered by foliation at mesoscopic scale oriented in northeastern direction. Most of the tight isoclinal folds were seen in the south eastern portion of the study area around Mahuta. D2 deformation is associated with development of an S2 crenulation cleavage and F2 major fold. The S2 cleavage cross cut the S1 cleavage into a small regular crinkle fold that is asymmetric in form called crenulation fold cleavage (Plate XXXIV). F2 fold occur at outcrop scale, upright, tight to isoclinal fold with NE-SW trend of axial plane (Plate XXXV). In other areas, they occur as open to tight isoclinalfolds forming a series of antiforms and synforms.

4.4.3 Third phase of deformation (D3)

The last stage of deformation (D3) can be attributed to brittle tectonics marked by late sub-vertical fractures which are granitic veins, pegmatites, joints and dextral fault with the orientation of the fault plane in NW-SE direction (Plate XXI and Plate XXII). These occur on the exposure of granitic rock in the southeastern part of the study area.



Plate XXXIV: S2 Crenulation cleavage fabric along Kamtu road, (11° 43' 33.6"N, 4° 50' 01.8"E).

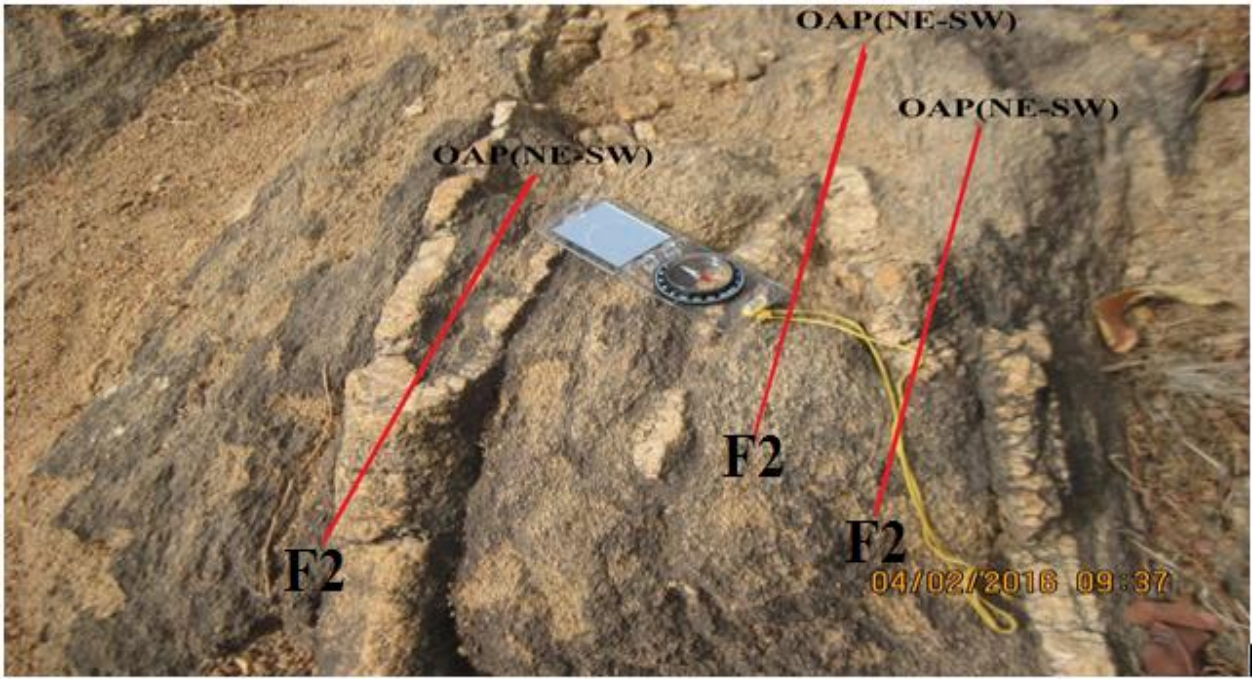


Plate XXXV: F2 tight to isoclinal fold south of Mahuta, OAP (Orientation of axial plane),(11° 31' 55.8"N, 4° 57' 14.7"E).

4.5 Strain Analysis

Strain estimation were carried out to determine bulk strain and to interpret correctly the degree and variability of deformation effects on rocks in the study area, resulting from tecto metamorphic cycle. Several methods of estimating two dimensional strain from deformed rocks have being proposed, according to Hari (2009) most of which require the measurement of long and short axes of deformed objects called the strain markers. The Fry method according to Fry (1979) is adopted in this work; sampled rocks from 12 different locations within the study area were used forthe strain analysis from its photomicrographs. Angle to reference line and average axial ratios of the fry haloes were determined (Table 4.9) and selected samples of the fry haloes generated is shown in Figure 4.31.

Ellipsoidal shapes of the grains generated using the GeoFry package suggest a heterogeneous deformation and varying grain orientations in the NW-SE, NE-SW and NNE-SSW and NW-SE directions (Figure4.32). The shapes of the fry hallows varies from near circular type around Mahuta on exposures of granite and northern part of the study area. This suggests a low degree of deformationas compare to the flattened type in west, central and extreme northwestern parts of the study area which suggested high degree of deformation.

Medium grained granite in southeastern part around Mahuta and quartz-mica schist around Chesgu suffered least deformation while quartz-micaschist in central, extreme northwest and mica schist in the east suffered high deformation.

Table 4.8: Slide numbers, Angle to reference line and Average axial ratios of the Fry haloes.

S/N	Slide Numbers	Angle To Reference Line (Degrees)	Average axial Ratio
1	MK 1	48	1.57
2	MK 2	63	1.52
3	MK 3	23	1.49
4	MK 4	48	1.53
5	MK 5	37	1.57
6	MK6	71	2.90
7	MK7	73	2.74
8	MK8	72	2.10
9	MK9	25	1.77
10	MK10	16	1.22
11	MK11	64	2.72
12	MK12	13	1.77

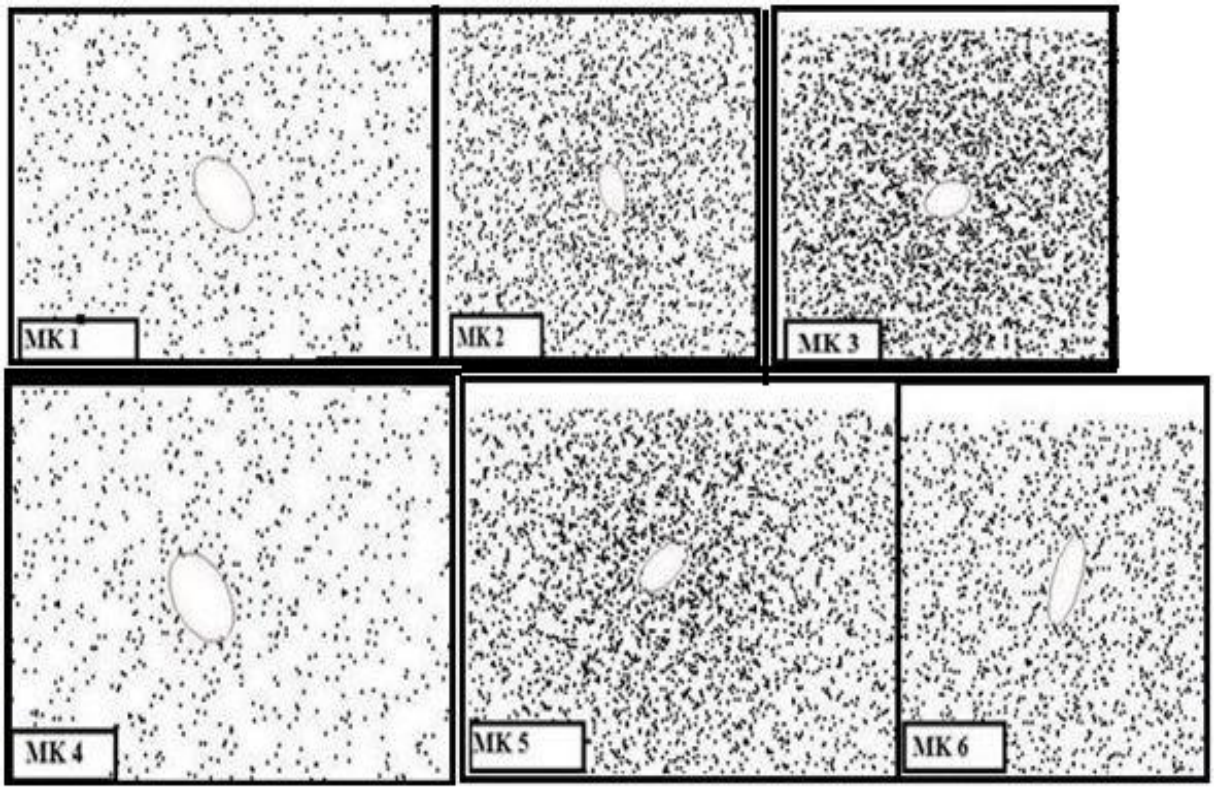


Figure 4.31: (MK 1-12) Fry haloes from selected samples generated from photomicrographs of rocks in the study area.

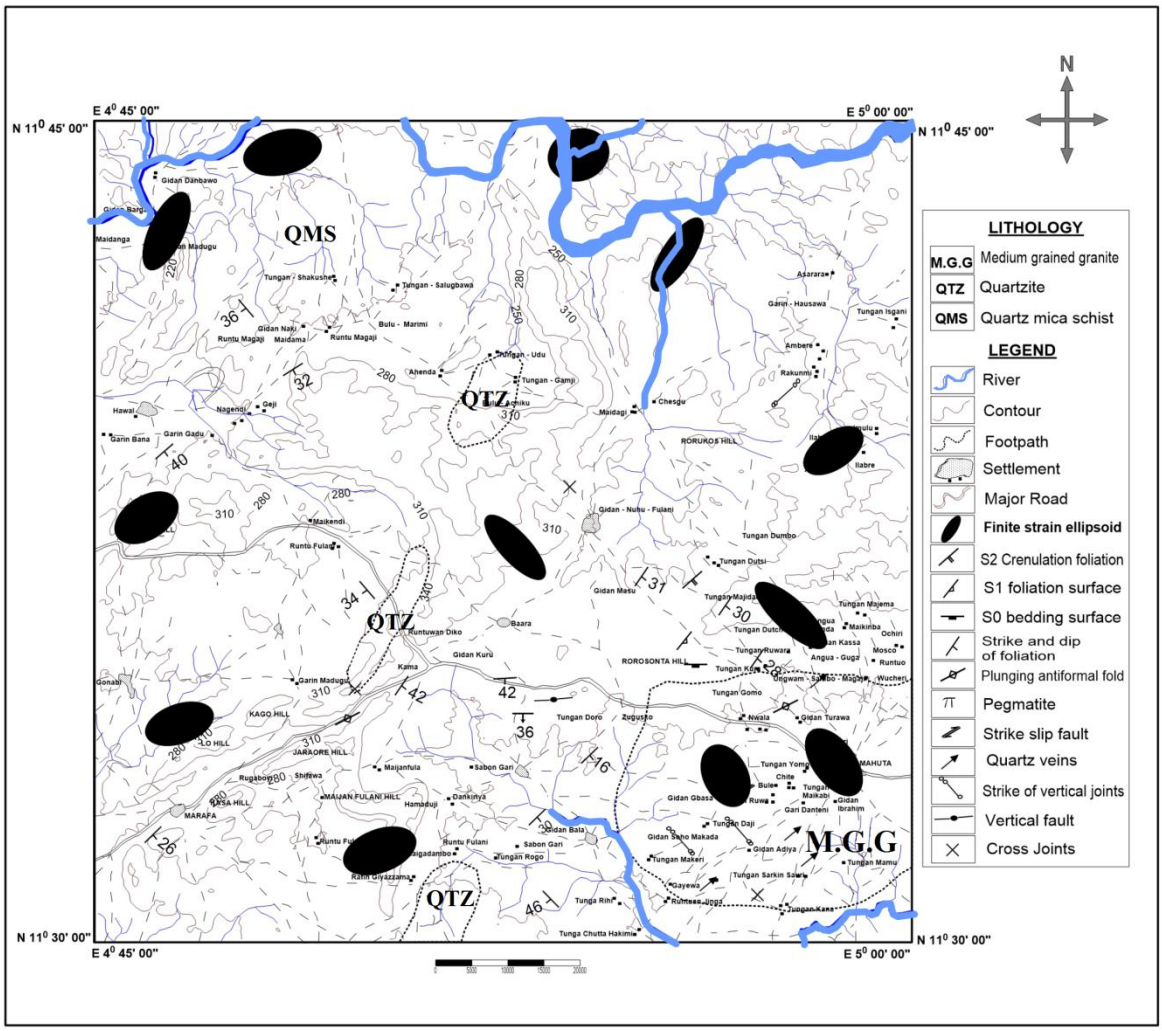


Figure 4.32: Strain ellipsoid and orientation distribution map of the study area

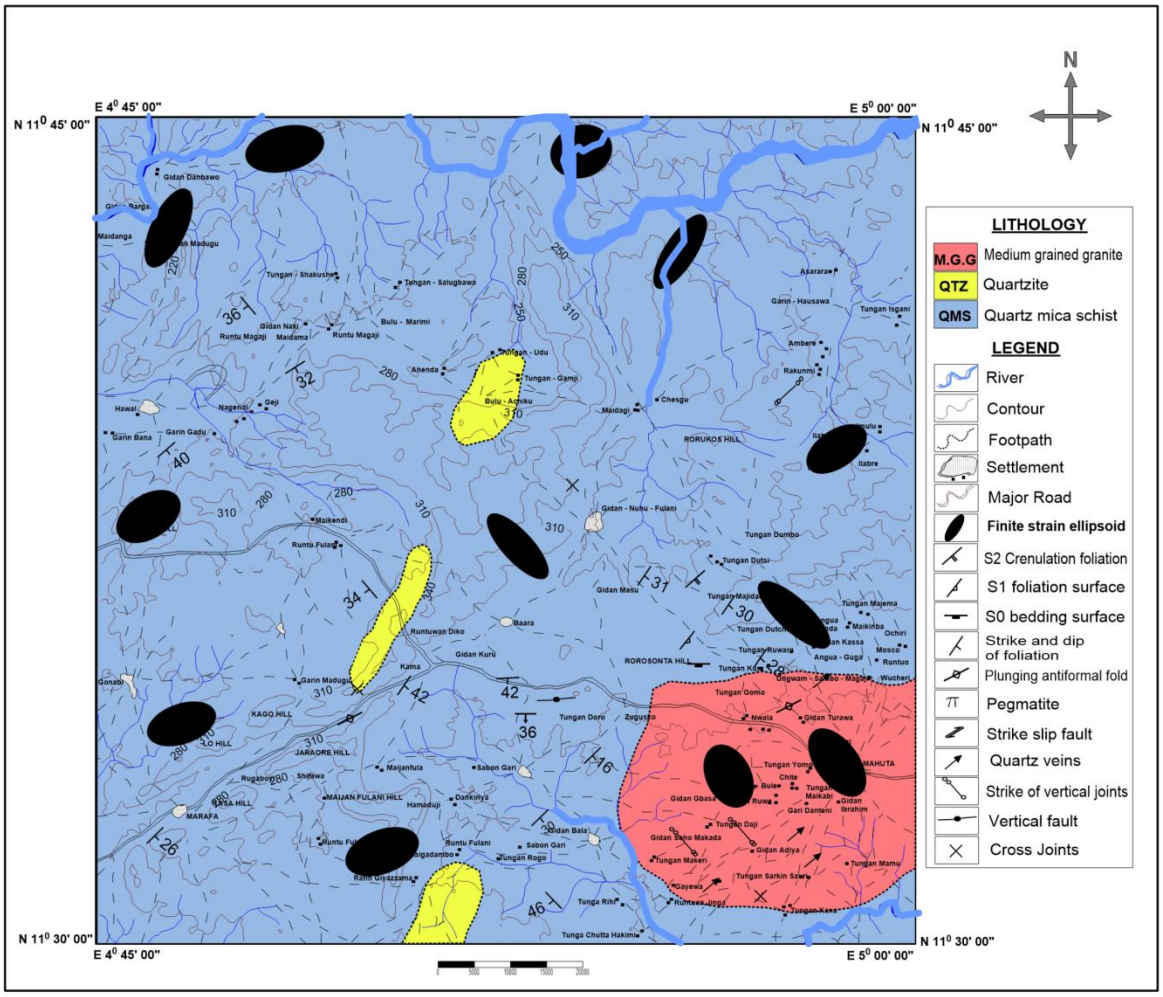


Figure 4.33:Strain ellipsoid and orientation distribution map of the study area superimposed on the geological map

4.6 Structural Evolution of the Study Area

The study area comprises of three rock units namely; fine-medium grained granite, quartz-mica schist and mica schist, other minor lithologies are: quartzite, pegmatite and aplitic dyk.The oldest rock unit within the stud 0y area is the mica schist which was derived possibly from a previous existing sedimentary sequence of possibly Eburnean age (Ajibade *et al.*, 1987) that have been deformed and metamorphosed. The reactivation of the basement during early Pan-African times

brought about mountain building processes (orogeny), subsequent deformations and metamorphism. The Older Granites (medium grained granites) intruded the pre-existing lithologies in the late Pan-African regimes bringing about the fracturing and faulting of the basement.

The schist belts of Nigeria are complexly deformed with earlier folds being refolded by later ones (Burke *et al*., 1976).The rocks of the study area are polydeformed, evident from the complex nature of structures and their varying attitude in terms of their strikes and dips. The geologic structures showed that the area hasbeen affected by three episodes of deformation denoted as D1, D2 and D3 respectively.

Table 4.9: chronological order of events of rock types within the study area

Classification	Geological History	Rock Types
Late Pan-African	Granite intrusion and fracturing	Older granites, jointing, faults, quartz veins and quartzofieldspathic pegmatite veins.
Early Pan-African (Younger metasediments)	Orogenesis, deformation and metamorphism.	Quartzites,
Kibaran / Eburnean	Geosynclinal deposition, deformation and metamorphism	Mica schist schists. Quartz-mica schists

The D1 is the earliest deformation episode the D2 and D3 are the intermediate and late deformation episode. Olangbanyi (1997) ascribed D1 to the Eburnean event and D2 to the Pan-African event in the metasediments of the Egbe-Isanlu area. It is suggested that the Eburnean

closure along an easterly dipping Beniof zone led to D1 deformation and metamorphism in the schist belts (Dada *et.al.,* 1993). The D1 was a major ductile deformational event which affected the mica schist rock unit. It brought about an early banding S0 parallel to the earliest NE-SW trending schistosity S1. F1 folds of this deformation episode were rarely seen as they have been largely overprinted by subsequent deformations D2. They occurred as flat lying and obliterated minor asymmetrical folds with an ENE-WSW trend of axial plane. Mullan (1978) was of the opinion that the E-W structures were probably pre-Pan African (Eburnean) in age.

Subsequent deformations D2 (ductile-brittle event) affected the mica schist and quartz-mica schist rock units. It is suggested that movements associated with the Pan-African compression coupled with the prevalent temperature conditions may have led to D2 deformations, reactivation of pre-existing rocks and fractures (Van Breemen *et al*., 1977). This deformation event led to the development of an S2 crenulation cleavage of the initial S1 schistosity and also a folding of an S1 into a major tight to isoclinal F2 folds with a NE-SW trend of axial plane. Late stages of deformation (D3) can be attributed to brittle tectonics marked by late sub-vertical fractures which are normal fault, dextral faults, granitic veins, pegmatites and joints that trend in a NNE-SSW direction. The summary of the chronological order of structures within the study area, their deformational episode and most affected lithological unit (Table 4.9) and (Table 4.10).

Table 4.10: Chronological order of events of structures within the study area

Stages of deformation	Structural imprints	Trends	Types of structures	Most affect rock unit
(D3) Late tectonic stage	Brittle deformation that produced fractures	N-S, NW-SE, NE-SW, NNE-SSW,	Joints, faults (Dextral fault), joints, quartz-vein	Fine –medium grain granite
Second deformation (D2)	Ductile and Brittle deformations events that produces second generation structures.	NE-SW, NNE-SSW, N-S	S2 crenulation cleavage F2 major isoclinal folding	Quartz-mica chist and mica schist
First deformation Event (D1)	Ductile deformation that produced the first generation of structures.	ENE-WSW, NE-SW.	F1 minor obliterated assymetrical folds S0 rock bedding S1 schistosity	Mica schist

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

5.1.1 Field Observations and Petrographic Descriptions

The study of rocks in and around Mahuta area reveals lithologies with distinctive textural, petrographic and structural characteristics which helped in interpreting the structural evolution of the study area. The study area consists of three dominant lithology, fine-medium grain granite, quartz-mica schist and mica schist. The areais characterized by hilly and undulating terrain especially in the western portion of the map.

Field observation and remote sensing studies revealed that fine-medium grained granite covers about 15% of the study area and occurs in pockets as low lying outcrops west of Mahuta town. Quartz-mica schists occur as hills; highly weathered covering about 70% of the study area. The attitudes of beds varywidely in strike (006-346) and dip (9-52) while both brittle and ductile structures are associated with this rock unit. The occurrence of mica schist in the study area is restricted to river channel and dug pits, it covers about 5% of the study area, varying widely in dip and strike. Quartzofeldspathic dyke, quartz vien, aplitic dyke, and quartzite are the minor lithologic unit.

Petrographic analysis of the three main lithologic units in the study area agrees with the estimation of the mineralogical composition using handlens, which shows that fine to medium grained granite contains; quartz, muscovite, biotite, plagioclase and k-feldspars. Quartz-mica schist contains minerals; muscovite, quartz, and plagioclase, the presence of micro cracks on the quartz grains indicate brittle deformation mechanism, while mica schist contain minerals like;

muscovite, quartz, biotite and opeque mineral. Mica schist shows foliation evident from the parallel alignment of the mineral grain. The presence of garnet minerals on hand specimen of mica schist suggests a high metamorphic grade. Extinction observed on quartz grains in all slides suggests an intra-crystalline deformation and the polycrystalline nature of the quartz grains suggest a high temperature deformation as a result of grain boundary migration. Undulose extinction in quartz suggests intra crystalline deformation.

5.1.2 Lineament Analysis

Lineaments were generated from digital elevation model (DEM) andArcGIS softwares. A total of 46 lineaments were produced. The lineaments had a maximum length of 22.885 km, a minimum length of 1.891 km and a mean length of 3.8032km Rose diagram constructed from these lineaments showed that their dominant orientation is NW-SE and NE-SW, corresponding with the dominant orientations of structural features such as joints, foliation trends, and lineation recorded and ploted during the conventional field work.

Lineament density map showed that the central and eastern parts have the highest density accounting for about 0.43% while the southeastern portion has the lowest density accounting to about 75.64% of the study area. Lineament intersection map showed that areas with low intersection density dominates and covers about 98.022% while area with high intersection density occupies about 0.0479% for the study area. Lineament mean length map of the area showed that short lineament lengths dominate the area and account for about 50.54% while the very long lineaments account for about 0.617% in the central and southwestern parts.

5.1.3Structures and Deformational History

The E-W collision of the West African Craton and westward moving Plateof the Congo Craton created a N-S to NE-SW trending structures parallel to the edge of the West African Craton (Black *et al*., 1979; Champenois *et al*., 1987; Oluyide, 1988; Egesi and Ukaegbu, 2010).The regional effect of these movements is reflected as highly deformed series of multidirectional orientations found in folds, lineaments, faults and joints in the entire Nigerian Basement Complex (McCurry, 1976; Rahaman, 1976; Onyeagocha, 1982; Toteu *et al*., 1990).Joints are palaeostress markers that provide record of stress orientation at the time of propagation (Dyer, 1983; Pollard and Segall, 1980).

Structures mapped within the study area have been identified and analysed (geometric, dynamic and kinematic analysis) thebrittle structures are the joints and faults whileductile structures are folds, foliations, lineations and cleavages. The joint analysis was carried out on each lithologic unit; the general result revealed that joints in the study area trend in NNW-SSE, NE-SW, E-W and N-S. Categorizing them to the individual lithologic units, the fine-medium grained granite showed a dominant trend in NW-SE and slight NNE-SSW, the joint array is systematic and joint type is orthogonal with dihedron angle of 90. The quartz-mica schist showed a dominant trend in NE-SW, the joint array is systematic, the joint types are cross-strike, strike joint and conjugate joint which are characteristic of a polydeformation. The orthogonal cross joint in the study area reveals the orientation of the paleostress field. Stress rotation model is suggested for the formation of the orthogonal joint.

The faults on granitic rocks are strike slip (dextral), with the orientation of the fault plane in NW-SE having an average displacement of 30cm. The faults on quartz-mica schist are normal faults, with vertical deformation effect, the apparent horizontal component of deformation is

elongation (10-30cm), and the apparent stratigraphic effect of deformation is neutrality while the tectonic polarity is right-dipping (synthetic).

The dynamic and kinematic analysis of normal faults show the orientation of the three principal stress σ1 (87/091), σ2 (02/224) and σ3 (03/314),and their kinematic axis; P-xis (compressional), T-axis (tensional), and B-axis (transitional). The direction of the movement on the fault plane is indicated by black arrow oriented to the southwest. Fold analysis shows that the trend of the axial plane is approximately NW-SE; the plunge of the fold axis is about 15°, concentrated in the NW axis of the stereoplot. The small scale folds are mostly isoclinal, suggesting a coaxial deformation with the orientation of the axial plane in NE-SW direction corresponding with joint trend.

According to Onyeagocha and Ekwueme, (1982) and Toteu *et al*., (1990), the N-S and NE-SW structures are presumably associated with the Pan African orogeny, while pre Pan-African structures are oriented differently to these directions in the basement complex rocks. The NE-SW trend which is persistent with some of the foliations, lineations, joints, veins, pegmatites and axial plane of folds showed that they are also Pan-African orogenic structures.

The study area was subjected to three episode of deformation (D1, D2 and D3).The D1 phase was associated with the development of S0 bedding; S1 schistosity and F1 minor asymmetrical open fold, the nature of its asymmetry suggesst a non-coaxial deformation.The D2 tectonic phase is associated with an S2 crenulation cleavage and an F2 tight to isoclinal fold mostly associated with quartz-mica schist.The major folding associated with the second phase deformation is similar in style and orientation to the major folding events recognized as F2 in other parts of Nigerian Basement Complex rocks (McCurry, 1973;Grant, 1978; Holt, 1982; Egbuniwe,

1982;Danbatta, 1991; 2002; 2003). While the imprint of D3 is associated with strike slip fault and other minor structures such as quartz vien, aplite dyke on the granitic rock.

5.1.4StrainAnalysis

Fry haloes obtained from the strain analysis of photomicrographs of samples suggest that the area suffered a heterogeneous deformation. The orientations were basically in NNE-SSW, NE-SW and NW-SE directions. Mica schist outcrops north of Mahuta and quartz-mica schist around Bulu Achiku suffered highdegree of deformation. Areas in southeast and northsuffered the least deformation.

5.2 Conclusions

Geological mapping of the area west of Mahuta was carried out on a scale of 1: 50, 000 which covers about 770 Km^2in northeastern part of the Zuru Schist Belt.Optical studies of the thin sections prepared from fifteen representative rock samples collected revealed three major rock units, which are; medium grained granites, quartz-mica schist and quarzite.The mineralogical assemblages of these rocks are; quartz, micas (muscovite and biotite) and plagioclase for fine-medium grained granite, quartz and muscovite for quartz-mica schist and quartz, muscovite, plagioclase and biotite for mica schist.

The study area has been subjected to three deformational phases (D1, D2 and D3) and the imprint of the deformation resulted in the development of structural elements such as schistosity, crenulation cleavage, joints, faults and folds.

The analysis of normal fault on quartz-micaschist revealed the orientation of paleostress for their formation; the σ1 (87/091), σ2 (02/224), andσ3 (03/314), while the strike-slip fault show the orientation of the fault plane in NW-SE, Statistical data of joints, foliations, lineations and veins

were integrally processed. Rose diagrams, stereographic projections, lineament analysis and bar charts plotted from the joints revealed a major trend of NW-SE and NE-SW orientation which showed that most of the trends were Pan-African. The dominent joint type in the study area is orthogonal cross joint and model for their formation is suggested to be stress rotational model. Result from strain analysis shows that the study area suffered a heterogeneous deformation.

The following are the contributions to knowledge from this research:

i. The geological map of the study area was updated.

ii. The lineament maps of the area was produced.

iii. Paleostress orientation from fault data and their kinematic axes was determined.

iv. Bulk strain estimation using photomicrographs of representative samples was determined.

v. The strain ellipse distribution pattern and strain map of the study area was produced.

vi. The deforamtional episodesthat affected the study area were determined.

5.3 Recommendations

It is recommended that similar work should be carried out in other parts of sheet 73, so as to come up with a general conclusion on the structural style and deformational history of the entire sheet of Shanga northeast.Also, quantitative estimation of deformation should be carried out, as this research work covers only the qualitative aspect.

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APPENDICES

APPENDIX I

JOINT READINGS ON FINE-MEDIUM GRAINED GRANITE

306 °		309°	308°	306°	312
307°	,308°	322°	305	,313°	315°
320°	318°	322°	316°	17°	314°
309°	322°	306°	309°,	318°	306°
320 °	144°	136°	136°	136°	136°
126°	128°	128°	139°	142°	137°
139°	140°	129°	130°	140°	140°
129°	130°	142°	137°	129°	130°
106°	116°	005°	005°	049°	106°
117°	006°	007°	007 °	118 °	

APPENDIX II

JOINT READINGS ON QUARTZ- MICA SCHIST

186°	182°	200°	179°	170°	170°
180°	171°	181°	185°	182°	187°
186°	186°	187°	180°	182°	170°
171°	190°	190°	187°	189°	189°
190 °	273°	222°	275°	272°	250°
285°	260°	255°	225°	227°	262°
265°	212°	221°	241°	271°	225°
270°	264°	227 °	270°	82°	58°
64°	04°	68°	25°	12°	,52°
85°	67°	74°	73°	79°	78°

APPENDIX III

ATTITUDE RECORDED ON FOLD LIMB

STRIKE	N292W	N272W	S263E	S269E	S268E	N90E	S110E	N90E	S105E	S130E	N145E
DIP	20°	28°	28°	18°	31°	18°	56°	19°	28°	20°	22°