GEOLOGY AND STRUCTURAL EVOLUTION OF DANKO, SHEET 74SW PART OF ZURU SCHIST BELT, NORTHWESTERN NIGERIA

BY

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FACULTY OF SCIENCE

AHMADU BELLO UNIVERSITY,

ZARIA, NIGERIA

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BY

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A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIAIN PARTIAL FULFILLMENT OF THE REQUIMENTS FOR THE AWARD OF AMASTERS DEGREE IN GEOLOGY (STRUCTURAL)

DEPARTMENT OF GEOLOGY
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ZARIA, NIGERIA

OCTOBER, 2016

DECLARATION

I declare that the work in this thesis entitled GEOLOGY AND STRUCTURAL EVOLUTION OF DANKOSHEET 74SWPART OF ZURU SCHIST BELT, NORTHWESTERN NIGERIA, has been carried out by me in the Department of Geology. The information derived from the literature has been duly acknowledged in the text and list of references provided. No part of this thesis was previously presented for another degree or diploma at this or any other institution.

UMARU, AliyuOhiani		
Name of student	Signature	Date

CERTIFICATION

This thesis titled "**GEOLOGY AND STRUCTURAL EVOLUTION OF DANKOSHEET 74SWPART OF ZURU SCHIST BELT, NORTHWESTERN NIGERIA"** by UmaruAliyuOhiani, meets the regulations governing the award of the Degree of Master of Science (Structural Geology) in Ahmadu Bello University, Zaria, Nigeria.

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Member, Supervisory Committee Dr. T. Najime	Signature	Date
Head of Department Dr. H. Hamza	Signature	Date
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In the name of Allah the most gracious, 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, may His peace and blessings be upon his messanger Prophet Muhammad (S.A.W).

My profound gratitude goes to my parents, AlhajiM.J.Umaru and Hajiya Aisha Umaru for their guidance, love, encouragement, prayers and financial support towards the achievement of this academic programme.

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DEDICATION

I dedicate this work to the almighty Allah (SWT), 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 AlhajiM.J.Umaru and Hajiya Aisha Umaru.

ABSTRACT

The study area is located within the northwestern part of the Zuru Schist Belt, which is the largest schist belt in northwestern Nigeria. The major rock types in the study area consist of quartzites, muscovite schists and medium grained granite; while the minor rocksare quartz veins and pegmatites which have a dominant NE-SW trend.Petrographic studies have shown that quartzite is composed of quartz and muscovite. Muscovite schist is composed of quartz, biotite and muscovite while medium grained granitesiscomposed of quartz, muscovite, microcline, perthite and sericite. Structures identified were classified into ductile and brittle structures. Folds and foliations constitute the ductile structures, while joints are the brittle structures. Analysis of these structures using rose diagrams and stereographic projections shows that they are dominantly oriented in the E-W, NW-SE, NE-SW and N-S directions. E-W is the minor trending direction, NW-SE, NE-SW and N-S are the major trends. Remote sensing analysisof linear structures within the study area using Global Mapper V15 and ArcGis software reveals a dominant NNE-SSW trend, as well as abundant N-S lineaments and E-W lineaments.Field studies such as attitude of planar and linear structures, orientation of fold axial planes, styles of folding and over-printing of one fabric by another reveal that the study area has experienced polyphase episodes of deformation denoted as D1 and D2. The first phase D1 is associated with the development of an S1 schistosity foliation and a low-lying and partially obliterated minor F1 folds. The second phase D2 involved heterogeneous deformation which gave rise to an S2 crenulation foliation of the earlier S1 structure and an F2 major tight to isoclinal folds. Strain analysis employing (Fry, 1979) technique shows that the study area is heterogeneous in nature as is evident from the varying orientations of halos in the NW-SE, NE-SW and N-S directions.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The Nigerian Basement Complex is characterized by different grades of metarmophism, orogenies and structural modifications (Odeyemi, 1981; Rahaman *et al*., 1983; Caby, 1989) and these have been reflected in its complex petrological and structural composition. The polycyclic nature of the basement rock suggest 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 *et al*., 1987; Ajibade *et al*., 1987; Omosanya *et al*., 2010, 2011, 2012).

The Zuru Schist Belt is the most westerly schist belt in the Nigerian basement and the broadest with a length of about 280 km and a maximum width of 40 km. Its geology is little known and the main rock types are quartzites (locally feldspathic that are interbedded) with quartz-muscovite schist (McCurrry, 1976). The geological structures within the Zuru Schist Belt are very complex varying widely in dips and strikes. Not much research works on this schist belt are available although it has complex structure features that could be correlated with the Kushaka Schist and other belts. Structural evolution of rocks is concerned with identification of various deformation episodes associated with the rock structures based on studies of present day structural styles and orientations. Danbatta (1991) recognized three deformation episodes in the southwestern portion of the Zuru Schist Belt (D1, D2 and D3). This research therefore is focused on the geology and analyses of structures of the northwestern part of the Zuru Schist Belt so as to document its structural evolution.

1.2 LOCATION, EXTENT AND ACCESSIBILITY OF THE STUDY AREA

The study area is located within the Zuru Schist Belt which is the largest schist belt in northwestern Nigeria. It lies within Latitudes 11°30′ 00″ and 11° 45′ 00″N and Longitudes 5° 00′ 00″ and 5° 20′ 00″E (Fig.1.1) and forms part of Danko Sheet 74 SW. It covers an area of approximately 1020 km^2. The study area can be accessed through a minor road that runs from Zuru town through Danko to Maga in the northeast. It can also be accessed from a well tarred road that runs from Mahuta (a major town) in the southeast to Zuru town. From the northern boundary it can be accessed from a minor road that runs from Barkin Daji through Danko to Zuru town. Access to outcrops was made following footpaths (Fig.1.1).

1.3 CLIMATE AND VEGETATION

The study area is characterized by a Tropical Continental type of climate. It is characterized by two dominant rainy and dry seasons. The rainy season usually starts in June and last till October while the dry season commences in late October to February. Mean annual rainfall is about 800 to 1000 mm. temperature is generally high with mean annual temperature of about 26^0C, however during the harmattan season , the temperature can be as low as 21^0C and rises up to 40^0C during the months of April to June. Night temperatures are generally lower. 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

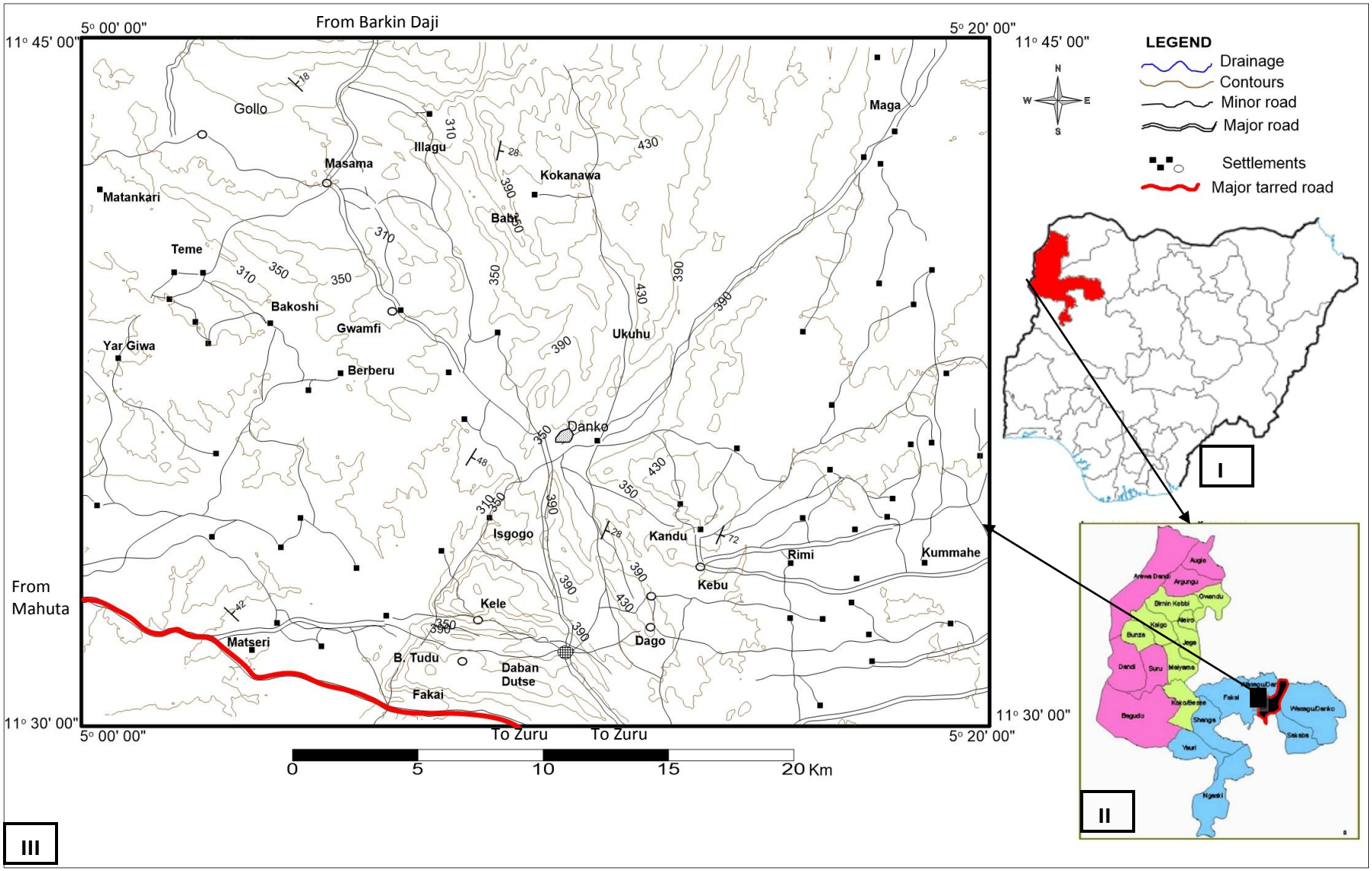


Figure 1.1: I) Map of Nigeria showing Kebbi State II) Map of Kebbi State showing Zuru area III) Location map of the study area.

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

1.4 RELIEF AND DRAINAGE

The area is generally undulating with the highest peak in Kokanawa area where elevation is about 432 m above mean sea level and Dago area with elevation of about 410 m in the southeastern parts of the study area. The lowest point is at Masama with elevation of about 260 m in the northwestern parts of the study area.

In broad term, the general relief of the area is defined by low lying ridges, hills and minor domes which rise above the surrounding areas. The drainage pattern of the study area is dendritic (Fig.1.2). All the streams in the area are seasonal, flowing only during the rainy season such as river Matseri, Gollo and Matsama.

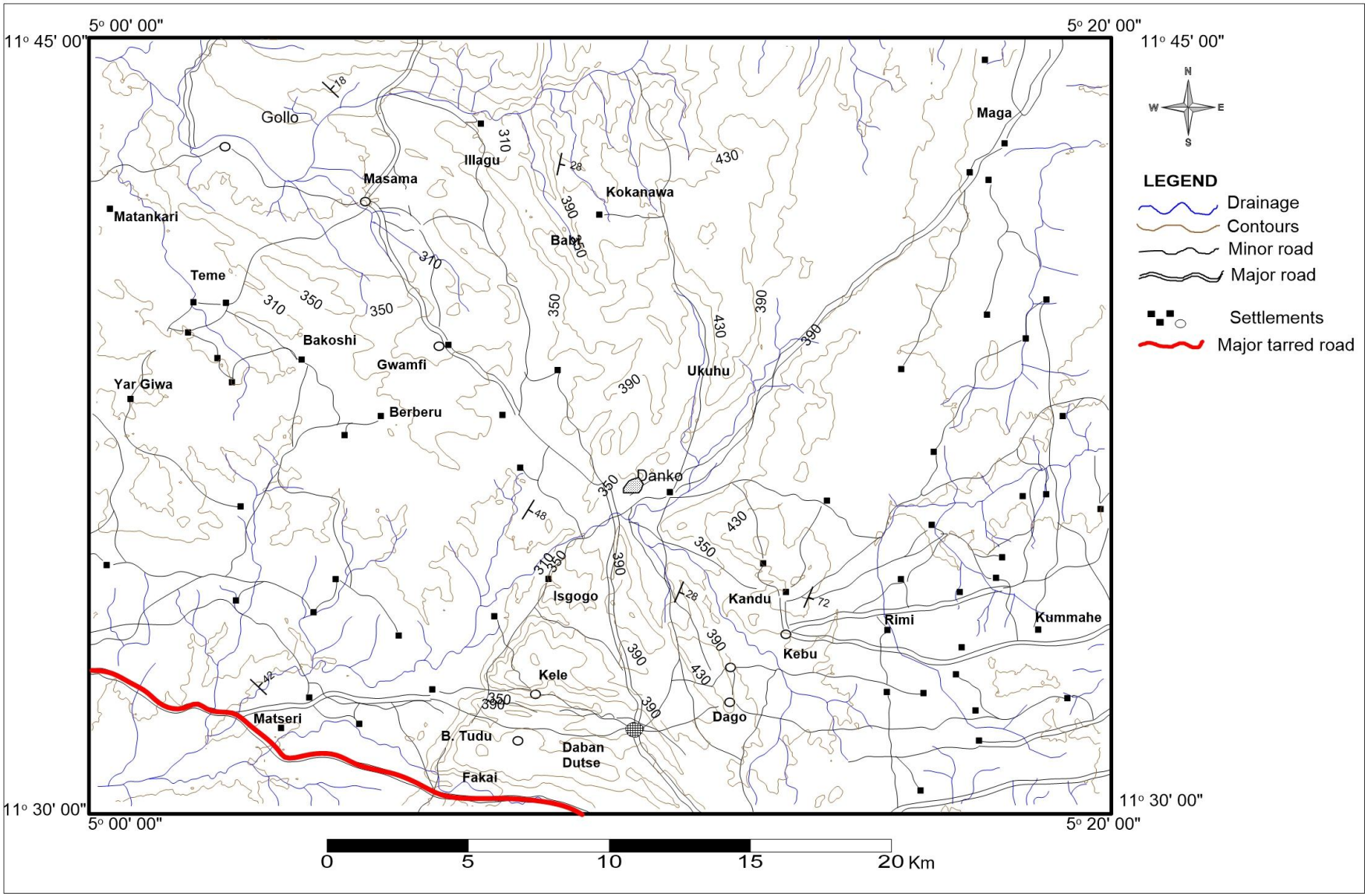


Figure 1.2: Drainage and Relief map of the study area.

1.5 STATEMENT OF RESEARCH PROBLEM

The Zuru Schist Belt is the most westerly and the widest of schist belts within the crystalline Basement Complex rocks in northwestern Nigeria with a length of about 280 km and a maximum width of 40 km. It forms a N-S trending belt in its northern part, but bifurcates into western and eastern arms in its southern part. The Zuru Schist Belt consist of assemblage of muscovite-biotite banded gneisses, porphyroblastic gneisses, migmatites, schists, quartzites, metavolcanics (amphibolites), Older Granites and minor rocks such as gabbro, andesite, granulites and calc-silicates (Adefila,1966; McCurry, 1978; Turner, 1983; Udoh, 1987).

Adefila (1966) was the first to map parts of the belt on a reconnaissance basis when he noted the occurrence of quuartzites, mica schists, granulites and calc-silicates rocks.

McCurry (1978) carried out the geological investigation of the northeastern sector of the Zuru Schist Belt, where she identified the Yelwa and Ribah faults and also produced a generalized geological map of parts of northwestern Nigeria and recorgnised quartzites, schists, metavolcanics and Older Granites as the major rock units in the area (Fig.1.3).

Turner (1983) carried out on reconnaissance studies the Zuru Schist Belt and described low angle dips and E-W folds upon which steep N-S cleavages were superimposed.

According to Ajibade and Wright (1989), the Zuru area contains two crustal blocks that were formerly separated by an unknown distance and became welded together during the Pan-African aggregation. The boundary between these blocks is now represented by the major NE-SW shear zone that crosses the Zuru Sheet.

Udoh (1987; 1988) undertook remote sensing interpretation of parts of the area and also recorgnised the presence of the Yelwa and the Ribah faults.

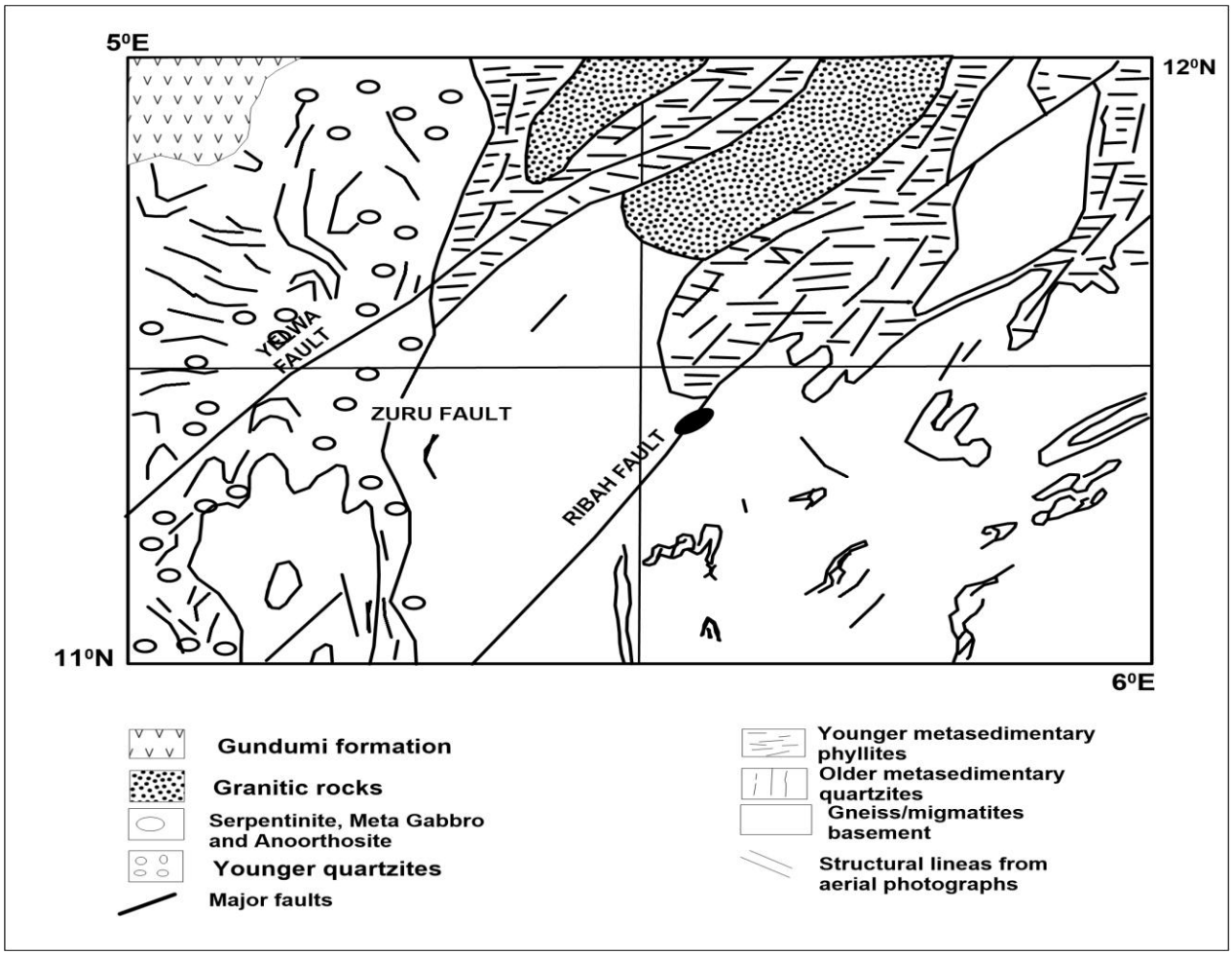


Figure 1.3: Simplified geological map of the Zuru area (after McCurry, 1978).

Danbatta (1991) carried out the Geological investigations of the southwestern portion of the Zuru Schist Belt. He noted the three deformation episodes, (D1, D2 and D3) that affected the rocks of the southwestern portion of the Zuru Schist Belt and documented the occurrence of amphibolite, quartz schist, Zuru anticlinorium and Iri dome.

Danbatta (2005) undertook the structural interpretation of the southwestern part of the Zuru Schist Belt using remote sensing data and identified a number of structural elements. These are the three major NNE-SSW to NE-SW trending Yelwa, Yauri and Ribah dextral faults, a NW-SE trending Gunu sinistral fault and a major N-S trending anticlinorium called the Zuru anticlinorium.

Danbatta and Garba (2007) worked on the Geochemistry and petrogenesis of Precambrian amphibolites within the southwestern part of the Zuru Schist Belt and noted that 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.

Danbatta (2008b) studied the Precambrian crustal development in the southwestern part of Zuru Schist Belt. He noted that the Zuru Schist Belt is lithologically different from the other schists belt in northwestern Nigeria in that it is predominantly composed of quartzites with very surbodinate schists and amphibolites, but no B.I.Fs.

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, B) for regional geologic mapping and structural investigations, and discovered three gold bearing shear zones. According to them, 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.

However, apart from the previous works on the study area by Adefila (1966), McCurry (1978) Turner (1983), Udoh (1987; 1988), Danbatta (1991), Danbatta (2005), Danbatta and Garba (2007), there is no documented studies on the structural evolution of the northwestern part of the Zuru Schist Belt (ZSB).

1.6 AIM AND OBJECTIVES OF THE STUDY

The aim of this work is to carry out a comprehensive geological mapping of the northwestern part of the Zuru Schist Belt to identify the rock types and structural features present in the area.

The objectives of the study are:

i. To carry out remote sensing interpretation of the lineaments within the study area

ii. To undertake detailed petrographic description of the various rock types

iii. To study the deformation pattern of the area through strain analysis on photomicrographs of rock samples.

iv. Produce a geological and structural map of the area on a scale of 1: 50,000.

1.7 SCOPE OF THE PRESENT WORK

The present work reviewed previous works carried out by authors that have studied and worked on the Zuru Schist Belt. The fieldwork exercises involved reconnaissance and detailed surveys of the study area, collection of rock samples, measurement of linear and planar rock structures and recording their strikes, dips, thicknesses and coordinates. Instruments such as Global Positioning System (G.P.S), geologic compass, tape and the topographic map of the study area were used during the field mapping exercise. Laboratory analysis such as petrographic analysis; strain analysis and stereographic projections were undertaken on samples obtained within the study area

CHAPTER TWO

REGIONAL GEOLOGY

2.1 PREAMBLE

This chapter reviews the geology, tectonic evolution, metamorphism and structures within the Nigerian Basement Complex. 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 it 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)

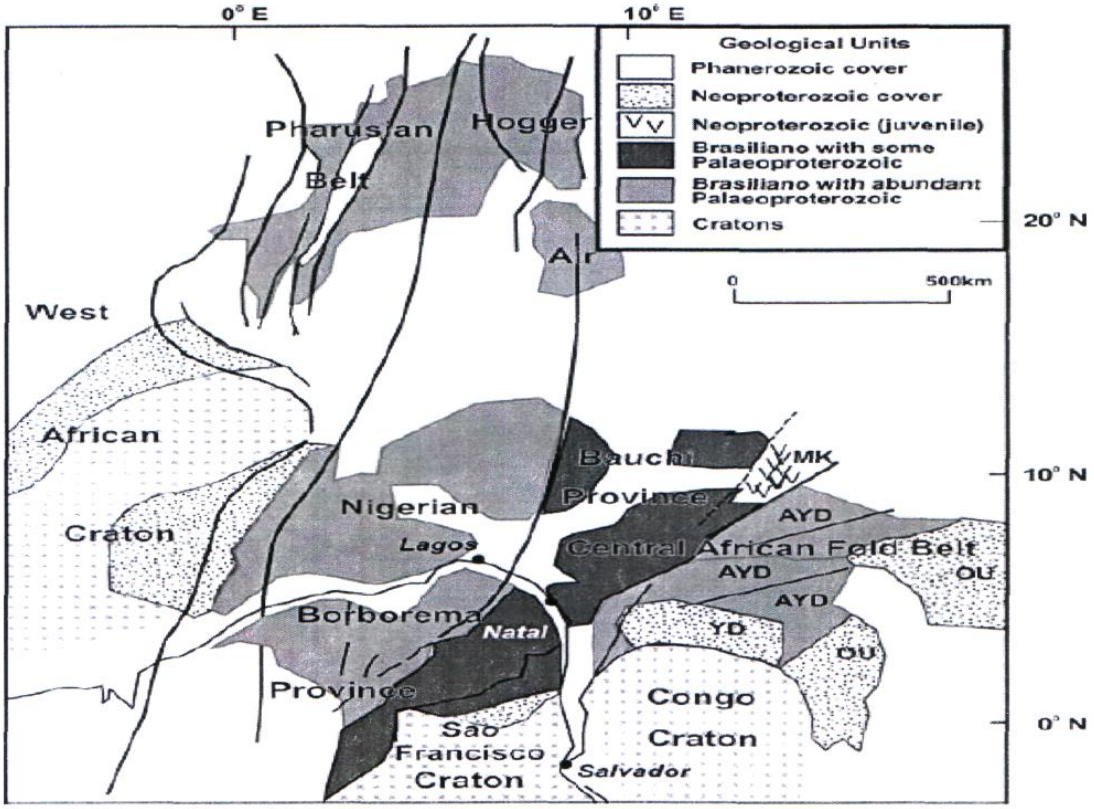


Figure 2.1: Location of the Nigerian Basement Complex between the West African Craton and Congo Craton (Dada, 2008).

Geochronological data indicates that the Nigerian Basement Complex is polycyclic and comprises rocks of Achaean (2.0 – 3.0 Ga), Eburnean (2000 ± 200 Ma) and Pan African (750 – 450Ma) (Turner, 1983; Fitches *et al*., 1985; Ajibade *et al*., 1987; Elueze, 2000).

Intruding and truncating the Nigerian Basement are a number of Younger Granites ring complexes of Mesozoic age (Falconer, 1911; Jacobson *et al*. 1964). The structural framework of

Nigerian Basement Complex is defined by both brittle deformation structures (joints, faults and shear zones) and ductile deformational structures (folds, lineations and foliations).

2.2 LITHOLOGY

The Nigerian Basement Complex rocks have been classified into three petro-lithological units (Fitches *et al*., 1985; Ajibade *et al*., 1987) namely:

i. Gneisses and migmatites
ii. Schist Belts (metasedimentary and metavolcanics rocks), and
iii. Older Granites.

2.2.1 Gneisses and Migmatites

The migmatite gneiss complex is composed of the oldest rock Basement Complex and have been dated as Birrimian age (about 2500 million years). It is generally considered to be the Basement Complex sensu stricto (Rahaman, 1988; Dada, 2006) and it is the most widespread of the component units, 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, 1985).

2.2.2 Metasedimentary and Metavolcanics (Schist Belts)

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 (green schist facies) rock (Fitches *et al.*, 1985). All the schist belts are predominantly composed of metamorphosed

pelitic and semi-pelitic rocks (Ekwueme, 1995) but each belt differs in the amount of such lithologies as conglomerates, greywacke, quartzite, calcareous rocks and volcanic rocks.

Turner (1983) and Ajibade *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. These schist belts 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 (Ebguniwe, 1982); and Zuru (McCurry, 1978; Danbatta, 1991; Danbatta and Garba, 2007; Ramadan and Abdel-Fattah, 2010).

2.2.3 Older Granites

The intrusive granitoids of northwestern Nigeria were first named Older Granites by Falconer (1911), to distinguish them from the tin-bearing Younger Granites of Jurassic age which occurs in central Nigeria. The Older Granites occur as distinct plutons of limited petrographic types (Ekwueme and Onyeagocha, 1982; Rahaman, 1988) such as the Zaria granite batholith (Ike, 1988) and Mainchi granite batholith (Egbuniwe, 1982) which are oriented in a general N-S direction.

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

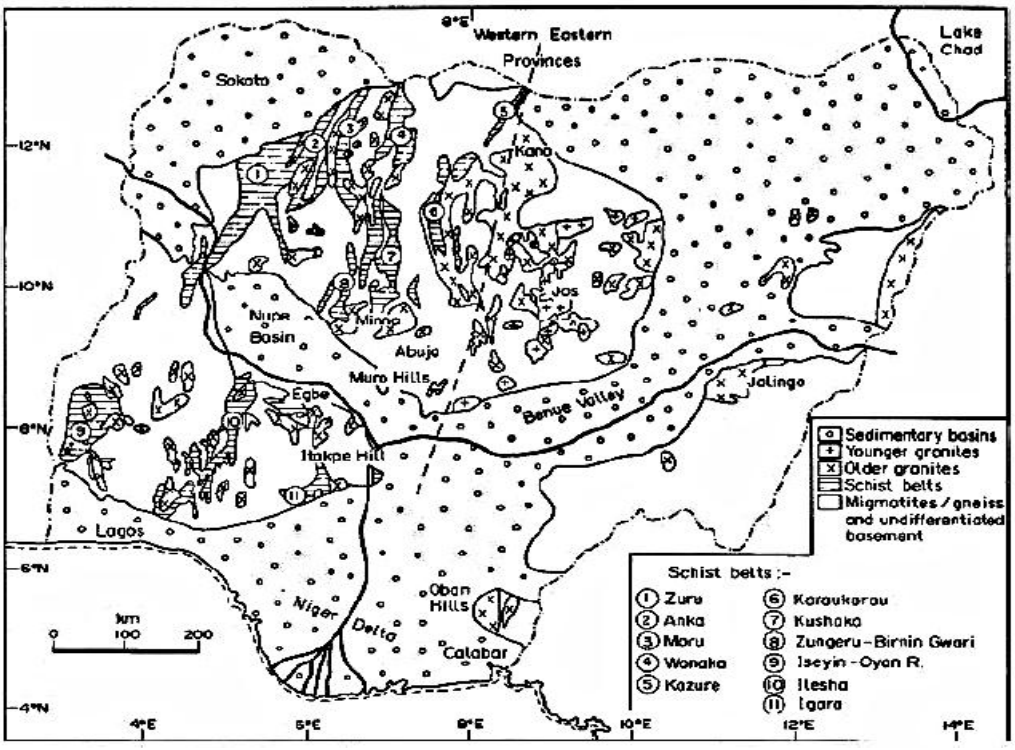


Figure 2.2: Schist belt locations within the context of the Geology of Nigeria (after Woakes *et al.*, 1987).

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 500-700 Ma (Van Breemen *et al.*, 1977; Rahaman *et al.*, 1983).

2.3 EVOLUTIONARY MODELS OF SCHIST BELTS

2.3.1 Background

The Nigerian schist belts are believed to be of two types (Danbatta, 2007) those composed of Older Metasediments (mainly found in southwestern Nigeria) and the low-grade Younger Metasediments (mainly found in northwestern Nigeria).

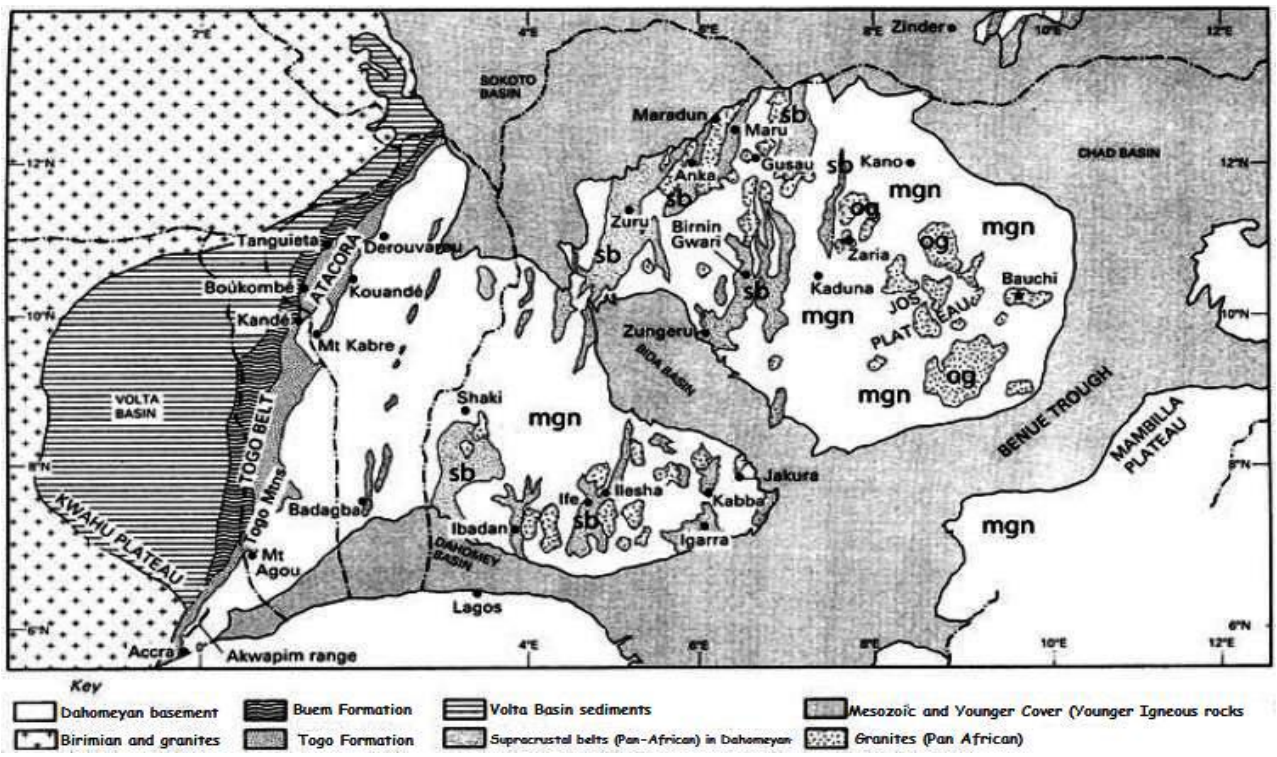


Figure 2.3: Basement Geology of Nigeria and adjacent areas. Note the locations of migmatite-gneiss complex (mgn), the schist belts (sb) and the Older Granites (og) (Wright, 1985).

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). But Vaniman (1976) considered the existence of a major sedimentary trough to be responsible for the deposition of the Nigerian schist belts.

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 belts with 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, 2008). 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.

Structural control is also important for the evolution of the schist belts. The huge Anka-Yauri-Iseyin (AYI) and the Kalangai-Zungeru-Ifewara (KZI) lineaments that run throughout the Nigerian Basement Complex are considered as deep faults defining tectonic blocks (Danbatta, 2008). 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, the reactivation of pre-existing rocks and the formation of the remaining schist belts and syn orogenic plutonism.

All the models of evolution of Nigerian Schist Belts over the years could be classified under ensialic and ensimatic processes.

2.3.2 Ensialic 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, Chukwu-Ike (1978) argued that the schist belts in NW Nigeria are fault bounded ensialic troughs.

Turner (1983) also considered the Anka belts with the 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. In supporting this view, 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 Olobanyi (1997) emphasized the role of Eburnean events in the formation of the Egbe-Isanlu basin due to plume induced continental rift.

2.3.3 Ensimatic Models

Ensimatic models of evolution had also been 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). For the Anka, Ife-Illesha and Zuru belts, earlier works suggested that oceanic basins closed to form some of the schist belts, 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 microcontinents 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, thus the Anka and Zuru belts are considered as a pair of belts that evolved through ensimatic processes.

2.3.4 Ensialic 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 in view of common characteristics such as the presence of BIFs and close proximity to KZI fault zone. He 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 new model 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 where 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 Pan-African models. Herein D1 is ascribed to Eburnean compression and D2 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 STRUCTURAL FRAMEWORK OF THE BASEMENT COMPLEX OF NIGERIA

2.4.1 Faults and Shear Zones

A characteristic feature of the Nigerian Basement Complex tectonics is the widespread occurrence of fractures, a general term used to describe a break or rupture in a rock. It is indicated by such lineaments as silicified shear rocks and zones, which form as dykes and ridges, also straight channeled streams which exploit the weak zones of the earth. 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 following streams e.g. the lower Niger and are also found around the Jos plateau. They are traceable as far north as the taureg area of the Niger republic (Ball, 1980). These fractures are also marked by considerable shearing and brecciation features, 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, as 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 Table 2.1.

Wright and McCurry (1970) discussed major N-E trending faults in Nigeria. These faults are strike-slip faults which he considered connected to the initiation of fractures in the south Atlantic. Present landsat studies also revealed the existence of these lineaments west of Kaduna and Zaria. These are Yelwa and Kalangai (Truswell and Cope, 1963) shear faults, whose traces possibly passes beyond Katsina and Kano and are suspected to continue under sediments into Niger Republic (Danbatta, 1999).

Danbatta (2003b) showed that the Kalangai fault (K.Z.F) lineaments pass through the Kazaure Schist Belt (KZSB) in a general NE-SW to NNE-SSW, the direction along which the belt was emplaced. He showed that the major NE-SW KFZ is parallel to a number of other faults showing a similar dextral displacement, which together form an important set of faults throughout the whole of Nigeria.

Two main trends have been captured through Landsat TM study by Goki *et al*. (2011b) and these include NW-SE lineaments and a second pair of NE-SW and NNE-SSW trends, which appear to be abundant but spatially discontinuous and shorter. These trends coincide with deep aeromagnetic trends, which have been attributed to an extension of Atlantic fracture zone that extends into Nigerian Basement Complex (Olaselinde *et al*., 1990). The north westerly trends are not apparent in the aeromagnetic trends, even though they are very pronounced in the landsat TM 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 the 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 sets.

2.4.2 Folds and Foliations

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

Multiple phase folding have 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 superposed 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 (Grant, 1978; Ajibade, 1980) and Abuja. 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, 2008).

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 disharmonic 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

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 to middle belt metamorphic facies of metasediments on one hand and upper amphibolite facies of the crystalline rocks on the other hand (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).

Grade of metamorphism varies from one place to another. In Zungeru area for example, Ajibade *et.al*. (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, 2003a).

The study of microscopic domains of rocks within the Kazaure area enabled Danbatta (2003a) enabled the identification of two generations of progressive metamorphism, M1 and M2 and a static one M3. The mineral assemblages showed evidence of being either syn or post D1 and syn or post D2 and the earliest metamorphic event reached lower amphibolite facies condition while the second metamorphic event which is the main metamorphic event reached a low grade greenschist facie grade of metamorphism.

Retrograde metamorphism occurred in sheared fractured zones, with chloritization of biotite, sericitization of feldspar and conversion of hornblende to biotite as a result of reduction in temperature and pressure (Ajibade, 1987; Egbuniwe, 1982; Garba, 1992). Texturally, muscovite (or sericite) probably of regional metamorphism are lath like and aligned in the schistocity, while the larger ones are tabular and overgrew the schistocity during contact metamorphism. Thermal

metamorphism is recognized in the Anka and Maru Belts which results from the emplacement of Older Granites. This has formed a narrow contact aureole. In the Maru area, mineral assemblages of quartz, muscovite, biotite, chloride, opaque minerals (magnetite and pyrite) in 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 (Miyashiro, 1973).

CHAPTER THREE

MATERIALS AND METHODS

3.1 DESK STUDY

Desk study involves reviewing reports (both published and unpublished) and journal articles to obtain relevant information about the study area.

3.2 FIELD WORK

The field work exercise lasted for three weeks and a total of 30 fresh samples were collected at different locations within the study area for laboratory analysis. The orientations (strikes and dips) of structural elements were measured using compass clinometer. Sampling sites were recorded using a global positioning system (G.P.S). Photographs of outcrops were taken and a brief description was made.

3.2 REMOTE SENSING ANALYSIS

This was used in the study of the structural elements within the study area and to produce a lineament map of the study area. Remote sensing analysis was carried out by first downloading the digital elevation model (DEM) of the 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.

3.4 LABORATORY WORK

Laboratory work carried out for this study include: Petrography, strain analysis, stereographic projections and rose diagram preparations.

3.4.1 Petrography

A total of twenty (20) fresh samples were selected for thin section preparation in Department of Geology, Ahmadu Bello University. These rocks were sliced both perpendicularly and parallel to the foliation plane.

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

3.4.2 Strain Analysis

The Fry (1979) method was employed to accomplish this task. This technique is based on the asumption that initially anti-clustered distribution of points will change after deformation into a non-uniform distribution. Based on this method, the centre of the entire quartz grains screen were digitized on selected micrographs of the quartzites, using Geofry package which created a vacancy called the Fry hallow of ellipsoid shapes giving the long and short axes. The orientation of the ellipses also gave the orientation of the strain ellipse. the finite strain ellipsoid that is almost circular shows low degree of grain deformation, while the flattened type shows a greater degree of grain deformation.The analytical procedures adopted has been discussed in detail in the work of Goki *et al*., (2011a).

3.4.3 Rose diagrams and Stereographic projections

Structural analysis of rocks is often done using orientation diagrams such as rosette and stereographic projections. These tools have invaluable application in geology and could unravel the history of deformation in several geological settings.

Stereographic projections were produced with stereoplot software using the values obtained from measurements of dips and strike of structures within the area so as to have a general knowledge on the orientation of structural elements. Rose diagrams were also produced using GeoRose software to have an idea on the orientation of structural elements within the area.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 BACKGROUND

Field observations, petrographic descriptions, lineament analysis and structural analysis of rocks within the study area are discussed in this chapter.

The study area falls within the Zuru Schist Belt and comprises of the following major rock types; quartzites, muscovite schists and medium grained granite as well as minor rocks such as quartz veins and pegmatites (Fig 4.1). A cross section showing the relationships between the mapped lithologies was also drawn and presented in (Fig 4.1). The field relationships and thin section microscopic description of the major rock types are given below.

Both ductile and brittle deformational structures were mapped in the study area. They include joints, folds, foliations and faults and the deformational episodes responsible for their formations were analysed.

The rocks of the study area are deformed. From field studies, it can be inferred that the muscovite schist and quartzites have been affected by two episode of deformation denoted as D1 and D2. The symbols used for the structural descriptions are D for deformation, F for folds and S for foliations. The relative ages of events are designated by subscript numbers. These deformational episodes are characterized by varieties, magnitude and styles of folding.

4.2 GEOLOGY AND FIELD RELATIONSHIPS

4.2.1 Quartzites

Quartzites occur mostly as hills (Plate I) with fragments of the rock on the ground in the vicinity of the hill within the study area (Plate 1I). It constitutes about 60% of the rock types within the study area. Two different varieties of quartzite varieties are distinguished based on textural and compositional relationships. These are: i) a grey variety that contains a considerable amount of micaceous minerals occurring in areas around Kokanawa and Ulasa Sarki (Plate III) and ii) a brownish white variety which is poor in micaceous minerals occurring around northwestern parts of Isgogo area and extending to areas around Kandu, Kebu, Dago (Plate IV).

In other parts of the study area, quartzites occur intercalated with schists and were highly fractured displaying different styles of joints, while in other localities, quartzites are highly folded forming very large isoclinal folds. No clear contact between the quartzite and other rock types was recorded.

In hand specimen, it is massive, medium grained and showing interlocking crystals of quartz grains. Mineralogically it is composed dominantly of quartz and minor occurrence of muscovite. In thin section plane polarized light view, quartz appears colorless, anhedral and completely lacking cleavage with a low to medium relief (Plate VA). In cross polarized light view, quartz shows a gray to white and sometimes to light yellowish white interference colour. It is granoblastic with seriate grain boundaries (Plate VB). Most of the quartz grains exhibit undulose extinction and mylonitic texture is also common in some places. Muscovite occurs as elongate minerals with low relief and has a second order interference colour of red and green (Plate VIA and VIB).

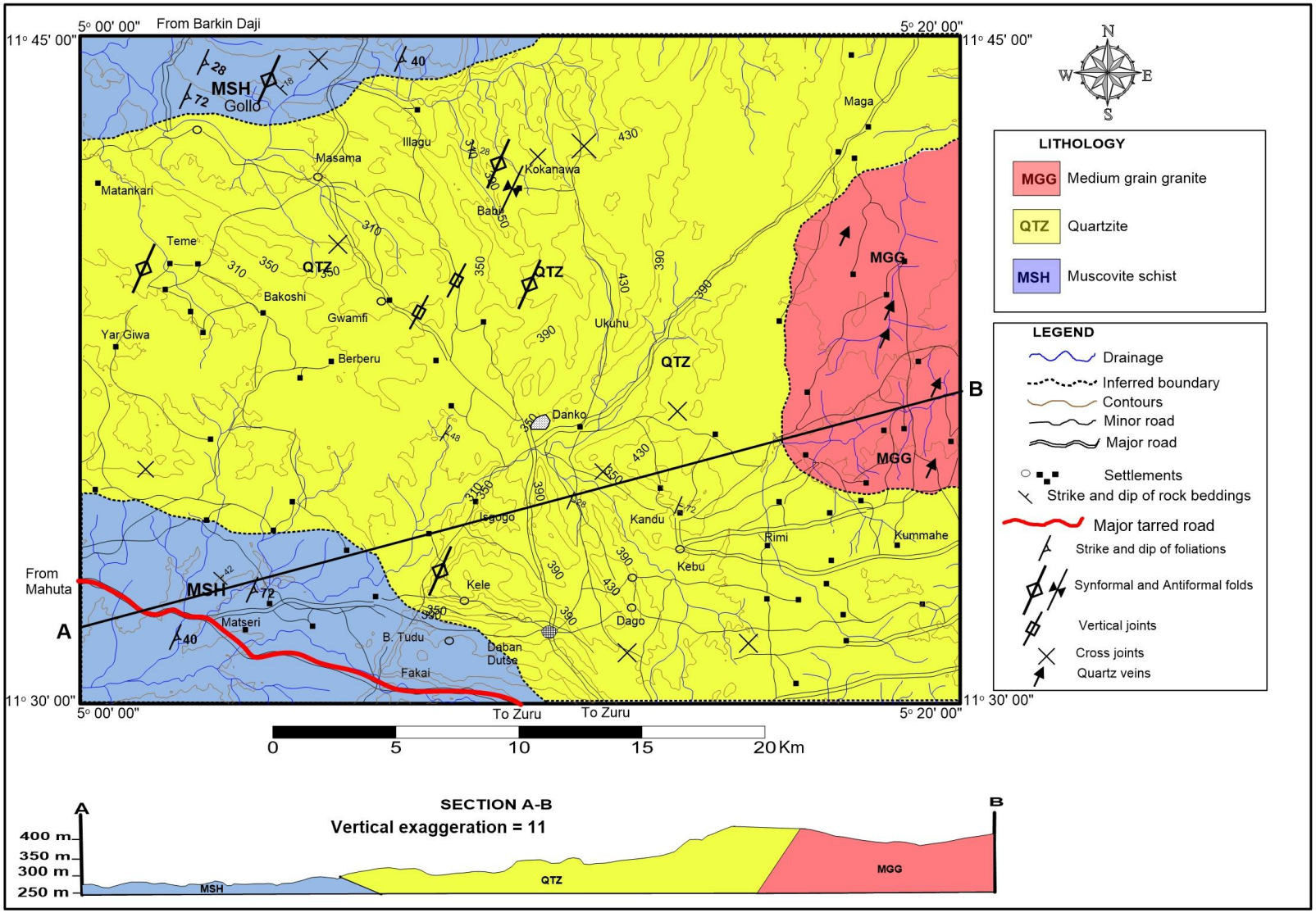


Figure 4.1: Geological map and cross section A-B of the study area.



Plate I: Outcrop of quartzite occurring as a hill at Kokanawa 11^0 42' 5.9"N and 5^0 10' 0.1"E



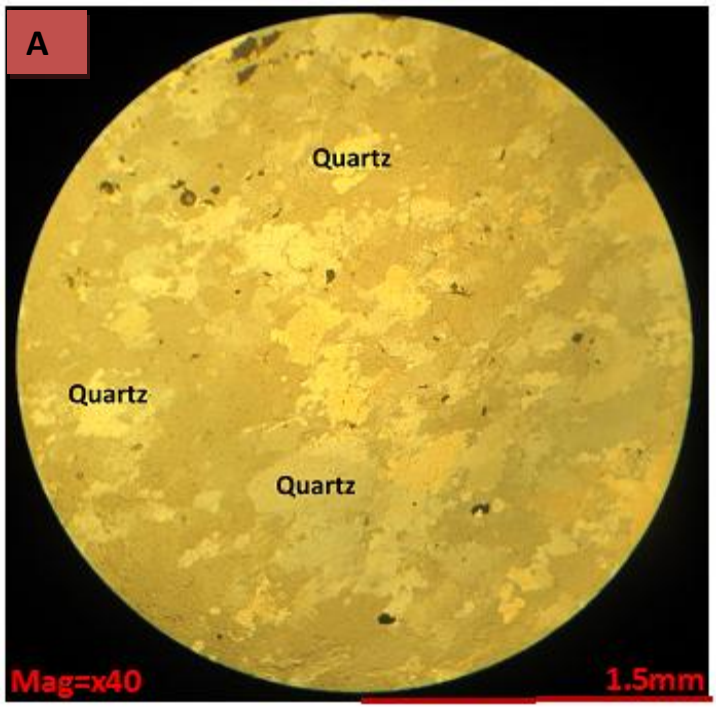
Plate II: Photograph of broken fragments of quartzite 11^0 39' 4.0"N and 5^0 07' 12.4"E



Plate III: Outcrop of grey quartzite at Kokanawa 11^0 42' 7.0"N and 5^0 10' 0.9"E



Plate IV: Outcrop of brownish white quartzite at Isgogo 11^0 34' 10.6"N and 5^0 08' 5.6"E



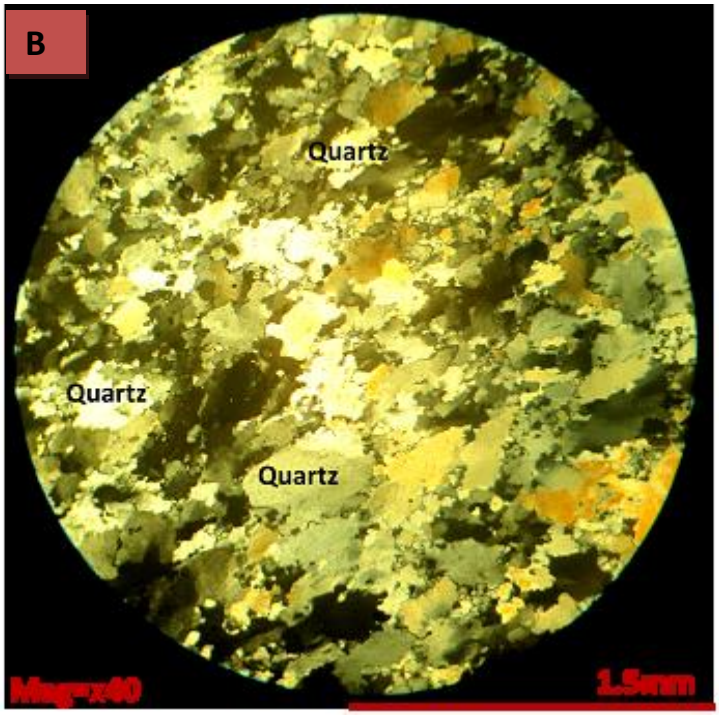


Plate V: A) Photomicrograph of quartzite under P.P.L completely composed of quartz; B) Photomicrograph of quartzite under X.P.L with seriate grain boundaries (Slide AL1).

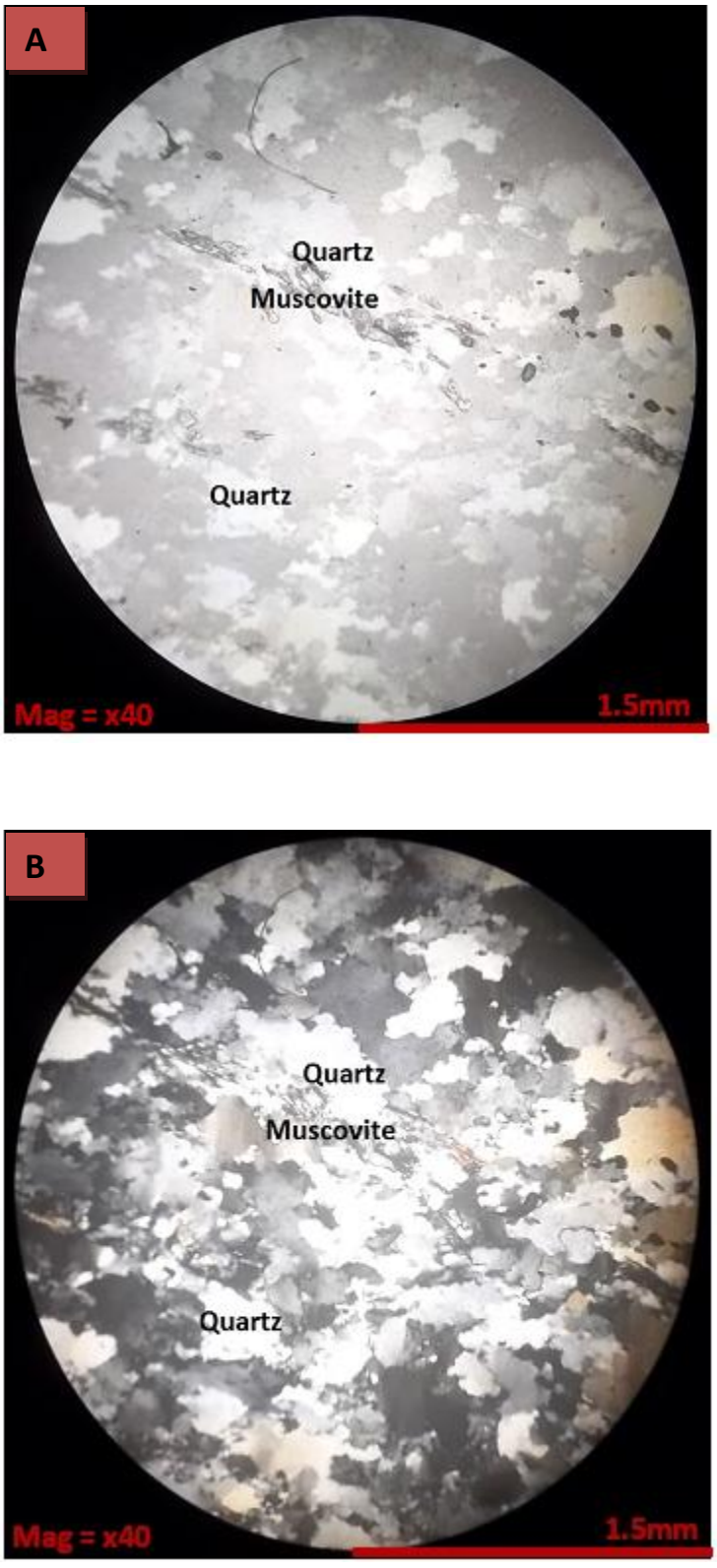


Plate VI: A) Photomicrograph of quartzite under P.P.L B) Photomicrograph of quartzite under X.P.L Showing lineated muscovite minerals (Slide AL12).

4.2.2 Muscovite schist

Muscovite schist occurs as low lying outcrops around river channel and road cut exposures (Plate VII). It constitutes about 25 percent of the study area. It outcrops mostly in the northwestern parts of the study area around (Gollo, Masama) and southwestern parts of the area around Matseri. In areas around Matseri, muscovite schist occur with intercalation of quartz stringers (Plate VIII), the rock is fractured and cleaved with cleavage direction mostly in the NE-SW direction.

In hand specimen the muscovite schist has a silky shinny appearance due to the abundance and the reflective ability of muscovite mica. The shiny flakes of mica were conspicuous enough to allow megascopic determination. It is generally medium grained and dark gray in color. In plane polarized light, quartz is colourless, has a low relief and not pleochroic while muscovite display colourless to pale green hue, weak pleochroism, low to medium relief and has cleavage in one direction (Plate IX). In cross polarized light, quartz shows low interference colour of first order grey and undergoes undulose extinction while muscovite undergoes parallel extinction (Plate X).



Plate VII: Photograph of Muscovite schist occurring along a river channel at river Masama 11^0 42' 5.8"N and 5^0 5' 21.3"E



Plate VIII: Photograph of Muscovite schist showing quartz stringers at Matseri 11^0 32' 13.2"N and 5^0 05' 2.4"E

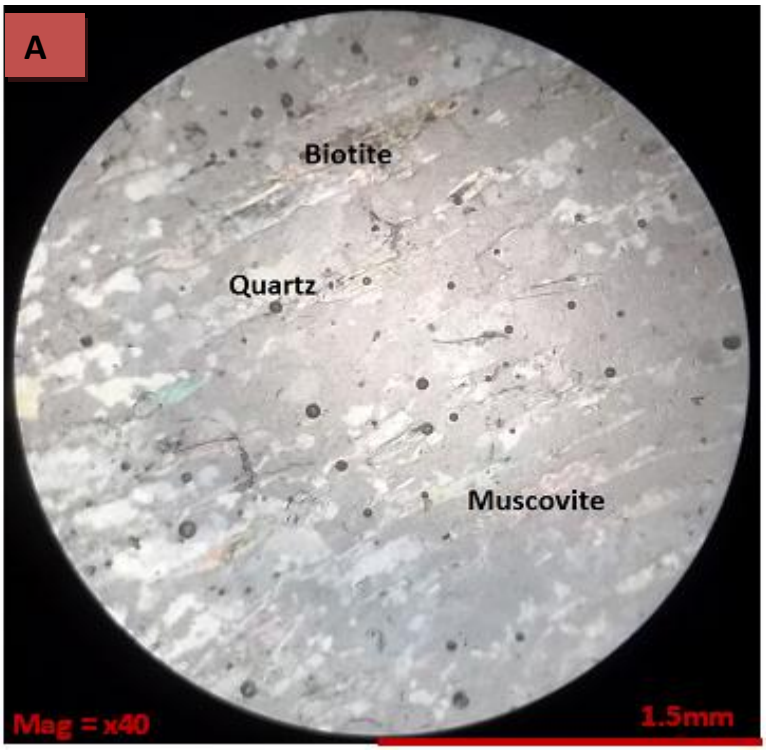


Plate IX: Photomicrograph of muscovite schist in plane polarized light (Slide AL5).

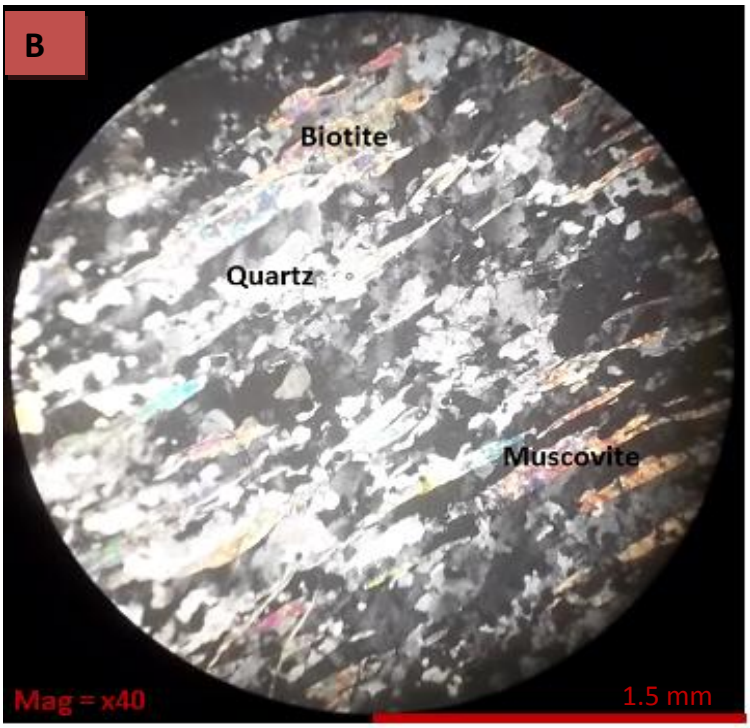


Plate X: Photomicrograph of schist in cross polarized light (Slide AL5).

4.2.3 Medium - coarse grained granite

This rock is light grey in colour and covers about 15% of the study area. In most places it outcrops as whalebacks and dome and covers nearly the entire eastern parts (North of Kumahhe and South of Maga) (Plate XIII) of the study area. Phenocryst of feldspar minerals on this rock range in thickness from about 1.0cm to 1.5cm. The rock contains a lot of quartzo-felspathic pegmatite and veins of different thicknesses and orientations Plates (XI and XII).

In plane polarized light, quartz is colourless with low relief and has anhedral form. Microcline show medium reliefs with two dimensional cross-cutting cleavages. Perthite and sericite also show a perfect cleavage and has moderate relief (Plate XIV). In cross polarized light (X.P.L), microcline show a tartan twinning pattern and a gray to white interference colour, muscovite show a green interference colour, quatz undergo undulose extinction while alteration of perthite to sericite is also visible (Plate XV)



Plate XI: Photograph of quartzo-feldspathic pegmatite at 11^0 35' 2.6"N and 5^0 19' 44.9"E



Plate XII: Quartz veins on a medium grained granite outcrop 11^0 39' 21.6"N and 5^0 13' 39.1"E



Plate XIII: Whaleback outcrop of medium grained granite at 11^0 35' 2.6"N and 5^0 19' 44.9"E

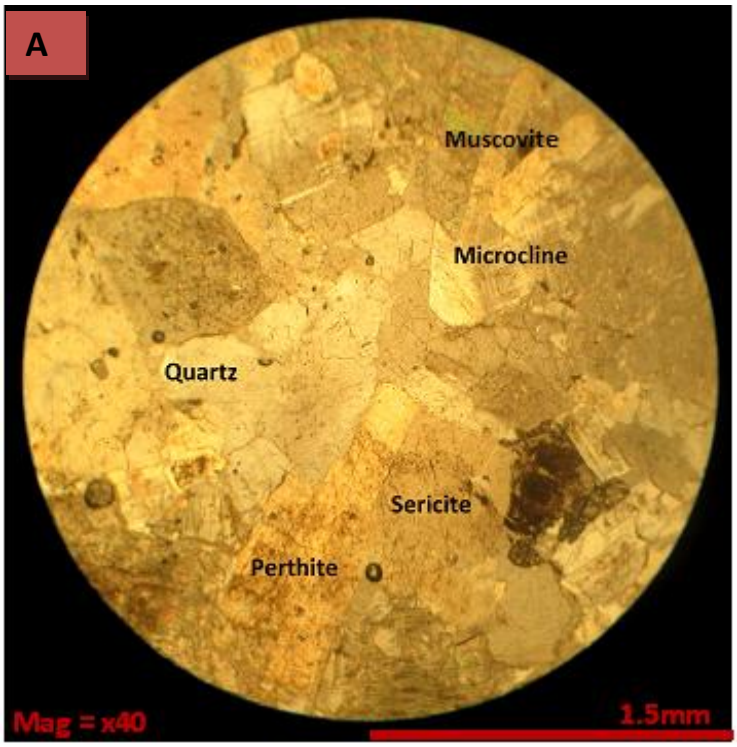


Plate XIV: Photomicrograph of medium to coarse grained granite in plane polarized light (Slide AL26).

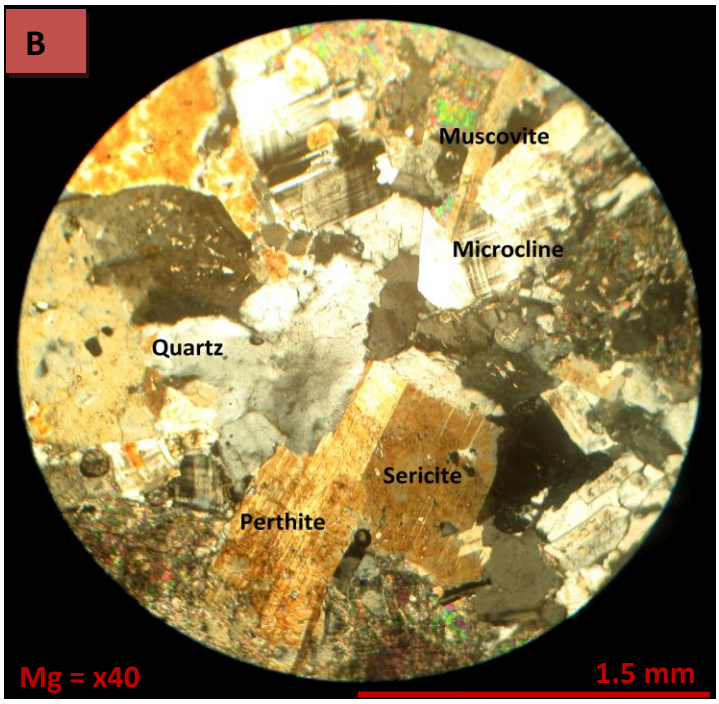


Plate XV: Photomicrograph of medium to coarse grained granite in cross polarized light showing perthite altering to sericite (Slide AL26).

4.2.4 Minor Rocks

Minor rocks constitute about 6% of the study area and includes; quartz veins, xenoliths and quartzo-feldspathic pegmatite dykes. Quartz veins occur only on the granites and are widely distributed. They are glassy and vary widely in length and width. The average length of quartz vein recorded is about 25 m (Plate XVII) and average width is 2.5cm (Plate XVI). Measurements of orientation (strike and dip) of the veins showed that they trend in an NE-SW direction. Quartzo-feldspathic pegmatite dyke shows large crystals of quartz and orthoclase feldspars. The pegmatite range in width from 30 cm to 50 cm intruding concordantly into the granites.



Plate XVI: Photograph of quartz vein with thickness of about 2.5 cm 11^0 34' 2.3"N and 05^0 20' 00"E



Plate XVII: Photograph of a quartz vein with length of about 25 m 11^0 34' 2.3"N and 05^0 20' 00"E

4.3 LINEAMENT ANALYSIS

4.3.1 Extraction and Digitization

Extraction of lineaments was carried out manually (Fig.4.2). Lineaments were imported into the Arc GIS software and manual digitization of lineaments was carried out to generate a lineament map (Fig 4.3). Lineaments digitization was done using DEM due to its high resolution and ability to display only lineaments of geological origin. Digitization of lineaments was carried out following change in tone on the digital elevation model. After the digitization of lineaments, statistical analysis of lineament properties in terms of its length, density and relative abundance and orientation was carried out.

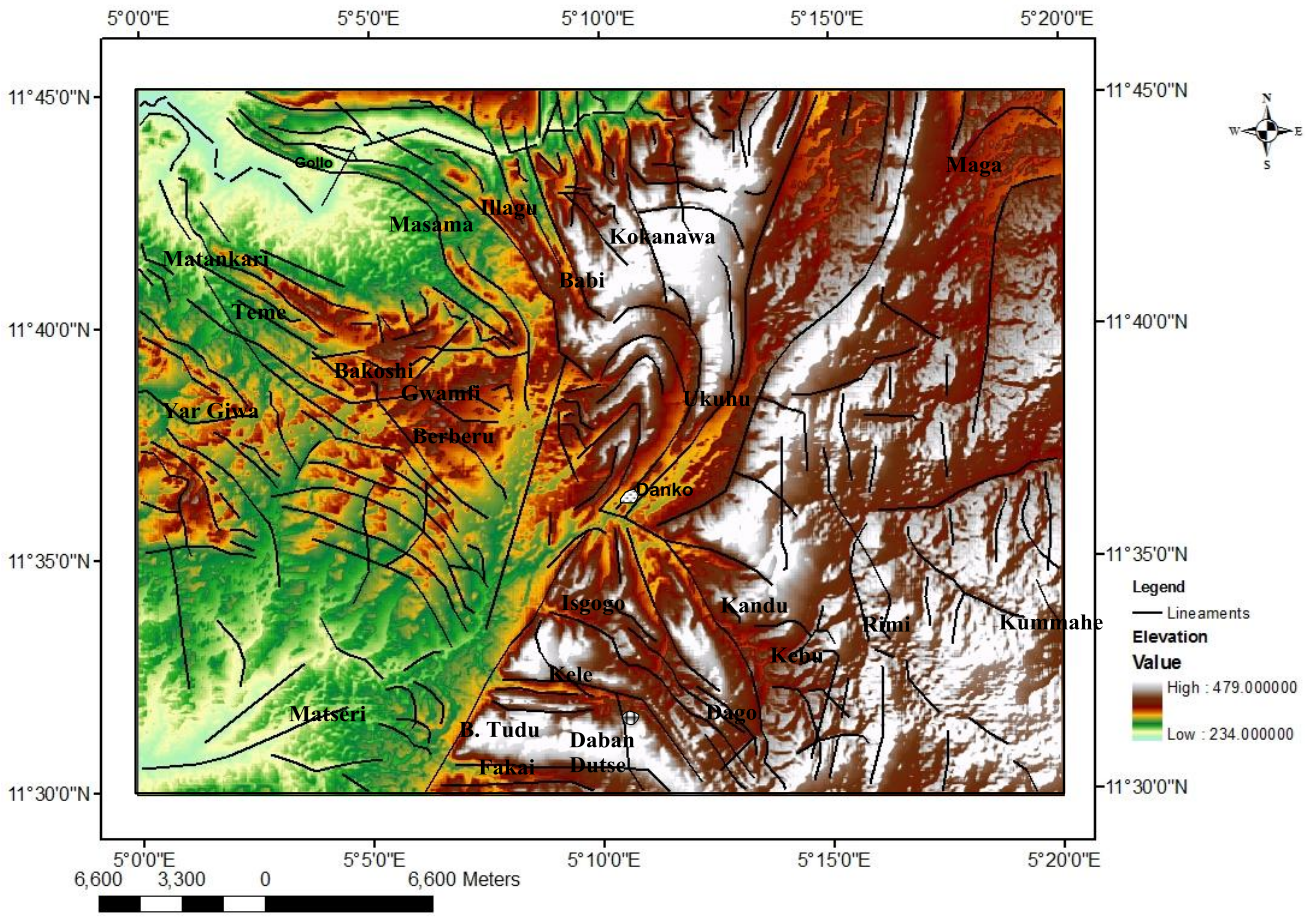


Figure 4.2: Lineament extraction from ArcGIS showing Danko lineaments.

4.3.2 Lineament Orientation

Analysis of lineaments was carried out and lineaments were group into four classes (E-W, NW-SE, NE-SW, N-S). A total of 211 lineaments were digitized and 8 (3.791%) have E-W orientation, 120 (56.87%) have NW-SE orientation, 47(22.27%) have NE-SW orientation and 36 (17.06%) of this lineaments have a N-S orientation (Table 4.1). Using a rose diagram, a dominant NW-SE direction for the lineaments was observed (Fig 4.4).

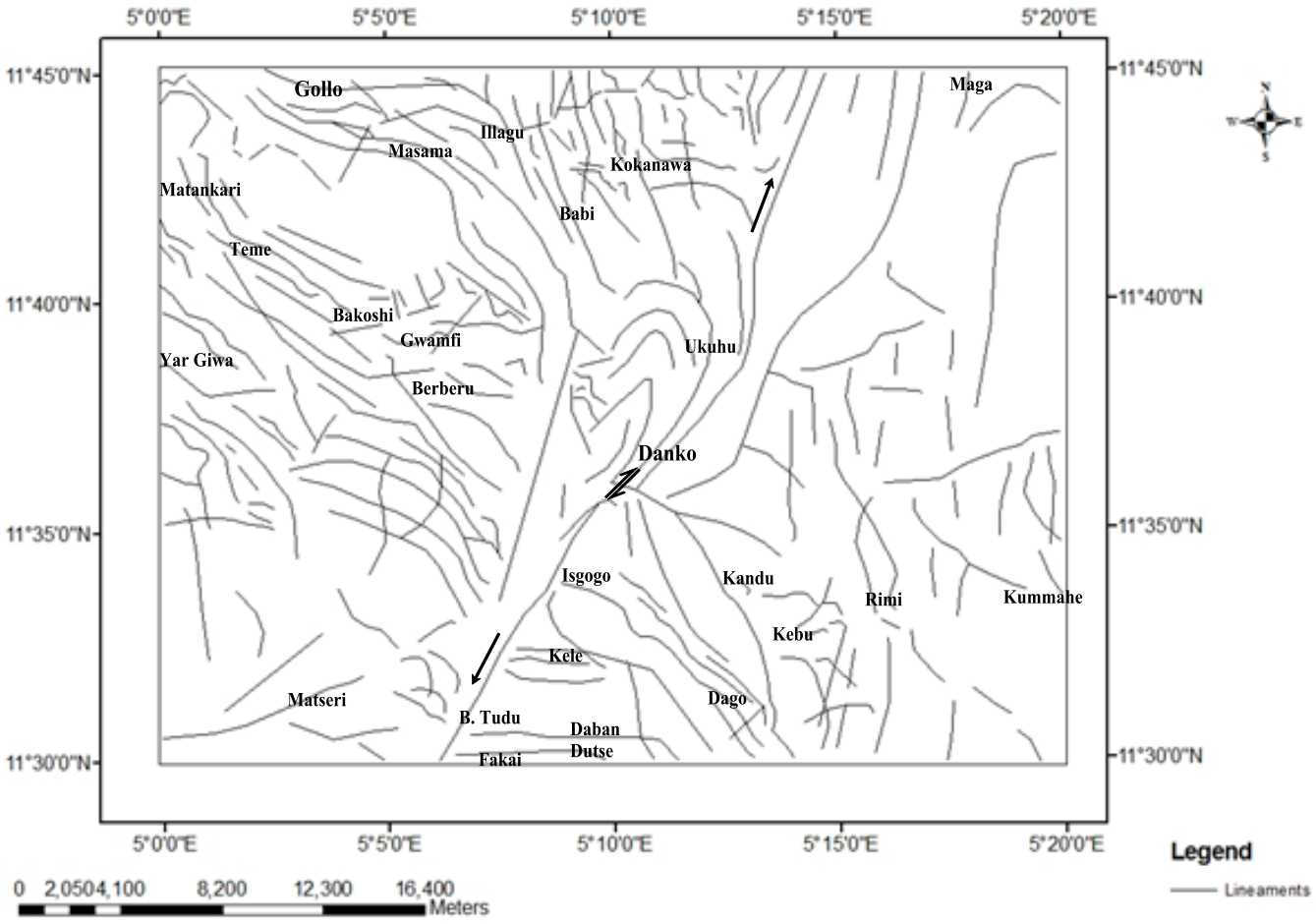


Figure 4.3: Lineament map of the study area showing a major dextral transcurrent fault.

Table 4.1: Lineament orientation properties

S/N		E-W	NW-SE	NE-SW	N-S
1	Number	8	120	47	36
2	Percentage	3.791%	56.87%	22.27%	17.06%

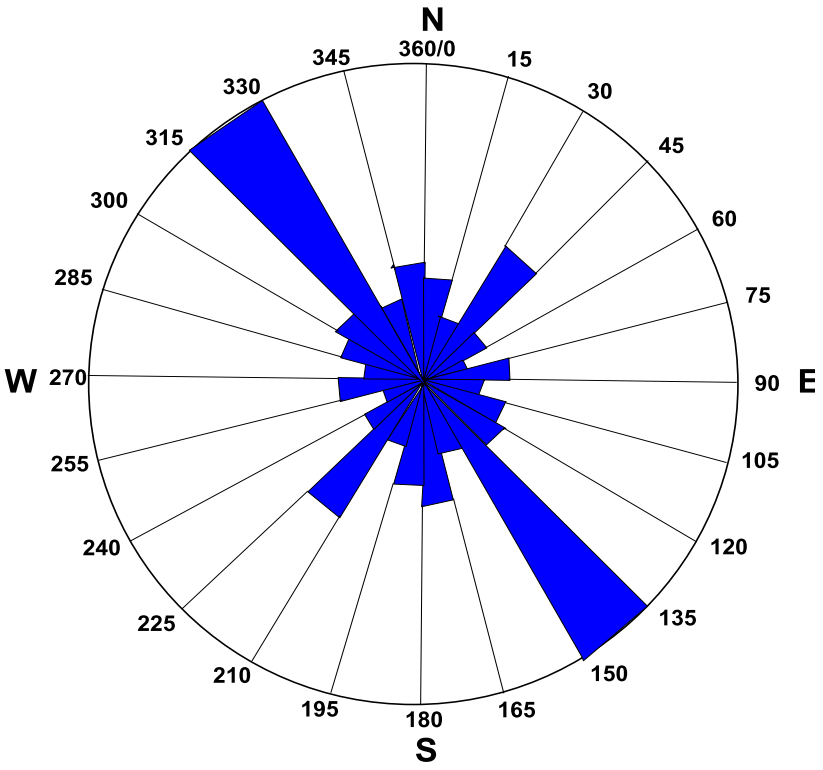


Figure 4.4: Rose diagram of direction for lineaments in the study area.

4.3.3 Lineament Length

Digitized lineaments have a maximum length of 21.07 km, a minimum length of 0.37 km, and a mean length of 3.816 km. Lineament length was divided into five classes. Out of the 211 digitized lineaments, 78 (36.96%) were very short, 97 (45.97%) was short, 30 (14.218%) was moderate, 5 (24%) were long and 1 (0.5%) was very long (Table 4.2). Histogram for lineaments length display positively skewness (Fig 4.5).

Table 4.2: Lineament Length

S/N		Very Short	Short	Moderate	long	Very Long
1	Number	78	97	30	5	1
2	Percentage	36.96%	45.97%	14.2%	2.4%	0.5%

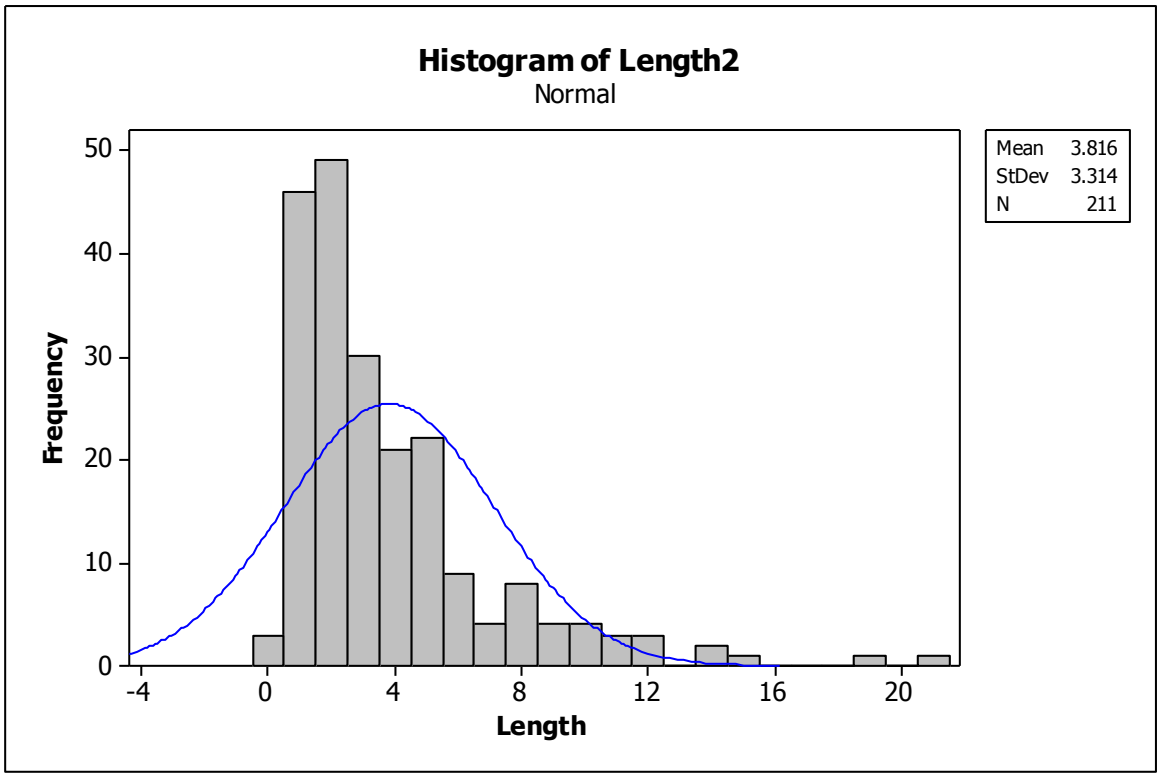


Figure 4.5: Histogram of Frequency against length of lineaments.

4.3.4 Lineament Density

Lineament density provides us information on 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 2.85 lineaments per unit area. Areas with very low lineament density are located in the eastern, south western and northern part accounting for 51.2% of the study area. Areas with low lineament density are located in the central and northern part of the study area accounting for 38.197%. Areas with

moderate lineament density are located in the northern, central and southern part of the study area and account for 9.7% of the study area. Areas with very high lineament density are located in the northern, central and south eastern part of the study area and account for 0.87% of the study area (Figure 4.6).

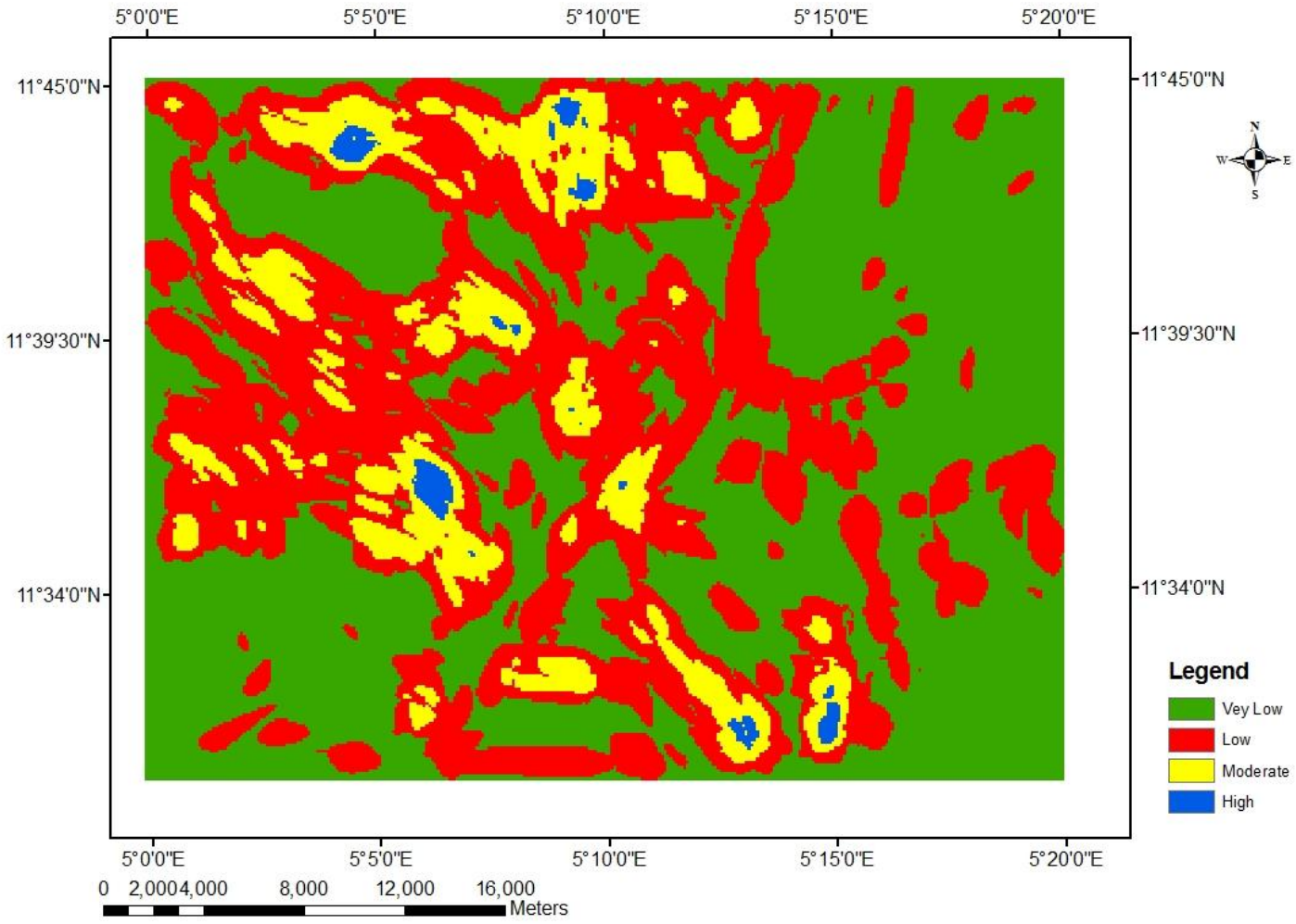


Figure 4.6: Lineament density map of the study area.

4.3.5 Lineament Intersection Density

Lineament intersection density ranges from 0 to 3.144 intersections per unit area. Lineament intersection density was classified into 3 classes, low moderate and high. Areas with low

lineament intersection density dominate the study area and account for 98.17% of the study area. Areas with moderate intersection density are located in the northern, central and southwestern part of the study area and account for 1.64% of the study area. Areas with high lineament intersection density are located in the northern, central and southern part of the study area and account for 0.179% of the study area (Figure 4.7).

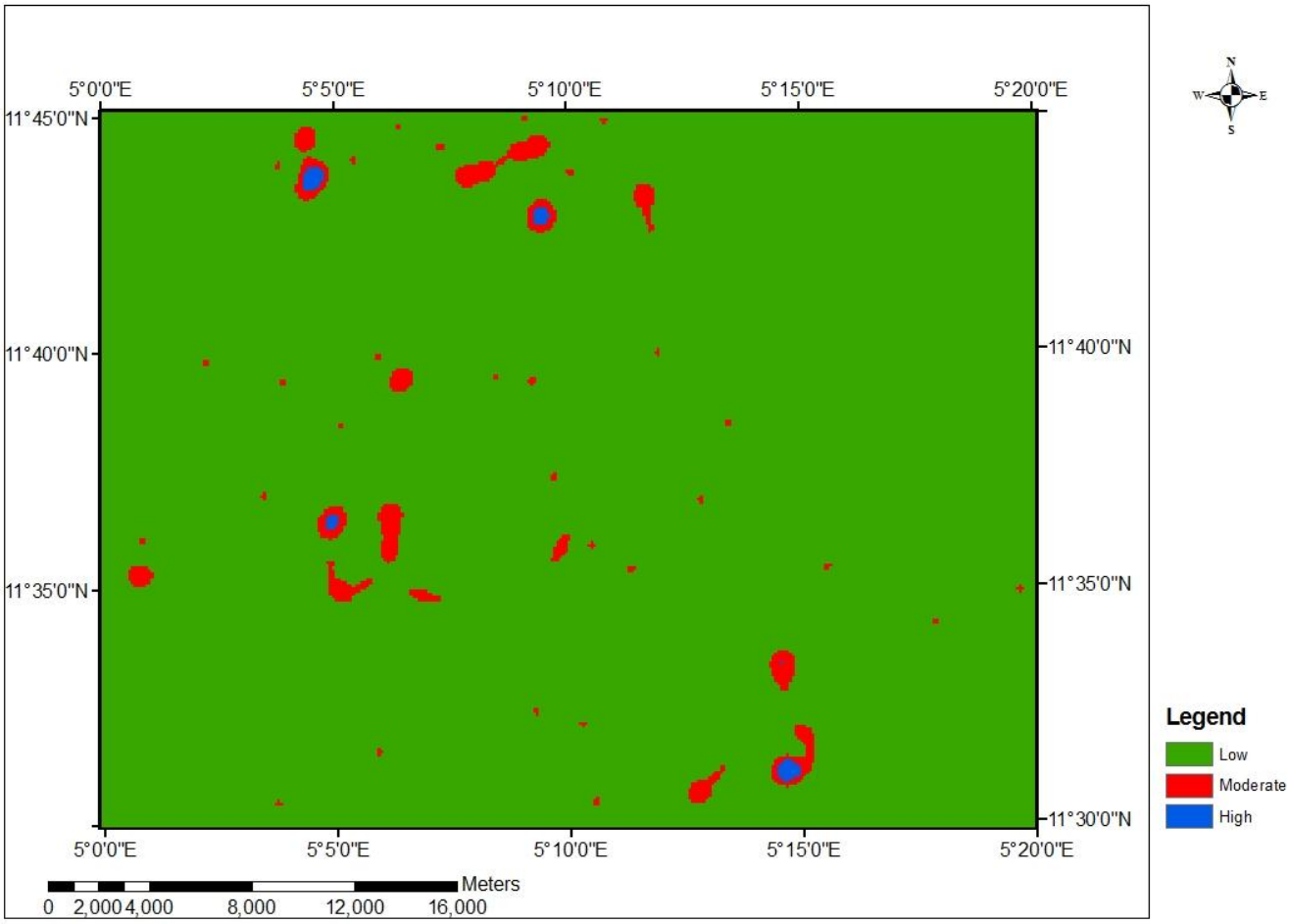


Figure 4.7: Lineament intersection density map of the study area.

4.3.6 Lineament Mean Length

Lineament mean length for the study area ranges from 0.187 km to 10.51 km. lineament mean length was classified into five classes. Areas of very short lineament length dominate the study

area and account for 61.7% of the study area. Areas of short lineaments account for 34.40 and occur in the northeastern, south and southwestern part of the study area. Areas of moderate lineament length account for 3.683% of the study area and occur in the north central part of the study area. Area of very long lineament length is located the north central, north and southern part of the study area and accounts for 0.638% of the study area. Area with extensive lineament length is located in the north central part of the study area and account for 0.177% of the study area (Figure 4.8).

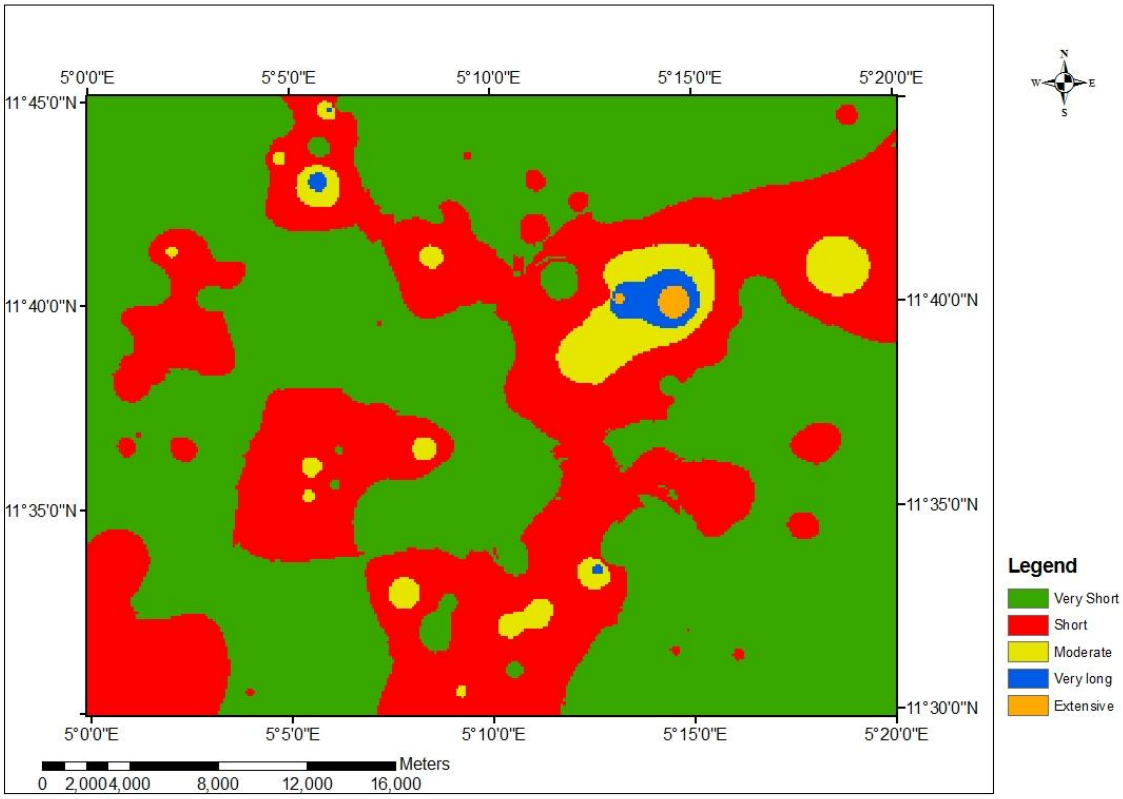


Figure 4.8: Lineament mean length map of the study area.

4.3.7 Lineament Relative Abundance

The relative abundance of lineaments was used to show the distribution of different lineament specie within the study area.

4.3.7.1 East- West Lineament Relative Abundance: The East-West trending lineaments are the least occurring lineaments within the study area. Relative abundance of these lineaments ranging from 0 – 1.5 lineaments per unit area. Areas with low lineament analysis are spread throughout the study area and constitute 99.31% of the study area. Areas with moderate lineament relative abundance are located in north, central and south western part of the study area and constitute 0.5% of the study area. Areas with high E-W relative abundance are located in the north, central and southwestern part of the study area and constitute 0.127% of the study area (Figure 4.9).

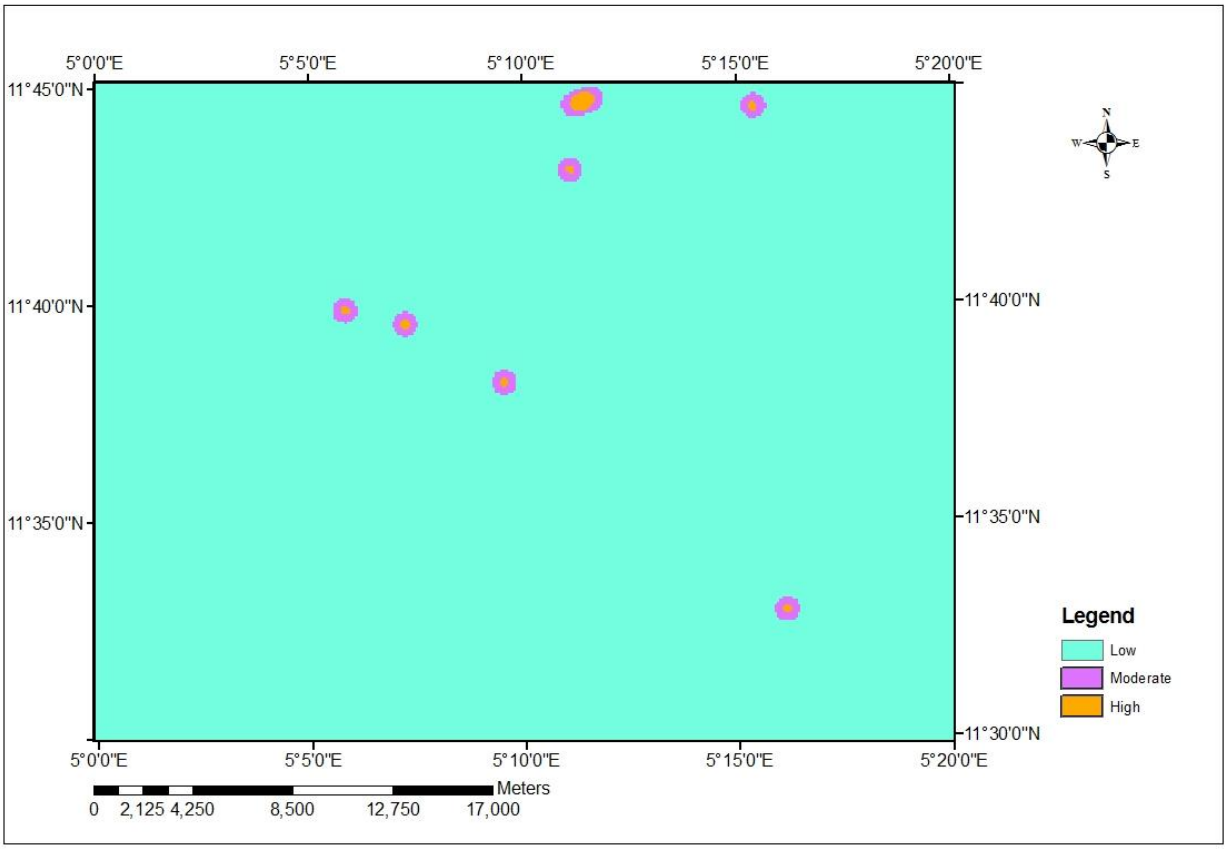


Figure 4.9: East- West lineament relative abundance map of the study area.

4.3.7.2 Northwest–Southeast Relative Abundance: These lineaments have a relative abundance ranging from 0-0.191 lineaments per unit area. Areas with low NW-SE lineaments are spread throughout the study area and constitute 97.1% of the study area. Areas with moderate NW-SE lineament relative abundance are located in the northern and southern part of the study

area and constitute 1.632% of the study area. Areas with low NW-SE lineament abundance are located in the northern and southern part of the study area and constitute 1.23% of the study area (Figure 4.10).

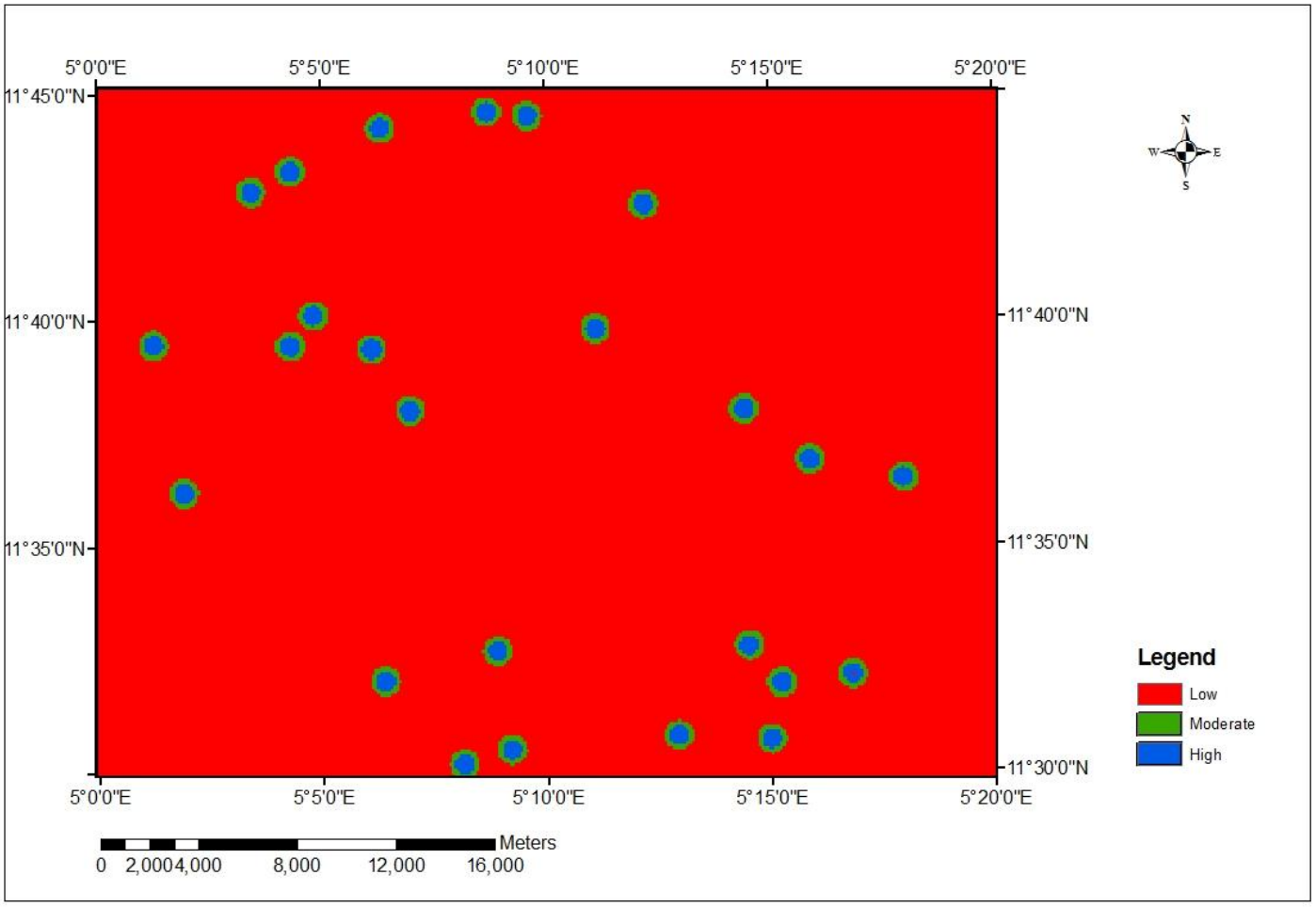


Figure 4.10: Northwest –Southeast relative abundance map of the study area.

4.3.7.3 Northeast –Southwest Relative Lineament Abundance: NE-SW lineament abundance ranges from 0-1.092 lineaments per unit area. Areas with low NE-SW abundance are spread out throughout the study area and constitute 97.6% of the study area. Areas with moderate lineament analysis are located in the north through the central to southwestern part of the study area and

consist of 1.34% of the study area. Areas with low NE-SW lineament abundance are located in the north to the central to the southeastern part of the study area and constitute 1.0257% of the study area (Figure 4.11).

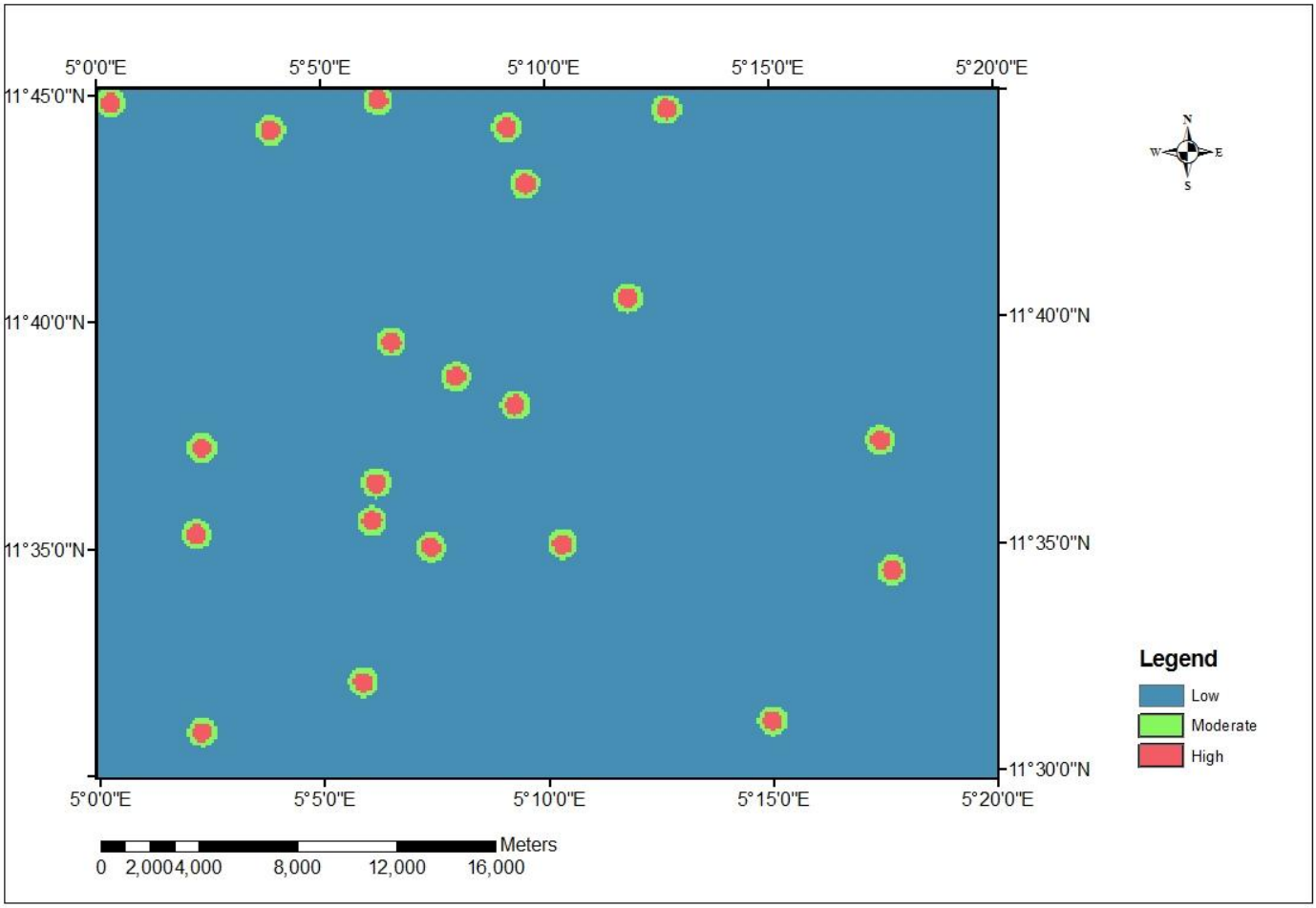


Figure 4.11: Northeast –Southwest relative lineament abundance map of study area.

4.3.7.4 North – South Relative Lineament Abundance: N-S lineaments for the study areas have a relative abundance from 0 to 2.163 lineaments per unit area. Areas with low N-S lineament abundance dominate the study area and account for 91.043% of the study area. Areas with moderate N-S lineament abundance account for 8.17% of the study area and are spread throughout the study area. Areas with high N-S lineament abundance account for 0.7% of the

study area and occur in the northern, northwest, east and southern part of the study area (Figure 4.12).

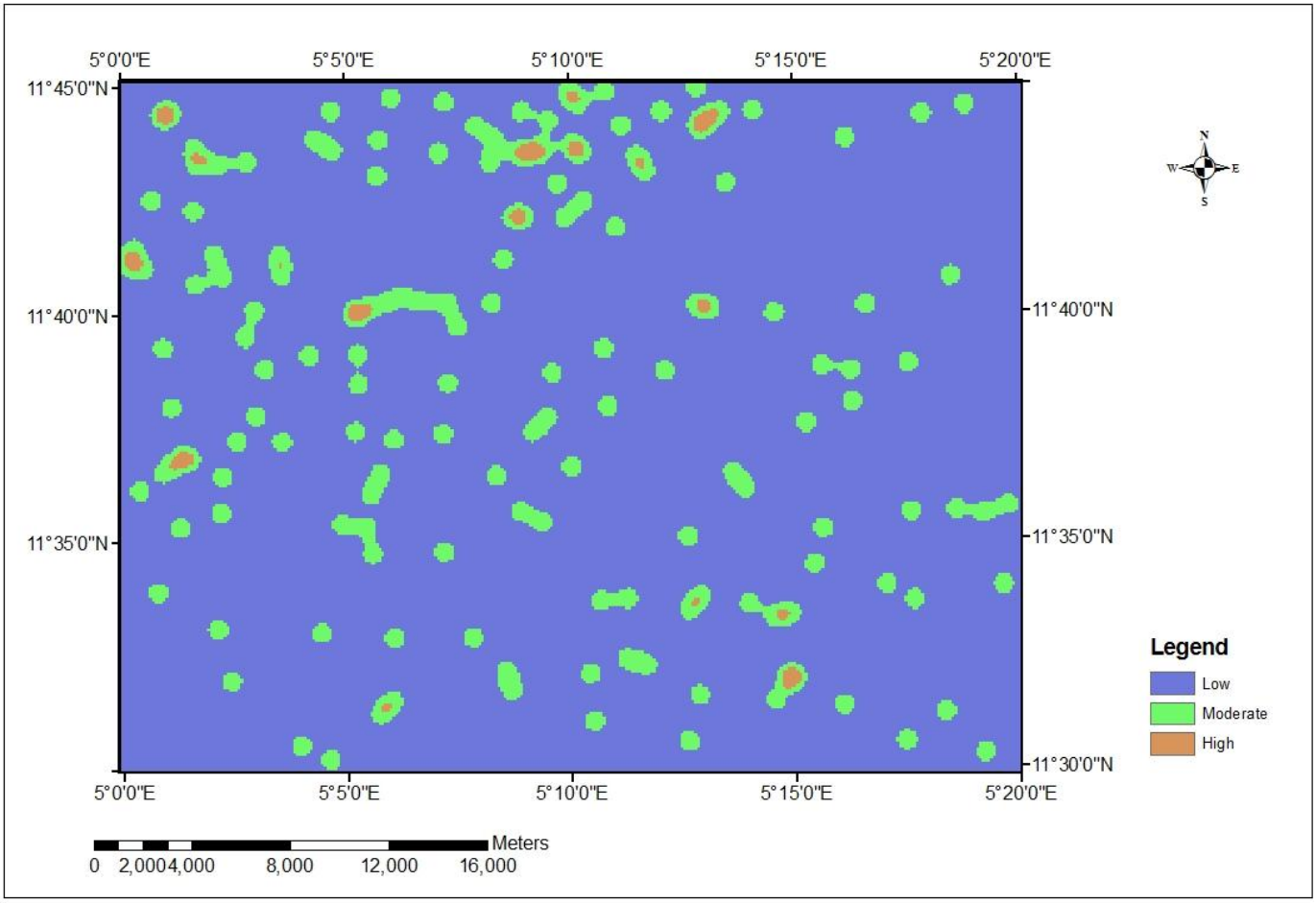


Figure 4.12: North - South relative lineament abundance map of the study area.

4.3.8 Statistical relationship between mean length and Azimuth

Relationship between mean length and azimuth was compared using Tables and diagrams. Mean length for lineament orientation N-S, NW-SE, NE-SW and E-W was used for this analysis. It was observed that the NW-SE lineaments are the most abundant (56.87%) while the short

lineament specie is the most abundant (45.9%). Furthermore, the E-W lineaments are the least abundant (3.79%), the extensive lineaments are the least abundant (0.47%) (Table 4.3).

Table 4.3: Mean length and azimuth correlation of lineaments within the study area

	E-W	**NW-SE**	**NE-SW**	**N-S**	**Sum**	**Percentage**
Very Short	5	11	10	52	78	36.9%
Short	2	11	9	75	97	45.9%
Long	1	3	2	24	30	14.2%
Very Long	0	0	0	5	5	2.3%
Extensive	0	0	0	1	1	0.47%
Sum	8	25	21	157	211	
Percentage (%)	3.791%	56.87%	22.27%	17.06%		

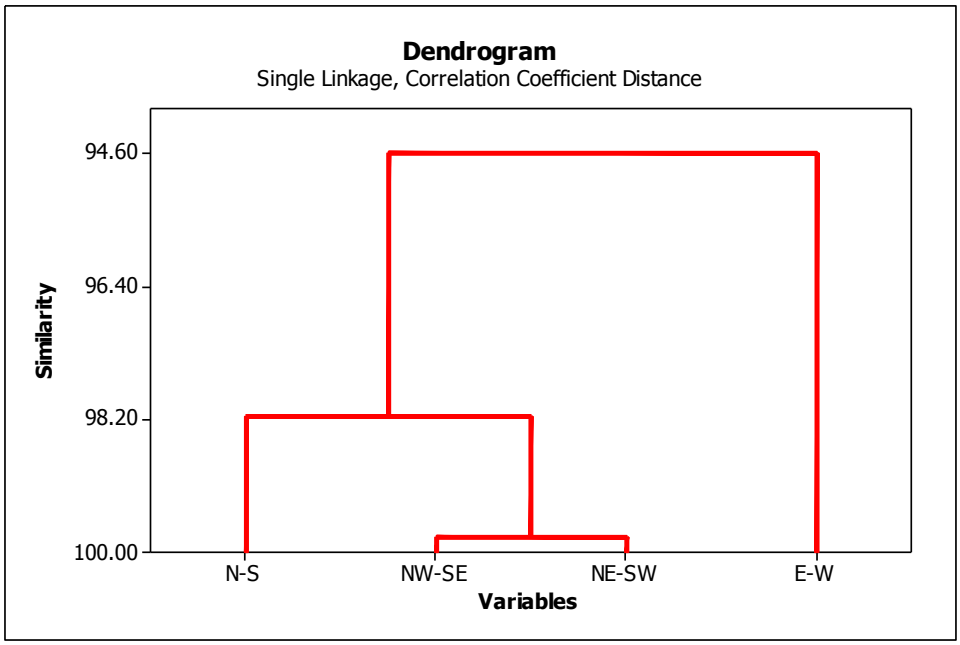


Figure 4.13: Dendogram for single linkage, correlation coefficient distance

The dendrogram shows the similarity between all the variables (N-S, NW-SE, NE-SW and E-W) lineaments in terms of correlation. In terms of similarity, we observed in the dendrogram that the NW-SE and NE-SW lineaments are most correlating with similarity value close to 100. This lineaments are more correlating to the N-S lineaments specie than the E-W lineamemts which is

the list correlating (Fig. 4.13). Close correlation in dendrogram between the NW-SE and NE-SW lineaments suggest these lineaments species are conjugate pair, with one being dextral and the other sinistral. This agrees with Ball (1980) who had earlier noted that a major conjugate system of strike slip faults affects the Tuareq and Nigerian shield with both fault directions having a consistent trend and sense of displacement; a NE-SW trending system having a dextral sense of movement and a NW-SE trending system a sinistral sense.

4.4 STRUCTURAL ANALYSIS

4.4.1 Folds

Large scale and small scale folds have been recorded in the study area. The large scale folds are common on the quartzite which is the most structurally complex rock unit. Majority of these folds occur around Kokanawa where large antiforms and synforms were recorded (Plates XVIII and XIX). Also, there are buckled folds showing a continuous range of antiforms and synforms (Plate XX) with close wavelength intervals within the study area. One prominent antiform (Kokanawa antiform) about 200 m northwest of Kokanawa has an amplitude of about 10 m with a NE-SW trend fold axis. About 80 m east of this antiform a very large synform was also observed with a NE-SW trend axial plane.

In Teme, exactly NW of this settlement, another large scale fold was observed with its outcrop pattern suggesting an antiform and has its fold axis in a NE-SW direction. Folds on the muscovite schist occur mostly as mesoscopic folds (Plate XXI). Large scale fold on this rock type was observed only in one location, about 500 m NE of Gollo settlement, with its fold pattern suggesting an antiform and the fold axis trending NE-SW direction.

The orientations of these folds were measured and plotted stereographically in (Figure 4.14) which shows that the trend and plunge (Table 4.4) and axis of the folds concentrate in the NE axis of the stereoplot and approximate axial surface to be NNE-SSW. The folds have moderate to steep plunge as revealed by the stereoplots of its attitudes (Figure 4.14).



Plate XVIII: Photograph of an antiformal (isoclinal) fold at Kokanawa 11^0 $42^{'}$ 5.9"N and 5^0 10' 0.1"E, Note the person standing at the crest of the fold.



Plate XIX: Photograph of a synformal fold at Kokanawa 11^0 42' 14.8"N and 5^0 09' 49.9"E



Plate XX: Photograph of a buckled fold at Kokanawa 11^0 42' 30.2"N and 5^0 09' 25"E



Plate XXI: Photograph of an assymetrical meso fold on a muscovite schist rock at Kele 11^0 33' 10.5"N and 5^0 07' 17.4"E

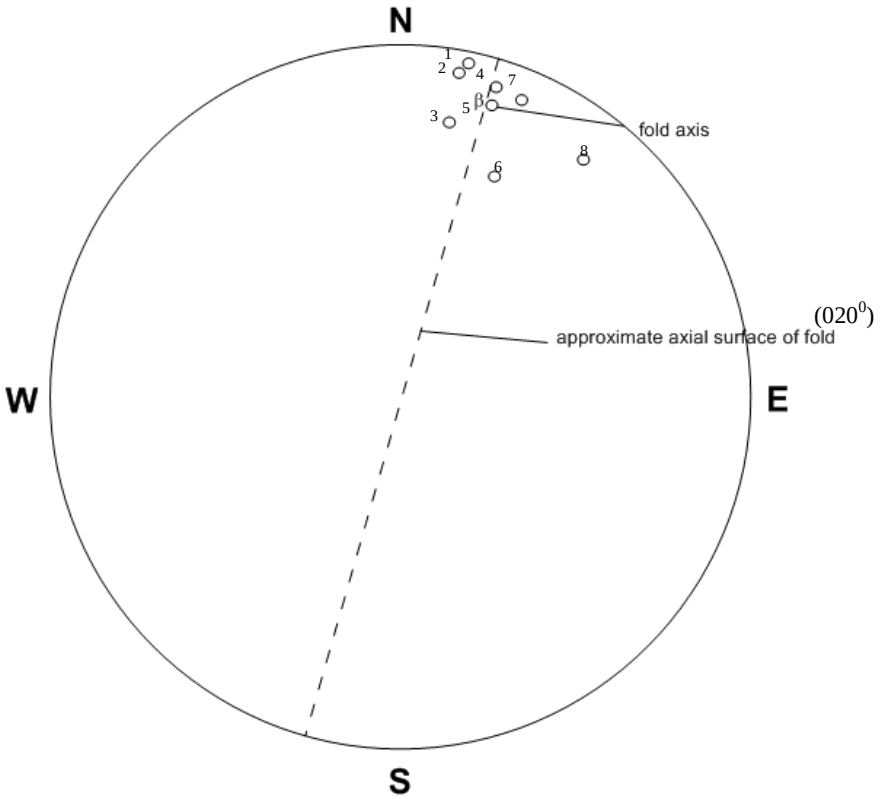


Figure 4.14: Lower hemisphere equal area projection of fold axis showing concentrations in the NE and approximate axial surface of folds

Table 4.4: Trend and Plunge reading of fold axis

S/N	TREND (degrees)	PLUNGE (degrees)
1	010	004
2	008	006
3	010	022
4	016	008
5	017	014
6	022	034
7	020	009
8	038	016

4.4.2 Schistosity and Crenulation cleavage

Schistosity is the dominant foliation pattern that occurred on the muscovite schist in the study area. Schistosity foliation on this rock is defined by the allignment of micaceous minerals (muscovites), giving the rocks a silky shiny lustre. Muscovite shist outcrop along river channels and road cuts (Plate XXIII). Schistosity was observed in areas arround Masama, Gollo and Matseri.

Crenulation cleavage in the study area is very distinct in that it cuts the host rock that possesses a pre-existing continous cleavage (schistosity) into microfolds (Plate XXII) the foliation is typically a zonal crenulation cleavage because the cleavage domains coincides with tight limbs of microfolds in the pre-existing continous cleavage (schistosity). Crenulation cleavege was recorded about 300 m east of government secondary school, Barkin Tudu Matseri.



Plate XXII: Photograph of schist with crenulation cleavage at Matseri 11^0 32' 13.2"N and 5^0 05' 2.4"E

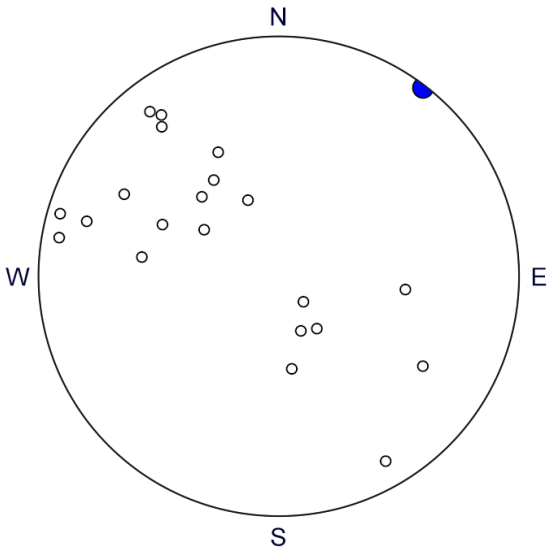


Plate XXIII: Photograph of schistosity developed on a muscovite schist outcrop at Masama 11^0 42' 5.8"N and 5^0 5' 21.3"E

A total of 21 measurements of strikes, dips and dip directions of foliation surfaces were taken during the field work. The raw data of the foliation surfaces measured is presented in (Table4.5). The predominant foliation is schistosity which occurs on the muscovite schists. The foliation surfaces have low to high dips between (10^0 to 82^0) predominantly to the southeast. These data which was plotted on stereonets (β-diagrams and π-diagrams) shows that the foliation planes have a NE-SW trend (Fig 4.15A). To get an overall orientation of the foliation, the poles of these planes were plotted (Fig 4.15B) using conventional techniques of (Ragan,1973). These plots show that the poles of the foliation concentrated in the NW and SE portions of the net (Fig 4.15B), thus confirming the dominant NE-SW trends. In order to determine the specific orientation of the foliations, cummulative rose diagrams for the entire locations from which measurements were taken. The rose diagrams defne the dominant direction for the foliations to be NE-SW (Fig.4.16). Bar charts were also plotted to show the highest frequency intervals of foliations within the study area (Fig.4.17).

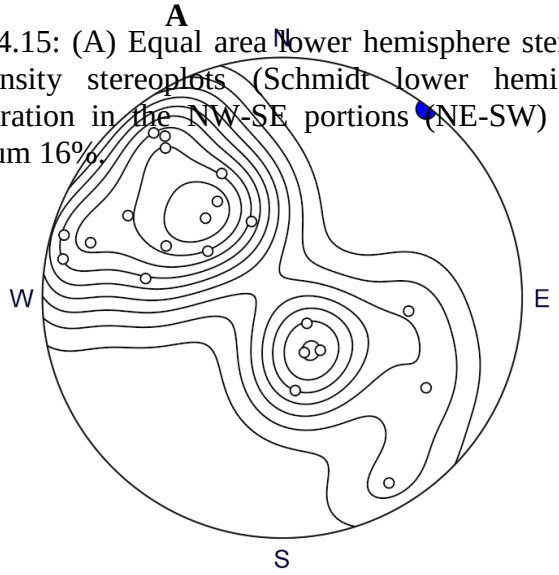
Table 4.5: Strike, Dip and Dip Direction of Foliations within the study area

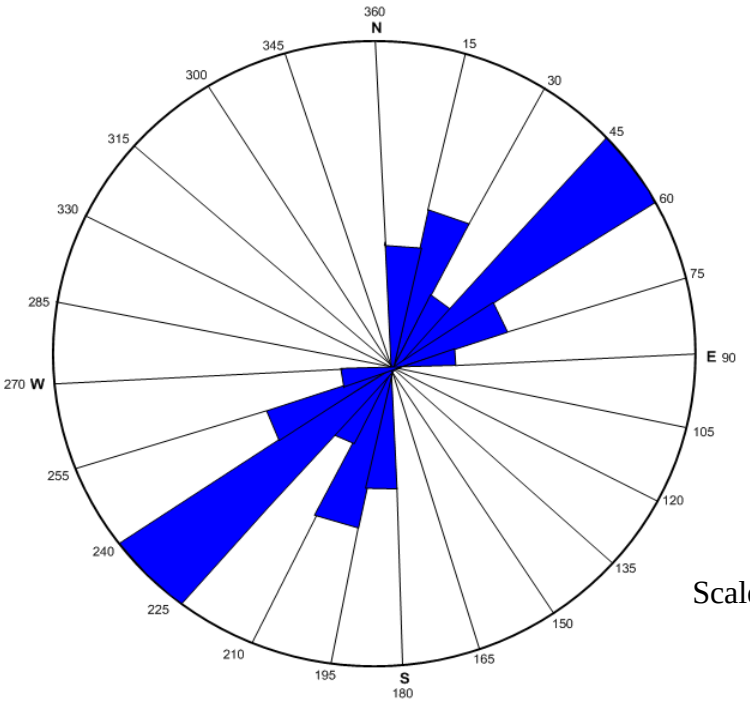
S/N	STRIKE (Degrees)	DIP (Degrees)	DIP DIRECTION	S/N	STRIKE (Degrees)	DIP (Degrees)	DIP DIRECTION
1	010	82	SE	12	064	48	SE
2	016	72	SE	13	056	40	SE
3	052	76	SE	14	068	28	SE
4	054	72	SE	15	046	38	SE
5	032	30	SE	16	248	20	NW
6	016	84	SE	17	234	22	NW
7	024	44	SE	18	226	12	NW
8	186	44	NW	19	052	68	SE
9	262	32	NW	20	028	62	SE
10	240	78	NW	21	008	48	SE
11	212	60	NW				



A **B**

Figure 4.15: (A) Equal area lower hemisphere stereographic projection of poles to foliation and (B) density stereoplots (Schmidt lower hemisphere projection) for 21 points showing concentration in the NW-SE portions (NE-SW) trends. Contours 2-4-6-8-10-12% per %area, maximum 16%.





Scale = 1cm rep 2unit

Figure 4.16: Cumulative rose diagram of foliation planes showing two main structural trends ($N00^0$-030^0E and $N030^0$-060^0E)

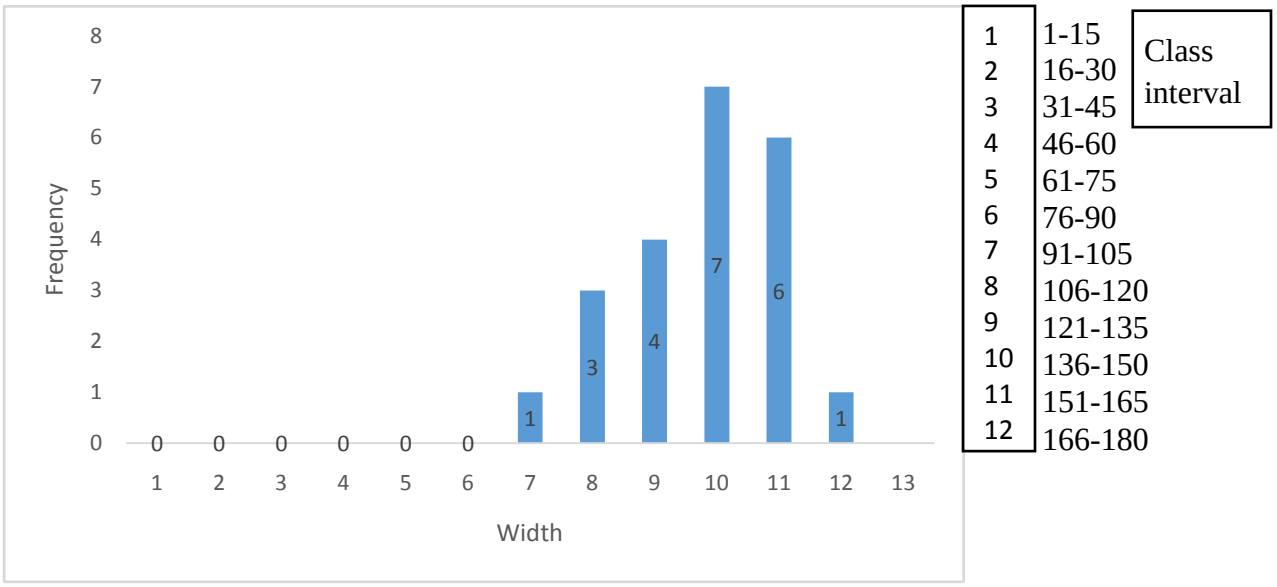


Figure 4.17: Bar chart of foliations of muscovite schist within the study area.

Table 4.6: Frequency distribution of Foliations, Strike amount and Directions

Class interval	Frequency	Width
1-15	-	1
16-30	-	2
31-45	-	3
46-60	-	4
61-75	-	5
76-90	-	6
91-105	1	7
106-120	3	8
121-135	4	9
136-150	7	10
151-165	6	11
166-180	1	12

4.4.3 Joints

All the rocks within the study area are jointed. The joint pattern in the mapped area suggest that the study area suffered cataclastic deformation. Joint is most common in the quartzite compared to the other rock types, probably due to the high competent nature of the quartzite. Different joint styles have been recorded during the field mapping exercise. This include; cross joints and vertical joints (Plates XXIV; XXV and XXVI). The dominant joint style displayed is cross joints, which occurred majorly on the quartzite.

A total of three hundred and eighty two (382) joints were recorded in the area. Joint analysis was undertaken while all the measured joint planes were plotted on rose diagrams. The joints were oriented in the E-W, NW-SE, NE-SW and N-S directions. Rose diagrams were also plotted

for the individual rocks, the granite has a dominant NNE-SSW trend (Fig 4.18), the quartzite have NE-SW and NW-SE trends (Fig 4.19), while the schist has NNE-SSW and NNW-SSE trends (Fig 4.20). Class interval, frequaency and width tables of joints were prepared (Tables 4.10, 4.11 and 4.12) while Bar charts were plotted which showed the frequency intervals with the dominant occurrence of joints (Figures 4.21, 4.22 and 4.23).

The joint set includes systematic joints with average distances of about 10 to 78 cm. The nonsystematic joints have inconsistent average perpendicular spacing. In general, the surfaces of joints appear irregular and haphzard.

The common intersection geometry of the joints includes T-geometries where the individual joint trace meets at right angle and X-intersection geometeries where the individual joint sets meets at acute angles. Tip geometries include gradual die out, branch out and y tips.

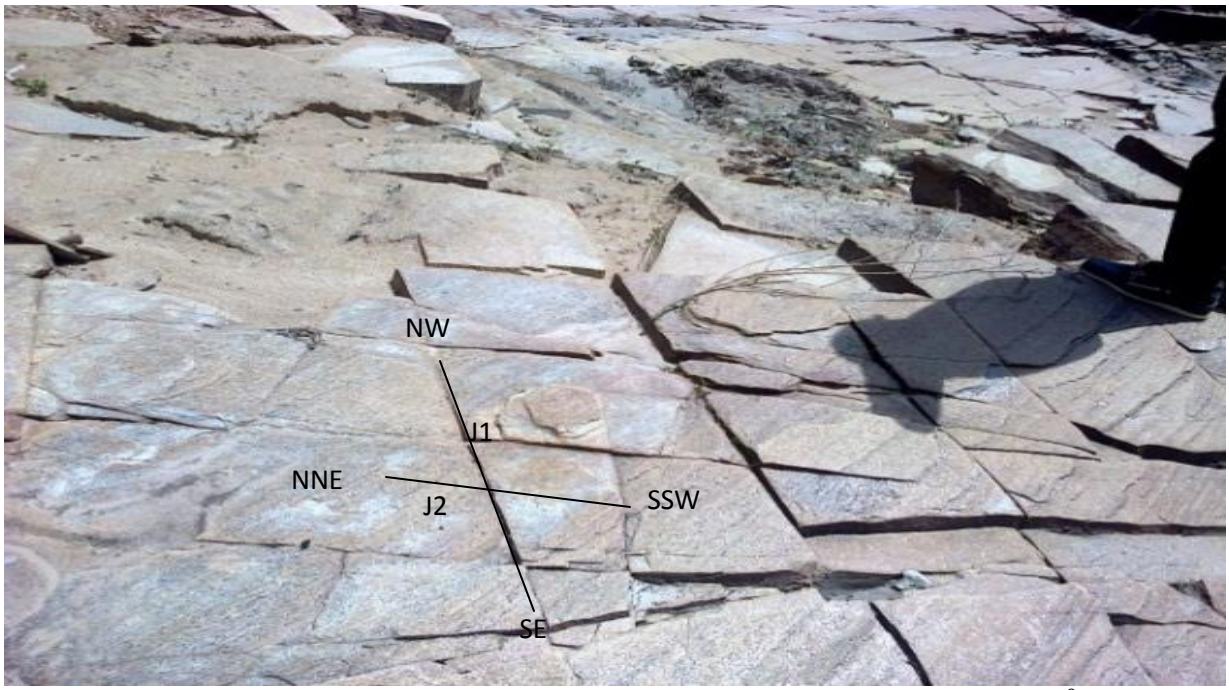


Plate XXIV: Cross joints on muscovite schist outcrop at Gollo with T-geometry 11^0 42' 5.8"N and 05^0 05' 21.3"E

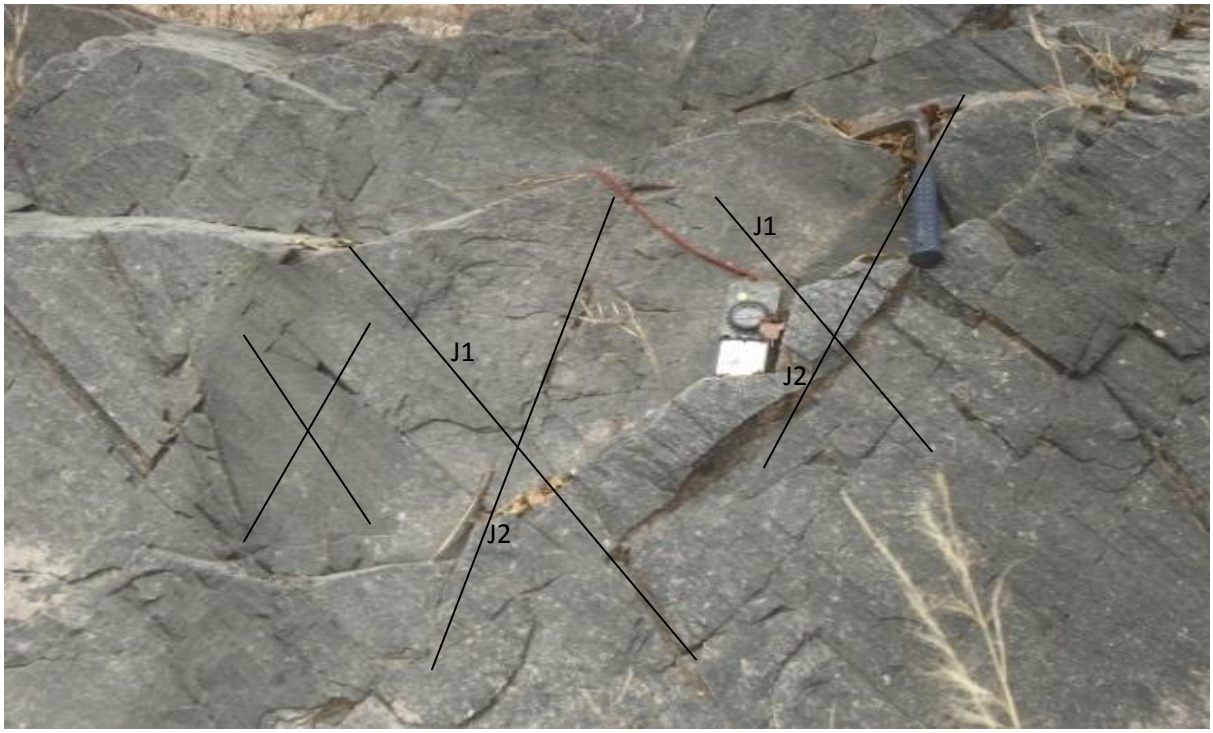
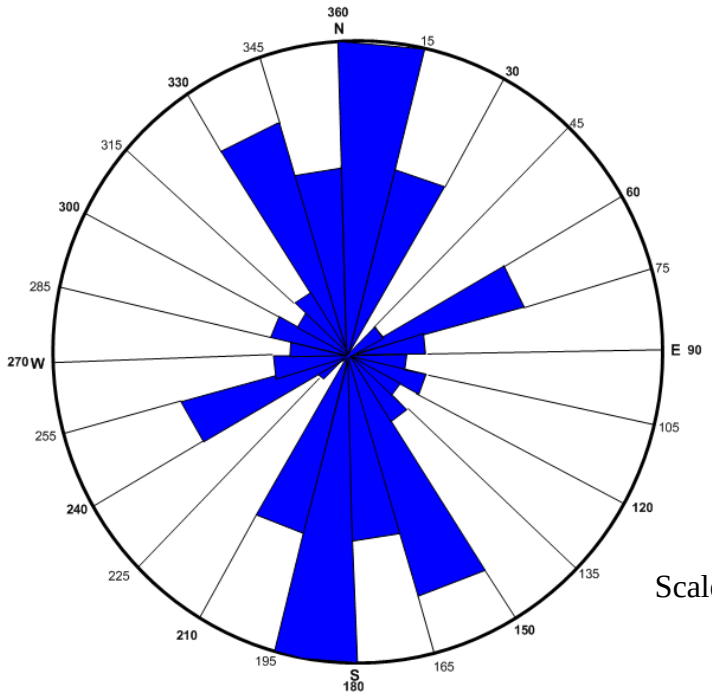


Plate XXV: Cross joints on a quartzite outcrop at kokanawa with X-geometry 11^0 42' 34.6"N and 05^0 09' 29.9"E

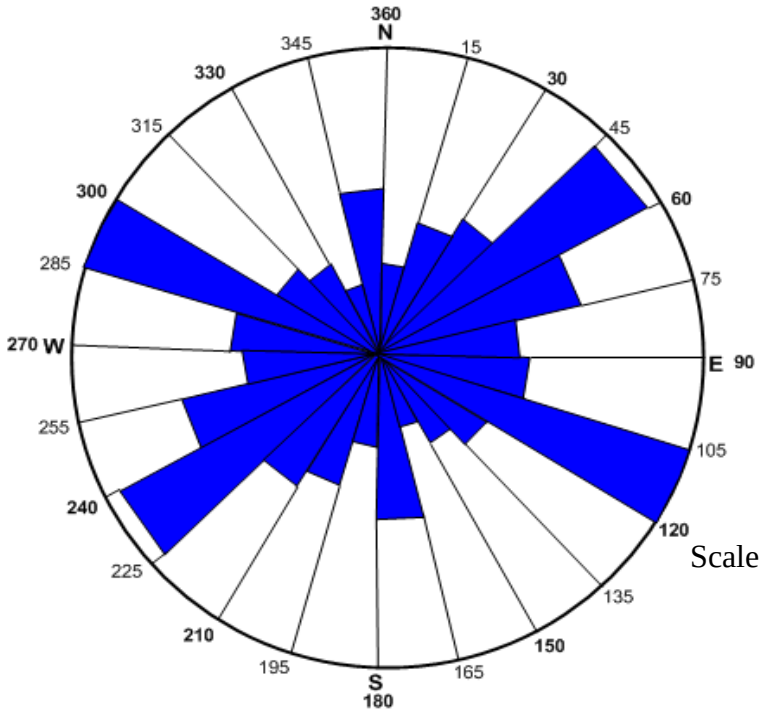


Plate XXVI: Vertical (parallel) joints on quartzite outcrop at 11^0 39' 12.2"N and 05^0 07' 10"E



Scale = 1cm rep 3units

Figure 4.18: Rose diagram for medium grained granite with orientations in the NNE-SSW directions



Scale = 1cm rep 5units

Figure 4.19: Rose diagram for quartzites with orientation in the NE-SW and NW-SE

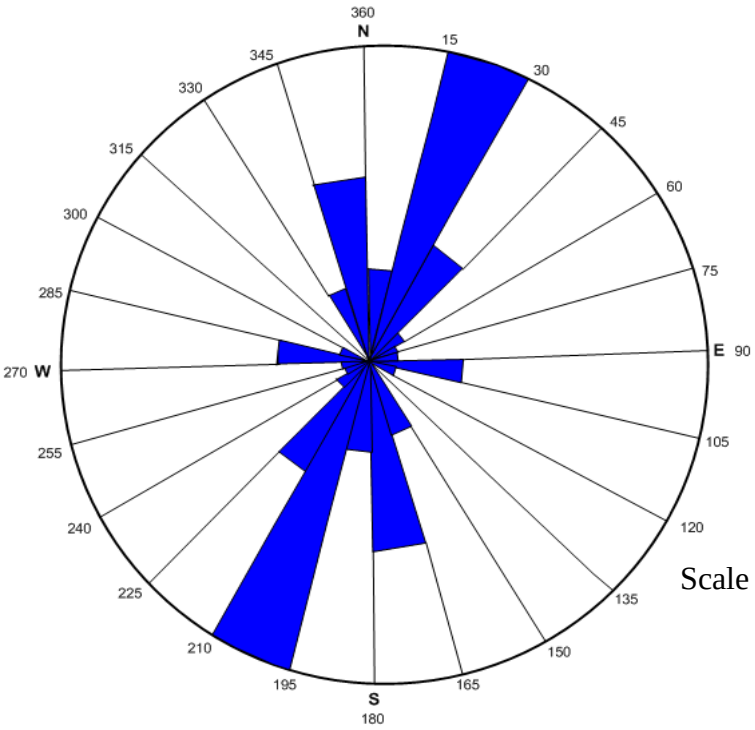


Figure 4.20: Rose diagram for muscovite schist with orientation in the NE-SW direction and NNW-SSE directions

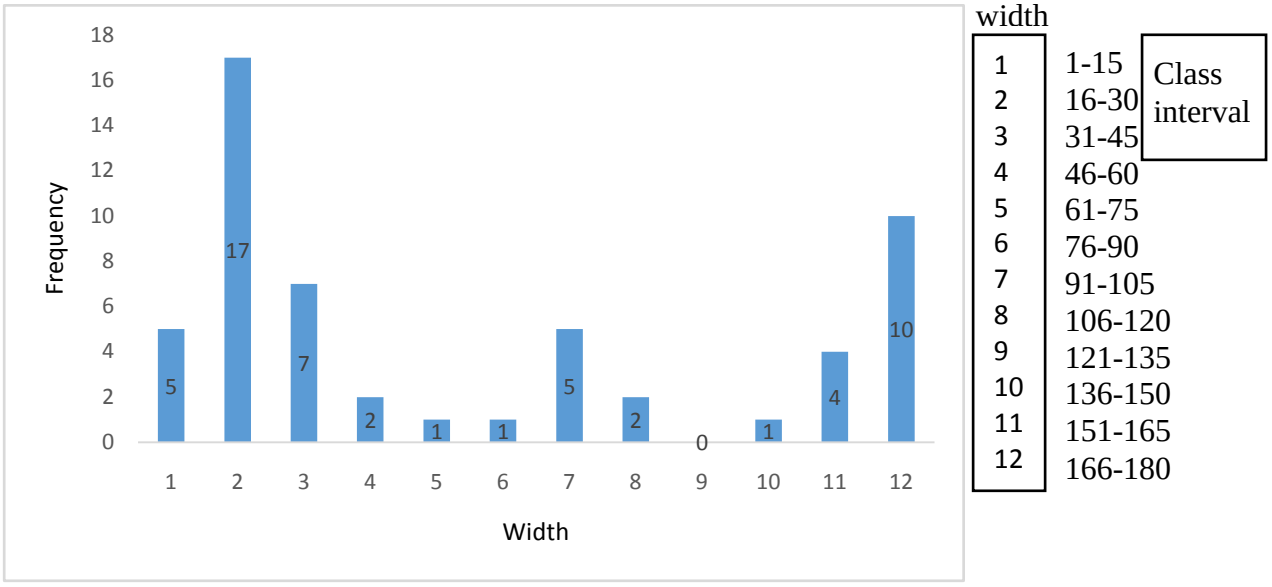


Figure 4.21: Bar chart for joints on Muscovite schist within the study area.

Table 4.10: Frequency distribution of Joints, Strike amounts and Direction on Muscovite Schist within the area.

Class interval	Frequency	Width
1-15	5	1
16-30	17	2
31-45	7	3
46-60	2	4
61-75	1	5
76-90	1	6
91-105	5	7
106-120	2	8
121-135	0	9
136-150	1	10
151-165	4	11
166-180	10	12

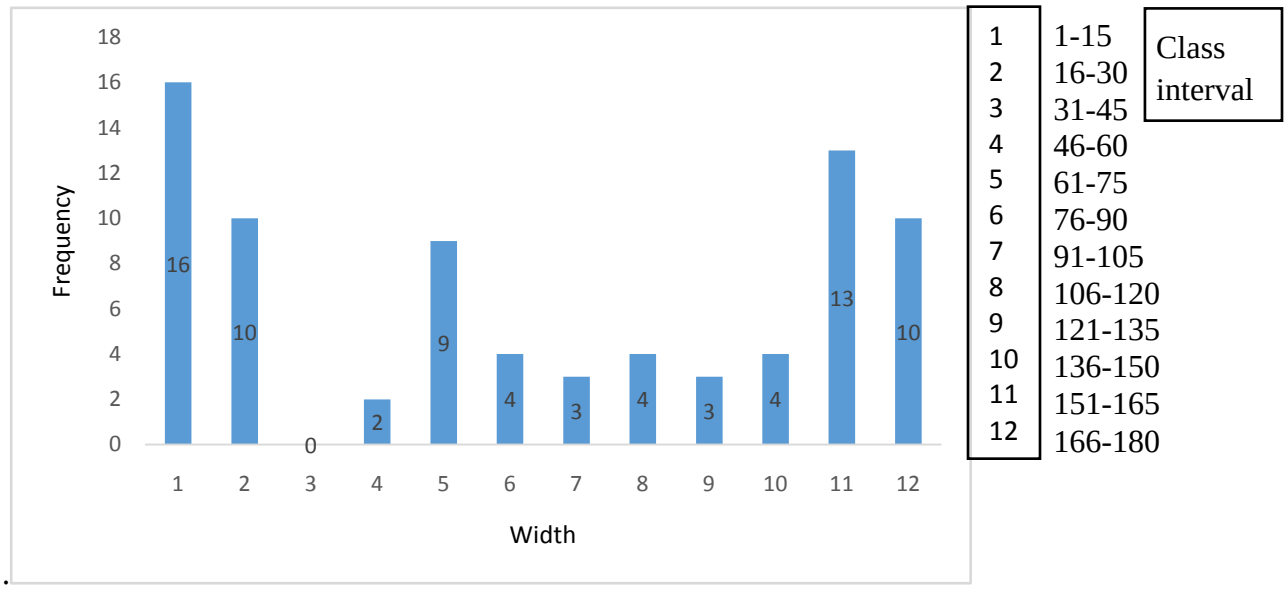


Figure 4.22: Bar chart for joints on Medium grain granite within the study area

Table 4.11: Frequency distribution of Joints, Strike amounts and Direction on Medium Grained Granite within the area.

Class interval	Frequency	Width
1-15	16	1
16-30	10	2
31-45	0	3
46-60	2	4
61-75	9	5
76-90	4	6
91-105	3	7
106-120	4	8
121-135	3	9
136-150	4	10
151-165	13	11
166-180	10	12

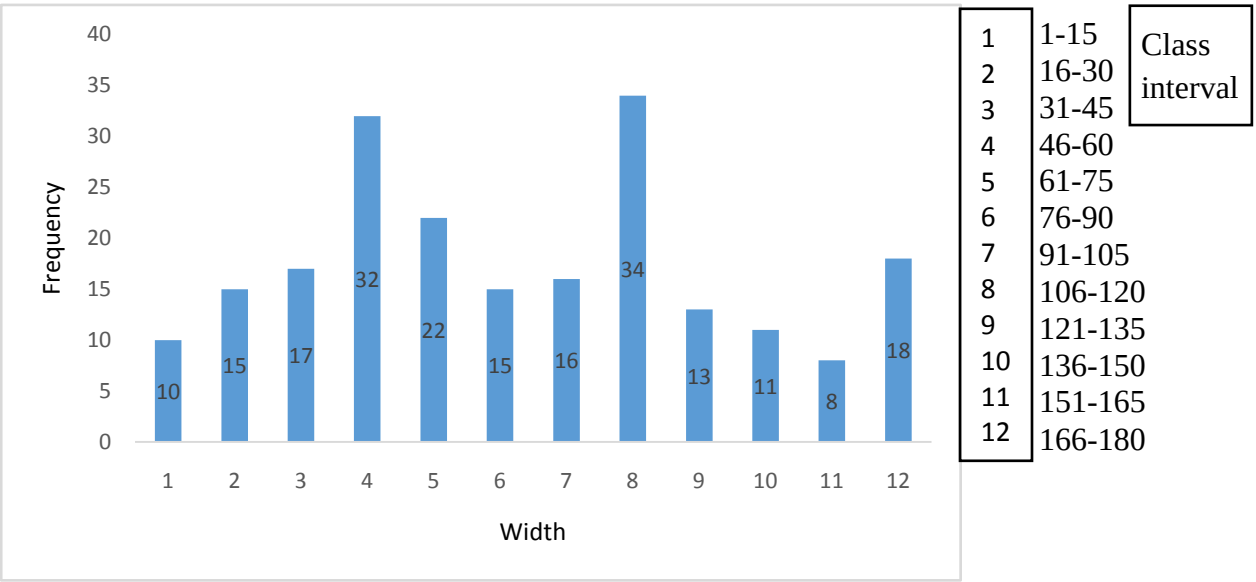


Figure 4.23: Bar chart for joints on Quartzite within the study area

Table 4.12: Frequency distribution of Joints, Strike amounts and Direction on Quartzite within the area

Class interval	Frequency	Width
1-15	10	1

16-30	15	2
31-45	17	3
46-60	32	4
61-75	22	5
76-90	15	6
91-105	16	7
106-120	34	8
121-135	13	9
136-150	11	10
151-165	8	11
166-180	18	12

4.4.4 Faults

In the study area, faults occur on an outcrop scale (mesoscopic) as strike- slip faults with a dextral (right) sense of shear, displacements of about 20 cm and NE-SW trend. Aerial imageries of the study area also revealed the existence of a major dextral fault which is the Bin Yauri- Zuru fault zone that cuts through the area with a displacement of about 15 m in a NE-SW direction (Plate XXVII). This fault zone was characterized by deep fracture, abundant folded quartzite veins and strong penetrative cleavage (Plates XXVIII and XXIX).

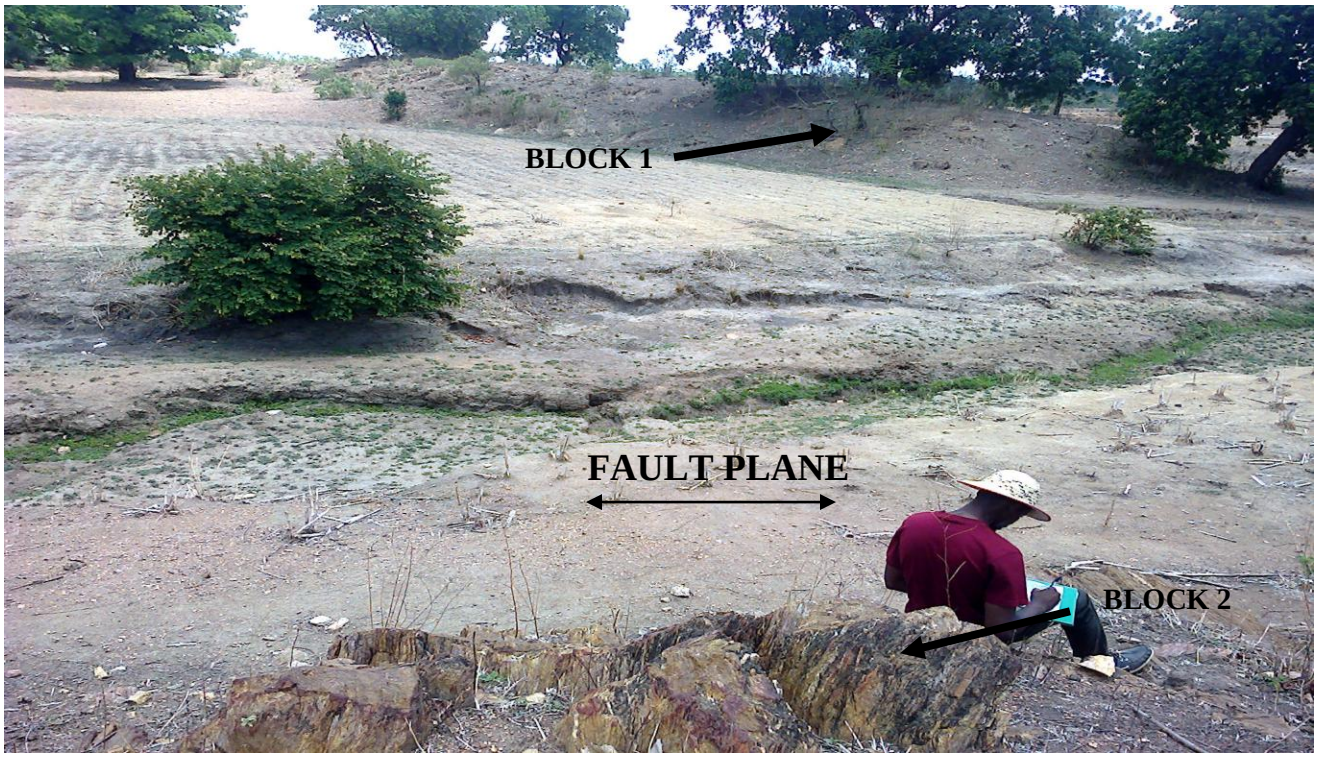


PLATE XXVII: Bin Yauri fault zone that cuts through the study area at Barkin Tudu 11^0 31' 48"N and 5^0 7' 17.4"E



PLATE XXVIII: Photograph of Block 1 of the Bin Yauri fault zone that cuts through the study area at Barkin Tudu 11^0 31' 48"N and 5^0 7' 17.4"E



PLATE XXIX: Photograph of Block 2 of the Bin Yauri fault zone that cuts through the study area at Barkin Tudu 11^0 31' 48"N and 5^0 7' 17.4"E

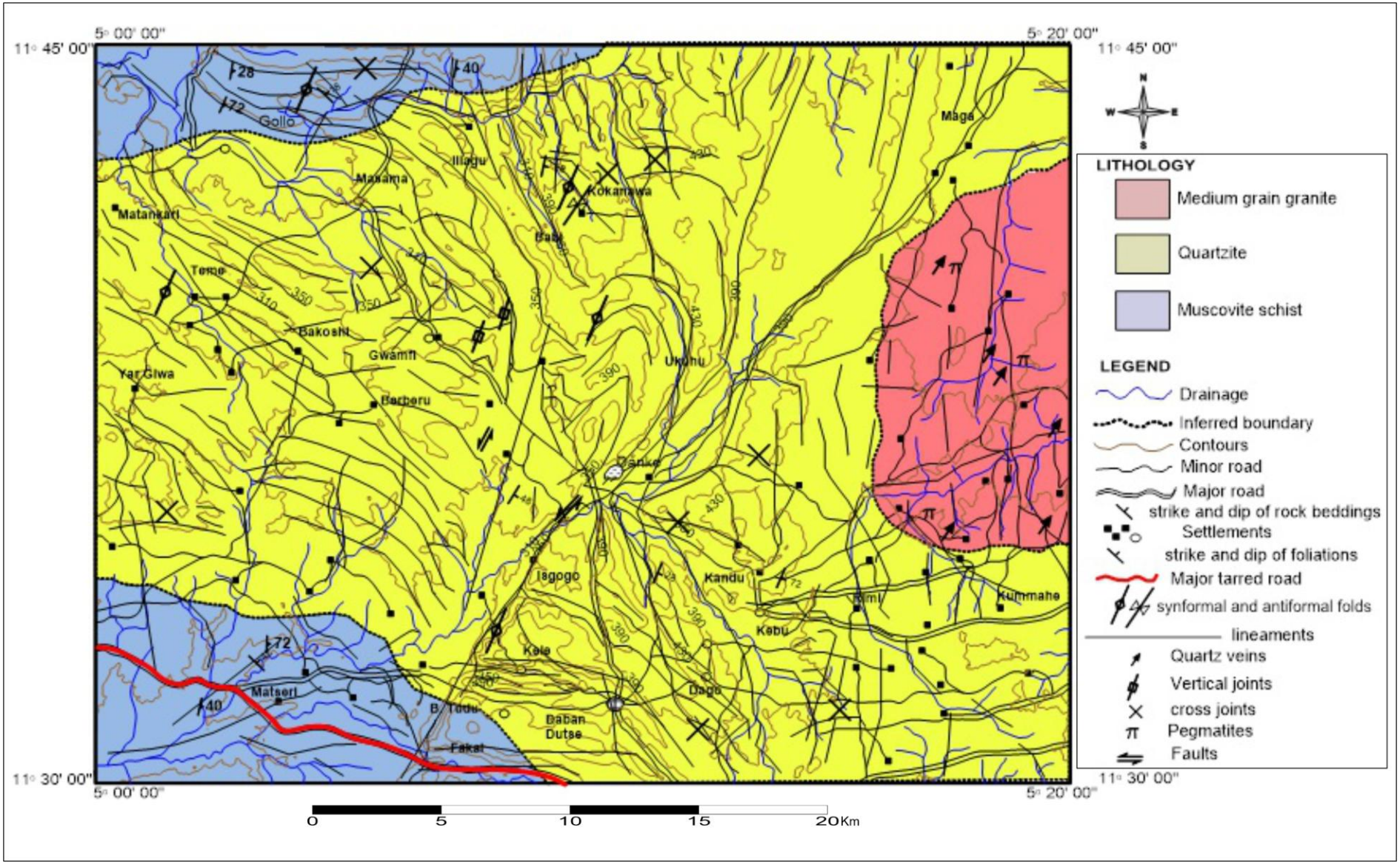


Figure 4.24: Structural map of study area.

4.5 DEFORMATION EPISODES

4.5.1 First Phase of Deformation (D1)

The D1 event is recorded only on the metamorphic rocks and it is associated with the development of S1 schistosity and an F1 folding.

The earlier planar structure S1 is generally parallel to the bedding surface and defined by the preferred orientation of muscovite micas. At microscopic scale, S1 schistosity is marked by elongated shape of muscovite and biotite flakes. A total of 21 measurements of strikes and dips of S1 surfaces were recorded. The foliation surfaces have low to high dips (10^0 to 82^0) mainly to the southeast. The poles to S1 surface lie on the NW-SE axis of the stereographic projection thus confirming the dominant NE-SW trends.

F1 folds were rarely seen as they occurred as flat lying minor folds on the muscovite schist, with the axial plane trending ENE-WSW. The dominant foliation S1 occurs as axial planar cleavages to this folds (Plate XXX). This relationship is common in Matseri area where quartz stringers invaded the muscovite schist. No major folds of this generation have been recognized.

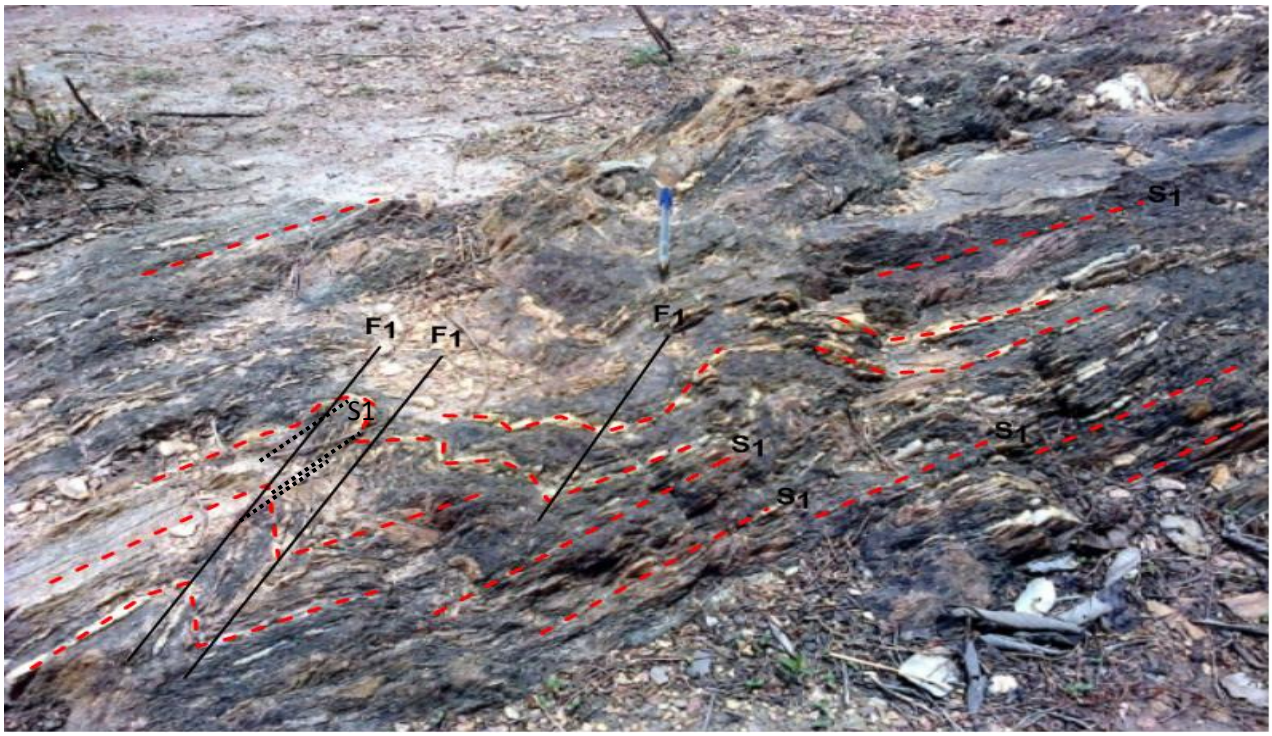


Plate XXX: Quartzite veinlet invading schist showing F1 folding and S1 schistosity at Kele 11^0 33' 10.5"N and 05^0 07' 17.4"E

4.5.2 Second Phase of Deformation (D2)

This tectonic phase is well developed in both the muscovite schist and the quartzite. It is characterized by heterogeneous deformation affecting the previous D1 fabric. D2 deformation is associated with the development of an S2 crenulation cleavage and F2 major folds.

The S2 cleavage cross cut the S1 cleavage into a small regular crinkle folds that have asymmetric form called the crenulation cleavage (Plate XXXI).

F2 folds occur as large scale upright tight to isoclinal folds with a NNE-SSW trend of axial plane (Plate XXXII and XXXIII). In other areas, they occur as open to isoclinal folds were they form a continuous series of antiforms and synforms. Late stages of deformation can be attributed to brittle tectonics marked by late sub-vertical fractures which are granitic veins, pegmatite dykes and joints (cross and longitudinal joints). These veins are generally filled with quartz and trend in

a NE-SW direction, while joints displayed two main orientations which are NE-SW and NW-SE with minor E-W trends

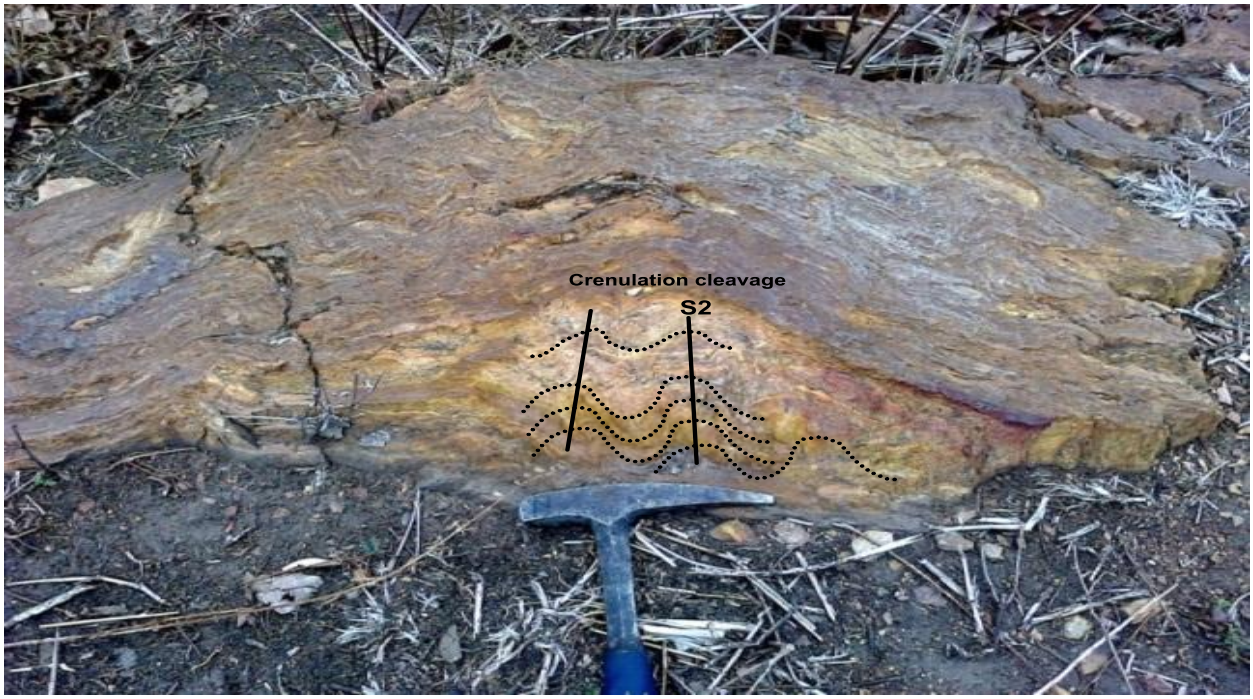


Plate XXXI: S2 crenulation cleavage fabric at Matseri. 11^0 32' 13.2"N and 05^0 05' 2.4"E

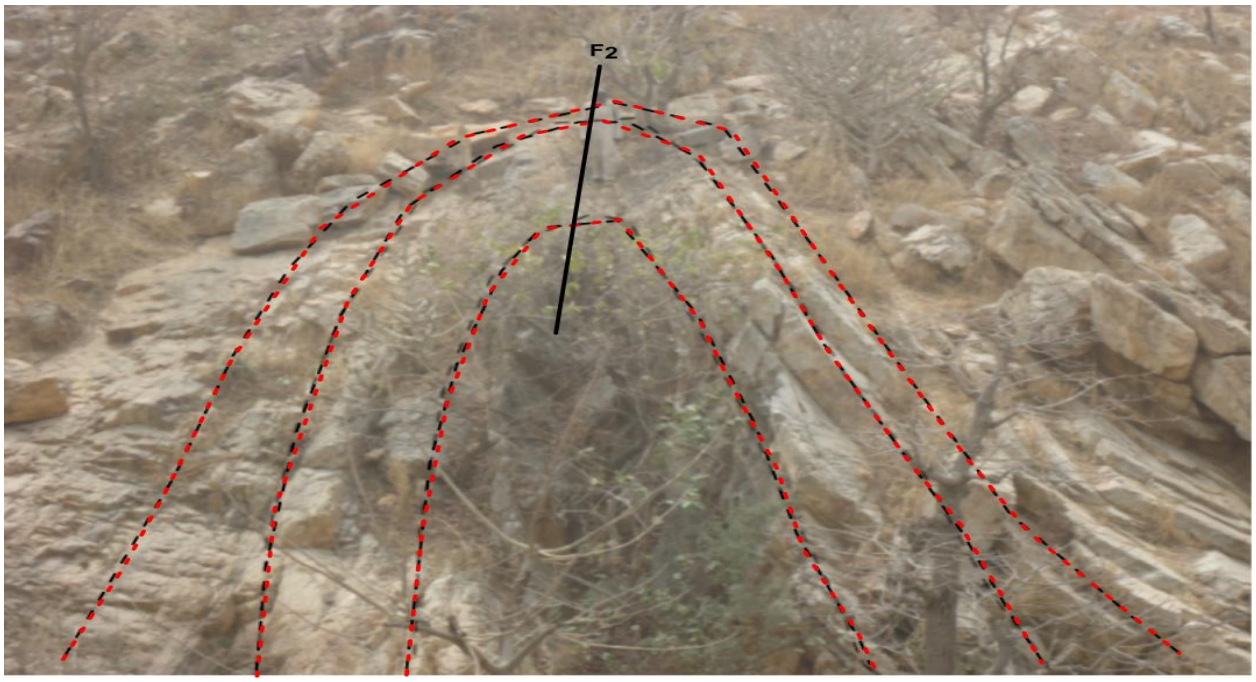


Plate XXXII: F_2 tight to isoclinal fold at Kokanawa 11^0 42' 5.9"N and 05^0 10' 0.1"E

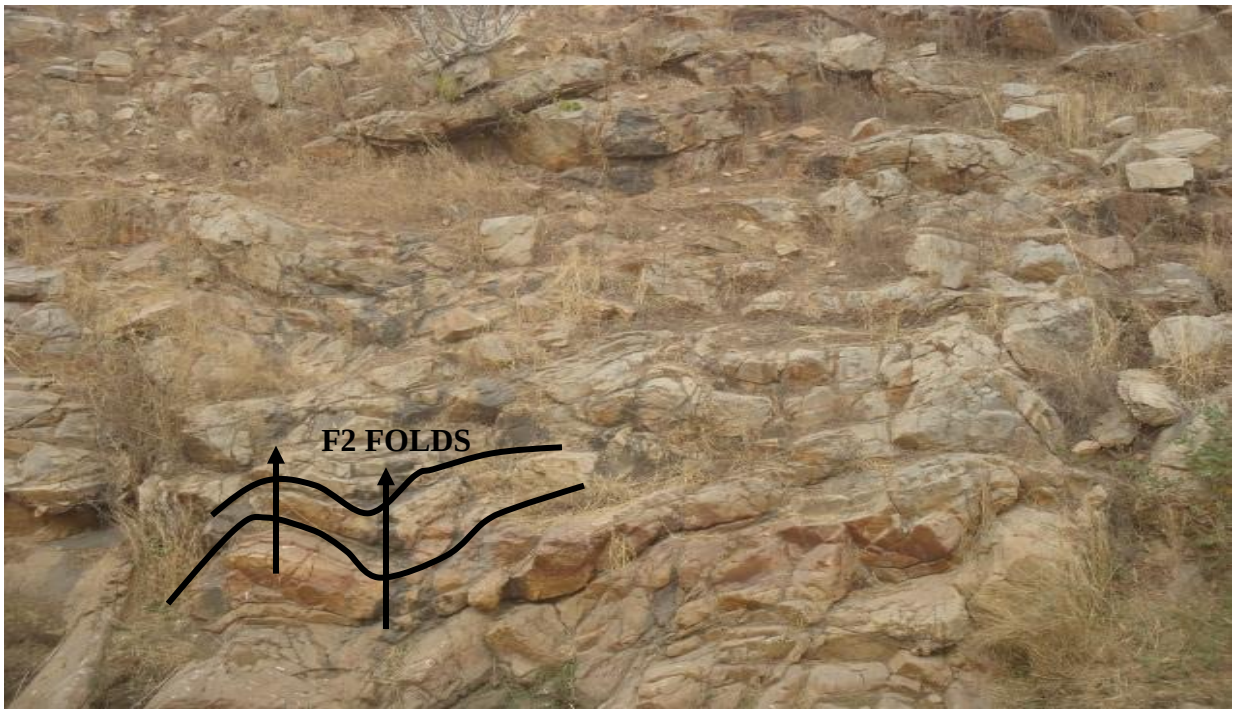


Plate XXXIII: F_2 folding on a quartzite outcrop showing continuous open antiforms and synforms 11^0 42' 30.2"N and 05^0 09' 25"E

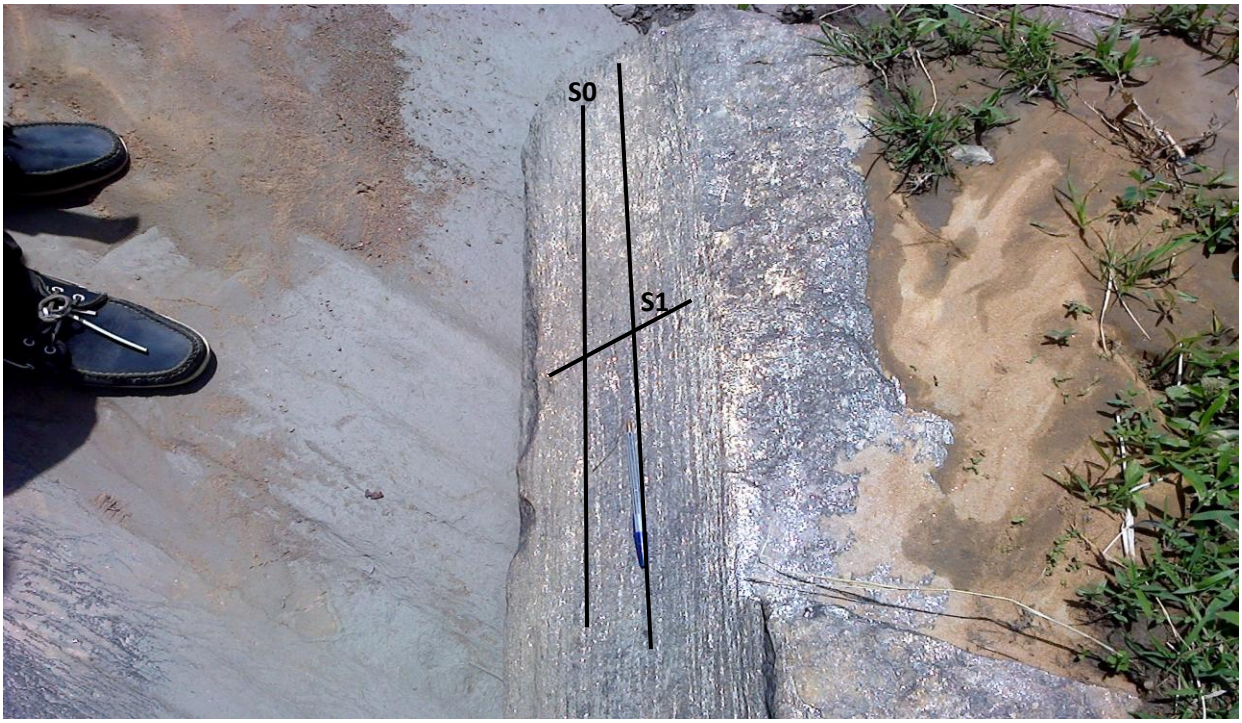


Plate XXXIV: S1 schistosity on S0 surface on a muscovite schist at Masama 11^0 42' 5.8"N and 05^0 05' 21.3"E

4.6 STRAIN ANALYSIS

4.6.1 Fry Hallows

Strain analysis was carried out solely for the purpose of detrmining the extent of deformational effects on the rocks from the different locations within the study area. A total of 15 photomicrographs were used for strain analysis. These are slide numbers AL4, AL5, AL7, AL9, AL13, AL15, AL17, AL18, AL25, AL4i, AL14, AL23, AL12, AL2 and AL8. Angle to reference line and axial ratios were determined and presented in (Table 4.13).

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. The shapes of the Fry hallow range from the near circular type mainly in the northwestern, southwestern and extreme southern parts of the study area. This suggests a low degree of deformation to the flattened type in the northern parts of the area which showed the highest degree of deformation.

Quartzite around Masama, Illagglu and Kokanawa exhibits the highest degree of deformation while areas where muscovite schist occurs show the least deformation. The result of the strain analysis is presented on the strain map in (Fig 4.25 and 4.26).

Table 4.13: Slide numbers, Angle to reference line and Average ratios of Fry halos.

S/N	SLIDE NUMBERS	ANGLE TO REFERENCE LINE (degrees)	AVERAGE RATIO
1	AL4	036	1.14
2	AL5	038	1.62
3	AL7	040	1.77
4	AL9	068	1.38
5	AL13	034	1.54
6	AL15	052	1.63
7	AL17	068	1.38
8	AL18	052	1.10
9	AL25	056	1.86
10	AL4i	052	1.08
11	AL14	056	2.48
12	AL 23	042	2.08
13	AL12	058	1.91
14	AL2	048	1.69
15	AL8	060	1.44

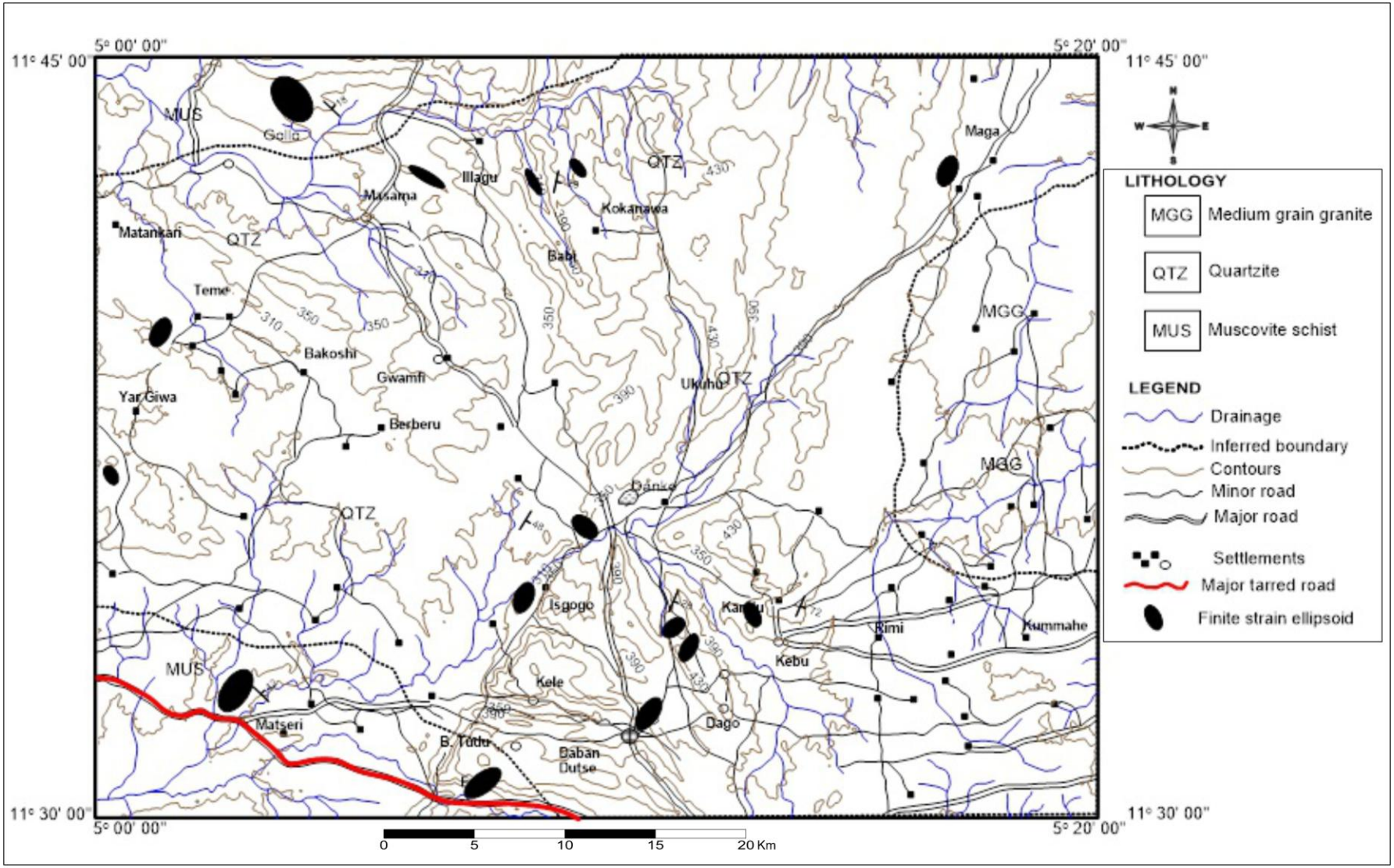


Figure 4.25: Strain ellipsoid and orientation distribution map of the study area

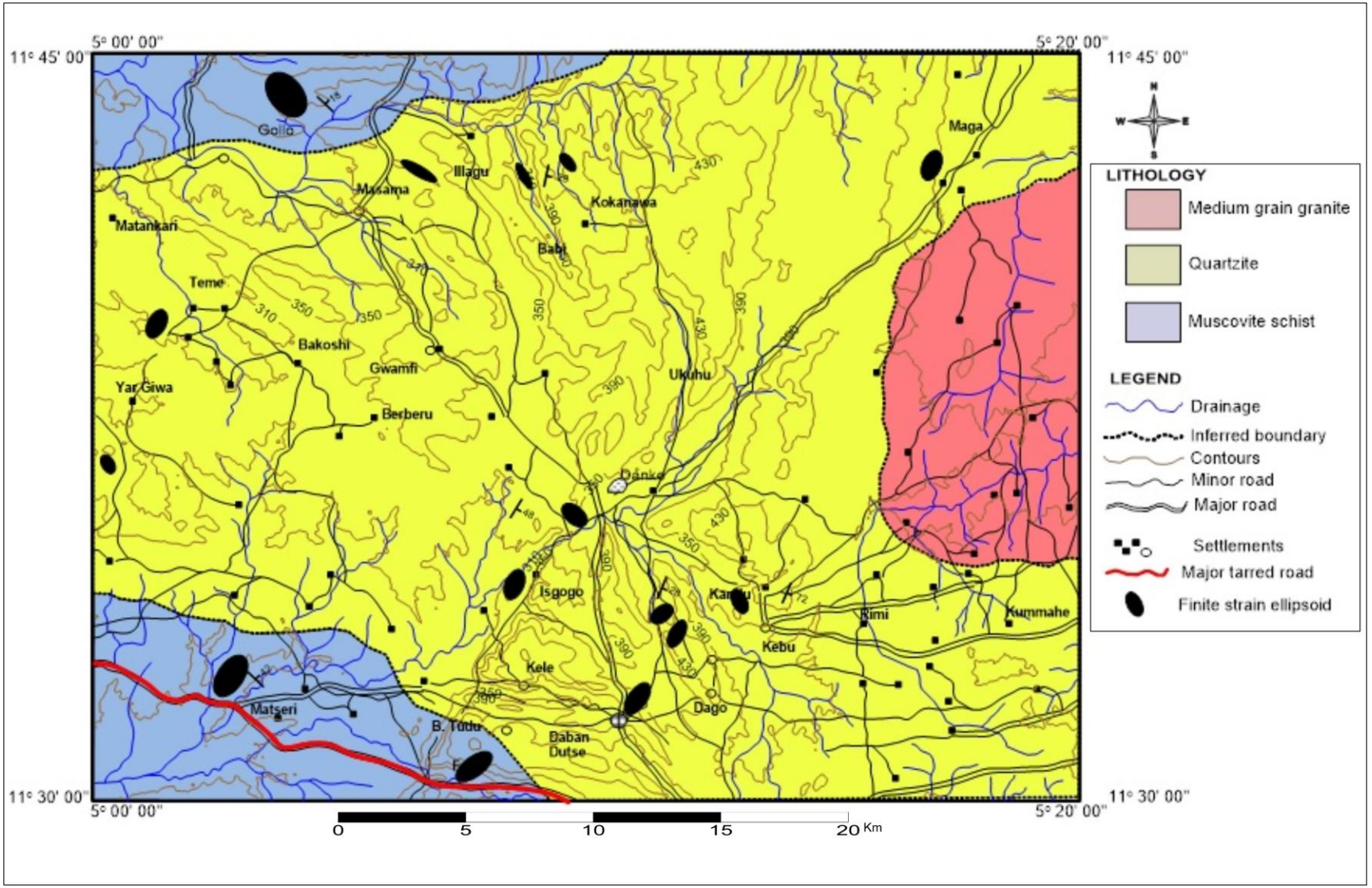


Figure 4.26: Strain ellipsoid and orientation distribution map of the study area, super imposed on the geological map

CHAPTER FIVE

STRUCTURAL EVOLUTION

All models of evolution of the schist belts of Nigeria proposed over the years have been classified under ensialic and ensimatic processes of formation (Ogezi, 1977; McCurry and Wright, 1977; Holt *et al*., 1978; Utke, 1987; Danbatta, 1991; Elueze, 1992). Shibayan (1990) and Danbatta (1991) presented a model that considers the Zuru and Anka belts as a pair of belts that evolved through ensimatic processes.

The study area is a part of the Zuru Schist Belt, which like other schist belts has been deformed and metamorphosed. The study area comprises of three rock units namely: quartzites, muscovite schist and medium grained granites. The oldest rock unit within the study area is the muscovite schist which was derived from previously existing sedimentary sequence of possibly Eburnean age that have been deformed and metamorphosed (Ajibade *et al*., 1987). Overlying the muscovite schists are the quartzites. 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 of the basement. Below is a summary of events of emplacement of the rock types within the study area (Table 5.1).

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 deformed. Field studies (attitude of planar and linear structures, orientation of fold axial planes, styles of folding and over printing of one fabric by another) of the rocks show that they have been affected by two episodes of deformation denoted as D1 and D2 respectively.

Table 5.1: Order of events of rock emplacement within the study area

CLASSIFICATION	GEOLOGICAL HISTORY	ROCK TYPES

Late Pan-African	Granite intrusion and fracturing	Older granites, jointing, faults, quartz veins and quartzofeispathic pegmatite veins.
Early Pan-African (Younger metasediments)	Orogenesis, deformation and metamorphism.	Quartzites
Kibaran ?/ Eburnean	Geosynclinal deposition, deformation and metamorphism	Muscovite schists.

The D1 is the earliest deformation episode and D2 the late deformation episode. Olobanyi (1997) ascribed D_1 to the Eburnean event and D_2 to the Pan-African event in the metasediments of the Egbe-Isanlu area. It has been 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 muscovite schist rock unit. It brought about an early 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 assymetrical 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 muscovite schist and quartzites 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 folding of S1 into major tight to isoclinal F2 folds with NNE-SSW trend of axial plane. Late stages of deformation can be attributed to brittle tectonics marked by late sub-vertical fractures which are

veins, pegmatites and joints that trend in a NNE-SSW direction. Below is a summary of the chronological order of structures within the study area (Table 5.2).

Table 5.2: Chronological order of events of the structures within the study area

Stages of deformation	Structural imprints	Trends	Types of structures
Late tectonic stage	Brittle deformation that produced fractures	E-W, NW-SE, NE-SW, NNE-SSW, N-S	Joints, faults
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
First deformation Event (D1)	Ductile deformation that produced the first generation of structures.	ENE-WSW, NE-SW.	F1 minor obliterated assymetrical folds S1 schistosity

CHAPTER SIX

SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 SUMMARY

6.1.1 Field Observations and Petrographic Descriptions

Geological studies of rocks of Danko area reveal lithologies with distinctive textural, petrographical and structural characteristics which have implication on their overall geology. The study area consists of quartzite, muscovite schist and medium grained granite. Quartzite outcrops as hilly bodies and is underlain by the muscovite schist. The medium grained granite occupies the eastern part of the study area.

Field observations reveal that quartzite is the dominant rock type covering about 60% of the area and occurs as hills, muscovite schist covers about 25% of the area and occurs as low lying outcrops along river channels and road cuts while medium grained granite covers about 15% of the area occurring mainly as whalebacks and dome outcrops. This conforms to the studies of McCurry (1978) who mapped the Zuru Schist Belt on a large scale and shows that the northwestern part of the belt is dominated by quartzites, but the occurrence of the schist and medium grained granites were not reported. Minor rocks (quartz veins and quartzofeldspathic pegmatites) constitute the remaining percentage.

Quartz veins occurr as fracture infilling minerals on the granite. In parts of the study area quartz veins exhibit cross-cutting relationship which helps in determining their order of formation (age relationships).

Petrographic analysis shows that the quartzite is composed of; quartz, muscovite and biotite. By contrast, the muscovite schist contain; quartz, biotite, muscovite and chlorite while the medium grained granite is composed of; quartz, biotite, microcline, perthite and sericite. Extinction observed on quartz grains 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. The presence of cracks within the quartz grains suggests brittle deformation. Undulose extinction in quartz suggests intra crystalline deformation, lineation in muscovite suggest the readjustment of minerals during metamorphism. The nature of seriate grain

boundary of the quartz grains suggests a high grade of metamorphism, while alteration of perthite to sericite in the granites suggests the effect of weathering on this rock.

6.1.2 Lineament Analysis

Lineaments in the study area were obtained using DEM and ArcGIS softwares. A total of 211 lineaments were produced. The lineaments have a maximum length of 21.07 km, a minimum length of 0.37 km and a mean length of 3.816 km. Rose diagram constructed from this lineaments shows that the dominant orientation is NW-SE with 120(56.87%) lineaments; other orientations are N-S with 36(17.06%) lineaments, NE-SW with 47(22.27%) and E-W with 8(3.791%). Dominance of the NW-SE lineaments suggest widespread effect of the Pan- African Orogeny within the study area. According to Ike (1988), the NE-SW lineaments developed along pure shear axis perpendicular to the maximum principal stress. The E-W lineaments are less dominant within the study area may be due to being rotated north or south away from their original direction.

Lineament density map shows that the northern, central and southeastern parts have the highest density accounting for about 0.87% while the eastern, southwestern and a portion of the northern parts have the lowest density accounting to about 51.2% of the study area. Lineament intersection map shows that areas with low intersection density dominates and covers about 98.17% while area with high intersection density occupies about 0.179% of the area. Lineament mean length map of the area shows that very short lineament lengths dominate the area and account for about 61.7% while the very long lineaments account for about 0.638% in the north central, northern and southern parts. Dendrogram of lineaments produced shows that the NW-SE and NE-SW lineaments are most correlating. These lineaments are more correlating to the N-S lineament specie than the E-W lineaments. Close correlation in dendrgram between the NW-SE and NE-SW lineaments suggest these lineaments species are conjugate pair, with one being dextral and the other sinistral. This agrees with the work of Ball (1980) who noted that a

major conjugate system of strike slip faults affects the Tuareq and Nigerian shield with both fault directions having a consistent trend and sense of displacement; a NE-SW trending system having a dextral sense of movement and a NW-SE trending system a sinistral sense.

6.1.3 Structures and Deformational History

The E-W collision of the West African Craton and westward moving plate of 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 and Ekwueme, 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. The ductile structures are folds, foliations and lineations while brittle structures are the joints and faults. Fold analysis undertaking shows that they have an approximate axial plane trend in a NNE-SSW direction also the trend and plunge of the fold axis of these folds are concentrated in the NE axis of the stereoplot. Most of the large scale folds within the area are isoclinal suggesting a coaxial deformation; majority of the large scale folds occurred on the quartzite with minor occurrence on schist rocks. Analysis of foliations on stereoplots shows that they have a NE-SW trend, and this is confirmed by the construction of stereographic projections of poles to foliation surface which shows that the poles are concentrated in the NW and SE axis.

Joint analysis undertaken on all the locations shows an E-W, NW-SE, NE-SW and N-S directions in all the individual lithologic units. The muscovite schist shows a NNE-SSW and a slight NNW-SSE trend, the quartzite rock had a NE-SW and a NW-SE trend suggesting

polydeformation, while the granite had a dominant NE-SW trend. The dominant fault type is a transcurrent dextral strike slip fault with a NE-SW trend.

According to (Onyeagocha and Ekwueme, 1982; 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 shows that they are also Pan African orogenic structures while the E-W, NW-SE trends of this structures are likely pre-Pan-African thus suggesting that they are associated with an earlier D1 deformation phase.

The resultant orientation of the structures which are NW-SE, NE-SW, N-S is analogous to the direction of tectonic events responsible for the fracturing in other parts of the Zuru Shist Belt (Danbatta, 2005; Ramadan and Abdel- Fattah, 2010).

The study area was subjected to two episode of deformation (D1 and D2). The D1 phase was associated with the development of an S1 schistosity and an F1 minor asymmetrical fold, the nature of its asymmetry suggest a non-coaxial deformation The D2 tectonic phase is associated with an S2 crenulation cleavage and an F2 tight to isoclinal fold. The intensity of folding increased with time as D2 was more intense and occurred majorly on the quartzite rock units, while D1 was moderately intense with asymmetrical minor folds geometry and mostly occur on the muscovite schist. The major folding associated with the second phase of 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; 2003b).

6.1.4 Strain Analysis

Fry haloes obtained from the strain analysis of photomicrographs of samples suggest that the area suffered a heterogeneous deformation. The orientations were basically in a NNE-SSW, NE-SW and NW-SE directions. Quartzite outcrops around Masama, Illaglu and Kokanawa experienced the highest degree of deformation compared to other parts of the area. Areas where muscovite schists were mapped experienced the least deformation.

6.2 CONCLUSION

Geological mapping of Danko area was carried out on a scale of 1: 50, 000. It is about 1020 km^2 in areal extent and is a part of the northwestern part of the Zuru Schist Belt. Petrographic studies of the thin sections prepared from twenty rock samples collected from the study area revealed three distinct rock units, namely quartzites, muscovite schists and medium grained granite. Prior to the work, both muscovite schist and medium grained granites have not been reported in the study area. The mineralogical assemblages of these rocks are quartz, micas (muscovite and biotite), chlorite, sillimanite, garnet for the quartzites; quartz, muscovites, biotite, chlorite for the muscovite schist and quartz, biotite, microcline, perthite, sericite for the medium grained granite.

Strain analysis shows that the area underwent a multiple deformation and the northern parts have been subjected to high deformation effect as compared to the other parts. The area has been subjected to at least two deformational phases (D1 and D2) and the imprint of deformational tectonic events resulted in the development of structural elements such as lineations, foliations, jointing, folds and veins.

Statistical data of joints, foliations, lineations and veins were processed. Rose diagrams, stereographic projections, lineament analysis and bar charts plotted from these data reveal a NW-SE trending for foliations, E-W, NE-SW, NW-SE and NNE-SSW trends for the joints and a NNE-SSW trend for the lineations thus suggesting that most of the trends were Pan-African.

CONTRIBUTION TO KNOWLEDGE

The following are the contributions of this to knowledge

i. The geological map of the study area on a scale of 1:50,000 was produced

ii. The lineament maps of the area was produced

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

iv. The metamorphic and structural history of the area was documented

6.3 RECOMMENDATIONS

Further detail studies solely devoted to better understand the geotectonic evolution of the Zuru Schist Belt as a whole so as to correlate its structural geometry, age and mineralogical composition with other schist belts within the Nigerian Basement Complex should be undertaken. Other strain analytical techniques should be employed to further improve our understanding of the deformation patterns of the Zuru Schist Belt and to correlate its deformation pattern with other schist belts within the Nigerian Basement Complex should be carried out.

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PPENDIXES

APPENDIX I

Joint readings for Medium Grained Granite (degrees)

106	112	114	114	106	098	182	114	074	094
060	052	302	320	358	352	280	270	262	352
342	028	020	020	026	312	358	008	014	084
012	014	016	008	006	344	022	020	308	126
120	124	020	020	350	358	358	246	240	240
244	340	340	342	340	250	348	358	248	252
228	262	296	298	340	286	242	280	252	326
346	008	008	006	014	012	014	016		

APPENDIX II

Trend readings for Muscovite Schist (degrees)

286	274	278	282	276	348	352	346	348	342
342	348	194	200	214	196	194	202	210	026
024	018	020	022	016	014	018	112	086	048
008	008	022	064	024	038	036	038	034	038
210	138	212	178	050	358	168	028	332	168
028	332	092	208	350					

APPENDIX III

Trend readings for Quartzites (degrees)

068	070	146	058	134	052	040	058	170	188
148	222	234	046	108	052	032	040	040	152
200	096	084	032	046	048	050	056	046	056
046	060	068	006	026	112	106	104	236	170
066	048	036	088	100	050	050	024	250	250
108	042	054	118	118	072	296	322	290	310
244	172	090	174	234	278	290	192	028	358
046	136	050	058	032	124	066	104	004	122
082	284	308	270	074	282	294	296	294	292
294	296	292	298	276	272	294	280	288	134
112	230	002	088	072	174	220	022	024	020
336	326	296	288	268	262	298	300	252	036
126	056	062	156	134	204	084	184	122	124
202	108	074	176	236	186	086	084	070	076
168	152	064	088	054	106	138	080	178	060
052	338	350	064	284	358	282	354	350	290
292	294	292	270	336	176	274	310	292	204
250	228	222	226	220	358	018	348	344	354
054	094	152	036	088	024	028	026	190	182
214	252	152	136	204	330	170	184	132	138
302	036	110	346	138	348	040	320		