THE STRUCTURE AND PETROGRAPHY OF THE NORTH-EASTERN PART OF NINGI-BURRA COMPLEX YOUNGER GRANITE PROVINCE NORTH CENTRAL NIGERIA, USING REMOTE SENSING TECHNIQUES

BY

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

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JULY, 2017

DECLARATION

I declare that the work of this dissertation en titled “Structures and Petrography of the north-eastern part of Ningi-Burra Complex Younger Granite Province north central Nigeria using Remote Sensing Techniques” is carried out by me in the Department of Geology, Ahmadu Bello University, Zaria. The information derived from the literature has been duly acknowledged in the text and a list of references also provided. No part of this thesis was previously presented for another degree or diploma at this or any other institution.

.....	.....	.....
Name of Student	Signature	Date

CERTIFICATION

This dissertation titled "**THE STRUCTURE AND PETROGRAPHY OF THE NORTH-EASTERN PART OF NINGI-BURRA COMPLEX YOUNGER GRANITE PROVINCE NORTH CENTRAL NIGERIA, USING REMOTE SENSING TECHNIQUES,"** meets the regulations governing the award of degree of master of Science in geology, Ahmadu Bello University Zaria, is approved for its contribution to knowledge.

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DEDICATION

I dedicate this work to my family

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ABSTRACT

The structure and petrography of the north-eastern part of Ningi-Burra Younger granite Complex of north central Nigeria was investigated using remote sensing techniques, field mapping, sampling and petrographic studies. This is in order to compile and interpret lineament and lithological features and to determine the sequence of structural events in the study area as well as correlate the result with the data compiled from previous workers on the Ningi-Burra Complex. A single scene of Landsat Enhanced Thematic Mapper plus (ETM+) data was georeferenced using the coordinates of the Nigeria Topographic Map Sheet 127 SE and 128 SW of Gwaram and Birnin-Kudu respectively, so as to delineate its lineament and lithological patterns. ERDAS imaging software was used for the satellite image processing, while image enhancement including (filtering and edge enhancement), as well as interpretation and digitization were carried out using ILWIS 3.3. After various image enhancement processes, the mapped lineament structures were interpreted as fractures, joints, drainage lines and dykes and ring structures. Analyses of the traced lineaments were conducted by visual and manual inspections, and the statistical results are characterized by positively skewed values. The total length of the interpreted drainage lineaments from the satellite images is 11.579 km with an average of 5.7895 lineaments per km and a data mean of 1.908 drainages per km. The interpreted fractures/joints lineaments have a combined total lineament length of 46.931 km, average of 23.4655 lineaments per kilometer, and a data mean of 1.456. The values of lineament density documented are 0.085, 0.086-1.70, 1.70-2.56, 2.56-3.41 and 3.41-4.26 square kilometer representing low, intermediate and high density values respectively. Values of the trend and/or strike of the interpreted lineaments were organized into bin sizes (class intervals), where each bin represents the number of values that fall within the specific angular region. The result of these structural analysis shows that numerous fractures and lineaments occur at the western, central and eastern part of the area on the satellite imagery. The common orientations of lineaments are NW-SE and NE-SW, while a dolerite dyke related to a major NE-SW striking fracture occurs in Western part of the study area. The study area is composed of rhyolite that commonly represents the earliest igneous activity and is intruded by porphyries, granites and less commonly by syenites. The rhyolites include lavas ash fall tuffs and agglomerates, as well as abundant ignimbrites that were deposited from ash flows (synonymous with ash-flow tuffs), including both welded and non-welded tuffs. The magmatic cycle in the studied north-eastern part of Ningi-Burra Younger Granite ring complex occurred repeatedly, with the location of magma generation migrating progressively westwards, resulting in a chain of rhyolitic cauldrons. It is also revealed that localities with high lineament density within the study area are mineralized with topaz and cassiterite deposits.

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CHAPTER ONE

INTRODUCTION

1.1 BACKROUND

Remote sensing is the acquisition of data about an object or scene by a sensor that is far from the object (Colwell 1983). Aerial photography, satellite imagery, and radar are all forms of remotely sensed data. Usually, remotely sensed data refer to data of the Earth collected from sensors on satellites or aircraft. Most of the images used as input to the ERDAS IMAGING system are remotely sensed.

Recent advances in technology and methods of integrating maps and data are making the task of mapping lineament structures and mineral potential in large areas by computer more appealing to practicing geologist (Starr and Este, 1990; Berry, 2000). Remote sensing and image processing techniques provide additional approach in mineral exploration (Goudarzi and Smith, 1978; Kaufman, 1988; Rowan and Bowers, 1995; Baker et al., 2001; Ashano and Olasehinde, 2010). They reveal the geologic structures which help to establish the tectonics and mineral potential zones relating to alteration (Dunning et al., 1998; Jefferies et al., 2000; Ashano and Olasehinde, 2010).

There has not been any thorough investigation of the lineament pattern in the Younger Granite province of Nigeria using remote sensing techniques. Spatial distribution and lineament density provide useful database in mineral exploration, geophysics, hydrogeology, water borehole drilling, road and dam location and alignments, environmental planning as well as potential hazard monitoring and control (Odeyemi et al., 1999).

1.2 LOCATION, EXTENT AND ACCESSIBILITY OF THE STUDY AREA

The study area is located within Birnin-Kudu Sheet 127 SE and Gwaram Sheet 128 SW, and is bounded between Latitudes 10o 55’ N to 11o 10’ N and Longitudes 9o20’ E to 9o 35’ E (Figure 1). The area falls within the Younger Granite province of Nigeria (Jacobson et al., 1958), and forms the eastern part of Ningi-Burra Ring Complex that is situated about 150 km north of the Jos Plateau.

The area of study is accessible from Ningi town by a tarred road that runs westward through Guda - Ari through Tabela towns and up to Burra town. To the north of Ningi town is also a tarred motorable road which trends westwards to Kaffin chakuna through Dengir, Jigawa and Lumbu towns to Burra town. In addition there are several foot paths, cattle and lumberers tracks that run through the Complex thus making the area quite accessible.

1.3. SETTLEMENTS AND LAND USE

Settlements within the study area are typical of those found in most parts of northern Nigeria. Highly populated areas are confined to major towns such as Ningi, Guda, Ari, Tabula, Zadanga, Jigawa and Lumbu. Outside the towns, settlement is essentially sparse and composed of hamlets Fulani settlements. The major occupation of the people in the area is farming. A dark soil which was formed from the weathering of the basalt are common in the area while the crops, commonly formed in the area are millet, guinea corn, beans and cassava.

Local mining and stone crushing activities are also common in this area, while the streams are used mainly for washing. Main sources of drinking water in this area are hand dug well and shallow boreholes fitted with hand pumps.

Figure 1: Location map of the Study Area

1.4 RELIEF AND DRAINAGE

The study area has a distinct rugged topography with hills of various heights (Fig. 1). The relief is relatively high with the highlands situated in the western, north western, southern and north eastern parts.

Topographically, the Ningi-Burra Complex forms a range of hills with NE-SW trend over a distance of about 70 km and a width of about 20 km. The range of hills rise about 100 - 300 m above the surrounding basement plains. Volcanic rocks occupy areas of high topography.

The drainage pattern is mainly dendritic. The main river and its tributaries take their source from surrounding hills. The area is drained by Rivers Tsangaya, Dagwalo, Tabula and Tebbi to the south and Rivers Dengir, Jigawa and Lumbu to the north, which empties their water to river Dilimi and subsequently to Lake Chad (Fig. 1). The streams and rivers in the area are seasonal with the water having their highest flow in the rainy season around August and lowest flow during the dry season around March

1.5 CLIMATE AND VEGETATION

The climate of the area is marked by three distinct seasons:-

i Late November – February: Harmattan (NE trade wind from the Sahara that blows toward the south western coast of Africa).

ii. March - May: Dry season, usually very hot with few isolated rain fall. The wind blows from northeast to southwest and temperature may rise more than 350 C.

iii. May - September: Wet or rainy season, wind blows to the south-westerly direction with occasional sunshine and temperature reaches more than 350 C. September-Late November is characterized by wind from south-west to north east.

Rainfall is usually very heavy in August and finally fading in early November. The mean annual rainfall is about 100 cm. while the mean relative humidity at 0600 hours and 1200 hours is 50 percent and 58 percent respectively (Schroeder, 1974).

The vegetation in the area corresponds to the Sudan-Savannah type, which is characterized by a sparsely distributed shrubs and grasses. The grasses can be as tall as 1m above ground surface during the raining season. Common trees include; Acacia albida, Adansonia digitata, Meliaindica, Delamixregia, Pamae Adenium obtusum due to their ability to survive dry season.

1.6 PREVIOUS WORK IN THE STUDY AREA

The geology of the Ningi-Burra Complex has been described by Falconer (1911), Falconer and Raeburn (1923) and a short account of the eastern part of the complex provided by Jacobson and Jaques (1944), who mapped the double ring dyke near Ningi and recognised a grouping of rhyolites into crystal-rich and crystal-poor types.

The Ningi-Burra Complex has being studied by Turner and Bowden (1979) that worked on the dissecting Calderas and migrating magmatic centers in the area. Those authors describe it as a series of overlapping ring structures which contain varied pre-caldera volcanic sequences,

overlain by massive intra-caldera rhyolitic ignimbrites and enclosed within ring dykes of fayalite-hedenbergite granite-porphyry.

Ike (1984) studied post magmatic arfvedsonite - aenigmatite paragenesis in the area. Despite the successes recorded in the study of the Mesozoic granites which have now been studied extensively because of their Tin-bearing affinity, Ike (1983) has dealt in detail with the structural evolution of these granites, where he provided a model for the structural evolution of the Tibchi ring-complex.

Bennet et al. (1984) describe the basalts as hypersthenes-normative but may originally have been alkaline or transitional to nepheline-normative they are linked through a series of andesine basalts, mugearites and trachyandesites to aphyrictrachytes.

The Ningi-Burra complex is exposed at a high structural level which means erosion has cut down to the roof zones of several granite plutons and has completely removed the flanks of the original volcanic structures, leaving only the circular or elliptical central volcanic masses which foundered during caldera formation.

These volcanic subsidence structures cauldrons as defined by Smith and Bailey (1968) provide nearly complete sections through the volcanic accumulations, from the basement floor almost to the products of the final eruptions. Although the volcanic rocks are recrystallized and hydrothermally modified to varying degrees, petrological and chemical data enable magma compositions to be defined broadly within acid, intermediate and basic groups. The volcanic sequences provide evidence on the order in which magmas of widely different compositions arrived at the surface, their degree of crystallization, mode of eruption and abundance.

Ningi-Burra Complex includes almost all of the rock types known in other parts of the province. In the early stages of each caldera-forming cycle, the ignimbrite eruptions were of small volume and the The rocks have varied crystal contents Later, large high level magma chambers must have developed, from which crystal-rich ignimbrites with volumes in the order of 100 km3 were erupted, with accompanying caldera collapse (Jacobson and Jaques 1944).

The form of the complex as a whole shows that the cycle occurred repeatedly, but with the location of magma generation migrating progressively westwards, resulting in a chain of rhyolitic cauldrons, into which sub - volcanic granites and syenites have been emplaced.

1.7 AIM, OBJECTIVES AND SCOPE OF THE PRESENT WORK

The aim of this research work is to study the structural lineaments and petrography of the north eastern part of Ningi-Burra Complex using remote sensing techniques.

The objectives of the research work are to:-

i. Compile the satellite imageries of the study area and interpret the lineament features associated with eastern portion of the Ningi-Burra ring complex.

ii. Produce geological and lineament map of the eastern part of Ningi-Burra ring complex on a scale of 1:50,000, and remote sensing studies.

iii. Determine the sequence of structural events in the study area.

iv. Delineate the lineament and lithologic patterns in the study area and correlate the result with existing data as compiled by previous workers.

The scope of the present study is outlined under research methodology and it involves;

i) Literature review of relevant previous works

ii) Interpretation of landsat images

iii) Field work at a scale 1:50,000 and collection of representative rock samples.

iv) Laboratory analysis and lineament analysis

v) Data interpretation.

CHAPTER TWO

LITERATURE REVIEW

2.1 REGIONAL GEOLOGY

Nigeria lies approximately between latitudes 4o and 15o N and Longitudes 3o and14o E within the Pan African mobile belt between the West African to the west and Congo cratons. The geology of Nigeria is dominated by crystalline and sedimentary rocks both occurring approximately in equal proportions (Woakes et al., 1987). The crystalline rocks are made up of Precambrian basement complex rocks and the Phanerozoic rocks which occur in the eastern region of the country and in the north central part of Nigeria. The Precambrian basement in Nigeria consists of the Migmatite Gneissic – Quartzite complex dated Archean to Early Proterozoic (2700-2000 Ma) (Figure 2). Other units include the N-S trending schist belts mostly developed in the western half of the country and the granitoid plutons of the Older Granite suite dated Late Proterozoic to Early Phanerozoic (750-450Ma). The main phase of acid magmatism in Nigerian Younger Granite complexes commenced during Triassic times and continued to migrate in a southerly direction until the close of the Jurassic (Bowden et al., 1971). The cessation of magmatism was synchronous with the initiation of the South Atlantic.

The Younger Granites petrographic province is exposed in Niger and Nigeria consists of north south trending belt of igneous centers ranging from Ordovician (470 Ma) in northern Niger (Karche and Vachette, 1976) to Jurassic (144 Ma) in the most southerly complex in Nigeria (Martin and Bowden, 1981). The ring structures and cupolas represent roots of volcanoes. Igneous activity occurred during 50 to 60 Ma, and for each of these cycles, the igneous centre defines an ENE trend (Bowden et al., 1979).

Fig. 2: Younger Granite Complexes in Nigeria and Southern Niger (after Turner, 1972).

The eroded volcanic complexes of northern Nigeria are either isolated (e.g. Ririwai, Banke) or coalesced into groups owing to the migration of the centre of magmatism e.g., Ningi-Burra (Turner and Bowden, 1979) and Tibchi (Ike, 1979). These complexes were emplaced in a mixed assemblage of metamorphic and calc-alkaline meta-igneous rocks (Olarewaju, 1978) that yield late Precambrian to Cambrian ages (Van Breemen et al., 1977). The migmatites and gneisses are considered to be reworked older crustal materials. The Younger Granites provide classic examples of intraplate, rift-related magmatism. They are unrelated to any orogeny and owe their development on a regional scale to thermal anomalies in the mantle (Martin and Bowden, 1981).

There is a regional migration of magmatic activities that indicated Rb-Sr age of (218Ma) in the oldest complex occurring in the North and (144Ma) the youngest in the south. The Ningi-Burra complex yields a Rb-Sr mineral age of 187 Ma (Rahaman et al. 1984). This age was obtained on feldspar separates from one of the eastern center of the Ningi-Burra Complex and may be representatives for the whole multicentre complex (Turner, 1963). Earlier work by Van Breemen et al. (1975) has shown that initial strontium isotopic ratios in the Nigerian Younger Granite province are variable but related to the mineralogical composition of the rocks. Low values (0.704) are found in oversaturated syenites, intermediate values (0.706-0.709) in fayalite granites, and increasingly higher value (up to 0.723) in biotite granites and (up to 0.752) peralkaline granites On this basis, no one source area of magma generation can be defined. It must be concluded, if the strontium isotopic evidence is reliable, that the parental magmas in the Nigerian Younger Granite province were derived from mantle and crustal sources (Bowden et al., 1976).

2.2 GEOLOGY OF THE YOUNGER GRANITES

The geology of Nigeria comprise of Precambrian to Lower Paleozoic Basement Complex rocks into which the Younger Granites suites are emplaced (MacLeod et al., 1965). Basement rocks consist of ancient sediments of granulitic gneiss, dioritic rocks, migmatites, granite-gneiss, older granites and granodiorites (MacLeod et al., 1965; Oyawoye, 1964, 1972). The ring dykes dip outwardly both on the inner and outer contacts but some have steep or vertical contacts (MacLeod et al, 1965). The Younger Granite complexes trend in N – S belt with the ages of the complexes decreasing southwards. Rahaman et al., (1984) pointed out that major local magmatic activities were concentrated along ENE and WSW zones.

Several individual complexes have been identified with varying sizes and named after their localities, individual massifs range from 640 km2 (Ningi, Jos-Bukuru and Shakaleri) to less than 1.68 km2 (Banke, Rope and Zuku), Ogezi (1986) referred to them as Cenozoic (Jurassic) igneous granitic rocks suites that occur in a north – south trending belt, restricted to the northern part of the country, indicating that the suites extend from Afu (near River Benue) in central Nigeria to Zinder and A'ir in Niger Republic and covers an area of about 1300 km2 within Nigeria – enclosing parts of Plateau, Nassarawa, Bauchi, Jigawa and Kaduna states (Fig. 2).

The Nigerian Younger Granites emplaced as an anorogenic rocks from high level magmatic activities and controlled by ring fracturing, faulting and cauldron subsidence (Turner, 1971) and hence their evolution as near ring (circular) complexes. They are however known to be associated with earlier acid volcanoes such as ryholites and syenites (Elebe, 1990).

Individual Younger Granite suites are known to contain different rock types in the various sub provinces despite their age differences that decrease towards the south, suggesting that their emplacement was fundamentally controlled by thermal anomaly in the mantle or lower crust but not related to any orogenic activity and are thus referred to as unorogenic (Garba, 1987). This is also supported by their non-foliated surfaces (Idumah, 2005), in contrast to the foliated calc-alkaline older granites (Turner 1989). Emplacement of the Younger Granites is associated with epeirogenic uplift (Turner, 1989), and their age is Jurassic. The Older Granites and accompanying metamorphism of the basement are of Pan African age (Jacobson et al., 1958; Van Breeman and Bowden, 1973).

2.3 STRUCTURAL FRAMEWORK OF THE EASTERN PART OF NINGI-BURRA

Bowden and Turner (1974) reported on the geology of Ningi-Burra ring complex. There are two principal hill massifs; the eastern or Ningi Massif and the western or Burra Massif, which are remarkably similar in shape and size (about 20-30 km). Between them lies a plateau underlain by rhyolite and granophyres (the Kah Massif) south of which is a U-shaped ridge formed by a ring dyke enclosing basement rocks-the Jimmi ring dyke.

Geologically, the Ningi-Burra Complex can be divided into 6 cauldrons or 'ring centers' (Fig. 3), which show progressive shift to westward direction as a faults and local upward displacement as seen adjacent to intrusions due to doming. A seventh cauldron, the Tibchi complex, lies to the south of the Burra massif. According to Turner and Bowden (1979), each cauldron comprises of three main structural units: (i) a peripheral ring dyke (or ring fault); (ii) volcanic rocks; and (iii) granite and syenite intrusions (not exposed in some of the centers).

Figure 3. Cauldrons or 'ring centers' of the Ningi-Burra (after Turner and Bowden 1979). Note; the area of study is located within the Ningi massif as defined by centre's 1, 2 and part of 3.

In each of the centre the volcanic rocks typically form basin-like structures, dipping inwards around the margins but flat-lying in the interior (Turner and Bowden, 1979). The basement floor is often exposed close to the ring dykes. The lower parts of the succession can include basalts, trachybasalts, trachyandesites and trachytes as well as varied rhyolitic ignimbrites and lavas, while the upper parts are more massive units of porphyritic rhyolite (Turner and Bowden, 1979).
The inward dips of the volcanic could be as a result of subsidence within inward dipping ring fracture. Minor basic rocks, early basalts and gabbroic intrusions and late dyke rocks are widely distributed (Bowden and Turner, 1974). There is lateral shift in ring complex emplacement as indicated in Figure 3, as well as a regional migration of magmatic activity as pointed out by Turner (1963).
Internal movements within the Earth generate stresses that are capable of deforming rocks; the deformation occurs in brittle ways, where the rocks change shape by fracturing, joints are the most common fractures (Maltman, 1990). Virtually every rock exposure has joints in it, joints and other geological structures are linear structures or lineaments. The presence of these geological structures in rocks favors migration and trapping of fluids on the surface or within the subsurface which is one of the main tasks in geology for the recognition of lineaments. The traditional approach involves the inspection of rock outcrops. However, because of their limited breath and continuity, many segments of lineaments may be overlooked on the ground.
Fiamme and eutaxitic structure are prominent features found in weakly recrystallized ignimbrites with low or moderate phenocryst content, these structures are commonly associated with ignimbrite in the Ningi-Burra Complex.
Growth of quartz and feldspar crystals within the ignimbrites has destroyed most of the original pumice structures; they may be zoned with inward growing alkali feldspars and large central crystals of quartz and sometimes alkali amphibole, biotite or fluorite, Schmincke (1975) interpreted similar textures in comenditic and pantelleritic tuffs from Gran Canaria as due to growth of crystals into cavities developed through re-vesiculation of pumice fragments.

2.4 LITHOLOGICAL FRAMEWORK OF THE EASTERN PART OF NINGI- BURRA COMPLEX

2.4.1 Rhyolites

According to Turner and Bowden (1979), the volcanic rocks of rhyolite composition include minor lavas, ash-fall tuffs and agglomerates, and abundant ignimbrites, all of which show the effects of post depositional devitrification, recrystallization or hydrothermal alteration. The ignimbrites generally have structural and textural features which correspond to modern comendites and pantellerites rather than the more calc-alkaline rhyolites. It seems probable that the rhyolite magmas of the Ningi-Burra Complex were equivalent in composition to the associated granite-porphyry intrusions containing fayalite and hedenbergite, but with a peralkaline fluid phase which locally caused post-depositional alteration and the subsolidus crystallization of alkali silicates.

2.4.2 Ash-fall tuffs and Agglomerates

As observed by Turner and Bowden (1979), the earliest eruptions in several of the main phases of volcanic activity were explosive, depositing ash-fall tuffs and interbedded agglomerates. In Centre 1, the Tebbi-Guda tuffs form a 13 m thick band outcropping along a strike length of 3km. They are well stratified, individual beds typically being several centimeters thick, sometimes graded but with particle size not generally greater than 2 mm, although occasional bands have lapilli sized fragments. The tuffs consist of angular rock particles in a very fine-grained quartz-sericite matrix. The lithic fragments are derived from the underlying rock - basement granodiorite and gneiss and basic to intermediate volcanic rocks. In contrast, the agglomerates and tuffs of Kibara in Centre 2 are composed almost entirely of rhyolite, they form massive agglomerate beds, locally with thinly bedded tuffs and minor intercalated lavas, at the base of the Kibara volcanic succession. Their total thickness is at least 150m and they have a basin-like structure, possibly because of deposition in a valley or a marginal trough in the early Centre 2 caldera. According to Turner and Bowden (1979), they were deposited at a later stage than the Tebbi-Guda tuffs, after thick rhyolites had accumulated in Centre 1 and the main rock type is agglomerate made up of rounded blocks of crystal-rich rhyolite, derived from the nearby Centre 1 caldera rhyolites. Less abundant blocks are of granite-porphyry (some reaching 1 m in diameter) and of basement granite-gneiss. The matrix, and associated tuff bands, is composed of comminuted rhyolite material with splintered crystals, and of small pumice fragments representing new lava.

2.4.3 Ignimbrites

The majority of the rhyolitic rocks are ignimbrite rocks that are deposited from ash flows, synonymous with ash - flow tuffs and including both welded and non-welded tuffs (Macdonald, 1972). They range from very finely crystalline devitrified rocks, in which original shards and fiamme are well preserved, to relatively coarse-grained rocks with a groundmass of quartz-feldspar mosaic having crystal diameters of 0.01 to 0.05 mm. Lateral and vertical variation in individual units has not been studied in detail and their recognition as ignimbrite is based on the following five (5) petrographic features as described by Macdonald (1972) and others:

i) Shards: Occasional ignimbrites show undeformed shards, indicating absence of welding. More frequently in the less recrystallized ignimbrites, shards are locally preserved in highly deformed areas around crystals or lithic fragments. In many rocks classed as ignimbrites, however, the whole groundmass is so thoroughly recrystallized that no trace of shards can be seen.

ii) Lithic fragments: A small proportion-usually less than 5% by volume of rhyolite, basalt, trachyte or basement fragments are characteristic of most ignimbrites and often the lithology and abundance of such fragments can be diagnostic of individual units.

iii) Laminar flow in ignimbrite rocks: One of the main characteristics of peralkaline ignimbrites is their low viscosity on deposition so that intense flattening and welding are achieved even in very thin deposits (Gibson and Tazieff, 1967) and post depositional laminar flow can take place (Ragan and Sheridan, 1972; Schmincke, 1975). An example of flow structure is seen in a welded tuff, which occurs within the basalt trachyte sequence SW of Jigawa. This forms a distinctive unit about 30 m thick, containing 12-13% of phenocrysts. The lower part has conspicuous lenticular fiamme, giving a eutaxitic foliation which dips at a constant 'angle of about 10o to the South. However, the fiamme are intensely flattened to give a banded structure which is deformed in broad folds with amplitudes of several meters producing variable dip and strike.

iv) Broken crystals: Quartz and feldspar phenocrysts range from about 5% to over 50% by volume. Characteristically these crystals are separate and fragmented, in contrast to phenocrysts in the rhyolite lavas and the granite-porphyry intrusions which are mainly in synneusis-type aggregates. Final disintegration of the crystals sometimes took place during compaction or late flow, as shown by trails of partly disrupted crystals or crystal groups in some ignimbrites. Intrusive rocks with the same broken phenocrysts are located at several points along the ring dyke system of the complex.
These are fayalite-hedenbergite porphyries and generally form broader sections of the ring dykes than the normal ring-dyke rock, the latter being coarser-grained granite-porphyry (porphyritic microgranite) which has aggregated, unfractured phenocrysts. The link between the fayalite-hedenbergite porphyries and the ignimbrites is probably that the former were emplaced as fluidized material and mark the sites of ash-flow vents.
v) ‘Eutaxitic rhyolite' (a possible transition between ignimbrite and lava): A crystal-poor rhyolite with an unusual type of eutaxitic structure occurs both as a thick sheet and as a series of pipe-like bodies, which form an arc defining the Centre 1 ring structure. The rhyolite, both in the pipes and sheet, contains light colored bands in a finer-grained darker matrix. The bands are up to a few millimeters thick and usually several tens of centimeters long. They are often linear or rod-like, with irregular branching crossections, differing greatly from the flattened fiamme of normal ignimbrites.
The rhyolite of the pipes often shows a large scale columnar jointing, oblique to the eutaxitic structure and ranging in attitude from vertical to inward dipping at about 50°. Xenolithic fragments are abundant; they are mainly pink basement granite as rounded blocks of up to a few centimeters in diameter which locally form 50% of the rock of the pipes. In the rhyolite sheet of the Ningi succession, basalt and rhyolite fragments are also present, xenoliths being more abundant in the lower part of the flow.

The rhyolite is peralkaline, containing from 5 to 8% of phenocrysts, mainly quartz and alkali feldspar in separate, partly resorbed and broken crystals, but also a little hedenbergite and some crystals of zircon and allanite. The groundmass is very fine-grained quartz and feldspar, usually with green sodic hedenbergite and arfvedsonite and small magnetite octahedral. The eutaxitic bands contain more coarsely crystallized quartz and feldspar, the larger ones having a zoned structure with crystals growing inwards from the walls-especially albite which forms well-twinned cloudy crystals up to 0.5 mm long. The central parts of the larger bands contain late crystallized quartz, arfvedsonite and sometimes biotite and minor fluorite

2.4.4 Rhyolite Lavas

Recognition of lava flows is difficult in the devitrified and altered rhyolites of the Ningi-Burra complex, depending mainly on the presence of flow banding (which can also develop in ignimbrites) and of synneusis aggregates in the quartz and feldspar phenocrysts. However the work of Turner and Bowden (1979) has confirmed that Lavas form only a small part of the Ningi-Burra rhyolites, according to them they appear at the early varied pre-caldera stage of the eruptive cycle: in the vents and in the Guda -Tebbi succession of Centre1, and in the Kibara volcano of Centre 2 and in the lower rhyolite-basalt sequence of Centre 6. The lavas have low phenocryst content and many of them are slightly silica-poor compared with the average rhyolites. The almost aphyric rhyolites of the inner vents of Centre 1 are flow banded, giving place locally to breccias and agglomerates of the same material, and are interpreted as lava domes extruded at the beginning of the Centre 1 sequence.

An example of a relatively crystal-rich lava flow is the purple banded rhyolite which forms an extensive thick unit in the lower part of the Kabara succession. This contains about 20% phenocrysts in synneusis aggregates. The quartz:feldspar ratio is less than 1: 4, compared with1:1 in ash flow tuff of the same crystal content. Fayalite and hedenbergite probably also formed early phenocryst phases, suggested by iron oxide pseudomorphs which enclose prismatic zircon. As with the other lavas, hematite is the main mineral in the groundmass. The appearance of rhyolite lavas early in the volcanic cycles is presumably because their extrusion took place before volatile pressures had become sufficient for ash flow eruptions

2.4.5 Crystallization of the Rhyolites

The numerous ignimbrites and lavas in the Ningi complex provide a record, through their varying phenocryst content of successive stages of crystallization in the subvolcanic magma chambers Turner and Bowden (1979). Quartz and alkali feldspar are the only important phenocryst minerals in abundances. In most rhyolites with low crystal content, they are about equal abundant but with advancing crystallization, feldspar becomes dominant. This crystallization path shows that, for most of the rhyolitic magmas, the composition lay on the quartz-feldspar cotectic. However, a few nearly aphyric lavas in the inner vents of Centre 1 contain only feldspar phenocrysts, and two samples of crystal poor rhyolites from Centre 1 and 2 also contain a high proportion of feldspar. These rocks appear slightly silica-poor and lie within the alkali feldspar field.

The rhyolite lavas have low crystal content; the maximum recorded being about 20%. When crystallization went beyond this point, perhaps only vesiculated and fluidized material reached the surface. Although the crystal content of the ignimbrites ranges from 5% to 60%, the majority are crystal rich, with 40-60% phenocrysts.

The eruptive mechanism of ash flows requires a buildup of gas pressure and it is likely that favorable conditions for large eruptions were achieved only after substantial crystallization had taken place. When more than 50-60% of the magma in a sub volcanic chamber was crystalline, it evidently ceased to be eruptible altogether.

As observed, a few specimens of crystal-rich ignimbrites contain patches of loosely aggregated crystals which probably represent the beginnings of a crystal mush, whose complete formation would prevent further eruption. Ferromagnesian phenocrysts are generally replaced by secondary iron oxides but occasionally they are unaltered. Hedenbergite, zircon, allanite and possibly magnetite are present in rhyolites with only 56 % of the total phenocryst content.

2.4.6 Basic and Intermediate Volcanic Rocks

Basaltic rocks occur mainly in the lower parts of the volcanic successions where they are associated with both rhyolites and trachytes, but occasional basalts are interbedded with the later intra-caldera rhyolites. Trachytes and related intermediate volcanic are known only in the Ningi massif.

According to the petrographic work of Turner and Bowden (1979), Bowden and Kinnaird (1984) and Kinnard (1985); the basaltic rocks are black to greenish in colour, sometimes amygdaloidal and sometimes containing large plagioclase phenocrysts. They retain little of their primary mineralogy of pale-brown augite, labradorite and iron ore; usually the pyroxene is entirely replaced although the plagioclase is relatively unaltered. Assemblages accompanying the relict plagioclase include hornblende-sphene, tremolite-actinolite, brown biotite, iron oxide, tremolite - actinolite-sphen, calcite; breakdown of plagioclase leads to the assemblage epidote-chlorite tremolite, sphene-pyrite. Some basalt contain large phenocrysts of labradorite (about An55), up

to several centimeters in length, often aggregated and containing rounded inclusions of amphibole, which probably pseudomorphs original olivine or pyroxene. In some rocks the labradorite is rimmed by andesine and accompanied by a second generation of smaller phenocrysts of zoned andesine (An45-40). These porphyritic andesine basalts are part of a series leading through trachyandesites and mugearites to trachytes.

Trachyandesites are found as highly porphyritic rocks in the upper part of the basal succession near Jigawa in the north of Ningi massif. Here they form a group of flows totaling 100 to 150 m thick. They have some features in common with the rhombo-porphyries of the Oslo district, and similar rocks occur in greater abundance in the Kila-Warji complex east of Ningi. The phenocrysts are often broken and fragmented; analogy with the rhyolitic ignimbrites and with the Oslo rhomb porphyries suggests that they may have been erupted as ash flows. They contain large feldspar phenocrysts (typically 5-10 mm, sometimes larger) with a wide composition range, each flow having a phenocryst assemblage distinctive in size, composition and abundance. For example, one flow contains as observed (Turner and Bowden, 1979):

i) Labradorite-andesine (An50) with broad albite twin lamellae, fresh except for sericite along cracks;

ii) Andesine (about An35), smaller crystals with narrow albite twins, strongly sericitised;

iii) Perthite, rounded, strongly resorbed and altered, sometimes as rims to andesine;

iv) Quartz, rounded crystals with mafic reaction rims. This rock is an exceptionally plagioclase-rich and mafic-rich member of the series but most contain some plagioclase, varying in composition from An50 to about An25 as separate individuals and often also as cores to alkali feldspar. Mafic minerals are almost entirely secondary (very fine-grained amphibole, epidote and chlorite) occurring with turbid feldspar and calcite in the groundmass and also as pseudomorphs suggesting original pyroxene, amphibole and possibly olivine phenocrysts. Minor early-crystallized phases are zircon, apatite and iron oxide.

Aphyric trachytes and mugearites occur in association with the earliest basalts and rhyolites near Ningi and also underlie the porphyritic trachyandesites at Jigawa. Here they are at least 200 m thick and their total volume in the Ningi massif is probably in the order of 30 km3 (Turner and Bowden, 1979).

The trachytic rocks consist of small feldspar laths (in some, entirely alkali feldspar but in others andesine-oligoclase as well) and secondary iron oxides, chlorite, epidote and calcite and usually a little quartz. Original mafic crystals are never preserved, but an aphyric trachyte from Jigawa composed mainly of alkali feldspar, contains small mafic pseudomorphs (0.2 mm) outlined by iron oxide, probably marking early crystals of olivine and pyroxene, and also crystals of apatite and zircon. The alkali feldspar rocks are true trachytes, but the more plagioclase-rich types are mugearites or approach andesite in composition although alteration, and especially the development of calcite, makes the composition range hard to define. At the other extreme some rocks in this group, especially those inter-bedded with the Centre 2 rhyolites are relatively quartz-rich and mafic-poor, trending towards rhyolite (Turner and Bowden, 1979).

2.4.7 Intrusive Rocks

The intrusive rocks are counterparts of the volcanic material, crystallized in the subvolcanic magma chambers or in the conduits connecting to the surface. Similar rocks have been described from other Nigerian complexes (see for example MacLeod et al., 1971; Bowden and Turner, 1974). There are no basic intrusions, apart from occasional minor dykes. Near Ningi (Centre 1) a syeno-monzonite intrusion is probably the subsurface equivalent of the trachytes and

trachyandesites of the eastern part of the complex. It is a dark porphyritic rock with plagioclase (An35) as cores to alkali feldspar, augite, hastingsite, secondary biotite and minor quartz.
Peralkaline granites with arfvedsonite also occur near the eastern extremities of the complex, Centers 1, while the sub-alkaline biotite in Centre 2, granites show extensive alteration to quartz-siderophyliite greisens, with minor associated zinc-tin mineralization. Granite porphyries, containing phenocrysts of quartz, alkali feldspar, fayalite and hedenbergite with groundmass quartz, alkali feldspar, hastingsite or sometimes arfvedsonite, represent the infilling of ring fractures during the final phase of volcanic activity.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 PREAMBLE

The methodology that is adopted for this research work involves; i) Literature review, ii) Remote sensing techniques using satellites imagery. iii) Field study, and iv) Laboratory analyses. The literature review is as presented in chapter two while the other employed methodologies are outlined below

3.2 REMOTE SENSING TECHNIQUES

3.2.1 Overview

The procedure of lineament analysis on remotely sensed images involves the computer-aided processing of large amounts of data sets (Koronovskii et al. 1986) as well as the performance of real density distributions by means of contour line maps.

For this study, the Landsat 7 ETM+ image data was used, the application of the Landsat spectral bands is presented in Table 1. Band 7 of this image data, according to this table is useful for the discrimination of minerals, rocks, lineament and structural types (Lilles and Kieffer, 1994). Satellite images acquired in this band have high information content that means there is large variation in the spectral response of materials in the environment. This is because Band 7 is the least affected by atmospheric attenuation compared with the reflected infrared bands. Landsat 7 also carries a panchromatic band (visible through near infrared), with 15 meters resolution for "sharpening" of multispectral images.

Table 1: Applications of Landsat Spectral Bands (Global Land-Observing Program, 2003).

S/N	Band Designation	Spectral Bands Used
1	Blue-green	Useful for bathymetric mapping and distinguishing soil from vegetation and deciduous from coniferous vegetation
2	Green	Emphasizes peak vegetation, which is useful for assessing plant vigor
3	Red	Discriminates vegetation slopes
4	Reflected IR	Emphasizes biomass content and shorelines
5	Reflected IR	Discriminates moisture content of soil and vegetation; penetrates thin clouds
6	Thermal IR	Useful for thermal mapping and estimated soil moisture
7	Reflected IR	Useful for mapping hydrothermally altered rocks associated with minerals deposits.

A single scene of Landsat Enhanced Thematic Mapper plus (ETM+) 2000-08-11, path 188/ Row 052 acquired on forth December two thousand and three (4/12/03) from National Centre for Remote Sensing, Jos, National Space Research and Development Agency (NASRDA). The data has seven bands sensitive to different wavelength. Six of these bands detect visible (7, 4, 1), near

infrared “NIR” (3) and short wave infrared “SWIR” (5) one thermal and one panchromatic, the study area was sub-settled from the single scene and was used in the present study.
The raw data was georeferenced using the coordinates of the Nigeria Topographic Map Sheet 127 SE and 128 SW of Gwaram and Birnin-Kudu respectively. The georeference projection in Universal Transverse Marcator (UTM), Minna Datum (Table 2).
ERDAS imagine software (Version 8.6) was used for image processing, while image enhancement including (filtering and edge enhancement) as well as interpretation and digitization were carried out using ILWIS 3.3.
Image enhancement operations carried out include filtering and edge detector, these were to enhance ‘sharpness’ of the satellite image for better visual interpretation, to reduce noise in the image prior to a multi-band image classification, to detect line features or edges in the satellite image as to aid structural interpretation amongst others. Edge detector shadow (linear and nonlinear features) was used in delineating lithological boundaries and edges thereby aiding image interpretation. Image classification was in unsupervised classification and was used to classify the image into unique characters comprising of pixels with similar spectral characteristics and unique clusters according to some statistically determined criteria.
Various layers were created from existing topographic and geological maps by on-screen digitization using ILWIS. The layers are drainage, contours and lithological units. Also after enhancement of the image, various layers/segments were extracted from the image of onscreen digitization, including fractures, lineaments, dykes and lithological units.
Table 2: Coordinates Projection Parameters

Projection	Datum Area	Datum	Ellipsoid Parameters		Ellipsoid	Hemisphere	Zone
UTM	NigeriaMinna	a	6378249	Clarke	Northern	32	
		1/f	293.465	1880			

(Source, ILWIS, 2005)
3.2.2 Global Digital Elevation Model (GDEM)
GDEM has been produced as a joint activity of the Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA). However, Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) instrument was built by METI and launched onboard NASA’s Terra spacecraft in December 1999. It has an along-track stereoscopic capability using its near infrared spectral band and its Nadir-viewing and backward-viewing telescopes to acquire stereo image data with a base-to-height ratio of 0.6. The spatial resolution is 15 m in the horizontal plane. One Nadir-looking ASTER VNIR scene consists of 4,100 samples by 4,200 lines, corresponding to about 60 km-by-60 km ground area (Table 3).
The methodology used to produce the ASTER GDEM involved automated processing of the entire 1.5-million-scene ASTER archive, including stereo-correlation to produce 1, 264, 118 individual scene-based ASTER DEMs, cloud masking to remove cloudy pixels, stacking all cloud-screened DEMs, removing residual bad values and outliers, averaging selected data to create final pixel values, and then correcting residual anomalies before partitioning the data into 1°-by-1° tiles. It took approximately one year to complete production of the beta version of the ASTER GDEM using a fully automated approach. The ASTER GDEM covers land surfaces between 83° N and 83° S and is composed of 22,600 1°-by-1° tiles. Tiles that contain at least

0.01% land area are included. The ASTER GDEM is in GeoTIFF format with geographic (latitude / longitude) coordinates.

Table 3: Basic characteristics of the ASTER GDEM

Grid	Coordinate system	Accuracy 0	
	Data format		
	Horizontal	Vertical	
1”			
	WGS84 /EGM96	CE95	
30 m	LE95		
20 m			
	GeoTIFF (16bit)		

Pre-production estimated accuracies for this global product were 20 meters at 95 % confidence for vertical data and 30 meters at 95 % confidence for horizontal data. Initial studies to validate and characterize the ASTER GDEM confirm that pre-production accuracy estimates are generally achieved for most of the global land surface, although results do vary and true accuracies do not meet pre-production estimates for some areas.

In addition, Version 1 of the ASTER GDEM does contain certain residual anomalies and artifacts that affect the accuracy of the product and may be impediments to effective utilization for certain applications.

Consequently, METI and NASA acknowledge that Version 1 of the ASTER GDEM should be viewed as “experimental” or “research grade.” Nevertheless, they are confident that the ASTER GDEM represents an important contribution to the global earth observation community.

The Structural lineaments were extracted from ASTER DEM through manipulation in four GIS environments, as outlined below:

i) Erdas Imagine 9.2 GIS Environment: Erdas imagine 9.2 GIS environment was used to generate the shaded relief through following stages:

- Interpreter was clicked, topographic analysis, shaded relief and the DEM was imported via the displayed inter phase. The intended output file location was also selected.

Solar Azimuth was set at 00, solar elevation at 30 and ambient light at 0.2 to ensure good contrast as shown by Abdullah et al., (2010). Projected UTM coordinate was selected, UTM WGS 84 North, and UTM zone 32 (range 6E-12E) chosen before Okaying the menu.

- Successive shaded relief images were created by varying the azimuth (Sun Angle) of DEM from 00 to: 450, 900, 1350, 1800, 2250, 2700, and 3150 (Fig. 4).

Figure 4: Eight Shaded Relief Images derived from DEM with Illumination Directions (Sun Azimuth),0°,45°,90°,135°, 180°,225°, 270° ,and 315° and a Solar Elevation of 3.

iii) ArcMap 9.3 Software GIS Environment: The ArcMap GIS environment was used to determine the coincidence between the two extracted lineaments and these points formed the lineaments that were digitized and used for the lineament density thematic map. The methodologies involved are;

- Importation of the lineament shape file extracted from the azimuth 00, 450, 900, and 1350 shaded relief image by using the "add" tab on the software interface.
- Generating a buffer around the lineaments by clicking analysis tools, proximity and multiple ring buffers. Feature was inputted (lineament shape file), distances of 300, 600, 1100 and 15000 were added. Buffer unit was changed to metres and "ok" clicked
- The generated multiple ring buffered map was reclassified into two classes (0-300m and 300-15000m) using the spatial analyst and reclassify menu and the resulting reclassified map converted to a raster image using the spatial analyst, convert, and feature to raster tabs.
- The above process was repeated for the other lineament map extracted from the combined azimuth 00, 450, 900, and 1350 shaded relief.
- The resulting raster images are then combined using the raster calculator under spatial analyst to display areas of coincidence.
- Areas of maximum coincidence are then digitized having imported the lineament "Personal Database Feature Class" as saved by Arc Catalogue in the beginning (see creation of drainage thematic map above).

- Drainage density was calculated using the "density" tab under spatial analyst, choosing "kernel density" and then clicking "ok".
- The resulting map was converted to a "raster image" by clicking "spatial analyst", "convert", then "feature to raster";
- View was changed to "Layout view", and the data frame properties were edited to impute coordinates.
- Legend, scale and northern arrow were inserted, and the map exported to produce the thematic map of lineament density.
- Reclassification was done on the map and weights assigned as calculated with the aid of Expert Choice 11.0 software using Saaty (1980) Analytical hierarchy procedure (AHP) (Table 3.1). Under the spatial analyst menu, reclassification was clicked, new weighted values inputted (Table 3.1), and "ok" clicked. The resulting reclassified lineament density thematic map was exported.

3.2.3 Generation of Rose Diagrams

This was done once the final lineament map is completed in the Arc Map GIS environment. The procedure involved the following stages;

i) Opening the attributes table under the lineament map layer in the Arc Map environment, right-clicking on the layer and clicking "open attributes table"

ii) Once the attributes table was opened, a new field was added to indicate the X coordinate of line start by clicking on options then "add field". The name of line is "X1" and the type of line is "float".

iii) With the field created, it is registered as X coordinate of line start of the lineament by right-clicking on the field, clicking "calculate geometry", choosing "X coordinate of line start" and then ok.
iv) Three additional fields are created as before for X2, Y1 and Y2 indicating X coordinate for line end, Y coordinate of line start and Y coordinate of Y end respectively.
v) Under options, the attribute table was exported as a "dbF file".
Rockworks 15 software was used to complete the generation of the rose diagram. The methodology adopted after launching the software (under utilities) was:
i) Importing of the dbf file saved from ArcMap. Once imported, four columns were added and named to contain lineation properties namely: bearing, length, midpoint X and midpoint Y respectively.
ii) The lineation properties were automatically calculated by clicking linear, lineation properties, and after adjusting input table to correspond with X1, X2, Y1, and Y2 respectively, and output table to correspond with the newly created column titles, "Process" was clicked.
iii) From the resulting bearings, a rose diagram is generated by clicking linear, rose diagram, and "from bearing". The correct bearing column was imputed and the process started to generate the rose diagram.

3.3 FIELD INVESTIGATIONS

The field investigations were carried out in three (3) stages; first was a reconnaissance survey to secure the consent of the local authority to undertake the field investigation to assess the terrene best traverses. This lasted for one week.
The second phase lasted for two weeks and involved field mapping of the area on a scale of 1:50,000. Rock samples were collected and coordinate of every sampling point recorded with hand-held GPS (GARMIN). Measurements of dip and strike direction of structures was also undertaken using compass-clinometer (Bruntun type) and delineating the boundaries of different rock types.
The third phase of the field work involved correlation of the observed lineaments in the field with those deduced from the interpretations of the satellite imageries, which lasted for one week.

3.4 LABORATORY WORK

3.4.1 Petrography

The petrographic laboratory work involved thin sections preparation of representative rocks samples for detail petrographic study using the polarizing microscope in the petrography laboratory of Geology Department Ahmadu Bello University Zaria.
Thirteen (13) representative samples were cut into chips with a cutting machine and subsequently grind using carborundum powder of 0.6, 0.4 and 0.2 mm to obtain slides with required thickness and surface. The prepared slides were examined under petrological microscope for petrographic description and representative photomicrographs were taken.

3.4.2 Lineament Extraction and Analysis

Identification and analysis of lineaments from drainage, satellite images, and combination of these sources were conducted by visual and manual inspection of each of the data and imagery on the same scale.

Lineaments were identified and digitized on screen using the tools in Integrated Land and Watershed Information System3.3, (ILWIS 3.3)) software. The same software was used to geo-reference all the maps.

Individual lineaments were analyzed for trends direction in the ILWIS 3.3 submenu. Rose diagrams were created from the lineaments maps and presented as directional trends on 100 orientation class intervals in Grapher5 environment. Individual lineament lengths were statistically analyzed and plotted on frequency distributions of lineaments length per lineament length class also in the same Grapher5 environment.

The two sources of the lineaments were superimposed into a single map. Lineament density was calculated for each section of cell of the source data using the total lineaments lengths contained within each unit section. Nodes were determined at the central points of each of the sections in ILWIS 3.3 for extraction of geographic coordinates and data file management of corresponding lineament density values. The resulting X, Y, Z data file was imported into Surfer9 software for contouring using kriging interpolation algorithm. The interpolated density contours were exported from Surfer9 into ILWIS 3.3 for spatial projection.

CHAPTER FOUR

PRESENTATION, INTERPRETATION AND DISCUSSION

4.1 LINEAMENT STATISTICAL ANALYSIS

Descriptive statistical analysis results gave the cumulative distance of both the streams and the rivers derived from the drainage lines at 35.352 km and its average at 17.67 lineaments per kilometer (Table 4). The total length of the lineaments from the satellite image is 11.579 km and its average is 5.7895 lineaments per kilometer. This yielded data mean of 1.908 drainage lineaments per kilometer and a data mean for the satellite lineament of 1.456 combined lineaments have total length of 46.931 km and average of 23.4655 lineaments per kilometer.

Table 4: Statistical distribution of the Lineaments

Standard Dev.	Lineament Type	Minimum (km)	Max (km)	Population	Mode	Skewness
2757.592	Drainage	0.225	35.127	288	1.908	6.959689
1.468	Satellite Lineament	0.165	11.414	201	1.456	3.093771

4.2 LINEAMENT HISTOGRAM

The most common method of graphical data presentation is the histogram, which is a plot of the proportional frequency of observed values lying within given numerical values. The ordinate of the plot is obtained by dividing the number of values within the particular interval by the total number of values. For the purpose of this work, the frequency of the lineaments was plotted against the lineament length class.

The lineament density lengths of the histograms were grouped into class intervals of twenty (Fig. 5). Satellite lineament histogram is also positively skewed. The class interval within 0 – 1 has lineament frequency of 110, while the range within the 20 – 40 class has lineament frequency value of 0-3 kilometers.

The drainage lineament histogram in Figure 6, is positively skewed with the highest lineament frequency of 140 occurring within class interval of 0 – 1 and the lowest lineament frequency of one occurring within the class interval of 4 – 5.

Fig. 5 Satellite lineament histogram (Lineament length vs. lineament frequency)

Fig. 6: Drainage lineament histogram (Drainage length Vs Drainage frequency).

The combined lineament density histogram in Figure 7 produces numerical lineament frequency value of 140 within the class interval of 0 – 1 kilometer. The lineament density histogram within the class of more than 12 kilometers produces lineament frequency of less than 1.

Fig 7: Combined Lineament Density Histogram

4.3 DRAINAGE NETWORK

The drainage network extracted from DEM and analyzed with respect to local geology and drainage pattern of the study area were assembled to give the lineament map of the study area. This method of representation shows the distribution of lineaments over the study area and it is useful in the sense that it offers a quick glance of the spatial distribution and density of the lineaments.

Drainage responds rapidly to tectonic changes and thus it is a potential parameter for tectono-geomorphological analysis. Drainage network of the area is a good geological record of movement, displacements, regional uplifts and erosion of the tectonic units.

Drainage network of the area is a good geological record of movement, displacements, regional uplifts and erosion of the rock units and is controlled by the geological structures of the area (Fig. 8), which coincide with the general trends of geologic structures in the area.

Fig. 8; Distribution of lineaments and drainages extracted from the satellite imagery of the Study Area.

4.4 SATELLITE LINEAMENTS

In this study, only linear features equal or greater than 1km were considered. Laplace and edge enhancement filters were used to enhance the linear features. The structural analysis revealed that numerous fractures and lineaments that occur at the north eastern and south western parts of the study area. The major orientations of the lineaments are in the NE- SW and NW-SE directions. The length of all lineaments were measured, computed and used to generate the rose diagram.

The trend surface analysis of the structural features of the ring complexes in relation to the lineaments based on the rose diagram in Figure.12 and 13, revealed several trends of the lineaments in the NE-SW, NW-SE, N-S and E-W directions; with the major and dominant structural trends being in the NE-SW and NW-SE directions.
The Landsat+TM data of the study area was digitally processed and enhanced to produce to single band images, band ratios, color composite and classified images complemented by digitized geological map of the study area. The structural map revealed that major structures in north-south direction from field survey provide good supporting evidence for the work, and that the north-south lineaments deduced from the Landsat image data constitutes the lineament of the study area (Fig. 8, 9 and 10).

Fig. 9; Distribution of lineaments and drainages of the Study Area, after Turner and Bowden (1979).

Fig. 10: Superimposition of the lineaments deduced from satellite with those earlier deduced by Turner and Bowden (1979).

4. 5 LINEAMENT DENSITY MAP

This concept refers to the area of the unit circle needed to calculate the lineament density factors distributed within the circle; length counts and cross-points counts. The circle is a unit circle where one calculates the sum of the lineament length, lineament counts and the number of cross-points within it.
Lineament density maps display the distributions of the lineaments in two-dimensional maps. The area was divided into equal area grids; the number of lineaments in each grid were counted and recorded, lineament that extended into another domain boundary was counted within the grid area that extended into, the numbers were assigned to the centre of each grid area and then contoured at appropriate intervals.
The lineament density map (Fig.10) shows low density structures (0.00 – 0.85) along a NW – SW direction at the western part, the north central and the eastern parts. Structural features of low density values are at the extreme edge of the western part, intermediate density value from 1.70 - 2.58 sandwiches both the low and high density value within the entire map. High density value is around the southern part; predominantly along the southeast, high density value at extreme edge of the northeast.
Majority of low values structural lines of the satellite lineament density lies within the western half of the map. These structures enclose intermediate and high values lineament density lines at the southwestern part. Lineaments density of low values are at the extreme north and northwestern part, the values are within domains of 0.85 – 1.70.

Lineament structural density of intermediate values around 1.70 – 2.58 occupy more than half of the area and are sandwiching those of high structural density values throughout the map. High lineament density values within 3.41 - 4.26 interval trend along the E –W at the southern part and strike in the N E – SW at the western part.
The low values lineament density structures occur in patches mainly at the western half of the area, values ranges from 0.85 – 1.70. The structures lineaments align in the NE – SW direction of the southern part of the mapped. The intermediate values lineament density structures cover

up to thirty five percent of the area. Lineament density structural values of 1.70 – 2.58.00 form lineament density of high structural values. These linear features cover more than forty percent of the area and are found mainly at the eastern and southeastern parts. Low structural values are approximately 0.85 – 1.70 of the lineament density in Fig. 11, and lie within four isolated domains that consists of three pockets at the south and three pockets at the east. These lineament density structures trend along the NE – SW direction.
However, lineament density structures of intermediate values in the range of 2.58 – 3.41 occupy about sixty percent of the area which they occur at the western part, central part and the northern parts. High values lineament density structures are observed in the north central, southwest and southeast their values range from about 3.41 – 4.26

Fig. 11: Lineament Density map extracted from the area of study.

4.6 TRENDS OF LINEAMENTS

Data showing trending directions were extracted during analysis of the fractures are summarized on Table 5 and presented in rose diagrams (Figures 12 and 13). For the rose diagrams, the trend and / or strike data are organized into bin sizes (class intervals) of 100, where each bin represents the number of values that fall within the specific angular region. A family of concentric circles provides scaled control for the number of fracture orientation values that occupy each bin size.
Drainages rose diagram in Fig.14 produces a primary (10) trend of N 3200 W along with a tertiary (30) conjugate trend of N 3500 W; the same primary (10) trend of N 3200 W trend along with a tertiary (20) trend of N 3100 W and a tertiary 30 trend of N 3500 W can also be observed along with a conjugate tertiary 30 trend of N 3500 W. However within the satellite imagery lineament rose diagram; one primary (10) trend of N 3500 W and a secondary (20) of N3250 W along with a conjugate quaternary (40) trend of N 150 E is prominent.
Table 5: Lineament Orientation Trend

Data Type	Number of Trends	Orientation Description			
	10	20	30	40	
Drainage	6	N3200 W	N3100 W	N3500 W	N3400 W
Satellite	16	N3500 W	N3250 W	N50 E	N150 E

Fig. 12: Drainages Rose Diagram as deduced from the study area

Fig. 13: Satellite Lineament Rose Diagram

4.7 FIELD RELATIONSHIPS AND LITHOLOGY

The study area is composed of Migmatites overlain by basaltic rocks which occur in the lower parts of a volcanic succession where they are associated with both rhyolites and trachytes, but occasional basalts are interbedded with rhyolites,. The constituent rock units of the morth eastern part of Ningi-Burra ring complex as shown on geological map (Fig. 14) comprise;

a) Volcanic rock of rhyolitic composition this include; i) minor lavas, ii) ash-fall tuff, iii) agglomerate; and iv) ignimbrite. All of these show the effect of post-depositional devitrification, recrystallization or hydrothermal alteration.

b) Basic and intermediate volcanic rocks which comprises of; i) basalt, ii) trachyte, iii) trachyndesites, iv) aphyric trachytes v) mugearites.

c) intrusive rocks include; i) syenomonzonite; ii) Per alkaline granite, iii) sub-alkaline-biotite granite, and iv) granite porphyries.

Numerous fractures that represent break in a rock due to mechanical failure correspond solely to the regional neotectonic stress field (Scheidegger and Ajakaiye, 1985). They include cracks, joints and faults. They are the most common structural features observed within the study area and include volcanic structures, cone sheets, ring dykes, granitic plutons, basic dykes and joints.

4.7.1 MIGMATITE

The migmatite is an intimate mixture of igneous material of granitic composition and high-grade metamorphic rock characterized by banded or veined appearance often accompanied by evidence of plastic deformation.

Migmatite is medium grained in texture and occurs as igneous material of granitic composition, consist of two components; one light coloured granitic component, called neosome, and a dark metamorphic component called paleosome.

Thin section studies revealed that the neosome (mafic part) consist of hornblende, biotite, while the paleosome (felsic) consist of plagioclase, quartz and muscovite. The hornblende occurs as xenomorphic crystals with moderately high relief (Plate I and Slide NG. I a and b). Biotite also occurs as xenomorphic crystals with high relief, the crystals are brown in color, occurs as subhedral crystals which are distinguished by a double cleavage at an angle of about 870 and 930, while plagioclase occurs as colorless crystals which are distinguished by their lamella twining under cross polar.

Fig 14: Geologic map of the North Eastern part of Ningi-Burra (after Turner 1979).

Plate I: Photograph of outcrop of migmatite showing leucosomal and melanosomal units of ptygmatic fold structure at 11007.993’N and 9025.695’E.

PPL XPL

Plate II: Photomicrograph of migmatite under (NG Ia) PPL and (NG.Ib) XPL showing alighnment of felsic and mafic minerals. Qtz=Quartz, Mcn=Microcline, Plg=Plagioclase, Bt=Biotite Hb=Hornblend, Aug=Augite, at Latitude 11007.993'N and Longitude 90 25.695'E. Magnification X 40.

4.8 YOUNGER GRANITE LITHOLOGIES

4.8.1 Ignimbrites

The majority of the eastern part of Ningi rhyolitic rocks are ignimbrites, it is a very fine crystalline devitrified rock which include welded and non welded tuffs, it is light colored in hand specimen, the shard and fiamme structure are well preserved, the growth of quartz and feldspar destroyed the pumice structure which show lenticular fiamme-like patches, the weathered rock surface show an eutaxitic structure. The ignimbrites are observed around Guda, Ningi and Old Ningi and Dengir area and the entire part of the study area, latitude 100 58'15.6'' N and longitude 9026'06.0''E, latitude 110 05.314' N and longitude 9034.063'E and latitude 11004.876' N and longitude 0090 33.197' E and latitude 110 08.5578' N and longitude 90 30.460' E, latitude 110 05.890' N and longitude 090 21642' E, latitude 110 06.166' N and longitude 90 21.156' E. Plates II show the succession of ignimbrites along a quarry of Mould engineering Construction Company at Tabula village.

Plate III: Basalt, rhyolite and ignimbrites succession at Mould quarry near Tabula latitude10o 58'15.6'' N and longitude 9o26'06.0'' E showing succession of Horizontal layer of lavas.

The minerals in thin-section include; Phenocrysts of quartz and a groundmass of mainly quartz and plagioclase with lesser amounts of orthoclase, biotite, amphibole (augite), pyroxene and glass. (Slide number NG IIa and NG IIb).

PPL XPL

Plate IV: Photomicrograph of Ignimbrite with subhedral quartz grains in fine grained Groundmass of quartz and plagioclase feldspar, under PPL and XPL (Slide NG IIa & b). Latitude 100 5.890'' N and Longitude 90 21642' E. (Magnification X40).

4.8.2 Layered agglomerates and Tuffs

Agglomerates and Ash-fall tuffs indicate the earliest eruptions of volcanic activity in which the explosive eruption resulted in the deposition of ash-fall tuffs and interbedded agglomerates, the outcrop is observed at centre 1; Tebbi-Gudda area, 110 01.916'N and 90 31.82'E; 11002.780'N and 90 32.860' E, 110 02.021' N and 90 31.887' E, 110 330' N and 090 386' E, plate III, which form a well stratified bed with a thickness of about 13 m thick, and a strike length of about 3km. The Particle size is about 2 mm. Consists 50 % tuff of angular rock particles in a fine-grained matrix of quartz, alkali feldspar and biotite, slide NGIII.

Plate V: Photograph of Tebbi-Gudda rhyolitic tuff, trending E-W direction, (Latitude 110 01.916 N and Longitude 009 0 31.82 E).

PPL XPL

Plate VI: Photomicrograph of fine grained layered tuff showing granular intergrowth of quartz, biotite and Plagioclase feldspar in Tebbi-Gudda tuff, Qtz=Quartz, Plp=Plagioclase feldspar, Bt=Biotite, (slide NG IIIa & b). Latitude 11o 01.916 N and Longitude 9o 31.82 E. (X40).

The agglomerates and tuff of Kabara in centre 2; (latitude 110 00.077' N and 0090 28.307' E, latitude 11000.455'N and longitude 009027.758'E, latitude 11000 .396'N and longitude 0090 28.640'E), composed entirely of rhyolite which formed massive beds, with thinly bedded tuff and minor intercalated lavas of total thickness of about 150m, (Plate VII) which have a basin-like- structure, are deposited at later stage than the Tebbi-Gudda tuff, it has rounded blocks of crystal rich rhyolite. Minerals includes; Olivine, anorthite, hornblende, augite, biotite and leucite, (Slide NG VIII).

Plate VII: Photograph of Kabara agglomerates showing thin layer of flow lava. Latitude 110 00.077' N and Longitude 090 28.307' E.

PPL XPL

Plate VIII: Photomicrograph of Kabara Agglomerate showing quartz and plagioclase feldspar phenocryst. Qtz=Quartz, Plp=Plagioclase feldspar, Gms=Groundmass, (slide NGIVa and b). Latitude110 00.077' N and Longitude 90 28.307' E. (magnification x 40).

4.8.3 Rhyolite lava

Rhyolite lava is flow banded light-colored, fine-grained volcanic rock, which is principally volcanic lava, is identical to granite, and composed essentially of feldspar and quartz which form extensive thick unit (plate IX) observed at kibara latitude 100 58' 15.6" N and longitude 090 26' 06" E. Microscopic observation on plate X.

Plate IX: Rhyolite lava showing flow structure at Kibara, at Latitude 100 58'15.6''N and Longitude 009026'06.0''E)

PPL XPL

Plate X: Photomicrograh of Rhyolite showing euhedral phynocrysts of quartz, plagioclase and orthoclase feldspars in a fine grained groundmass. slide NGVa PPL and slide NG Vb XPL, at latitude 110 05.314 N and Longitude 90 34.063 N. Magnification X40.

4.8.4 Basalt

Basalt is among the basic and intermediate rocks of the eastern part of Ningi-Burra ring complex, occurs in the lower part of the volcanic succession, associated with both rhyolite and trachytes. Basalt is the most common variety of volcanic rock, found mostly along the river channel and as boulders scattered in the study area latitude11005.470′ N and longitude 9034.121′ E (Plate XII).

Basalt composed almost entirely of dark color which is determined by the presence of mafic minerals and little amount of plagioclase feldspar, pyroxene, and magnetite. The basalt is observed around Tabula (Lat.10058’15.6’’N and Long. 009026’06.0’’E) and Old Ningi (Lat.11057.903’ N and Long. 009024.134’E), and are usually dark-gray in color, in some places the basalt has a vesicular texture, preserving vestiges of bubbles produced by expanding steam as lava cools and solidifies. It is also characterized by pillow-shaped masses similar to those caused by rapid cooling of lava erupted on the sea floor. In addition to lava flows, basalt is also found in the form of dikes as observed running along stream channels, which show columnar jointing (Plates XI).

Plate XI: Photograph of a volcanic succession of horizontal layers of rhyolite overlaying basaltic lava that runs parallel to the trend of a ring dyke at about 30o - 40oE. (Latitude 10o 58’15.8’’and Longitude 9o 26’ 06.0’).

Plate XII: Boulders of basaltic rock in the study area (Latitude11005.470′ N and Longitude 9034.121′ E).

Mineralogically, basalt sometimes contained large plagioclase phenocryst, they retained little of its primary mineralogy of pale-brown augite, iron ore, pyroxene is entirely replaced, plagioclase is relatively unaltered accompanying assemblages which include; hornblende-sphene, tremolite-actinolite-sphene-calcite (Plate XIII).

The phenocryst of quartz and plagioclase, groundmass is generally made up of pyroxene (augite), plagioclase and olivine. Quartz appears as whitish in color, moderate relief, and zoning is common with pale brown and darker rim, but week pleochroism.

PPL XPL

Plate XIII: Photomicrograph of basalt showing euhedral phenocryst of biotite, quartz and orthoclase feldspar in a Groundmass of opaque minerals. Plp=plagioclase feldspar, Qtz=quartz, Bt=Biotite, Ocp=Othoclase feldspar (Slide NGVIa & b) at latitude 110 05.470′ N and longitude 90 34.121′E. (magnification X40).

4.8.5 Trachyte

Trachyte is a Fine grain, light colored, generally light phencryst of orthoclase with minor plagioclase, biotite hornblende and augite (Plate XV).

Occur around Zadanga hill near Jigawa area. Latitude 110 06.56'N and Longitude 90 34.075'E, (Plate XIV). The trachyte has a total volume of about 300km3 and a thickness of about 200m thick, consist of feldspar laths (some entirely alkali feldspar, others andesine-oligoclase as well) secondary iron oxides, chlorite, epidote and calcite and usually a little quartz. The centre 2 trachyte (110 00.224'N and 0090 28.652' E) are relatively quartz and mafic poor, trendind towards the rhyolite.

Plate XIV: Photograph of trachyte around Dengir at Latitude110 07.945'N and Longitude 90 28.095' E.

PPL XPL

Plate XV: Photomicrograph of trachyte showing alteration in feldspar to perthite (white) in places under PPL and XPL, Plp,Plagioclase feldspar, Bt= Biotite, Qtz=Quartz, (Slide NGVIIa and b), latitude110 07.945'N and logitude 0090 28.095' E. (X40).

4.8.6 Trachyandesites

Trachyandesites is 70% by volume of prismatic to rectangular crystal of andesine with aligned and radiating texture, few crystal of orthoclase with mymerkitic texture are also present, about 15 % of the rock by volume is made up of prismatic to non-prismatic crystal of aegirine and aegerine augite, the pyroxenes are embedded within the feldspars and are randomly distributed in the interstices of the irregular shaped crystals of ilmenite and interlocking feldspars. Ilmenite and accessory prismatic grains of olivine and hornblend make up the remaining 15% of the rock volume (Plate XVI).

Plate XVI: Photograph of Trachyandesite with broken and fragmented blocks at the North-western part of Ningi (Latitude11o 04.876’ N and Longitude 9o 33.197’ E).

PPL XPL

Plate XVII: Photomicrograph of trachyandesite showing phynocrysts of anhedral plagioclase and quartz in a fine grained grandmas of mafic mineral (amphibole, epidote,and chlorite). (Latitude 11o 05.470’ and Longitude 9o 34.121’). Qtz=Quartz Gms=Groundmass, Plp=Plagioclase (Slide NGVIIIa and b). Magnification x40).

4.8.7 Syenomonzonite

Syenomonzonite is among the intrusive rocks of the eastern part of Ningi Ring complex, and may be an intrusive equivalent of trachyte and trachyandesites of the eastern part of the complex, (Latitude11005N and Longitude 9032.5’E).

Dark colored sometimes greenish rock with phenocryst of quartz and feldspar, showing flow structure striking 2100 and dipping 600 South, is also observed at latitude 11000.00’N and longitude 9032.00’E; and latitude 11006’N and longitude 9031’E, (Plate XVIII).

Syenomonzonite containing 32–38 percent perthitic microcline, 25–37 percent sodic oligoclase, 18–25 percent quartz, 7–10 percent biotite, and as much as 4 percent muscovite, with accessory sphene, apatite, and iron oxide minerals. (Plate XIX).

Plate XVIII: Photograph of Syenomonzonite outcrop showing flow structure, with phenocryst of quartz and feldspar, Latitude 11000.00’N and longitude 9032.00’E

PPL XPL

Plate XIX: Photomicrograph of Syenomonzonite showing; plp= plagioclase feldspar as core to alkaline feldspar with biotite and quartz as Gms= groundmass (Slide NGIXa & b). Latitude 100 57’ 42.2’’N and Longitude 9020’ 24.1’’E. Magnification X40.

4.8.8 Riebeckite granite

Riebeckite granite is coarse-grain igneous rock dominated by perthite (50%) and quartz (40%) with minor riebeckite, aegerine augite and plagioclase and accessory titanium, biotite and zircon. Perthite occurs as euhedral to subhedral to tabular crystals about 1cm in size and comprise of orthoclase with albite lamella. Ningi-Riebeckite granites is observed at latitude110 05.314’ N and longitude 9034.063’E, latitude 110 05.234’ N and longitude 90 32.946’ E (Plate XXI).

Riebeckite granite is some time holocrystalline, coarse-grain igneous rock dominated by perthite (50%) and quartz (40%) with minor riebeckite, aegerine augite and plagioclase and accessory titanium, biotite and zircon. Perthite occurs as euhedral to subhedral to tabular crystals about 1cm in size and comprise of othorclase with albite lamella.

Plate XX: Photograph of an outcrop of Riebeckite Granite at the eastern part of the area of study showing columnar jointing (Lat.11005.34N and Long.9034.063E) with elevation of 1690ft.

PPL XPL

Plate XXI: Photomicrograph of riebeckite granite showing feldspar phenocryst, perthite and Ocp=orthoclase feldspar in fine grained groundmass. Gm= Groundmass (quartz, aegerine-augite, biotite,) (slide NGXa and b). Latitude11005.314'N and Longitude 9034.063'E, magnification x40).

4.8.9 Granite Porphyries;

Granite Porphyries occupy the northwestern part of Ningi massif (latitude 11004'N and longitude 9024'E, 11004' N and 9023'E) This is a coarse-grained granular rock dominated by perthite (55 % by volume), quartz (40 % by volume), plagioclase (5 % by volume) and minor biotite. Perthite forms subhedral equant crystals up to 6 mm in size and have been extensively altered to clay minerals. Contained phenocrysts of quartz, alkali feldspar, fayalite and hedenbergite with groundmass quartz, alkali feldspar, hastingsite or sometimes arfvedsonite. They represent the infilling of ring fractures during the final phase of volcanic activity.

Quartz occurs as subhedral to anhedral crystals up to 6 mm in size. Plagioclase occurs as partially altered crystals up to 4 mm in size mostly within intergranular areas and preserves polysynthetic twinning. Biotite occurs as subhedral to euhedral crystals.

PPL XP

Plate XXII: Photomicrograph of porphyritic granite, Qtz=Quartz, Bt=Biotite, Ocp=Othoclase feldspar, Plp= Plagioclase feldspar (slide NG Xia & b), latitude 110 04' N and longitude 90 24' E. magnification x40.

4.8.10 Biotite Granite

The coarse grained biotite granite is voluminous, covering the western part of the area (Tabula-Suma, latitude 100 59'N and longitude 9025'E, latitude11001'N and longitude 90 25'E), the mapped biotite-granite is coarse-grained igneous rock dominated by phenocrysts 35% by volume of microperthitic feldspar in a groundmass of quartz, 40% plagioclase, 10% orthoclase and 10%. Some crystals show simple twinning. Phenocrysts are up to 8 mm in size. The groundmass has an inequigranular texture; with a maximum grainsize of 3 mm. Plagioclase occurs as laths. Biotite is present as green-pleochroic, subhedral platy minerals up to 1 mm in size. Rounded titanite grains up to 0.2 mm are spatially associated with the biotite and often occur as inclusions. Several small (<0.5 mm) grains of colourless augite were also present. Feldspars have experienced moderate alteration to sericite Plate XXIII.

PPL XPL

Plate XXIII: Photomicrograph of Tabula-Suma biotite granite latitude 100 59'N and longitude 90 25'E. Qtz= Quartz, Plp= Plagioclase feldspar, Bt= Biotite, Ocp= Othoclase feldspar, (Slide NG XIIa & b). Magnification x 40.

4.9 FIELD STRUCTURAL INTERPRETATION

4.9.1 Volcanic Structures

The main structural forms are bedded lava and ash sequences, vent- fillings and more massive sheet and stock-like rhyolite bodies. A two volcanic fold sequence is observed around the study area: i) Early rhyolites-varied lavas tuffs and ignimbrites usually accompanied by minor basalts and trachytes, and ii) Late rhyolites-massive homogeneous porphyritic rhyolites.
These volcanic successions are observed at latitude 11o 08' N and longitude 9o 31' E at RRC quarry of Tashar Leda, western part of Ningi town (Plate XXIV).

Plate XXIV: Early rhyolites-varied lavas tuffs and ignimbrites usually accompanied by minor basalts and trachytes, observed at RCC Quarry around Tashar Leda (latitude11o 08' and longitude 9o 31').

Plate XXV: Basaltic dyke showing Joints trending NE-SW, Latitude110 00.224' N and Longitude 9o 28.654' E).

4.9.2 Cone Sheet

A cone sheet is a type of high-level igneous intrusion found in partly eroded central volcanic complexes. Cone sheets are relatively thin inclined sheets, remark of erosion of volcanic pile generally just a few meters thick, with the geometry of a downward-pointing cone. Viewed from above, their outcrop is typically circular to elliptical.

These thin, inward - dipping ring structure observed within the study area, attain a thickness of about 60 m, although some are only a few centimeters thick. This characteristic form is usually explained by reference to a stress field, shaped like an inverted umbrella by the parent pluton at depth (Plate XXVI).

Plate XXVI: A side view of a Cone sheet that form a Swarms outside the peripheral ring dyke at Lumbu (Latitude 11o 06.012' N and Longitude 90 21.606'N).

A dike swarm or dyke swarm is a large geological structure consisting of a major group of parallel, linear, or radially oriented dikes intruded within continental crust. They consist of several to hundreds of dikes emplaced more or less contemporaneously during a single intrusive event, and are magmatic and stratigraphic; such dike swarms may form a large igneous province and are the roots of a volcanic province.

4.9.3 Ring Dyke

Ring dyke is an intrusive igneous body that is circular, oval or arcuate in plan and has steep contacts. While the widths of ring dikes differ, they can be up to several thousand meters. The most commonly accepted method of ring dike formation is directly related to collapse calderas. The outer limits of Younger Granite complexes are define completely or partly by a ring dyke.

The alignment and distribution of vents and major surface cauldrons were controlled by ring-fractures that extended to the surface striking E-W, N-S, and NW-SE directions as shown on the satellite lineament maps (Fig.14) and Plate XXVII. The ring dyke intrusion is generally composed of granite porphyry and is the main structural element of the complex controlling the distribution of the earlier volcanic rocks and also the extent of the later intrusions.
Ring dyke emplacement marked the end of major surface volcanism and the beginning of sub-volcanic intrusive activity in which granite ring dykes and more massive stock-like bodies were emplaced.

Plate XXVII: A side view of a ring dyke striking S-E, Latitude 11o 03’59.7’’N and Longitude 9o 34’06.8’’E.

4.9.4 Joints

The study area is strongly jointed and individual outcrops are broken into joints (Plate XXVIII) the size of which is roughly proportional to the coarseness in grain size of the rock. Major joints usually control the drainage pattern within the area and can be traced for distances of up to 10 or 20km.

Plate XXVIII: Fractures, trending NE-SW and NNE-SSW at 050. Fracture cross-cutting each other. (Latitude 11o 00.194’N and Longitude 9o 28.511’E.

The mapped joints correspond to a homogeneous stress field (the principal stress directions) being NE-SW. The dominant joints are striking in a general NW- SE direction (Fig. 15).
Joints are signature of the plate tectonic stress field (Scheidegger, 1993), joints are shear features caused by plate tectonic stress with maximum compression axis lying in the smaller quadrant formed by the regional sets.

Fig.15 Distribution of lineaments in the study area.

Plate XXIX: Photograph of joints with displacement of boulders around the study area.

4.9.5 Veins

These are tabular or sheet like bodies of mineralization which were introduced into fissures and joints within the study area. They are brought about by the infilling of fractures by mineral fluid before recrystallization. Most of the veins are quartz veins, although, some are fine grained felsic materials. In some places the size of the quartz vein is as thick as 17cm. Plate XXXI shows a typical quartz vein within the area of study and the dominant trends are N- S and NE-SW.

Plate XXX: A typical quartz vein around Kibara (Latitude11o 00.455'N and Longitude 9o27.758'E).

4.9.6 Xenoliths

Xenoliths are rock fragment which become enveloped in a larger rock during the latter's development and hardening. In geology, the term xenoliths are almost exclusively used to describe inclusions in igneous rock during magma emplacement and eruption. Xenoliths may be engulfed along the margins of a magma chamber, torn loose from the walls of an erupting lava conduit or explosive diatreme or picked up along the base of a flowing body of lava on the Earth's surface.

Xenoliths can be contrasted with autoliths, or cognate xenoliths, which are pieces of older rock within the intrusion that are genetically related to the intrusion itself. The general term for all such incorporated bodies is inclusions.

Xenoliths of the ash-fall tuff which mark the base of the stratigraphical succession have been found in the ignimbrites at the extreme north of the complex and also in the quartz porphyry of the western extremity of the area (plate XXXII).

Plate XXXI: Xenoliths within the ring complex of the study area 110 07.015' and 0090 34.073'

Rock fragment within an intrusive igneous body that is unrelated to the igneous body itself, represent pieces of older rock incorporated into the magma while it was still fluid, may be located near their original positions of detachment or may have settled deep into the intrusion, if their density is greater.

4.10 DISCUSSION

4.10.1 PETROGRAPHY

The petrography of the rocks hosting the structural lineament as well as field relations, evolution and a model explaining the evolution of the area of study is presented in this chapter, in addition a satellite image enhancement and transformation of lineament analysis on landsat is also presented.

Field observations have revealed that the volcanic rocks are recrystallized and hydrothermally modified to varying degrees; volcanic sequences provide evidence on the order in which lavas of widely different compositions arrived at the surface, their degree of crystallization, mode of eruption and abundance. This evidence is then used to interpret the stages of magma generation, evolution and analyze the structural development of the cauldrons and the underlying magma chambers.

In the initial volcanic stage, a considerable volume of acid lavas and associated pyroclastic was erupted, and volcanic succession also includes occasional flow of basalt. It is believed that the volcanism was accompanied by formation of large surface cauldron or caldera which the bulk of the effusive volcanic material accumulated. The extrusive volcanic rocks are well preserved in the north-west; the underlying structures show the area of mineralization as shown on the lineament density map. Towards the end of the volcanic cycle, quartz – fayalite - porphyry was emplaced in the centre of the Ari, Ningi and Zadanga vent complex at the north-eastern part of the area (Fig. 6). During the plutonic cycle, the peripheral ring dyke of granite-porphyry (one of the major structural feature of the complex) and the central granite plutons of biotite and riebeckite - granite were emplaced beneath the volcanic pile, lavas, ash fall tuffs, agglomerates and abundant ignimbrites which show the effects of post depositional, which is a rock deposited from ash, flows, synonymous with ash-flow tuffs and including both welded and non-welded tuffs. They range from very finely crystalline devitrified rocks, in which original shards and fiamme are well preserved, to relatively coarse-grained rocks with a groundmass quartz-feldspar mosaic having crystal diameter of 0.01-0.5mm.

The strong recrystallization of these ignimbrites may be partly as a result of their peralkaline character, other likely controls being their occurrence in thick caldera-filling deposits and an abundance of trapped volatiles. The crystalline texture of the eutaxitic bands suggests growth into vapor - filled cavities Schmincke (1975) has interpreted very similar features in per alkaline ignimbrites as originating through revesiculation in collapsed pumice fragments. Mc Call (1964) described a comparable eutaxitic structure in a pantelleritic ‘froth flow’ from Kenya and suggested that it formed as areas of vesiculation in a flowing lava, but this was re-interpreted by Schmincke (1975) as an example of post - depositional vesiculation in an ignimbrite. These two alternative explanations may be applied to the Ningi eutaxitic rhyolite.

The fiamme structures seem to indicate remobilization of the upper part of an ash-flow deposit. Like most of the Ningi-Burra ignimbrites, this rock is not now peralkaline; containing only quartz, feldspar and iron oxides, but the evidence for post depositional flow is consistent with an original per alkaline character.

The complex assemblage of large phenocrysts, often showing evidence for instability and reaction, probably indicates an early phase of crystallization at depth. The quartz - bearing porphyritic trachyandesites of the Ningi-Burra complex may represent the partly crystalline differentiates of a basaltic parent liquid evolved at very deep crustal or subcrustal levels. The hydrous, carbonated mafic assemblages may be the products of groundwater reaction but it

seems possible that the trachyandesite differentiates had developed relatively high concentrations of water and carbon dioxide, leading to an ignimbritic mode of emplacement.

4.10.2 MODELS FOR THE EVOLUTION OFTHE NIGERIAN YOUNGER GRANITE PROVINCE

4.10.2.1 Caldera and Ring Complexes

The cauldrons of the Ningi-Burra complex are interpreted as the basal parts of a series of calderas and the upper parts of a series of intrusive ring complexes. The relationship between calderas, ring complexes and ignimbritic volcanism is well established. The numerous published descriptions of recent calderas and the previously studied Nigerian ring complexes model for caldera and ring complex development in the Nigerian Younger Granite province can be suggested to provide a framework for an analysis of the Ningi-Burra complex. Three major lithological structural units (i.e. three stages in an igneous cycle) can be recognized: i) Pre-caldera eruption; ii) Caldera forming; and iii) Post-caldera eruption.

4.10.2.2 Pre-caldera Eruptions

Most commonly these build up a volcanic cone, the central part of which becomes the site of subsequent caldera collapse. However, the early volcanic structures do not always control the location of the calderas, for example some of the calderas in the San Juan Mountains, Colorado have no obvious relationship to the andesite volcanoes that preceded them (Steven and Lipman, 1976). Many workers have found evidence for early doming of an area larger than the eventual caldera the regional tumescence of Smith and Bailey (1968); especially important where a central vent volcano is absent, and perhaps an essential process in the formation of the ring fractures controlling caldera collapse.

In the Nigerian ring complexes, the products of this eruptive stage have been recognized as varied acid pyroclastic rocks with some lavas, designated as 'early rhyolites' by Jacobson et al., (1958), together with minor basalts and occasionally trachytes. Little is known of the form of the pre-caldera volcanic structures but the dominance of ignimbrites and the apparent localisation of activity in the central complexes suggest that these may have been very flat shield volcanoes, comparable to the 'shield sheets' of Tibesti (Vincent, 1970). Direct evidence for regional tumescence is absent in Nigeria. Possibly cone sheet swarms found in the basement around a few complexes, and also circular lineaments, with diameters of about 18 km visible on satellite photographs around the Banke, Kila-Warji. Kudaru and Buji complexes were produced by pre-caldera doming.

4.10.2.3 Caldera-Forming stage

The importance of rapid emission of magma in ash flows for bringing about caldera collapse was first fully recognized by Williams (1941). One of the most striking demonstrations of this has been given by Steven and Lipman (1976) who have shown that each of the 18 calderas in the San Juan Mountains was the source of an enormous ignimbrite sheet whose eruption was often contemporaneous with caldera collapse, the deposit being thicker inside the caldera than outside.

Ring fractures presumably acted as conduits, and Vincent (1963) has demonstrated the link between feeder ring intrusions and intra-caldera ignimbrites in the Yega and Toon calderas, Tibesti.

The ring fractures and dykes that follow them are shown by Vincent, 1963 to be inward dipping near the surface (contrary to Anderson's model), steepening at depth and this results, on collapse, in the pre-caldera volcanic developing centripetal dips, as pointed out earlier by Reynolds, (1956). In some volcanic regions the caldera-forming stage corresponds to an abrupt change in

magma type. For example, in Gran Canarias a pre-caldera basalt shield was succeeded by caldera-forming eruptions of trachytic and soda-rhyolite ash flows (Schmincke, 1967).

In the Nigerian ring complexes rhyolitic ignimbrites continue into the caldera-forming stage, but they are distinctive in having high phenocryst content. These rocks occur as thick sheets, as in the Banke complex, and also as dykes and plugs, representing near - surface feeders, although the main feeder channels are likely to have been the peripheral ring dykes which are almost constant feature of the complexes. Rhyolitic ignimbrites interpreted as belonging to the caldera forming stage are very abundant in the Ningi-Burra complex.

4.10.2.4 Resurgent Doming and Sub-caldera Granite Emplacement

Resurgent doming is an uplift of a caldera floor in response to magmatic pressures at depth and has been described by Smith and Bailey (1968) from Valles and other calderas. In Nigeria, dome-like granite plutons are found in the central part of most of the complexes where extensive rhyolites occur but there is little evidence that they have caused uplift of the volcanic rocks-indeed they often truncate inward dipping rhyolite successions.

There is, however, some evidence for resurgent doming in the Kila-Warji complex (Turner, 1968) and in Centre 6 of the Ningi-Burra complex. At deeper levels, represented mainly in the southern complexes, a series of annular and roofed granite intrusions indicate long continued adjustments within the crystallizing sub-caldera magma body which from gravity measurements may extend to depths of more than 10 km (Ajakaiye, 1968; 1976).

4.10.2.5 Post-caldera Eruptions

Following collapse calderas often show a renewal of eruptive activity. This may follow and accompany sedimentary deposition and may occur before, during and after resurgent doming. The Valles caldera with its ring of pyroclastic cones and rhyolite lava domes is a typical example. Evidence for this final eruptive phase in the Nigerian complexes is normally lost at the surface products are destroyed by erosion and the conduits are destroyed by the emplacement of internal granite plutons. Smith and Bailey (1968), consider that resurgence marks a renewal of upward magmatic pressure and leads to this second phase of volcanic activity.

In Nigeria there is a very strong tendency for igneous activity to shift laterally to give chains of ring complexes, the control probably being lithospheric plate movements. The Ningi-Burra complex seems to exemplify this situation and the problems of repeated renewal of magmatic activity as resurgence and renewal of volcanism at the site of previous collapse may be relatively uncommon.

4.11 SATELLITE IMAGE ENHANCEMENT AND TRANSFORMATION OF LINEAMENT ANALYSIS

The uses of remote sensing techniques in the areas of geological mapping, seismology, metallogeny, mineral exploration, and the search for sites of oil and gas deposits, have known large advances (Weber, 1985). From the remotely sensed techniques, the recognition and analysis of linear features on satellite images has provided very useful devices for mineral exploration, mainly when combined with geochemical, geophysical and field data (Antón-Pacheco and Sanderson, 1989; Martinez-Alonso et al. 1989; Tsombos and Kalogeropoulos, 1989; Widdowson, 1989) and groundwater exploration (Sanz de Galdeano et al., 1985). In the same way, lineament analyses are often related to tectonic studies at all scales, from the micro tectonic (Mekarinia et al., 1989) through the fold-belt and plate-boundary geodynamics (Poscolieri and Salvi, 1985; Wise et al., 1985). As a consequence of this, the lineament tectonics rises as an independent branch of Structural Geology and Geotectonic in which consideration is

given to the structural lineament analysis of ancient and modern mountain belts, platforms, sedimentary basins, as well as to the lineament genesis and its relationships to the characteristics and anomalies known in the crust and the upper mantle (Kats et al., 1986).
The procedure of lineament analysis on remotely sensed images involves the computer-aided processing of large amounts of data sets (Koronovskii et al., 1986) as well as the performance of areal density distributions by means of contour line maps (which may lead to the identification of regional structural trends), the consideration of sub parallel lineament swarms rather than individual lines, and the rejection of some linear elements while others are combined into lineament zones or lineament frameworks.

The interpretation of lineaments is based on the spatial correlation of remotely sensed images of geological objects as well as on the density of the available geological-geophysical data. This interpretation involves successive approximation to the object, generating the remote-sensing image from the better known to the less studied areas (Trofimov, 1985).

4.11.1 Edge Enhancement

Edge enhancement is an image processing filter that enhances the edge contrast of an image or video in an attempt to improve its acutance (apparent sharpness). The filter works by identifying sharp edge boundaries in the image, such as the edge between a subject and a background of a contrasting color, and increasing the image contrast in the area immediately around the edge, this has the effect of creating subtle bright and dark highlights on either side of any edges in the image, called overshoot and undershoot, leading the edge to look more defined when viewed from a typical viewing distance.
The Landsat+TM data of the study area was digitally processed and enhanced to produce single band images, band ratios, color composites, and classified images complemented by digitized geologic maps of the area of study. Drainage patterns and, bare rocks and vegetated areas were enhanced in single band images which were identified in image ratios. Similarly, the SRTM data was used together with the (Landsat+ETM) data in the production of the Digital Elevation Model (DEM) which proved very reliable in the identification of the complex (Fig. 16).The color composites were used as background data for both supervised and unsupervised image classification. The Landsat+ETM data obtained was further subjected to various image enhancement and transformation routines.

Fig. 16: Edged enhancement of the satellite imagery of study area

4.11.2 Color Composite

False Color Composite (FCC) image is an effective means for visual interpretation of multi-spectral imagery. This is because the human eye is more sensitive to color than grayscale brightness variations thus interpretation is easier.
For the image transformation, band ratios were generated using the calculator module in IDRISI 32. The ratios generated (3/4, 4/2, 3/1, 5/4) were employed to reduce the effects of shadowing as well as to enhance the detection of certain features of interest. For image enhancement, three bands (RGB) color composites were created using the composite module of IDRISI 32. This process was employed to enhance the spectral quality of the images. Generated composites include RGB 432, RGB 532, RGB 753 and NDVI composite. Figure 14 and Figure 15 show typical composite maps generated in the study area. The NDVI map was used to establish a relationship between structure, drainage and vegetation within the Younger Granite Ring

Complexes. This study revealed an indirect relationship between structures /lineaments and NDVI composite maps especially in basement areas, areas of intense structural deformation with high lineament density were observed to be associated with higher NDVI values. Similarly, unsupervised classification was carried out using the cluster module in ILWIS 3.2 academic. From the generated color composites, dark and whitish colors corresponded to the Younger Granite Ring complexes. Structurally, there is a correlation of the Younger Granite Ring Structures with areas of intense deformation as revealed on the land sat color composite map (Figure 17 and 18). Blue or Green colors partly correspond to ring complexes whereas pink or yellow colors correspond to areas covered by the basement rocks and blue wish linear correspond to the drainage.

Fig.17: Landsat False Color Composite (RGB) image of the area of study.

Fig. 18: Landsat False Color Composite image of the area of study

In addition, the correlation of the lineament map and the younger granite distribution map revealed that the emplacement of the lavas and the granitic rocks may have been controlled by ring fracturing and large-scale cauldron subsidence. Besides, the granitic bodies' are generally fractured and fissured with these weak zones used as pathways for the greisenisation fluids. Thus, within the younger granite province, in addition to the N-S, NE-SW and NW-SE fracture systems, ring fractures were developed and the granitic complexes themselves were fissured and mineralized.

4.12 EVOLUTION OF THE NINGI-BURRA COMPLEX

4.12.1 Pre-caldera succession in the Ningi massif (Stage 0)

The westward migration of igneous activity is clear from the geological map, and satellite imagery, in which a sequence of volcanic and intrusive events can be reconstructed, with varying degrees of confidence, for the whole complex. It is assumed that the 6 centers in the Ningi-Burra complex were active consecutively this is true at least for their caldera-forming stages. However, the earliest volcanic strata, common to Centers 1 and 2 in the Ningi massif may not be related to a single ring centre.

4.12.2 Structure and Composition

The lower part of the inward dipping marginal successions around the Ningi massif, dominantly basalt and aphyric trachyte, appear to correlate broadly with each other as shown on geological map in figure 6.The only observed contact with the basement is at Old Ningi (Latitude 10o 58'N and Longitude 9o 24'E), where basalt is the lowest member of the succession, but the order of eruption of basalt, trachyte and rhyolite is not constant. Exposed thicknesses range from 350 m of mainly trachytes and trachyandesites at Jigawa, to over 100 m of mixed basalts and trachytes, and 100m of mainly basalts at Tabela (longitude 10058'N and 9058'E). Their eruptive sources are not known but their distribution suggests that there were probably separate basalt and trachyte vents or fissures. There is, however, no evidence for fissure eruptions, in the form of dykes, in the surrounding basement.

Probably a fairly long-lived trachyte volcano existed in the Jigawa (Latitude 11007' and Longitude 9025') area where a thick succession of aphyric trachytes occurs, interbedded with minor rhyolites, and is overlain by the porphyritic trachyandesites and trachytes which were the

final products of this early stage. The thicknesses, together with the simple layered structures along exposed strikes, suggest a plateau-like landform, built of flat cones with flows inter digitating from several eruptive sources.

4.12.3 Regional Volcanic Field

Most recent calderas are developed within fields of lavas and ash flows of regional extent and it seems possible that the Stage 0 volcanic may be relics of a pre-ring complex succession that covered most of the Nigerian Younger Granite province. They resemble, for example, the flood basalts and interbedded ignimbrite sheets that preceded the central volcanoes and calderas of Tibesti, (Vincent, 1963; 1970). Similarly in the San Juan volcanic field, Colorado, pre-caldera andesites are overlain by rhyolites erupted as ignimbrites from the calderas (Steven and Lipman, 1976). However, although basalts are locally interbedded with pre-caldera rhyolites in other Nigerian complexes, and in places form the lowest flow, a basal succession resembling that at Ningi has not been found in neighbouring complexes, or even in the Burra massif. The very long age spread of the Nigerian ring complexes-at least 50 Ma makes a single regional precursor unlikely.

Finally, there is little evidence around the Ningi massif, or in the province as a whole, of early eruptive sources outside the ring complexes. Thus the basalts and trachytes are believed to represent only a local accumulation, although no doubt spreading well beyond the present boundaries of the Ningi massif.

4.12.4 Source of the Rhyolites

Rhyolites inter bedded with the basalts and trachytes are mainly ignimbrites, including some very crystal rich types resembling the so-called late rhyolites of Jacobson et al. (1958). They may be from external sources, for example the Kila - Warji or Birnin Kudu complexes 40 km to the E and N respectively. But the ignimbrites would require a favorable topographic gradient, not available if the Stage 0 trachytes and basalts had by then built significant volcanic structures. Thus it seems likely that small batches of rhyolite magma were produced in the Ningi-Burra complex in this initial volcanic phase, and were erupted as ash flows, some of them already in a highly crystallized state.

4.12.5 PROGRESSION OF THE NINGI CENTRE

Centre 1 differs from other Ningi-Burra cauldrons: aphyric and crystal-poor rhyolites are much more important, there is no granite porphyry ring dyke, but instead the cauldron is defined by a ring of rhyolite vents. The beginning of Centre 1 sequence is taken to be the bedded ash fall tuff overlying the Stage 0 basalts and trachytes between Guda and Tebbi. This was followed by varied crystal poor rhyolite lavas and ignimbrites. Crystal-rich ignimbrites occupy the eastern part of the Centre 2 cauldron. They are earlier than the Kabara sequence in Centre 2 and probably represent thick ash flow deposits that accumulated in the subsiding Centre1 caldera and later underwent further subsidence in the Centre 2 caldera.

Centre 2 marks the site of unusually large caldera associated with very abundant extrusive. Within the ring dyke, (which measures 28 x 18 km), the rhyolitic volcanic have a volume in the order of 300 km, and an unknown but presumably large quantity must originally have existed outside the ring structure. In the East the ring dyke encloses part of the Centre 1 cauldron and in the West it is cut across, but not obliterated, by Centre 3 ring structure.

Three main volcanic stages can be recognized; First, inward dipping sequences of varied rhyolitic ignimbrites with occasional trachytes conformably overlie the basal Stage 0 sequence around the margins. In the south these are overlain by an early intra-caldera succession, the nearly horizontal Kibara sequence is a typical of the caldera-filling successions, beginning with thick agglomerates and ash-fall tuffs and including several rhyolitic ignimbrite units and flows of rhyolite lava, trachyte and basalt.

Eruption of the Kibara (Latitude 110 22'N and Longitude 90 28'E), ignimbrites may have initiate a second stage of collapse and caldera formation in Centre 2. The granite-porphyry ring dyke was emplaced at this stage, acting as a feeder to intra-caldera rhyolites preserved only in the western part of the cauldron. These overlie the more varied ignimbrites of the pre-caldera succession near Yekwa and consist of crystal-rich ignimbrites and also porphyries, with aggregated phenocrysts resembling the ring dyke rocks, which were probably lava flows or domes.

4.12.6 STRUCTURAL FEATURES

The structural features associated with the study area are primary igneous structures that formed at the time the rock formed, and secondary brittle structures like joints. Late magmatic activity during the mid-Jurassic (170-180 million years ago) led to the intrusion of the Orogenic Younger Granites. Their great difference in age with the Older Granites aged (500-600 million years), and the lack of sediment associated with the Younger Granites, suggest as eipirogenic uplift (Jacobson et al., 1958).

The basement rocks appear to have exerted some control over the emplacement of the Younger Granites. Pan-African Orogenic activity re-deformed and re-metamorphoses these basement rocks, giving N - S trends to for the emplacement of the Younger Granites. On a more detail scale, the structures within the basement appear to have influenced the location of the ring complexes; these follow in a number of different directions with no dominant single trend (Turner, 1972). According to Ajakaiye (1983), aeromagnetic anomalies suggest that a series of buried NE-SW lineaments of incipient rifts controlled the disposition of the individual complexes.

In the study area, volcanic rocks commonly represent the earliest igneous activity and they are intruded by porphyries, granites and less commonly by syenites. In most cases both extrusive and intrusive rocks are now confined to a roughly circular area bounded by a ring dykes or ring faults. These same ring fractures were earlier utilized as feeder channels for the eruption of the intra-caldera suite of acid volcanic rocks, and subsequently provided access for the post-caldera lavas now mainly removed by erosion.

The volcanic rocks have evidently been down faulted originally in great collapse structures, forming calderas at the surface.

Structural interpretation in the study area revealed four structural trends in the NE-SW, NW-SE, N-S and E-W directions with the dominant trends being in the NE-SW and NW-SE directions. Generally, the fractures in the Nigerian Basement complexes and associated areas are oriented in four principal directions: E-W, N-S, NE-SW and NW-SE (Chukwu-Ike and Norman, 1997; Bala, et al., 2000). The E–W fractures are discernible locally, having been overprinted by latter events. The N-S fractures are very prominent and are often conformable with other geological trends. They have been identified on "Imageries" as depressions and prominent scarp surfaces and appear to have determined the causes of the major N-S flowing streams. They are traceable across most part of the country. The N-S fractures are also found on both sides of the River Niger and around the Jos-plateau.

These fractures are products of brittle deformation and are marked in the field by considerable shearing and brecciaing. There is no doubt that the fractures are of regional extent as similar structures have been identified in the Tuareg area of Niger Republic. Furthermore, each complex often exhibits a centripetal arrangement of successive phases along a linear direction. The spatial arrangement of the totality of the complexes suggests the basement control of the igneous activities and the reactivation of the existing lines of weakness during the Mesozoic.

Thus, within the Younger Granite province, in addition to the N-S, NE-SW, and NW-SE fracture systems, ring fractures were developed and granitic complexes themselves were fissured and mineralized.

The emplacement of the lavas and the granitic rocks were controlled by ring fracturing and large scale cauldron subsidence. Numerous ring dykes and cone sheets which fringe the complexes are evidence of the ring structures. Besides, the granitic bodies were fractured such that fissures and crushed zones developed in them serve as pathways for the greisenisation fluids (Akanbi et al. 2012; Bowden and Kinnaird, 1984; Samaila, and Solomon, 2011; Turner, 1989).

Results of this study are in line with previous works, which suggested that Nigeria has a complex network of fractures and lineaments with dominant directions of NE-SW, NW-SE and N-S (Ananaba and Ajakaiye 1987; Udoh 1988; Chukwu-Ike and Norman, 1997, Olasehinde et al., 2012). A comparison of the lineament density map with the primary mineral occurrences map of the study area showed a good correlation indicating that primary mineralization in the area may be tectonically controlled (Ananaba, 1991). Primary ore bodies in Nigeria are probably oriented following lineament trends. There is therefore a good correlation between the lineament density map and the areas where the occurrence of most primary minerals like iron, cassiterite, lead-zinc and uranium have been reported.

Finally, those structural features such as faults, joints and fractures besides controlling primary mineralization may also control drainage. Lineaments most often are underlain by zones of localized weathering and increased permeability and porosity. Therefore, lineament maps such as the lineament density map produced in this work may be a tool that can enhance the detection of areas of high groundwater recharge, flow and development. Groundwater flow and yield in mountainous areas composed of crystalline rocks with several features and faults are governed mainly by flow dynamics within the lineaments.

Study of the lineament trends in the study area revealed that the granite province of the Ningi-Burra constitutes a distinct unit as it is bounded by northerly fractures. Similarly, many of the lineaments are drainage lines. This means that the drainage is structurally controlled (Samaila and Solomon, 2011). However, the absence of visible fractures and lineaments in parts of the study area may not be indicative of complete absence of geological structures. High lineament frequencies are obtained in areas where basement rocks outcrop or are closer to the surface (i.e. area with thin overburden) whereas low lineament frequencies are characteristics of areas with deeply buried basement rock.

Based upon the lineament analysis, suitable areas for further mineral exploration can be selected within the eastern part of Ningi-Burra complex, the study area according to Wright et al. (1985), produced geological structures with north-south orientation, some of the fractures in the image bear this strike. Also studies by Mamven (1990) and photo geological interpretation by Onwusulu (1995) indicated that extensive dyke swarms with trends in north east and north - west directions are found cross-cutting the major basement lithological units, i.e. porphyritic biotite granite, and the migmatites.

The drainage pattern of the area extracted from the image and existing topographic map, revealed a great deal of information concerning the parent rock materials. The dentritic pattern is indicative of lithological, structural and topographic homogeneity. It is also indicative of crystalline rock which is typical of the geology of the area that consists mainly of crystalline rocks. The drainage texture of the area is coarse which a characteristic resistant, permeable bedrock material is coarse permeable soil material, such as the course grained porphyritic which is in conformity with the findings of Olowolafe (2000).

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 LINEAMENT MAPPING AND ANALYSIS

After the image enhancement processes; observable structural geological features were carefully traced out. These are; fractures, joints, drainage and dykes as linear features and ring structures. The structural trends were found to be controlled by structures in the underlying Precambrian rock of the Basement complex.

The result of the structural analysis shows that numerous fractures and lineaments occur at the western, central and eastern part of the satellite image. The common orientations of lineaments are NW-SE and NE-SW. a dolerite dyke related to a major NE-SW striking fracture occurs in Western part of the study area.

5.2 FIELD RELATIONSHIPS AND LITHOLOGIES

The volcanic rocks of rhyolite composition of the north eastern part of Ningi-Burra include minor lavas, ash-fall tuffs and agglomerates, and abundant ignimbrites which all of them show effects of post-depositional devitrification, recrystallization or hydrothermal alteration. The lithology of the younger granite of the north eastern part of Ningi-Burra is represented on table 6; below;

Table 6: Lithology of the mapped Younger Granite Rocks in the Study Area.

Center 1	Ningi riebeckite granite,
	Ningi Syeno-monzonite,
	Intra-caldera rhyolites,
	Rhyolite lavas and ignimbrites,
	Aphyric vent rhyolite and breccias,
	Hedembergite-hastingsite micro granite,
	Eutaxitic rhyolites,
	Layeared tuffs.
Centre 2	Tabula-Suma biotite granite,
	Hedenbergite-hastingsite granite porphyry,
	Fayalite-hedenbergite porphyry,
	Intracaldera rhyolites.
Kabara Succession	Upper Kabara ignimbrites,
	Lower Kabara ignimbrites,
	Basalts / rhyolites,
	Rhyolite lava,
	Crystal rich ignimbrite,
	Quartz trachyte,
	Layered agglomerates & tuffs,
	Peralkaline ignimbrite,
	Aphyric quartz trachyte,
	Crystal rich ignimbrites and
	Crystal poor ignimbrites.
Center 3	Hedenbergite-hastinsite granite porphyry.

Using edge enhancement techniques, the Younger Granite rocks clearly defined boundary from the country rock. The drainage pattern of the area extracted from the image and existing geological map revealed a great deal of information concerning the parent rock materials. Blue / Green colors on the land sat image mostly correspond to Younger Granites which correlates to structural interpretation of ring structure; Blue color partly corresponds to ring dykes, red/yellow color may generally correspond to the Basement Complex rocks.

5.3 PETROLOGY

The petrology of the eastern part of Ningi-Burra is a series of overlapping ring structures in which each contain varied, pre-caldera volcanic sequences, overlain by massive intra-caldera rhyolitic ignimbrites and enclosed within ringdykes of fayalite-hedenbergite granite-porphyry which includes basalts and rhyolites, and also a whole range of intermediate types which fill the compositional gaps previously supposed to separate basalt, trachyte and rhyolite (or their intrusive equivalents). Most of the rocks are metamorphosed and possibly metasomatically altered, and many of them are porphyritic. The beginning of Centre 1 sequence is taken to be the bedded ash fall tuff overlying the Stage 0 basalts and trachytes between Guda and Tebbi. This was followed by varied crystal poor rhyolite lavas and ignimbrites. Crystal-rich ignimbrites occupy the eastern part of the Centre 2 cauldron, they are earlier than the Kabara sequence in Centre 2 and probably represent thick ash flow deposits that accumulated in the subsiding Centre 1 caldera and later underwent further subsidence in the Centre 2 caldera.

Volcanic succession begins with water-deposited rocks: detrital sediments and basaltic and rhyolitic tuffs and breccias, followed by thick basalts, varied rhyolitic ignimbrites and minor rhyolite lavas. The intrusive sequence consists of syenite, granite porphyry, peralkaline granites and biotite granite.

5.4 EVOLUTION OF THE STUDY AREA

The field observations confirm what is obtainable on the Landsat Image of the study area; suggest a relationship between lineament densities and Younger Granites occurrences in the study area which is an indication of tectonic control probably associated with paleo-tectonic structures. A model for caldera and ring complex development in the Nigerian Younger Granite province can be suggested to provide a framework for an analysis of the Ningi-Burra complex. The structural and petrologic evolution of the Nigerian ring complexes as well as the Ningi-Burra ring complex can be summarized as a sequence of three main stages which was repeated at different time and places throughout the province to give the pattern of separate and overlapping ring complexes include; early volcanic stage, Caldera and ring dyke stage, as well as an Intrusion stage.

This correlation is an indication that the emplacement of the Younger Granite ring complexes may be associated with epeirogenic uplift. The epeirogenic uplift is believed to result from the intrusion of large masses of basic magmatic materials into the lower part of the continental crust in the study area.

5.5 CONCLUSION

A lineament refers to a linear topographic feature possibly related to an underlying structure such as a fault, fracture zone or lithologic contact (Scalon et al., 2002). Generally, regional linear or curvy-linear features expressing deep-seated geological structures are usually visible on remote sensing image products such as aerial photographs or satellite imageries.

N-S is conformable with other geological trends (flowing over) mostly found along side of the river; E-W is over pointed by local events. The dominant trends in NE-SW are related with the dyke. The function of the lineament determined the causes of major N-S flowing streams. Emplacement of lavas and granitic rocks where controlled by ring fracture and large scale cauldron subsidence. The lineaments serve as pathways for the gresinization fluids, control primary mineralization and also drainage.

The structural orientation in the study area has greatly controlled the geological setting, relief, drainage, geological boundaries and trend of younger granite rocks.

The trends of the field observation confirm what is obtainable on the Landsat Imagery of the study area. The geological structures relevant to mineralization and groundwater occurrence within the study area are expression of high lineament density. Structural trends along the NE – SW, NW – SE and the ENE – WNW responded to both stress difference and orientation of the principal stresses.

The NE - SW set is interpreted as belonging to fractures generated by tectonics activities control the evolution of the ring complex which includes occasional flow of basalt and the volcanisms was accompanied by formation of large surface couldron or caldera.

5.6 CONTRIBUTIONS TO KNOWLEDGE

The following are contributions to knowledge.

i) Satellite imagery of the study area was compiled and interpreted.

ii) Geological and lineament maps of the area was compiled and updated.

iii) The sequence of structural events of the study area was determined based on the lithology that was revealed from the field work, structural and geological map.

iv) Lineaments and lithological patterns in the area were delineated and correlated with results of existing data as compiled by the previous workers.

5.7. CHALLENGES

Limitations and challenges encountered during the process of data collection and interpretation includes; limited spectral resolution, deep-down structures cannot be reached, and the fact that various features / objects tend to display almost the same color. The same applies to identification of difficult lithilogical units.

Interpreter therefore needs a lot of experience to carry out reliable supervised classifications. Intensive research works are required to develop appropriate classification scheme for imagery for geological and other application.

5.8 RECOMMENDATIONS

1. There is a need for the delineation of the linear structures using other techniques such as digitized Aeromagnetic data, Gravity survey, and seismic data to study the sub-surface structures.

2. Intensive research works are required to develop appropriate classification scheme for imagery. There is need for improvement of existing linear feature extraction methods by developing a new framework that facilitates automatic image discontinuities extraction and mapping using remote sensing data and digital elevation model (DEM). These frameworks need to be implemented as a set of algorithms (TecLines) that allows the satellite image pre-processing, spatial filtering, Hough transformation and polynomial fittings.

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