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## Tectono-Metamorphic Deformational Features of Dumne area, Hawal Massif, Northeastern Nigeria

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### ABSTRACT

*The Dumne area forms part of Hawal Massif in the northeastern sector of the Nigerian Basement Complex. The region has experienced multiple phases of tectono-metamorphic deformations denoted as D1, D2 and D3 which have played a significant role in the emplacement of various structural elements and the formation of extensive granitoid bodies. The structural elements are classified into plastic (foliation and lineation), ductile (fold) and brittle (fractures, faults and joints) respectively. They strike dominantly in the N - S (0 - 20°), NNE - SSW (25 - 35°), NE - SW (45 - 55°) and ENE - WSW (65 - 85°) directions as well as minor E-W (90 - 95°) and NW - SE (120 - 150°) directions. The N - S, NNE - SSW and NE - SW are the most dominant and penetrative structures representing a widespread effect of Pan-African orogeny in the area. These structural trends also serve as host to epigenetic vein-type, baryte-fluorite mineralization in the study area. The less dominant ENE - WSW structural trends are pervasive and largely offset in places, suggestive of structures that pre-date the Pan-African events.*

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### INTRODUCTION

The Nigerian Basement Complex is part of the Nigerian – Benin – Congo shield situated fully within the Pan-African mobile belt and extends between West African craton and Congo craton to the east and west respectively (Black, 1980). The Basement Complex underwent multiple deformational episodes and metamorphism during Proterozoic and early Phanerozoic periods (Ekwueme, 1994). Large scale thermo-metamorphic events were believed to affect the Basement Complex about 600±150 Ma (Grant, 1970). Geochronological and isotopic studies show that intermittent tectono-thermal activities occurred between late Proterozoic and early Palaeozoic periods (Grant, 1970). The Basement Complex consists of Archean and Proterozoic rocks which suffered the effect of four orogenic episodes and are Liberian (2800±200 Ma),

Eburnean (2000±200 Ma), Kibaran (1100±200 Ma) and Pan-African (600±150 Ma) tectonic events (Baba et al., 2020). The whole of Africa was affected by the Liberian and Eburnean events but Kibaran and Pan-African events were not pronounced in some areas of African continent. In Nigeria, the Liberian and Eburnean events resulted in the emplacement of rocks represented by migmatite-gneiss complex. The rocks are low-lying, highly deformed and petrologically confusing and structurally ghost looking units (Baba et al., 2020). Kibaran activity which is largely sedimentation and volcanism with subsequent metamorphism was responsible for the emplacement of low-grade, N-S and NNE-SSW trending gold and banded iron formation bearing meta-sedimentary schist belts was better developed in the western half of Nigeria (Baba, 2005; Baba et al., 2020).

The Pan-African orogeny engulfed the whole of Nigeria making it fully fall within the Pan-African mobile belt and the event largely obliterated the fingerprints of older episodes. It resulted in the emplacement of large volume of mafic and felsic plutons.

Dumne and its surroundings are located on the southeastern tip of Hawal Massif, which together with Adamawa and Oban Massifs constitute the eastern block of the Nigerian Basement Complex. The Hawal basement is bounded to the north by the Quaternary sequences of the Nigerian sector of the Chad Basin. It is bounded to the west by the Cretaceous sediments of the Yola sub-Basin of the Northern Benue Basin and to the east by the Cretaceous deposits of the Gongola sub-Basin of the Northern Benue Basin.

The study area is part of the Federal Survey of Nigeria sheet 175, Shellen NE. It is bounded by latitudes  $N09^{\circ} 45' - N10^{\circ} 00'$  and longitudes  $E12^{\circ} 15' - E12^{\circ} 30'$  covering an area of about  $255 \text{ Km}^2$ . The area is accessible via Hombo – Dumne – Prambe lateritic road and through the lateritic roads that passes through Prambe – Waltandi – Dikir and through minor paths connecting Dumne – Kalche – Pella areas. It is

also accessible through numerous footpaths and cattle routes that traverses and criss-cross the area (Fig. 1). The major geological features of the study area constitute the highlands and lowlands of the area. The highland is typified by rugged and highly elevated mountain ranges with heights reaching up to 738 m above mean sea level occurring dominantly in the western half and the northeastern parts of the study area (Fig. 2). The lowlands is typified by plains, low-lying outcrops and valleys having heights below 300 m above mean sea level occupying the southeastern portion of the study area. The drainage of the area is controlled by the highlands where water flows down hills and mountains draining into low relief areas to the valleys forming dendritic patterns and consequently draining into River Busangi. The primary objective of this study is to thoroughly document the tectono-metamorphic evolution of the Dumne area. This will be achieved through a comprehensive approach that involves integrating aerogeophysical studies with ground geological and structural investigations. Additionally, the study aims to assess and document the mineralization potential within the study area.

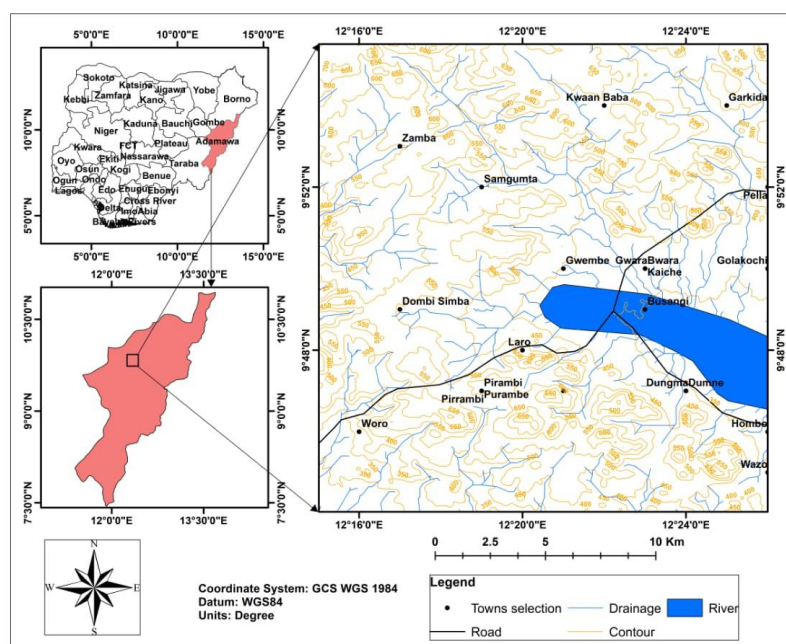


Figure 1: Location Map of the Dumne area

## REGIONAL GEOLOGY

### Basement Complex

The Precambrian Basement Complex rocks of North-eastern Nigeria have been investigated by various workers notable among whom are Carter *et al.* (1963); Baba *et al.* (1991, 2006); Dada *et al.* (1995); Ntekim and Adekeye, (2004); Bassey, (2006a, b, c, d) and Joseph *et al.* (2008)

Carter *et al.* (1963) observed that the north-east Basement Complex consist of scattered remnants of highly metamorphosed sedimentary rocks as well as diverse, predominantly granitic, plutonic masses collectively known as Older Granites. Lithologically these include hornblende gneisses, biotite gneisses, quartzo-feldspathic gneisses, marble and quartzite. Gabbro, diorite, pyroxenite, granites, and quartz-diorite are some of the Older Granite lithologic units. Islam *et al.* (1986) differentiated the basement rocks of north-east Nigeria based on studies of aerial photos, detail field mapping and laboratory studies into major and minor types. Islam *et al.*, (1989) mapped and divided the north-east basement into four: the Mandara mountain, the Alantika mountain, the Shebshi mountain and the Adamawa massif.

Bassey (2006a) studied the Madagali Hills with emphasis on structures as well as tectonics and noted that the area comprises of migmatite gneisses, schists, tectonized and undeformed granites, and that the tectonics of the rocks is correlative with the evolutionary tectonics of Chad Basin Tenere rift in Niger Republic. Bassey (2006b) observed that the Madagali area is polygenetic where magmatism, metamorphism and structural deformation have been witnessed. Bassey (2006c) deduced the tectonic synthesis of structural data from Uba area in Hawal Massif to be of metamorphic rocks intruded by massive and deformed Pan-African granites aligned at N30°E direction and submitted that shear zones, faults and folds are

the commonest deformational features which are NW-SE and NE-SW in orientation. Bassey (2006d) worked in Chibok area and revealed evidence from satellite data, physiography and field structural mapping showing that the area shares geostructural similarities with faults /shear zones of Kaltungo and Wuyo-Gubrunde inliers of the Upper Benue Trough. Bassey (2007) carried out field geological investigation of Michika area and reported brittle deformation in metamorphic rocks extensively intruded by Pan-African granites within mainly fault/shear zones. Ntekim and Adekeye (2004) deduced the geology of Song area and reported that granites, granodiorites and Tertiary basalts as the lithologic units of the area where they observed major rock units showing gradational contacts with each other but sharp contacts with the surrounding sediment.

Bassey *et al.* (2013) conducted radiometric mapping of Song area and the study revealed the presence of gneisses, migmatites, granites, pegmatites, aplites and basalts with isoradiometric anomalies align in N-S, NE-SW, NW-SE and E-W directions. Kwache and Ntekim (2014) studied the geology of Dumne area and reported that gneisses, migmatites, Older Granites and Tertiary basalts dominate the lithology of the area. They concluded based on geochemical data that the granites has high alkalis with low amount of other oxides whereas the basalts has high total iron with lower values of other oxides.

Bassey and Maunde (2017) conducted structural investigations of the Sugu part of Adamawa Massif and indicated that faults of the area displayed conjugational relationship and trends NE-SW and NW-SE directions. The conjugal fault system is believed to be part of giant shear zone termed the Jos-Adamawa basement block. Yusuf *et al.* (2018) investigated the tectonic lineament patterns of western part of Adamawa Massif and reported lineaments such as iron-mineralized veins and non-mineralized fractures (joints and faults)

oriented in NE-SW and NW-SE directions. The lineaments are concordant to micro features such as foliation and fractures and major features such as rivers and stream channels.

## Materials and Methods

### Aeromagnetic Data

Digitized aeromagnetic data of sheet 175 Shellen NW was acquired from the Geophysical unit of the Nigerian Geological Survey Agency (NGSA) Abuja. Geosoft Oasis Montaj software was used to obtain the Regional-Residual Maps and the Source Parameter Imaging (SPI) of the study area (Figs. 3 and 4). The Total Magnetic Intensity (TMI) map was utilized to produce the lineaments by application of Centre for Exploration Target (CET) plug-in of the Geosoft Oasis Montaj (Fig. 5). The data was filtered and allowed to pass through Fast Fourier Transformation and the lineament map was produced there from and the strike of each lineament was plotted on the Rosenet software and the rose diagram was produced (Figs. 6 and 7).

### Structural Mapping

Geological and structural mapping of the Dumne area was conducted on a scale of 1:50,000 using systematic traverse-compass mapping technique. A total area of 255Km<sup>2</sup> was covered with the help of compass-clinometer, Global Positioning System (GPS), digital camera, measuring tape, Geological hammer, Field notebook, indelible marker pen, base map and writing materials. Structural features such as foliation, lineation, fold, fault, joints, fractures and dykes were diagnosed and recorded.

## RESULTS AND DISCUSSION

### Local Geology

Detailed Geological and structural mapping has revealed that the Dumne area is underlain by Basement Complex rocks identified as

migmatite-gneiss, porphyritic granite, coarse-grained granite, dolerite and pegmatite; Cretaceous Sediments typified by sandstone of Bima Formation and Tertiary-Quaternary Volcanics represented by basalt. Structurally controlled epigenetic, vein-type baryte-fluorite deposits occur in three distinct locations hosted by migmatite-gneiss and porphyritic granite in the Dumne area (Fig. 2). Detailed geological and petrographic studies of the Dumne rocks of Dumne area is given in Kamale and Haruna (in press).

### Aeromagnetic Structures

The total magnetic intensity map (TMI) map shows the presence of deep and shallow seated features represented by various tone of colours. The lower values represented by blue tone are interpreted to the occurrence of sedimentary rocks while the higher values in red tone represents the presence of magnetic minerals in rocks. The TMI (Fig. 3) was obtained from the Geophysical unit of the Nigerian Geological Survey Agency (NGSA) Abuja. It consists both deep and shallow features having values that ranged from -129 – 91 nT. The TMI data was separated using regional – residual separation technique using Oasis Montaj software and regional magnetic anomaly map along with residual magnetic anomaly map were obtained. They show deep-seated and shallow level features but the regional feature was discarded and the residual magnetic intensity map was used which has values that ranged from -65 – 42 nT. The lineament map along with the rose plot of the lineament is deduced and presented in Fig. 4. The lineaments in the Dumne area exhibit a predominant structural trend, mainly striking in ENE – WSW, NE – SW and NW – SE directions. Additionally, there are minor trends observed in NNE – SSW directions. These lineaments are believed to be influenced by the Pan-African and earlier orogenic movements that affected the rocks in the Dumne region.

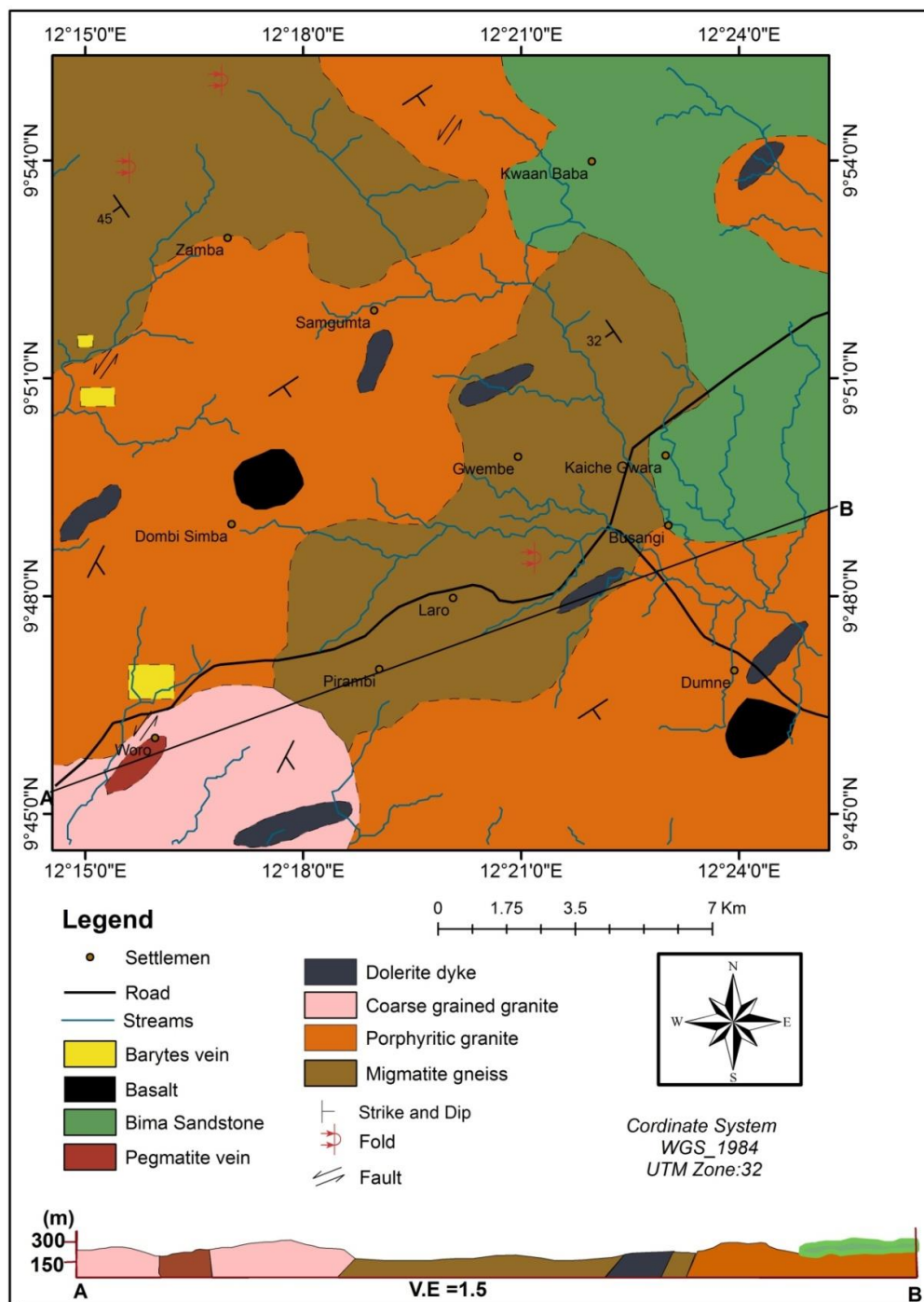


Figure 2: Geological map and cross-section of the Dumne area showing lithostratigraphic units.



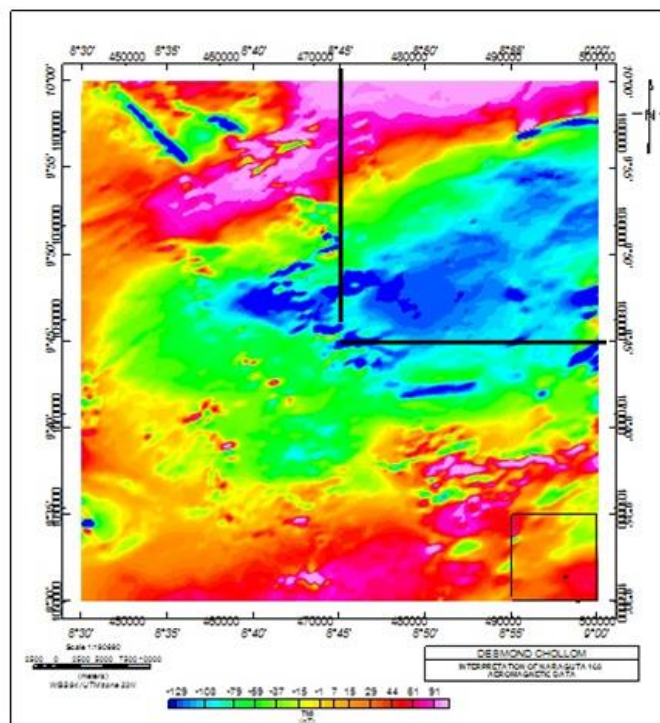


Figure 3: Total Magnetic Intensity Map of Dumne area showing areas of high magnetic intensity in the northern region.

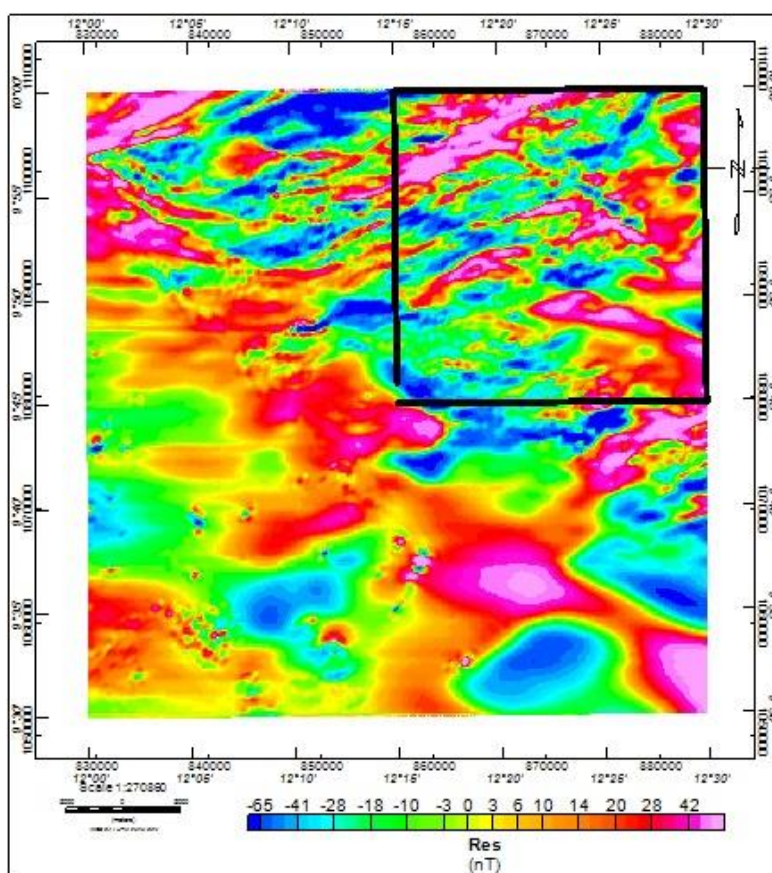


Figure 4: Residual Magnetic Intensity Map of Dumne area

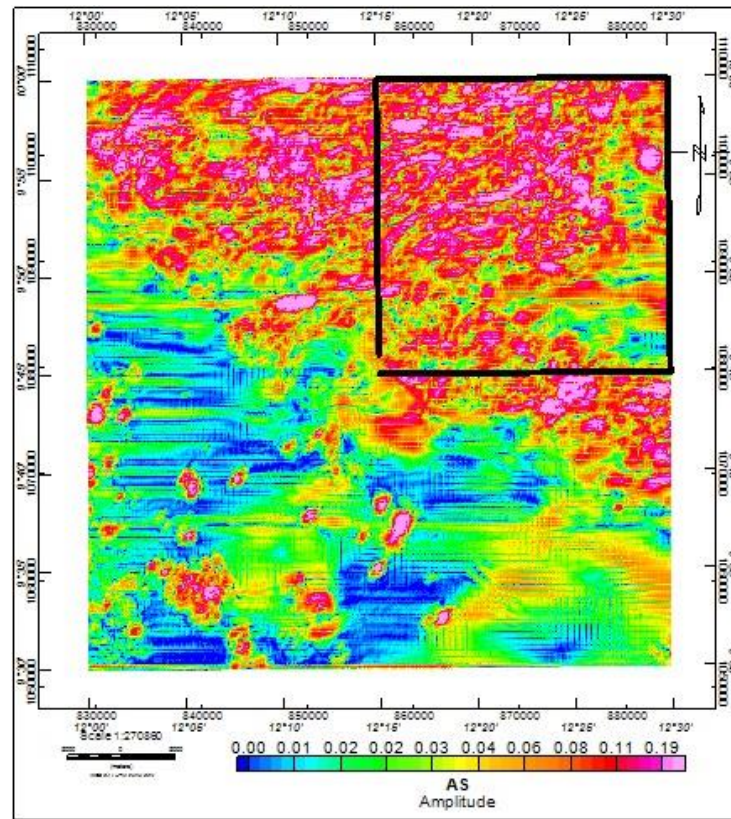


Figure 5: Amplitude map of Dumne area

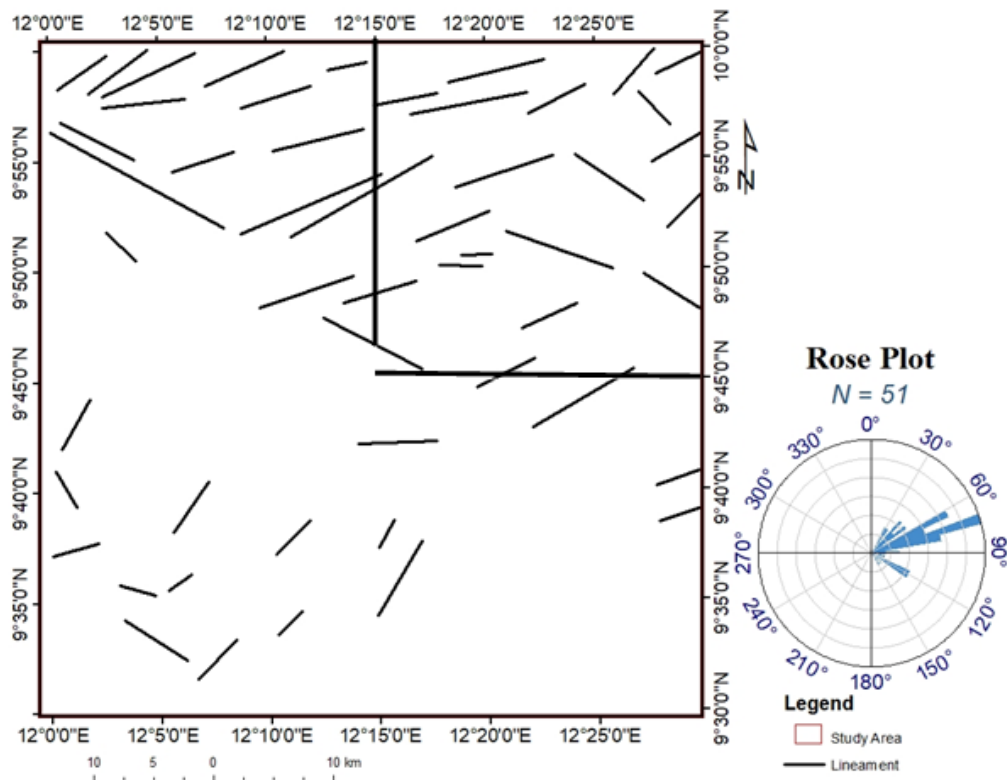


Figure 6: Lineament Map of Dumne area showing a dominant ENE-WSW trend.

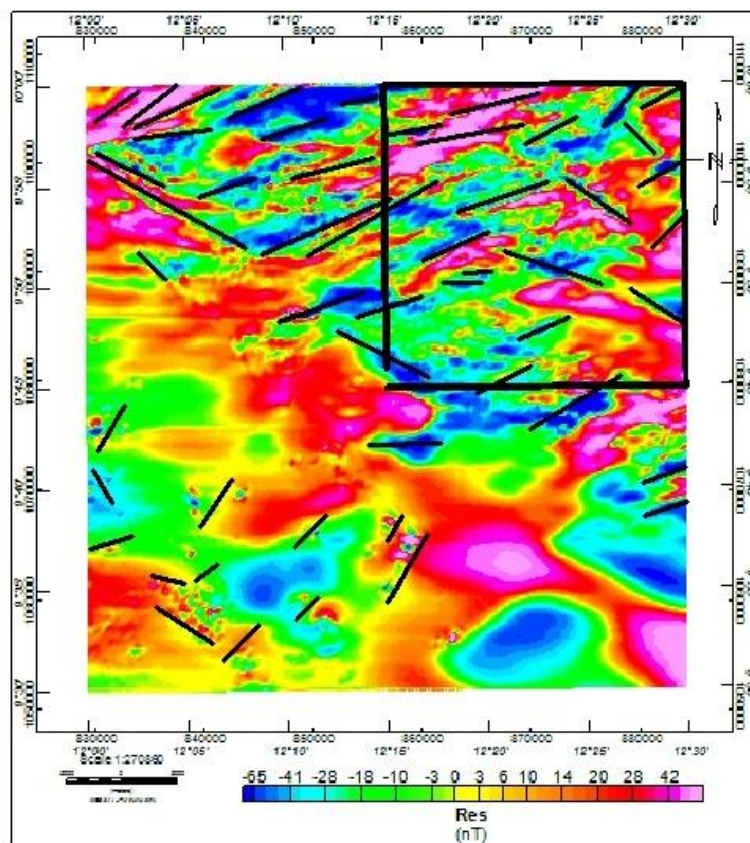


Figure 7: Lineament superimposed on the Residual intensity map of Dumne area

### Structural Geology

Field relationship and structural investigations reveal that Dumne area witnessed multiple tectonic episodes of deformation responsible for the formation of various structural features in the field which include foliation, lineation, folds, fractures, joints, veins and dykes. These deformational structures measured in Dumne area are categorized into plastic (Foliations and lineation), ductile (folds), brittle (fractures, joints and dykes).

### Plastic and Ductile Structures

Plastic and ductile structures are planar structures which was formed due to plastic and ductile deformational pressures and consequently exhibits parallel alignment or preferred orientation and elongation of minerals without break in the continuity or cohesion of the of the deformed rocks. Rocks responding to ductile deformation are bent, kinked or folded without breakage.

Foliations and lineation were observed and measured on the migmatite-gneisses as mineralogical bandings characterized by



segregated leucosome (felsic) and melanosome (mafic) minerals (Plate 1). The leucocratic and melanocratic bands were formed due to planar alignment of dimensionally oriented minerals formed by recrystallization and segregation of the

minerals under elevated pressure, shear stress and temperature designated as D1 deformation. The principal structural orientation of the foliation and lineation are ENE - WSW (65 – 85°), NE - SW (45 – 55°) and E - W (90 – 95°) direction (Fig. 8).

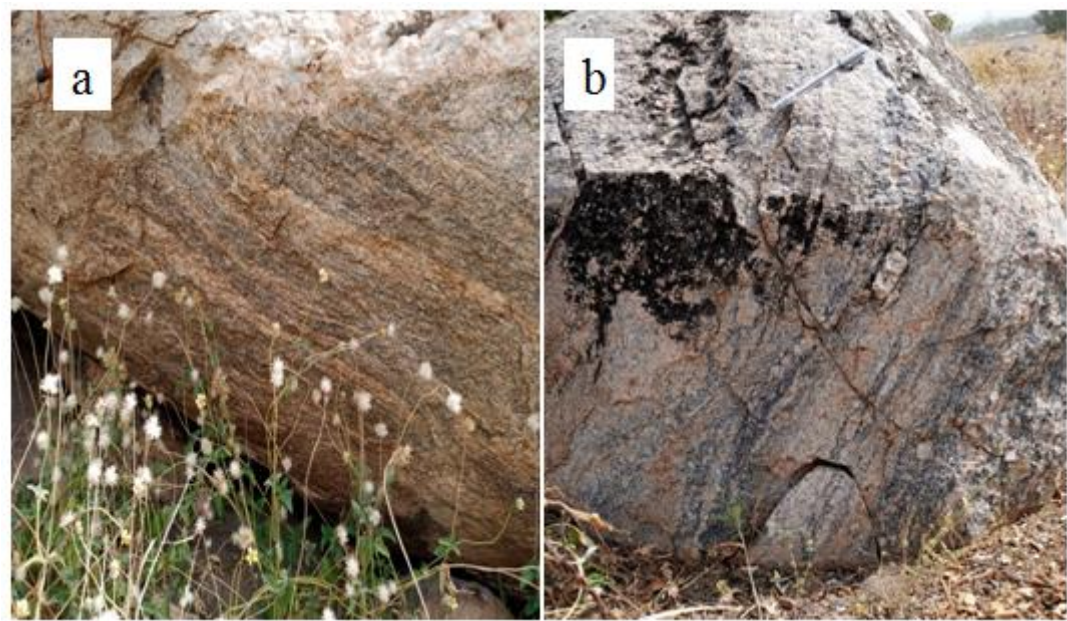


Plate 1: Migmatite-gneiss (Banded Orthogneiss) (a)- incline parallel foliation of mafic and felsic bands, (b) vertical parallel bands of felsic and mafic components (N09° 49.660' and E012° 13.498').

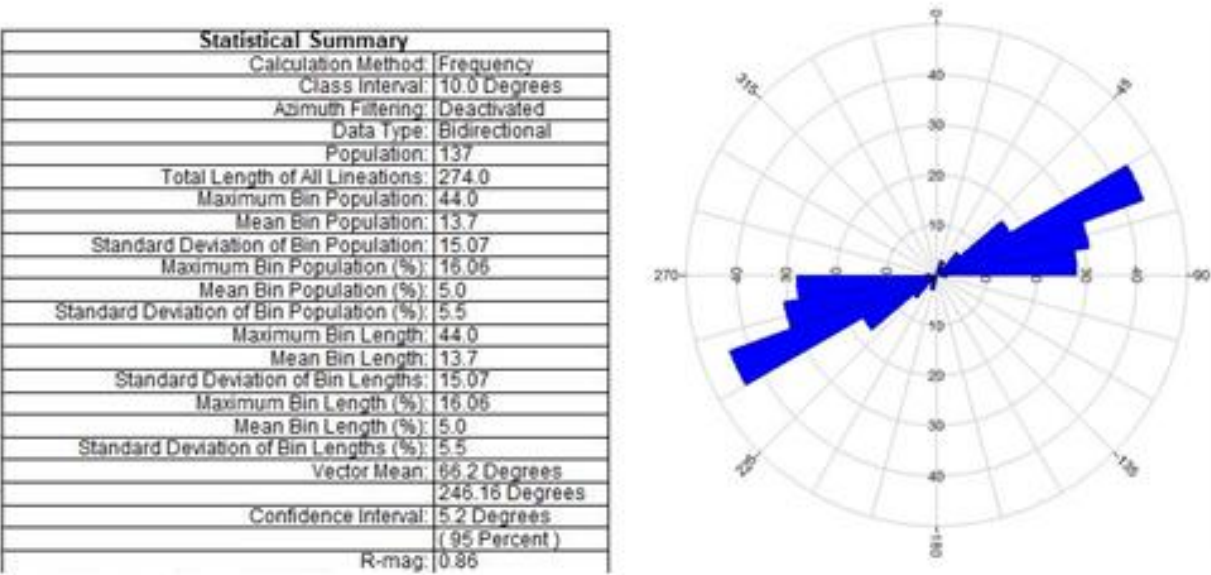
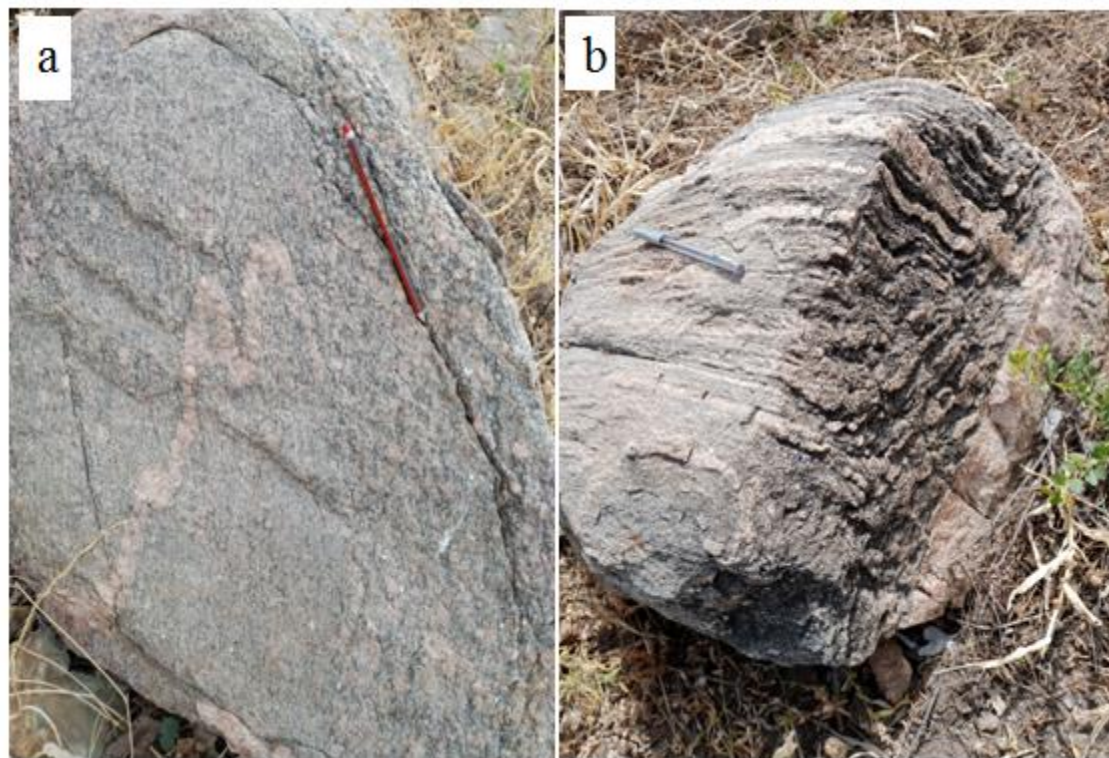


Figure 8: Rose diagram plot of foliation and lineation

Folds are typically characterized as antiforms and synforms and mostly occurred on the migmatite-gneisses (Plate 2). The folds occur as minor structures which vary in morphology and architecture from closed folds, open folds, M-shaped and W-shaped folds (Plate 2a). These

variations in morphology are reflection of uneven deformational activities which simply and complexly folded the rocks designated as D2 deformation (Plate 2b). The plunge directions of the folds are largely in N-S ( $0-25^\circ$ ) and NNE-SSW ( $25-35^\circ$ ).



*Plate 2: Field photograph of migmatite-gneiss displaying: (a)-Nebulitic diatexite exhibiting M-shaped ptygmatic folding, (b)- synformal and antiformal folds shown by metatexite.*

### Brittle Structures

These are structures that are formed from brittle deformation in which there is failure of the rocks and consequent loss of cohesion and continuity (Sawyer, 2008). The term fractures, joints, faults and dykes had been applied to the brittle structures (Ekwueme, 1994).

Fractures, joints and faults occur in all the rocks of Dumne area but most dominantly on the porphyritic granite followed by coarse-grained granite and migmatite. Several cross-cutting

joints and fractures with aperture distance ranging from few mm to tens of centimetres occur on the rocks. These structures represent the D3 deformation features. The joints in Dumne area trend largely in (NE – SW ( $50-60^\circ$ ), ENE – WSW ( $75-85^\circ$ ) and NNE – SSW ( $20-40^\circ$ ) directions (Fig. 5). Fractures in the rocks of Dumne area trend in N - S ( $0-20^\circ$ ), ENE – WSW ( $60-80^\circ$ ) and NNE – SSW ( $25-40^\circ$ ) (Fig. 6). The veins and dykes (pegmatitic, quartz, dolerite and baryte-fluorite) strikes mainly in N – S ( $0-20^\circ$ ), NE – SW ( $45-65^\circ$ ), ENE – WSW



(75 – 85°) (Figs. 9 and 10). The Ba and F rich aqueous hydrothermal mineralizing fluids in the Dumne area exploited the joints, fractures

and faults as migratory pathways and deposition sites for the baryte-fluorite mineralization.

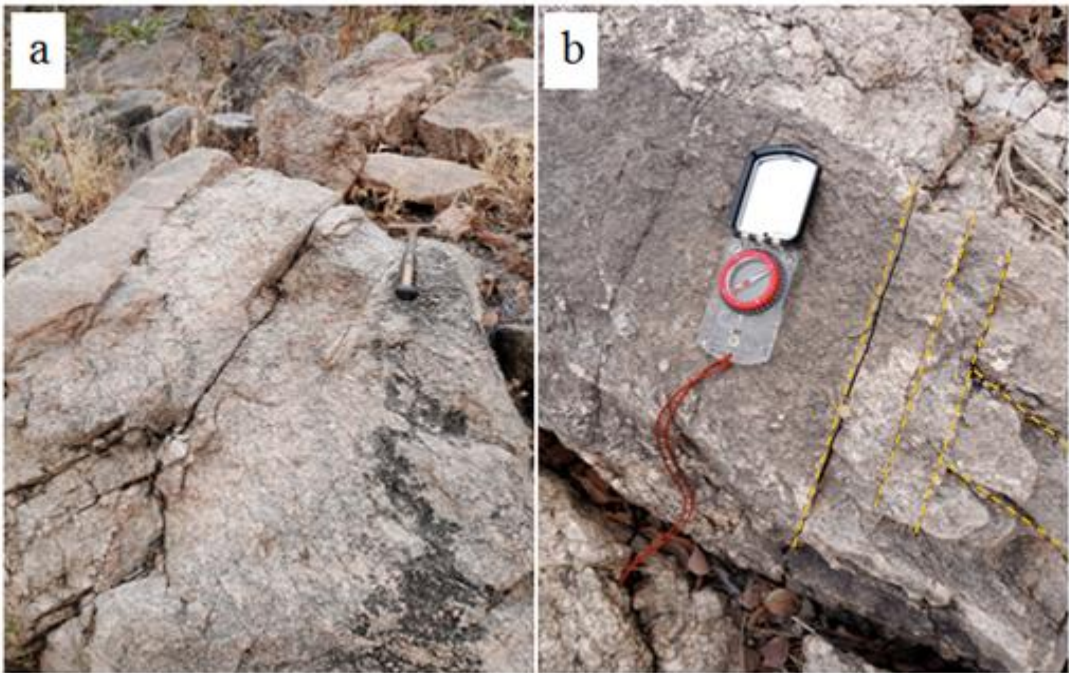


Plate 6: Field photograph of porphyritic granite showing (a)systematic jointing pattern, (b) parallel vertical and cross joints.

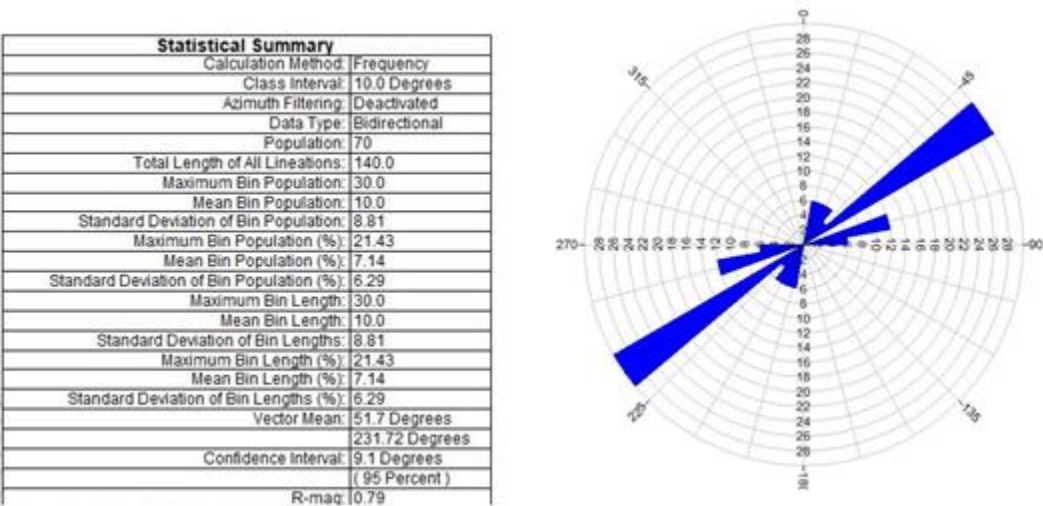


Figure 9: Rose diagram plot of Dumne area joints showing dominant NE-SW trend.

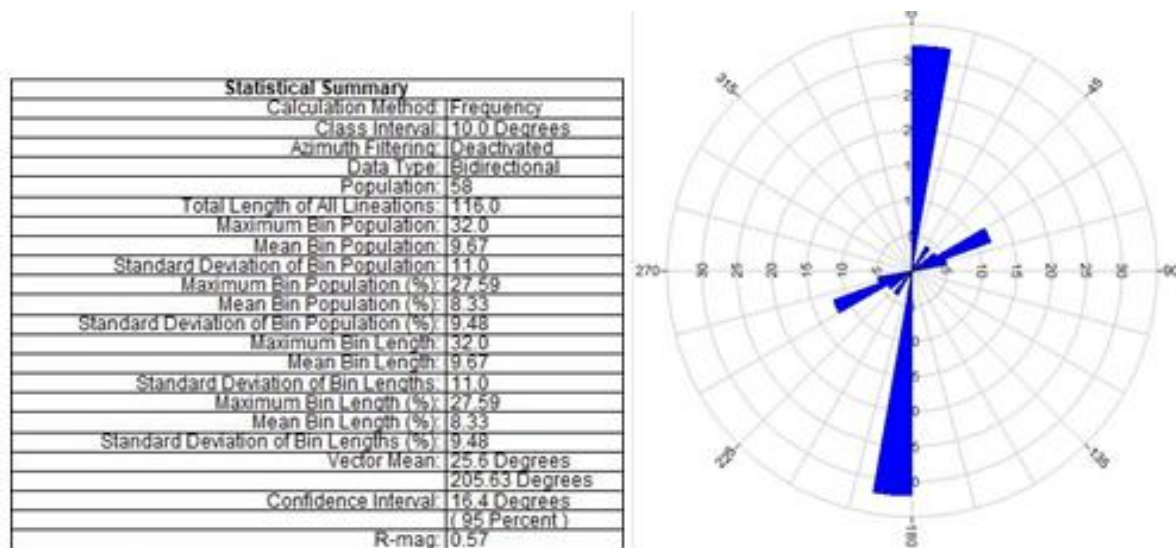


Figure 10: Rose plot of fractures of Dumne area showing dominant N-S trend.

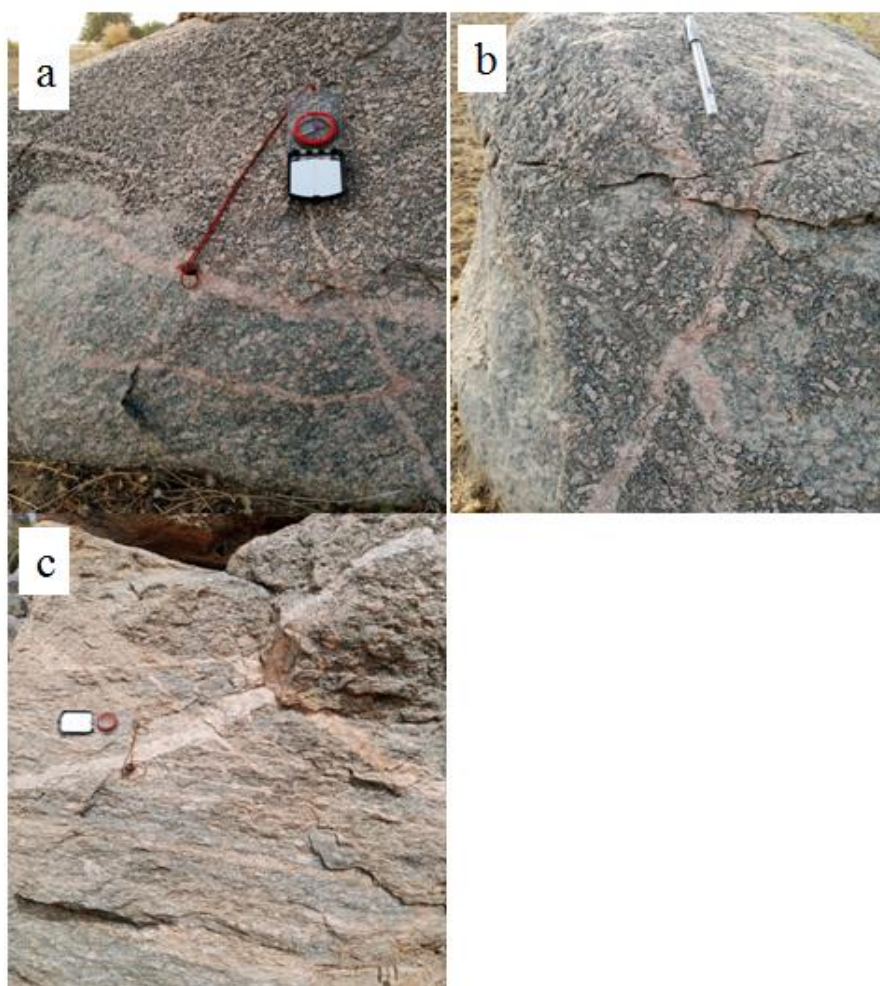


Plate 9: Strike-slip faults on porphyritic granites (a) sinistrally and dextrally displaced, (b) dextrally displaced, (c) multiple faults.





Plate 10: Strike direction of dyke and veins (a) dolerite and pegmatite (b) baryte-fluorite (c) baryte only.

Statistical Summary	
Calculation Method	Frequency
Class Interval	10.0 Degrees
Azimuth Filtering	Deactivated
Data Type	Bidirectional
Population	30
Total Length of All Lineations	60.0
Maximum Bin Population	12.0
Mean Bin Population	4.29
Standard Deviation of Bin Population	3.95
Maximum Bin Population (%)	20.0
Mean Bin Population (%)	7.14
Standard Deviation of Bin Population (%)	6.58
Maximum Bin Length	12.0
Mean Bin Length	4.29
Standard Deviation of Bin Lengths	3.95
Maximum Bin Length (%)	20.0
Mean Bin Length (%)	7.14
Standard Deviation of Bin Lengths (%)	6.58
Vector Mean	52.5 Degrees
	232.55 Degrees
Confidence Interval	9.4 Degrees
( 95 Percent )	
R-mad	0.9

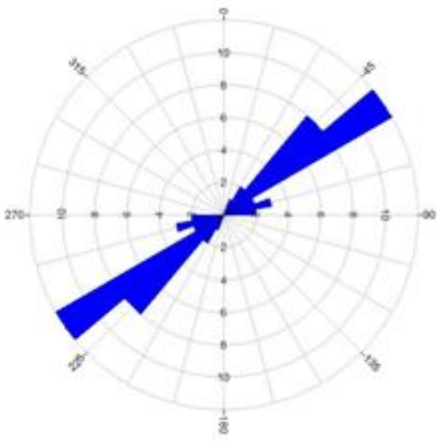


Figure 11: Rose plot of strike of dolerite dykes of Dumne area showing dominant NE-SW trend.

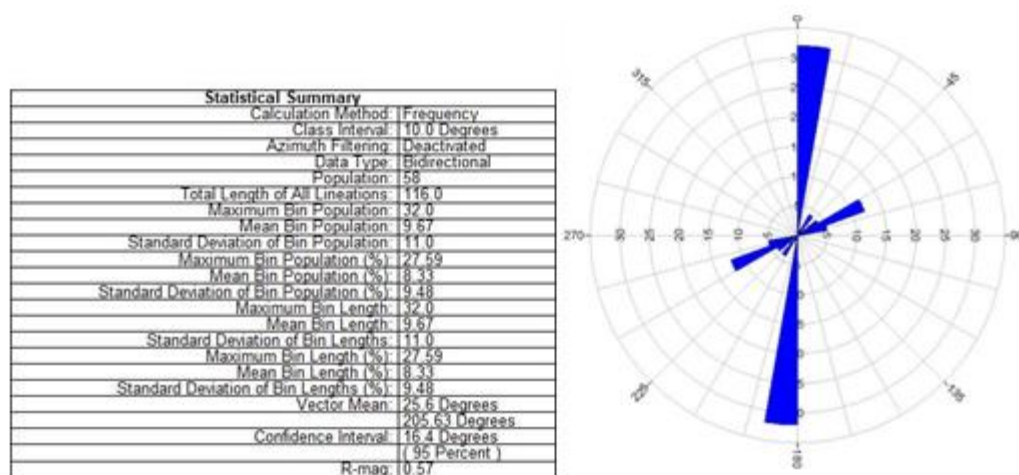


Figure 12: Rose plot of strike of veins showing dominant N-S trend.

## Discussion

The analysis of the interpreted aeromagnetic data reveals that the structures in the Dumne area predominantly exhibit orientations along the ENE-WSW, NE-SW and NW-SE directions with lesser NNE-SSW direction. These structural elements generally reflect the Pan-African and pre Pan-African thermotectonic events (Ekwueme, 1994; Bassey, 2006).

Field relationship and structural characteristics reveal that the study area was subjected to several tectono-metamorphic events. The first deformational event denoted as D1 is responsible for injection and segregation of minerals in the migmatite leading to the formation of foliation and mineral lineation on the migmatite-gneisses. The second deformational event identified as D2 and was characterized by folding of the segregated and foliated components of the migmatite-gneisses into folds of various morphological styles including antiforms, synforms, M-shaped and N-shaped folds as observed on the migmatite-gneiss. The third deformational episode D3 was recognized by the development of varying fractures, joints and faults. The faults were observed to be sinistrally and dextrally displaced and are most abundant on the porphyritic granite followed by migmatite-gneisses. Joints occur in all the rocks which are

localized and oriented in multiple directions indicating several phases of deformational stress. The fractures and joints exhibit parallel and cross-cutting relationships in many places suggesting complex tectonic events as well as similar origin of the brittle structures of the Dumne rocks (Yusuf et al., 2020).

These deformational phases relate to pre-tectonic, syn-tectonic and post-tectonic events of the Pan-African orogenic cycle which affected the entire basement complex rocks of Africa (Baba, 2011). The pre-existing rocks were converted to migmatite and gneisses before and during tectonism by D1 event with consequent development of foliation and lineation which generally trends NE-SW direction. The D2 event marked the development of ductile structures such as folds whereas the D3 event was typified by the large-scale development of brittle structures such as fractures, veins, joints and faults having striking directions corresponding to N-S, NE-SW, NNE-SSW and lesser ENE-WSW. Joseph (2016) identified similar features in the Mubi-Hong area and inferred that the structures are conduits for the flow of mineral charged hydrothermal fluids. The Dumne baryte-fluorite mineralizations were therefore observed to be structurally controlled as all the deposits formed as fracture and pore-space filling

minerals in the dominant N-S, NE-SW and ENE-WSW structural features.

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