IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)
e-ISSN: 2321–0990, p-ISSN: 2321–0982.Volume 5, Issue 4 Ver. III (Jul. – Aug. 2017), PP 01-12
www.iosrjournals.org

Structural Deformational Features of Sugu Hills and Environs Adamawa Massif, Northeastern Nigeria

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Abstract: *This work presents the structural deformational features of Sugu Hills and environs. The study area falls within the northern sector of Nigerian Basement Complex called the Adamawa Massif. Gneisses and granitoids with some minor acidic and basic intrusions characterize the area. These rock units are Basement Complex rocks, which formed during the pan African thermotectonic event (600 ±150 Ma). The granitic rocks are similar to those found in the Hawal Basement Complex north of the study area. The mapped faults in the area show a conjugational relationship, which dominantly strike in the NE and NW direction, the conjugational zones are were aquifers abound. Paleostress analysis of some conjugate faults show stress directions that initiated fault propagation in the NE (60^0) with low angle plunge, and NW (N80^0) with high angle plunge. Bulk strain analysis using Fry plot also show a NE and NW orientation of the strain ellipsoids. Field evidences indicate the study area is part of a larger shear zone namely the Jos-Adamawa Basement block and probably the Central Africa Shear Zone (a wrench fault system) in the neighbouring Cameroun Republic. Structural trends in the area are in geologic consistency with those observed by earlier workers in the southern sector of the Adamawa Basement Complex (Obudu Massif). This work presents the first attempt at structural investigation of part of the northern sector of Adamawa Massif in Nigeria.*

Key Words: *Bulk strain, Sugu Hill, Shear zone, Conjugate faults and Adamawa Massif*

Date of Submission: 12-07-2017 Date of acceptance: 10-08-2017

I. Introduction

The study area lies within longitudes 12^0 $02'$ - 12^0 $06'$E and latitudes 8^0 $15'$- 8^0 23'N, covering an area of about 103.68 km^2. The area falls within the eastern sector of the Nigerian Basement Complex called the Adamawa Massif (Fig. 1). The Massif is bounded by the Yola Trough (sub basin of Benue Trough), to the north, the Benue Trough to the west and the Mamfe Embayment (another sub Basin) to the south. The Massif extends beyond Nigeria in to Cameroun. The rocks of the Massif have been shown to belong to the Nigeria Basement Complex [5]. These are predominantly metamorphic rocks, intruded by Pan African granitoids. The Nigerian Basement Complex is said to be polycyclic. The evidences show in the polyphase deformations, which abound in the area. The Pan African granites in Nigeria evolved during the Pan African (thermotectonic) orogeny, which involved intrusion, uplift, fractionation, faulting and high level magmatism resulting in granitic intrusion [15]. [13] Reported the occurrence of granodiorites, migmatite, porphyritic granite and fine-grained granite in the Adamawa Massif. These are all rocks of Pan African Orogeny (600 ± 150 Ma). Tertiary volcanic rocks belong to the Cameroun Volcanic line and their emplacements follow well-defined structural pattern similar to the trend of the Benue Trough and its sub basins. These rocks are found in the Adamawa Massif as basalts and related rocks. This work seems to be the first attempt at structural investigation of part of the northern sector of the Adamawa Massif. Such attempts have been made on the southern sector of Obudu Plateau by [7]. [20] did an analysis of lineament of Obudu and Oban areas from the structural geological stand point. Other works on the Southern (Obudu Plateau) massif have been largely on the geology [5, 8]; others are in hydrogeology/ engineering geology in Obudu area e.g [4]. In this work, data acquisition was done by lithological/ structural mapping. Paleostress analysis, bulk strain determination, and assessment of geotectonic environment from shear sense indicators are done. Structural synthesis of data and relating the results to other sectors of the Nigerian basement terrains have been done.

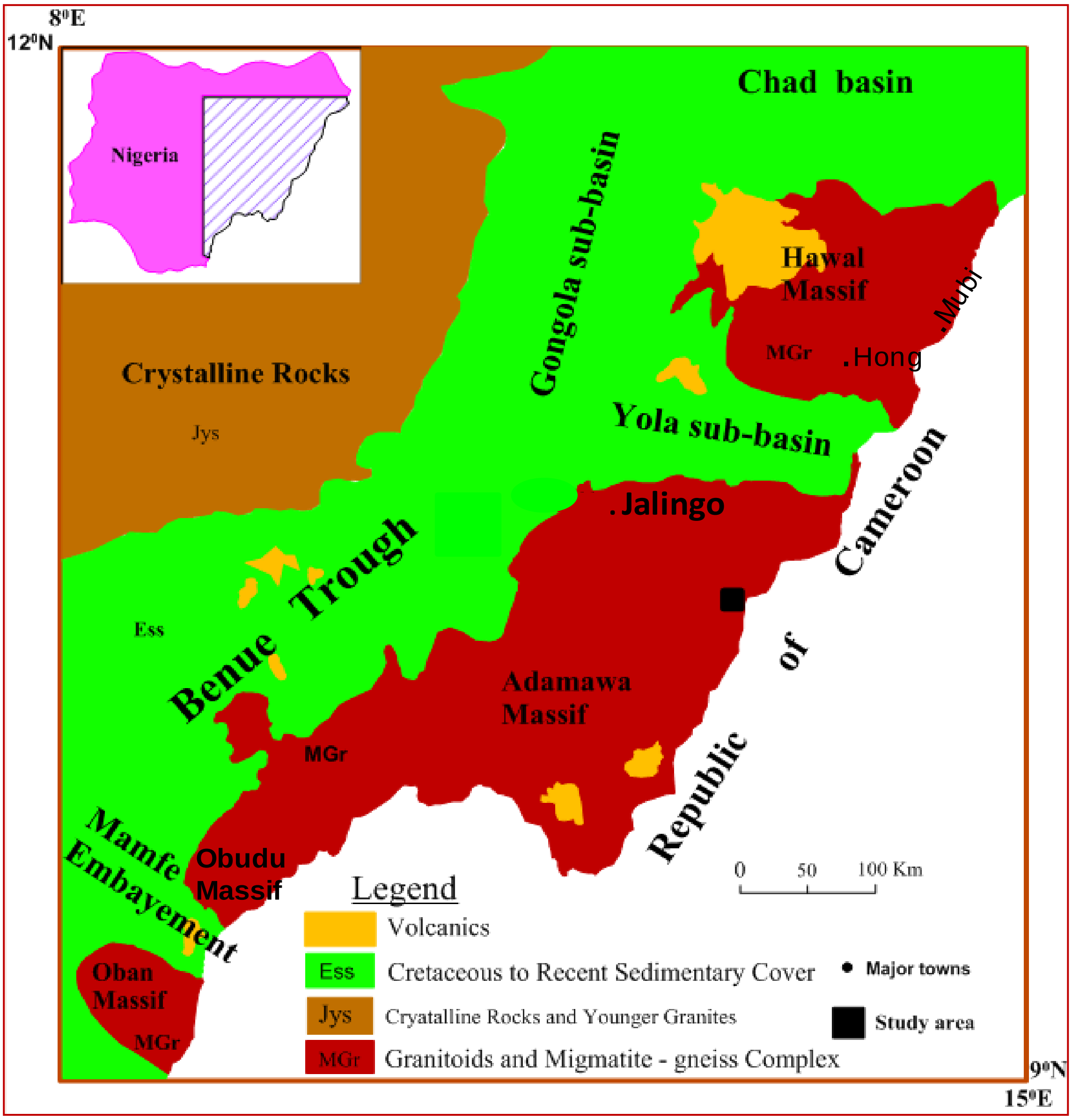

Fig. 1: Regional geological map of Nigeria's eastern Basement Complexes, showing location of study area. Adapted from: Haruna et al., (2011)

II. Lithologies

The main rock groups in the study area are gneisses and granitoids, while the basic, acidic intrusive and alluvial deposits occur as minor rock groups (Fig.2).

2.1 Gneisses

The Gneisses are the oldest rock group but are exposed in relatively few locations. They consist of fine-grained Porphyroblastic gneiss. The Porphyroblastic gneiss is exposed at N8^{0}20' 44.6", E12^0 3' 35.1" (but at unmappable scale) along the NE flowing river (west of Kangesa hill) where it foliation strikes NE and dips between 24-32^0 NW (Fig.2). It is well exposed in the central part of the study area near Sakamidere, see Fig.2, (N08^0 19' 0.4", E12^0 03' 34.3"). The porphyroblast vary in grain size from 0.9-3.1cm, and have well defined strain ellipsoids of quartz and feldspar. The foliation here is near horizontal. The alignments of the strain ellipsoids define the foliation. The rock is intensely jointed with the joints striking N-S, NE and NW. The rock grades to the fine grained variety uphill (Kangesa hill) but with the quartz and feldspar porphyroblast still prominent. This change in grain size indicates increase in metamorphic intensity from the hill towards the river valley. SE of Batal Fulani, the Porphyroblastic gneiss has large porphyroblasts with foliation attitude N90^0,

18^0N. South of Daka hill are exposures of granites gneiss. The foliation attitude on this rock is N70^0, 30^0 NE. Here an acidic dyke concordant to foliation intrudes the rock.

2.2 Granitoids

The Granitoids are found as intrusions in the metamorphic rocks. They consist of pegmatitic variety which outcrops at Sugu Hill (N08^0 22' 40.2", E12^0 03' 47.4") and Daka, the coarse-grained variety outcrops at Jakusum in the southern of study area and the tectonized granite (*fault rock*) found southwards at Bisher hill (N08^0 17' 11.3", E12^0 04' 34.7") and west of Dantaba. The pegmatite granite has large grain sizes, which vary from 1.2 – 3.7cm. This rock is similar to the ones observed by the first author in Hong and Mubi areas of the Hawal Basement Complex to the north of the Yola Trough. The coarse-grained granite outcrop largely at the SW on Jukusum hill (N08^0 16.5', E12^0 3.14'). Mineralogically the rocks is similar to the pegmatite granite but with textural variation (smaller grain size). The tectonized granite is so named because the rock has lies within a tectonic (fault) zone, where the rock is granitic mineralogically but tectonized by faulting. The faults impart a foliation to the rock marked by deformed quartz and feldspar (ellipsoids). The foliation is vertical with a strike of N64^0. The tectonic trend is traceable to part of Jukusum hill southwestward. Minor rock units exist as basic intrusions (dolerite dyke) and acidic intrusions (quartz veins) in both the metamorphic rocks and granites. The granitoids were emplaced in the metamorphic Basement Complex during the 600 ± 150 Ma Pan African Orogeny (Kennedy 1965). The dolerite dyke intrusions marked the last phase of this orogenic event as reported by [8].

2.3 Alluvial deposits

Alluvial deposits of clay, sand, gravel and cobbles constitute recent sedimentary deposits in the area and are restricted to river channels (Fig.3a and b). The sedimentary sections are well expressed along the river NE of Bijiri, where a section of about >2m in thickness is seen (Fig.3c). The section is well-stratified cross-bedded unconsolidated sand. The alluvial sediments are derived from the basement complex hills by river erosion and deposition. Magnetite occurs with the alluvial sands along the channel near Biriji. They are eroded from the granitic Sugu hills placing the rocks in the magnetic – series granites [9]. The study area has a major portion (>70 percent) covered by weathered (mantle) material. Since the underlying geology could not be accessed in such places (this work was based on surface exposures/outcrop), they are tagged as undifferentiated basement.

III. Deformational Features

3.1 Faults

Attitudes of 25 faults were measured in the field. These are presented in Table 1. Many of the measurement were made in fault zones consisting of several fault planes. Many rivers/streams are fault controlled –see: Fig.4. An attempt was made to study the orientation of principal Paleostress directions from attitudes of conjugate faults (2 sets) along the SE flowing river near Bisher hill (Fault No 5 in TABLE 1). The faults are found in coarse-grained granite. The Paleostress determination was done by stereographic analysis following the technique presented by [19]. The stereograms are presented in (Fig.5a and b) and the results are presented in TABLE 2. Summarily the direction of slip of fault is mainly NE with only one in the N-S direction. The maximum paleostress orientation for conjugate faults set (a) is NW (N80^0W) at high (65^0) angle plunge, hence the sense of slip is vertical i.e. normal fault. For set (b) it is NE (N60^0) with low angle (23^0) plunge, hence the sense of slip is horizontal (strike slip). This possibly explains why the granitic Bisher hill is tectonized and the fault that affects it is NE in orientation. It also explains the NE orientation of the fault that controls the river north of Bisher hill. The minimum Paleostress are NW with low (38^0) angle plunge, and N-S with low angle (05^0) plunge also. Joints are common in the area but they were not mapped because of their ubiquitous.

3.2 Folds

Low amplitude (open) and high amplitude (tight isoclinic) folds were observed, but only the picture of the latter is presented here (Fig.6a), the field sketch of the low amplitude fold is shown in Fig.6b. The low amplitude fold is a quartz vein in host granite near Bisher hill (N08^0 17' 02", E12^0 04' 18"). The folding of the quartz vein is attributed to the late phase of Pan African deformation, the fold axis trends N-S, a pan African deformational direction. [27] Have reported axial planar foliation of N-S orientation in the crystalline complex of Obudu area. The second fold in gneiss is also a quartz vein. The foliation in the gneiss is axial planar. Other folds can be inferred from the presence of dipping foliation such as found at riverbank near Kangase hill (see geologic map). The attitude of the foliation is N64^0; 32^0NW.

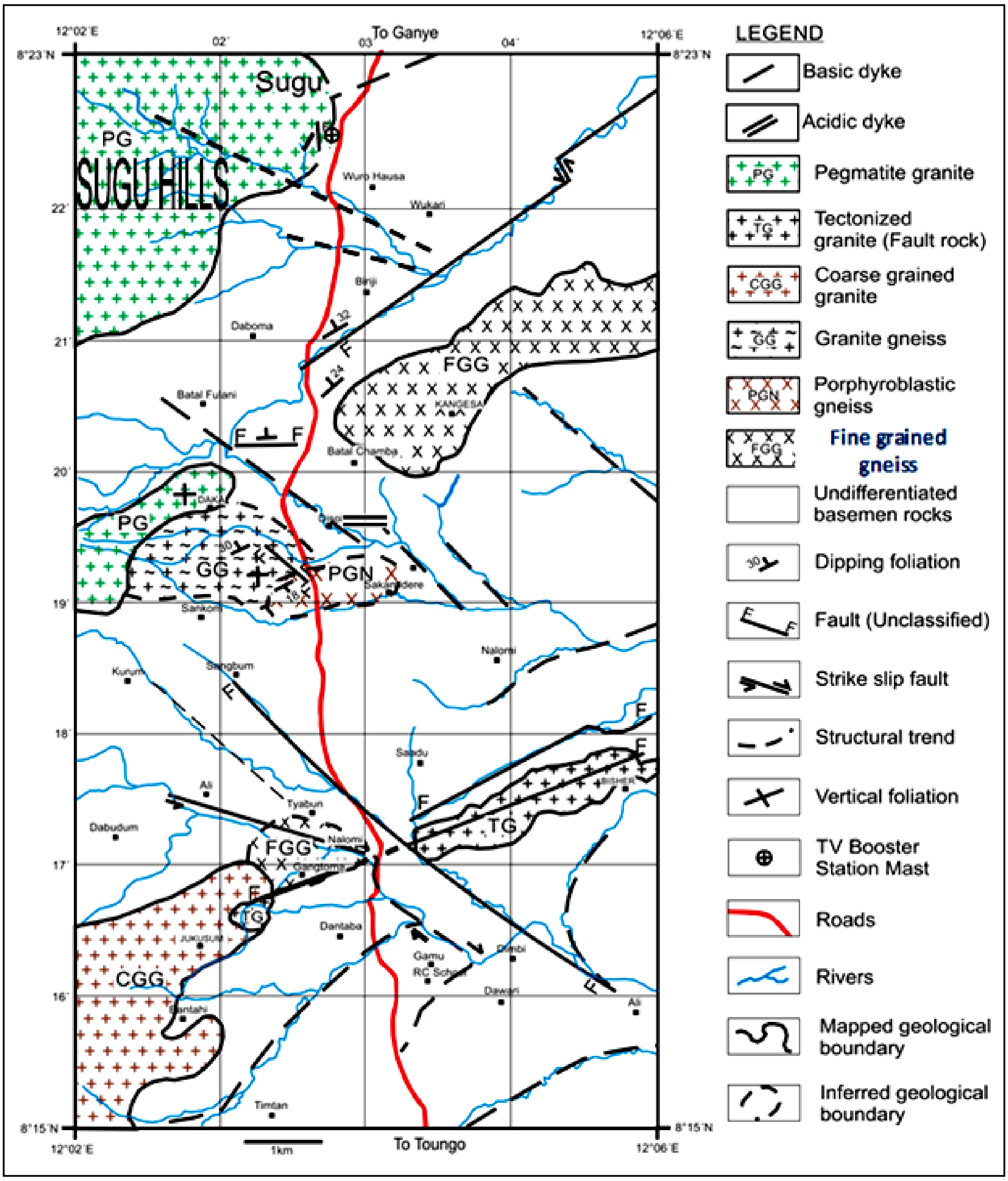

Fig.2: Geological map of Sugu hills and environs

3.3 Dykes

Few dykes were observed in this survey. Their emplacements are controlled by earlier geological structures (foliation and fault). Near the TV (Adamawa Television) booster station at Sugu hill a dolerite dyke is found at geographic coordinates N08^0 22$'$ 40.22$''$ and E12^0 03$'$ 47.4$''$. This dyke has a width of about 12 cm (Fig.6c) and exposed length of about 30m. It strikes in the N-S with vertical dip (see; Fig.6c). The dyke intrudes a fault zone, and the host rock is pegmatitic granite. At Tyabun village (N08^0 17.3$'$, E12^0 3.14$'$) another dolerite vertically dipping dyke is found. It has an exposed width of 1.4m. The host rock is gneiss. The dyke is emplaced along foliation direction of the gneiss and relicts of the host rock are seen in the dyke, as xenolith .The attitude of dyke is N50^0, 90^0. Near the plains of Disol in the central part of the area (N08^0 19$'$ 48.2$''$, E12^0 03$'$ 10.3$''$) a fine-grained acidic dyke intrudes the granite gneiss along foliation direction (N70^0, dip 30^{0}NE). The strike of the dyke is N80^0 with dip 90^0.

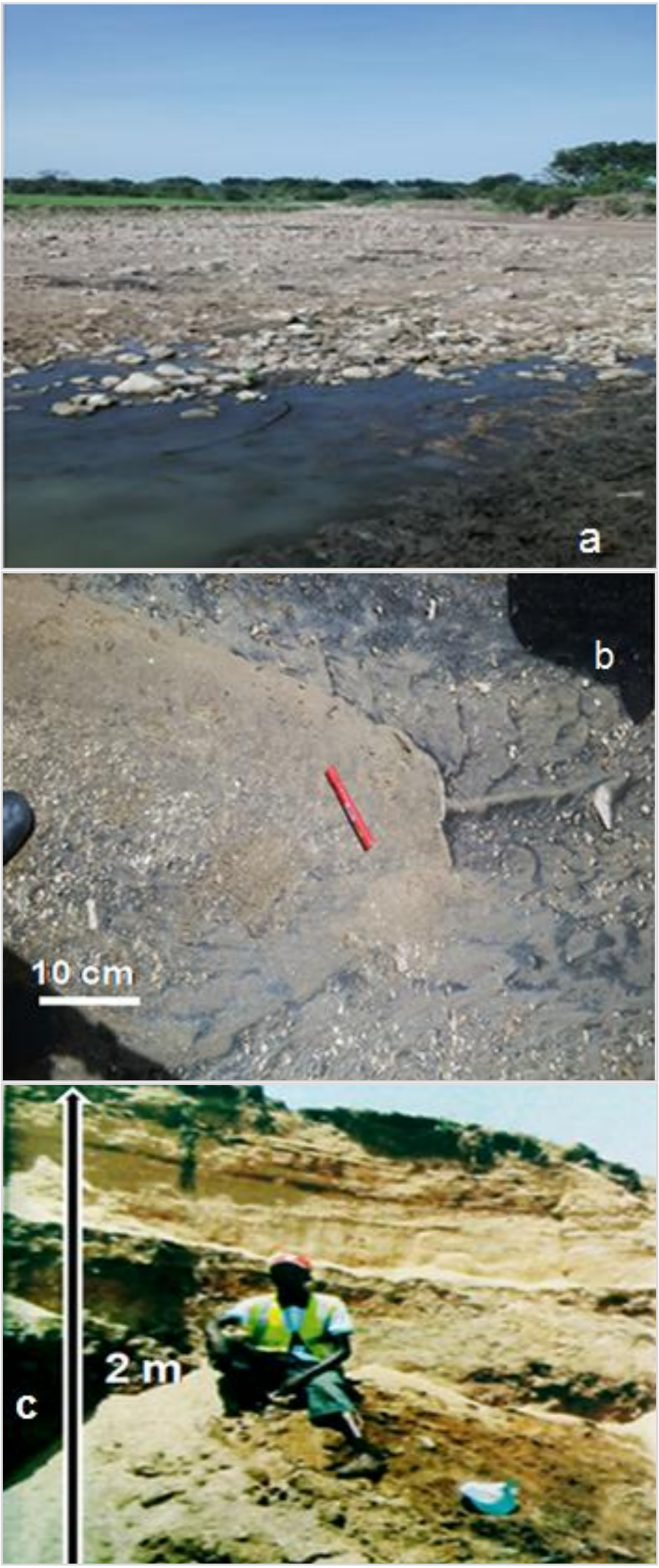

Fig. 3a Alluvial deposits of sand and gravel, (b) Cobbles and (c) Sedimentary section along a river channel in the study area.

Fig.4: Fault zones and fault controlled river channels.

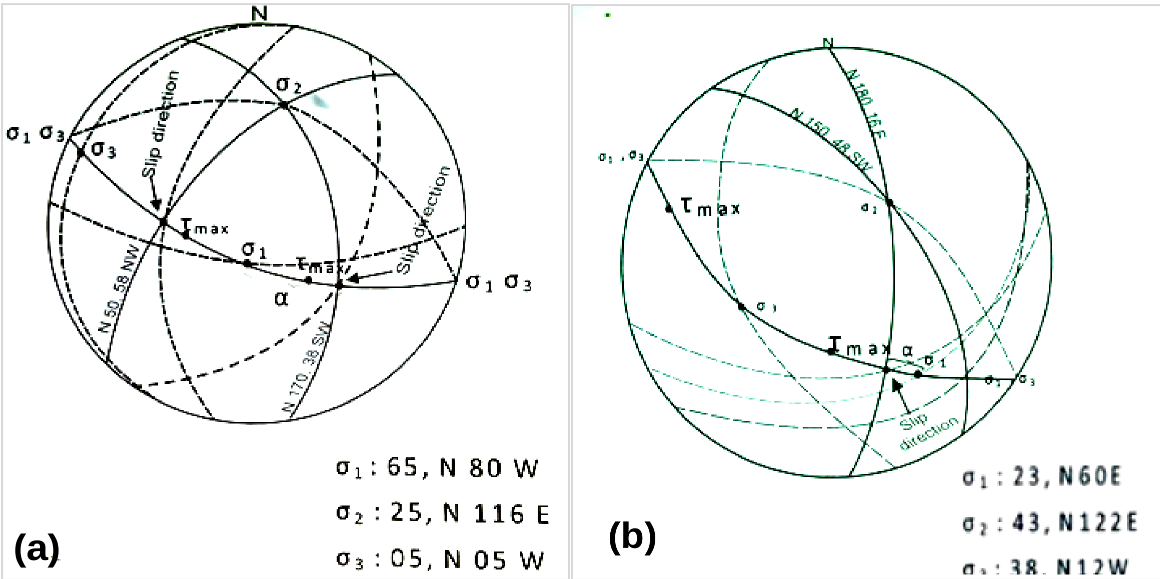

Fig. 5a and b: Stereograms of paleostress analyses from two sets of conjugate faults near Bisher hill (See Table 2 for results)

IV. Strain Analysis

Strain estimates have been done to determine bulk strain and to interpret correctly the extent of deformation on some of the rock types. Not all rocks mapped could be analysed due to some constraints faced during the field exercise. The rocks analysed are pegmatitic granite (at shear zone), granite gneiss and porphyroblastic gneiss. According to [12] most strain estimate methods require the measurements of the long and short axes of deformed objects or strain markers. In the present work, the *Fry method* [10] is used and is based on the assumption that initially uniform anti-clustered distribution of points will change after deformation into non-uniform distribution. Similar work was done by [11] on the bulk strain estimation on gneisses in central Nigeria. In this method, centres of all grains are digitalized on the field photographs of the rocks using software

(GeoFry Package), which creates a vacancy called *fry halo* of ellipsoidal shape, which yields directly the long and short axes. The orientation of an ellipse also gives the orientation of the strain ellipsoid. Consequently, the finite strain ellipsoid that is almost circular shows low degree of grain deformation.

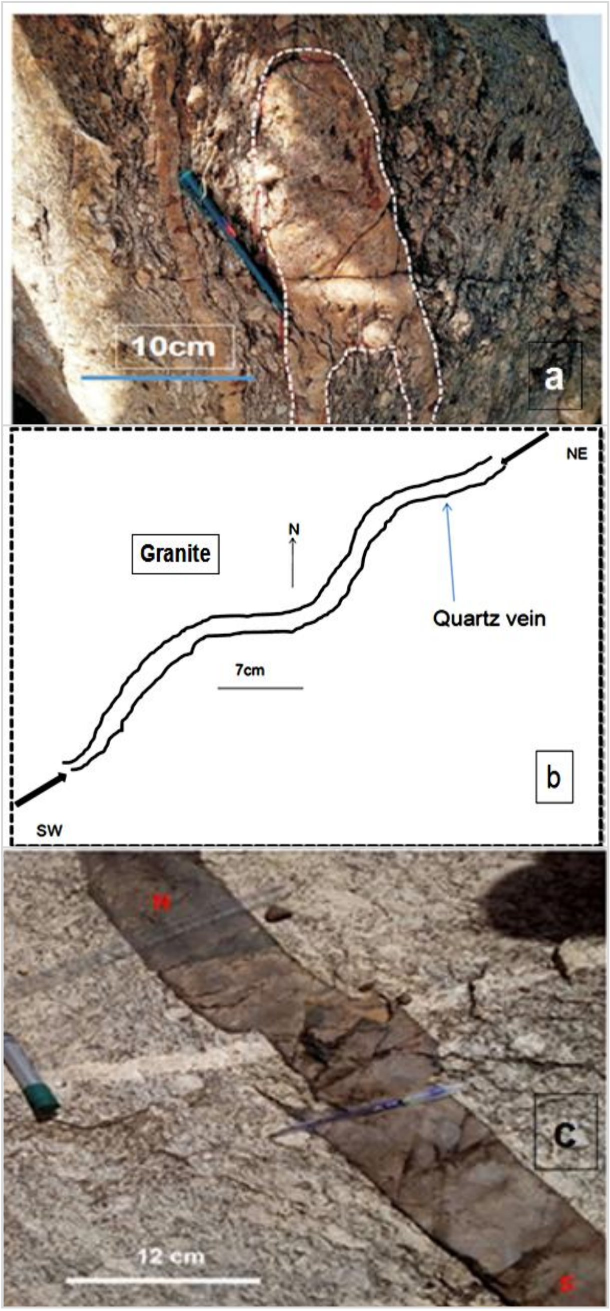

Fig.6 (a). Isoclinic fold in gneiss, (b) Field sketch of low amplitude - open fold of quartz vein in granite at the foot of Bisher hill and (c) Dolerite dyke in pegmatitic granite at Sugu hill

Of the three rock samples analysed, the granite gneiss near Disol (N8^{0}19$'$48.2$''$, E12^{0}03$'$10.3$''$) shows the highest deformation with axial ratio: 2.95 and a flattened ellipsoid oriented WNW-ESE (Fig.7a). At intermediate level is pegmatite granite at a shear zone at Sugu hill (N08^0 22$'$ 40.2$''$, E12^{0}03$''$47.4$''$) with axial ratio 2.82 oriented NNE-SSW (Fig.7b). The least deformed rock is the porphyroblastic gneiss along the river near Tyabun town (N08^{0}17.3', E12^0 3.14$'$) with axial ratio 1.55. This has a near circular ellipsoid oriented NW-SE (Fig.7c). The study of shear sense indicators will determine the geotectonic environment. Shear sense criteria in the field take the forms of pressure shadows on porphyroclasts, helisilic inclusions, displaced quartz veins and rolling structures. In the present study, rolling structures occasioned by extremely elongate pressure shadows were used as shear sense indicators in the gneiss at Kangesa hill. The photo illustration is shown in Fig.8, which shows dextral shear sense.

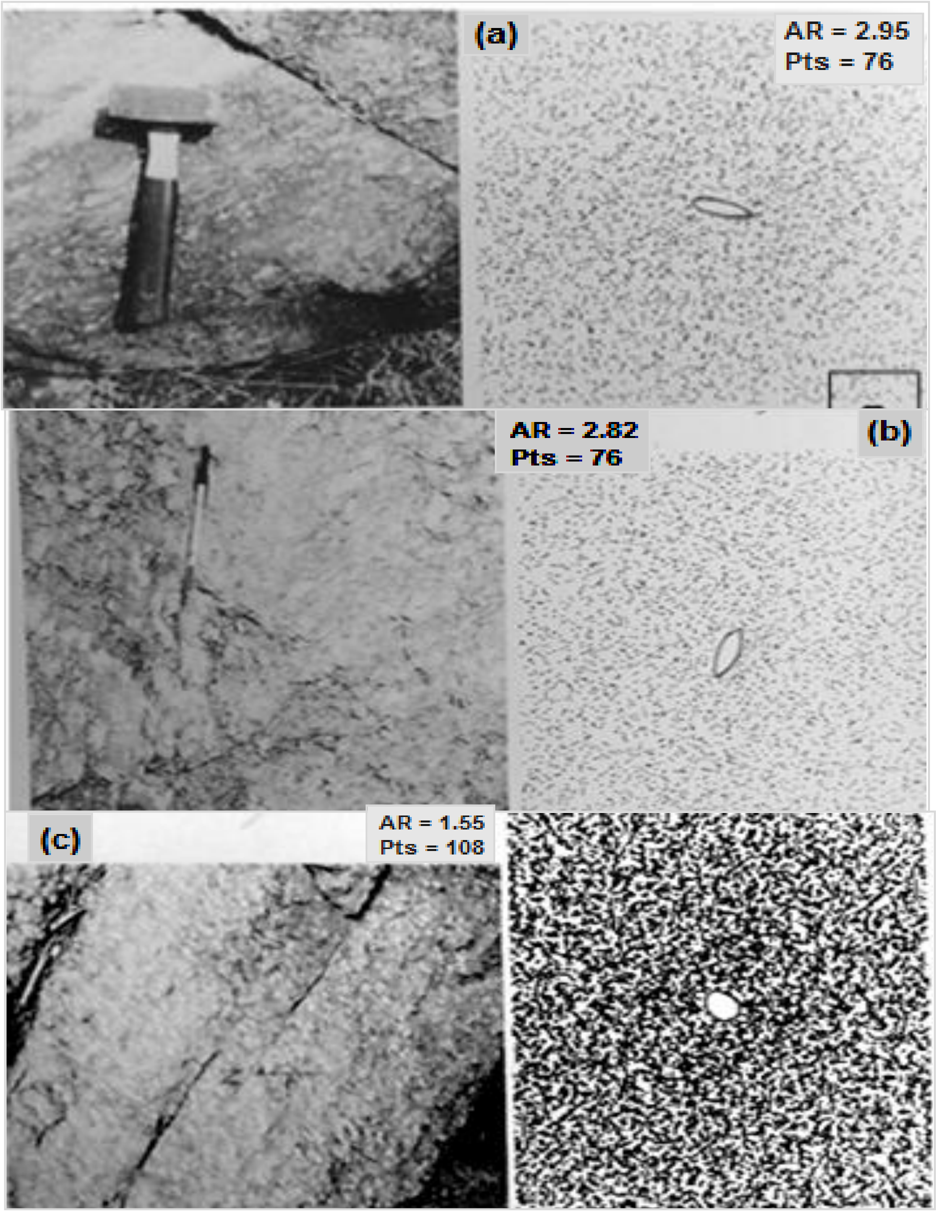

Fig.7: Fry haloes generated from pictures of rock samples in study area. AR is axial ratio, Pts: Points

V. Discussion

The area of study is part of the polygenetic Basement Complex of Nigeria, which has witnessed magmatism, metamorphism and structural deformations of brittle and ductile types. Faults are common brittle features and exercise control over several rivers. Some control emplacements of dykes. Of the mapped faults the major trends are NE (40-60^0), NW (120-140^0) and NNW-SSE (160-180^0), see Fig.2. [7] Reported that some dolerite dykes are associated with faults in Obudu area. This observation applies to the fault at Sugu hill near the ATV booster station, NW of study area. Here the dyke (N40^0, 90^0) is displaced by a N-S striking fault. Some faults predate the granitic rocks and were possibly reactivated after granite emplacements. The conjugate fault systems found at Nalomi, Disol, Biriji e.t.c are considered to be part of a regional conjugate lineament system that control the flow of River Benue in Yola area [1,2]. The conjugational zones of the faults are areas of high human population in the study area because they serve as groundwater conducts producing high yielding aquifers, which are abstracted by hand, dug wells and bore holes. Such areas are Nalomi, Gamu, and Dimibi in the South. Sakamidere, Disol in the central part Bijiri, Wuro Hausa in the north.

Fig.8 (a) Shear sense indicator (dextral shear) in gneiss in study area, (b). Regular layering of constant thickness in gneiss as an indication that the study area is part of a shear zone, such layering is also seen in (a)

[21] Mapped more NE and NW diagonal lineaments than any other fracture trends in the Nigeria Basement Complex. He said that fracturing is more intense on the Cameroon flank of the country (present study area inclusive) than other part of the country. This may be attributed to the Tertiary Cameroun Volcanic Line magmatism in which magmatic extrusion produced widespread fracturing of the rocks. The predominance of NE and NW structural trends has also been reported in Obudu area (Southern Adamawa Massif) by [20, 27]. [23] Was of the view that NW and NE conjugates represent strike slip faults. Several strike slip faults have observed in the area (See TABLE1). [17] used *Hilbert transform* (a geophysical processing tool) on residual magnetic data over Jalingo and Environs (a predominantly Basement Complex terrain within Adamawa Massif) to generate analytic signal map. He also reported preponderance of northeast trending magnetic lineaments followed by easterly and northwesterly lineaments. He also said that these lineaments have surface expressions as stream channels. The paleostress analysis has enabled us to see the orientations of principal paleostresses directions, directions of slip and slip angles of fault types (TABLE 2). The folding of quartz vein (open fold) in granite in Bisher hill is attributed to a late phase Pan African tectonics. The fold axis trends of N-S is consistent with the observation of [27] who reported that in Obudu area the axes and axial planes of folds are approximately parallel to regional foliation trend of N-S. This is also consistent with trends in northern Nigeria [15, 16, 24] and southern Nigeria [22]. The presence of dolerite dykes is also evidence of late Pan African tectonics [8].

Northwest orientation of strain ellipsoids near Disol and near Tyabuu is in line with northwest striking faults and the structural trends in these places. At Sugu hill the NE orientation of the strain ellipsoid aligns with the NE striking basic dyke. The presence of brittle structures (faults and joints) and ductile features (folds and foliation) indicate that the Pan African thermotectonic attained low temperature, low-pressure, and high temperature, high-pressure conditions in the area. The shear deformation observed is an evidence of brittle – ductile transition. The presence of dipping foliations is pointer to the existence of synclinal structures in the area. A good example of the dipping foliation is in gneiss at River bank near Kangase hill (N64^0, 32^0NW). The synclines are common in the metamorphic complex in Nigeria. The shear sense indicators in gneiss of Kangesa hill indicate that the study area is part of larger shear zone. According to [25] Isoclinal folds develop in shear zones. The authors also said that an unusually regular layering of constant thickness in gneisses is also a factor in recognizing shear zones. This is evident in Fig.8b. Here the quartz – feldspar layers are interspaced with the melanocratic matrix. [9] Working on Solli hills (a part of Nigeria's north central basement with Jos Plateau at centre- Fig. 9) said that Pan African granite plutons are closely associated with the activity of dextral shear zones. They also said that the late Pan African emplacement of the Solli hills pluton is indicated by the localized nature of NNE-SSW dextral and strike slip shear zone. Probably the study area is structurally related to the northern Nigeria Basement named by [9] as the Jos- Adamawa block (Fig. 9). It could also be regionally related to Central African Shear Zone (CASZ) which is a wrench fault system in Cameroon (Fig.9.) found to the east of Nigeria, extending in an ENE direction from the Gulf of Guinea [14] through Cameroon to Sudan. The CASZ dates back to at least 640 MA (a Precambrian age as the rocks of the present study area) [3]. In Cameroon, the CASZ cuts across the Adamawa uplift (massif). The area of study has experienced high strain rate based on the rolling nature of the porphyroblasts (Fig.8a) and the presence of isoclinals folds. Economically the cobbles, gravel and sand are exploited in the local construction industry while the clay deposit can be exploited for pottery making.

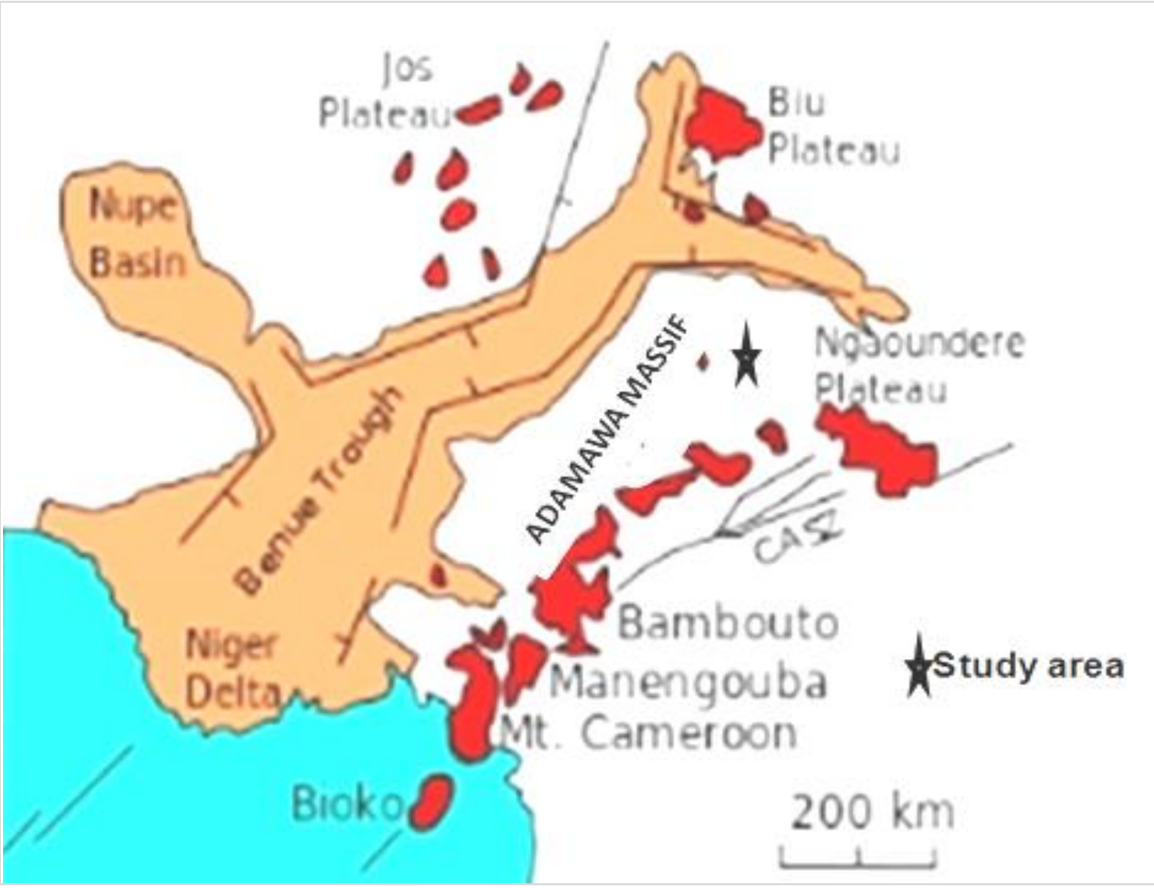

Fig.9. Possible relation between study area and Central Africa Shear Zone (CASZ)

VI. Conclusion

Hitherto publish geological information of the northern massif have been largely on lithologies, geo-hydrology, or economic mineral occurrences. This work has revealed some aspects of the structures, lithologies, tectonics, and structural history of this part of Adamawa Massif. Faults mapped are predominantly in the NE, NW and NNW directions. Some faults served as emplacement zones for dykes, and conjugational zones of faults serve as major groundwater accumulation zones, which support large human populations than other areas. The maximum paleostress direction are NE with low angel plunge and NW (N80^{0}W) at high angel plunge. Presences of folded quartz vein and dolerite dykes are attributed to late phase of Pan African tectonics. Preliminary strain analysis shows granite gneiss has highest degree of strain. The strain in the area is heterogeneous but more pronounced in the gneisses. Alignment of strain ellipsoids accords with NW and NE trends of structures. There is evidence to show that the study area is part a larger shear zone likely the Jos-Adamawa basement block and the Central African Shear Zone.

Table 1: Locations and attitudes of faults in the study area

SN	Location (GPS)	Identification Features in Fault Plane	Attitude of Fault Plane		Fault Type	Remark
1	Sugu hill, near ATV booster station (N 08^0 22' 40.2") (E 12^0 03' 47.4")	Fault plane poorly exposed, but fault plane is polished	Strike N170^0	Dip -	Strike Slip	Fault in pegmatite granite served as avenue for dolerite intrusion.
2	West of Batal Chamber (N 08^0 20' 13.6") (E 12^0 03' 15.0")	Slicken sides	N 90^0	18^{0}N	Strike Slip	-
3	River Channel near Tyabuu Village (N 08^0 17.3') (E 12^0 3.14")	Slicken sides/ Striations	i) N100^0 ii) N90^0 iii) N135^0 iv) N60^0 v) N130^0 vi) N180^0 vii) N128^0	Vertical ,, ,, ,, ,, ,, ,,	Strike Slip	Fault zone, with direction of movement based on orientation of majority of faults is NW-SE, fault zone controls river channel.
4	North of Kangesa hill (N 08^0 20' 49.8") (E 12^0 03' 42.6")	Striations	i) N120^0 ii) N40^0 iii) N140^0	Vertical ,, ,,	-	Fault zone, faults control NE flowing river, and probably controls SE flowing river in Kangase hill area.
5	SE flowing river south of Bisher hill (N 08^0 17' 02") (E 12^0 04' 18")	Slicken sides, presence of breccias between fault planes	i) N50^0 ii) N170^0 iii) N80^0 iv) N50^0 v) N70^0 vi) N01^0 vii) N20^0 viii) N135^0 ix) N180^0 *x)* N150^0 xi) N40^0 xii) 180^0	58^{0}SW 38^{0}SW 36^{0}N 60^{0}NW 32^{0}NW 51^{0}E 90^0 90^0 61^{0}SE 48^{0}SW 90^0 43^{0}E	}conjugate set }conjugate set	Fault zone which extends > 7km, controls river flow between Sangbuu and Ali towns. Fault types: normal, strike slip.
6	Bisher hill (N08^0 17' 11.3") (E12^0 04' 34.7")	Polished surfaces broken slabs, breccias	N50^0	90^0	Unclassified	Fault zone, faults have crushed the granite resulting in slaps and boulders
7	Jukusum hill (N08^{0}16.5'), (E12^0 13.4')	Polished surfaces broken slabs, breccias	N50^0	90^0	Unclassified	Similar remark as at Bisher hill. This fault is a continuation of the Bisher hill fault zone.

Table 2: Paleostress Orientations from Conjugate faults on Bisher hill area.

SN	Conjugate Fault		Principal Paleostress Orientation			Direction of Slip	Slip Angle	Remark
	Strike (degree)	Dip (degree)	σ_1	σ_2	σ_3			
1a	N180	61E	23,N60E	43,N122E	38,N12W	N 56 E	31	σ_1 <45^0, Displacement is largely horizontal i.e. strike slip
2b	N150	48 SW				N 74 E	13	
2a	N50	58NW	65,N80W	25,N116E	05,N05W	N 05 E	40	σ_1 >45^0, Displacement is largely vertical i.e. normal fault
2b	N170	38SW				N 40 E	36	

Acknowledgement

The authors acknowledged the people and community head of Sugu area for their cooperation during the field mapping exercise as well as the Provost and Registrar for College of Agriculture Ganye for providing accommodation within the campus.

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