Classification and Provenance of Lower and Upper Cretaceous Sandstones of the Bornu Basin, Ne Nigeria

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ABSTRACT

Representative sandstone samples from different formations such as the Bima Group (Lower, Middle and Upper Bima Sandstones), Yolde Formation and Dumbulwa Member of the Pindiga Formation in the study area were classified on the basis of their mineralogical compositions for sandstones. Samples 4, 5, 7, 24, 27, 28, 34, 35, 36, 38, 40 and 41a are classified as arkosic arenites due to the high percentage of feldspars and quartz than rock fragments in majority of the samples, whereas samples 12, 21, 25 are classed as lithic arenites because rock fragments have higher mineral aggregate than feldspar. The compositional maturity of the sandstones was identified, the matured is composed of arkosic arenites and the immature ones are related to lithic arenites.

Keywords: Classification, provenance, sandstones, Cretaceous, Bornu Basin,

INTRODUCTION

The study area, which is part of the Nigerian sector of the Chad Basin (Bornu Basin) is the largest intracratonic basin in Africa (Obaje *et al*., 2004) covering an area of about 2,335,000 km^2. The Chad Basin straddles five countries, namely; Nigeria, Cameroon, Chad, Niger and Central African Republics. Approximately one- tenth of the surface area of the Chad Basin is in northeastern Nigeria, bounded to the east by the Northern Highland (Mandara Mountains) and to the south by the Benue Trough and Biu Plateau Basalts. The Chad Basin lies between Latitudes 11^{o}N and 13^{o}43'38"N longitudes 8^{o}21'49" and 14^{o}22"E. It forms part of the Western and Central African Rift System (WCARS) that was formed during the separation of African crustal blocks in the Cretaceous and belongs to the West African Rift Subsystem (WAS) (Genik, 1992, 1993). The West and Central African Rift Systems have attracted much attention from the oil industry because the Cretaceous sedimentary basins are deep, extensive; have formed along zones with enhanced geothermal gradients, and have been blanketed by thick Cenozoic sediments which might have further aided its hydrocarbon maturation.

Discovery of "oil and gas" in the Chad Basin (Chad and Niger) in the 1970's have given rise to exploration activities in the Bornu Basin. Such discoveries are based on the occurrences of oil and gas "shows" in the eastern and western parts of the Chad Basin in the neighbouring Chad and Niger Republics (Petters, 1981; Whiteman, 1982; Genik, 1992, 1993). Whiteman (1982) stated that, there might be prospect for hydrocarbons in structures located within the zone of interdigitation between marine and non- marine facies, especially in Turonian rocks which were laid down when the south of the Bornu Basin was connected via the Gongola Trough with the Benue Trough.

The study area is located in the southwestern part of the Nigerian sector of the Chad Basin (Bornu Basin) (Fig. 1). The area falls between Latitudes 10^0 52'3"to 11^0 15'N and Longitudes 11^0 37'30"to 12^0 E, Mutwe sheets 110 SW, and part of Mutwe sheet 110 SE and parts of Gulani sheets 132 NW, NE, covering a total area of 1640.5 km^2 insert Fig.1: Location map of the study area. The study area is accessible through tarred and untarred road from Kukuwa Gari to Bara, and most other locations accessible through footpaths and untarred roads.

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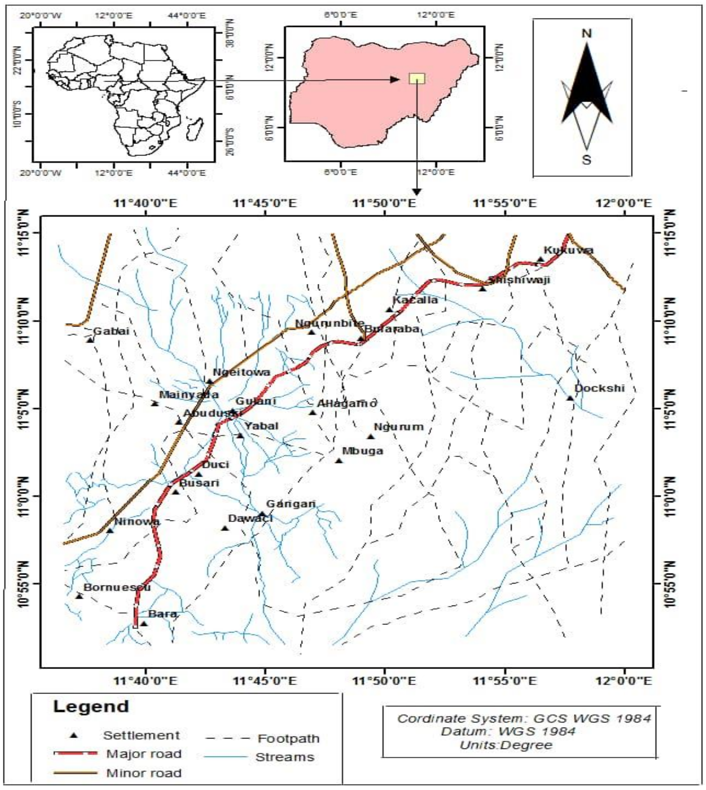

Fig. 1: Topographic map showing the location of the study area

Lithostratigraphy and Depositional Environments of the Bornu Basin

Bima Sandstone (Albian- Turonian)

Sedimentation began in the Bornu Basin in the Albian (?) times with a continental, sparsely fossiliferous, poorly sorted, medium to coarse- grained feldsathic sandstone, which unconformably overlies the Precambrian Basement (Carter *et al*., 1963). Okosun (1995) reported that the formation consists of thin to thick beds of fine to coarse- grained sandstone of variable colours ranging from white, brown, reddish brown to gray, and the coarse textures are more common towards the bottom of Kinasar-1 well. Hamza *et al*. (2012) reported a strata with a thickness of 45m in Tuma- 1 well which corresponds to the Bima Sandstone, while the lower part of “Formation 1” in Murshe- 1 well also related to the Bima Sandstone. Mohammed (2010) reported a thickness of 30m from Kanadi- 1 well which is moderately sorted, fine- medium grained and dark brown in colour. Avbovbo *et al*. (1986) reported seismic sequences to represent the Bima Sandstone. They described sequence la as their lower sequence to be the deepest in the Bornu Basin with upper boundary varying from toplap to concordant, suggesting a variation from an unconformity boundary to a conformable strata surface. The lower boundary which presumably rest on the basement is marked mainly by baselap. A seismically transparent pattern indicative of possible continental fluvial sands with alternating high and low energy suggests paralic deposit.

Avbovbo *et al*. (1986) further stated that the boundary relation between sequences below, especially that of the latter was deposited as a marine onlap on top of sequence 1a which is possible to correlate with the Middle and Lower Bima Sandstone of (Carter *et al*., 1963), sequence 1b is said to have a thickness of 3000m with a monolithic characteristic facies. Sequence 2 of Avbovbo *et al*. (1986) corresponds with the Upper Bima Formation with alternating high and low amplitudes reflection patterns exhibiting divergent configuration indicating active differential subsidence contemporaneous with deposition. There is more than 3000m thick of sediments and seismic data suggests fluvial environment of deposition, but having facies changes towards the edge of the basin and that the sequence is presumed to be dominantly shale with increasing sand to the northeast, they concluded that the apparent lack of feature as in salt tectonics suggest that the sequence to be shale. Carter *et al*. (1963) reported earlier that the Bima Sandstone is wholly continental in the northern part of the basin, while in the south, shale (marine) occurs in its lower part.

Gongila Formation (Turonian- Santonian)

The Gongila Formation is a transitional sequence between the underlying continental Bima Sandstone in the Bornu Basin, stratigraphic equivalent of Yolde Formation in the Gongola Basin which is overlain by the marine Fika Shale. It is a calcareous shale- sandstone unit, deposited in a shallow marine environment and regarded as transitional facies (Avbovbo *et al*., 1986) or passage beds of (Carter *et al*., 1963) accompanying marine incursion (transgression of the Tethys Sea across the Sahara and the northeastern of Nigeria). The marine incursion which started in Late Albian time reached its peak in the Turonian, during which the entire Benue- Chad axis become inundated.

Carter *et al*. (1963) assign Gongila Village as the type locality of the Gongila Formation, which they divide the formation into an upper sandstone- shale member and a lower limestone- shale member. The lower part of the Gongila Formation consists of limestone, shale and marl and has been dated Cenomanian- Turonian (Popoff *et al*., 1988) and Lower Turonian (Barber, 1957; Obi, 1990). Obi (1990) reported that the limestone of the Gongila Formation at Ashaka Quarry from his mineralogical and petrological studies which reveals that the limestone were deposited under low energy, shallow marine to hypersaline. Okosun (1995) reported that the formation consists of thin to moderately thick interbeds of shale, silty sandstone and sandstone. The shale is gray to dark gray, while the sandstone has variable colours ranging from white, brown, yellow, purple and gray, and has fine to coarse- grained texture. He further stated that volcanic intrusive which occur as diorite sills are seen at several horizons of the formation from Kanadi- 1, Sa- 1, and Wadi- 1 wells. Okosun ((1995) concluded that the shale adjacent to the intrusive have become thermally degraded and are very brittle and soft. Carter *et al*. (1963) reported numerous Cenomanian- Lower Turonian ammonites from the basal limestone facies and dated as Lower Turonian.

The formation corresponds to ("Formation 2") of Hamza *et al*. (2012) which they described as having the first appearance of shaly limestone at a depth of 3240m in Murshe- 1 and 3565m in Tuma- 1 wells, while the upper part of the ("Formation 2") is marked by the first appearance of fine- grained micaceous sandstone or siltstone intercalated with gray to black shale at depths of 3215m in Murshe-1 and 3530m in Tuma-1 wells respectively. Mohammed (2010) reported shale units in Kadaru-1 and Herwa-1 wells which intercalates with silt and sandstone. The formation have thicknesses of 1035m (4705- 3670) m in Herwa-1 and 765m (4980- 4195) m in Kadaru-1 wells with varying colours ranging from blackish brown, dark brown dark gray and grayish black.

Zaborski *et al*. (1997) pointed out that, there is however, some doubt concerning this point while in an event the term "Gongila Formation" is inappropriate for these beds, because they stated that Gongila village itself lies upon the Lower Bima Sandstone. Carter *et al*. (1963) cited the hill near Gongila Village as the type locality of the Gongila Formation. Zaborski *et al*. (1997) went further to say the hill, presumably nearest to the southeast of Gongila village, is made up of Middle and Upper Bima Sandstones overlain by the attenuated Yolde Formation and a sandy limestone, the basal part of the Kanawa Member. This relationship has led to erroneous previous mapping in the Dumbulwa- Bage High. Geological Survey of Nigeria maps {Sheets 25 (Potiskum) and 36 (Gombe)} indicated the Dumbulwa and Bage Hills consisting of the Bima Group, they are infact made up of Dumbulwa Member of (Zaborski *et al*., 1997).

In the light of criticism concerning the name "Gongila Formation" indicated above, it was proposed by Zaborski *et al*. (1997) that the term "Dumbulwa Member" be used for the sandstone and shale sequence in the middle part of the Pindiga Formation in and around the Dumbulwa- Bage High.

Fika Shale (Turonian- Maastrichtian)

During the Turonian, bluish black ammonite rich, open marine Fika Shale was deposited (Carter *et al*., 1963). The formation is occassionally gypsiferous and contains limestone which is very prominent and well exposed around Mutwe Syncline. Okosun (1995) stated that it has a thickness of 890m and that volcanic intrusive (diorite sill) have degraded the adjacent shale to thermally britlle. The sedimentation, resulting from the Atlantic transgression from the south continued into the Senonian. The Turonian- Senonian depositional phase that produced the Gongila Formation and Fika Shale was succeeded by a regressive phase. Marine transgression in the Cenomanian- Turonian inundate large parts of Africa (including Bornu Basin), reaching a maximum extent of about 80Ma (Hartley and Allen, 1994) or approximately 94- 84 Ma (Petters, 1996). The formation is diachronous and has been assigned a Turonian- Maastrichtian age (Carter *et al*., 1963). Mohammed (2010) studied two wells and reported that the formation is moderately sorted with variation in colour ranging from brown, dark brown, dark gray, and black from the top to bottom of Kadaru-1 well and dark brown, dark gray, grayish brown, blackish brown, and black, in Herwa-1 well. They have thicknesses of 1695m (3670- 1995) m in Herwa-1 well and 2550m (195- 1645) m in Kadaru-1 well. The Fika Shale is generally monotonous except where it forms boundary with other formations, or break occurs.

Hamza *et al*. (2012) reported the base of Fika Shale ("Formation 3") which is taken to be the first appearance of whitish gray shaly limestone at depths of 2845m and 2950m in Murshe-1 and Tuma-1 wells respectively. The middle part as "Formation 4" and upper part as "Formation 5" and concluded that the three "Formations" (3, 4, and 5) are the equivalents of Fika Member of (Zaborski *et al*., 1997). Avbovbo *et al*. (1986) reveal from their seismic sections that sequence 4 is characterize primarily by discontinous, low- amplitude seismic facies bounded above and below by conformable strata surfaces. They reported a 500m thickness, with monolithic unit deposited in an environment of uniform energy but increases in sand content to the southwest. Regression led to Maastrichtian- Palaeocene continental sedimentation.

Gombe Sandstone (Maastrichtian)

In the Late Maastrichtian time, a phase of tensional deformation occurred in the basin and continued until the end of the Cretaceous, restructuring the basin with a widespread uplift, arching along the basin axis and creation of an elongate NE- SW graben system (Avbovbo *et al*., 1986). The Gombe Sandstone is believed to be a fluvial- lithoral sequence of sandstone, siltstone, shales, clays, and thin coals beds were encountered in Gombe (Upper Benue Trough) from a well sunk near Gombe Sandstone- Kerri- Kerri Formation boundary were observed at several localities by (Carter *et al*., 1963). Such deposits are common shelf or delta platform environments. Zaborski *et al*. (1997) reported that the formation have been folded, faulted and dissected during the deformational episode. Avbovbo *et al*. (1986) stated that sequence 5 has an angular unconformity relationship with the overlying Tertiary beds while maintaining a conformable boundary with adjacent sequence. They concluded that the sequence is not present everywhere in the basin because of erosion; therefore the thickness ranges from 0- 500m. Similarly, Okosun (1995), Mohammed (2010), and Hamza *et al*. (2012) are of the view that the formation is not present in their studied wells from Maiduguri sub- basin to the shores of Lake Chad.

Folding and deformational events that followed the deposition of the Gombe Sandstone are believed to have commenced in the Late Cretaceous time (Odusina *et al*., 1983) and resulted in the development of large anticlinal and synclinal structures in the Cretaceous rocks. Subsequent erosion removed parts of the Cretaceous- Tertiary boundary (Avbovbo *et al*., 1986; Popoff *et al*., 1986)

Kerri- Kerri Formation (Tertiary)

Overlying the Gombe Sandstone is the continental Lacustrine- deltaic deposits refer to as Kerri- Kerri Formation of Palaeocene age. The formation is unaffected by folding, but dips gently to the north and northeast below the Chad Formation. Okosun (1995) reported that the formation consists of thin and thick beds of sandstone, grits and clays in Dawasa and Damagum boreholes. Carter *et al*. (1963) earlier stated that the sandstones is locally cross- bedded and ferruginized, and that laterite capped the erosional surface towards the top of the formation. The Kerri-Kerri Formation developed as a result of E-W extension (Benkhelil, 1986, 1988); NNE-SSW trending faults occur along its western margin and N-S faults to the east (Adegoke *et al*., 1986; Zaborski *et al*., 1997). The formation is more extensive and varied in the Upper Benue Trough where three distinct lithologies; comprising ferruginous sandstone, kaolinitic sandstone and laterites have been recognized.

The formation is regarded as sequence 6 by Avbovbo *et al*. (1986) and dips at low angle toward the northwest and has a thickness of 350m with parallel to sub- parallel reflection characters. The continental clastic nature has also been described by Adegoke *et al*. (1986) and Dike (1995) with a thickness of 320m. The Kerri- Kerri Formation appears to have been derived from Cretaceous sedimentary rocks where relief was much more subdued (Carter *et al*., 1963). Pliocene and Quaternary eruptive and associated volcaniclastic depositional phases were separated by an interval of weathering and erosion (Turner, 1978; Braide, 1994).

Chad Formation (Quaternary)

Chad Formation is the youngest stratigraphic succession in the basin. In the Pleistocene and probably Pliocene, fluvial lacustrine clays with diatomite and coarse fluviatile sands were deposited. Okosun (1995) reported variable colours of the formation ranging from white, yellow, brown to gray, and that the clay is massive and locally gritty in texture due to the presence of angular to sub- angular quartz grains. Mohammed (2010) stated that the formation unconformably overlies the Fika Shale in both Herwa-1 and Kadaru-1 wells at depths of 1255m and 1250m respectively, with thicknesses of 975m and 925m, and the thickness of sand increases towards the shores of Lake Chad region. The base of the “Chad Formation” is marked by the appearance of fine to medium grained sandstone or sandy clay at depths of 620m and 706m in Murshe-1 and Tuma-1 wells (Hamza *et al*., 2012). The topmost seismic sequence 7 in the Maiduguri sub- basin is characterized by a lower concordant boundary and parallel seismic reflections that dips from 1^o to 2^o northwest, and has an approximate thickness of 150m which is neither folded nor faulted (Avbovbo *et al*., 1986). The formation is at least one kilometre thick in the deeper parts of the basin (Wright *et al*., 1985) and is a product of erosion from the watershed into the Chad Basin accompanied by episodic and sporadic uplift and volcanism (Burke, 1976).

According to Burke (1976), during the Neogene and Quaternary about 0.5km of sediments over an area roughly 500km in diameter has accumulated in the Chad Basin. Towards the end of the Tertiary and until recent times, widespread volcanic activity occurred in the uplifted southern and central area where ssuch volcanic activity occurred in the NE- SW and localized on the southern edge of the Bornu Basin and the eastern edge of the Gongola Basin (Saugy, 1987). Today, sand dunes, river alluvium, deltaic and lagoonal clay flat, blanket wide areas to the south and southwest of the Lake Chad.

MATERIALS AND METHODS

Field Study and Geological Mapping

Rock outcrops in the research area were stu died sedimentologically and stratigraphycally from surface and pits (after augering), the augering involves a helical shaft that is used for boring holes in the soil to collect sub-surface samples. The methodology of the study comprises the hardware design and analytical procedures. There are many variables used in the field for the geological mapping. The following materials were employed during the study for effective acquisation of viable information in this exercise;

Global Positioning System (GPS)

Locating rocks outcrops on a map can be time consuming, especially where the base map lacks detail such as moorland and deserts. GPS was used to provide multi-satellite- based radio-navigation, timing and positioning system. It also aids data collection in the field and helps in locating points of sampling. Three dimensions were achieved in the field which includes (latitude, longitude and height above a global datum WGS-84). Coordinates were taken at different points of sampling.

Sampling

During the mapping exercise, sedimentary rocks were sampled at different locations from both surface and sub- surface using auger and hammer to ensure fresh samples. The samples were then kept in polyethene recording with their coordinates and other physical characteristics such as (e.g. grain-size, structures, and textures) in a field notebook. Handlens was also used in identifying some of these physical proerties. Some of the rock samples were selected for Petrographic Studies, while others were selected for trace element petroleum geochemistry.

Logging of Stratigraphic sections

Logging of stratigraphic sections was employed in the field to log lithostratigraphic sections and to measure vertical thicknesses of different sequences and their boundaries. Several lithostratigraphic sections were plotted. Rock samples collected in the study area provided sedimentological data that allow their interpretation in terms of transport and deositional processes. Sampling interval depends on the thickness of the sections, mostly it is between 2-5 metres interval. The choice of sampling is based on favourable outcrops that have fresh rock materials that can provide good analytical result.

Petrography

Thin Sections

A thin slice of (16) samples of sandstone from different formations in the study area were used; detail procedures have been discussed by (Pettijohn, 1987). In preparing for thin sectioning, a thin slice of rock sample was cut using rock cutter and mounted on a glass slide using araldite. The mounted rocks were then treated gently over the glass slide to remove excess araldite and air present. The rock slice was later scrubbed using abrasive powder and a thickness of 0.3mm is obtained. It was then polished and another glass is used to cover the prepared thin section.

Petrographic microscopy was employed to identify and distinguish different mineral grains within the sandstone slides so as to possibly determine the source area, and compositional maturity level of the rocks. The microscopic determination of minerals used in this study was adopted from previous works such as (e.g. Mackenzie and Adams, 1994; and Scholle; 1979).

Petrographic analysis was carried out using 16 selected sandstones samples from the Bima Group, Yolde Formation and Dumbulwa Member of Pindiga Formation. The study involves examining rock samples with the aid of polarized microscope to obtain mineralogical information on the constituents. The Petrographic view aide in provided information on different minerals based on their physical properties and structure observed on the slides. Quartz, feldspars and lithic fragments all have varying characteristics.

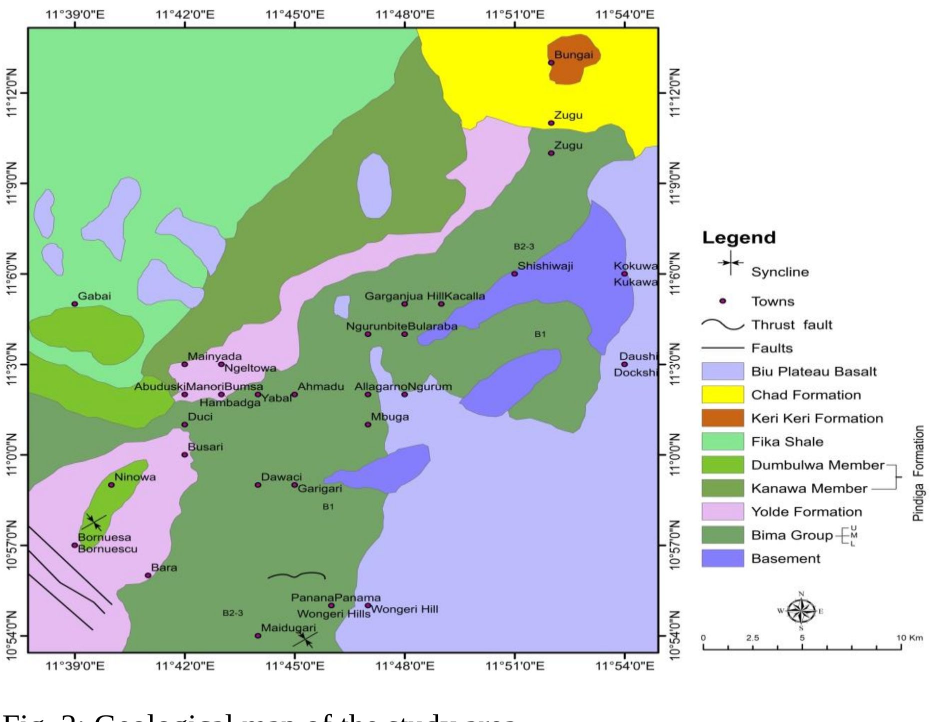

Fig. 2: Geological map of the study area

RESULTS AND DISCUSSIONS

Petrography

About sixteen (16) rocks samples were analysed to determine their mineral distribution for sandstone classification based on Loren (2002) scheme. Table 4.2 below shows the mineral distribution from sandstone

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slides and Table 4.3 is a scheme for classification of sandstones.

Point counting method deduced from petrographic studies showed that quartz distribution ranges from 31.20- 67.74%, altered feldsper ranges from 5.37- 34.61%, microcline ranges from 0.97- 3.65%, orthoclase ranges from 17.47- 33.33%, albite ranges from 1.12- 6.66%, zircon ranges from 0.96- 4.34%, limonite ranges from 9.38- 22.21%, muscovite ranges from 2.08- 2.87%, biotite appeared only once and has a percentage value of 0.22. Andesine has a distribution value which ranges from 1.92- 2.66% and hematite ranges from 4.87- 25.64%.

Below are 16 slides 24 a, b, 26 c, d, e, f, 27 g, h, I, j, 28 k, l, m, n, 29 o and p observed under cross- polars. They represent different sandstone groups encountered in the field.

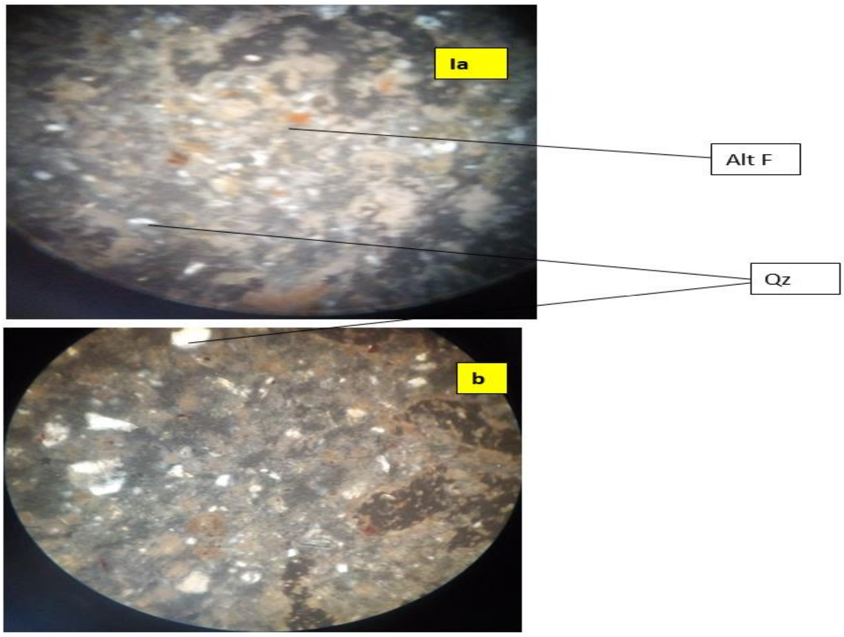

Plate I. a- arkosic arenites, b- arkosic arenites, Alt F- altered feldspar, Qz- quartz. Photomicrograph under cross- polars.

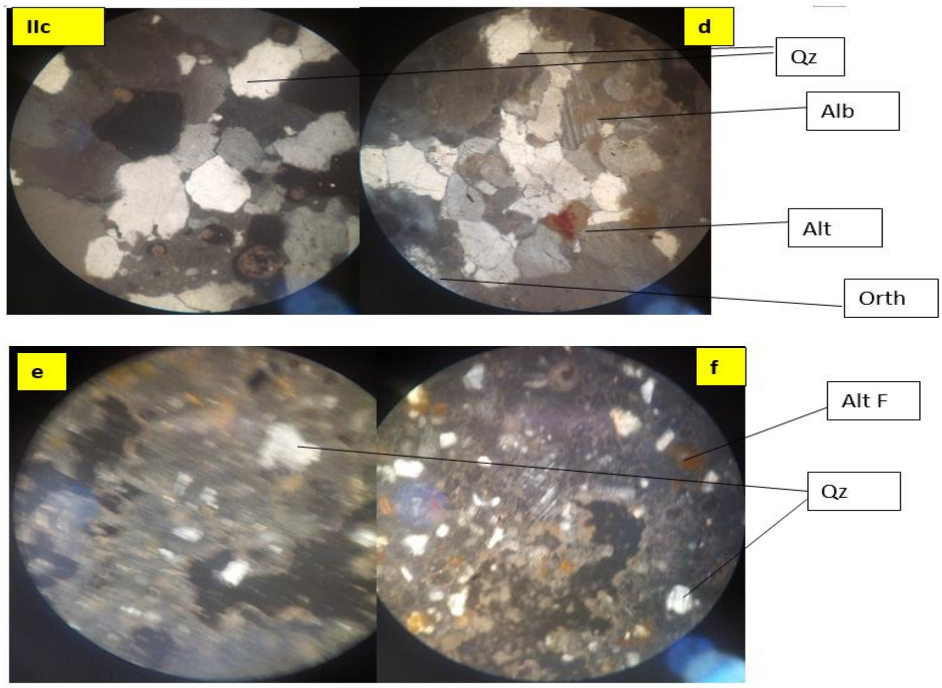

Plate. II. c- lithic arenite, d-arkosic arenite, e- lithic arenite, Qz- quartz, Alt F- altered feldspar, Orth- orthoclase, Alb- albite. Photomicrographs under cross- polars.

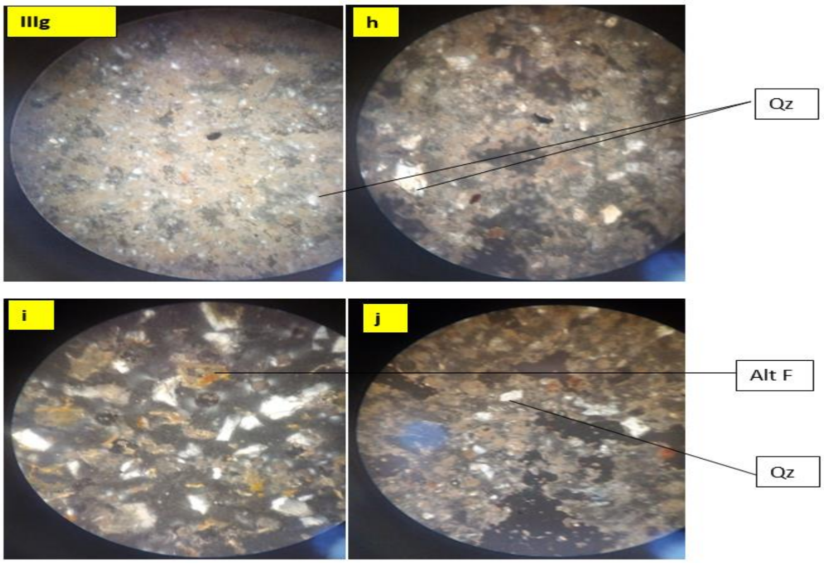

Plate III. g- lithic arenites, h- arkosic arenites, i- arkosic arenites, j- arkosic arenites, Qz- quartz, Alt F- altered feldspar. Photomicrographs under cross- polars

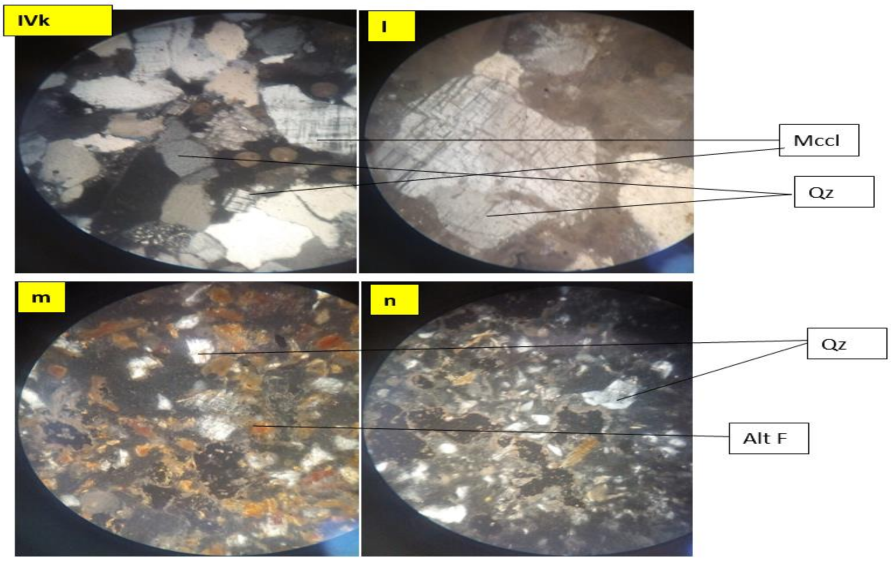

Plate. IV k- arkosic arenites, l- arkosic arenites, m- arkosic arenites, n- arkosic arenite, Mccl- Microcline, Qz- quartz, Alt F- altered. Photomicrograph under cross- polars

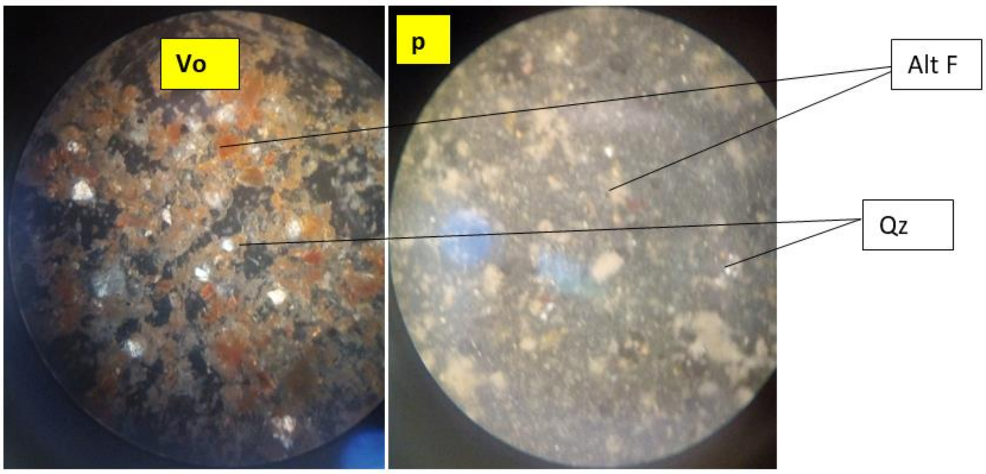

Plate V. o- arkosic arenites, p- arkosic arenites, Alt F- feldspar, Qz- quartz. Photomicrographs under cross- polars

Table 1: Mineral composition of Sandstones of Bima Group, Yolde Folde Formation and Dumbulwa Memnber of Pindiga Formation in the study area

Mineral Constituents	**4**	**5**	**7**	**12**	**21**	**24**	**25**	**26**	**27**	**28**	**34**	**35**	**36**	**38**	**40**	**41a**
Quartz	39.02	46.66	67.74	46.15	45.83	39.42	43.43	39.74	35.92	29.56	50	61.11	33.70	49.33	39.13	31.20
Altered Feldsper	18.29	25.33	-	-	17.70	15.38	-	34.61	30.09	22.60	5.37	-	26.96	13.33	24.63	28.80
Hematite	4.87	17.33	-	13.46	17.70	17.30	25.25	25.64	13.59	23.47	8.92	-	16.85	-	-	20.80
Microcline	3.65	2.66	-	-	2.08	1.92	3.03	-	0.97	1.73	-	2.77	3.37	1.33	1.44	-
Orthoclase	28.04	-	32.25	24.03	-	23.07	-	-	17.47	20.86	29.46	33.33	17.97	32	18.84	19.20
Albite	3.65	6.66	-	2.88	3.13	-	-	-	-	1.73	-	2.77	1.12	-	-	-
Zircon	2.43	1.33	-	-	2.08	0.96	1.01	-	1.94	-	-	-	-	1.33	4.34	-
Limonite	-	-	-	13.46	9.38	-	27.27	-	-	-	-	-	-	-	11.59	-
Muscovite	-	-	-	-	2.08	-	-	-	-	-	2.87	-	-	-	-	-
Andesine	-	-	-	-	-	1.92	-	-	-	-	-	-	-	2.66	-	-
Biotite	-	-	-	-	-	-	-	-	-	-	3.57	-	-	-	-	-
Total	**99.95**	**99.97**	**99.99**	**99.98**	**99.98**	**99.97**	**99.99**	**99.99**	**99.98**	**99.95**	**99.99**	**99.98**	**99.97**	**99.98**	**99.97**	**100**

Table 2: Percentage of mineral grains for classification of sandstones of the Bima Group, Yolde Formation and Dumbulwa Member of Pindiga Formation in the study area

Mineral Grains	**4**	**5**	**7**	**12**	**21**	**24**	**25**	**26**	**27**	**28**	**34**	**35**	**36**	**38**	**40**	**41a**
Quartz	39.02	46.66	67.74	46.15	45.83	39.42	43.43	39.74	35.92	29.56	50	61.11	33.70	49.33	39.13	31.20
Feldsper	53.63	34.65	32.25	26.91	22.91	42.29	4.04	34.61	48.53	46.92	34.83	38.87	49.42	49.32	44.91	48
Rock Fragments	7.30	18.66	-	26.92	31.24	18.26	52.52	25.64	15.53	23.47	15.16	-	16.85	1.33	15.93	20.80
Name of terriginous sediment	Arkosic arenite	Arkosic arenite	Arkosic arenites	Lithic arenite	Lithic arenites	Arkosic arenites	Lithic arenites	Arkosic arenites	Arkosic arenites	Arkosic arenites	Arkosic arenites	Arkosic arenite	Arkosic arenite	Arkosic arenite	Arkosic arenite	Arkosic arenite
Total	**99.95**	**99.97**	**99.99**	**99.98**	**99.98**	**99.97**	**99.99**	**99.99**	**99.98**	**99.95**	**99.99**	**99.98**	**99.97**	**99.98**	**99.97**	**100**

Petrography and Sandstone Classification

Mineral Distribution

Table 2 showed the distribution of mineral percentages obtained from point counting deduced from Petrographic examination. The distribution of the minerals from the study area followed the usual trend for classification of sandstones such that quartz and feldspar being the major rock- forming minerals constituting between 47.48% in sample 25 to 99.99% in sample 7 and 35.

Quartz being the most stable and abundant rock- forming mineral occurs in all the samples and has values that range from 31.20% to 67.74%. The presence of quartz is attributed to its resistance to both mechanical abrasion and chemical dissolution. Altered feldspar range from 5.37% to 34.61%, hematite, a class of iron oxide range from 4.87% to 25.64%, such mineral result from dissolution of unstable ferromagnesian minerals. Microcline, a potassic feldspar has values ranging from 0.97% to 3.65%, orthoclase, another potassic feldspar mineral has values ranging from 17.47% to 33.33%, while albite, a plagioclase feldspar series range from 1.12% to 6.66%. Zircon is considered as one of the most stable mineral that is highly resistive and is believed to have undergone several sedimentation cycles, it has values ranging from 0.96% to 4.34%, limonite, a variety of iron oxide that forms from the hydration of hematite or formed from oxidation and hydration of iron rich sulphide minerals and chemical weathering of iron rich minerals like biotite. It range from 9.38% to 27.27%, it is often the major component of lateritic soils. Muscovite is a stable authigenic mineral that is present in samples 21 and 34, this can be attributed to its unstability, it range from 2.08% to 2.87%, biotite being a second variety of mica is only present in sample 34, this showed that sample 34 is composed of both mica minerals and may be close to the source area, it has value of 0.22% which is considered to be the least abundant mineral in all the samples. Andesine, a ca- rich plagioclase which is an unstable mineral is present in samples 24 and 36, its values range from 1.92% to 2.66%.

Therefore, from Table 1, shows that mineral abundance tends to obey Bowen reaction series in such a way that most of the mafic high temperature minerals tend to dissolves and weather to secondary minerals, while the low temperature minerals that are more reisistant tends to dominant the sedimentary cycle.

Sixteen (16) samples were used in the point counting procedure carried out with the aim of classifying the sandstones using petrographic examination in distinguishing the sediments into different arenitic groups on the basis of quartz, feldspars and rock fragments distribution as observed under the microscope. From the results obtained in Table 1, quartz being the most stable rock- forming mineral tends to have higher percentage of mineral inherent in it. It range from 31.20% to 67.74% with an average 38.44%, sample 1a has the least value when compared to feldspars put together, but higher than the rock (lithic) fragment. Feldspar being the second most abundant rock- forming mineral range from 4.04% to 53.63%, with an average value of 38.25%, it has the highest percentage of 53.63% in sample 4 with least in sample 25 having a value of 4.04%. Rock (lithic) fragments has values ranging from 0.00% to 52.52% with an average of 18.10%, this shows that it has the least value when compared with quartz and feldspars that constitutes the bulk of rock- forming minerals. Additionally, samples 7 and 35 have no occurrence of any rock fragment, while in sample 25 it has the highest percentage of 52.52% more than quartz and feldspar put together. It also has higher value than feldspar in samples 12, 21, and 25, which result in naming the rock samples lithic arenites. Figure 3 below shows the distribution pattern of different sandstones in the study area.

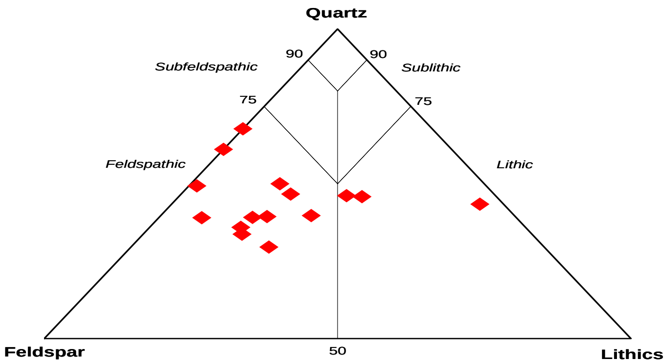

Fig. 3. Sandstone types within the study area using Loren (2002) classification scheme

Photomicrographs 1 a and b (Plate I) were classified as arkosic arenites based on point count, while photomicrographs (Plate IIa, b, c, d, f) are classed as arkosic arenites and lithic arenites, point count from photomicrographs (Plate IIIg, h, i and j) consist of 3 arkosic arenites and 1 lithic arenites. All the other photomicrographs (Plates IV k, l, m, and n and IV o and p) are arkosic arenites. These photomicrographs were used for identifying minerals for classification of the sandstones studied in the research area.

Sandstones are usually classified according to the relative proportions of the three components;

i) Quartz
ii) Feldspar (Potassium + plagioclases)
iii) Rock (lithic) fragments

Point counting method was employed to classify the sandstones after petrographic microscopic examination has been carried out to identify the mineral composition of the sixteen (16) samples analyzed in order to assign petrologic names for distinguishing them characteristically.

Loren (2002) classification scheme was adopted for the classification using the identified minerals, basically quartz, feldspar (potassium + plagioclase) and rock fragments. Sandstones in the study area were classified as arkosic arenites due to the fact that their quartz content is less than 75% and their feldspar ratio higher when compared with rock fragment, it shows that the appropriate names according to Loren (2002) classification scheme is arkosic arenite for the samples listed above, Table 1 distribution supported this scheme. Likewise, samples 12, 21, and 25, are classified as lithic arenites because the quartz constituent is less than 75% as well and have greater percentage of mineral lithic fragments than feldspars put together.

The classification carried out is based on the distribution of the three constituents having higher than 25% between feldspar and rock (lithic) fragment and less distribution of quartz (<75%), the percentage values is responsible for naming the arenites. The percentages of quartz within the mineral grains influence the type of sandstone that would be produced. From the study carried out, quartz has the highest percentage of mineral grains, followed by feldsper (potassium + plagioclase) put together, while rock (lithic) fragment has the least number of mineral grains which can be attributed to the stability of the minerals couple with the resistance from weathering and erosion.

Sandstone Composition

The composition of sandstone is largely a reflection of the geology and climatic condition of the source area. Some grains and minerals are chemically and mechanically more stable than others such as zircon, tourmaline, rutile and quartz.

Compositional Maturity

Compositionally, the sandstones from the study area can be said to be matured and immature. These are the two categories of sandstones observed petrographically and are; arkosic and lithic arenites. Mature sandstones from the study area are the arkosic arenites which consist of quartz, some feldspars, and some rock (lithic) fragments, such that the feldspars have higher constituents than the rock fragments, whereas the immature sandstones here are the lithic arenites which basically contain higher percentage of feldspars and rock fragments put together than quartz, but the rock fragment has higher percentage of fragments inherent in it than feldspars. Most immature sandstones as the case may be in this study consist of higher percentage of rock fragments and feldspars put together than quartz.

Provenance of Sandstone

Climate, through the influence on weathering processes, can have a significant effect on the ultimate composition of sandstones and thus on provenance interpretation. Hot, humid climate promote alteration and destruction of less- stable minerals and rock fragments, whereas very cold and very dry climates favour preservation of these less- stable constituents. Furthermore, conditions of low- relief and gentle slopes enhance chemical weathering because particles are eroded from such areas slowly. By contrast, high relief and steep slopes promote rapid erosion of detritus before it is significantly weathered.

Plot of QFRF (Fig. 3) suggests that the Cretaceous sandstones may be derived mostly from provenance which is cratonic interior as well as recycled orogeny (Dickenson, 1985). He states that the main source of the cratonic/continental- derived sandstones is low- lying granitic exposures. These accounts for the study area having low- lying basements around northeastern part of Dokshi Village and Buni Yadi, and the basement complex of northeastern Nigeria might be possible sources. Orogenic recycling occurs in tectonic settings where stratified rocks are deformed, uplifted and eroded (Dickenson, 1985). This is typical of the Lamurde Anticline which is the type section of the Bima Group, it falls within the Yola arm of the Upper Benue Trough formed during the Santonian (compressional phase) thermotectonic event, which resulted in the folding and uplifting of the Lamurde area. Young *et al*. (1975) studied composition versus size of first- cycle sands released from metamorphic and plutonic rocks in semi- arid and humid climates. They conclude that regardless of crystalline source- rock type, weathering in semi- arid climate generates greater amounts of rock fragments, feldspars and accessory minerals. Weatherimg in humid climate produces relatively more polycrystalline and monocrystalline quatz because less- stable minerals and rock fragments are more easily destroyed by various chemical weathering under humid conditions.

Heavy minerals suites as source- rock indicators, rounded and angular zircon mineral are present within some samples and are believed to have been derived from two sources; igneous and recycled sedimentary rocks. Rock fragments has two sources; volcanic and metamorphic, metamorphic maybe more possible source. Potassium feldspars often suggest sources of alkaline igneous rocks. Quartz is believed to have been sourced from high- grade metamorphic rock or plutonic source rocks. Continental block provenances: quartzose sand and feldpsars with high ratios of potassium feldspars to plagioclase feldspars and metamorphic and sedimentary rock fragments.

CONCLUSION

The geological investigation carried in this study shows that there is a regional basin differentiation in terms of facies distribution as observed in the field based on their sedimentary characteristics.

Petrographic analysis carried out was used for classification of sandstone into two classes, viz; arkosic and lithic arenitic sandstones. This was achieved from deducing the percentages of quartz, feldsper, and rock fragments. The classification scheme is based on the distribution of the three constituents, and a compositional maturity was also determined (matured and immature). Matured sandstones contain more quartz with some feldspers, with apppreciable rock fragments, whereas immature sandstones consist of high percentage of rock fragments than feldsper and quartz.

In conclusion, this study has provided new information on the geology of the Nigerian sector of the Chad Basin (Bornu Basin) at its boundary with the Upper Benue Trough (Gongola Basin) which highlight the petrographic analysis carried out revealed two classes of sandstones and their compositional maturity in terms of transportation and provenance.

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