Depositional Environments and Petrographic Characteristics of Bida Formation around Share-Pategi, Northern Bida Basin, Nigeria

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Abstract

The Campanian Bida Formation is the oldest stratigraphic unit in the northern Bida Basin, central Nigeria. Facies analysis of the investigated sections indicates three main facies which include conglomerate, sandstone and claystone. The poorly sorted, matrix and grain supported conglomeratic facies which overly unconformably the weathered schists and granites is interpreted as gravity induced debris flow deposit. The massive to crossbedded sandstone facies with unidirectional paleo-flow dominantly to the NNE were deposited in braided fluvial channels. The sequence grades into claystone facies which probably was formed in localized non-marine floodplains.

Results of grain size analysis; standard deviation and skewness which range from 0.65 to 1.69 and -0.02 to 0.96 (average values of 1.29 and 0.11ϕ) respectively suggest that the sandstones are predominantly texturally immature and, thus, imply fluvial origin. Average mean sizes of 0.79ϕ suggest predominance of coarse sands and this suggest that saltation is the most prevalent mode of transportation. Pebble morphology study also indicates mainly fluvial processes for the clasts from the conglomerates and conglomeratic sandstones. Few individual clasts with sphericity and Oblate – Prolate (OP) index values less than 0.66 and -1.5 respectively, however, provide evidence of recycling of some of the clasts from older sediments.

Petrographic study reveals that quartz is the dominant framework grain ranging from 66.3 to 88.5%. Feldspar dominated by plagioclase type constitutes between 10 to 27.7%. The plotted QFR diagrams suggest subarkosic sandstones derived from rifted and uplifted continental basement rocks in a warm humid paleoclimatic setting.

Keywords: Debris flow, Paleocurrent, Immature, Share, Sphericity

1. Introduction

The Bida Basin, located at central Nigeria, is one of the hinterland sedimentary basins in Nigeria, having a sedimentary fill of about 4km (Ojo, 1984; Udensi & Osasuwa, 2004). It is a northwest-southeast trending intracratonic structural depression adjacent and contiguous with Sokoto and Anambra Basins in the northwest and southeast respectively (Figure 1). The Bida Basin is subdivided into the northern and southern sub-basins to accommodate the fast and wide facies changes across its long and large areal extent (Jones, 1955; Braide, 1992 a&b).

A review of available literature is indicative of rift related origin of the basin (King, 1950; Kennedy, 1965; Kogbe *et al*., 1981, 1983; Ojo & Ajakaiye, 1989). The referred authors show robust arguments, supported by geophysical data and landsat images, in favour of rift origin associated with drifting apart of South America and Africa plates. The authors agreed that Bida Basin is part of the tectonic evolution of the Benue Trough which began in the early Jurassic to early Cretaceous with the opening of Gulf of Guinea about a triple junction. The main dissenting position on the origin is that of Braide (1992a) which advanced a wrench fault tectonics for its evolution and, thus, suggested a pull – apart origin for the Bida Basin.

Stratigraphic framework in this basin has been along the geographic subdivision of the basin into north and south Bida basins. Adeleye (1974) and Adeleye and Dessauvagie (1972) established four stratigraphic horizons in the northern Bida Basin and these include; the basal Campanian - Maastrichtian Bida Formation (conglomerate, sandstone), Sakpe Ironstone, Enagi Formation (sandstone, siltstone, claystone) and Batati Ironstone (Figure 2). Their lateral equivalents in the southern Bida Basin are Lokoja Formation (conglomerate, sandstone), Patti Formation (sandstone, shale, claystone) and Agbaja Formation (ironstone). Stratigraphic nomenclatures in the present study area is not well defined, however, the present investigated sediments, which were referred to as depositional unit I in Ojo & Akande (2011), have characteristics best comparable to type section of Bida Formation and are hereby held as Bida Formation.

Interest has grown among researchers to understand the mineral potential, depositional history and paleogeography of the Bida Basin in the last few years, particularly the southern part of the basins. Among the previous studies include; Braide (1992a), Idowu & Enu (1992), Ojo & Akande (2003, 2009), Obaje *et al*. (2004), Akande *et al*. (2005). In the northern Bida Basin, particularly areas north of Niger River, Adeleye (1974), Braide (1992b), Olaniyan & Olabaniyi (1996), Olugbemiro & Nwajide (1997) examined the pebble morphology, grain size distribution, facies distribution and suggested fluvial environments for the sandstones and the conglomerates. It is an incontrovertible fact that the realistic predictions of source rocks, reservoir rocks and mineral prospect of frontier basins will depend on adequate and detail reconstruction of the depositional history and provenance of the sediments. This is best achieved through detailed bed measurements, precise description of outcrop locations, systematic sampling and petrography. So far, this type of study, is unavailable in the areas south of the Niger River where preliminary field study (Oluyide *et al*., 1998; Ojo & Akande, 2011) have shown that the sedimentary package has hundreds of metres thick clastic sediments preserved and well exposed. In this study, we focus on the areas south of the Niger River (Share-Pategi, Figure 1b) and use field sampling and facies analysis of outcrops to deliver the following objectives: a) construction of composite lithologic sections of the Bida Formation; b) petrographic characterization of the sediments; and c) reconstruction of their paleo-environments. This is expected to provide a platform for more advance detail reservoir potential evaluation in view of the ongoing interest of the Federal Government in testing petroleum potential of the inland basins in Nigeria.

2. Location, Materials and Methods

The investigated outcrops are; road cuts, stream and erosion channel exposures located around Share – Pategi traverse (Figure 1) within latitudes and longitudes. The main access roads include Share – Pategi highway, a major interstate road and Gbugbu – Lafiagi road. The area has subequitorial type of climate and vegetation is typically Guinea Savannah. The geomorphology is characterized by elongated ridges with flat tops and low lands. Vertical profiles of the sedimentary successions showing variations in texture, thickness and sedimentary structure were constructed in each location based on bed by bed measurements and lithologic description. Precise location of the ouctcrops were obtained using GPS and recorded. Paleocurrent measurement of the cross stratifications were taken. Clasts of pebble and cobble were carefully and randomly collected from the conglomerates and conglomeratic sandstones for pebble morphometry analysis. The various morphology of the clasts was determined by measuring their three axes; Long L, Intermediate I and Short S using vernier caliper as described by Stratten (1973). The morphometric elements; Flatness Ratio (FR) and Elongation ratio (ER), and Oblate – Prolate Index (OP index) were calculated using the formula of Luttig (1962) and Dobkins & Folk (1970), respectively. Maximum Projection Sphericity Index and Roundness were obtained according to Sneed & Folk (1958) and Sames (1966) respectively. Ojo & Akande (2003) applied this method to study the conglomerates facies of the Lokoja Formation and obtained reliable results. Representative samples of the sandstone were collected for mechanical grain size distribution analysis and the various textural parameters obtained according to Folk & Ward (1957). Thin sections of the sandstones were prepared and mounted on glass slides for microscopic study.

3. Lithofacies Analysis and Interpretation

Based on sedimentary structures and texture, the following sedimentary facies of the Bida Formation are recognized in the study area.

3.1 Conglomerate Facies

This facies is frequent in most of the studied locations. The conglomerate facies can be distinguished into matrix supported conglomerate and clast - matrix supported conglomerate subfacies. The composition of this subfacies also varies from one location to the other. At Share, Yikpata, Sabagina, Zambufu and Gbugbu (Figures 3-5), the matrix supported conglomerates are massive, friable and poorly sorted with red, muddy to sandy matrix. Their pebbles and cobbles include rounded to angular quartz, feldspars and fragments of quartzite, schist and granite. At Yikpata, Share 1 and Gbugbu sections, the matrix supported conglomerate subfacies occur at the basal part of the sections where they overly unconformably the weathered basement complex (Figure 6). Some of the beds have irregular, scoured lower bounding surfaces. Average size of the clasts is 5cm, that is, most are of pebble size. Cobble size clasts constitute less than 3%. The pebbles and cobbles are mostly well rounded to sub angular quartz, schist, quartzite and in few cases granite. Sedimentary clast is rare. These clasts “float” within poorly sorted matrix consisting of ferruginous sand and clays. Generally, this subfacies is non-imbricated and lack any internal organization and they commonly grade upward into conglomeratic sandstone i.e fine upward (Figure 7). In some other locations at Zambufu and Sabagina, it is noticed that, the conglomerates there have larger fragments (cobble size) and the components are more indurated. Few imbrications and burrows are observed (Figure 7). Also in these locations, the basal crystalline rocks are not exposed probably because of the higher topographic elevation. The average thickness of these conglomerate beds is 3m and, in most cases, they show sheet-like geometry and thick tabular bodies that are laterally continuous for few tens of metres.

The grain - matrix supported conglomerate subfacies in the study area is observed only at middle part of the Tsaragi and Yikpata sections. This conglomerate bed appears to have less matrix and the pebbles mostly of well rounded quartz are well indurated. The beds with average thickness of 2m are massive and bioturbated. Generally, the conglomerates are immature.

The proximal alluvial fan processes were preserved in the stratigraphic record as conglomerates in various parts of the study area (Ojo & Akande, 2011). Both the matrix supported and grain - matrix supported conglomerate subfacies contain features that are indicative of continental environments dominated by gravity induced alluvial processes (Wasson, 1979; Nilsen, 1982). Comparison of the sedimentary features of these conglomerate beds with well known and documented conglomerates in various parts of the world suggest that the matrix supported conglomerates in the present study area suggest cohesive debris flow sediments deposited from dense and viscous fluids (Hampton, 1979; Collinson, 1996; El – Arabi & Abdel Motelib, 1999). Guiraud (1990) and Ojo & Akande (2003) interpreted similar conglomerates characterized by poor sorting, lack of internal organization and non imbricated clasts in the upper Benue Trough and southern Bida Basin respectively as gravity induced proximal alluvial fan deposits. This conglomerate also closely compared with the alluvial fan conglomerates around Doko and Baro north of Niger River, central Bida Basin described and interpreted as deposition from rapid cohesive debris flows by Braide (1992b). The occurrence of grain - matrix supported conglomerate towards the upper part of Tsaragi and Yikpata sections suggests a change in texture and, consequently, the flow system. The well rounded clasts, which are significant or prominent in the conglomerates, suggest possible derivation from older sedimentary rocks probably in adjacent sedimentary basins.

3. 2 Sandstone Facies

This facies, widely distributed in the study area comprises conglomeratic sandstone, medium to pebbly sandstone, and fine grained sandstone subfacies. The conglomeratic sandstone sub facies are well represented in the sections exposed at Share, Tsaragi, Gbugbu, Manganiko and Wariku (Figures 3-5). Generally, they are friable and feldspathic, that is, some of the pebbles embedded within the clay and sand matrix are feldspars. The thickness ranges from 0.5 to 2m averaging 1m. In most sections, they are massive and occur as localized cycles of coarsening upward sequences, and commonly pass upward into conglomerate bed. Occasionally, the pebbly clasts form irregular bands on the erosional surface defining a bounding surface between it and the lower bed. A variant of this is graded bedded and stratified conglomeratic sandstone with average thickness of 1m which was observed at the basal part of the Tsaragi erosional channel section In Gbugbu, Share 2, Wariku and Oro River, both trough and planar cross bedding are observed (Figure 8). The trough cross bedding type is most common occurring in most of the sections, with the sets varying in thickness from 0.4 to 1m. The tangential surfaces are sharp and marked by train of pebbly to cobbly clasts (Figure 8) showing impacts of the erosion of older sets. Paleocurrent data obtained from the cross beddings show dominant NNE direction (Figures 3 and 5).

The medium to coarse grained sandstone subfacies is the next in terms of size of grains to conglomeratic sandstone subfacies in the study area. They are composed mainly of sands, minor silts and pebbles and their thickness range from 0.3 to 1m. At Share**,** Gbugbu and Wariku, this is frequently interbedded with claystone and they both grade upward into conglomeratic sandstones (Figures 3 and 5). At Share 1 location, the sandstone is water-bearing (aquifer) and forms a spring that serves the community throughout the year. The porous sandstone with interconnected pores is confined at the base by the sealing clayey unit (Ojo & Akande, 2010). Also, at Tsaragi and Wariku, the medium to coarse grained sandstone passes upward into the conglomeratic sandstones. It is observed that the medium to coarse grained sandstone subfacies is commonly massive and rarely cross or parallel stratified, such planar cross bedded sandstone type occur in Oro River where a small scale low angle cross stratification is displayed.

The sandstone facies comprising of the conglomeratic sandstone and medium to coarse grained sandstone subfacies is interpreted as braided fluvial deposits. The fluvial origin is supported by unidirectional paleocurrent pattern and absence of marine biogenic features (Rust & Jones, 1987; Amireh & Abed, 1999; Ojo & Akande, 2003). The frequently interbedded conglomeratic sandstone and medium – coarse grained sandstone in the study area is suggestive of development of low sinuosity channel bars arising from high discharge, channel switching, and lack of point bar sedimentation (Allen, 1982; Selley, 1985; Blair, 1987). The conglomeratic sandstone lithofacies is thought to represent deep braided channel deposits and channel lag deposits. The massive conglomeratic sandstones were probably deposited rapidly from a high velocity current whereas the graded and trough cross stratified conglomerate sandstones developed from downstream migration of dunes of possibly straight crested bedforms in a low flow regime conditions (Cant, 1982; Miall, 1988, 1990; Amireh *et al*. 1994). The thinly bedded medium to coarse grained sandstone (massive to planar cross stratified) subfacies is however interpreted as mid to distal channel bars deposited in upper flow regimes (Cant & Walker, 1978).

3.3 Claystone Facies

This facies is made up of claystone and siltstone and it rarely occurs in sedimentary sections of the Bida Formation. A very thin bed of the claystone occurs at Share, Gbugbu and Wariku where it reaches a thickness ranging from 0.2 to 0.4m. It is intercalated with siltstone and fine sand at Wariku. They are well bedded (laminated) and kaolinitic. Colour is dominantly brown.

The argillaceous nature of the claystone facies coupled with the thin lamination suggest a low energy depositional system within floodplain or overbank environment. Lack of association with any marine fauna or sedimentary features suggest a non marine floodplain or ox bow lake environment adjacent to the braid channels (Miall, 1990; Ojo & Akande, 2011).

4. Grain Size Data and Interpretation

The results of the grain size analysis of the sandstones were used to compute the textural parameters such as mean, standard deviation (sorting), skewness and kurtosis (Table 1). The mean size of the samples range from -0.28 to 1.80ϕ with average of 0.79ϕ and thus suggesting they are predominantly medium to coarse grained. Standard deviation (sorting) and skewness values range from 0.65 to 1.69 (average of 1.29ϕ) and -0.02 to 0.96 (average of 0.11ϕ), respectively, indicating that the sandstones are mainly poorly sorted and positive – symmetrically skewed. Kurtosis values also suggest they are leptokurtic to platykurtic. The poor sorting and positive skewness suggest fluvial environments for the sandstones. Several authors have used poor sorting and positive skewness as indicators of low energy environment characterized by current inconsistency and typical of fluvial system (Selley, 1985; Tucker, 1988; Amajor & Ngerebara, 1990). To further constrain the paleo-environments according to Friedman (1967, 1979) and Moila & Weiser (1968), bivariate plots of the grain size paramaters (skewness versus standard deviation and mean versus standard deviation) were plotted and the plots suggest predominant fluvial origin (Figure 9). We would like to note the observations of the previous workers on the reliability and limitations of grain size as a tool for diagnosing paleoenviroments (Solohob & klovan, 1970; Amaral & Pryor, 1977; Pettijohn, 1975). In this study, however, the results corroborate the other sedimentological signatures (sedimentary structures, geometry and lithofacies assemblage) of fluvial origin for the sandstone facies of the Bida Formation presented in the preceding section.

5. Pebble Morphometry and Implications for Paleoenvironment

The sizes of randomly selected clasts from the conglomerates fall within granule, pebble and cobble classes according to Wentworth scale (1922). Generally, pebbles are the most abundant in the conglomerates, constituting about 50 to 76 % with average of 60%. This is followed by granules which range from 20-60%. Cobbles constitute 3-20%. The cobbles are relatively higher in samples from Tsaragi and Gbugbu. More than 300 pebbles and cobbles were measured and the values of the pebble morphometric parameters are presented in Table 2. The wide variation in the clast size shows that the conglomerates are poorly sorted and compositionally immature. Majority of the clasts from the conglomerates are quartz. Others include feldspar, and rock fragments of schist, gneiss and pegmatite.

The coefficient of flatness and sphericity, Maximium Projection sphericity index and Oblate – prolate index were plotted to generate scatter diagrams (Figures 10 a&b) for distinguishing the environments (Dobkins & Folk, 1970; Stratten, 1973; Nwajide & Hoque, 1982). The samples mostly fall within the low energy fluvial fields and only few falls within high energy beach environment. Dobkins & Folk (1970) suggested that 0.66 sphericity line separate beach and river samples; whereas values lower than 0.66 are indicative of beach, and values higher than 0.66 indicate fluvial processes. The results obtained in this study are closely compared with deductions of Olugbemiro & Nwajide (1997) on the Bida sandstones exposed north of the Niger River, northern Bida Basin. The few clasts that have sphericity and OP index values less than 0.66 and -1.5, respectively, were probably recycled from older sedimentary rocks or far from the source.

6. Petrography and Provenance

The relative abundance of the constituent minerals in the sandstone samples of the Bida Formation is presented in Table 3. Quartz is predominant among the framework components and it ranges from 66.3 to 88.5% with average of 78.1% in fourteen samples. Both polycrystalline and monocrystalline types are present in almost equal amounts but the polycrystalline is more abundant in some samples (Figure 11). Most of the quartz grains exhibit straight to undulose extinction. The quartzs are mostly angular to sub-angular, whereas subrounded ones are few and poorly sorted. Feldspar constitute between 10 to 27.7% with average of 17.6%. Samples of the sandy matrix of the conglomerates are richer in feldspar and polycrystalline quartz. Plagioclase feldspar is more abundant than k-feldspar. In most samples, feldspars are fresh and well preserved and show twining (Figure 11). Rock fragments occur in most of the samples but in small amounts ranging from 2-10%. Other constituent of the framework component is mica, particularly muscovite and it occurs as thin flake.

Matrix is 3 to 16% of the whole rock. The matrix, which in places is ferruginised, is, essentially, composed of clay minerals. The other grains "float" within the matrix, thus, in most cases the quartz grains are not in contact and where they do; point contact is the most visible.

The composition of the sandstones presented above shows that the sandstone samples and the sandy matrix of the conglomerates in the study area, using Folk (1974) classification, are essentially subarkosic sandstones (Figure 12). The provenance with respect to paleoclimatic, paleotectonic setting and transportation history is interpreted using QRF ternary diagram (Figure 13). The plot shows that the sandstones of the Bida Formation have rifted and uplifted continental block provenance. According to Dickinson & Suczek (1979) and Dickinson (1970), framework components of the sandstones are genetically linked to the geodynamic environment of the source area. Subarkose characterized by abundant fresh feldspars are typical of high relief and uplifted source where sediments shed from faulted and uplifted basement rocks are deposited proximally without much transportation (Amajor, 1990). The angular to sub angular nature of the quartz grains and relatively substantial matrix supports this thesis. A warm humid paleoclimate is envisaged based on Suttner *et al*. (1981) QFR ternary plot (Figure 13). Amajor (1990) deduced humid paleoclimatic and rifted continental basement settings for the provenance of sandstone facies of the Azu river group in the Benue trough based on the QFR diagrams.

7. Conclusions

The Conglomerate and sandstone facies of the Bida formation were deposited in proximal alluvial and braided river environments respectively. The claystones facies are interpreted as non marine floodplain deposit. Paleoflow is unidirectional and mainly to the northeast.

The poorly sorted conglomerates are made up of clasts that show morphological characteristics which reflect predominant low energy fluvial processes. Grain size parameters; standard deviation indicates the sandstones are poorly sorted and the largely positive skewness is due to substantial presence of silt to clay size fractions. The textural indices suggest predominance of first cycle, river deposited sediments.

Thin section study shows that the sandstones are mineralogical immature and classified as subarkose. The framework composition suggests uplifted continental block provenance, warm humid paleoclimate and short transportation history.

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Table 1. Values of textural parameters and interpretation

Location	Sample No	Values (phi)				Interpretation		
		Mean	Sorting	Kurtosis	Skewness	Mean	Sorting	Skewness
Manganiko Ndanagi	MN1A	0.83	1.55	0.47	0.28	Coarse sand	Poorly Sorted	Fine Skewed
Manganiko Ndanagi	MN1B	1.00	1.44	0.91	-0.05	Coarse sand	Poorly Sorted	Symmetrical Skewed
Manganiko Ndanagi	MN1C	1.10	1.24	0.43	0.68	Medium sand	Poorly Sorted	Strongly finely Skewed
Oro River	OR2B	0.46	0.65	0.90	0.96	Coarse Sand	Moderately Sorted	Strongly finely Skewed
Oro River	OR2C	1.50	0.77	2.05	0.17	Medium Sand	Moderately Sorted	Fine Skewed
Oro River	OR2D	1.26	1.29	0.61	0.10	Medium Sand	Poorly Sorted	Fine Skewed
Oro River	OR2E	1.20	1.12	1.29	0.14	Medium Sand	Poorly Sorted	Fine Skewed
Oro River	OR3A	1.80	0.85	1.04	0.15	Medium Sand	Moderately Sorted	Fine Skewed
Oro River	OR3B	1.60	0.91	1.67	0.12	Medium Sand	Moderately Sorted	Fine Skewed
Oro River	OR3C	0.83	1.61	1.01	-0.06	Coarse Sand	Poorly Sorted	Symmetrical Skewed
Tsaragi	TG1A	0.17	1.58	1.12	0.11	Coarse sand	Poorly sorted	Near symmetrical
Tsaragi	TG1B	0.40	1.51	1.25	0.34	Coarse sand	Poorly sorted	Fine skewed
Share 1	KG1B	1.20	1.25	1.14	0.15	Medium sand	Poorly sorted	Fine skewed
Share 2	SH12A	1.27	1.21	1.17	0.10	Medium sand	Poorly sorted	Near symmetrical
Share 2	SH11B	-0.55	1.29	0.60	0.36	Very coarse sand	Poorly sorted	Fine skewed
Share 2	SH11C	0.35	1.17	1.17	-0.05	Coarse sand	Poorly sorted	Coarse skewed
Share 1	KG1A	-0.57	1.30	1.18	0.10	Very coarse sand	Poorly sorted	Near symmetrical
Gbugbu	GB1A	0.02	1.58	1.15.	0.12	Coarse sand	Poorly Sorted	Fine Skewed
Gbugbu	GB2B	1.10	1.66	1.16	-0.20	Medium Sand	Poorly Sorted	Coarse Skewed
Gbugbu	GB3B	0.20	1.47	1.13	-0.47	Coarse sand	Poorly Sorted	Coarse Skewed
Gbugbu	GB3C	1.61	0.75	1.12	0.57	Medium Sand	Moderately Sorted	Strongly fine Skewed
Gbugbu	GB3D	-0.28	1.36	1.19	0.05	V. Coarse Sand	Poorly Sorted	Symmetrical Skewed
Gbugbu	GB3E	0.65	1.26	0.97	0.03	Coarse Sand	Poorly Sorted	Symmetrical Skewed
Zambufu	ZB1A	0.76	1.86	0.85	-0.02	Coarse Sand	Poorly Sorted	Coarse Skewed
Zambufu	ZB1B	0.51	1.28	1.13	0.27	Coarse Sand	Poorly Sorted	Fine Skewed
Zambufu	ZB2B	1.23	0.96	0.24	0.29	Medium Sand	Moderately Sorted	Coarse Skewed
Zambufu	ZB2C	1.12	1.46	1.18	-0.09	Medium Sand	Poorly Sorted	Coarse Skewed
Zambufu	ZB2D	0.78	1.69	1.08	-0.32	Coarse Sand	Poorly Sorted	Strongly Coarse Skewed
Zambufu	ZB3A	0.93	1.66	1.01	-0.31	Coarse Sand	Poorly Sorted	Strongly Coarse Skewed
Wariku	W1C	0.90	1.37	1.20	-0.04	Coarse sand	Poorly sorted	Coarse skewed
Wariku	W1D	1.23	0.96	1.37	-0.07	Medium sand	Moderately sorted	Coarse skewed

Table 2. Mean values for the pebble morphometric parameters from conglomerate and conglomeratic sandstones of the Bida Formation

Location	Sample No	Flatness Ratio (S/L)	Coefficient of flatness (S/LX100)	Elongation Ratio (I/L)	Maximum Projection spher Index $3\sqrt{S^2/LI}$	Olate-Prolate Index $\frac{10\{\frac{L-I}{L-S}-0.50\}}{S/L}$	Roundness (Visual estimation after Sames, 1966)
Zambufu	ZB1A[1]	0.76	76	0.93	0.85	-2.74	32.50
Zambufu	ZB2A[1]	0.73	73	0.90	0.84	-0.01	35.00
Zambufu	ZB3A[1]	0.66	66	0.82	0.81	1.27	40.00
Gbugbu	GB1B[1]	0.71	71	0.89	0.58	-1.81	42.50
Manganiko Ndanagi	MN 1A	0.74	74	0.87	0.81	-0.21	37.50
Manganiko Ndanagi	MN 1C	0.70	70	0.44	3.91	-1.02	35.70
Oro River	OR3D	0.68	68	0.84	0.80	-3.36	32.70
Oro River	OR1B	0.62	62	0.86	0.77	-2.04	38.50
Oro River	OR2B	0.63	63	0.83	0.79	-0.82	29.70
Oro River	OR2D	0.66	66	0.83	0.83	0.03	30.00
Tsaragi	TG1C	0.60	60	0.81	0.16	2.26	39.33
Tsaragi	TG1D	0.71	71	0.44	0.19	2.44	31.33
Tsaragi	TG3B	0.56	56	0.82	0.11	3.53	35.00
Yikpata	YP1A	0.64	64	1.06	0.18	-2.74	34.69
Share 1	KG1C	0.72	72	0.86	0.84	0.10	24.7
Share 2	SH11D	0.62	62	0.74	0.69	0.05	42.06
Sabagina	SB1A	0.79	79	0.89	0.88	0.48	31.32
Wariku	W1C	0.55	55	0.74	0.72	-2.24	32.70

Table 3. Relative abundance of the constituents and framework composition of the sandstones

Location	Sample No	% Quartz			% Feldspar					Others		Framework Composition		
		MQ	PQ	TQ	M	P	TF	Mica	R.F	Matrix	Cement	Q	F	R.F
Gbugbu	GB2A	32	37	69	3	8	11	1	5	10	4	81.2	12.9	5.9
Gbugbu	GB1B	36	28	64	7	11	18	3	4	9	2	74.4	20.9	4.7
Gbugbu	GB3B	48	24	72	5	3	8	3	-	5	4	90.0	10.0	-
Zambufu	ZB2B	40	28	68	5	8	13	4	8	5	2	76.4	14.6	9.0
Zambufu	ZB2C	37	37	64	4	11	15	5	6	9	1	75.2	17.7	7.1
Zambufu	ZB1A	35	36	61	6	10	16	5	8	8	2	71.8	18.8	9.4
Manganiko Ndanagi	MN1A	45	30	75	6	5	11	4	2	6	2	85.2	12.5	2.3
Oro River	OR3A	46	25	71	11	8	19	6	1	2	1	78.0	20.9	1.1
Oro River	OR3B	36	32	68	3	9	12	3	-	13	3	85.0	15.0	-
Oro River	OR2C	28	31	59	11	10	21	4	7	8	1	67.8	24.1	8.1
Tsaragi	TG1A	44	27	71	9	12	21	4	1	2	1	76.3	22.6	1.1
Share 1	KG1B	25	30	55	16	7	23	7	5	8	2	66.3	27.7	6.0
Share 2	SH11B	51	26	77	4	6	10	8	-	4	1	88.5	11.5	-
Wariku	W1B	41	28	69	10	6	16	4	4	5	2	77.6	17.9	4.5

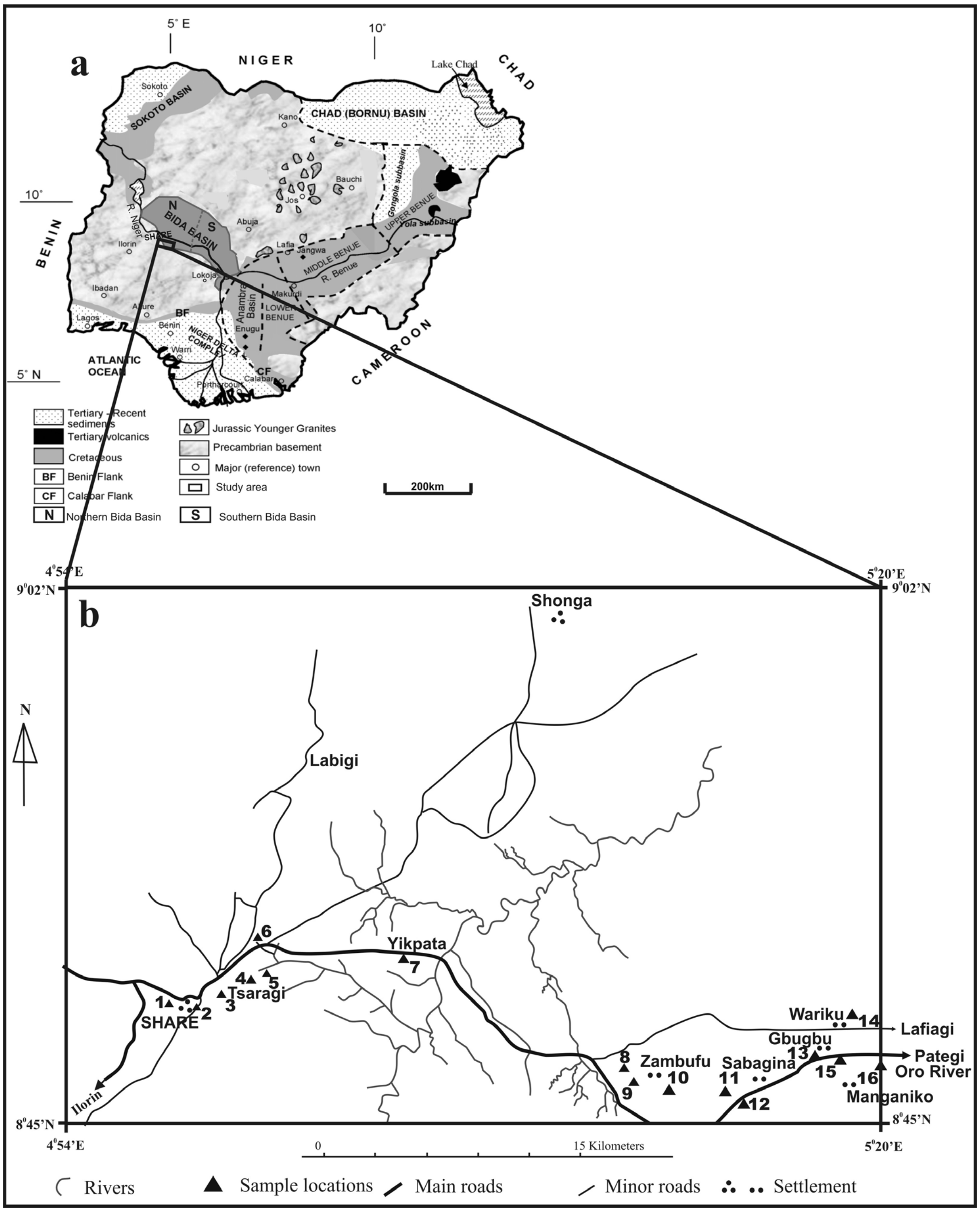

Figure 1. (a) Geological map of Nigeria showing the position of Bida Basin (b) Map of the study area and locations of the investigated outcrops (boxed area of Figure 1a)

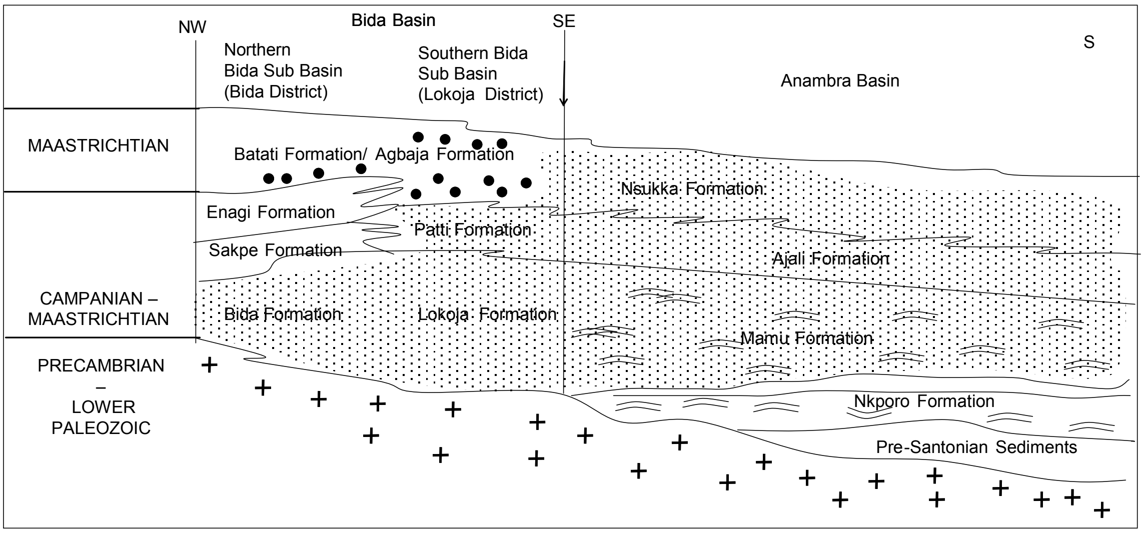

Figure 2. Regional stratigraphic successions in the Bida Basin and their lateral equivalents in the Anambra Basin (Ojo and Akande, 2009)

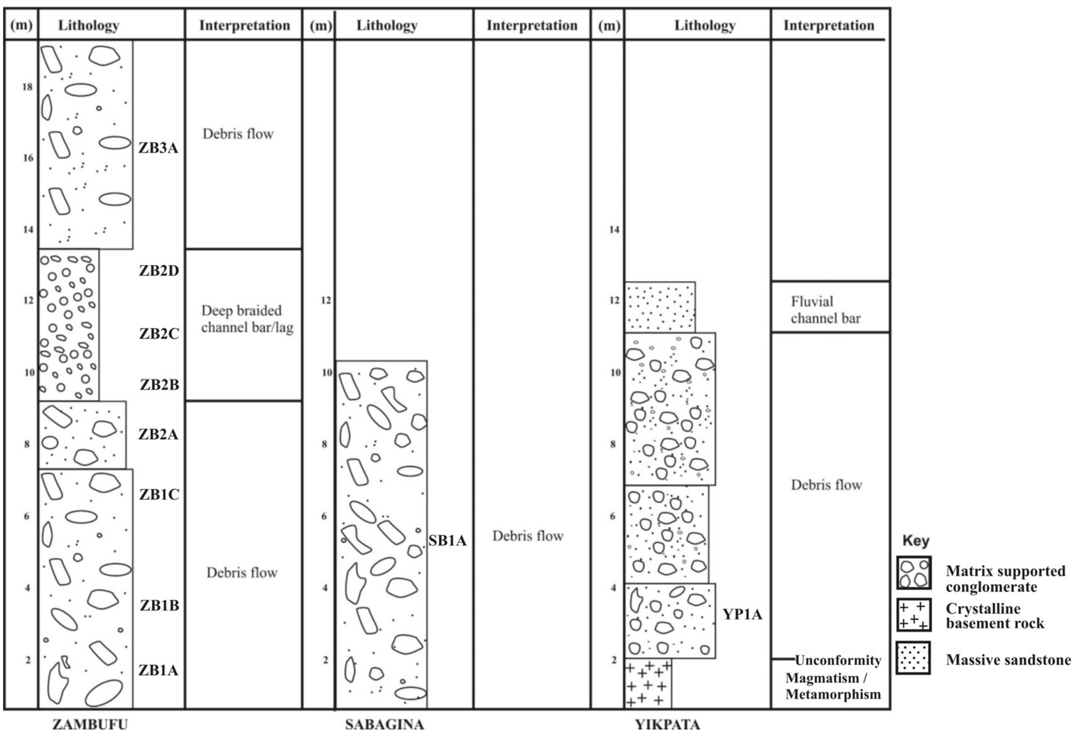

Figure 3. Lithostratigraphic sections of the Bida Formation exposed at Zambufu, Sabagina and Yikpata

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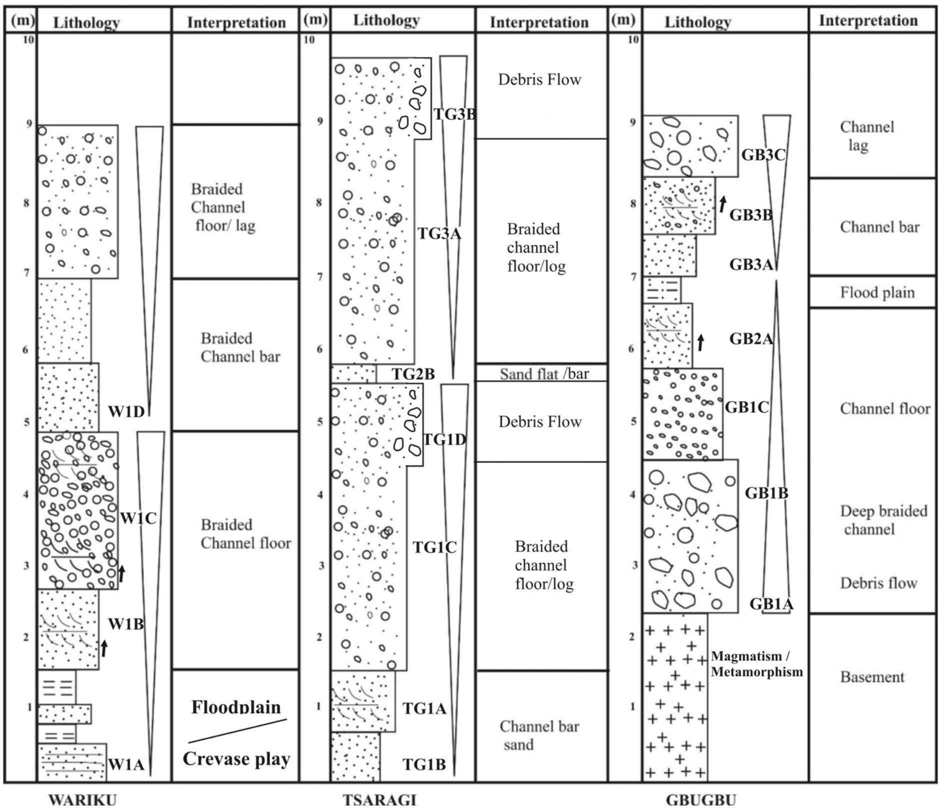


Figure 4. Lithostratigraphic successions of the Bida Formation exposed at Wariku, Tsaragi and Gbugbu

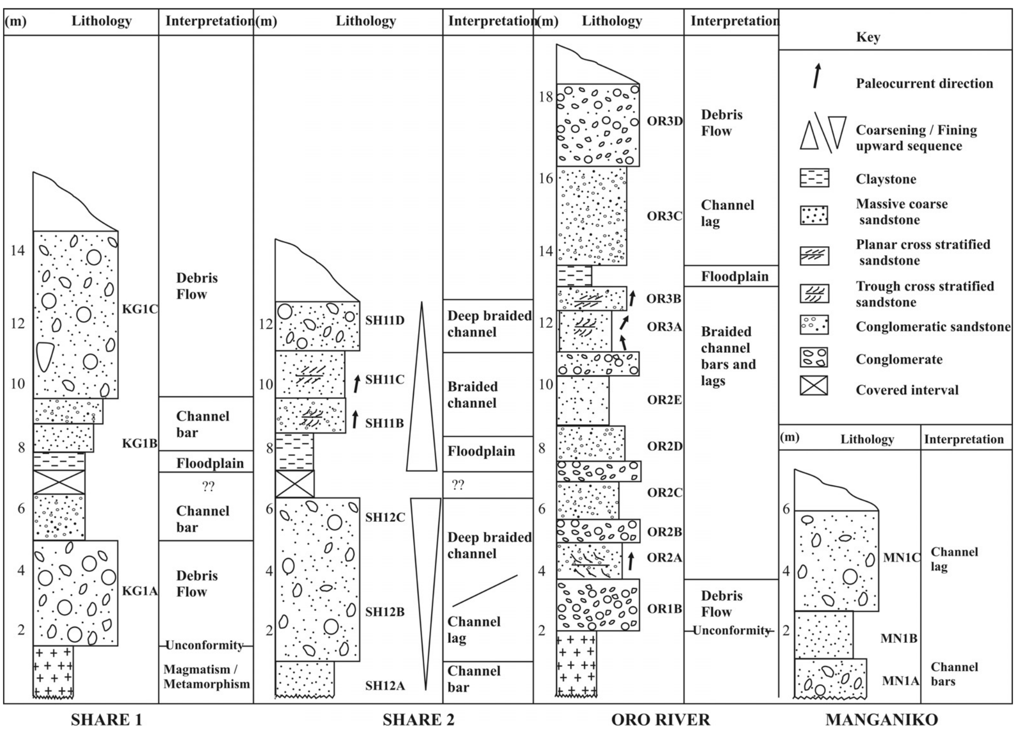
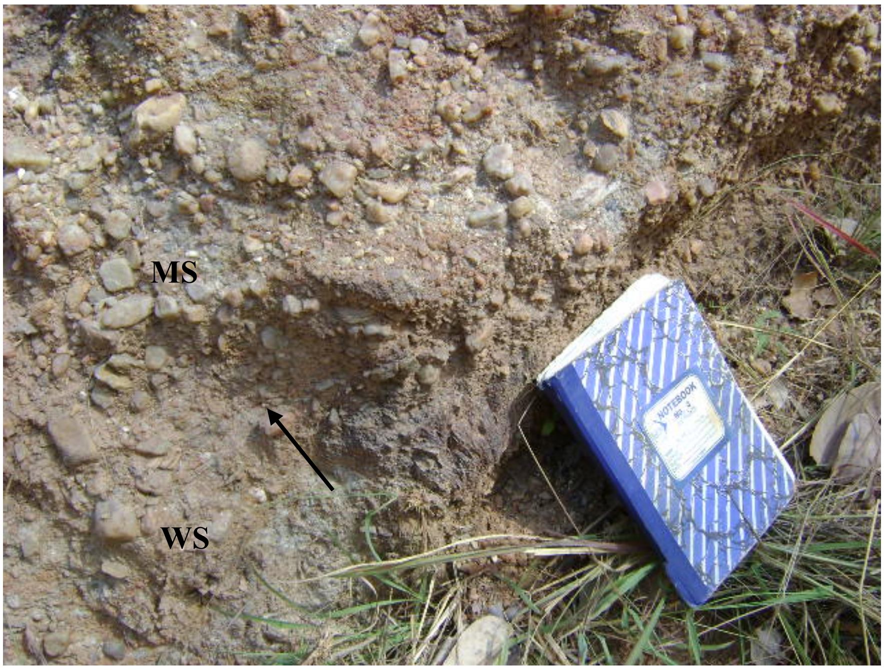


Figure 5. Lithostratigraphic successions of the Bida Formation exposed at Share, Oro River and Manganiko



a

b

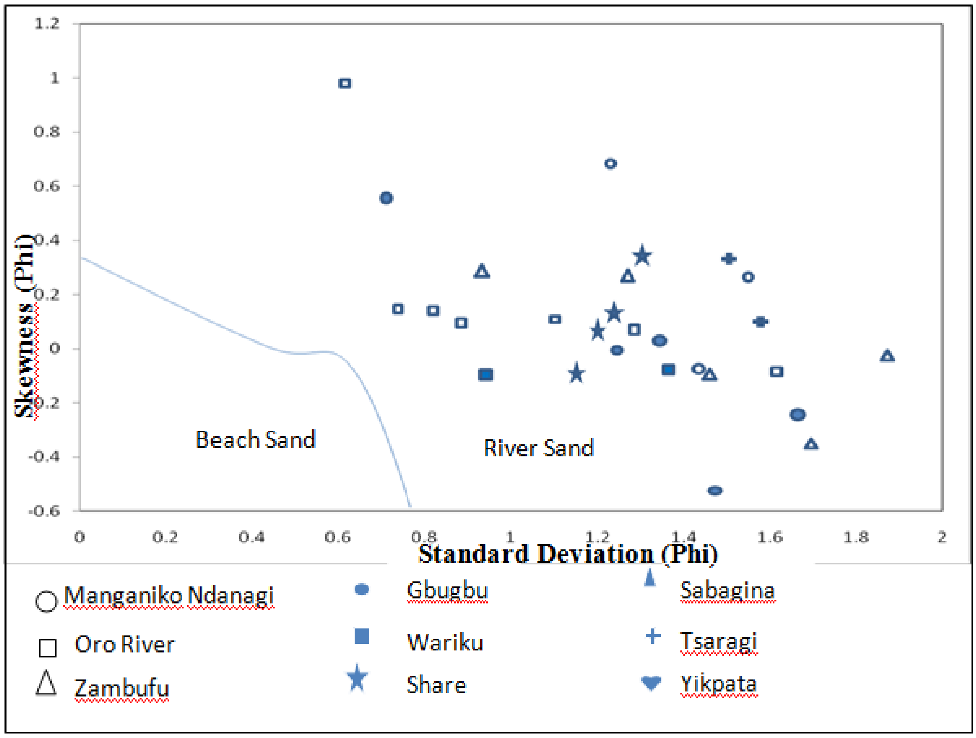
Figure 6. Matrix supported conglomerate (MSC) characterized by sharp base erosional and non conformable contact with older weathered schist (WS) at (a) Yikpata (arrow) and (b) Gbugbu (geologist finger). Note fresh feldspars and angular clasts are common

a b

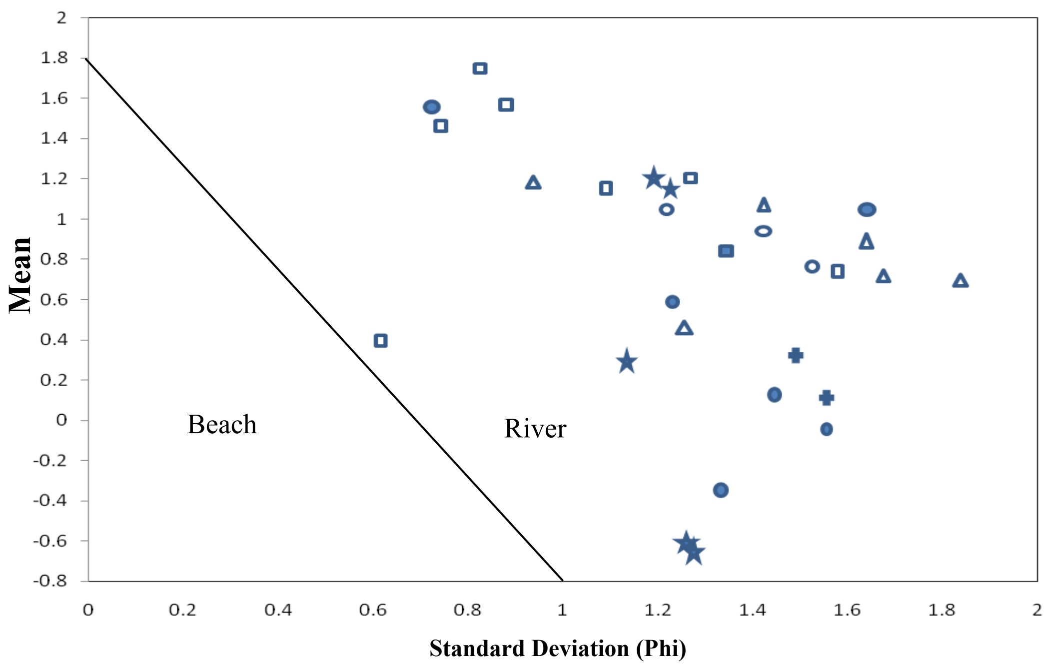
Figure 7. (a) Matrix supported conglomerate characterized by non imbricated clasts, sandy to clayey matrix and burrow (arrow) at Sabagina. (b) Matrix supported, poorly sorted conglomerate characterized by normal grading towards top, few oriented clasts and sandy matrix at Zambufu

a b

Figure 8. (a) Trough cross bedded sandstone subfacies (braided channel bar facies) of Bida Formation characterized by tangential surfaces marked by train of pebbles (arrow) at Gbugbu. (b) Planar to trough cross stratified sandstone (hammer) grading up to conglomerate sandstone bed (Lady Geologist) at Share 2

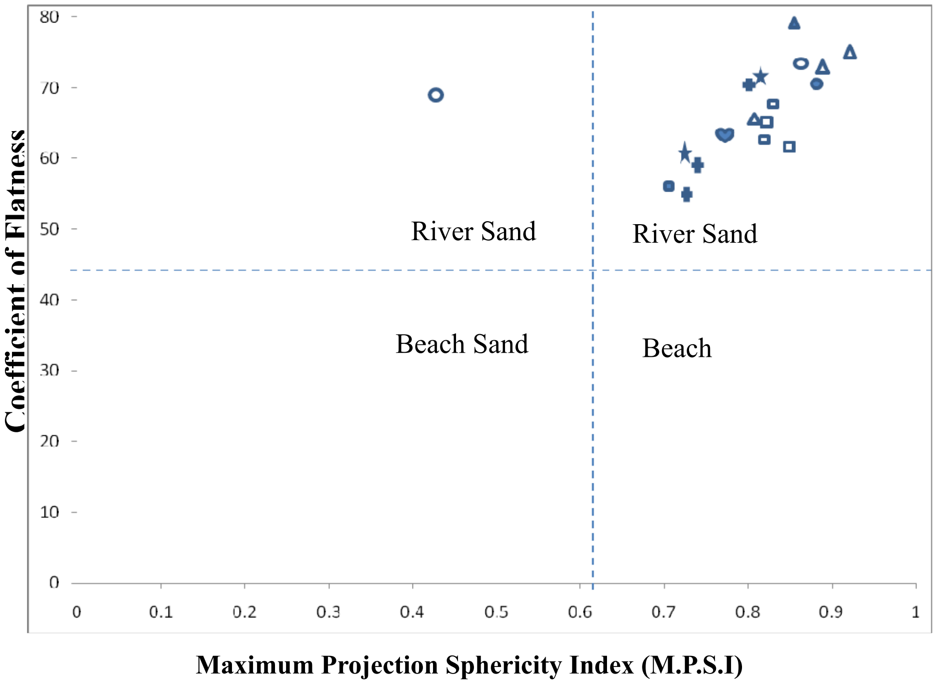


a

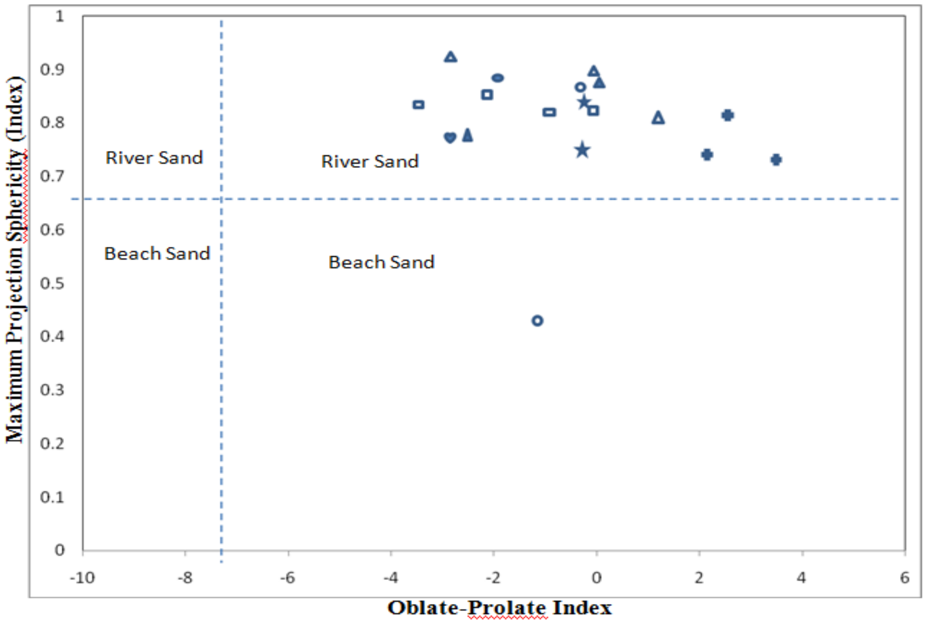


b

Figure 9. (a) Plot of skewness versus standard deviation for the sandstones facies of Bida Formation and (b) Plot of mean size versus standard deviation

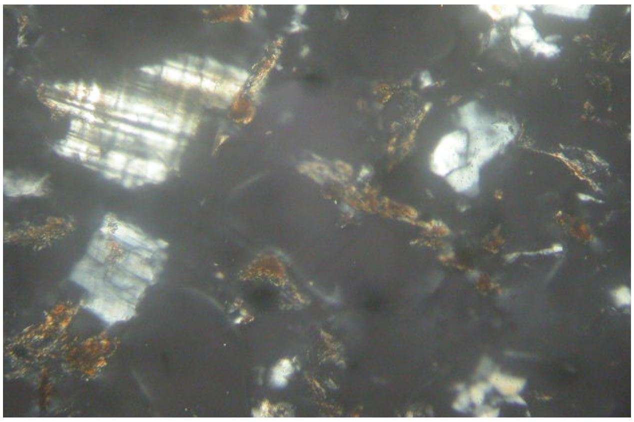


a

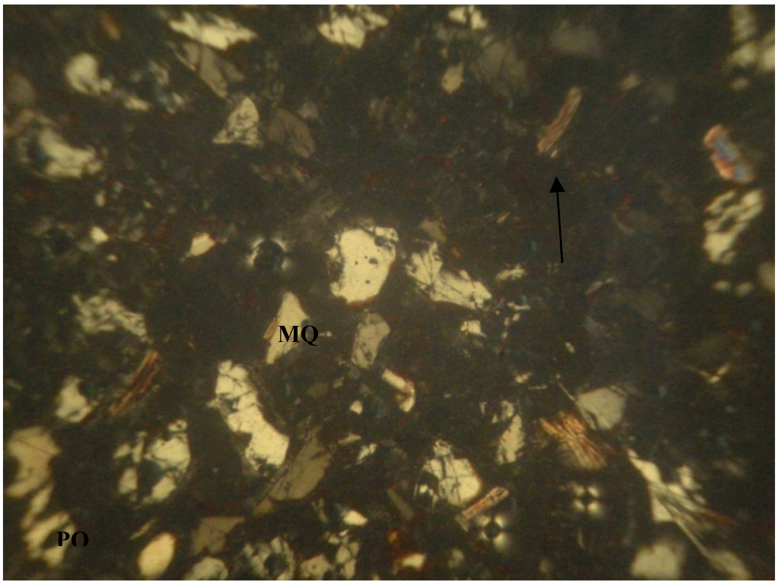


b

Figure 10. (a) Scatter plot of coefficient of flatness versus sphericity (Stratten, 1973) and (b) Scatter plot of maximum projection sphericity index (sphericity) versus oblate – prolate index (Dobkins and Folk, 1970)



a



b

Figure 11. (a) Photomicrograph of subarkosic sandstone characterized by high matrix and well preserved feldspar at Manganiko. (b) Subarkose sandstone characterized by angular quartz grains (MQ & PQ) and mica flakes (arrow) at Share 2. Bar is 0.2mm is long

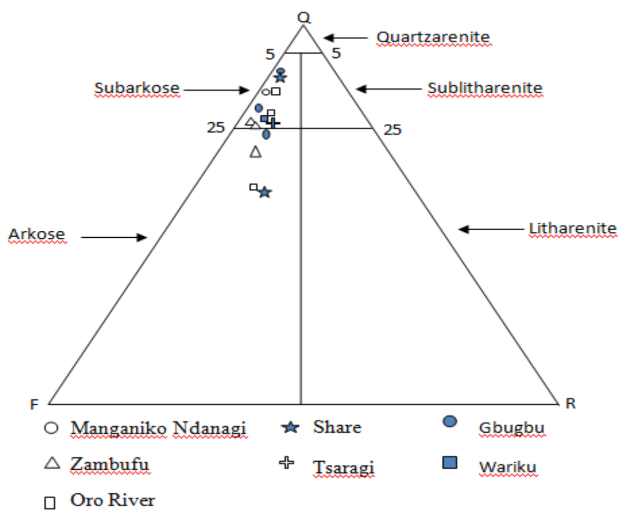
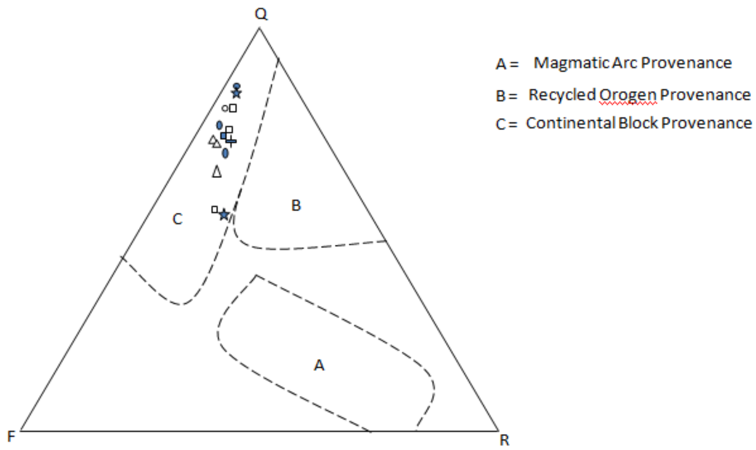


Figure 12. Ternary diagram for the sandstones after Folk (1974) indicating that the sandstones are subarkose



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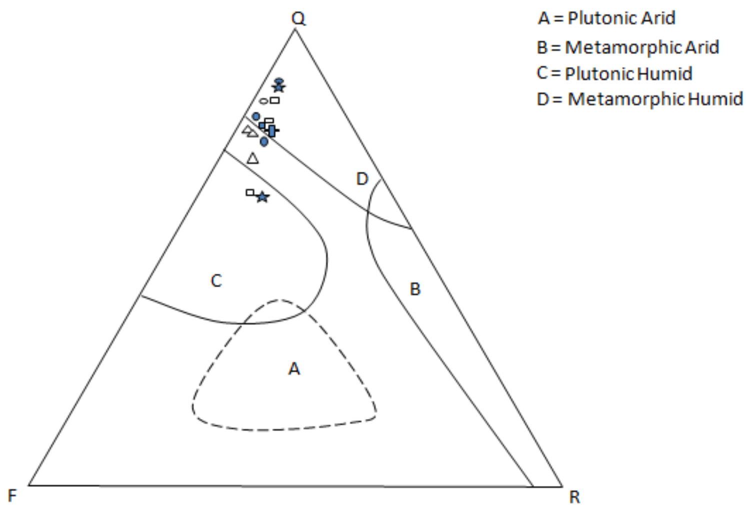

b

Figure 13. QFR Ternary plots of provenance setting for sandstones of the Bida Formation (a) Modified after Dickson (1988) and (b) Modified after Suttner *et al*. (1981). Note Q = Total Quartz, F = Feldspar and RF = Rock Fragments