SEDIMENTOLOGICAL AND GEOCHEMICAL CHARACTERISTICS OF OUTCROP SEDIMENTS OF SOUTHERN BIDA BASIN, CENTRAL NIGERIA: IMPLICATIONS FOR PROVENANCE, PALEOENVIRONMENT AND TECTONIC HISTORY

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ABSTRACT

Integrated sedimentological and geochemical studies have been carried out on the sediments of the Lokoja and Patti Formations within the southern Bida Basin with a view to deducing the provenance, palaeodepositional characteristics and tectonic history of the sediments. Field observations show that the Lokoja Formation is made up of conglomerates, coarse to medium grained sandstone and claystone while the Patti Formation consists of medium – fine grained sandstone, claystone, shale, siltstone and ironstone. Pebble morphometry of the Lokoja Formation indicates fluvial environment while granulometric study of the sandstone indicates that they are medium to coarse grained and poorly sorted. Sandstone petrography showed that quartz is generally > 65.98 % while feldspar ranged from 6.45 to 25.97 % and classified the basal Lokoja Sandstone as arkose while the upper sequence and the sandy facies of the Patti Formation are subarkose. Heavy mineral assemblages are mainly; zircon, rutile, tourmaline and staurolite, with ZTR index ranging from 62 to 78%, indicating immature sandstone. The dominant major oxide constituent within the Lokoja Formation are; SiO_2 (55.4 - 64.10%), Al_2O_3 (18.65 - 19.66%), Fe_2O_3 (1.76-3.15%) while the composition each of MgO, CaO, Na_2O and K_2O is < 4%. On the other hand, sediments of the Patti Formation have higher SiO_2 (56.62-79.26%) and relatively lower values for Al_2O_3 (13.28 - 19.28%) and Fe_2O_3 (0.84 - 1.65%). The trace elements are dominated by Sr (165.4-411.9ppm) and Ba (635-908ppm) in the Lokoja Formation while Zr (644.9-1969.8 ppm) has higher values in the Patti Formation. In both units, Ce (46.6-235.8 ppm), La (25.8-116.4 ppm), and Nd (18.1-95.9 ppm) are the most abundant rare earth elements with both trace and rare earth elements concentrating more in the finer clastics of the Patti Formation. The ternary plots of framework composition indicated a passive continental block provenance, oxidizing and humid paleoclimatic condition for the sediments. The plots of Th-Sc-Zr/10, Th/Co versus La/Sc and K_2O/Na_2O against SiO_2 lie within felsic rocks region. The study concluded that the sediments were sourced from the adjacent south-western and north-central basement complex of Nigeria and deposited in a fluvial setting.

Keywords: Provenance, Tectonic, Paleoenvironment, Paleoclimate, Bida Basin, Nigeria

INTRODUCTION

The Bida Basin, which is one of the major inland sedimentary basins in Nigeria, is oriented in the northwest – south-eastern direction and perpendicular to the main axis of the Benue Trough and the Niger Delta basin of Nigeria (Fig. 1). It is frequently regarded as the northwestern extension of the Anambra Basin to the southeast, both of which major depocentres were during the third major transgressive cycle of southern Nigeria in the Upper Cretaceous times (Obaje *et al*., 2004). Its sedimentary fill is about 4700m, estimated from magnetic data (Udensi and Osazuwa, 2004). Previous geological investigations in the Bida basin include among others; Falconer (1911), Jones (1953, 1958), Adeleye (1973, 1974, 1989), Jan du Chene *et al.* (1978), Agyingi (1991), Braide (1992), Ladipo *et al.* (1994), Abimbola (1997), Abimbola *et al.* (1999), Ojo and Akande (2003, 2006, 2009), Obaje *et al.* (2004, 2011), Akande *et al.* (2005), Okunlola and Idowu (2012) and Nton and Okunade (2013). These studies covered the geology, stratigraphy, sedimentology, mineralogy and hydrocarbon potential of the different formations within the basin.

Ojo and Akande (2003) and Ojo and Akande (2009) reported on facies relationship and depositional environments of the Upper Cretaceous Lokoja Formation as well as the sedimentology and depositional environment of the Patti Formation within the Bida basin respectively. Their study however centered solely on field relationship, textural and palaeocurrent characteristics. It has been reported that the chemical composition of clastic sedimentary rocks is a function of a complex interplay of several variables, including the nature of source rocks, source area weathering and diagenesis (Bhatia, 1983; Roser and Korsch , 1986; McLennan *et al.,* 1993). In addition, the tectonic setting of a sedimentary basin has been considered as the overall primary control on the composition of sedimentary rocks as different tectonic environments have distinctive provenance characteristics and also distinctive sedimentary processes (Dickinson, 1985; Osae *et al.*, 2006).

The present study therefore integrates from outcrop studies, sedimentology, petrography and elemental geochemistry in predicting the provenance, tectonic settings, as well as palaeodepositional environment of the sediments of the Lokoja and Patti Formations of southern Bida Basin. This study, no doubt will provide additional information that would be useful to researchers and explorationists.

Location of Study Area and Geology

The Bida Basin constitutes a series of Cretaceous and later rift basins in Central and West Africa whose origin is related to the opening of the South Atlantic. The study area covers road cut exposures along the Lokoja – Abuja highway (Fig. 1) and lies within latitudes 07° 51' to 08° 26' and longitudes 006° 41' to 006° 56'. The Bida Basin is divided into northern and southern Bida Basin, each varying in lithostratigraphic succession (Adeleye, 1973). The regional stratigraphic succession in the Bida Basin and its relationship to the Anambra Basin is shown in Figure 2.

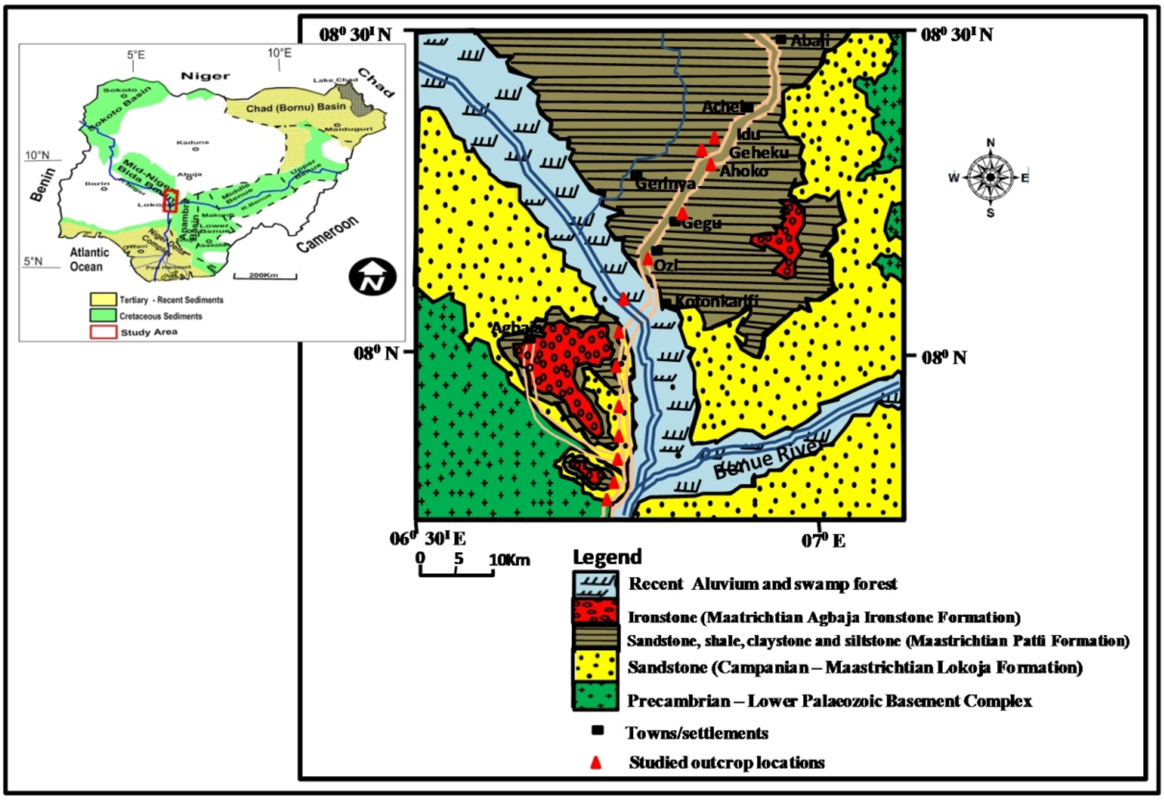


Figure 1: Geological Map of Study Area Showing Locations of Studied Sections with Inset Map of Nigeria Showing NW/SE Trending Bida Basin (Modified After Agyingi, 1991)

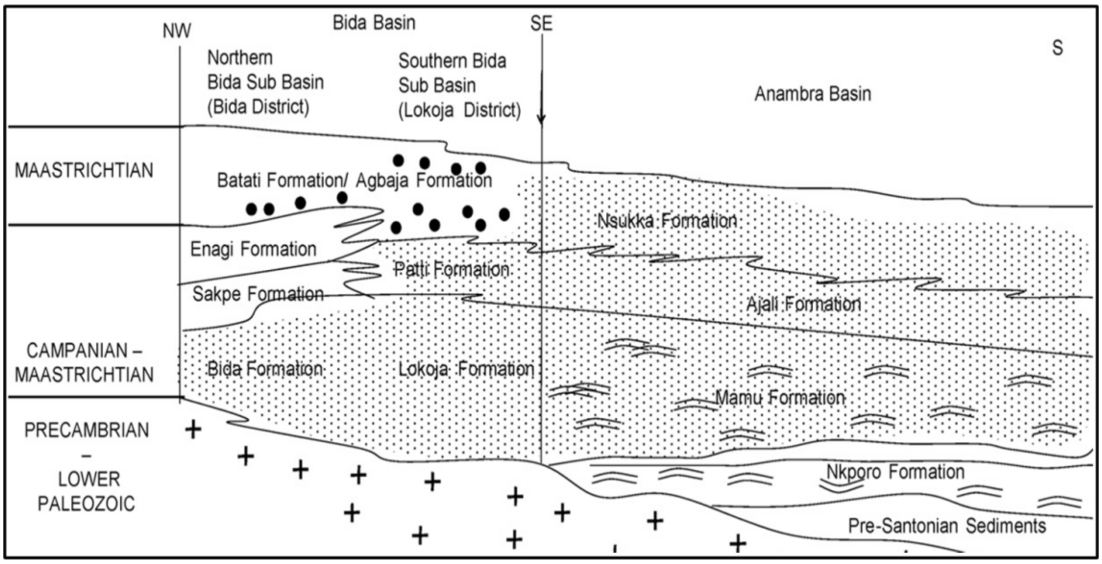


Fig. 2: Regional Stratigraphic Successions in the Bida Basin and Restored NW-SE-S Stratigraphic Relationships from the Bida Basin to the Anambra Basin (After Akande *et al.*, 2005)

The Southern Bida Basin, which is the focus of this study, extends from the confluence of the Niger-Benue River at Lokoja to Abaji, near the Federal capital Territory. It is made up of three formations from oldest to youngest; Lokoja, Patti and Agbaja Formations.

The Lokoja Formation is the oldest stratigraphic sequence in the Southern Bida Basin and unconformably overlies the Precambrian Basement Complex. It consists of basal conglomerate, subrounded to well rounded quartz, feldspar, pebbles and cobbles, especially at the sediment–basement contact. The pebbles are embedded in whitish clayey matrix. The basal conglomerate is overlain by fine to very coarse-grained conglomeritic sandstone, coarse-grained, cross bedded sandstone, and few thin oolitic iron stones (Fig. 3a; 3b). The sandstones are continental deposits, generally poorly sorted, composed mainly of quartz and feldspar and therefore texturally and mineralogically immature (Ojo and Akande, 2003).

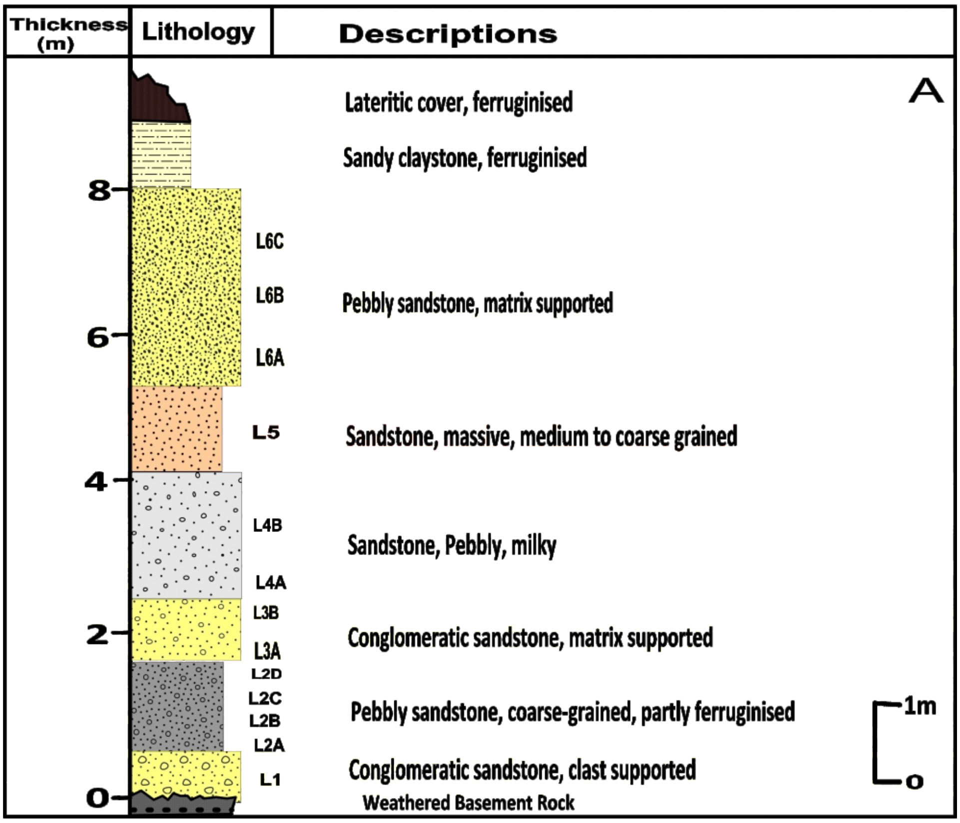


Figure 3a: Composite Lithologic Section of Lokoja Formation

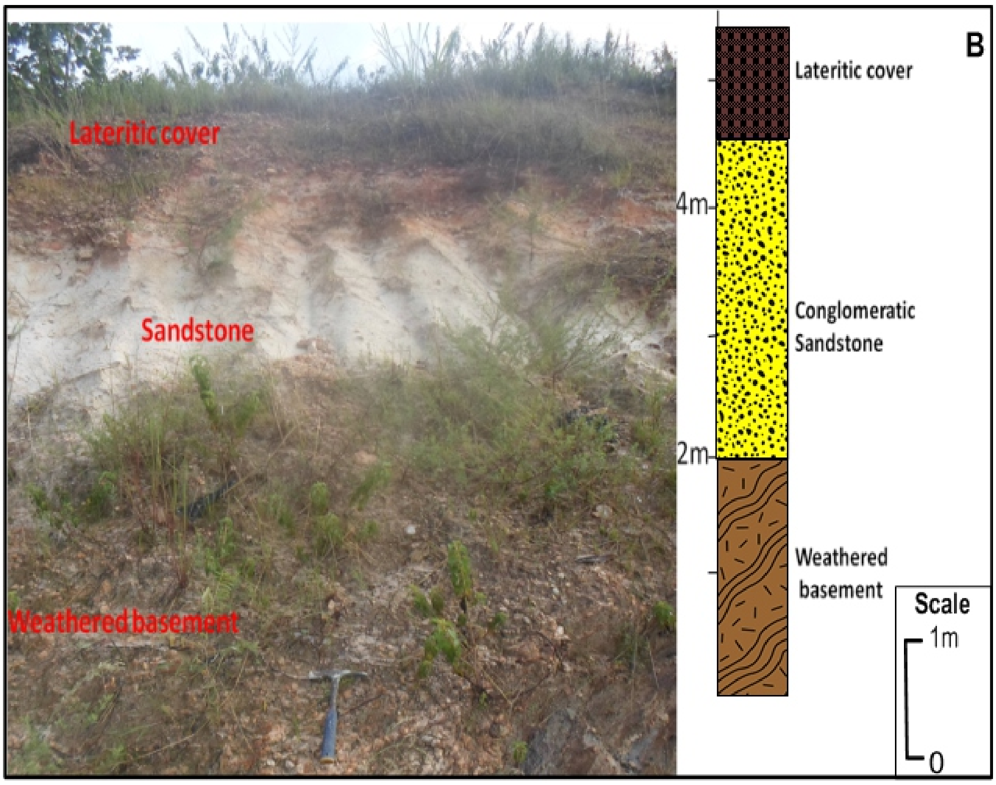


Figure 3b: Field Photograph taken at Filele, Lokoja Formation (N07° 51.306' and E006° 41.890')

The Patti Formation conformably overlies the Lokoja Formation and comprised up to 100m thick sequences of fine to medium-grained, grey and white sandstones, shale, siltstone, claystone, coaly units and oolitic ironstone exposed between Korton-Karfi and Abaji (Ladipo *et al.,* 2011). The formation extends to the Northern Bida basin to form the Sakpe Ironstones and Enagi Formation (Fig. 2). Figure 4a shows a composite lithology of Patti Formation while Figure 4b shows field photograph of Patti Formation at Ahoko as encountered in this study. The maximum exposed thickness is 70 m (Jones, 1955) while the oolitic ironstones range from 7-16m thick. Nton and Okunade (2013) has reported that the associated claystone is kaolinite and sourced from the nearby basement rocks while the organic matter is terrestrial, immature with prospect to generate gas at appropriate maturation. A Maastrichtian (and possibly Senonian) age was thus assigned to the formation based mainly on correlation with other formations. As reported by Ladipo *et al.* (2011), the associated sandstone units are more mineralogically and texturally matured compared to the Lokoja Formation. The Patti Formation is considered as flood plain deposits which developed into tidally influenced lacustrine facies in parts of the basin.

The Agbaja Ironstone Formation is the youngest rock sequence in the area and overlies the Patti Formation. This forms the protective lateritic capping, consisting of oolitic to pisolitic, concretionary and massive ironstone facies, with a thickness of 20m (Abimbola *et al.,* 1994). It forms the lateral equivalence of the Batati Ironstone of the Northern Bida basin and deposited in a continental- shallow marine environment.

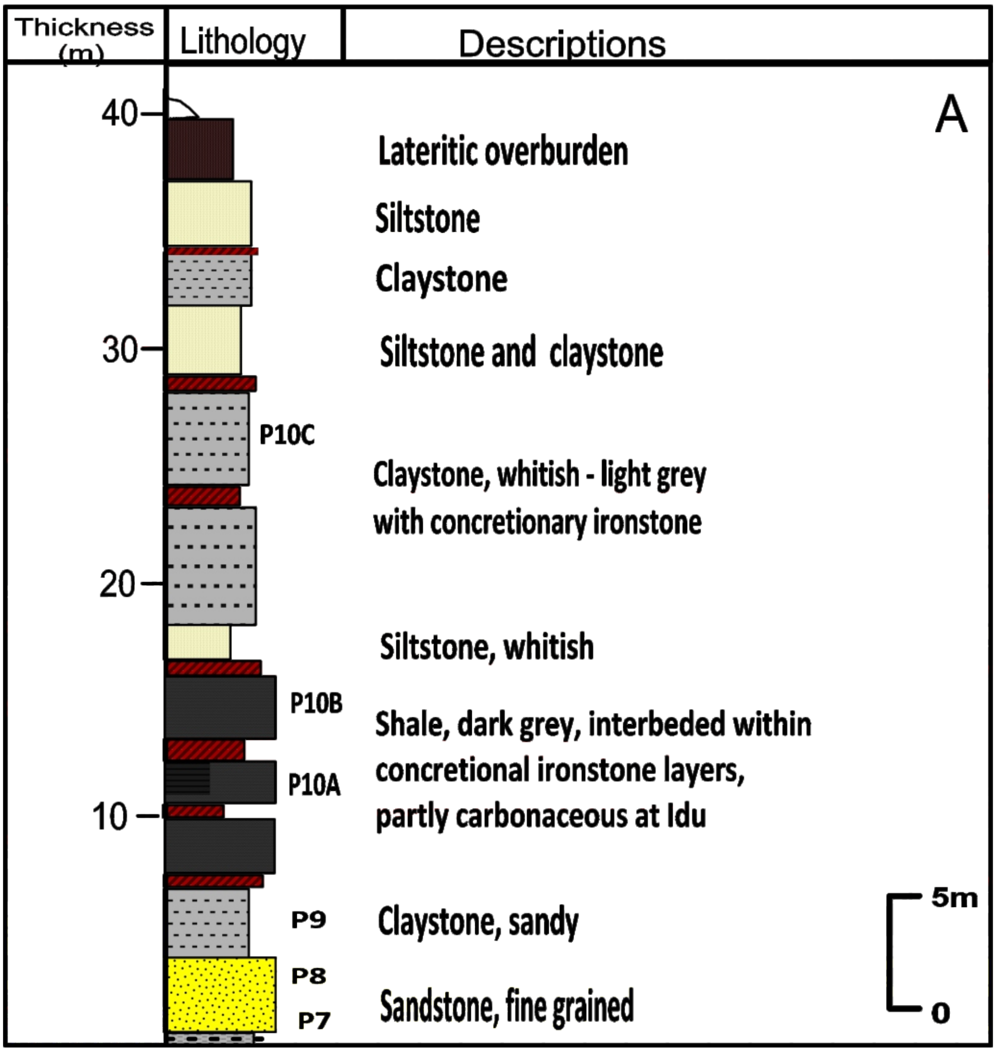


Figure 4a: Composite Lithologic Section of Patti Formation

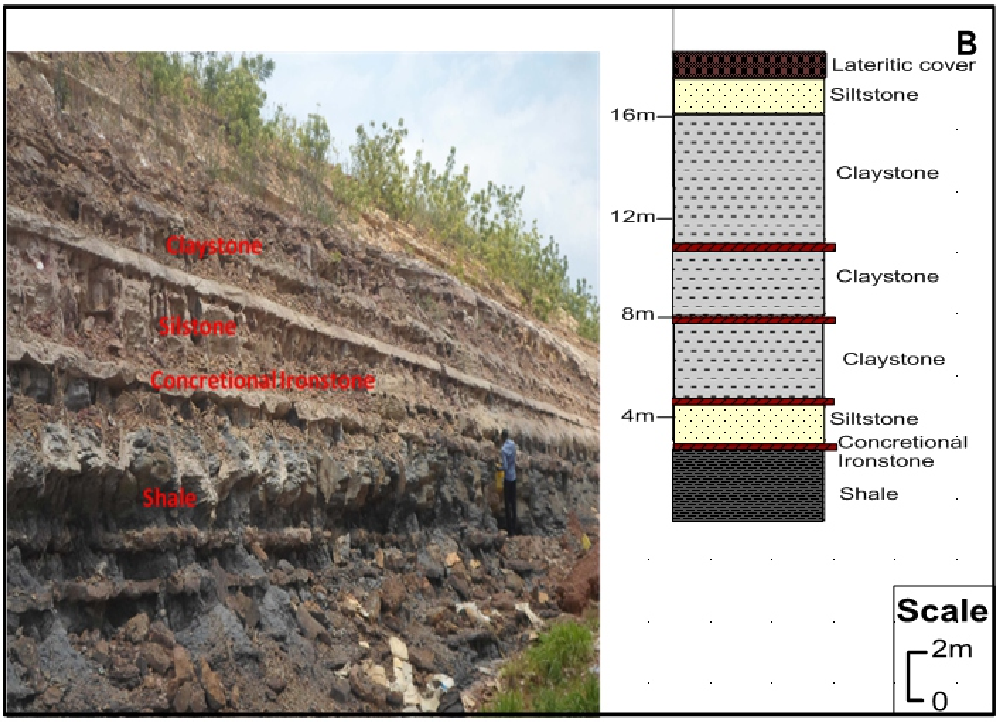


Figure 4b: Field Photograph taken at Ahoko, Patti Formation (N08^0 18.62' and E006^0 51.461')

METHODOLOGY

Field Sampling and Lithologic Description

A systematic field sampling method was employed involving taking vertical profiles of the sedimentary successions and noting variations in lithology, texture, thickness and sedimentary structures. Composite lithologic logs were generated for the investigated outcrop exposures (Figs. 3b and 4a). Field photographs of features of interest of Lokoja Formation at Filele and Patti Formation at Ahoko were taken and shown respectively in Figures 3b and 4b. Attempts were made to collect fresh and un-weathered samples at each location. A total of nineteen samples; thirteen from the Lokoja Formation and six from Patti Formation were used in this study. The samples were made up of pebbles, sandstone, shale and claystone. Each sample was labelled and the clasts of pebble and cobble were carefully and randomly collected where present for pebble morphometry analysis.

Textural Analyses

Selected sandstone samples were subjected to textural analyses involving pebble morphometry and granulometric studies at the Sedimentological Laboratory, Department of Geology, University of Ibadan, Nigeria.

Pebble Morphometry

Ten (10) individual pebbles from six pebbly units of the Lokoja Formation were used for the pebble morphology study. Various morphometric parameters of the clasts were determined by measuring their Long (L), Intermediate (I) and Short (S) axes using vernier calipers as described by Folk (1974). The various average ratios of the morphometric parameters were computed as shown below:

Flatness Ratio (FR) = S/L (After Lutig, 1962); Elongation Ratio (ER) = I/L (After Lutig, 1962); Maximum Projection Sphericity Index (MPSI) = $(S^2/LI)^{1/3}$ (After Sneed and Folk, 1958) and Oblate – Prolate Index (OPI) = [10(L-I)/(L-S)]/S/L-0.5(After Dobkins and Folk, 1970). Pebbles roundness was estimated according to the chart of Sames (1966). The sphericity form diagram of Sneed and Folk (1958) was used to determine the form name of each pebble.

Granulometric Analysis

A total of fifteen (15) sandstone samples were used for granulometric studies. The samples were air dried, disaggregated and subjected to standard methods of grain size analysis using a set of sieves at 1/2phi intervals (ASTM) on a Ro-tap sieve shaker for 15 minutes. Arising from the grain size distribution, cumulative curves were plotted from which statistical parameters were computed based on Folk and Ward (1957). The grain size analysis was conducted at the Sedimentological Laboratory, Department of Geology, University of Ibadan, Ibadan, Nigeria.

Thin Section Petrography

A total of ten (10) representative sandstone samples were selected for thin section petrography. Since the samples were loosely consolidated, they were impregnated with resin before cutting. Each sample was mounted on a glass slide using Canada balsam and later examined under the *Brunnel* petrological microscope. Point count method was used and individual percentages of the minerals were computed. Photomicrographs of features of interests were taken and classification of the sandstone was based on Folk (1974).

Heavy Mineral Studies

Based on lithological characteristics, heavy mineral analysis was carried out on nine (9) sandstone samples. Bromoform (S.G., 2.85) extracts of the heavy minerals were rinsed with acetone, dried and mounted on slides using epoxy. Petrographic examination was conducted using the *Brunnel* petrological microscope. Photomicrographs of features of interests were taken. The maturity index (ZTR) (Hubbert, 1962) was estimated for each sample. Both the thin section petrography and heavy mineral studies were conducted at the Petrology Microscope Laboratory, Department of Geology, University of Ibadan, Ibadan, Nigeria.

Geochemical Analysis

On the basis of lithologic variation, nine (9) representative samples constituting five (5) sandstone, two (2) shale and two (2) claystone were selected for whole rock geochemical analysis. An ICP emission spectrograph (Spectro Ciros Vision or Varian 735) was used for determining the major oxides and some trace elements after preliminary acid treatment. The Loss on ignition (LOI) was determined by measuring the weight loss after heating a 1g split sample at 95°C for 90 minutes.

Each sample was digested by weighing 0.2g aliquot in a graphite crucible mixed with 1.5g $LiBO_2/LiB_4O_7$ flux. The crucibles were placed in an oven and heated at 980°C for 30 minutes. The cooled bead was dissolved in 5% HNO_3 (ACS grade nitric acid diluted in demineralised water). Calibration standards and reagent blanks were added to sample sequences. The basic package consisting of thirty-four elements was determined for the shale and claystone samples. A second 0.5g split sample was digested in Aqua Regia and analysed by Inductively Coupled Plasma-Mass Spectrometer (Perkin-Elmer, Elan 6000) on powdered and pressed pellets to determine Au, Ag, As, Bi, Cd, Cu, Hg, Mo, Ni, Pb, Sb, Se and Zn. The major oxides, trace and rare earth metal were analyzed at the AMCE Analytical Laboratories Ltd, Canada.

RESULTS AND DISCUSSION

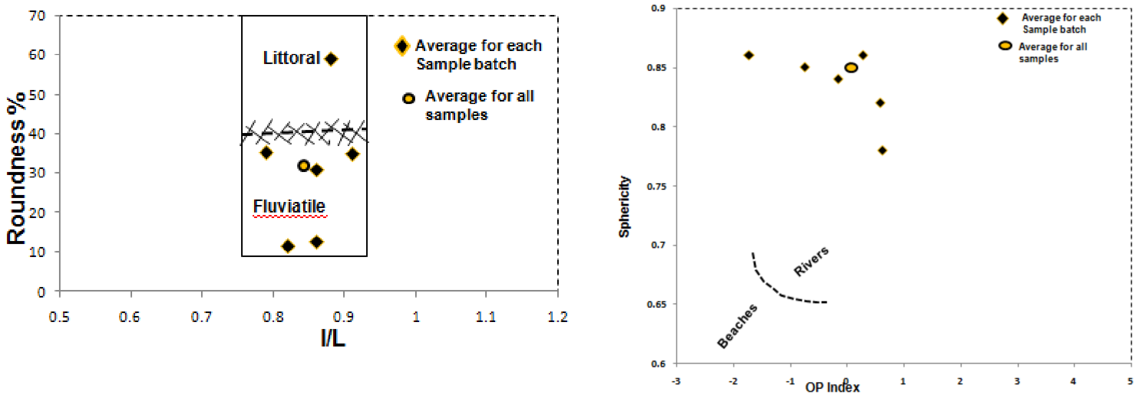
Textural Characteristics

The average values of pebble morphometric parameters for each sample batch are as presented in Table 1. The average long axis of the pebbles of Lokoja Formation is 4.46cm and lies within the coarse size. The mean elongation for the pebbles is 0.86, while the flatness ratio and sphericity values are 0.71and 0.84 respectively. Average value of oblate- prolate (OP) index is -0.15, and indicates forms ranging from compact to compact bladed. The average roundness value for the study samples is 31.

Following Sames (1966), a bivariate plot of roundness versus elongation (I/L); (Fig. 5a), shows that the majority of the pebbles plot in the fluviatile field with a lone sample in the littoral field. The bivariant plots of sphericity against oblate – prolate index (Dobkins and Folk, 1970; Fig. 5b) indicate that the pebbles from the study area are within the river field. Arising from the morphometric parameters and bivariant plots, it is obvious that majority of the pebbles under study have fluvial influences.

Table 1: Average Values of Pebble Morphometric Data (ten pebbles in each data).
Where L, I and S are the long, intermediate and short axes respectively, S/L = Flatness, I/L = Elongation, $(S^2/LI)^{1/3}$ = Sphericity, OP = 10(L-I-0.5)/(L-S)/(S/L) = Oblate - Prolate Index. Compact (C) = 33.33%, Compact Bladed (CB) = 66.67%.

Sample No.	Formation	L (cm)	I (cm)	S (cm)	S/L	I/L	(L-I)/(L-S)	$(S^2/LI)^{1/3}$	OP Index	Form Name	Roundness (%)
L1	Lokoja	5.44	4.7	4.02	0.74	0.86	0.52	0.86	0.29	C	31
L2A	Lokoja	4.56	3.74	3.04	0.67	0.82	0.54	0.82	0.59	CB	12
L2B	Lokoja	5.11	4.05	3.14	0.61	0.79	0.54	0.78	0.62	CB	35
L2D	Lokoja	4.29	3.91	3.26	0.76	0.91	0.37	0.86	-1.72	C	35
L3B	Lokoja	3.47	3.07	2.57	0.74	0.88	0.44	0.85	-0.75	C	59
L6A	Lokoja	3.87	3.33	2.8	0.72	0.86	0.5	0.85	0.06	C	13
Mean	Lokoja	**4.46**	**3.80**	**3.14**	**0.71**	**0.86**	**0.49**	**0.84**	**-0.15**	**C**	**31**



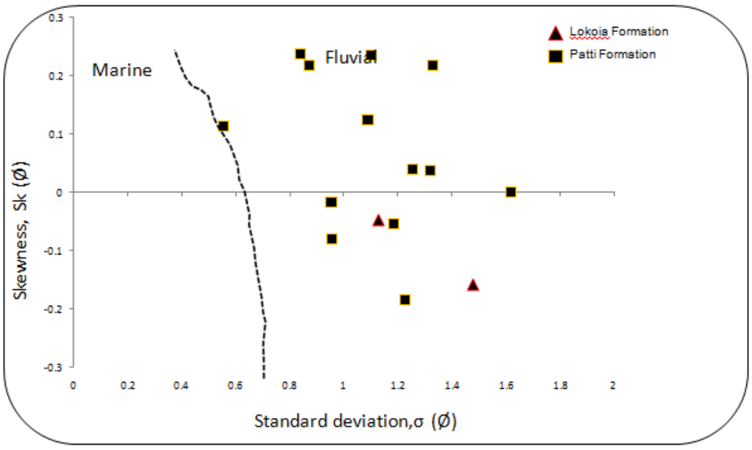
(a) (b)

Fig. 5: (a) Pebble Roundness Plotted Against the Elongation Ratio for the Studied Sediments Using the Environmental Determination Chart of Sames (1966). (b) Plot of Maximum Projection Sphericity against Oblate-Prolate Index for the Studied Sediments (Modified after Dobkins and Folk, 1970)

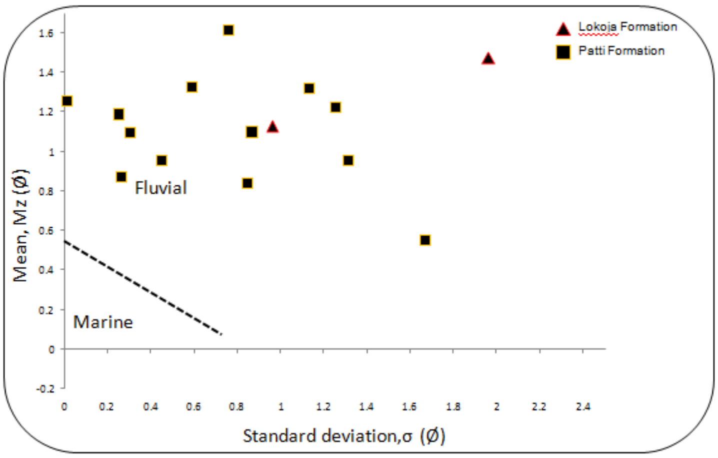
The result of grain size analysis is shown in Table 2. The sandstones range from medium to coarse grained with > 60% in the coarse grain size; the standard deviation reflects mainly poorly sorted population and ranges (0.55-1.62; av. 1.09). Skewness values range from -0.02-0.23, while kurtosis ranges between 0.96-1.52, with leptokurtic population dominating. Bivariant plots of skewness versus standard deviation (Friedman, 1967; Fig. 6a); mean size vs standard deviation (Moiola and Weiser, 1968; Fig. 6b) as well as plot of skewness versus median (Stewart, 1958; Fig. 6c) strongly amplify a fluvial environment for the siliciclastics in the study area.

Table 2: Summary of Grain Size Parameters and their Descriptive Terms (After Folk and Ward, 1957)

Parameters / Sample No.	**Formation**	**Graphic Mean**	**Standard Deviation**	**Coefficient of Skewness**	**Kurtosis**
L1	Lokoja	0.25 (Coarse sand)	1.18 (Poorly sorted)	-0.05 (Symmetrical)	1.24 (Leptokurtic)
L2A	Lokoja	0.87 (Coarse sand)	1.09 (Poorly sorted)	0.13 (Fine skewed)	1.14 (Leptokurtic)
L2B	Lokoja	0.76 (Coarse sand)	1.62 (Poorly sorted)	0 Symmetrical	1.10 Mesokurtic
L2C	Lokoja	1.31 (Medium sand)	0.96 (Moderately sorted)	-0.08 (Symmetrical)	1.52 (Very leptokurtic)
L2D	Lokoja	1.13 (Medium sand)	1.32 (Poorly sorted)	0.04 Symmetrical	1.12 Leptokurtic
L3A	Lokoja	0.26 (Coarse sand)	0.87 (Moderately sorted)	0.22 (Fine skewed)	1.22 (Leptokurtic)
L3B	Lokoja	1.25 (Medium sand)	1.23 (Poorly sorted)	-0.19 (Coarse skewed)	1.04 (Mesokurtic)
L4A	Lokoja	0.45 (Coarse sand)	0.96 (Moderately sorted)	-0.02 (Symmetrical)	1.06 (Mesokurtic)
L4B	Lokoja	0.84 (Coarse sand)	0.84 (Moderately sorted)	0.24 (Fine skewed)	1.21 (Leptokurtic)
L5	Lokoja	0.59 (Coarse sand)	1.33 (Poorly sorted)	0.22 (Fine skewed)	1.30 (Leptokurtic)
L6A	Lokoja	0.01 (Coarse sand)	1.26 (Poorly sorted)	0.04 Symmetrical	1.01 Mesokurtic
L6B	Lokoja	1.67 (Medium sand)	0.55 (Moderately sorted)	0.11 (Fine skewed)	1.35 (Leptokurtic)
L6C	Lokoja	0.30 (Coarse sand)	1.10 (Poorly sorted)	0.24 (Fine skewed)	1.135 (Leptokurtic)
P7	Patti	0.96 (Coarse sand)	1.13 (Poorly sorted)	-0.05 (Symmetrical)	0.96 (Mesokurtic)
P8	Patti	1.96 (Medium sand)	1.48 (Poorly sorted)	-0.16 (Coarse skewed)	1.16 (Leptokurtic)



(a)



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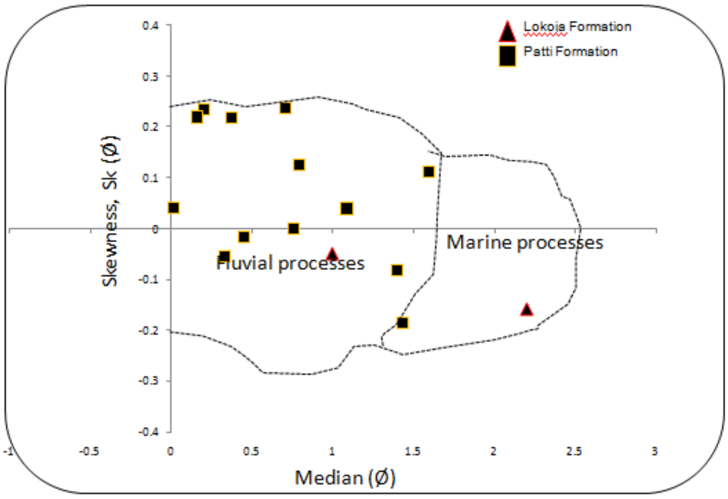


(c)

Fig. 6: (a) Binary Plots of Skewness versus Standard Deviation for Sandstone of Studied area (Boundary Modified After Friedman, 1967). (b) Binary Plots of Mean versus Standard Deviation for Sandstone of Studied area (Boundary after Moiola and Weiser, 1968) (c) Plot of Skewness against Median for Sandstone of studied Area (Boundary Modified after Stewart, 1958)

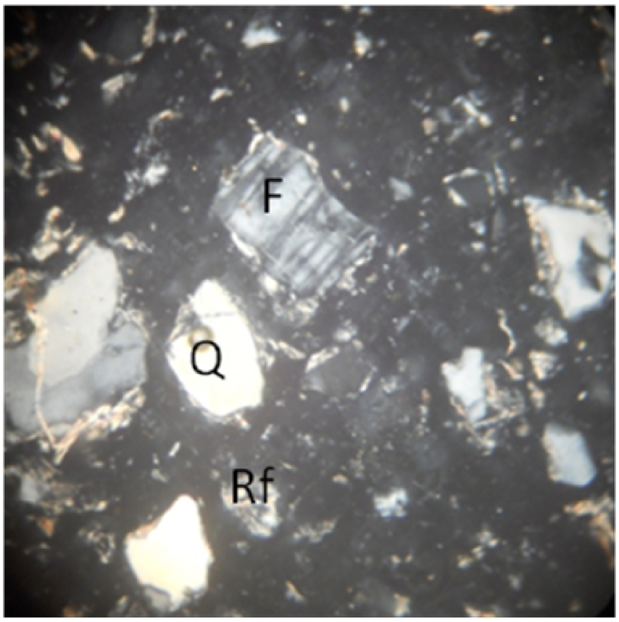
Petrography

The result of sandstone petrography is shown in Table 3. From the modal composition, the dominant mineral in the assemblage is quartz (> 65%) with feldspar and rock fragments as other constituents (Fig. 7). The feldspars are mainly microcline and range from 6.45 to 25.97%. The rock fragments are mainly that of igneous and metamorphic varieties of < 10% (2.13 – 9.76%). The cementing materials are mainly silica with optical continuity with the quartz grains. Polycrystalline quartz grains are more than monocrystalline variety. Most of the grains are angular to sub-angular; whereas sub- rounded ones are few.

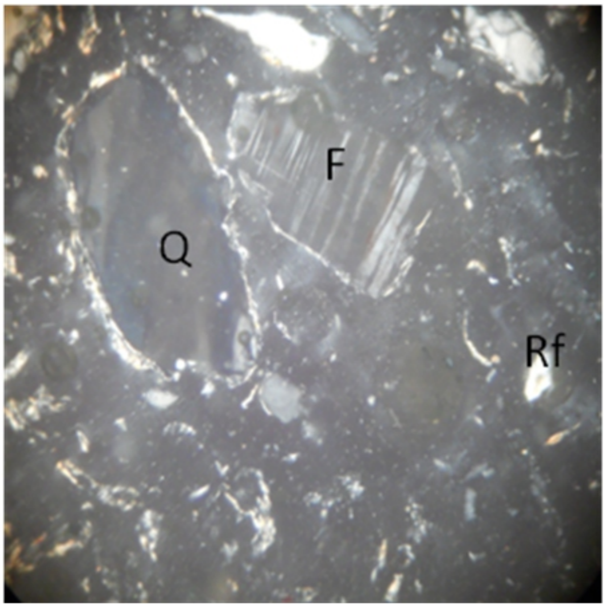
Table 3: Relative Abundance of the Constituents and Framework Composition of the Sandstones

	Quartz						Others				Framework composition (%)		
Sample No.	Formation	Qm	Qp	TQ	Feldspar	Rock Fragments (RF)	Matrix	Cement	Mica	Φ	Q	F	RF
L1	Lokoja	22.0	46.0	68.0	10.0	5.5	10.0	4.5	1.0	1.0	81.93	12.05	6.02
L2A	Lokoja	23.0	38.0	61.0	14.0	6.3	12.0	3.7	1.0	2.0	75.31	17.28	7.41
L2B	Lokoja	28.0	36.0	64.0	24.0	9.0	10.3	3.0	3.0	1.5	65.98	24.74	9.28
L2C	Lokoja	27.0	30.0	57.0	22.0	5.7	6.3	2.5	5.0	1.5	67.30	25.97	6.73
L2D	Lokoja	31.0	34.0	65.0	23.0	2.0	3.0	1.0	4.0	2.0	72.22	25.55	2.22
L4A	Lokoja	26.0	38.0	64.0	13.0	5.6	9.4	4.0	2.0	2.0	78.05	15.85	6.10
L4B	Lokoja	21.0	52.0	73.0	12.0	4.0	5.0	4.0	--	2.0	82.95	13.64	3.41
L6B	Lokoja	16.0	40.0	56.0	18.0	8.0	9.0	4.0	1.0	3.0	68.29	21.95	9.76
P7	Patti	32.0	53.0	85.0	7.0	2.0	2.0	1.0	1.0	2.0	90.43	7.45	2.13
P8	Patti	32.0	52.0	84.0	6.0	3.0	3.0	2.0	1.0	1.0	90.32	6.45	3.23

Qm = Monocrystalline quartz; Qp =Polycrystalline quartz; Qt-Total quartz; Φ= porosity; Q=Quartz; F= Feldspar; RF= Rock Fragments



L 2C



L 2D

Fig. 7: Photomicrograph of Arkosic Sandstone of Lokoja Formation (L 2C and L 2D; cross nicol, mag. = 40x) Characterized by Poorly Sorted and Angular grains of Quartz (Q), Rock fragments (Rf) and Fresh Feldspar (F)

Ternary plot of framework elements based on Folk (1974) shows that the sandstone plots as arkose to subarkose (Fig. 8).

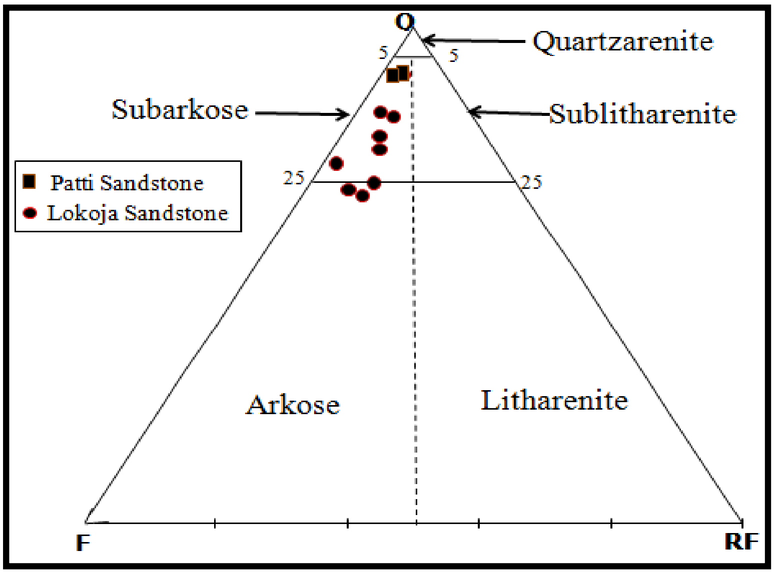
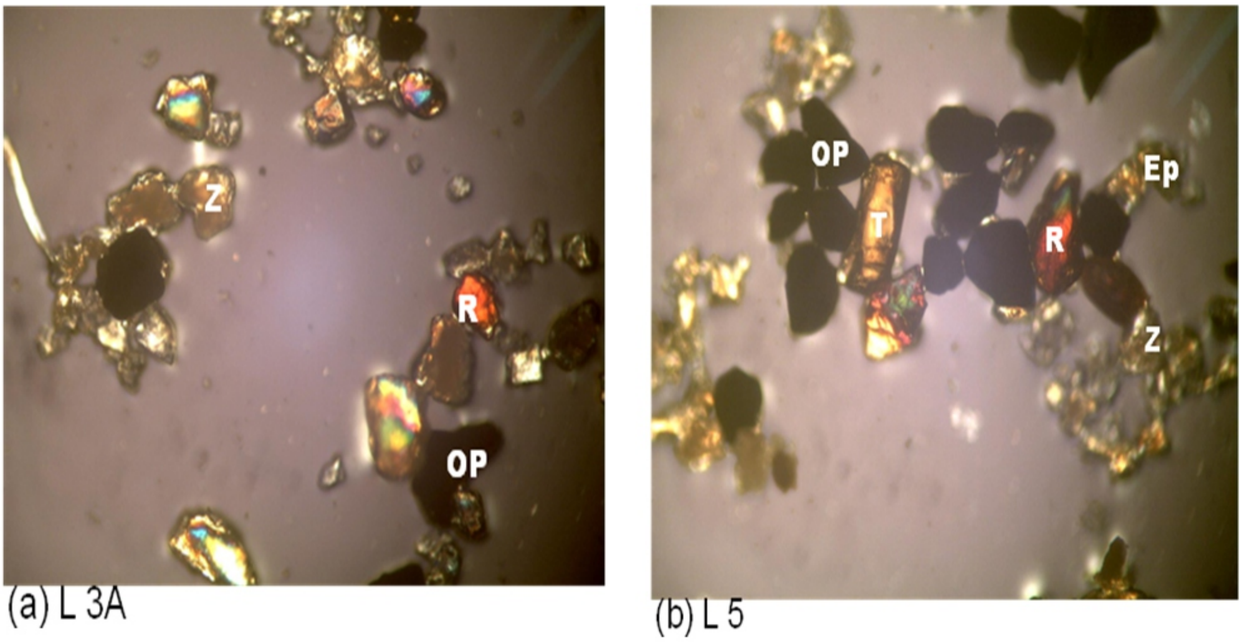


Fig. 8: Ternary Diagram for Sandstone Classification for Study Area (Modified After Folk, 1974)
Note Q = Total Quartz, F = Feldspar and RF = Rock Fragments

The result of heavy mineral suites is shown in Table 4 and revealed the following assemblages: zircon, tourmaline, rutile, staurolite, epidote, sillimanite, apatite and garnet (Fig. 9). Such heavy minerals assemblages are typical of igneous and metamorphic provenance of the nearby basement complex. The ZTR index (Hubbert, 1962) ranges from 62 – 78% (Table 4) which indicates immature sandstone derived from the nearby granite and gniesses probably the western basement complex around Lokoja.

Table 4: Composition of Heavy Mineral Suites in Lokoja and Patti Formations

Minerals / Sample No.	Formation	Zircon (%)	Rutile (%)	Tourmaline (%)	Staurolite (%)	Epidote (%)	Silimanite (%)	Garnet (%)	Apatite (%)	Total non opaque (%)	Opaque (%)	ZTR Index (%)
L1	Lokoja	18.0	6.0	4.0	6.0	7.0	3.0	1.0	-	45.0	42.0	62.0
L2A	Lokoja	30.0	9.0	2.0	6.0	5.0	-	3.0	3.0	58.0	30.0	71.0
L2B	Lokoja	35.0	9.0	2.0	3.0	8.0	4.0	-	-	61.0	57.0	75.0
L2C	Lokoja	30.0	8.0	4.0	4.0	7.0	-	3.0	-	56.0	47.0	75.0
L3B	Lokoja	33.0	16.0	4.0	4.0	10.0	-	1.0	4.0	72.0	47.0	74.0
L4A	Lokoja	28.0	7.0	4.0	7.0	6.0	-	2.0	-	54.0	46.0	72.0
L6B	Lokoja	28.0	12.0	3.0	4.0	11.0	-	-	8.0	66.0	48.0	65.0
P7	Patti	30.0	7.0	4.0	-	10.0	-	-	3.0	54.0	51.0	76.0
P8	Patti	27.0	8.0	3.0	-	4.0	-	-	7.0	49.0	22.0	78.0



Z = Zircon, T = Tourmaline, R = Rutile, Ep = Epidote, and Op = Opaque

Fig. 9: Photomicrographs of Heavy Minerals in Lokoja Sandstone samples (mag. = 40x)

Geochemistry

Major Elements Geochemistry

The results of the major oxides are shown in Table 5. The elemental oxides of the Lokoja Sandstone are; 54.4-64.12% SiO_2; 18.65-22.45 % Al_2O_3; 1.76-3.15 % Fe_2O_3; 0.44-2.04% CaO; 0.31-3.32 % Na_2O and 1.94- 3.31% K_2O. Other oxides such as TiO_2, P_2O_5 and Cr_2O_3 are <1 % each. The Patti Formation, with a lone sandstone facies has; SiO_2 (79.25%); Al_2O_3 (13.08%) making up > 90%, while MgO, CaO, Na_2O, K_2O and P_2O_5 < 1% each. The average composition of the claystone facies of the Patti Formation are; SiO_2 (72.39%); Al_2O_3 (17.23%; Fe_2O_3 (1.25%) making up > 90% while the shale facies are correspondingly; 65.11%, SiO_2; 16.97%, Al_2O_3; with other oxides < 2%.

The Fe_2O_3 value is relatively low (< 4%) in all the samples with the Lokoja sandstone having the highest value averaging 2.46%. This value is lower in sediments of Patti Formation with an average of 0.9%, 1.2% and 1.0% for the sandstone, claystone and shale respectively. Generally, there are lower values of TiO_2; CaO, Na_2O, P_2O_5 and MnO.

The comparatively higher values of K_2O and Na_2O in the sandstone of the Lokoja Formation as against that of Patti Formation (Table 5) indicate relatively compositionally matured sandstone of the Patti Formation.

The K_2O content of the Lokoja sandstone indicates slightly enriched K-feldspar or illite (Akpokodje *et al.*, 1991; Okunlola and Idowu, 2012).

Table 5: Major Oxide Concentrations for Sediments of Lokoja and Patti Formations, and the post-Archean Australian Average Shale (PAAS) (* Taylor and McLennan, 1985)

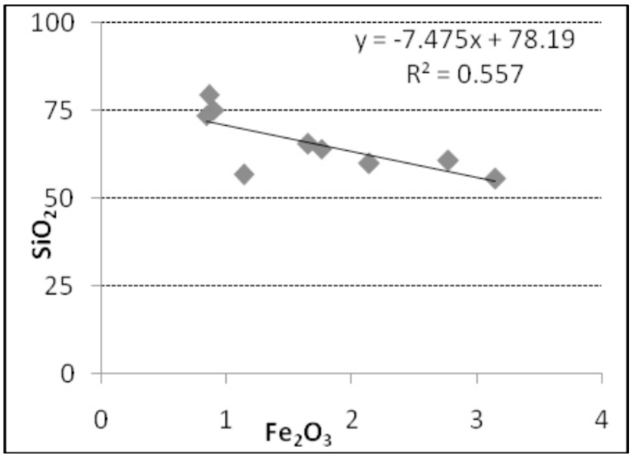
Sample No.	L2A	L2B	L2C	L6C	P8	P9	P10A	P10B	P10C	Average				PAAS
Formation	Lokoja	Lokoja	Lokoja	Lokoja	Patti	Patti	Patti	Patti	Patti	Lokoja	Patti	Patti	Patti	-
Rock type / Oxides (%)	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone	Claystone	Shale	Shale	Claystone	Sandstone	Sandstone	Claystone	Shale	-
SiO_2	59.80	60.61	64.1	55.4	75.11	79.26	56.62	73.59	65.52	59.98	75.11	72.39	65.11	62.40
Al_2O_3	19.46	19.66	18.65	22.45	15.91	13.28	19.28	14.65	21.18	20.06	15.91	17.23	16.97	18.78
Fe_2O_3	2.14	2.77	1.76	3.15	0.90	0.86	1.14	0.84	1.65	2.46	0.9	1.255	0.99	7.18
MgO	1.09	0.50	0.47	0.70	0.05	0.06	0.06	0.15	0.16	0.69	0.05	0.11	0.11	2.19
CaO	2.04	1.37	1.44	0.44	0.03	0.07	0.02	0.03	0.07	1.32	0.03	0.07	0.03	1.29
Na_2O	3.32	1.49	2.36	0.31	0.02	0.05	0.01	0.07	0.05	1.87	0.02	0.05	0.04	1.19
K_2O	1.94	3.20	2.67	3.31	0.10	0.55	0.34	1.55	0.81	2.78	0.1	0.68	0.95	3.68
TiO_2	0.40	0.29	0.34	0.5	1.12	1.37	1.43	1.88	2.07	0.38	1.12	1.72	1.66	0.99
P_2O_5	<0.01	<0.01	<0.01	<0.01	0.06	0.04	0.04	0.05	0.05	0.00	0.06	0.045	0.05	0.16
MnO	0.02	<0.01	<0.01	0.01	<0.01	0.01	<0.01	0.03	0.01	0.01	<0.01	0.01	0.02	-
Cr_2O_3	0.012	0.009	0.008	0.009	0.01	0.008	0.012	0.012	0.014	0.01	0.01	0.011	0.01	-
LOI	9.60	9.90	8.00	13.60	6.30	4.20	20.80	6.70	8.20	10.28	6.30	6.20	13.75	-
Total	99.82	99.80	99.80	99.88	99.61	99.76	99.75	99.55	99.78	99.82	99.61	99.77	99.66	97.86
SiO_2/Al_2O_3	3.07	3.08	3.44	2.47	4.72	5.97	2.94	5.02	3.09	2.99	4.72	4.20	3.84	-
K_2O/Na_2O_3	0.58	2.15	1.13	10.68	5.00	11.00	34.00	22.14	16.20	1.49	5.00	13.60	23.63	-
K_2O_3/Al_2O_3	0.10	0.16	0.14	0.15	0.01	0.04	0.02	0.11	0.04	0.14	0.01	0.04	0.06	-
Al_2O_3/TiO_2	48.65	67.79	54.85	44.90	14.21	9.69	13.48	7.79	10.23	52.43	14.21	10.02	10.25	-
$Log(K_2O/Na_2)$	-0.23	0.33	0.05	1.03	0.70	1.04	1.53	1.35	1.21	0.17	0.70	1.13	1.37	-
CIA (%)	73.00	76.00	74.00	85.00	99.00	95.00	98.00	90.00	96.00	77.00	99.00	96.00	94.00	-
CIW (%)	78.00	87.00	83.00	97.00	100.00	99.00	100	99.00	99.00	86.00	00	99.00	100.00	-

Titanium is mainly concentrated in phyllosilicates (Condie *et al.*, 1992) and is relatively immobile compared to other elements during various sedimentary processes and may strongly represent the source rocks (McLennan *et al.*, 1993). The sandstone of Lokoja Formation shows lower TiO_2 values than the post-Archean Australian average shale (PAAS; Taylor and McLennan, 1985), which suggests more felsic material in the source rocks. On the other hand, the values in Patti Formation are higher.

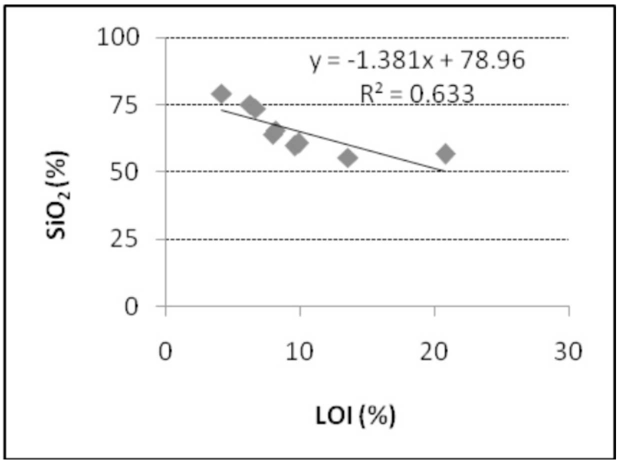
The low concentrations of Fe_2O_3+TiO_2+MgO (av 3.53% for Lokoja sandstone); (2.07%, 3.09% and 2.75% for sandstone, claystone and shale facies of the Patti Formation) imply that the sediments are chemically inert and non-corrosive. For the associated claystone, such concentration may offer good quality kaolin (Ojo *et al.* 2011). The values of the silica-alumina ratios for the samples strongly support that it is highly siliceous.

Cox *et al.* (1995) have utilized K_2O/Al_2O_3 ratio as an indicator of ancient sediments' composition. They proposed that K_2O/Al_2O_3 ratio for clay minerals and feldspars are; 0.0 to 0.3 and 0.3 to 0.9, respectively. The values obtained for all the samples (between 0.01 to 0.14) are closer to the lower limit of clay mineral range of Cox *et al.* (1995).

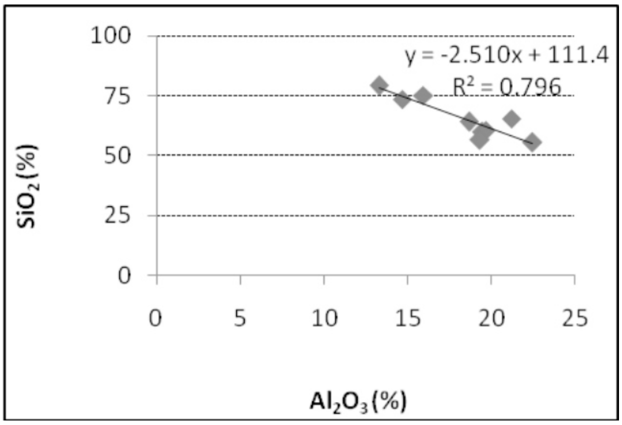
Cross plots of % SiO_2 versus Fe_2O_3 (Fig. 10a); SiO_2 versus Al_2O_3 (Fig. 10b) and SiO_2 versus LOI (Fig. 10c) all indicate negative correlation. These demonstrate influence of weathering processes through enrichment of silica and depletion of Fe and Mg as well as the decrease in LOI with increasing weathering and maturity of the sediments. The negative correlation between SiO_2 and Al_2O_3 is also an indication of the fact that most of the silica is present as quartz grains (Tijani *et al.*, 2010). However, the positive correlation between Fe_2O_3 and Al_2O_3 (Fig. 10d) is an indication of a common source. This suggests possible control by the proportion of clay (fines) contents as products of weathering/ferruginization processes. Positive correlations with Al_2O_3 are shown by most of the major elements. It can be concluded, therefore, that the enrichment of other major elements in the Lokoja and Patti Sediments is related to the enrichment of ferromagnesian minerals and feldspars probably due to short transportation of the source materials.



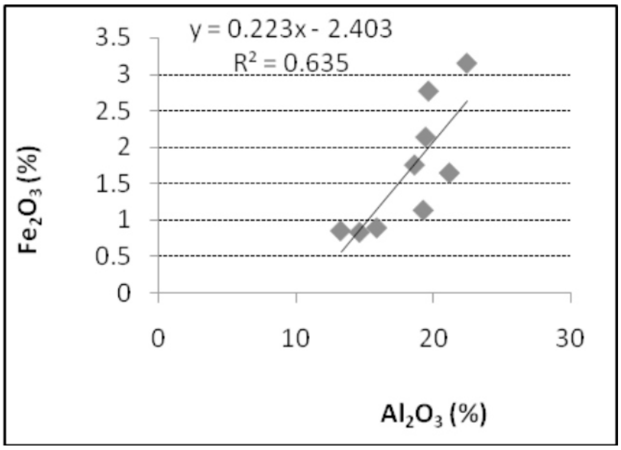
(a)



(c)



(b)



(d)

Fig. 10: Cross Plots of Major Oxides: (a). SiO_2 against Fe_2O_3. (b). SiO_2 against Al_2O_3. (c). SiO_2 against LOI. (d). Fe_2O_3 against Al_2O_3.

Trace Element Geochemistry

The results of the trace element geochemistry are shown in Table 6. Zr dominates the trace element suites with values ranging from 197.4 ppm to 481. 1ppm (av. 272 ppm for Lokoja Sandstone) and 644.9 - 2058.7 ppm for Patti Formation (av. 1968.8ppm; 899.05 ppm and 1492ppm for sandstone, claystone and shale facies respectively). Trace elements such as ;Y, Ni, Cr, Th, are enriched in the finer sediments of the Patti Formation than the more coarse Lokoja Sandstone with the exception of Sr, where the concentration is higher in Lokoja Formation. The negative correlation observed between $SiO_2$and the trace elements suggests most of the trace elements are concentrated in the clay fraction. The high values of Sr (165.4-411.9 ppm) and Ba (~635–908 ppm) in Lokoja Sandstone as against respective values of (31.3-59.8ppm) and (~141–401 ppm) in the Patti Formation as well as PAAS, are attributable to the associated feldspar in the adjoining basement provenance (Mielke, 1979; Elueze, 1987).

Table 6: Trace Element Concentration for Sediments of Lokoja and Patti Formations, Compared with the post-Archean Australian Average Shale (PAAS)

Sample No.	L2A	L2B	L2C	L6C	P8	P9	P10A	P10B	P10C	Average				PAAS
Formation	Lokoja	Lokoja	Lokoja	Lokoja	Patti	Patti	Patti	Patti	Patti	Lokoja	Patti	Patti	Patti	-
Rock type / Elements (ppm)	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone	Claystone	Shale	Shale	Claystone	Sandstone	Sandstone	Claystone	Shale	-
Ni	26.0	21.0	<20.0	<20.0	<20.0	<20.0	26.0	<20.0	<20.0	11.8	<20.0	0	13.0	55.0
Ba	635.0	908.0	804.0	753.0	147.0	170.0	141.0	401.0	250.0	775.0	147.0	210.0	271.0	650.0
Be	<1.0	<1.0	2.0	1.0	6.0	3.0	1.0	1.0	3.0	0.8	6.0	3.0	1.0	
Co	13.9	11.2	5.9	7.5	3.4	3.5	5.8	10.9	5.3	9.6	3.4	4.4	8.4	23.0
Cs	1.6	1.5	0.7	2.1	0.7	1.2	2.2	1.5	3.4	1.5	0.7	2.3	1.9	-
Ga	23.2	20.4	18.7	24.3	19.6	18.7	28	20.4	25.5	21.7	19.6	22.1	24.2	-
Hf	8.5	3.8	13.3	5.8	52.1	32.1	24.3	58.8	18.1	7.9	52.1	25.1	41.6	5.0
Nb	9.0	7.4	8.3	14.8	21.5	37.4	37.9	51.4	48.6	9.9	21.5	43.0	44.7	1.9
Rb	61.1	83.4	68	103.7	6.8	17.5	17.1	46.8	35.6	79.1	6.8	26.6	32.0	160.0
Sn	2.0	1.0	1.0	2.0	3.0	7.0	6.0	10.0	7.0	1.5	3.0	7.0	8.0	-
Sr	411.9	233.3	286.3	165.4	52.2	36.7	31.3	59.8	54.4	274.3	52.2	45.6	45.6	200.0
Ta	0.8	0.5	0.7	2.2	1.9	3.3	3.2	4.6	3.6	1.1	1.9	3.5	3.9	-
Th	8.1	9.9	12.9	7.9	42.4	18.0	22.1	37.7	15.4	9.7	42.4	16.7	29.9	14.60
U	3.1	3.4	4.8	3.7	8.7	5.1	7.3	16.1	8.4	3.8	8.7	6.8	11.7	3.10
V	37.0	52.0	37.0	60.0	73.0	46.0	82.0	62.0	94.0	46.5	73.0	70.0	72.0	150.0
W	0.7	1.1	<0.5	<0.5	1.4	2.2	2.5	3.4	3.7	0.5	1.4	2.95	3.0	-
Zr	267.0	142.5	481.1	197.4	1969.8	1153.2	925.5	2058.7	644.9	272.0	1969.8	899.1	1492.1	-
Y	16.3	29.0	31.8	21.2	66.4	41.7	48.3	92.6	43.8	24.6	66.4	42.8	70.5	-
Mo	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.3	0.6	<0.1	0	<0.1	0	0.5	-
Cu	7.8	3.1	2.3	5.5	1.7	0.9	24.2	17.9	8.2	4.7	1.7	4.55	21.1	50.0
Pb	2.6	2.7	1.7	5.7	2.5	4.5	31.8	16	7.3	3.2	2.5	5.9	23.9	-
Zn	13.0	4.0	4.0	5.0	2.0	<1.0	4.0	19.0	3.0	6.5	2.0	1.5	11.5	85.0
Ni	6.7	2.4	2.1	3.4	0.9	0.2	7.9	9.3	0.6	3.7	0.9	0.4	8.6	-
As	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0	<0.5	0	0	-
Cd	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0	<0.1	0	0	-
Sb	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0	<0.1	0	0	-
Bi	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.3	0.2	0.2	0	<0.1	0.1	0.3	-
Ag	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0	<0.1	0	0	-
Au	1.7	1.1	<0.5	2.3	<0.5	<0.5	1.8	0.7	1.5	1.3	<0.5	0.75	1.3	-
Hg	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.11	0.13	<0.01	0	<0.01	0	0.1	-
Ti	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0	<0.1	0	0	-
Se	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	1.3	<0.5	<0.5	0	<0.5	0	0.7	-
Total	1557.0	1542.7	1786.6	1393.9	2483.0	1602.2	1483.2	3000.5	1285.5	1570.1	2483.0	1443.9	2241.9	-
Cu/Zn	0.6	0.8	0.6	1.1	0.9	2.0	6.1	0.9	2.7	0.7	0.9	3.0	1.8	-
Ni/Co	1.9	1.9	3.4	2.6	5.8	5.7	4.5	1.8	3.7	0.4	0.3	0.1	1.0	-
(Cu+Mo)/Zn	0.6	0.8	0.6	1.1	0.9	1.0	6.1	1.0	2.8	0.7	0.9	3.0	1.9	-
U/Th	0.4	0.3	0.4	0.5	0.2	0.3	0.3	0.4	0.6	0.4	0.2	0.4	0.4	-
Th/Sc	0.8	1.1	2.2	0.9	5.3	2.3	1.7	2.0	1.2	1.1	5.3	1.6	1.9	-
Th/Co	0.6	0.9	2.2	1.1	12.5	5.1	3.8	3.5	2.9	1.0	12.5	3.8	3.6	-

Rare Earth Elements Distribution

Table 7 shows the result of the rare earth elements (REE) in the samples analysed. Variation in ΣREE content was observed between the sandstone, claystone and shale samples. Again, concentration is higher in the finer Patti samples (av. 206.98 ppm) than the coarse Lokoja sediments (199.005 ppm). This is because, bulk REE normally reside in the fine fraction (silt or clay) and it has also been inferred that trivalent REE is readily accommodated in most clay minerals enriched with alumina and ferric iron (Cullers *et al.*, 1987, 1988).

Table 7: Rare Elements Concentration for Sediments of Lokoja and Patti Formations, and the post-Archean Australian Average Shale (PAAS)

Sample No.	L2A	L2B	L2C	L6C	P8	P9	P10A	P10B	P10C	Average				PAAS
Formation	Lokoja	Lokoja	Lokoja	Lokoja	Patti	Patti	Patti	Patti	Patti	Lokoja	Patti	Patti	Patti	-
Rock type / Elements (ppm)	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone	Claystone	Shale	Shale	Claystone	Sandstone	Sandstone	Claystone	Shale	-
La	32.00	66.50	35.50	25.80	116.40	49.50	98.30	88.20	44.10	39.95	116.40	46.80	93.25	38.20
Ce	68.50	149.10	73.00	46.60	235.80	83.60	217.80	172.20	69.10	84.30	235.80	76.35	195.00	79.60
Pr	6.85	16.36	7.81	4.91	25.67	9.22	24.53	18.18	8.30	8.98	25.67	8.76	21.36	8.83
Nd	23.60	60.50	28.10	18.10	83.50	30.40	95.90	64.90	30.60	32.58	83.50	30.50	80.40	33.90
Sm	4.28	10.62	5.31	3.13	12.83	5.96	17.06	12.12	5.36	5.84	12.83	5.66	14.59	5.55
Eu	1.12	2.36	1.18	0.78	1.45	0.75	3.42	1.90	1.19	1.36	1.45	0.97	2.66	1.08
Gd	3.74	8.48	5.23	3.33	11.42	5.62	14.34	12.36	6.19	5.20	11.42	5.91	13.35	4.66
Tb	0.56	1.15	0.87	0.59	1.85	1.05	2.12	2.33	1.16	0.79	1.85	1.11	2.23	0.77
Dy	3.18	5.69	5.17	3.70	11.09	6.99	10.96	14.85	7.10	4.44	11.09	7.05	12.91	4.68
Ho	0.58	1.02	1.23	0.78	2.40	1.58	2.19	3.31	1.63	0.90	2.40	1.61	2.75	0.99
Er	1.83	2.91	3.73	2.40	7.14	5.01	5.97	10.14	5.18	2.72	7.14	5.10	8.06	2.85
Tm	0.28	0.43	0.58	0.34	1.14	0.76	0.88	1.60	0.76	0.41	1.14	0.76	1.24	0.41
Yb	1.85	2.36	3.84	2.40	8.07	5.07	5.54	10.60	5.10	2.61	8.07	5.09	8.07	2.82
Lu	0.32	0.41	0.63	0.40	1.32	0.84	0.87	1.77	0.84	0.44	1.32	0.84	1.32	0.43
Sc	10.00	9.00	6.00	9.00	8.00	8.00	13.00	19.00	13.00	8.50	8.00	10.50	16.00	16.00
Total	158.69	336.89	178.18	122.26	528.08	214.35	512.88	433.46	199.61	199.01	528.08	206.98	473.17	184.77
La/Sc	3.20	7.39	5.92	2.87	14.55	6.19	7.56	4.64	3.39	4.7	14.55	4.46	5.83	2.40

Source Area Weathering

Siliciclastic sedimentary rocks investigated in several regions of the world show that their chemical composition is largely dependent on the weathering conditions at the source rock area (Nesbitt and Young, 1989; Nesbitt *et al.*, 1996). A measure of the degree of chemical weathering/alteration of the sediments' source rocks can be constrained by the chemical index of alteration (CIA) as demonstrated by Nesbitt and Young (1982) also by , the chemical index of weathering (CIW; Harnois, 1988). However, both CIA and CIW are interpreted in similar way with values of about 50 for unweathered (fresh) upper crust material and about 100 for highly weathered residual soils, with complete removal of alkali and alkaline-earth elements (McLennan *et al.*, 1983; McLennan, 1993; Mongelli *et al.*, 1996).

The estimated CIA and CIW for this study are shown in Table 5 with values ranging; 73-85% (av. 77%); (78-97% (av. 86%) for Lokoja Sandstone; 99%, 100% for sandstone facie of Patti Formation while the claystone and shale facies have respective ranges; 95 – 96% (av. 96%); (99%) and 90 – 98% (av. 94%); (99-100%) (av.99.50%) (Table 5). The unexpectedly higher values of CIA and CIW for the Patti Formation samples clearly indicate the fact that the primary source material(s) must have been subjected to substantially high degree of weathering and reworking that resulted in the removal of the ferromagnesian minerals and feldspars as clearly revealed by the major element geochemistry (Table 5). Therefore, it can be concluded that Patti Formation sediments were derived from highly weathered and chemically matured terrain through primary weathering and reworking of the source materials compared to the Lokoja Sandstone.

From the observed mineralogical and elemental composition (quartz, feldspar, and micas, and SiO_2 >55%) the sediments are related to those from granitic provenance (acid to intermediate rocks), as typified by subarkose to arkose for the

Lokoja sandstone as well as the higher quartz content of the subarkosic sandstone and the associated shale and claystone of the Patti Formation. The composition of heavy minerals such as zircon, rutile, and tourmaline also point to a source in basement rock units, apparently from the adjacent southwestern and/or north central basement complex of Nigeria.

Provenance

It has been widely reported (Taylor and Mclennan, 1985; Condie *et al.*, 1992; Cullers, 1995; Armstrong-Altrin *el al.*, 2004; Okunlola and Idowu, 2012) that geochemical signatures of clastic sediments can be utilized to infer provenance characteristics of the sediment. Hayashi *et al.*, (1997) pointed out that Al_2O_3/TiO_2 ratio increases from 3 to 8 for mafic igneous rocks, 8 to 21 for intermediate rocks and 21 to 70 for felsic igneous rocks. The average Al_2O_3/TiO_2 ratio for Lokoja Sandstone; sandstone, claystone and shale facies of Patti Formation are 52.43, 14.21, 10.02 and 10.25 respectively. These ratios therefore suggest felsic source rock for Lokoja Sandstone and intermediate source rock for the Patti Sediments.

The abundance of Cr and Ni in siliciclastic sediments is considered a useful tool in sediments' provenance studies. As reported by Wrafter and Graham (1989), a low Cr concentration indicates felsic provenance, and high values of Cr and Ni are associated with ultramafic rock-derived sediment (Armstrong-Altrin *et al.*, 2004). In this study, Cr and Ni concentrations are low in all the samples under investigation (0.01 to 0.011ppm Cr and 0 to >20ppm Ni; Tables 5 and 6) and therefore suggest a felsic provenance.

There are significant variations in La/Sc, Th/Sc and Th/Co ratios from felsic to basic rocks and may lead to constraints on average provenance composition (Wronkiewicz and Condie, 1990; Cox *et al.*, 1995; Cullers, 1995). Ratios of Th/Co, Th/Sc and La/Sc from this study (Table 8) were compared with values of Cullers (1994, 2000), Cullers and Podkovyrov (2000), Cullers *et al.*, (1988) for felsic and mafic rocks.

The findings strongly imply contribution from a range of felsic source rocks. In addition, cross plots of Th/Co versus La/Sc (Fig. 11) strongly support felsic rocks provenance probably from the pegmatite, granite, gneisses and associated rocks of the southwestern and north central Basement complex of Nigeria.

This is further supported by the predominantly subarkosic to arkosic sandstones and the heavy mineral assemblages which indicate a source in the nearby basement rocks for the sediments. The heavy mineral assemblages are those from granitic and metamorphic provenances. Tourmaline, garnet and rutile are found in both igneous and metamorphic rocks, zircon however is a common accessory mineral of acid – intermediate igneous rocks, such as granite and pegmatite, while staurolite is mainly found in medium-grade regional metamorphic and/or plutonic rocks, such as mica-schict and gneisses. A similar setting was also reported for the adjacent Anambra Basin (Tijani *et al.*, 2010). In addition, the observed angular grains of the zircon and tourmaline may be attributable to short transportation. The kaolinitic clay bodies of the Patti Formation, implies weathering of feldspar rich rocks under humid climatic setting (Nton and Okunade, 2013).

Table 8: Selected Elemental Ratios in Sandstone, Claystone and Shale of Studied Samples Compared to Ratios for Similar Fractions Derived from Felsic and Mafic Rocks

Elemental Ratio	Southern Bida Basin[1]				Range of sediments[2]	
	SST_LKJ	SST_PT	CLST_PT	SH_PT	Felsic rocks	Mafic rocks
Th/Sc	0.81-2.15	5.3	1.18-2.25	1.7-1.98	0.84-20.5	0.05-0.22
Th/Co	0.58-2.19	12.47	3.81-5.14	3.46-3.81	0.67-19.4	0.04-1
La/Sc	2.87-7.39	14.55	3.39-6.19	4.64-7.56	2.5-16.3	0.43-0.86

[1]Present study, [2] Cullers (1994, 2000), Cullers and Podkovyrov (2000), Cullers *et al.*, (1988), SST_LKJ = Lokoja sandstone, SST_PT = Patti sandstone, CLST_PT =Patti claystone, SH_PT = Patti shale

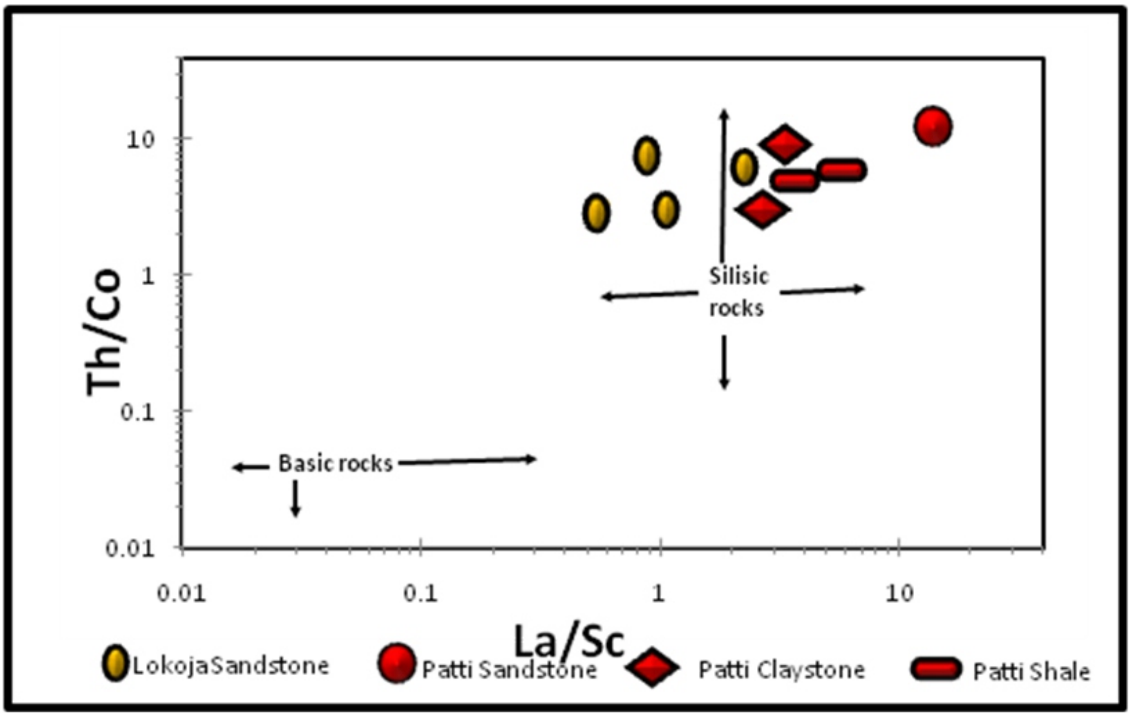


Fig. 11: Plot of Th/Co against La/Sc for the Studied Samples (Modified from Cullers, 2002)

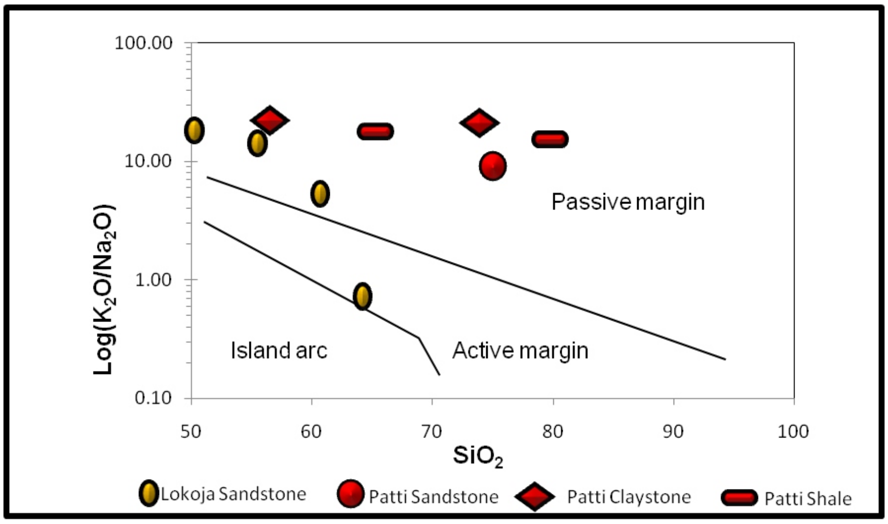
Tectonic History

The main assumption behind sandstone provenance studies is that different tectonic settings contain characteristics rock types which, when eroded, produce sandstones with specific compositional ranges (Dickinson, 1985). The analysis of sandstone with known provenance has been used to define these ranges from which the provenance of other samples can be deduced.

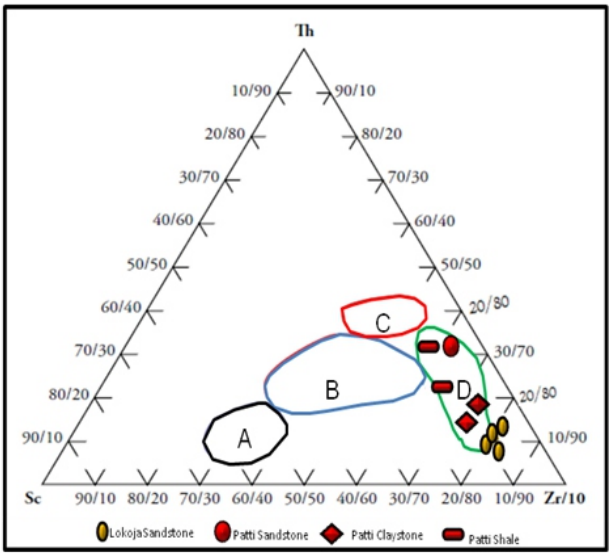
Based on the Roser and Korsch (1986) plots of log(K_2O/Na_2O) versus SiO_2 discrimination diagram and Th-Sc-Zr/10 discrimination diagram of Bhatia and Crook (1986) a passive margin tectonic setting is associated with this basin (Figure 12 a and b). According to Roser and Korsch (1986), passive margin (PM) are largely quartz-rich sediments derived from plate interiors or stable continental areas and deposited in intra-cratonic basins or on passive continental margins.

As reported by Obaje *et al* (2013), the Bida Basin is an intra-cratonic sedimentary basin. Intra-cratonic and rift-bounded grabens (e.g. the Benue trough) were formed on a thick continental crust that is included in the passive-margin tectonic setting. Passive-margin type sandstone is generally enriched in SiO_2 and depleted in Na_2O, CaO and TiO_2, suggesting their highly recycled and mature nature (Bhatia, 1983). From the major element oxides with enriched SiO_2 but depleted Na_2O, CaO and TiO_2, it is envisaged that the sediments were immature to slightly mature.

Ternary plots of framework composition viz; quartz, rock fragments and feldspar (QRF) (Fig. 13a and 13b) show that the sandstones are products of rifted and uplifted continental block provenance. As reported by Dickinson (1970) and Dickinson and Suczek (1979) the framework components of sandstones are genetically linked to the geodynamic environment of the source area.

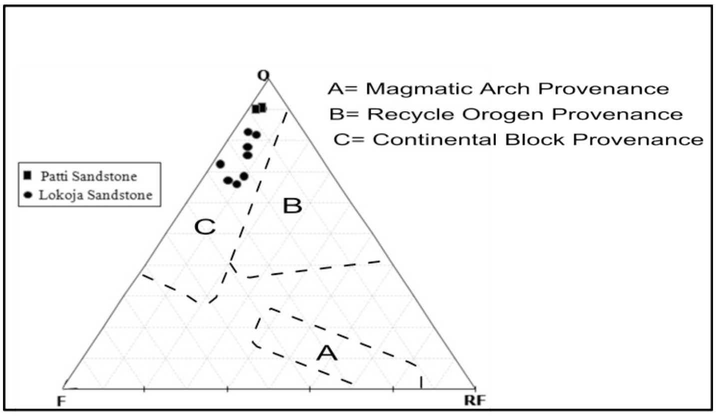


(a)

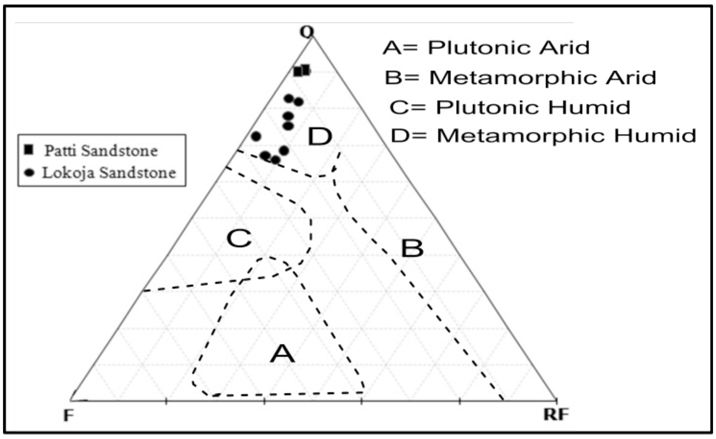


(b)

Fig. 12: (a) Plot of the log (K_2O/Na_2O) against SiO_2 Discrimination Diagram for Sandstone-Mudstone Suites Showing the Fields for a Passive Continental Margin, an Active Continental Margin and an Island Arc (After Roser and Korsch, 1986). (b) Th-Sc-Zr/10 Discrimination Diagram (After from Bhatia and Crook, 1986).The fields are: A - Oceanic Island–Arc, B - Continental Island–Arc, C -Active Continental Margin, D - Passive Margin



(a)



(b)

Fig. 13: (a) QFR Ternary Plots of Provenance Setting for Sandstones of the Studied Area (Modified After Dickson, 1988) (b) QFR Ternary Plots of Provenance Setting for Sandstones of the Studied Area (Modified After Suttner *et al.*, 1981). Note Q = Total Quartz, F = Feldspar and RF = Rock Fragments

Depositional Environment

The paleodepositional environment strongly indicated by various environmental diagnostic parameters obtained from pebble morphometry data is fluvial (Table 9). This is further corroborated by Sames' (1966) plot of roundness versus elongation (I/L) (Fig. 5a) which shows 83% of the pebbles in the fluviatile field while 17% lie in the littoral field. The pebbles under investigation fall within the river field using the bivariate plot of sphericity against oblate – prolate index (Dobkins and Folk, 1970; Fig. 5b). Positively skewed and poor sorting values obtained from the sediments are typical of river sands (Folk, 1974). A fluvial setting is further supported by crossplot of textural parameters (Fig. 6a-c) in this study which corroborate the findings of Friedman (1967); Moiola and Weiser (1968) and Stewart (1958).

Table 9: Summary of Environmental Diagnostic Properties of Lokoja Pebbles

Morphometric parameters	Characteristics exhibited by the Lokoja pebbles	Environmental indications	References
Size	Coarse; mean value = 4.46	Fluvial	Krumbein and Pettijohn (1938)
Flatness(S/L)	Mean value =0.71	Non diagnostic	Lutig (1962)
Elongation(I/L)	Mean value = 0.86	Fluviatile	Lutig (1962)
Maximum projection sphericity	Mean value = 0.84	Fluviatile	Dobkins and Folk (1970)
Pebble form	Compact = 66.67%; Compact bladed = 33.33%	Fluviatile	Dobkins and Folk (1970)
Oblate-prolate index (op)	Mean value = -0.15 (within the -1 to +5 range)	Fluviatile	Dobkins and Folk (1970)
Roundness	Mean value = 31%	Non marine	Lutig (1962)
Plot of roundness against elongation	83.33% Fluviatile; 16.67% Lithoral	Fluviatile	Sames, 1966
Plot of oblate-prolate index against sphericity	Cluster in the fluviatile zone	Fluviatile	Dobkins and Folk (1970)

SUMMARY AND CONCLUSION

Textural studies on the Lokoja and Patti Formations indicate a fluvial setting for the associated sandstones and pebbles. The sandstones are medium to coarse grained, poorly sorted and mainly arkose for the basal Lokoja Formation and subarkose for successive sequence and that of the Patti Formation. Heavy mineral assemblages are mainly; zircon, rutile, tourmaline and staurolite, with ZTR index ranging from 62 to 78%, indicating immature to slightly matured sandstone with a source in adjoining basement complex. The ternary plots of the framework elements of the sandstone indicate passive margin, continental block provenance and deposited in humid paleoclimatic environment.

Whole rock elemental analysis of the investigated samples revealed that SiO_2 content of the Lokoja sandstone are on the average 60% while that of Patti Formation is 75%; thus indicating more mature sediment of the Patti sandstone facies. The trace elements are dominated by Ba (635-908ppm) in the Lokoja Formation while Zr (644.9-1969.8ppm) has higher values in the Patti Formation. In both units, Ce (46.6-235.8ppm), La (25.8-116.4ppm), and Nd (18.1-95.9ppm) are the most abundant rare earth elements with both trace and rare earth elements concentrating more in the finer clastics of the Patti Formation. Interpretation of geochemical ratios such as La/Sc, Th/Sc and Th/Co and La/Sc versus Th/Co, suggests that the sediments were derived from felsic source rock.

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