Comparison of grain-clay fraction and particle morphogenesis as signatures of source and depositional environment (Cretaceous Lokoja formation, Niger Basin, Nigeria)

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PRELIMINARY COMMUNICATION

The Upper Cretaceous Lokoja Formation of southern Niger Basin in Nigeria is a dominantly sandy facies comprising of two distinctive members, the Lokoja and Patti Siltstone. The fluvial sandstone of the Lokoja Sandstone is petrologically defined as dominantly poorly sorted angular to sub-angular, fine to aly skewed, immature lithic arkose to sub-litharenite with a detrital clayey matrix of over fifteen percent (15%). The dominantly silty, marine to fluvial sediments of the Patti Siltstone is defined as massive, moderately sorted, sub-angular to sub-rounded, averagely fine skewed and minerologically mature but texturally immature quartz arenite. The quantitative analyses of light, heavy and clay fractions of sandstone samples from the Lokoja Formation also showed variation and made possible to group these sediments as lower and upper mineralogical units. A southwest terrain (basement rocks) with a peneplain topography that had relatively warm and humid tropical palaeoclimate served as the source of detrital materials for the Lokoja Sandstone whose deposition was rapid following a diastrophic movement (folding and faulting) in the continent. The Patti Siltstone sediments were derived from rapid erosion that characterized an area of high relief (crystalline West Africa basement rocks) with warm and tropical alkaline environment generating a uniform debris supply at slower but continuous rate of deposition.

Key words: Lokoja Formation, Niger Basin, Cretaceous, grain-clay fraction

1. INTRODUCTION

The Niger Basin generally includes the north-western part (often referred to as Bida or Nupe Subbasin) and its southern extremes where the Lokoja Formation is found.[4,19,26,27] It is a major Cretaceous sedimentary basin in Nigeria covering an area of almost 3 000 km² (Figure 1).

The Niger Basin is a shallow basin filled with marine to fluvial strata that varying in thickness from 3 to 4km.[24,5] Interest in the basin has been generated mainly due to the occurrence of iron ores, particularly in the southern part that constitutes the area of the present study (Figure 1). Adeleye[2] worked on the sedimentology and stratigraphy of the basin. Braide[9] reported the possible occurrence of gas and condensates in its southern part and this has initiated further probes on its petroleum potentials.

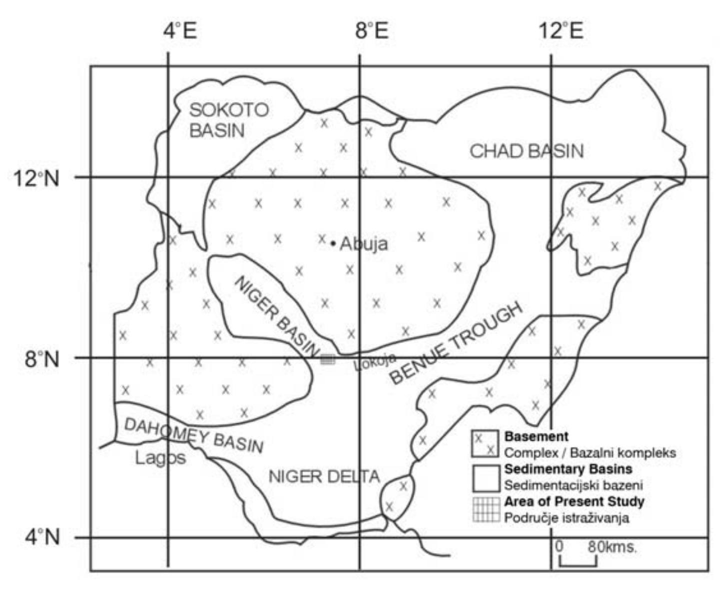

Fig. 1. Map of Nigeria showing distribution of sedimentary basins, location of the Niger Basin and study area (from ref.2)

Sl. 1. Karta Nigerije pokazuje rasprostranjenost sedimentnih bazena, lokaciju bazena Niger i istraživanog područja[2]

A total of 38 spot samples of Cretaceous facies from 19 localities were obtained from the study area, out of which 23 representative samples were selected for various analyses. Like every other sedimentary materials, the sediments of the Lokoja Formation bear imprints of their transportation and deposition which are useful in lithofacies, depositional, environmental and source material area analyses. The aim was to compare the grains and clay fraction (mineralogy) of sandstones occurring in the Lokoja area, deduce their mode and transportation history and eventually determine the provenance, palaeoclimate and palaeoenvironment of the sediments.

2. GEOLOGICAL SETTINGS

Two distinct types of rock are found within the study area. These are the Precambrian basement rocks and the Campanian to Maastrichtian sandstone facies (70 - 65.5 Ma). The Basement rocks consist of gneisses and migmatites with isoclinically infolded linear belts of Upper Proterozoic to Cambrian meta-sediments (500 Ma).[27] These are intruded by granites and later by numerous dolerite dykes.

The buried Precambrian complex is directly overlain by Cretaceous sediments (70 Ma) of rounded to sub-rounded coarse conglomeratic sandstone, clay-sand-pebble admixture, and cross - stratified sandstones locally with scattered pebbles, cobbles and boulders.[3] The basal sediments which may be of alluvial fan origin are unconformably overlain by lithologies comprising mainly sandstones and siltstones. The sandstones are known by various local names, such as the Bida Sandstone around Bida (middle Niger Basin) and the Lokoja Sandstone around the Niger - Benue River confluence in the southern Niger Basin. Jones[19] described the basal or lower part of the Lokoja sandstone series (i.e. the Lokoja Formation) as the Lokoja Sandstone and the upper part as Patti Siltstone. The basal strata are succeeded by dominantly goethitic, oolithic and pisolithic (pisolitic) ironstones of various thicknesses and are referred to Agbaja Ironstone around Lokoja area (Figure 2a & b) and Batiti Ironstone around Bida.[2]

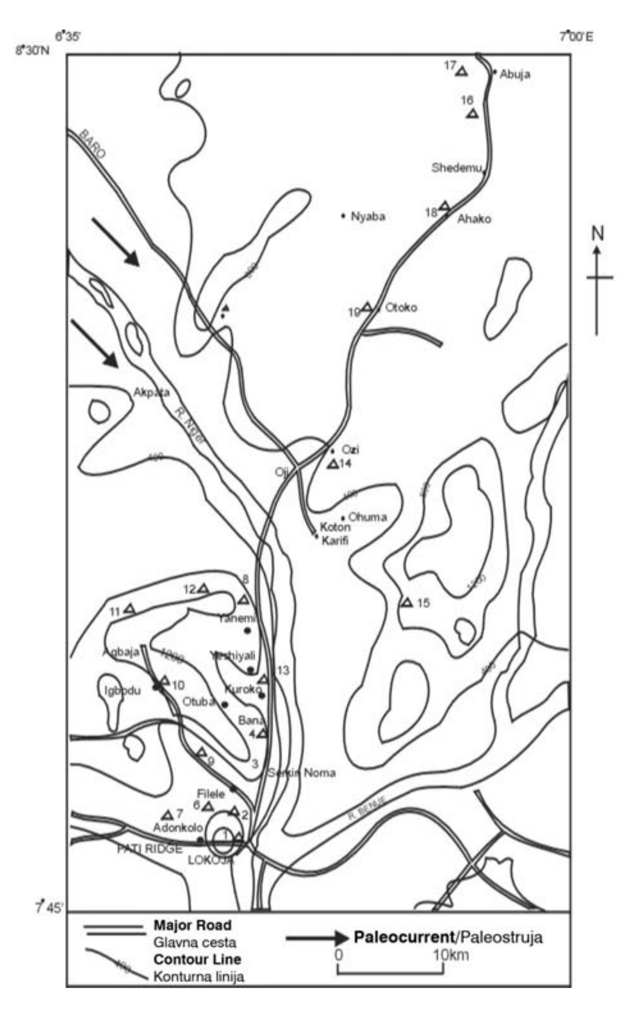

Fig. 2a. Map of the study area showing sample locations and thicknesses of the Lokoja Formation
Sl. 2a. Karta istraživanog područja pokazuje lokacije uzoraka i debljine Lokoja formacije

The origin of the Niger Basin has been attributed to the rift and isostatic subsidence which were associated with the separation of Africa from South America. Ojo and Ajakaiye[24] indicated that although rifting and associated volcanic and intrusive features are absent in this basin, gravity pattern does not completely ruled out rifting as possible origin, thus the basin is generally defined as an area of local subsidence. Adeleye[3] described the structural setting of the basin as a gently down-warped trough whose epeirogenesis seems to be closely connected with crustal movement of the Santonian orogeny (80 Ma) of southeastern Nigeria and the nearby Benue Valley. Landsat imageries suggested that the basin is controlled by a NW - SE trending faults.[20] The palaeogeographic history of the Bida Basin described by Aguingi[6] revealed that during the Maastrichtian basin served as a link for the

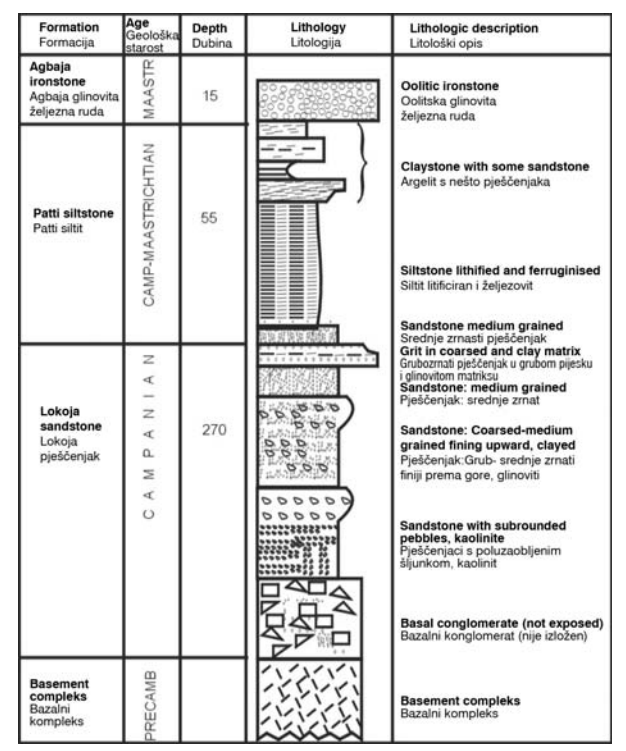

Fig. 2b. Lithostratigraphy of Lokoja Formation[2]
Sl. 2b. Litostratigrafija Lokoja formacije[2]

Table 1a. Pebbles Orientation (Lokoja Sandstone)

LOCALITY	VALUES (in degree)	ARITHMETIC MEAN
2	151, 151, 153, 200, 167, 169, 155, 204, 120, 145	162°
6	190, 209, 210, 181, 155, 170, 176, 176, 185, 183	184°
3	203, 205, 193, 160, 215, 196, 183, 150, 210, 181	193°
4	195, 199, 203, 205, 197, 188, 167, 154, 138, 195, 200, 196, 192	187°
7	208, 202, 175, 187, 174, 155, 169, 171, 215, 220, 212	190°

Table 1b. Cross Beds Measurement (Patti Siltstone)

140	36	14	46	45	52	14	43	38	15	41	123	23
40	45	11	51	20	42	12	46	11	51	43	38	32
18	43	42	135	51	16	23	53	46	33	29	31	50
06	59	60	10	40	133	14	48	42	21	40	51	59
29	43	35	08	45	47	47	04	43	21	08	40	23
41	48	19	30	52	21	50	36	53	59	45	46	126
43	42	38	33	45	46							

Epeiric Sea between the Gulf of Guinea in the south and the proto-Mediterranean (Tethys) Sea in the north.

3. METHODOLOGY OF FIELD AND LABORATORY PROCEDURES

Well exposed stratigraphic sections of sandstone formation exist in the study area. Field data were taken mainly from road cuts and river/stream channels. Detailed characteristics of each bed, such as thickness, grain size, orientation, texture, colour, sedimentary structures and other were studied and documented. Field work involved visits to 9 localities within Lokoja, Abaji, Agbaja and Kotonkarific (Figure 2a). A total of 23 representative samples were selected from totally 38 spot samples collected for various laboratory analyses including grain size analysis, petrographic and compositional analyses for light and heavy mineral fractions.

The orientation of pebbles and direction of cross stratification were measured with meter rule. Grain size analysis was carried out on the wet, weakly consolidated sandstone' samples after their oven drying and segregation. The weight percentages of grains retained in each of the sieves including the pan as well as their cumulative weight percentages were determined and recorded, and further used to plot the cumulative log probability curves and histograms, thus showing percentages of grains which are coarse or fine. Mean diameter, median, standard deviation, skewness and kurtosis were calculated using linear interpolation of the cumulative weight percentiles of Φ_5, Φ_{16}, Φ_{25}, Φ_{50}, Φ_{75}, Φ_{84}, and Φ_{95} in a mathematical solution proposed by Folk and Wards[15] and Friedman.[17]

The compositional analysis of the sandstones viewed over a petrographic microscope (x7.5) considered such components as quartz, feldspar, micas, rock fragments and matrix-cement recorded in terms of percentage compositions. Heavy minerals analysis was carried out on sand fractions of sieve sizes: 0.064 mm to 0.125 mm (3 to 4 microns) using specific gravity method after their acid treatment to eliminate carbonate, clay and/or iron oxide grains/coatings. Residual fraction of three selected sieved samples which were obtained from different points on the stratigraphic column was further sieved to retain the clay fraction (2 micron fraction) for X-Ray diffractometer analysis.[11] A semi-quantitative analysis of the clay mineral species in each sample was carried out by identifying the 1st, 2nd and 3rd order peaks of the clay minerals.

4. ANALITICAL RESULTS

Results of all analytical techniques employed in the study are presented below. A critical assessment of each set of the results has aided its proper interpretation and useful discussion of this work.

4.1. Results

Data on pebble orientation and direction of cross-stratification recorded are presented on Tables 1a and 1b. These were used to prepare rose diagrams (Figures 3a and 3b) that provided an inference of the paleocurrent direction and sediment source.

The palaeocurrent direction does not vary much for each of the member. It is mainly in the NNW for Patti Siltstone and SE direction for the Lokoja Sandstone (Figure 2a, Figure 3a and b). Summary of calculated results from grain size analysis is presented in Table 2. The sandstones are mostly poorly sorted, coarse to medium grained and angular to subangular. Samples from Lokoja Sandstone exhibit dominantly coarse to medium grains and are mainly bimodal in distribution. They are also poorly sorted and coarse to near symmetrical in skewness. The Patti Siltstone is dominated by siltstone subunits that are nearly symmetrical to fine in skewness and moderately sorted.

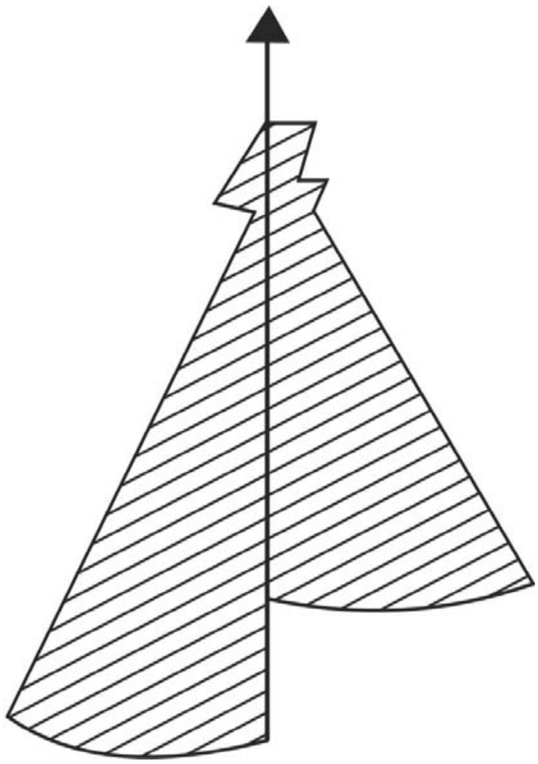

Fig. 3a. Palaeocurrent orientation of elongate pebbles
Sl. 3a. Orijentacija paleostruje izduženih valutica

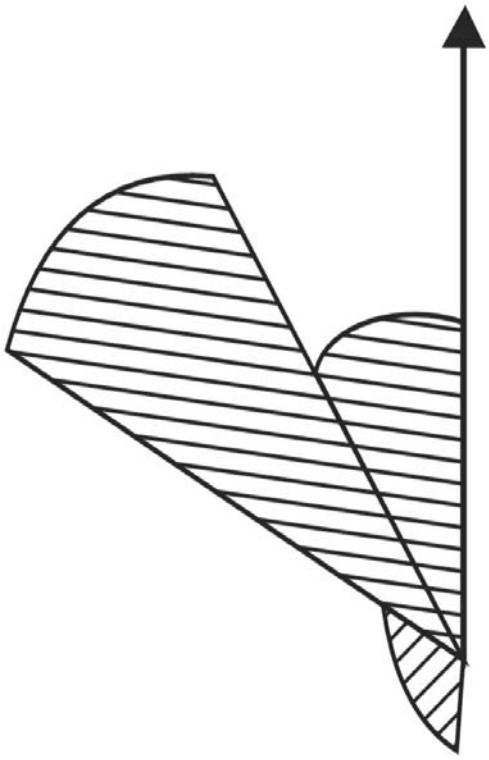

Fig. 3b. Palaeocurrent direction of cross beds
Sl. 3b. Smjer paleostruje kosih slojeva

Table 2. Summary results of grain size analysis (sorting classification from ref.[15])

SAMPE NO.	TEXTURAL NOMENCLATURE	MEAN GRAIN SIZE (f)	MEDIAN GRAIN SIZE (f)	SORTING (f)	SKEWNESS	KURTO-SIS
3c	V coarse to fine grain sand V krupnozrnati do finozrnati pijesak	0.55	0.35	1.20 Poorly sorted	-0.05 Nearly sym-metrical	1.30 Leptokurtic
4a	V coarse to medium grain sand	0.47	0.40	1.27 Poorly sorted	0.07	1.05 Leptokurtic
4c	Coarse to medium grain sand	0.48	0.40	1.25 Poorly sorted	0.03 Nearly symmet-rical	1.06 Leptokurtic
5b	V coarse to medium grain sand	0.35	0.31	1.15 Poorly sorted	-0.02 Nearly sym-metrical	1.00 Mesokurtic
6a	Medium To fine sand	2.00	1.91	0.77 Moderately sorted	0.06 Nearly symmet-rical	1.35 Leptokurtic
6b	Medium to fine sand	2.10	2.00	0.78 Moderately sorted	0.05 Nearly symmet-rical	1.35 Leptokurtic
6d	Medium to coarse	2.11	0.90	1.21 Poorly sorted	0.15 Fine skewed	1.42 Mesokurtic
10	Medium sand	2.10	1.98	1.30 Poorly sorted	0.16 Fine skewed	1.00 Leptokurtic

Associated bivariate plots of skewness against sorting and plots of sorting against mean grain size are presented in Figures 4a and 4b respectively. These are used to infer the environment of deposition as well as the conditions of transporting medium.[14, 16, 17] Tables 3a and 3b show thin section results (compositional analysis) of both light and heavy minerals of 14 samples.

From thin section compositional analysis, Lokoja Sandstone samples recorded an average of 0.8% fraction as heavy minerals while Patti Siltstone samples constitute 0.3% as heavy minerals. In both members, heavy minerals are dominantly opaque's, ranging from 65% to 90%, and include hematite, limonite, limonite and leucoxene in all grain sizes. Among the non-opaque minerals are zircon (most abundant in both members with average value of 9.1% for Lokoja and 15.1% for Patti Siltstone), micas (6% for Lokoja Sandstone and 2% for Patti samples), and tourmaline (3% for Lokoja Sandstone and 4%

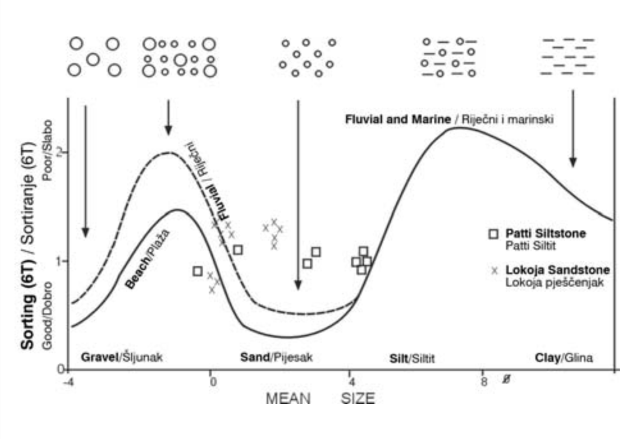

Fig. 4a. Plot of sorting versus means size[14]
Sl. 4a. Graf sortiranja u odnosu na srednju veličinu[14]

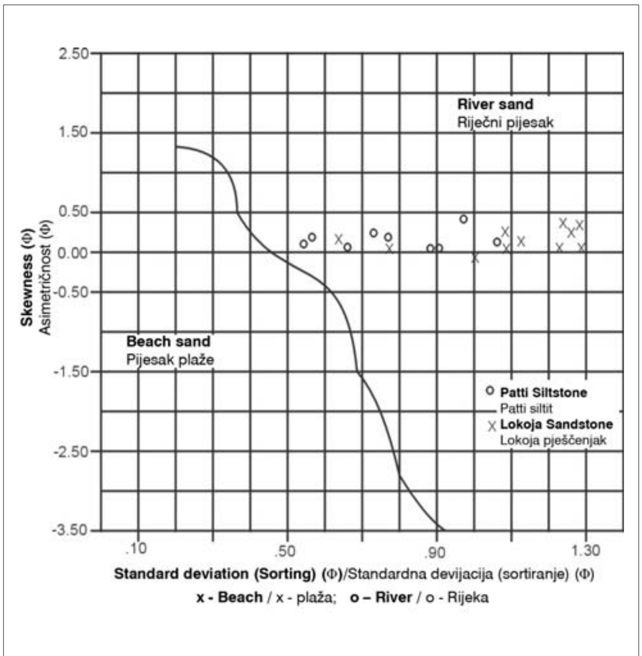

Fig. 4b. Bivariate plot graphic skewness versus graphic standard deviation
Sl. 4b. Dvomjerni graf asimetričnosti u odnosu na grafički prikaz standardne devijacije

for Patti Siltstone). The least abundant non- opaque is staurolite which is absent in Patti. The heavy minerals of the Lokoja Sandstone can be subdivided into two groups: (a) the ultrabasic group comprising zircon, tourmaline and rutile (which are common in entire formation) and (b) the metastable group including a variable proportion of garnet, epidote and staurolite. On this basis, Folk[12,13] and Pettijohn[25] classified these clastic sediments in the study area as immature and submature for the Lokoja and Patti members respectively.

Statistical treatment of the compositional data was undertaken by establishing four mineralogical indices ratios and calculated from the mean values in each member). It showed that the Lokoja Sandstone is rich in polycrystalline quartz and metamorphic fragments, with epidote, biotite and garnet being common heavy minerals. The main clay minerals are kaolinite and montmorillonite. Kaolinite (phyllosilicates of type 1:1) was identified based on the characteristics 7Å spacing of 001 basal reflection and is the more abundant clay mineral. Montmorillonite (the name assigned to all expanded clay minerals, except vermiculite), was identified by its characteristic basal reflection. It is lower in abundance but remarkably shows upward increase in percentage abundance up the stratigraphic column whereas kaolinite increases with depth. The type and abundance of clay mineral species in sediments reflect the provenance, palaeoclimate, chemistry of the depositional environment and diagenetic history of the sediments.[18]

5. INTERPRETATION AND DISCUSSION

An integrated approach used results of different analytical techniques and led to interpretation of analytical goals. This enhanced previous knowledge of the source areas and palaeoclimate for material today known as the Lokoja Formation.

Table 3a. Thin section modal (%) composition analysis of 14 samples from the Lokoja Sandstone

Members	sample No.	Epidote	Garnet	Zircon	Rutile	Mica	Tourma-line	Opaque	Z-T-R index
Lokoja	10	-	0.2	5.9	-	9.2	2.0	79	38
	6a	1.0	0.4	4.2	-	3.9	0.7	89	49
	6b	-	2.0	6.9	-	7.5	3.0	80	50
	4a	0.4	1.4	16.1	2.2	8.3	3.2	65	61
	3c	0.2	3.0	9.3	1.3	4.9	2.6	76	55
	11b	-	6.0	12.5	-	5.8	4.1	69	54
	12a	0.1	3.2	8.8	1.1	6.7	2.5	73	46
Patti	19a	0.1	0.1	5.4	2.3	1.2	2.1	88	80
	15c	-	-	10.7	1.7	1.1	2.9	82	85
	15a	-	1.0	19.5	1.5	5.2	3.0	68	75
	16b	-	0.2	19.4	1.3	2.5	8.6	66	86
	16c	0.5	-	12.9	0.8	3.8	6.2	75	80
	17a	0.1	0.7	20.1	1.0	0.3	3.0	74	92
	17b	-	-	18.0	0.4	3.0	2.4	77	83

Table 3b. Thin section (%) composition of non-opaque and opaque heavy minerals from the Lokoja Sandstone

Members	Sample No	Quartz	Feldspar	Mica	Rock fragment	Heavy minerals	Cement and Matrix
Lokoja	10	36.6	12.3	0.8	9.7	0.6	30.3
	6a	43.5	8.7	0.3	12.3	1.1	27.6
	6b	52.3	9.8	0.1	8.9	1.5	24.3
	4a	49.1	6.3	0.2	4.7	0.8	23.3
	3c	46.8	3.1	0.1	6.5	0.5	29.8
	11b	37.5	10.5	0.3	9.3	0.6	33.3
	12a	39.2	9.9	0.4	8.7	0.4	31.6
Patti	19a	50.1	2.2	0.3	2.5	0.6	35.2
	15c	58.3	0.1	0.1	0.6	0.4	19.4
	15a	52.9	-	0.1	0.8	0.3	22.1
	16b	60.2	0.6	0.2	1.9	0.2	20.8
	16c	67.0	-	0.2	1.8	0.4	11.6
	17a	55.3	0.1	0.1	1.9	0.5	26.0
	17b	65.7	-	0.2	2.1	Trace	21.1

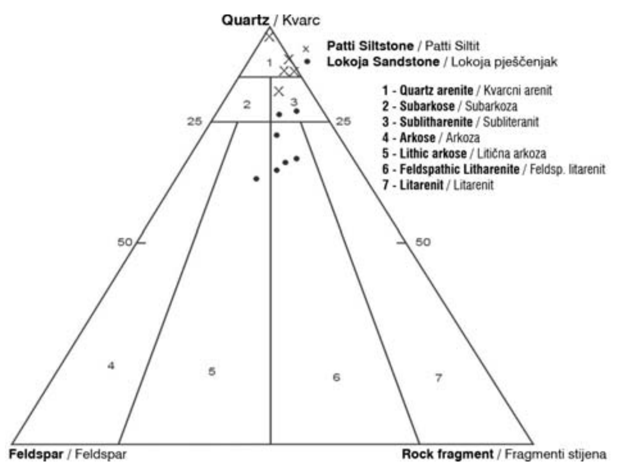

Fig. 5. Ternary diagram showing framework composition (%) of Lokoja Formation.
Sl. 5. Ternarni (trojni) dijagram prikazuje sastav (%) Lokoja formacije

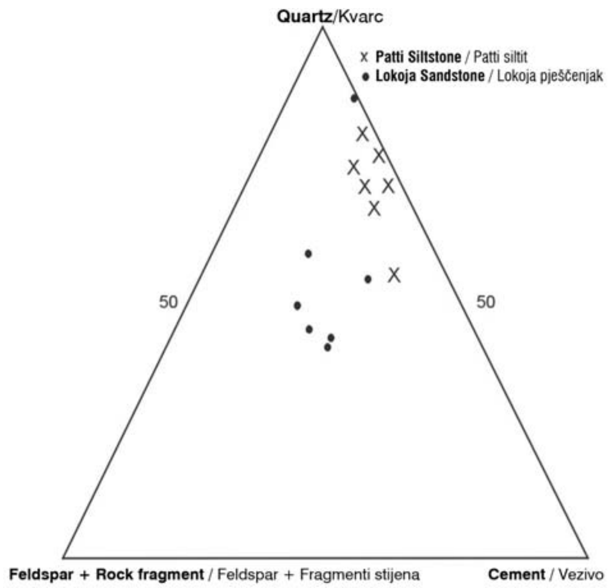

Fig. 6. Diagrammatic representation of modal composition of Lokoja Formation
Sl. 6. Dijagramatski prikaz modalnog sastava Lokoja formacije

5.1 Mineralogy and sandstone diagenesis

The sandstone mineralogy displays both light and heavy (opaque and non-opaque) components (Table 3). The Lokoja Sandstone is rich in polycrystalline quartz grains and metamorphic fragments, with epidote, biotite and garnet as common heavy minerals. The Patti Siltstone is rich in monocrystalline quartz grains and granitic rock fragments, with muscovite and garnet as common heavy minerals. The Lokoja Sandstone contained sodic plagioclase and a higher percentage of cement, mostly argillaceous type; while Patti Siltstone contained potassic feldspar, with ferrous cement (Figure 6). Kaolinite is the common clay mineral in Lokoja Sandstone while montmorillonite is more abundant in Patti sediments.

Diagenesis is commonly observed in both members. However, due to high cement content and poor to moderate sorting, compaction is stronger in the Lokoja Sandstone with observable deformed flakes. The quartz grains in the Patti Siltstone are mostly in point contact with lithification and ferrugination events connected with high iron content. The effects of compaction and high content of clay and iron minerals have equally contributed in reduction of original porosity and permeability.

5.2. Textural maturity of the sandstones

Textural maturity is one of the most important variables in determining depositional environment, i.e. for describing winnowing, sorting and abrasion of detritus. Both members are texturally immature (Table 2) because they have relatively high percentage of clay (<5%) and high sorting value (generally greater than 0.50).[14] Comparing crystallinity, the Patti Siltstone shows better maturity than the Lokoja Sandstone. Mineralogical maturity was considered on the basis of Zircon-Tourmaline-Rutile (abbr. ZTR) index that is statistically given as:

$$\text{ZTR index} = Z + T + R\ (100)/\text{Non-opaque} \quad (1)$$

The mean percentage of ZTR index for the Lokoja Sandstone is 50% whereas that of the Patti Siltstone is 83%, thus indicating the later to be mineralogically more mature. Patti Siltstone also have lower average feldspar content (<5%) when compared to the Lokoja Sandstone (8.7%), shown in Table 3a.

5.3. Transport history

It is common knowledge that grain size depends largely on current strength (velocity) of the local environment and the size of particles at source. The degree of sorting of grains is also a function of the persistence and stability of energy condition. The poor sorting and the angularity of clastic grains of the Lokoja Sandstone, coupled with the high percentage of polycrystalline quartz, rock fragments and fresh feldspar, clearly indicated that the sediments had short transport. This eliminates possibility that sediments came from second cycle of erosion and deposition. The low feldspar content in Patti Siltstone may indicate long transport. However, that may suggest a more intensive weathering and size of the source area. Other textural and mineralogical characteristics, such as the subrounded quartz grains, better sorting value, rare labile rock fragment, low metastable heavy minerals and higher monocrystalline/polycrystalline quartz ratio eventually indicated on the long distance transport during first cycle of erosion and sedimentation. In addition, samples of the Patti Siltstone from the Ozi area (Figure 2) displays a bimodal distribution which is viewed as mixed sediment from different source areas.

5.4. Provenance of the sandstones

The presence of granitic and metamorphic rock fragments in the Lokoja Sandstone samples and common occurrence of microcline, orthoclase, and high percentage of polycrystalline quartz grains all point to a granitic gneiss or preferably, migmatitic (basement) material source rock. This is further supported by widespread occurrence of zircon as the heavy mineral. According to Milner[23], detrital zircons normally originate from acidic and intermediate igneous rocks and are less common from schist and marble. Garnet and tourmaline (well known metamorphic rock accessory minerals) abound in the Lokoja Sandstone, as well as high percentage of kaolinite (commonly formed from intense weathering and depletion of cation through leaching of Al-silicate rocks).[8] The pebbles of the Lokoja Sandstone are often imbricated in more or less northerly direction (Figures 3a and 3b), in response to the main transporting current. This significantly portrays that the sediments of Lokoja Sandstone had to been derived from the basement rocks in southwestern Nigeria (Figure 1).

The Patti Siltstone classified as quartz arenite in Figures 5 and 6 shows the occurrence of claystones, massive siltstones and fine to coarse grained sandstone subunits, with dominantly subrounded monocrystalline quartz grains. The occurrence of higher percentage of montmorillonite clay (derived from alkaline and lime igneous rocks) pointed probably to a different source than in older member. Such source rocks may be metasediments or igneous rocks. Thick laminated, brown to black shales of marine origin, as well as perthite and orthoclase feldspar which are associated with sediments of the member further support the above claim. The heavy mineral suite comprises garnet, zircon and tourmaline, and points to a metamorphic source. Result of palaeocurrent analysis (Figure 3b) showed on longitudinal transport along the basin axis toward NW. It also reveals minor sediment contribution from the opposite side of the basin. This is supported by Braide[10] who showed that apart from longitudinal influx of sediments along basin axis, basin infilling also emanated from basin margin from both southern and northern sections of the Lokoja Formation.

From the foregoing discussion, it is obvious that whereas the Lokoja Sandstone was sourced entirely from the southwestern part of Nigeria Basement complex (Figure 1), the Patti Siltstone might have experienced mixing of sediments particularly at its early stage of deposition. This could correspond to period of high sea level which could have occurred when the Tethys Sea met with the prevailing Guinea Sea during transgression over the study area. The aftermath led to deposition of the lower sandstone in the Patti Siltstone. This is confirmed by bimodal display of grain size distribution curve. Later the Tethys Sea deposition resulted into layers of silt and argillaceous materials (particularly the brown and black laminated shales) and possibly the youngest sandstones. Adeleye and Dessauvage[4] have reported the presence of marine fossils including gastropods and oysters, and a characteristic marine warm water ammonite species of Maastrichtian (62 Ma) age in the area. They observed that the black shale bears minor marine influence what supported above postulation.

5.5 Depositional environment

Notable workers[13,15,16,17,21] in various sedimentologic studies have related statistical parameters from grain size analysis to environment. Nevertheless, integration of other measurable environmental parameters such as sedimentary structures and geologic settings, alongside with grain characteristics, gave effective environmental interpretation. Freidman[17] pointed out that textural parameters are environmentally sensitive. From the scattered plot of skewness against sorting and sorting against mean grain size, the probable inference is that the Lokoja Sandstone are river transported sediments deposited in a fluvial environment (Figures 4a and 4b). Freidman[16] points out that river transportation is unidirectional and as such is characterized by presence of both fine (fraction) and coarse fraction unlike the beach environment of swash and backswash that produces clean clastics with negative skewness. The Lokoja Sandstone is likely to have enjoyed a rapid rate of deposition, probably from a steep gradient and a quick burial, leading to the preservation of unaltered fresh, angular to sub-angular, feldspar grains and rock fragments with composite mineral grains and mica flakes. The presence of argillaceous rock fragments in fine grained sandstones suggest their environment of deposition as witnessing period of low energy as is the case in flood plain deposition flanking braided stream.[7] During flooding, a stream-shift may have redistributed the original flood plain deposits which became easily eroded away as granules and pebbles under prevailing hydrodynamic conditions.[7] Abundance of authigenic and detrital clay matrix/cement of dominantly kaolinite suggested the environment of deposition of Lokoja Sandstone was acidic, though the proportion of the authigenetic and/or detrital kaolinite is not certain.

The characteristics of the Patti Siltstone seem to suggest a more intense weathering at the source area or at the environment of their deposition. This could be a function of the maturity of the geomorphology of the source area or the environment of deposition. Feldspar content and labile rock fragments are eliminated through physical and chemical weathering. The sediments are viewed to have witnessed a sequential but slow rate of deposition couple with seasonal variation such that the feldspar and biotite together with the metastable heavy minerals were considerably altered, leading to mineralogical maturity of the sandstone. However, the poor to moderate sorting and high matrix/cement content brandished the sandstone as texturally immature. The sandstone probably documented channel deposition in some sluggish, fast waning meandering stream which is typical for flood plains. In part, the massive siltstone indicates quiet deposition of fine suspended load in a cut-off channel and flood basin in which this could be seasonal. The claystone indicates quiet lacustrine deposition of the finest terrigenous clastics that got stranded in the pond of the southern Niger basin during the Patti Siltstone sedimentation. The widespread occurrence of thick, ferruginised bands indicated a gradual emergence of the southern Niger Basin into predominantly sub aerial inland conditions. Similarly ferruginised bands have been reported in the Enagi Siltstone of Bida (middle part) in the Niger basin.[1] The black laminated shale typifies marine influence and probably confirms the contribution of the (marine) Tethys Sea to the Patti Siltstone deposition. The increasing quantity of montmorillonite with stratigraphic heights shows that the environment of deposition of the Patti sediments was alkaline under which montmorilloinite became very stable.

5.6. Palaeoenvironmental interpretation

The most distinctive property of the Lokoja Sandstone is the higher percentage of kaolinite (72% of all clay minerals).This signifies an acidic environment for which kaolinite is more stable. On the other hand, montmorillonite (38%) is stable in alkaline environment. Montmorillonite shows a remarkable increase in percentage abundance towards the top of the member. This could mean that the regular interstratifications of basic montmorillonite are degrading with depth and subsequently reconverted to kaolinite. This indicates a transition from a weak to very strong hydrolysis on the continent.

Climatically, while kaolinite is favoured in the source area with intense weathering where leaching of the cation is high, leading to the concentration of mobile anion as obtained only in warm, humid paleoclimates.[22] Montmorillonite is produced more in a weak, hydrolyzed terrestrial environment with warm but short humid palaeoclimates on a high relief. Since the relative proportion of clay minerals is determined by their source, it is correct then to say that sediments of the Lokoja Sandstone and Patti Siltstone must have emanated from two different palaeoclimatic sources or environments. Their differences in feldspar composition (alkaline feldspar occurs in the Patti Siltstone while sodic feldspar occurs in the Lokoja Sandstone) coupled with the presence of amphibole in sediments of Patti Siltstone further give credence to different source areas for the two sandstone members.

6. CONCLUSIONS

Provenance and palaeoclimate conditions, among others, are coded in clastic sediments, especially sandstones. Qualitative analyses of light, heavy and clay fractions of these rocks could reveal their petrographic variations which would lead to unveiling of their terrain, palaeoclimate and diastrophic regime. Proper understanding of initial morphology and morphologic evolution of framework grains of sandstones also contribute to reliable inference of their provenance, transport history and depositional environment. Those parameters were harnessed in assessing the various Upper Cretaceous (70 - 65.5 Ma) facies of the Lokoja Formation that outcrop in the southern Niger Basin (Nigeria). Intense weathering where leaching of cation prevailed in a warm, humid palaeoclimate characterized sediments of the Lokoja Sandstone. These sediments have high kaolinite content and are rich in sodic plagioclase. The montmorillonite-rich sediments of the Patti Siltstone being a product of intense weathering in a weak, hydrolyzed terrestrial environment with warm but short humid palaeoclimate on a high relief are potassic plagioclase rich and are associated with iron ore mineralization. These differences are partly related to the shallow inland depositional environment that favoured the prevalence of acidic condition for Lokoja Sandstone and alkaline condition for Patti Siltstone. This study has shown that comparison of grain-clay fractions as well as the morphogenesis of framework grains is reliable signatures for deciphering the source and depositional history of detrital sediments.

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