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SANDSTONE COMPOSITION AND PROVENANCE ANALYSIS OF PART OF BIDA FORMATION, NOTHERN BIDA BASIN, NIGERIA

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Abstract

Provenance studies is important for the sandstones of Bida basin in order to accurately decipher paleogeography and for assessment of the sandstone's aquifer and reservoir properties. Geochemical methods were used by earlier researchers but thin section petrography was not used for provenance studies in the basin. This project integrates outcrop studies and thin section mineralogical composition to determine the source lithology, plate tectonic setting and paleoclimatic conditions of part of Bida Formation exposed around Doko-Jima Junction in Northern Bida basin, Nigeria. Thin section mineralogy reveals quartz content to be averagely 63% while the feldspar content is less than 1% and the lithic fragment is 37% which classifies the sandstones as litharenites. Matrix was generally absent in the sandstones and the identified cements were mainly iron oxide. The sandstones display angular to subangular shapes which suggest short transportation of the sediments before deposition in fluvial environments. Plots of modal compositions of the sandstones on triangular QFL discrimination diagrams suggest that the paleo-plate tectonic setting was recycled orogens, while the source lithology was metamorphic and the climate was humid. These interpretations were supported by the lack of feldspar, abundant quartz and abundant lithic fragments composed of sedimentary and metasedimentary rock fragments such as chert and quartzite. This project has shown that the integration of field and thin section analyses is vital to sandstone provenance studies.

Keywords: Bida Basin, Bida Formation, Sandstone Composition, Sandstone Provenance, Doko

1.0 Introduction

The ultimate goal of studying sandstones and sedimentary rocks in general is to interpret the paleogeography of deposition of the rocks (Boggs, 2005). The physical, chemical and biological information gathered from sandstones are commonly used to reliably reconstruct the past environment within which the sediments were deposited. These sedimentary models for the past environments are further used to explore earths materials such as petroleum coal, solid minerals and groundwater resources (Boggs, 2006). In order to achieve this ultimate goal, geologist commonly set several objectives such as determining the provenance of the sandstones (i.e., determining the nature of the source lithology from which the sedimentary particles were derived (i.e., whether igneous, sedimentary or metamorphic and its tectonic setting), the transportation history of the particles from source area to depositional environment (water, glacier, wind, gravity), the conditions of deposition of the sediments (high or low energy), the depositional environments (lake, delta, river, marine, desert), transformations during burial and uplift of the sediments (diagenesis – compaction, cementation, dissolution etc), classification of the sandstones and so on.

Several works have been published in the Bida basin with the intention of understanding some of the objectives highlighted above. For example, Adeleye (1972), Adeleye and Dessauvagie (1972); Okosun et al. (2007), Obaje et al. (2015) and Goro et al. (2014; 2015; 2017; 2019) focused their research on the stratigraphy, sedimentology and petroleum resource potentials of the basin. A few research have been conducted and published on the provenance of the sandstones of this basin (for example, Ojo et al., 2020; Oladimeji and Ojo, 2022). However, all these works used geochemistry in their provenance analysis. None of them used detailed petrographic analysis for their studies. This project therefore focuses on the use of thin section petrography as a tool for provenance analysis of part of Bida Formation exposed near Doko-Jima junction in central Bida basin. The textural attributes and the composition of the sandstones would be utilized to reconstruct their provenance.

In order to achieve this aim, the following objectives were set for the research.

1. To produce sedimentological graphic log of part of Bida Formation exposed around Doko-Jima junction, near Bida, Central Bida basin, Nigeria
2. To collect representative outcrop samples of the sandstones for thin section preparation
3. To determine the texture and mineralogy of the sandstones by studying them using research petrological microscope (thin section petrography)
4. To classify the sandstones based on thin section modal analysis
5. To interpret the provenance of the sandstones (source lithology, tectonic setting and paleoclimate) using thin section petrography results

1.2 Study Area

The study area is situated in the central part of Bida Basin, near Bida, Niger State, Nigeria. The geographical positioning system (GPS) location falls between Latitude 08^{0}55’7” N and Longitude 05^{0}57’57” E. The place can be accessed through the Minna-Bida road or off Lambata-Mokwa Trunk A road at Poly junction Bida. The sedimentological log was produced from a burrow pit just by the side of Doko-Jima junction along Poly-Nupeko road. The area fall within the Pategi Sheet geographically.

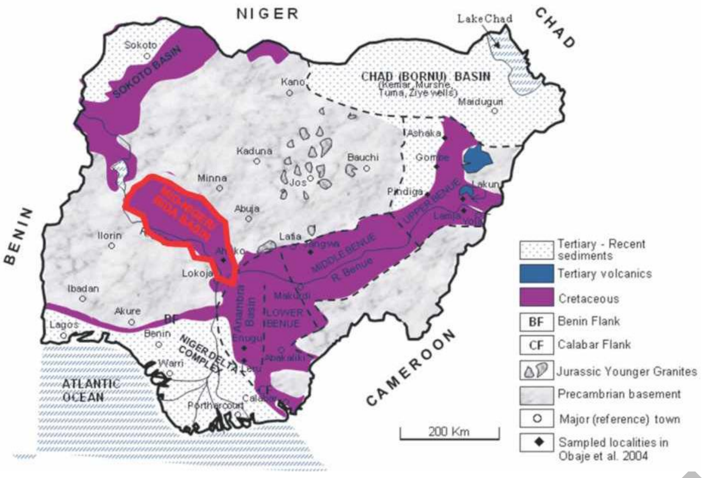

Figure 1: Geological map of Nigeria showing Bida basin (Obaje *et al.*, 2014)

Generally, the area is made up of medium to high ridges of about 120 m to 200 m and plains. Three obvious geomorphic features characterize the area; 1) the River Niger and its tributaries; 2) Floodplains that are more than 4km wide from both side of River Niger; 3) The belt of Mesas running NW-SE within the Bida basin characterize the landforms. The area of study has two different seasons; rainy season and dry season. The rainy season ranges from April to October whereas the dry (harmattan) period begins from October till March. The temperature ranges between 23^0C to 38^0C and the mean annual is estimated 32^0C. The average mean rainfall is 250mm; it is categorized as Guinea Savannah vegetation because is found in the central part of Nigeria. The vegetation contains herbs, grasses, cluster of trees, forests.

The most commonly occupational activities of the inhabitant of the area is farming because, the geology aid the framing activities. Certain species such as maize, yam, guinea corn, rice yield well on their land. The framing includes both commercial and subsistence farming system. The planting in this area is mostly of fallow agricultural set up and incessant from of planting annually. Rearing of the animals like goat, sheep, cattle also practicing because of the abundant grasses for animals to graze. Animals efficiently work more than human being when properly handle. The small rivers also provide means of fishing and irrigation farming practice especially during the dry season.

Bida basin is a linear structure about 350km long and between 75-150km wide trending NW-SE approximately orthogonally to Benue Trough (Zaborski, 1998) and situated between Sokoto and Anambra basins.

Four main lithostratigraphic suggested by Adeleye and Dessauvagie (1972) are in common use in the stratigraphy of the basin. They include from the base: Bida/Lokoja Formation, Sakpe Ironstone Formation, Enagi/Patti Siltstone Formation and Batati/Agbaja Ironstone Formation. Analysis of published works (Omali et al, 2011; Okosun et al., 2009; Braide, 1992b, c; Adeleye, 1975, 1989; Whiteman, 1982) and field studies on the sedimentology and stratigraphy of the sediments of Bida basin show that the following facies associations are the most dominant.

1. Alluvial fan facies association (Bida/Lokoja Formation) – conglomerate facies, debris flow, stream flow sediments.

2. Fluvial facies association (Bida/Lokoja Formation) – meandering stream facies, braided river facies, consisting of very coarse, coarse, medium and fine-grained sandstones,

floodplain mudstones and subordinate fine sandstones; mire facies are also included here.

3. Flood basin and lacustrine facies association (Enagi/Patti Formation) – distal fan facies, flood plain facies, lacustrine facies, they are for the most part mudstones, siltstones and fine sandstone with little coarse sandstones.

4. Ironstone facies association (Sakpe, Batati/Agbaja Formation) – predominantly ironstones.

5. Delta facies association (Enagi/Patti Formation) – grey shales, buff siltstones and red sandstones.

6. Shoreface, tidal channel, and tidal marsh to coastal swamp facies association (Enagi/Patti Formation) - medium- to coarse-grained, moderately-sorted quartz arenites.

3.0 Methodology

The study was conducted in three phases which are field work and sampling, rock thin section preparation and analysis in the laboratory and finally data analysis and interpretations.

The fieldwork phase involved the location of and mapping of the study interval by documenting field observations in field notebook and later on construction of sedimentologic graphic log of the study interval. Field observations include the recording of textural and structural features such as grain size, shape sorting, cross bedding, bioturbation, bounding surfaces between beds, bed thicknesses and measuring of paleocurrent directions using trough cross beds. All the above observations were noted in field notebook and sedimentologic graphic log was constructed in the field recording all the beds and their features. A neater graphic log was constructed after returning from the field and later digitized as presented in the report.

A total of four samples of representative sandstone beds were collected from the field from which the sandstone samples were prepared and labeled and then sent for thin-section preparation. The samples were cut and trimmed to thin section size. Then the surface was roughly grinded. The grinded surface was then impregnated on hot plate with araldite (adhesive glue). After cured, the surface was then re-grinded on lapping machine. Then the impregnated sample was mounted on glass slide with araldite. Then sample slide is grinded to 3mm grading on glass plate with caborundum (silicon carbide) and left to dry.

The thin sections were observed using research petrologic microscope at the Department of Geology laboratory of the university. Textural and mineralogical features of the sandstones were recorded. The textural features included grain size, grain shape, sorting and fabric.

The thin sections were examined under both plane and cross polarized light. Features such as grain color, cleavage, pleochroism and relief were observed under plain polarized light. Interference colors, twining, undulosity and extinction were all observed under plain polarize light.

Point counting using 300 counts was done on each sample and the percentage of the quartz, feldspar and lithic fragments (QFL) were computed from the point counting results. The QFL percentages were tabulated and used to plot on sandstone triangular classification diagram of Pettijohn et al. (1987) for the sandstone type. The triangular diagram of Dickinson (1985) was used to discriminate against different plate tectonic setting of the source sandstones. Furthermore, the triangular plot of Suttner et al. (1981) was utilized to establish the paleoclimatic conditions and source lithology.

4.0 RESULTS AND DISCUSSION

4.1 Field Results

The total number of nine beds have been described in the field. These beds are used to construct a sedimentological graphic log representing the summary of all the field observations (Fig. 2). Generally, the interval is composed sandstones and mudstones and field pictures are shown in Figure 3. The sandstones range in grain size from fine grained to very coarse grained (Figs. 2&3). Sedimentary structures observed within the sandstones are trough cross bedding, massive bedding and bioturbation and the bedding planes are either planar or irregular (Figs. 2&3).

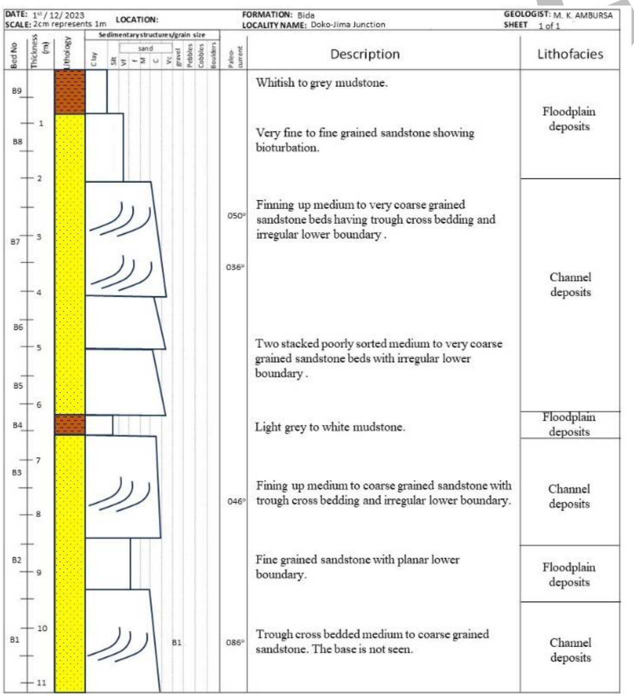

Figure 2: Sedimentological graphic log of the study interval.

Figure 3: Field photos showing (A) section view of trough cross bedding, (B) plane view of trough cross bedding, (C) & (D) fine grained sandstone with colour mottling indicating bioturbation, (E) grey mudstone.

4.2 Thin section analysis results

Detailed thin section description of two of the sampes are presented below.

4.2.1 Sample 1 Description

Texture:

Grain size: Medium to coarse grained
Grain shape: High sphericity, subangular to subrounded
Sorting: Moderately sorted
Fabric : Grain supported with touching to long contacts

Composition:

Framework grains:

Quartz: - Abundant quartz grains (colourless, very low relief, cleavage is absent, 1st order grey, yellow interference colours).
- Dominantly monocrystalline with some polycrystalline
- Mostly quartz show non-undulose extinction (Plate I A-F). A few display undulose extinction (Plate I B, D, F)

Feldspar: - No feldspar

Lithic fragment: - Fine grained sedimentary to metasedimentary lithic fragments (Plate I A-F)

Matrix: No matrix. What appears to be matrix is actually pseudo matrix of labile fine grained rock fragments that bend against rigid grains and smear between them (Plate I)

Cement: Rare reddish brown cement (ironoxide) are present (Plate I B). pseudomatrix occupy most of the spaces between the grains.

Point count: Q = 63%, F = 0%, L = 37%

Rock name: Lithic Arenite (based on more lithic fragments than feldspars and abundant quartz)

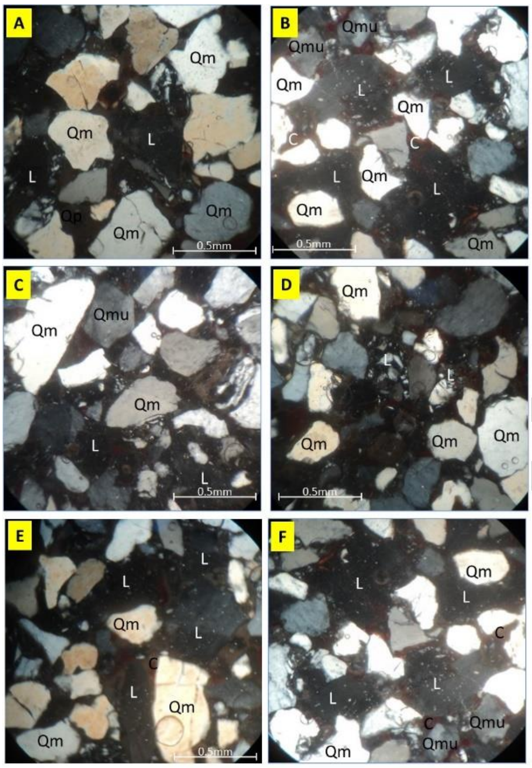

Plate I: Key Photomicrographs of Sp1 showing the following features Qm = monocrystalline quartz; Qmu = undulose monocrystalline quartz; L = lithic fragment (rock fragment).

4.2.2 Sample 3 Description

Texture:

Grain size: coarse to very coarse grained

Grain shape: Low sphericity, angular to subangular

Sorting: Poorly sorted

Fabric : Grain supported with floating to tocuching contacts

Composition:

Framework grains:

Quartz: - Abundant quartz grains (colourless, very low relief, cleavage is absent, 1st order grey, yellow interference colours).
- Dominantly monocrystalline with some polycrystalline
- Mostly quartz show non-undulose extinction (Plate II A-F). A few display undulose extinction (Plate II A, E)

Feldspar: - No feldspar

Lithic fragment: - Sedimentary metasedimentary lithic fragments (Plate II A-F)

Matrix: No matrix.

Cement: Reddish-brown cement (ironoxide) is abundant. Most of the grains are floating within it (Plate II B).

Point count: Q = 66%, F = 0%, L = 34%

Rock name: Lithic Arenite (based on more lithic fragments than feldspars and abundant quartz)

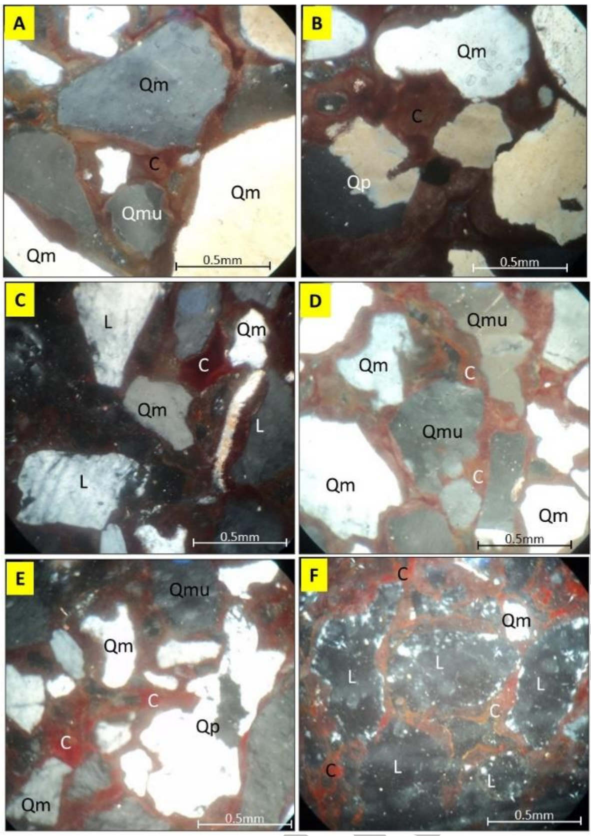

Plate II: Key Photomicrographs of Sp3 showing the following features Qm = monocrystalline quartz; Qmu = undulose monocrystalline quartz; L = lithic fragment (rock fragment).

The percentage of the framework grains based on 300 counts is displayed on Table 1 below. Generally, the Quartz ranges from 50% to 63% with average of about 62.3% of the total framework. Monocrystalline type dominates over the polycrystalline type. Feldspar is generally absent. Only some 2% was seen in sp2 (Table 1). Lithic fragments are abundant with percentages ranging from 27% to 50% with average of 37%.

Table 1: Framework composition of Bida Formation sandstones based on point counting of thin sections

Sample ID	**Quartz** (%)	**Feldspar** (%)	**Lithic Fragment** (%)
Sp1	63	0	37
Sp2	71	2	27
Sp3	66	0	34
Sp4	50	0	50
Average	62.5	0.6	37

4.3 Sandstone classification

The classification of sandstones according to Pettijohn et al. (1987) was used to classify the sandstones as displayed on Figure 4. All the four sandstones plotted within the field of litharenite. The plotting of these sandstones in this field is also supported by the composition shown by the thin section petrography. The lack of feldspars and matrix are common features of lithearenites (Tucker, 2005) which are clearly displayed by the sandstones of the present study. The lithic fragments found are fine grained sedimentary (Plate II) and metasedimentary fragments such as quartzite (Plate II C). The fine-grained sedimentary rock fragments appear as pseudo matrix because of their fragile nature when compared with the quartz grains (Plate I). The abundance of lithic fragments is a reflection of high rate of sediment production through weathering and short transport distance between source area and the environment of deposition (Tucker, 2005). High rate of weathering is favoured by humid climate. Litharenite account for 20 to 25 percent of all sandstones globally (Tucker, 2005; Boggs, 2006).

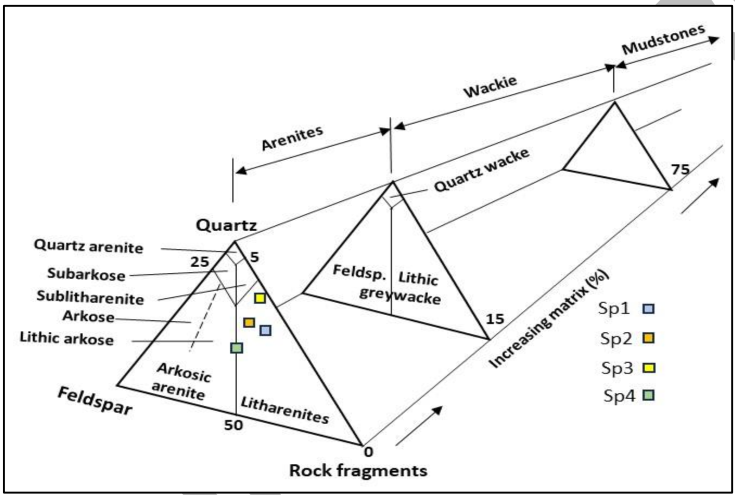

Figure 4: Sandstone classification diagram (Pettijohn et al., 1987)

4.4 Plate Tectonic Setting

Sandstone composition have been used by several researcher to unravel the tectonic region of its provenance. Most of the works use the triangular diagrams of Dickinson (1985) which shows the average compositions of both modern and ancient sands derived from different provenance terranes (Figure 5). the sandstones of the present work plotted on recycled orogen setting (Figure 5). Recycled orogen provenances are regions that rae formed by up folding and/or upfaulting of sedimentary or metasedimentary areas due to collision. They are classified into three provenance terrains: 1) collision orogens; 2) foreland uplift provenances and 3) subduction complex provenaces (Dickenson, 1985). The sandstones from these terranes display varied composition depending on which of the three provenances their sediments were sourced. The sandstones of Bida Formation in this study are generally composed abundant lithic fragment (sedimentary and metasedimentary rock fragments), lacks feldspars and matrix and have high quartz content which are characteristics of this type of source terrane according to Boggs (2006) and Tucker (2005). These attributes are also indicative of continental collision orogens as indicated by Tucker (2005).

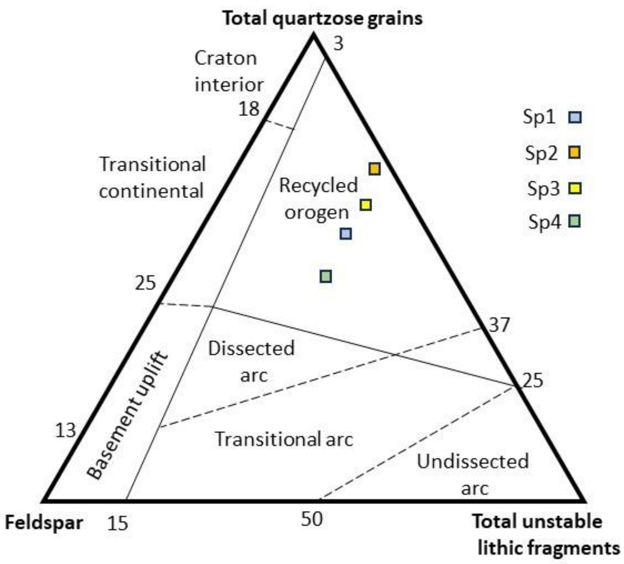

Figure 5: Triangular diagram showing average compositions of sand derived from different provenance terranes. After Dickinson (1985)

Sediment from a recycled orogen commonly fill adjacent foreland basins and remnant ocean basins or may be transported in major river systems to more distant basins in unrelated tectonic settings (Tucker, 2005). In the case of the study interval of this project, the sediments could have been sourced from the basement complex rocks surrounding the Bida basin especially from Lokoja area based on the paleocurrent direction of NW and they were transported within short distances into the basin through rivers.

4.5 Source Lithology and Paleoclimate

The triangular interpretation diagram of Sutter et al. (1981) is employed in order to infer the source lithology and paleoclimate of the studied sandstones. The sandstones plotted on the field of humid climate and metamorphic source lithology (Fig. 6). The work of Suttner et al. (1981) is based on the premise that sands derived from similar parent rock types in a similar climate are compositionally unique. Also, it has been shown that hot, humid climates promote alteration and destruction of less-stable minerals and rock fragments, whereas very cold or very dry climates favour preservation of these less-stable constituents (Boggs 2006). The absence of feldspar in the sandstones of the study interval may therefore reflect the humid condition which led to rapid weathering of feldspars.

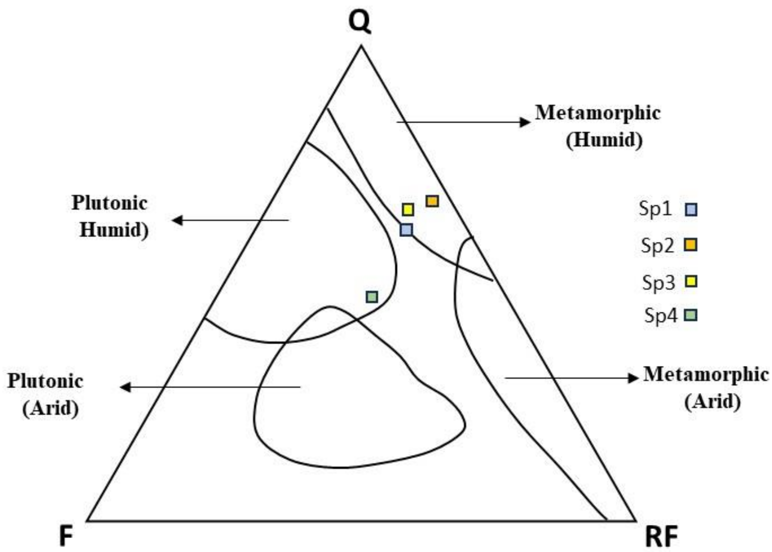

Figure 4.5: Climate discrimination diagram (Suttner et al., 1981)

5.0 Conclusions

The integration of field outcrop studies and thin section analysis of part of Bida Formation was done in order to infer the provenance of the sandstones based on thin section composition. The following conclusions were made based on the set objectives.

1. The study interval consists of fine to very coarse-grained sandstones and mudstones which were deposited in fluvial environments based on the fining upward cycles. The coarser lower parts reflect deposition in channel while the finer upper parts of the cycles were due to deposition on flood plain environment.
2. Based on the four studied thin sections. The sandstones are composed of angular to subangular grains which reflect short distance of transport before they were deposited.
3. The paleocurrent readings shows that the sediment came from the south (Lokoja area) and were transported towards the NW
4. The sandstones are interpreted as litharenites based on the abundance of lithic fragments, absence of feldspars and abundance of quartz. This immature nature of the sandstones due to the presence of abundant lithic fragment also reflects short distance of transportation
5. The paleo-tectonic setting of the source materials for the studied sandstones is recycled orogen. The absence of feldspar and abundance of lithic fragments points to continental collision orogen.
6. The paleoclimatic condition during the weathering and deposition of the sandstones was humid climate and the source lithology was metamorphic. This is reflected by the occurrence of metasedimentary lithic fragments such as quartzite in the study interval.

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