https://dx.doi.org/10.4314/ijs.v25i2.7

REVISED STRATIGRAPHIC SEQUENCE AND TYPE SECTIONS OF THE SOUTHERN BIDA BASIN, NIGERIA

Ozulu, G. U.[1], Aigbadon, G. O.[2,*], Okoro, A. U.[3] and Odiaka, N. I.[1]

[1]Department of Geology, Dennis Osadebey University, Asaba, Nigeria.
[2]Department of Geology, Federal University Lokoja, Nigeria.
[3]Department of Geological Sciences, Nnamdi Azikiwe University, Awka, Nigeria.
*Corresponding Author's Email: godwin.aigbadon@fulokoja.edu.ng or godwin.aigbadon@yahoo.com

(Received: 17th June, 2023; Accepted: 6th August, 2023)

ABSTRACT

A reassessment of the stratigraphy of the Southern Bida Basin has been attempted among various disagreements. For this work, field geological mapping and stratigraphic descriptions of exposed lithologic types on outcrop sections were used. Section-by-section descriptions of important outcrops based on field observations aided in identifying lithologic units and delineating the boundaries of the sub-basin's three formations (Lokoja, Ahoko, and Agbaja). The type sections for formations in the sub-basin were not properly erected, so Jones (1958) type section has been supplemented by a more comprehensive hypostratotype, and the name Patti Formation, which is considered a misnomer in this context, has been replaced with Ahoko Formation proposed by Rahaman *et al.* (2019). Ahoko village is the type locality. The Agbaja Plateau, where the Agbaja Formation is best exposed, has been presented as the lectostratotype for the formation, while the revised stratigraphic succession of the Lokoja region shows the Lokoja Formation directly encompassing the Paleozoic Basement terrain, with the Maastrichtian Agbaja and Ahoko Formations (former Patti) overlying it sequentially.

Keywords: Stratigraphy, Formations, Type Sections, Stratigraphic Model, Outcrops, Southern Bida.

INTRODUCTION

Over time, the stratigraphic description of sediments in the Bida Basin has been contentious. The Lokoja Series was named by Falconer (1911) for the Upper Cretaceous clastic sedimentary rocks. These rocks were described as the southerly continuation of the Sokoto region's Eocene facies. The Nupe Group was coined by Russ (1930) to define the geologic successions in both the northern and southern regions of the basin. Jones (1958) claimed that the sediments deposited in Lokoja sub basin were Campanian to Maastrichtian Lokoja and Patti Formations. Lokoja Sandstone refers to the whole Campanian to Maastrichtian deposits in the southern half of the basin (Jan du Chene *et al.*, 1978; ldowu and Enu, 1992). Akinyemi *et al.* (2014) incorrectly put the Lokoja - Basange Formation of the Benin Flank, Anambra Basin in the Bida Basin (Lokoja Sub-Basin), but Rahaman *et al.* (2019) corrected the geology of the basin while Ojo and Akande (2020) rebuttal did not help to resolve the confusion either. This has added a new layer of complexity to the debate regarding the basin's geological sequence. Their claim regarding the Lokoja/Bida Sandstone being directly overlain by the oolitic/pisolitic ironstone of the Agbaja/Sakpe Ironstone and succeeded by the Patti/Enagi Formation faced a challenge from Ojo and Akande (2020) in their rebuttal. This dispute questions the idea that the Ahoko Shale is stratigraphically younger than the Agbaja Formation.

Evidence from recent field geological mapping and discrete stratigraphic interpretations of outcropping sediments has necessitated this new review on the stratigraphy of the southern region pertaining to the basin presented in this paper. The Bida Basin is separated geographically into two sections: northern and southern. Although no concrete boundary between the north and south has been established, an approximate boundary established by Obaje *et al.* (2013) shows the southern part extending out of confluence river at Lokoja down to Abaji towards Abuja (Nton and Adamolekun, 2016). The boundary of the basin adjacent to the Anambra Basin lacks clarity and is not easily identifiable on outcrop (Figure 1). Nwajide (2013) suggests that sediments either interdigitate across this boundary or exhibit facies changes, indicating a regional lateral facies relationship between the stratigraphic successions of the Bida Basin and the Anambra Basin. Nwajide and Reijers (1996) further elaborate that

coeval inter-fingering of sediments exists between the facies of both basins. Understanding this relationship is crucial for interpreting the stratigraphic sequence of the exposed deposits.

Figure 1: The position of Bida Basin indicated in the geological map of Nigeria (Obaje *et al*., 2004).

STUDY LOCATION

The area studied is within the geographic coordinates of latitudes 7^0 51'N - 8^0 30'N and longitudes 6^0 30'E - 7^0 00'E in the southern Bida Basin, Nigeria. The research site includes Felele, Banda, Ohono, Koton-Karfe, Ozi, Uwah, Akpanya, Gerinya, Ahoko, Gada-Biyu, Agbaja, and Abaji. These locations feature rock outcrops visible along road-cuts or accessible through quarry pits. Major roads like the Lokoja - Abuja highway and the Gegu-Gerinya road provide access to these sites. Additionally, the minor road connecting Felele in Lokoja metropolis to Agbaja village (Figure 2) leads to the Agbaja Plateau.

METHODOLOGY

Field geological mapping and stratigraphic descriptions of exposed lithologic types on outcrop sections were used in this investigation. Section-by-section description of important outcrops based on field observations, with emphasis on lithology, texture, sedimentary structures, grain sizes, and bed geometry for accurate lithostratigraphic interpretation. Lithostratigraphic logs for each section, as well as a composite log for the Agbaja road portion, were created using the Photo-Shop software, version [cc 2020 (21.2.1)]. The lithological logged sections (Figures 4, 6, 8, 9, 11 & 13) produced was utilized to classify the sections into lithostratigraphic units with the interpreted chronostratigraphic units established to delineate the formation boundaries afterwards (Ojo and Akande, 2020; Aigbadon *et al.,* 2022, 2023).

In this work, the annotations employed by Ozulu *et al.* (2021) for various lithologic facies of sedimentary fills in the basin's studied sections have been utilized. The geologic map was produced by juxtaposing and combining the topographic maps regarding Lokoja NW and Koton-Karfe.

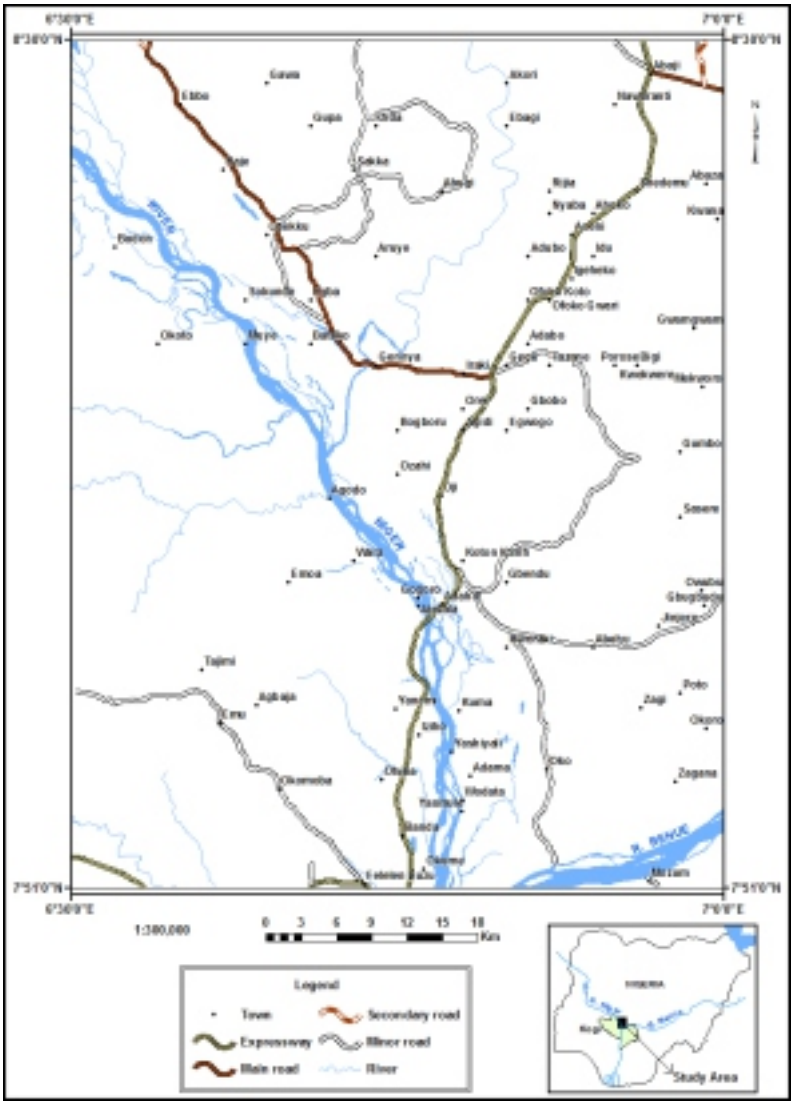


Figure 2: Showing research area within the location map (Ozulu *et al.,* 2021).

RESULTS AND DISCUSSION

Outcrops and Lithostratigraphic Descriptions

The Lokoja Formation is well exposed in Felele, Nataco, Banda, Ohono, and Koton-Karfe along the Okene - Lokoja - Abuja highway. The Ahoko Formation (formerly Patti Formation) is visible in Orehi, Garba, Achabo, Idu, Gegu-Beki, Etegi, Ahoko, Gerinya, and Aseni villages along the Lokoja - Abuja highway and at Gerinya along the Gegu-Beki-Gerinya Road. The Agbaja road section reveals the graphic perspective of the Lokoja Formation, which is part of the Ahoko Formation and the Agbaja Formation.

NE-SW trends of the outcrops noticed in Felele, Nataco, and Banda are made up of rock types that were deposited in a fining upward cyclic succession. Fanglomerates/conglomerates, sandstones, and claystones are examples. In Felele, the succession begins with clast-supported fanglomerate/conglomerate resting unconformably on an uneven basement (Figures 3 and 4). The angular to sub-rounded quartz pebbles, cobbles, and feldspar grains embedded in clay admixtures make up the basal clast-supported fanglomerate/conglomerate.

Figure 3: Matrix-supported fanglomerate/conglomerates exposed in a sandstone outcrop in Felele (Ozulu *et al.,* 2021).

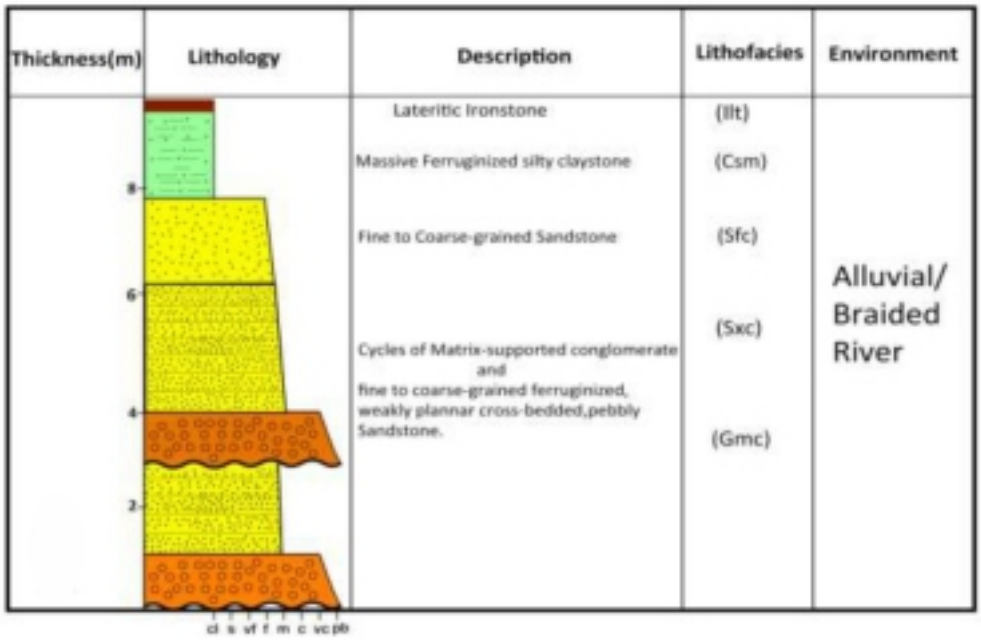


Figure 4: Stratigraphic record displaying cycles of matrix-supported fanglomerate/ conglomerate, along with fine to coarse-grained ferruginized weakly planar cross-bedded pebbly sandstone, all capped by claystone (Ozulu *et al.,* 2021).

General Legend for lithofacies

1. Matrix and clast-supported fanglomerate/ conglomerate lithofacies (Gmc)
2. Fine to coarse-grained ferruginized, weakly cross-bedded pebbly sandstone lithofacies (Sxc)
3. Fine to coarse-grained sandstone lithofacies (Sfc)
4. Massive silty claystone lithofacies (Csm)
5. Siltstone lithofacies (Slt)
6. Lateritic ironstones (Ilt)
7. Black-dark grey carbonaceous shale (Shc)
8. Bioturbated ripple-laminated siltstone (Sbr)
9. Poorly cross-laminated claystone (Cxl)
10. Concretionary/nodular ironstone (Icn)
11. Medium to coarse-grained sandstone (Smc)
12. Fine grained, well-sorted, friable bioturbated herringbone cross-bedded sandstone (Sxf)
13. Massive brownish claystone (Clm)
14. Massive claystone with lateritic ironstone (Cli)
15. Lateritic ironstones (Ilt)

At some other locations in Felele, the succession begins with a matrix-supported fanglomerate/conglomerate which has sub-rounded to well-rounded quartz and feldspar grains embedded in clay admixtures. This unit is overlain by weakly cross-stratified pebbly sandstones at some locations in Felele, or medium-grained brown sandstones with mud-cracked admixture at some other locations in Nataco and Banda. This is then overlain by medium to coarse-grained sandstones. The succession is repeated before being overlain by a ferruginized massive silty claystone. The top of the sequence is then capped by lateritic-oolitic ironstones. The geological features observed from Felele, Nataco, Banda, Ohono, up to Koton-Karfe represent the sequence of outcrops studied along the Okene - Abuja highway. The sedimentary succession in Abaji is prominently exposed on the road-cut section along the Lokoja - Abuja highway. The massive outcrop commences with monomictic paraconglomeratic sandstone (matrix-supported) at the sequence's base. Angular to sub-round quartz pebbles and cobbles are embedded in a purplish-white matrix-supported conglomerate, including sandstone. This facies is well-exposed at the sequence's base, followed by planar cross-bedded, fine to medium-grained feldspathic sandstones (Figures 5 and 6).

Figure 5: Outcrop section at Abaji showing planar cross-bedded sandstones (Ozulu *et al.,* 2021).

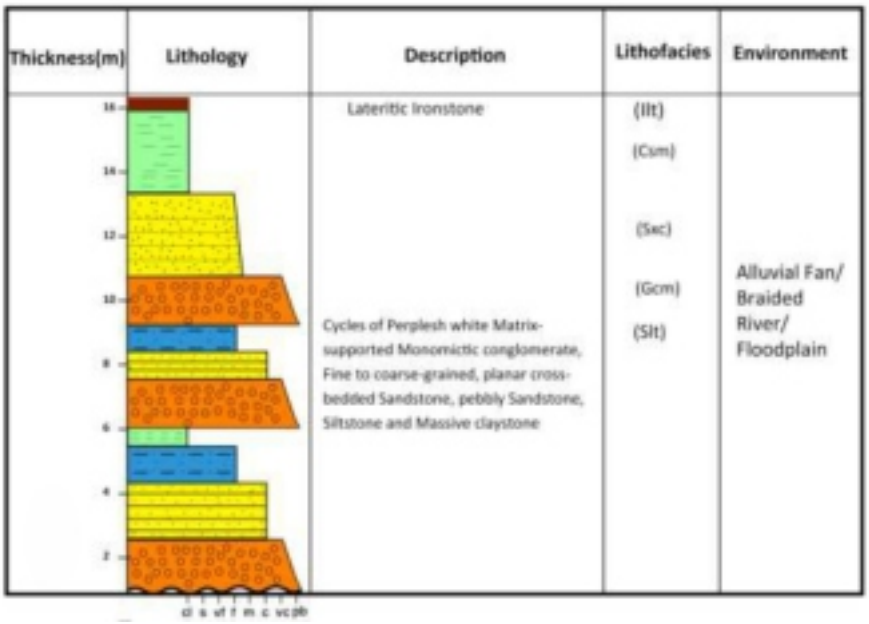


Figure 6: The lithosection at Abaji displaying cycles of massive purplish-white monomictic paraconglomerates, planar cross-bedded sandstones, and a cap of siltstone-claystone (Ozulu *et al.,* 2021).

This cycle is repeated and then succeeded by a claystone bed having abundant kaolinitic clay. In-between these successions are interbeds of siltstones and claystones. At the Gada-Biyu road-cut section, a 20 m thick unit is exposed with a white claystone bed at the base. This is overlain by medium-grained weakly cross-bedded feldsparthic sandstone. This sequence is again repeated before being culminated by lateritic ironstone cap (Figures 7 and 8).

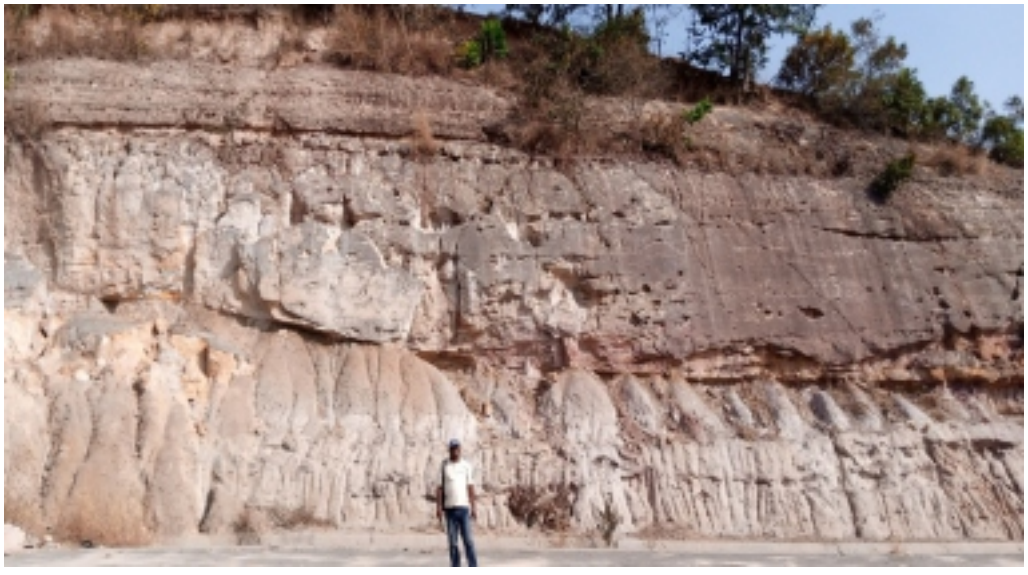


Figure 7: Gada-Biyu outcrop section showing a thick sequence of cycles comprising fining upwards sandstones and claystone (Ozulu *et al.,* 2021).

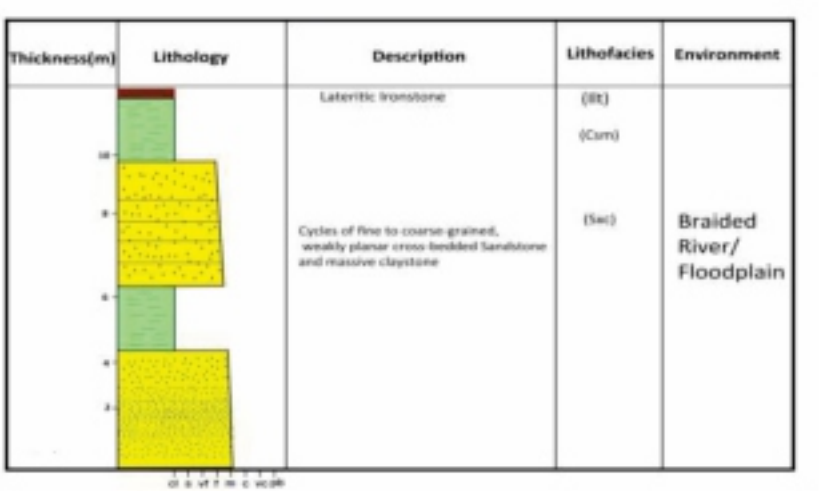


Figure 8: Litholog at Gada-Biyu, exhibiting a substantial sequence of cycles featuring fining upwards sandstones and claystone (Ozulu *et al.,* 2021).

At the foot of Agbaja road, the exposed units commence with a sequence of matrix-supported fanglomerate/conglomerate. This conglomeratic sandstone contains sub-rounded to well-rounded quartz pebbles and cobbles with clay admixtures. These formations are visible in stream channels at various locations on the hill along Agbaja road.

The fanglomerate/conglomerate is followed by units of sandstone with covered soil layers in-between; then, sandstones with clay drapes overlay this unit. The clay drapes are then covered by massive brownish claystone, succeeded by well-sorted, friable, ferruginized, bioturbated sandstones with herringbone cross-beddings, ranging from fine to medium-grained. Next, a bioturbated, wavy to ripple-laminated siltstone bed appears, with inter-bedded massive claystones containing lateritic ironstone, followed by interbedded fine to medium-grained sandstones and ironstones. Other outcrops on the Agbaja Plateau have ironstone-containing beds. Towards the top of this section, the ironstones transition from oolitic to pisolitic, granular to gravelly, muddy ironstones. The section demonstrates alternating bedding of oolitic and pisolitic ironstones, with the sequence becoming more pisolitic and concretionary towards the top. A composite lithologic log of this section is presented in Figure 9.

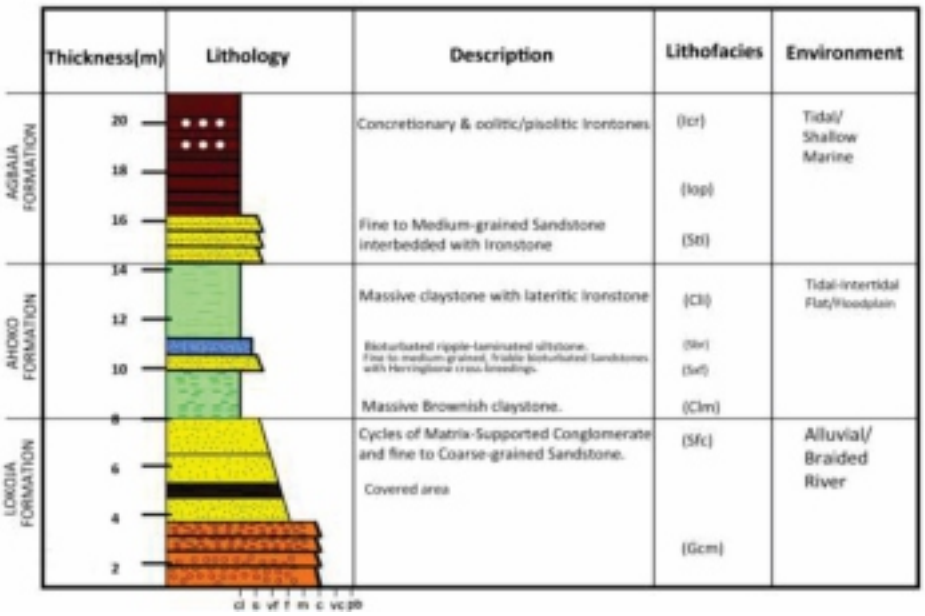


Figure 9: Lokoja-Agbaja road composite lithosection in the basin (Ozulu *et al.,* 2021).

Outcrops found in Ahoko, Idu, Gegu and Aseni as well as Gerinya, along Gegu-Beki-Gerinya Road within the basin, were of similar lithologies. This section has the thickest sedimentary succession reaching up to 50 m at the centre of the sub-basin and thins out completely northwards. Two of these outcrops at Ahoko and one at Aseni were studied in detail. The first outcrop observed in Ahoko has black carbonaceous fissile shales at the base of the thick rock sequence. The shale bed has been reported to contain abundant woody fragments and plant remains (Obaje *et al.,* 2011). This is overlain by a yellowish bioturbated ripple laminated siltstone bed having slump structures with burrows of *Chondrites*, *Thallasinoides* and *Ophiomorpha* ichnofossils. This is then overlain by a poorly cross-laminated claystone bed. These units are interbedded with concretional ironstones occurring in between as bands. Siltstones and claystones most commonly occur as heteroliths with concretionary/nodular ironstone bands in between. These were found in Ahoko, Gegu and Gerinya. The succession is capped by lateritic ironstone which acts as a cover (Figures 10 and 11).

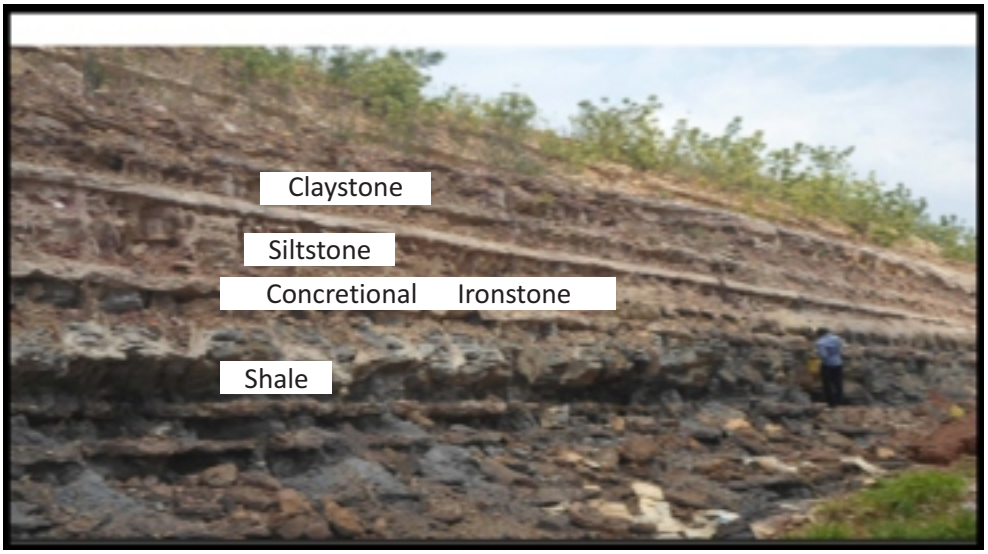


Figure 10: The outcrop section in Ahoko 1 displaying shale, siltstone, and claystone heteroliths (Ozulu *et al.,* 2021).

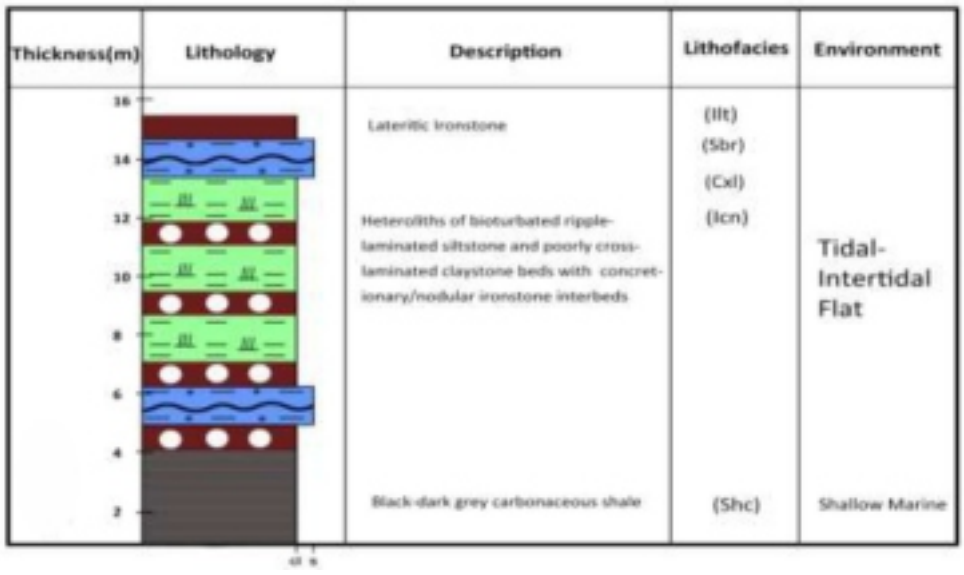


Figure 11: The lithologic log section in Ahoko - 1 showing shale, siltstone, and claystone heteroliths (Ozulu *et al.,* 2021).

The Ahoko road-cut section displays concretionary ironstone lithofacies, present as interbeds within ripple-laminated siltstones and claystone, forming thick heteroliths. These concretional ironstone within the sediments are thought to result from localized patches of differential cementation during early diagenesis. The geological features, including ripple-laminations, slump structures, concretional ironstone, and liesegang ring structures, point to a shallow marine depositional process. Additionally, the trace fossils such as Ophiomorpha burrows, Chondrites, and Thallasinoides suggest a possible sedimentation influenced by shallow marine - subtidal/intertidal conditions. By considering these chemical and biogenic sedimentary structures, we can interpret the environment as intertidal flat depositional settings in the Ahoko Formation (Ozulu *et al.,* 2021).

The second outcrop observed in Ahoko has dark grey fissile shales at the bottom of the thick sequence and laterally grades to a mudstone (claystone) bed. The sequence consists of medium to coarse-grained sandstones on top of it. The immediate aforementioned unit is found sandwiched in between two beds of ripple laminated siltstones with poorly cross-laminated claystone occurring as interbeds in-between the siltstone beds. The succession is then capped by lateritic ironstone as well. Clastic dykes are found intercepting the shale, sandstone, siltstone and claystone beds. The outcrop exposed at Aseni on the Lokoja – Abuja highway is over 12 m thick. The sedimentary rock has white claystone alternating with siltstones (Figures 12 and 13).

Figure 12: Aseni outcrop displaying thick section of cycles (siltstones – claystone sequence; Ozulu *et al.,* 2021).

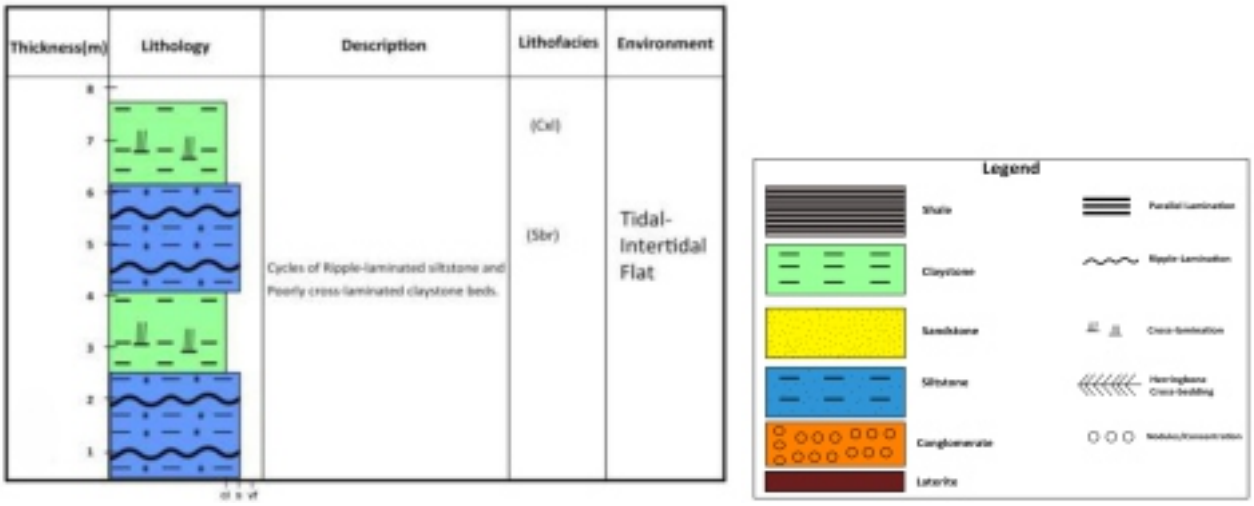


Figure 13: Aseni lithologic log, illustrating a thick section of cycles featuring fining upwards siltstones - claystone sequence (Ozulu *et al.,* 2021).

Lithostratigraphic Units

The lithologic logs were stratigraphically interpreted to analyze lithological characteristics, including textures, sedimentary structures, sand body geometry (grain size), contact types, and bed thicknesses in the studied sections. This enabled the assignment of the sections into lithostratigraphic units. The lithostratigraphic units representing the three formations in the sub-basin (Lokoja, Patti, and Agbaja) were accurately defined, illustrating the boundaries of these formations.

Lokoja formation:

At Felele, the Lokoja Formation is seen resting on the Basement Complex with non-conformity. Lithologic units of the formation are also exposed at several heights on the Agbaja road section, Felele, Banda, Ohono and down to Koton-Karfe in the basin.

Patti formation:

The Patti Formation were predominantly at Ahoko sections. The basal lithostratigraphic unit of this formation at the Ahoko section is a carbonaceous shale, which appears as dark-grey in colour.

This is overlain by bioturbated ripple laminated siltstones followed by poor cross-laminated claystones. These siltstones and claystones, most commonly, occur as heteroliths with concretionary nodular ironstone bands in between. This sequence occurs in places like Ahoko, Gegu and Gerinya. The succession is then capped by lateritic ironstones. At Aseni, a thick succession of claystones and siltstones occur alternately. The beds generally dip at between 4^0 - 12^0 SW at this section. At the Agbaja road section, exposed portions of this formation are also seen. It begins with well-sorted, friable, fine to medium-grained ferruginized, bioturbated sandstones with herringbone cross-beddings. It is then succeeded by a wavy to parallel laminated siltstone bed. This is followed by beds of claystone and siltstone interbedded with ironstone.

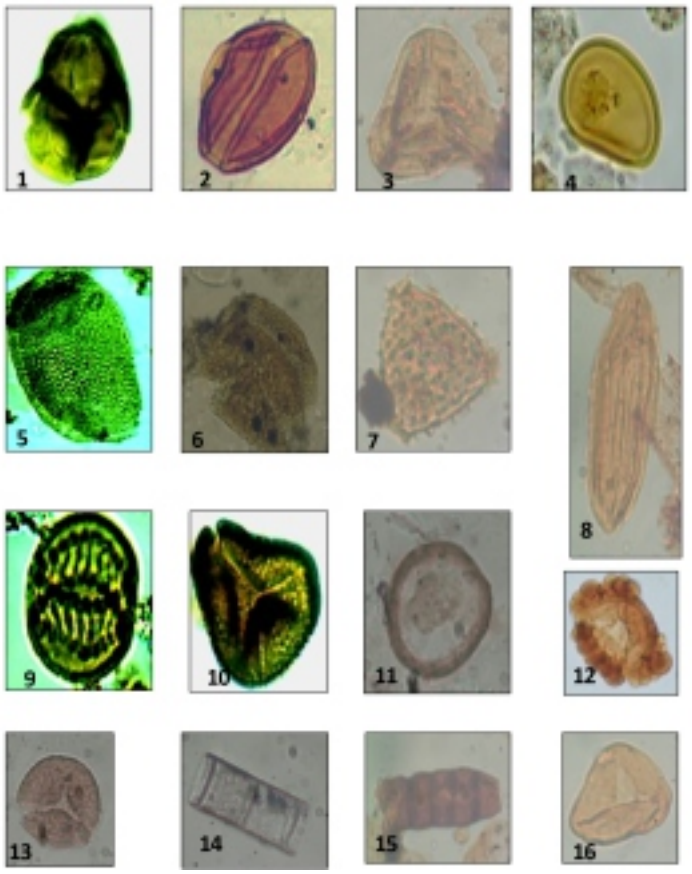
Agbaja formation:

The lithostratigraphic sequence of the Agbaja Formation can be reconciled from the several portions of the Agbaja road section exposed up the hill. The basal lithostratigraphic unit of the Agbaja Formation consists of sandstone - ironstone interbeds, which vary from fine to medium-grained. This unit is overlain by a thick succession of ironstones.

Palynological data

The shale, mudstone and claystone samples collected from outcrop studies in the Agbaja, Lokoja, and Ahoko sections of the basin exhibited rich concentrations of pollens and spores, alongside limited occurrences of fresh water algae and dinocysts (Plate 1). The presence of *Rugulatisporites caperatus* in the shale samples from the Patti Formation suggests a Campanian age. Additionally, the discovery of palynomorphs such as *Monocolpite marginatus, Tubistephanocolpite cylindericus, Psilastephanocolporite* sp.*, Cyathidites minor* and *Longapertites marginatus* in shale samples from the Ahoko and Agbaja outcrops points to an Early to Mid-Maastrichtian age for the Patti Formation, while the presence of *Proxapertite operculatus* is indicative of a Campanian–Early Maastrichtian age for the Lokoja Formation (Aigbadon *et al.,* 2022, 2023). Likewise, Ojo and Akande (2020) also identified Maastrichtian palynomorphs in the shale from the Ahoko area, and the co-occurrence of dinocysts and fresh water algae with Late Cretaceous spores and pollen in the Agbaja Shale samples supports a Maastrichtian age.

Plate 1: Photomicrographs for Agbaja-Ahoko-Lokoja outcrop sample (Aigbadon *et al*., 2023).



× 400 Magnification

1. *Tricolporopollenites* sp.
2. *Monocolpites marginatus*
3. *Gleicheniidites* sp.
4. *Laevigatosporites* sp.
5. *Longapertites marginatus*
6. *Longapertites sp.*
7. *Echitriporites trianguliformis*
8. *Ephedripites* sp.
9. *Tubistephanocolpites cylindricus*
10. *Foveolatus margaritae*
11. *Cingulatisporites ornatus*
12. *Distaverrusporites simplex*
13. *Rugulatisporites caperatus*
14. *Diatom frustules*
15. *Fungal spores*
16. *Cyathidites minor*

Type Sections of Formations

Lokoja formation:

Reviewed literatures show that the type sections for formations in the Southern Bida Basin were not properly erected. This, obviously, left a gap that needed to be filled. The pioneer author to first describe the sedimentary rocks of this area and classify them in what he called the Lokoja series (Falconer, 1911). His designated type section at Mount Patti, although quite detailed, did not correctly represent the lithofacies of the Lokoja Formation. In the same vein, Jones' (1958) holostratotype did not completely show all lithic units of the Lokoja Formation. Type section described at the exposed stream south of the Agbaja Plateau is not comprehensive enough and the sediments described do not completely match those exposed at the Agbaja road section.

The Lokoja Formation was described by Jones (1958) to comprise pebbly sandstone and clayey-grits, coarse false-bedded sandstones, conglomerates and ironstones. The coarse false-bedded sandstones do not occur anywhere else other than the northern part of Anambra Basin. It was necessary, therefore, that Jones' (1958) type section be supplemented by a more comprehensive hypostratotype (reference section). Exposed outcrops in Felele, Nataco, Banda, Gada-Biyu and sections on the road to Agbaja Hill; all showed characteristic fining-upward cyclic lithofacies succession typical of the Lokoja Formation. They have all been presented here as the hypostratotypes for the Lokoja Formation. The composite-stratotype for the Lokoja Formation now comprise Jones' (1958) holostratotype, that is the type section and the hypostratotype presented here as reference sections.

Patti formation:

Outcrops exposed at Orehi, Garba, Achabo, Gegu-Beki, Etegi, Aseni, Ahoko, Gerinya and Agbaja Hill section; all showed lithofacies characterizing the Patti Formation. The Patti Formation is reported to be exposed between Koton-Karfe and Abaji (Ladipo *et al.,* 1994; Ladipo *et al.,* 2011; Obaje *et al.,* 2011). Field observations, however, show that there are varying characteristic lithic units of the Patti

Formation exposed between Koton-Karfe and Aseni on the Lokoja – Abuja expressway and also on a portion of the Agbaja Plateau. Three lithologic units are quite distinct and unique in their environments. These are: (1) The well sorted friable, fine to medium-grained ferruginized, sandstone units with herringbone cross-stratification on the Agbaja road section; (2) the massive, brownish claystone unit at the Agbaja road section; and (3) the shale-claystone heterolithic unit at the Ahoko section (Ozulu *et al.*, 2021).

The description of the Patti Formation by Jones (1958) showed that the formation consists of fine to medium-grained, grey and white sandstones, grey clays, carbonaceous silts and shales, oolitic ironstones as well as thin coals and white, gritty clays. This is observed to be the characteristic feature of sediments at the Ahoko section. Over time, the designation "Patti Formation," employed in stratigraphic nomenclature, has been inaccurately utilized and needed to be reviewed. The name Patti was actually taken from Mount Patti, which is part of the outcropping ridges of mesas in Lokoja area. It is one of the sedimentary outcrops described by Falconer (1911) where the Lokoja Formation is found. The Patti Formation is not found here as it is clear that oolitic ironstone overly the Lokoja Sandstone. The unit-stratotype for the formation is well exposed at Ahoko village. Since the original description of Jones (1958) did not fit the Agbaja road section or any other locality other than the Ahoko sections, it is therefore logical to review the name of the formation to depict the type section. Furthermore, the nomenclature Patti Formation is a misnomer that needs to be corrected. The type locality for Patti Formation is actually at Ahoko village where a hypostratotype is here presented to augment Jones' (1958) holostratotype. The new name Ahoko Formation proposed to replace the name Patti Formation by Rahaman *et al.* (2019) should be upheld. Outcrops found in Ahoko village are hypostratotypes to supplement Jones (1958) holostratotype.

Agbaja formation:

No type section has been presented for the Agbaja Formation but several type localities have been identified (Nwajide, 2013; Imrana and Haruna, 2017). Oolitic - pisolitic ironstones that comprise this formation extends to Agbaja - Mount Patti - Lokoja area, the Koton - karfi area and the Bassa Nge area (Nwajide, 2013; Imrana and Haruna, 2017). Since the Agbaja Formation is best exposed on the Agbaja Plateau, where it successively overlies the Ahoko and Lokoja Formations, the outcrop exposed here is presented as the lectostratotype for the formation. Furthermore, this formation consists predominantly of oolitic – pisolitic ironstones and iron concretions therefore the nomenclature Agbaja Ironstones has often been used. The succession of fine-grained sandstones interbedded with iron bands overlying claystones, being part of the formation, should make the name all encompassing. It is recommended that the nomenclature Agbaja Formation be maintained while discarding the use of the name Agbaja Ironstones.

Stratigraphic sequences and Interpretation

In response to Ojo and Akande's (2020) refutation, Rahaman *et al.* (2020) repeated their viewpoint based on stratigraphic interpretations of Jones' (1955) geologic map of the area around the Niger-Benue confluence. According to their understanding, oolitic ironstones sit on top of the Lokoja Sandstone in both the Lokoja area and the Northern Anambra Basin. A detailed examination and interpretation of the map, however, revealed that this was incorrect (Figure 14). Even in the Agbaja Plateau, there are no geological limits between the Patti Formation and oolitic ironstones. The explanation notes and legend of the map showed that the Patti Formation and the Oolitic Ironstone occur as coeval sediments of Maastrichtian Age. In the Northern Anambra Basin, false-bedded sandstones lie on top of the sequence, followed by the coeval Patti Formation and Oolitic Ironstone, both overlain on the Lokoja Sandstone. Coeval inter-fingering relationship between lithologic facies of the Bida Basin and those of Anambra Basin were observed by Nwajide (2013) and illustrated by Ojo and Akande (2009). The facies interfingering, evident as the white friable, well-sorted and bioturbated herringbone cross-bedded sandstone unit of the Ahoko (former Patti) Formation, is unique to the Southern Bida Basin and is not found elsewhere. This sandstone unit has textural similarities to the Ajali Sandstones of the Anambra Basin. This unit,

which was not reported by Jones (1958) in his original section, was first assigned to the Patti Formation by Obaje *et al.* (2011) but was later reallocated to the Lokoja Formation by Rahaman *et al.* (2019). The stratigraphic interpretations in this study are based on the North American Commission on Stratigraphic Nomenclature terminology defined in Owen (2009).

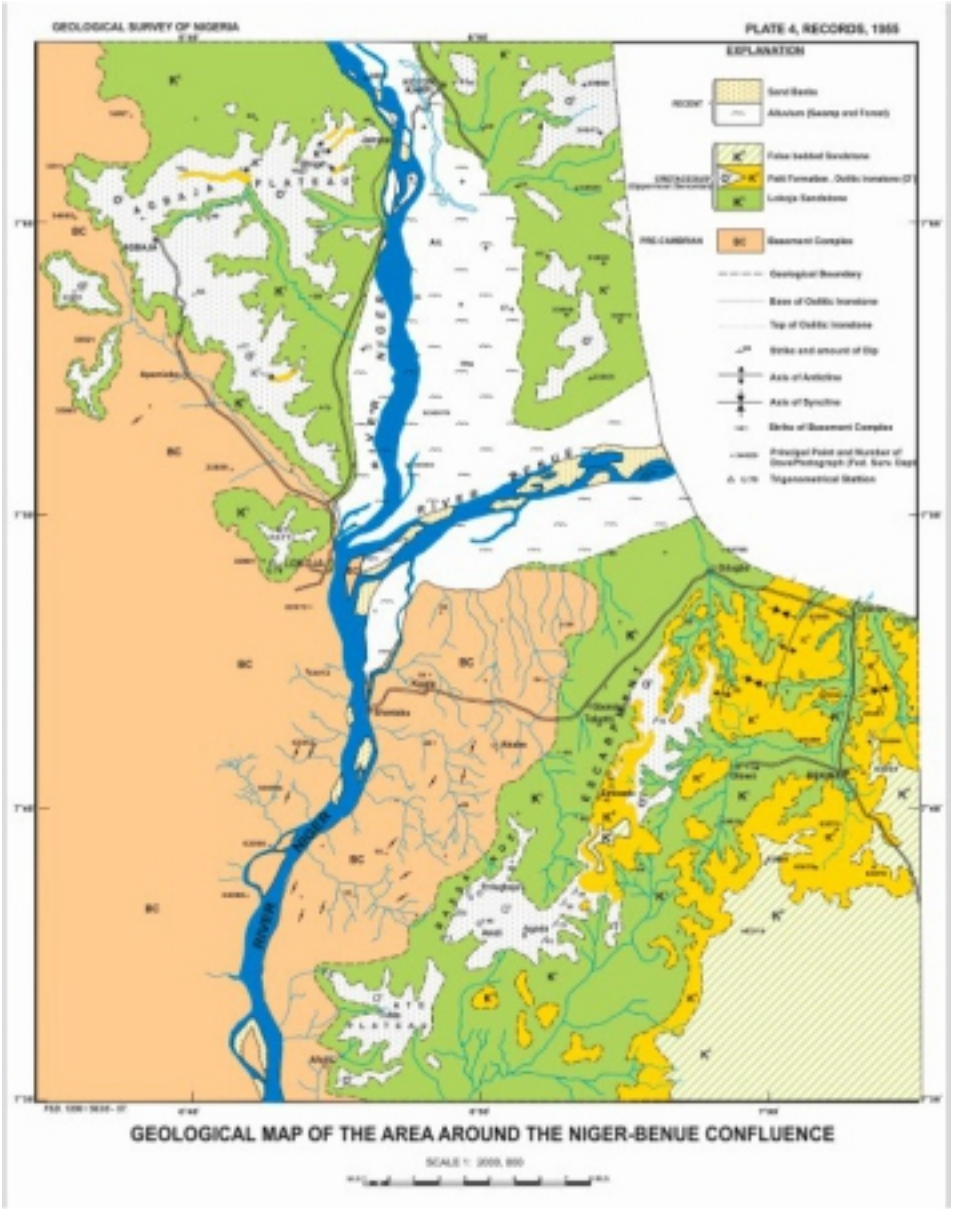


Figure 14: The geological map of the region surrounding the Niger-Benue Confluence (After Jones, 1955).

Similarly, records of two core logs penetrating the carbonaceous shale unit of the Patti (now Ahoko) Formation on the Agbaja Plateau, has been reported. The log profile show the penetrated shale sandwiched in-between an underlying sandstone unit and an overlying ironstone unit of the Agbaja Formation (Ojo *et al.,* 2015; Ojo and Akande, 2020). These showed that shale unit is overlain on a sandstone unit that is directly underlying the oolitic ironstone of the Agbaja Formation (Ojo *et al.,* 2015; Ojo and Akande, 2020). The age of this shale was determined to be Maastrichtian based on palynological correlation with the shale found at Ahoko town, as reported by (Ojo *et al.,* 2018). The lithostratigraphic correlation of logs from the two boreholes with the composite log section at the Agbaja road

section also showed the same sequence Ojo *et al.* (2020). In this study, the interpreted lithologic log of the Agbaja road section and those from the Ahoko road-cut sections have been employed to challenge the revised stratigraphy proposed by Rahaman *et al.* (2019) and confirm the stratigraphic sequence of the Southern Bida Basin. The lithostratigraphically correlated logs from the two drilled coreholes with the composite log at the Agbaja road section by Ojo *et al.* (2020) have strong supporting stratigraphic evidence. The erosional surface on top of the well-sorted friable, ferruginized, bioturbated herringbone cross-bedded sandstone unit, previously considered part of the Patti Formation in the Lokoja – Agbaja Road section by Rahaman *et al.* (2019), is, in fact, a disconformity (missing basal shale unit) that affected the basal part of the Ahoko Formation (Figure 15).

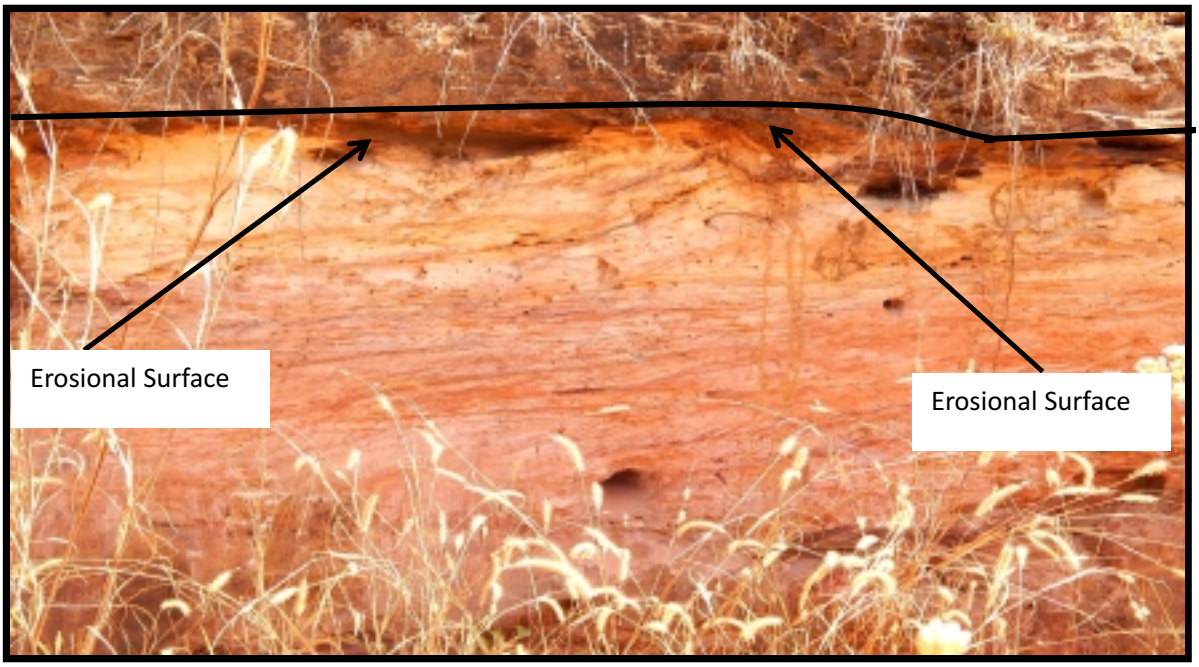


Figure 15: Bioturbated sandstone with herringbone cross-beddings and bioturbated ripple laminated siltstone showing an erosional surface (Ozulu *et al.,* 2021).

Geologic Map

By integrating the topographic maps of Lokoja NW and Koton-Karfe NW, geologic map obtained showed the diverse lithologic (rock) units within the study area (Figure 16). The presented lithostratigraphy is established through the examination of outcrops visible in road cut exposures, quarry pits, and stream channels.

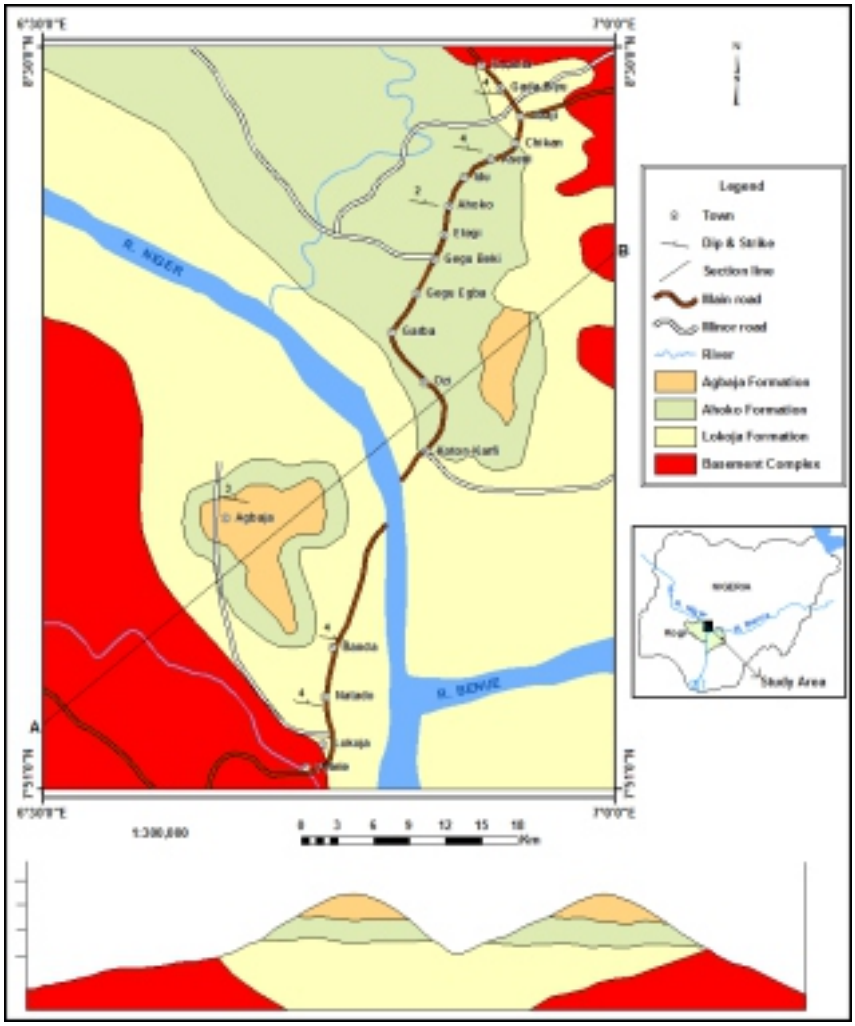


Figure 16: Geologic map and cross section of the Study Area (Modified after Ozulu *et al.,* 2021).

The interpreted log section revealed that, unlike the Lokoja Formation, the Ahoko Formation is of tidal/intertidal flat depositional origin (Figure 9). Outcropping sections identified lithologic units have been interpreted and presented as lithologic log sections. The thickest sedimentary sequence occurs in Ahoko village, which appears to be the sub-basin's center, according to these lithologic log sections. The bottom and upper borders for homogeneous lithologies identified in outcrops delineated the boundaries of each formation. At the sediment-basement contacts at Felele, Lokoja on the south-western periphery and Kwaita, FCT on the north-eastern fringe, the sedimentary sequence thins out. Interpreting the entire lithologic log sections as a composite section, the lithostratigraphic sequence of the Lokoja sub-Basin was inferred. The Basement Complex lies unconformably beneath the Lokoja Formation, which, in turn, is overlain by the Ahoko (former Patti) Formation, followed by the Agbaja Formation (Table 1).

Table 1: Revised Stratigraphic Succession in the Southern Bida Basin.

AGE	FORMATION	TYPE LOCALITY	ROCK DESCRIPTION
MAASTRICHTIAN	Agbaja Formation	Agbaja Plateau (Lectotratotype)	The ironstone exhibits various grain sizes, ranging from pisolitic to oolitic, and is characterized by concretions and interbeds of sandstone and ironstone.
	Ahoko Formation	Ahoko Village, Agbaja Hill (Hypostratotypes)	The lithology consists of black to dark grey shale, ripple/ cross-laminated siltstone - claystone heteroliths containing iron concretions, massive claystone, and medium to coarse - grained friable sandstones
CAMPANIAN	Lokoja Formation	Lokoja – (Mt.Patti, Felele, Nataco, Banda), Agbaja Hill, Abaji, Gada-Biyu (Hypostratotypes)	The rock formation consists of clast/supported fanglomerate/conglomerate with a range of grain sizes from fine to coarse-grained, The sedimentary layers include weakly cross -bedded and pebbly sandstones, siltstone, silty claystone, and bands of lateritic ironstone.
LOWER PALEOZOIC	Crystalline Basement Complex		

CONCLUSION

The numerous controversies that have surrounded the stratigraphic interpretation of the Bida Basin, particularly in the southern regions, are clearly the result of insufficient data acquisition from outcrop studies alone and an incomplete study of the basin. This study attempted to juxtapose obvious facts with distinct stratigraphic interpretations in order to revalidate and establish the stratigraphic succession of the sub-basin. It is suggested here that integrated subsurface geology and geophysical research using chemo-stratigraphy, core drilling, and seismic-stratigraphy be employed to improve a more comprehensive study of the basin's stratigraphy. Nevertheless, since subsurface data was not accessible, the utilization of palynological data, surface outcrop studies, and a re-interpretation of Jones' (1958) geologic map became essential to accurately review and revalidate the stratigraphy of the sub-basin.

CONFLICT OF INTEREST

The authors state that no conflict of interest, whether personal, financial, or intellectual, has influenced the report offered in this study.

ACKNOWLEDGEMENTS

The authors appreciate management of Dennis Osadebey University, Asaba for providing logistics for the field study.

AUTHORS' CONTRIBUTION

The field mapping was headed by Dr. Ozulu, G.U. He designed the methods for the research, manuscript writing, proof reading of the manuscript as well. Other authors were involved in the field mapping, writing and proof reading of the manuscript.

REFERENCES

Aigbadon, G.O., Igwe, E. O., Ocheli, A., Overare, B., Akakuru, O. C., Akudo, E. O., Obasi, I. A., Bala, J. A., Aminu, M. B., 2023. Sedimentary Facies, Paleoenvironments and Paleogeography of the Upper Cretaceous Succession in the Southern Bida Basin, Nigeria. *Arabian Journal of Geosciences*, 16:349. doi: 10.1007/s12517-023-11390-5

Aigbadon, G.O., Odoma, N.A., Obasi, I.A., Christopher, S.D., Nanfa, C.A., Baba Aminu, M., Akakuru, O.C., 2022. Hydrocarbon prospectivity of the southern Bida and northern Anambra Basin, Nigeria using palynological and geochemical studies. *J. Geosystems & Geoenviron.* Article ID 100103 doi: 10.1016/j.geogeo.2022.100103

Akinyemi, S. A., Adebayo, O. F., Ojo, A. O., Fadipe, O. A., and Gitari, W. M., 2014. Geochemistry and Mineralogy of the Campanian Sandstone of Lokoja - Bassange Formation, Middle Niger Basin (Lokoja Sub – Basin), Nigeria: Implications for Provenance, Weathering, Tectonic Setting and Paleo – Redox Condition. *Journal of Natural Sciences Research*, 16: 65–89.

Falconer, J. D., 1911. The Geology and Geography of Northern Nigeria, Macmillan Press, London. 295.

ldowu, J.O. and Enu, E I., 1992. Petroleum Geochemistry of some Late Cretaceous Shales from the Lokoja Sandstone of Middle Niger Basin, Nigeria. *Journal of African Earth Sciences*, 14: 443- 455. doi: 10.1016/0899-5362(92)90047-G

Imrana, A. and Haruna, I.V. 2017., Geology, Mineralogy and Geochemistry of Koton-Karfe Oolitic Iron Ore Deposit, Bida Basin, Kogi State, Nigeria. *International Journal of Scientific & Technology Research*, 6(8): 415 – 426.

Jan du Chene, R.E., Adegoke, O.S., Adediran, S.A. and Petters. S.W. 1978., Palynology and foraminifera of the Lokoja Sandstone (Maastrichtian), Bida Basin, Nigeria. *Revista Espanola de Micropaleontologia*, 10: 379-393.

Jones, H. A., 1955. The Oolitic Ironstone of Agbaja Plateau, Kabba Province, Record of the Geological Survey of Nigeria (1955), 20-43.

Jones, H. A., 1958. The Oolitic Ironstone of Agbaja Plateau, Kabba Province, Record of the Geological Survey of Nigeria, 20-43.

Ladipo, O., Akande, S.O. and Mucke, A., 1994. Genesis of Ironstones from Middle Niger Sedimentary Basin, Evidence from Sedimentological, Ore Microscopic and Geochemical Studies. *Journal of Mining and Geology*, 30: 161-168.

Nton, M. E. and Adamolekun, O. J., 2016. Sedimentological and Geochemical Characteristics of Outcrop Sediments of Southern Bida Basin, Central Nigeria: Implications for Provenance, Paleoenvironment and Tectonic History. *Ife Journal of Science*, 18 (2): 345-369. doi: 10.4314/1JS.V1811

Nwajide, C. S., 2013. Geology of Nigeria's Sedimentary Basins, CSS Press. 565p.

Nwajide, C. S. and Reijers, T. J. A., 1996. Sequence architecture in outcrops: examples from the Anambra Basin Nigeria. *Nigerian Association of Petroleum Explorationists (NAPE) Bulletin*, 11: 23-33.

Obaje, N. G., Wehner, H., Scheeder, G., Abubakar, M. B. and Jaura, A., 2004. Hydrocarbon prospectivity of Nigeria's inland basins: from the viewpoint of organic geochemistry and organic petrology. *American Association of Petroleum Geologists Bulletin (AAPG)*, 87: 325-353.

Obaje, N. G., Moumouni, A., Goki, N. G. and Chaanda, M. S., 2011. Stratigraphy, Paleogeography and Hydrocarbon Resource Potentials of the Bida Basin in North-Central Nigeria, Journal of Mining and Geology. 47. (2): 97-113.

Obaje, N. G., Balogun, D. O., Idris-Nda, A., Goro, I. A., Ibrahim, S. I., Musa, M. K., Dantata, S. H., Yusuf, I., Mamud-Dadi, N. and Kolo, I. A., 2013. Preliminary Integrated Hydrocarbon Prospectivity Evaluation of the Bida Basin in North Central Nigeria. *Petroleum Technology Development Journal*, 3(2): 41-71.
http://repository.futminna.edu.ng:8080/jspui/handle/123456789/12740

Ojo, O. J., Adepoju, S. A. and Adedoyin, D. O., 2015. Combined Petrographic and Geochemical studies of Patti Formation, Southern Bida Basin, Nigeria: Implications for provenance, tectonic setting, Source rock composition and weathering effects. *Ilorin J. Sci.,* 2 (1): 163-189.

Ojo, O. J. and Akande, S. O. 2009. Sedimentology and depositional environments of the Maastrichtian Patti Formation, Southern Bida Basin, Nigeria. *Cretac. Res.*, 30: 1415-1425.
doi: 10.1016/j.cretres.2009.08.006

Ojo, O. J. and Akande, S. O., 2020. A revised stratigraphy of the Bida Basin, Nigeria by Rahaman *et al.,* (2019) [J. Afr. Earth Sci., 151, 67-81]: A rebuttal. *Journal of African Earth Sciences*, 103983.
doi: 10.1016/j. afreaarsci. 2020. 103983

Ojo, O. J., Jimoh, A. Y., Umelo, J. C. and Akande, S. O., 2018. Organic geochemical and palynological investigations of Patti Shale Facies in the Bida Basin, Nigeria and implications for hydrocarbon prospectivity, In: Nigerian Association of Petroleum Explorationists NAPE 36th Annual International Conference and Exhibition, p. 138. Lagos.
doi: 10.1007/s13202-020-00989-z

Ojo, O. J., Jimoh, A. Y., Umelo, J. C. and Akande, S. O., 2020. Organic geochemical and palynological studies of the Maastrichtian source rock intervals in Bida Basin, Nigeria: Implications for hydrocarbon prospectivity. *Journal of Petroleum Exploration and Production Technology* , 10(8):: 3191-3206.
doi: 10.1007/s13202-020-00989-z

Owen, D. E., 2009. How to use Stratigraphic Terminology in papers, illustrations, and talks. Stratigraphy, A publication of The North American Commission on Stratigraphic Nomenclature, (1979-2009), 6(2): 106-116.

Ozulu, G. U., Okoro, A. U. and Onuigbo, E. N., 2021. Sedimentary Facies and Environments of the Sedimentary fills of the Southern Bida Basin, Nigeria. *Global Journal of Geological Sciences*, 19: 53-74.
doi: 10.4314/gjgs.v19i1.5

Rahaman, M. A. O., Fadiya, S. L., Adekola, S. A., Coker, S. J., Bale, R. B., Olawoki, O. A., Omada, I. J., Obaje, N. G., Akinsape, O. T., Ojo, G. A. and Akande, W. G., 2019. A Revised Stratigraphy of the Bida Basin, Nigeria. *Journal of African Earth Sciences*, 151: 67-81.

Rahaman, M. A. O., Fadiya, S. L., Adekola, S. A., Coker, S. J., Bale, R. B., Olawoki, O. A., Omada, I. J., Obaje, N. G., Akinsape, O. T., Ojo, G. A., and Akande, W. G. 2019. A Revised Stratigraphy of the Bida Basin, Nigeria. *Journal of African Earth Sciences*, 151: 67-81.
doi: 10.1016/j.jafrearsci.2018.11.016

Russ, W., 1930. The Minna-Birnin Gwari Belt, Geol. Surv. Nigeria Rept. 21 pp.