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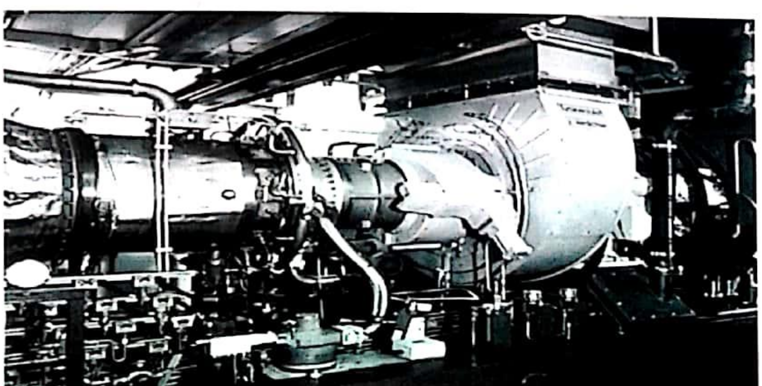

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STRATIGRAPHIC EXPLORATION OF THE BIDA BASIN IN NORTH CENTRAL NIGERIA

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Abstract
The Bida Basin is a NW-SE trending intracratonic structure extending from slightly south of Kontagora in Niger State in the north to the area slightly beyond Lokoja (Kogi State) in the south. All geological maps available on the Bida Basin had lumped the sediments in the basin as one undifferentiated Nupe Sandstone, making it impossible to infer the prospectivity of the basin for hydrocarbon exploration. The delineation of inferred boundaries between the formations in the basin is a significant initial criterion in evaluating the hydrocarbon prospectivity. The formations deposited in the Bida Basin comprise the Bida Sandstone at the base, followed successively upward by the Sakpe, Enagi and Batati Formations in the Northern/Central Bida Basin while the Lokoja, Patti and Agbaja Formations constitute lateral equivalents in the Southern Bida Basin. An institutional research project of the Ibrahim Badamasi Babangida University Lapai (IBBUL), supported by the Niger State Government, has carried out preliminary geological mapping and completed a prospectivity map for the Bida Basin. Based on the geological mapping and preiliminary proprietary geochemical and aeromagnetic geophysical data, the Bida Basin has been portioned into Less Prospective, Prospective and More Prospective areas. The prepared geological map is the first complete geological map to be produced on the Bida Basin. The map provides the basis for detailed further prospectivity evaluation by the University (IBBUL), NNPC, DPR and local and international investors in the search for oil and gas in the Bida Basin..

1.0. Introduction

Petroleum (oil and gas) accounts for up to 95% of Nigeria's foreign earning and has remained the major supporter of its economy since it was first discovered in commercial volume in 1956. Globally, petroleum as energy source will continue to dominate other primary energy sources and is expected to account for up to 60% of the world energy demand in the year 2030. Therefore the more oil and gas we can have as recoverable reserves, the better it will be for our national economy and development. Unfortunately however, petroleum is an exhaustible resource and dwindles on reserve with time. Therefore as a country, it is imperative to continue to search for more oil and gas to add to our reserves, if and only if, we are to maintain our lead as a major oil producer and meet up with our vision 20:2020.

In addition to the Niger Delta Basin from which all current production of petroleum is derived, Nigeria is blessed with numerous other sedimentary basins comprising the Anambra, Bida, Sokoto, Bornu (Chad), and Dahomey Basins, as well as, the Benue Trough made up of the Lower, Middle and Upper Benue Troughs. These basins have structural and stratigraphical similarities with contiguous intracratonic rifted basins of Niger Republic, Chad Republic and Sudan where commercial oil accumulations have been discovered.

The Bida Basin, also known as the Mid-Niger or Nupe Basin, is located in north-central Nigeria while the Sokoto Basin, sometime referred to as the SE Iullemmeden Basin is located in north-western Nigeria (Fig. 1). The two basins constitute two paleographically related sets (Fig. 2) of Nigeria's inland basins (mentioned above). These basins constitute another set of a series of

Cretaceous and later rift basins in Central and West Africa whose origin is related to the opening of the South Atlantic (Fig. 3). Commercial hydrocarbon accumulations have recently been discovered in Chad, Niger and Sudan within this rift trend. In SW Chad, development of the Doba discovery (with estimated reserves of about 1 billion barrels) resulted in the construction of a 1070 km long pipeline to the Atlantic coast. In the Sudan, "giant" fields (including Unity 1 and 2, Kaikang and Heglig) have been discovered in the Muglad Basin (Mohamed et al., 1999). The present study has been carried to shed more light on the hydrocarbon prospectivity of the Bida Basin which shall form the basis for evaluating the reserves and identifying prospects of commercial values and drillable sites in the basin.

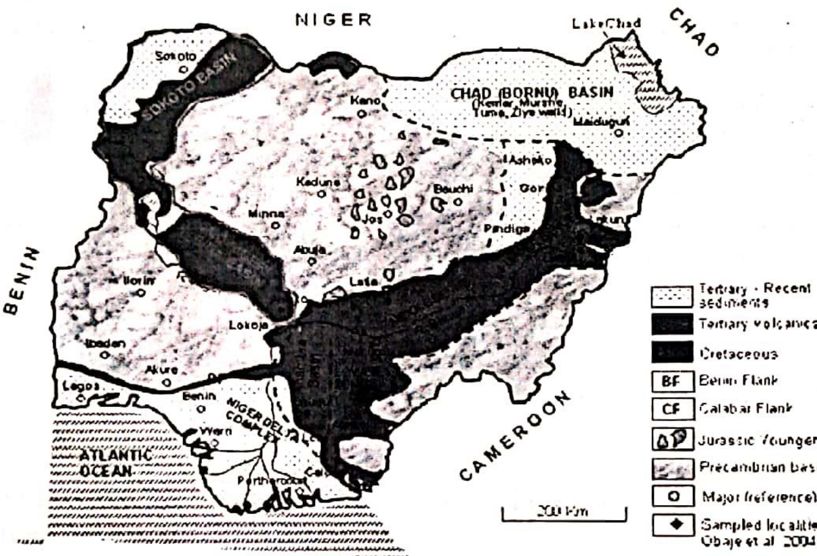

Fig. 1. Generalized geological map of Nigeria showing the location of the Bida and Sokoto Basins

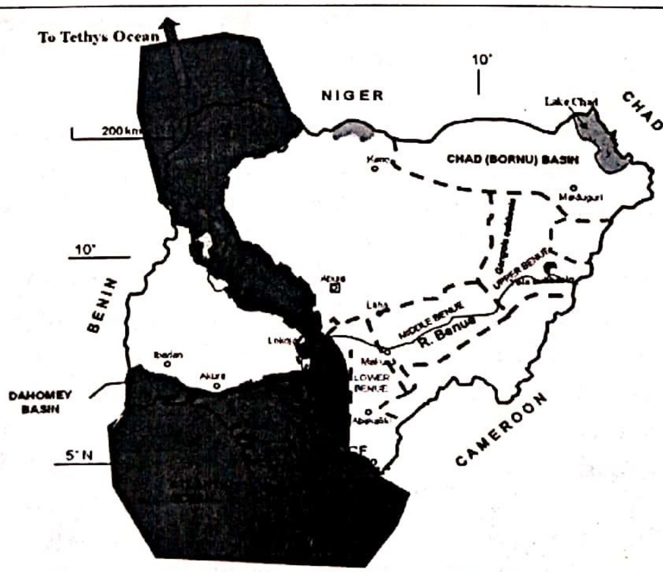

Fig. 2. Maastrichtian paleogeography of Nigeria; the sea passed through the Bida and Sokoto Basins to connect to the Tethys

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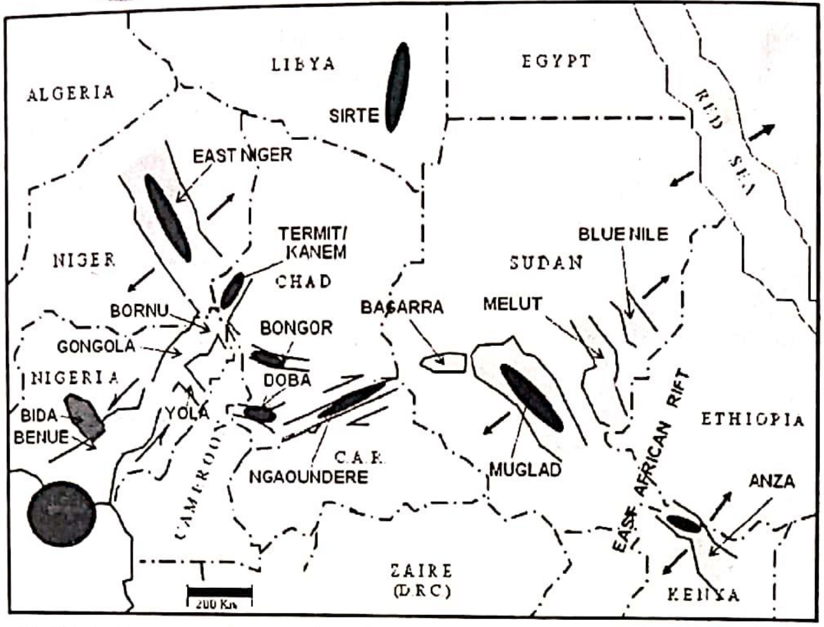


Fig 3 Regional tectonic map of western and central African rifted basins showing the relationship of the Muglad, Doba and East Niger Basins to the Benue Trough Gongola Basin. Locations of regional shear zones (marked with half-arrow) and major zones extension (complete arrow) are shown. (Adapted from Schull, 1988)

Major oil and/or gas discovery

2.0. Literature Review and Knowledge Gap

Literature on the Bida and Sokoto Basins is very scanty unlike on the other inland basins which have been widely more documented. The stratigraphy and sedimentation of Upper Cretaceous succession of the Bida Basin were documented by Adeleye and Dessauvagie (1972) in the central parts of the basin around Bida. The study defined and established the mappable litho-stratigraphic units that are currently being used for the Bida Basin. Interpretations of Landsat imageries and borehole logs, as well as geophysical data by Ojo (1984) suggested that the basin is bounded by a system of linear faults trending NW-SE while the gravity studies of Ojo and Ajakaiye (1989) point to a series of central positive anomalies flanked by negative anomalies, similar to the adjacent Benue Trough and typical of rift structures.

University-based research works on aero- and ground-magnetic and gravimetric geophysical surveys are available on parts of the Bida Basin (e.g. Adeniyi, 1985; Udensi and Osuzuwa, 2004). These works generally corroborate the interpretations of Ojo (1984) and Ojo and Ajakaiye (1989) that outlined the basin as being bounded by a system of linear faults. In addition to the preliminary stratigraphic investigations carried out by Adeleye and Dessauvagie (1972), further stratigraphic analyses were undertaken by Adeleye (1974, 1975 and 1989) in which the type localities and type sections for the geologic formations in the Bida Basin were located and described. Braide (1992a,b,c) attempted some sedimentological interpretations of sections in parts of the Southern Bida Basin. In that study, fluvial depositional models were ascribed to the Lokoja Formation and parts of the Patti Formation indicating some relatively good quality reservoir rocks in portions of these formations. Obaje et al. (2004) and Akande et al. (2005) presented some source rock geochemical results on a few samples from the Patti Formation in the Southern Bida Basin. Both studies indicated that based on the few samples analyzed, sedimentary organic matter in the basin were in the early stages of oil generation and postulated also that the organic matter are more gas-prone than oil-prone.

All the previous works on the Bida Basin are preliminary in nature. Nowhere were their implications on the hydrocarbon prospectivity of the basin evaluated. This is because the data were scanty and did not include detailed geological map interpretations nor organic geochemical, high-resolution biostratigraphical, petrographical and petrophysical inputs.

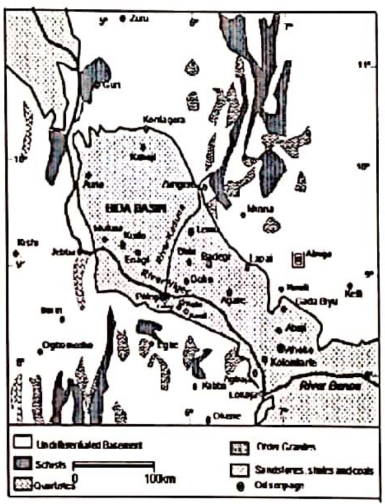
3. 0. The Bida Basin

While the overall focus of the study is on the Bida and Sokoto Basins, the present preliminary /pilot study focuses only on the Bida Basin. The Bida Basin is a NW-SE trending intracratonic structure extending from Kontagora in Niger State in the north to the area slightly beyond Lokoja in the south (Fig. 4). It is delimited in the NE and SW by the basement complex and merges with the Anambra and Sokoto Basins to the SE and NW respectively. Its sedimentary fill comprises post-orogenic molasse and thin unfolded marine sediments. The basin is a gently down-warped trough whose origin is closely connected with Santonian orogenic movements in SE Nigeria and the Benue valley. The basin trends perpendicular to the main axis of the Benue Trough and the Niger Delta Basin and is regarded as the NW extension of the Anambra Basin, both of which were major depocentres during the third major transgressive cycle in the Late Cretaceous.

Fig. 4. Extent of Bida Basin.

Available geological maps of the Bida Basin have lumped the sedimentary formations into one undifferentiated Nupe Sandstone.

In this way it is not possible to infer prospectivity



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The Bida Basin is generally subdivided into two portions, namely the Northern Bida Basin and the Southern Bida Basin. No concrete line of subdivision can be drawn but the boundary approximates the subdivision shown in Figure 5. In the Northern Bida Basin, four mappable lithostratigraphic units are recognized, namely, the **Bida Sandstone** (divided into the **Doko Member** and the **Jima Member**), the **Sakpe Ironstone**, the **Enagi Siltstone**, and the **Batati Formation**. These are correlatable with the stratigraphic units in the Southern Bida Basin (Fig. 6).

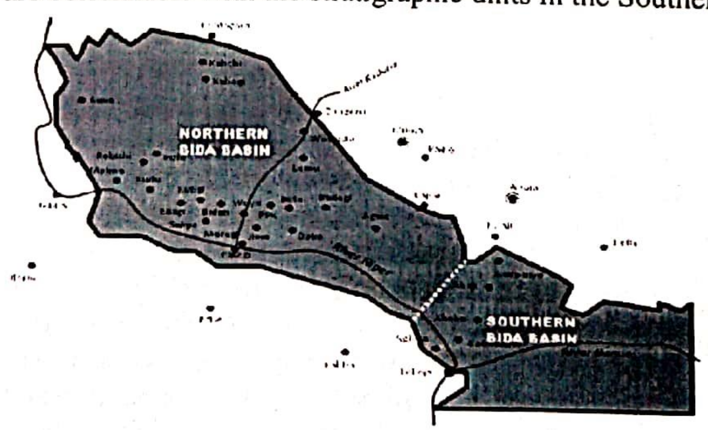

Fig. 5. Approximate boundary indication between the Northern Bida Basin and the Southern Bida Basin

In the Southern Bida Basin (which has been studied in more detail, e.g. Ladipo et al., 1994; Akande et al., 2005), exposures of sandstones and conglomerates of the **Lokoja**

Formation directly overly the Pre-Cambrian to Lower Paleozoic basement gneisses and schists. This is overlain by the alternating shales, siltstones, claystones and sandstones of the **Patti Formation** (ca. 70–100 m thick in the Koton-Karfi and Abaji axis). The Patti Formation is succeeded by the claystones, concretionary siltstones and ironstones of the **Agbaja Formation**.

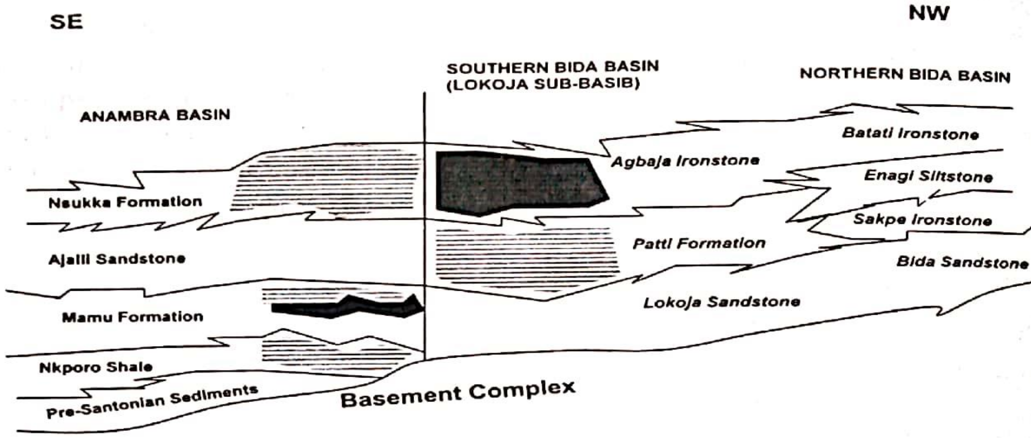

Fig. 6. The formations in the Nothern and Southern Bida Basin are correlatable with those in the Anambra Basin in the south-east.

4. 0. Scope of Work and Methodologies Adopted

The scope of the preliminary work comprises geological mapping, sample collection, sample processing, data generation and data analyses. The methodologies adopted comprise:

- Fieldwork and stratigraphical sample collection.
- Preparation of a geological / prospectivity map.

Geochemical and aeromagnetic geophysical data obtained on the basin are still proprietary and preliminary in scope such that this report is based entirely on the geologicl mapping and stratigraphic interpretation at this stage. Apart from departmental laboratories at the Ibrahim Badamasi Babangida University, Lapai, laboratory facilities available at the Nasarawa State University, Keffi; Getamme Lab, Portharcourt; Geo-Forschung Research Centre, Potsdam, Germany; and at the Federal Institute for Geosciences and Natural Resources, Hannover, Germany as well as facilities procured in the course of this project were used for this preliminary study. Funding for the project was provided overwhelmingly by the Niger State Government through the Gubernatorial Committee on Bida Basin Development (GCBBD).

4.1. Fieldwork and stratigraphical sample collection

Geological fieldwork and sample collection were carried out throughout the entire Bida Basin to produce a comprehensive geological map and to obtain good quality samples for analytical studies. Fresh outcrop samples and samples from drilled shallow wells at Agaie and Kudu were collected. Macrofossil assemblages as they occur on the field were used to validate the correlations of the rock units. Structural analyses were undertaken on the field. Anticlinorial cores were particularly targeted as they afforded opportunities to sample rock units that have been thrusted to the surface by tectonic processes and for which their equivalent units generally lie very deep down below the surface. The resultant geological map is used to construct subsurface cross-sections with the objective of delineating areas with thicker sediment piles.

The sampling design covered as much of the area as possible using road cuts and other exposed outcrops to collect stratigraphic samples. Rock types, bed thicknesses, textural features, sedimentary structures, structural features and depositional environments were recorded at every outcrop. The field study lasted 20 days, divided into transects of 10 days each in the months of December 2011 and February 2012.

5. 0. Results and Interpretations

5.1. Geological Mapping and Preparation of Prospectivity Map

The preliminary geological mapping undertaken reveals some details of the composition and aerial extent as well as the inferred boundaries of the formations in the Bida Basin. All previous geological maps available on the Bida Basin have lumped the sediments in the basin as one undifferentiated Nupe Sandstone, making it impossible to infer the prospectivity of the basin for hydrocarbon exploration and acreage assessment. The delineation of inferred boundaries between the formations in the basin is a significant initial criterion in evaluating the hydrocarbon prospectivity. The geological mapping exercises have identified the four lithostratigraphic formations in the Northern Bida Basin and the three in the Southern Bida Basin as discussed and interpreted bellow.

Northern Bida Basin

5.1.1. The Bida Sandstone

The Bida Sandstone is divisible into two members, namely the Doko Member and the Jika Member. The Doko Member is the basal unit and consists mainly of very poorly sorted pebbly arkoses, sub-arkoses and quartzose sandstones. These are thought to have been deposited in a braided alluvial fan setting (Braide, 1992a). The Doko Member underlies the Jima Member, and the two rock units show gradational relationships. They both contain sandstones, breccias and argillaceous rocks in varying proportions. The sandstones of the Doko Member are arkosic to quartzose, generally poorly sorted, with angular to sub-angular grains. Massive appearance is common. Wave ripples (ripple marks) and large scale cross beddings are very prominent in the Doko Member at Doko village (Fig. 7). Bioturbution structures consisting mainly of *Thallasinoides* and *Ophiomorpha* burrows exist within the Doko Member indicating some occasional marine inundations into the generally braided fluvial channel deposits of the Doko Member. Thick to very thick flat-bedding and localised cross-stratifications are also present. Many of the coarser quartz grains commonly show smooth, flat surfaces giving the impression of vein quartz. The quartz and feldspar grains are irregular, rod-like or roughly tabular. The arkosic sandstones are the basal units exposed. They are commonly medium to very coarse and pebbly. The sorting is fair to poor. The arkoses are often mottled: brown, yellow, grey and pink. They are interbedded with finer-grained lithic feldspathic and feldspathic sandstones. Very poorly sorted, very coarse to fine argillaceous and pebbly quartzose sandstones and subsidiary subgreywacke, however, dominate the subfacies. They succeed and grade into the basal arkoses. Some are friable, medium to very coarse and pebbly, whereas others are hard, medium to very fine, argillaceous and poorly sorted. Several paleo-channels exist in the Doko Sandstone subfacies. The channel-filling contrasts with the underlying beds. Some spherical to sub-spherical masses of coarse argillaceous sandstones with occasional quartz pebbles in the outer areas occur locally. Siltstone and mudstone pebbles, and some thin, indurated, ferruginized, dark-brown sandstone bands are present in several localities

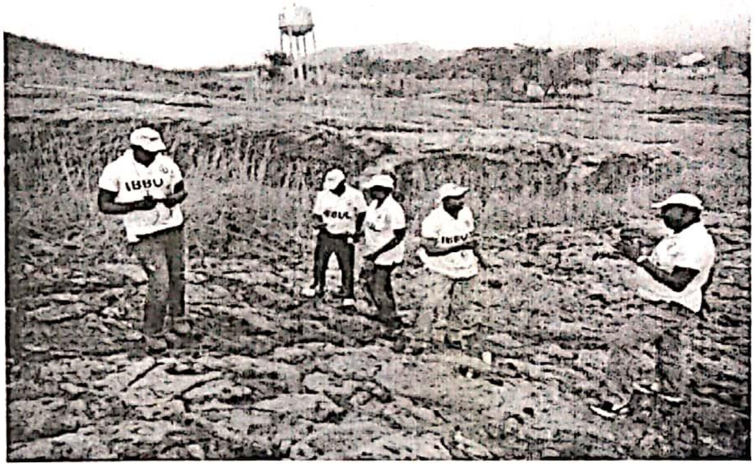

Fig.7. Mapping and logging of the Bida Sandstone (Doko Member) at Doko village near Bida

The Jima Member is dominated by cross-stratified quartzose sandstones, siltstones and claystones. Trace fossils comprising mainly *Ophiomorpha* burrows and *Thallasinoides* occur abundantly in the Jima Member (Fig. 8) suggesting a possible shallow marine subtidal to intertidal influence during sedimentation. The Jima Sandstone Member is considered as the more distal equivalent of the upper part of the Lokoja Sandstone, where similar features also occur. Planar and tabular cross-beddings occur in many horizons of the Jima Member.

Sediments of the Bida Sandstone occupy the flanks of the basin (Fig. 18) and they were mapped in detail at Bida, Doko, Jima and Baro. Areas covered by the Bida Sandstone are assumed to be the shallowest in terms of sediment thickness and constitute the "highs" or horst structures and are presumably the least prospective.

Fig. 8. Highly bioturbated coarse grained sandstones of the Bida Formation (Jima Member) exposed at Jima. The bioturbation burrows are very significance to increasing reservoir porosity and permeability.

5.1.2. The Sakpe Formation

The Sakpe Formation comprises mainly oolitic and pisolitic ironstones (Fig. 9) with sandy claystones locally, at the base, followed by dominantly oolitic ironstone which exhibits rapid facies changes across the basin, at the top. Exposures of the Sakpe Formation are rarely encountered in the basin; however, prominent outcrops and exposures of the Sakpe Formation occur in the village of Sakpe. The Sakpe Formation is the least geologically exposed as can be seen from the geological map in Figure 18.

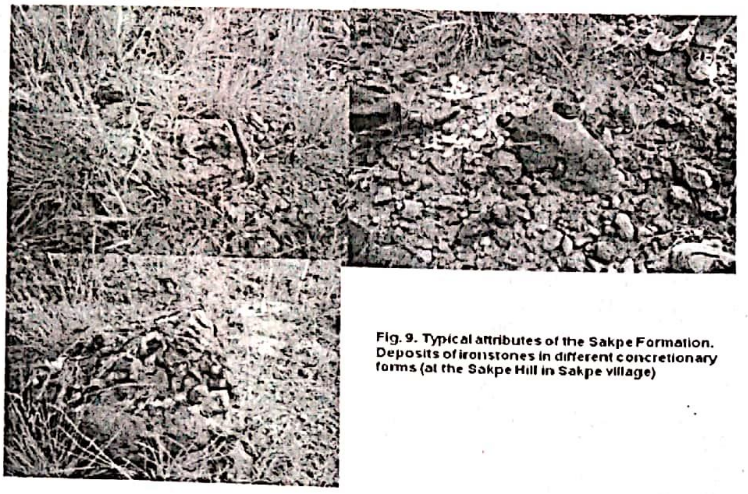

Fig. 9. Typical attributes of the Sakpe Formation. Deposits of ironstones in different concretionary forms (at the Sakpe Hill in Sakpe village)

5.1.3. The Enagi Siltstone

The Enagi Siltstone consists mainly of siltstones and correlates with the Patti Formation in the Southern Bida Basin. The siltstones are generally whitish to grey-white in colour and well-sorted, typified by those occurring within and around the town of Batati (Fig. 10). Other subsidiary lithologies include sandstone-siltstone admixture and in some places with abundant massive claystones. Fossil leaf impressions and rootlets occur occasionally within the formation. The formation ranges in thickness of between 30m and 60m. Mineral assemblage consists mainly of quartz, feldspars and clay minerals.

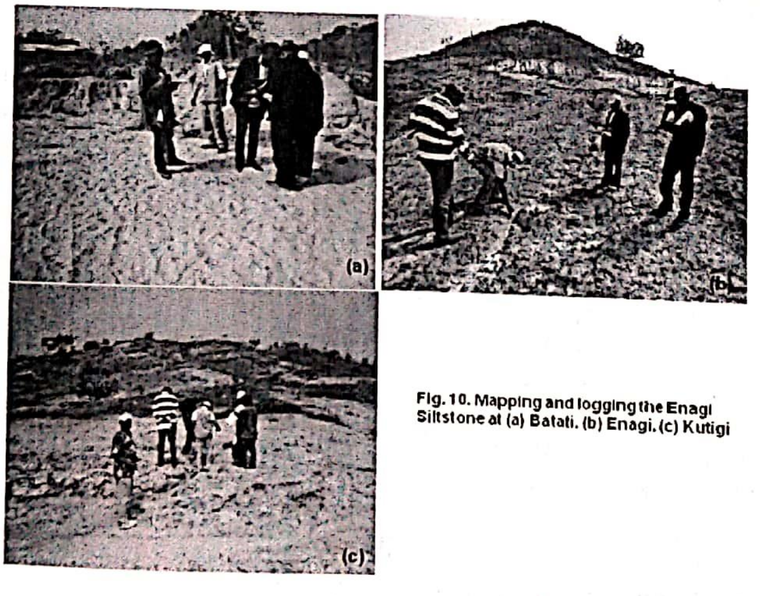

Fig. 10. Mapping and logging the Enagi Siltstone at (a) Batati, (b) Enagi, (c) Kutigi

Bioturbation structures are rarely encountered within the Enagi Formation but foraminiferal recovery indicates that the Enagi Formation is of shallow marine environments in most parts. The Enagi Formation correlates with the Patti Formation in the Southern Bida Basin. The Enagi Formation encompasses the Kudu Shale (Kudu Shale Member), a dark-grey, black shale unit (Fig. 11) envisaged to be the potential source rock for hydrocarbons that might have been generated in the Bida Basin. The Kudu Shale on the other hand correlates with the Ahoko Shale in the Southern Bida Basin. The Kudu Shale occurs generally in the sub-surface in the Northern Bida Basin. A shallow well drilled to a depth of 70m at Kudu village for the purpose of sample collection encountered the Kudu shales at a depth of 30m and continued up to the 70m end-depth (Fig. 11). A similar well drilled at Agaie indicates that the Kudu Shale occur at a depth below 70m as it was not encountered throughout the 70m depth (Fig. 12).

The Enagi Formation covers more than 70% of the surface area of the Bida Basin (see geological map) and most parts covered by the formation are expected to be prospective, at least more prospective than the areas covered by the Bida Sandstone and less prospective than the "sink" areas covered by the Batati Formation (see geological/prospectivity maps and cross-sections). In this study, the Enagi Formation was mapped and logged in detail at Agaie, Batati, Enagi, Kutigi, Mushegu, Kandi and Enwan.

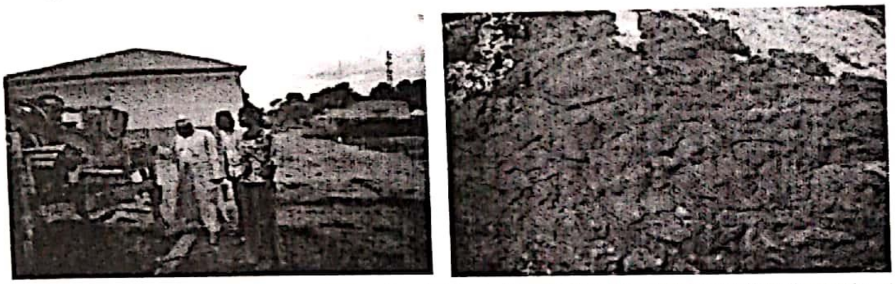

Fig. 11. Dark-black carbonaceous shales (Kudu Shale Member) from shallow well drilled at Kudu

Fig. 12. The shallow well drilled at Agaie did not encounter the Kudu shales

5.1.4. The Batati Formation

This Batati Formation constitutes the uppermost units in the sedimentary sequence of the Northern Bida Basin. The Batati Formation consists of argillaceous, oolitic and goethitic ironstones (Fig. 13) with ferruginous claystone and siltstone intercalations and shaley beds occurring in minor proportions, some of which have yielded nearshore shallow marine to fresh water fauna (Adeleye, 1974). The sporadic occurrences of surface exposures of the Batati Formation and its tight contoural relationship to the Enagi and Bida Formations wherever it occurs show that the Batati Formation occupies "rifted sinks" (grabens). These areas present the thickest sediment piles and consequently the most prospective for hydrocarbons in term of sediment thickness in the Bida Basin. Although these areas may be interpreted as synforms, they are actually rifted structures, where the Batati Formation remains deposited in the grabens and eroded on the horsts.

The Batati Formation was mapped and logged in detail at Pattishabakolo and Edozighi (near Bida) and at Kandi and Enwan (near Gulu).

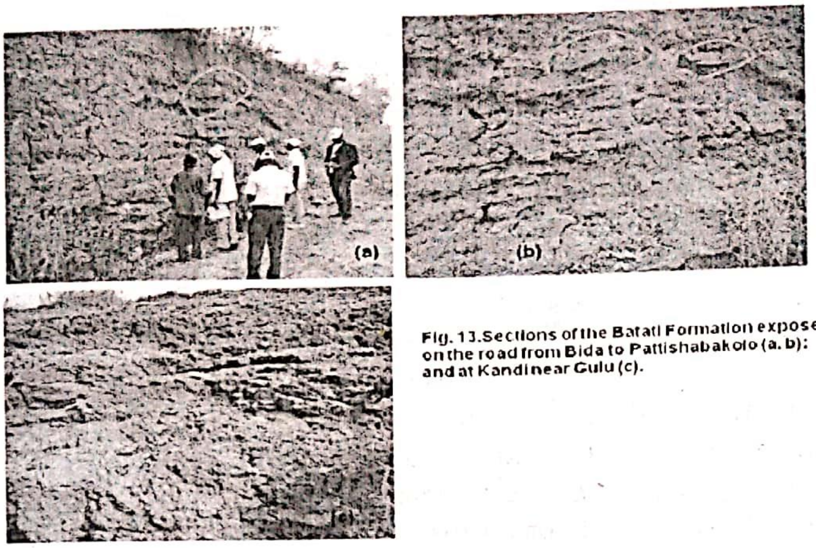

Fig. 13. Sections of the Batati Formation exposed on the road from Bida to Pattishabakolo (a, b); and at Kandi near Gulu (c).

Southern Bida Basin

5.1.5. The Lokoja Formation

Lithologic units in this formation range from conglomerates, coarse to fine grained sandstones, siltstones and claystones in the Lokoja area (Fig. 14). Subangular to subrounded cobbles, pebbles and granule sized quartz grains in the units are frequently distributed in a clay matrix. Both grain-supported and matrix-supported conglomerates form recognizable beds at the base of distinct cycles at outcrops. The sandstone units are frequently cross-stratified, generally poorly sorted and composed mainly of quartz and feldspar and are thus texturally and mineralogically immature. The general characteristics of this sequence especially the fining upward character, compositional and textural immaturity and unidirectional paleocurrent trends, suggest a fluvial depositional environment dominated by braided streams with sands deposited as channel bars consequent to fluctuating flow velocity. The fine grained sandstones, siltstones and clays represent flood plain overbank deposits. However, Petters (1986) reported the occurrence of some low diversity arenaceous foraminifera from clayey intervals of the Lokoja Formation indicating some shallow marine influence. These foraminiferal microfossils identified by Petters (1986) are however more common in the overlying Patti Formation where shallow marine depositional conditions are known to have prevailed more.

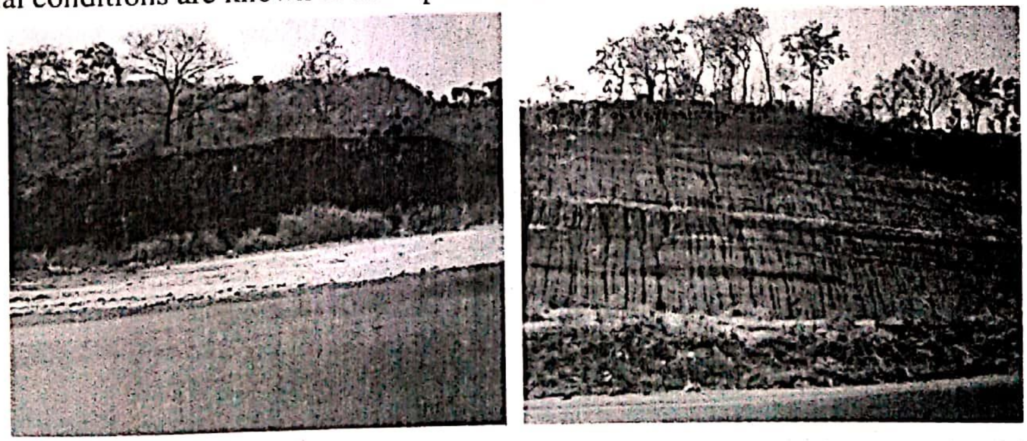

Fig. 14. Basal conglomerates (a) and poorly sorted muddy sandstones of the Lokoja Formation exposed 1 Km from the Lokoja-NATACO junction on the Lokoja – Abuja expressway

The Lokoja Formation, which correlates with the Bida Formation, occurs mainly in the areas from Lokoja up to Kotonkarfe. These areas have the same prospectivity interpretation as the areas covered by the Bida Sandstone.

5.1.6. The Patti Formation

Outcrops of the Patti Formation occur between Kotonkarfe and Gada-Biyu (Fig. 15). This formation consists of sandstones, siltstones, claystones and shales interbedded with bioturbated ironstones. Argillaceous units predominate in the central parts of the basin. The siltstones of the Patti Formation are commonly parallel stratified with occasional soft sedimentary structures (e.g. slumps), and other structures such as wave ripples, convolute laminations, load structures. Trace fossils (especially *Thallasinoides*) are frequently preserved. Interbedded claystones are generally massive and kaolinitic, whereas the interbedded grey shales are frequently carbonaceous. The subsidiary sandstone units of the Patti Formation are more texturally and mineralogically mature compared with the Lokoja sandstones. The predominance of argillaceous rocks, especially siltstones, shales and claystones in the Patti Formation requires suspension and settling of finer sediments in a quiet low energy environment probably in a restricted body of water (Braide, 1992c). The abundance of woody and plant materials comprising mostly land-derived organic matter, suggests prevailing fresh water conditions. However, biostratigraphic and paleoecologic studies by Petters (1986) have revealed the occurrence of arenaceous foraminifera in the shales of the Patti Formation with an assemblage of *Ammobaculites*, *Milliamina*, *Trochamina* and *Textularia* which are essentially cosmopolitan marsh species similar to those reported in the Lower Maastrichtian marginal marine Mamu Formation (the lateral equivalent) in the adjacent Anambra Basin (Gebhardt, 1998). The Patti Formation therefore appears to have been deposited in marginal shallow marine to brackish water condition identical to the depositional environments of similar lithologic units of the Mamu and Ajali Formations in the Anambra Basin (Ladipo, 1988; Adeniran, 1991; Nwajide and Reijers, 1996).

The Patti Formation encompasses the Ahoko Shale (Ahoko Member), a dark-grey, black shale unit (Fig. 16) envisaged to be, along with the Kudu Shale, the potential source rock for any hydrocarbons that might have been generated in the Bida Basin. The Ahoko Shale in the Southern Bida Basin correlates with the Kudu Shale in the Northern Bida Basin. Outside the outcrops / sections of the Patti Formation which occur along road-cuts from Kotonkarke – Gada-Biyu on the Lokoja – Abuja Expressway, the Patti Formation is also excellently exposed at Gerinya on the GeguBeki – Muye – Gulu road (Fig. 17).

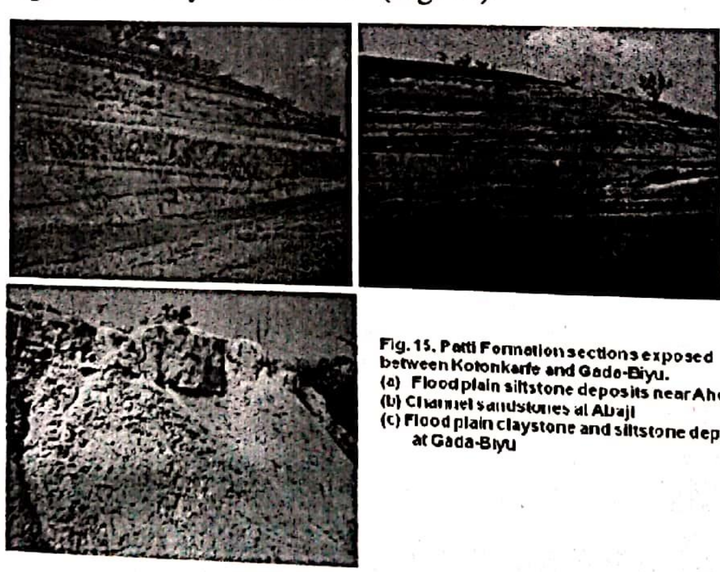

Fig. 15. Patti Formation sections exposed between Kotonkarfe and Gada-Biyu.
(a) Flood plain siltstone deposits near Ahoko
(b) Channel sandstones at Abaji
(c) Flood plain claystone and siltstone deposits at Gada-Biyu

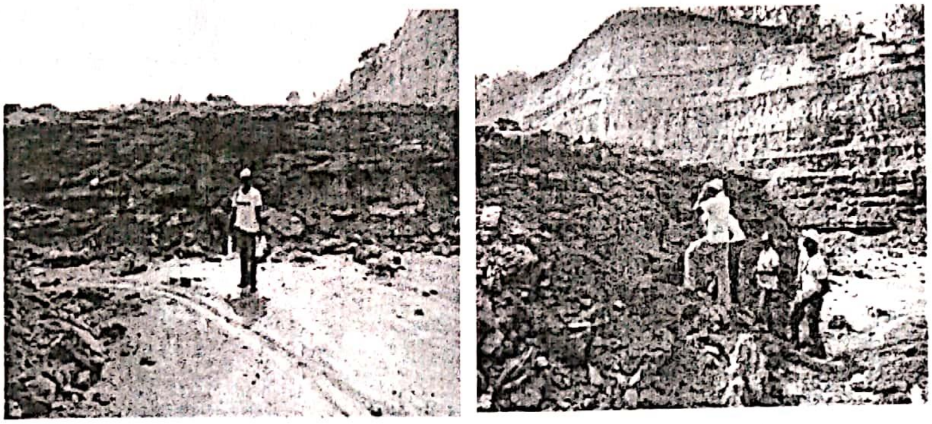

Fig. 16. Dark-grey, black shales of the Ahoko Shale Member (Patti Formation) exposed at a Quarry in Ahoko on the Lokoja – Abuja express (envisaged source rock in the Bida Basin equivalent to the Kudu Shale Member)

Fig. 17. Mapping and logging the Patti Formation (Enagi Formation equivalent) at Gerinya, near Gegu-Beki

5.1.7. The Agbaja Formation

The Agbaja Formation forms a persistent cap for the Campanian - Maastrichtian sediments in the Southern Bida Basin as a lateral equivalent of the Batati Formation in the Northern Bida Basin. The formation consists of sandstones and claystones interbedded with oolitic, concretionary and massive ironstone beds in this region. The sandstones and claystones are interpreted as abandoned channel sands and over bank deposits influenced by marine reworking to form the massive concretionary and oolitic ironstones observed (Ladipo et al., 1994). Minor marine influences were also reported to have inundated the initial continental environment of the upper parts of the Lokoja Sandstone and the Patti Formation (Braide, 1992b; Olaniyan and Olobaniyi, 1996). The marine inundations appear to have continued throughout the period of deposition of the Agbaja ironstones in the Southern Bida Basin.

The sporadic occurrences of surface exposures of the Agbaja Formation, just like the Batati Formation, and its equally tight contoural relationship to the Patti and Lokoja Formations wherever it occurs show that the Agbaja Formation occupies "rifted sinks" (grabens) in the Southern Bida Basin. These areas, just like in the Northern Bida Basin, present the thickest sediment piles and consequently the most prospective for hydrocarbons in the Southern Bida Basin (see geological / prospectivity map). Although these areas may be interpreted as synforms, they are actually rifted structures, where the Agbaja Formation remains deposited in the grabens and eroded on the horsts.

On the basis of the geological mapping and identification of the different formations in the basin as discussed above, the first complete geological map of the Bida Basin has been prepared as shown in Figure 18.

5.2. Interpretation of Prospectivity Map

The prospectivity interpretable from the geological map in Figure 18 shows that the Bida Basin is made up horst and graben structures, whereas the deepest grabens lie bellow the Batati and Agbaja Formation outliers. These outliers which may be considered as "geological bright-spots" represent the most prospective areas in the Bida Basin. Pattishabakolo, Edozighi, Kandi and Enwan make up the localities within these geological bright-spots in the Northern Bida Basin (Fig. 19), whereas Agbaja and some localities around Gegu-Beki constitute the geological bright-spots in the Southern Bida Basin (Fig. 20).

Most of the areas covered by the Enagi and Patti Formations are presumed to be of relatively moderate depth to basement, with the depth increasing towards the centre of the basin (Fig. 21). These areas are prospective in terms of sediment thickness but relatively less prospective than those areas covered by Batati / Agbaja Formations but more prospective than the areas covered by the Bida Sandstone. Such prospective areas include localities around Adogo, Pizhi, Duba, Kachegi, Kutigi, Ndaba, Badegi, Agaie, Gulu, Muye, Gerinya, Abaji, Ahoko and Gegu-Beki.

The least prospective areas are those localities covered by the Bida Sandstone. These least prospective areas include Bida, Doko, Jima, Baro, Wushishi, Pategi, Kotonkarfe and Lokoja (Fig. 18).

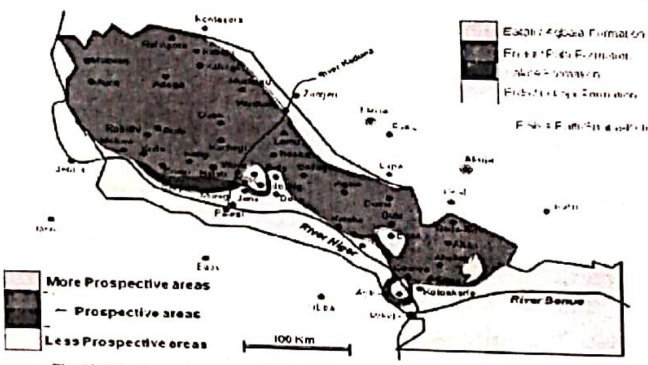

Fig. 18. Constructed preliminary geological map of the Bida Basin based on the surface geological mapping.

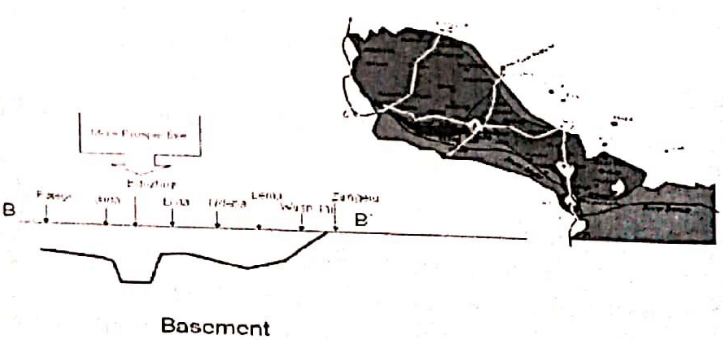

Fig. 19b. Estimated subsurface topography, relative sediment thickness and delineation of prospective areas for the section B-B': Pategi - Zungeru

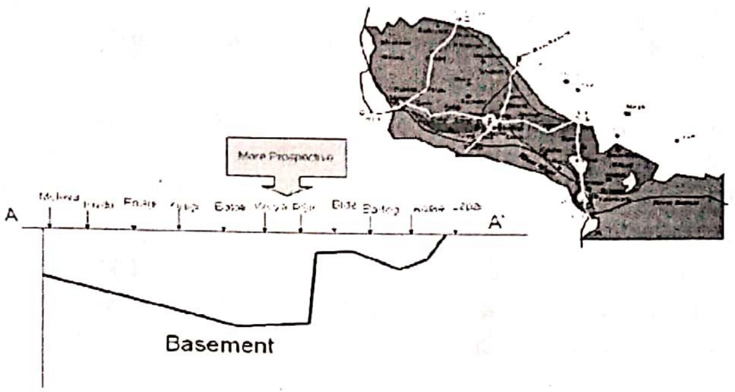

Fig. 19a. Estimated subsurface topography, relative sediment thickness and delineation of prospective areas for the section A-A': Mokwa - Lapai

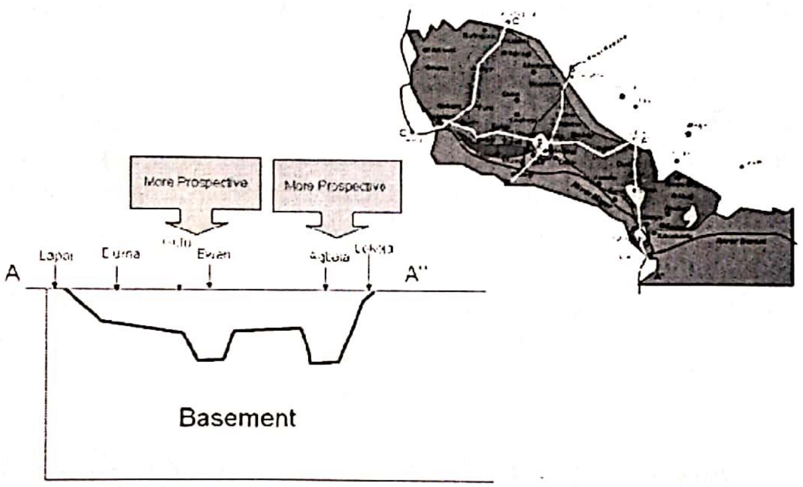

Fig. 20. Estimated subsurface topography, relative sediment thickness and delineation of prospective areas for the section A-A': Lapai - Lokoja

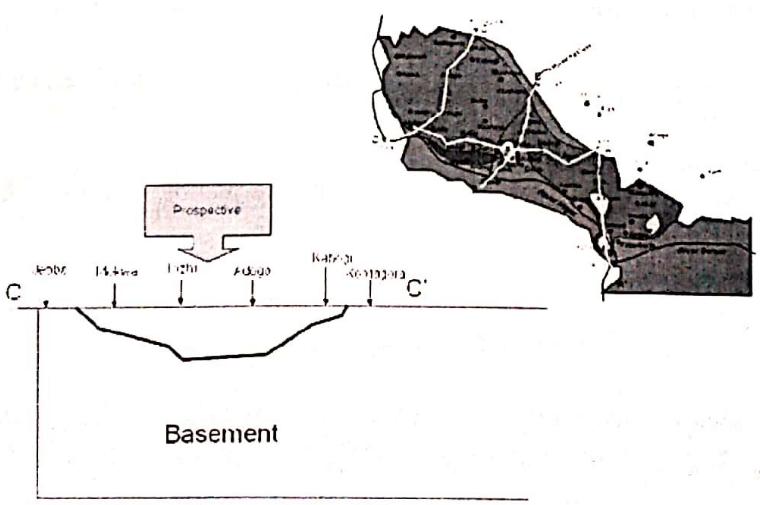

Fig. 21. Estimated subsurface topography, relative sediment thickness and delineation of prospective areas for the section C-C': Jebba - Kontagora

6.0. Conclusions

The Bida Basin is the least studied of all Nigeria's inland frontier basins. This is because not a single exploratory well has penetrated the sequences in the Bida Basin, making access to subsurface data very difficult. This project has carried out preliminary geological mapping and completed a prospectivity map for the Bida Basin.

From the preliminary geological map prepared, prospective areas, ranked as Less Prospective, Prospective and More Prospective are discernable. Pattishabakolo, Edozighi, Kandi and Enwan make up the More Prospective localities (geological bright spots) in the Northern Bida Basin, whereas Agbaja and some localities around Gegu-Beki constitute the geological bright-spots in the Southern Bida Basin. Most of the areas covered by the Enagi and Patti Formations constitute the Prospective areas. These areas are prospective in terms of sediment thickness but relatively less prospective than those areas covered by Batati / Agbaja Formations but more prospective than the areas covered by the Bida Sandstone. Such prospective localities include the areas around Adogo, Auna, Pizhi, Duba, Kachegi, Kutigi, Ndaba, Badegi, Agaie, Gulu, Muye in the Northern Bida Basin and Gerinya, Abaji, Ahoko and Gegu-Beki in the Southern Bida Basin.

The work carried out is still in the preliminary stages. Detailed field mapping, core drilling, sedimentological logging, bulk and biomarker geochemistry, satellite data collection and analysis, and 2-D, 3-D seismic investigations are still needed to further de-risk the identified prospective areas.

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References

Adeleye, D.R. and Dessauvagie, T.F. J. 1972. Stratigraphy of the Mid-Niger Emabyment near Bida, Nigeria. In: Dessauvagie, T. J. F. and Whiteman, A. J. (Eds), Proceedings of the Conference on African Geology, Ibadan University Press, Ibadan, p181-186.

Adeleye, D.R. 1974. Sedimentology of the fluvial Bida Sandstones (Cretaceous), Nigeria. Sedimentary Geology 12, 1-24.

Adeleye, D.R. 1975. Nigerian Late Cretaceous stratigraphy and paleogeography. AAPG Bulletin 59, 2302-2313.

Adeleye, D.R. 1989. The Geology of the Mid-Niger Basin. In: Kogbe, C.A. (Ed.), Geology of Nigeria, 2nd ed. Elizabethan Publishing Co., Lagos, p283–287.

Adeniran, B.V. 1991. Maastrichtian tidal flat sequences from the northern Anambra Basin, Southern Nigeria. Nigerian Association of Petroleum Explorationists (NAPE) Bulletin 6, 56–66.

Akande, S.O., Ojo, O.J., Erdtmann, B.D. and Hetenyi, M. 2005. Paleoenvironments, organic petrology and Rock-Eval studies on source rock facies of the Lower Maastrichtian Patti Formation, southern Bida Basin, Nigeria. Journal of African Earth Sciences 41, 394-406.

Braide, S.P. 1992a. Geologic development, origin and energy mineral resource potential of the Lokoja Formation in the southern Bida Basin. Journal of Mining and Geology 28, 33-44.

Braide, S.P. 1992b. Syntectonic fluvial sedimentation in the central Bida Basin. Journal of Mining and Geology 28, 55–64.

Braide, S.P. 1992c. Alluvial fan depositional model in the northern Bida Basin. Journal of Mining and Geology 28, 65–73.

Gebhardt, H. 1998. Benthic foraminifera from the Maastrichtian Lower Mamu Formation near Leru (Southern Nigeria): paleoecology and paleogeographic significance. Journal of Foraminiferal Research 28, 76–89.

Ladipo, K.O. 1988. Paleogeography, sedimentation and tectonics of the Upper Cretaceous Anambra Basin, south-eastern Nigeria. Journal of African Earth Sciences 7, 865–871.

Ladipo, K.O., Akande S.O. and Mucke, A. 1994. Genesis of ironstones from the Mid-Niger sedimentary basin: evidence from sedimentological, ore microscopic and geochemical studies. Journal of Mining and Geology 30, 161-168.

Mohamed, A.Y., Pearson, M.J., Ashcroft, W.A., Illiffe J.E. and Whiteman, A.J. 1999. Modeling petroleum generation in the Southern Muglad rift basin, Sudan. AAPG Bulletin 83, 1943-1964.

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

Obaje, N.G., Wehner, H., Scheeder, G., Abubakar, M.B. and Jauro, A. 2004. Hydrocarbon prospectivity of Nigeria's inland basins: from the viewpoint of organic geochemistry and organic petrology. AAPG Bulletin 87, 325–353.

Obaje, N.G. 2009. Geology and Mineral Resources of Nigeria. Springer, Heildelberg, 221pp.

Ojo, O.M. 1980. Prospects of finding uranium deposits in Nigeria. Nigerian Journal of Mining and Geology 17, 1-12.

Ojo, S.B. and Ajakaiye, D.E. 1989. Preliminary interpretation of gravity measurements in the Mid-Niger Basin area, Nigeria. In: Kogbe, C.A. (Ed.), Geology of Nigeria, 2nd edition, Elizabethan Publishers, Lagos, p347–358.

Petters, S.W. 1986. Foraminiferal biofacies in the Nigerian rift and continental margin deltas. In: Oti, M. N. and Postma, G. (Eds.), Geology of Deltas. AA Balkema, Rotterdam, pp219-235.

Udensi, E.E. and Osazuwa, I.B. 2004. Spectral determination of depths to magnetic rocks under the Nupe Basin, Nigeria. Nigerian Association of Petroleum Explorationists (NAPE) Bulletin 17, 22–27.