ISSN 2347-4289

Litho-Biostratigraphy And Paleoenvironment Of Synclinal Dukul Formation, Ne Nigeria.

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Abstract: The Upper Benue rift comprising the Gongola and Yola Basins in Nigeria consist of the Aptian-Albian Bima Formation. The Yolde Formation (Cenomanian-Turonian), Gongila/Pindiga/Dukul Formation (Turonian-Coniacian) and Gombe Formation (Campanian-Maastrichtian). The Dukul Formation is situated on latitudes 9°52'00" N to 9°45'00"N and longitudes 11°50'00"E to 12°00'00"E. Shale from Turonian strata of the Dukul Formation has been characterized by stratigraphical and paleontological techniques. The aims of this study were to analyze the lithostratigraphy; determine the age and paleoenviroment of the formation; highlight its potential as a source rock and possibly briefly illustrate the petroleum systems within the region. The lithofacies of the unit is composed of shales with thin interbedded limestone that measures a few centimeters to a maximum of 1m, and siltstones. The section of the unit described at Dukul contains thicker beds of limestone when compared with the other sections from the area. There are two limestone sections; the basal limestone which measures about 2.2 m and an upper limestone bed intercalated between shales. The second limestone bed measures about 2.1 m. The limestones are grain supported and rich in bivalves and gastropods. The limestone have average thickness of about 0.5 m, they are grey and grain to mud supported. The shales have average thickness of 0.45 m. The siltstone beds occur near the top and at the base of the section. The limestones are rich in macrofossils as demonstrated by the frequency occurrence of bivalve shells and shell fragments. The presence of biomicritic limestone suggests deposition under low energy environments.

Keywords: Benue Trough, stratigraphy, sourc rock, biomicrite, foraminifera, paleoenvironment.

INTRODUCTION

The Dukul Formation is located at latitudes 9°52'00" N to 9°45'00"N and longitudes 11°50'00"E to 12°00'00'E of Yola basin in the Upper Benue Trough, Northeastern Nigeria (Fig. 1). The Benue rift basin is a sediment-filled northeast trending structure in Nigeria [1], [2]. It is divided geographically into the lower, middle and upper Benue regions (Fig. 1) and has been a subject of several publications and discussions [3], [4], [5], [6], [7]. Although the associated basins are thought to have formed from extensional processes, recent studies by [8], [9], [10] suggest the importance of sinistral wrenching as a dominant processes for the structural readjustment and geometry of the different subbasins. Two subbasins, the NNE/SSW trending Gongola and the E/W trending Yola Basins, are delineated in the Upper Benue Trough (Fig. 2). The petroleum geology of the upper Benue rift basins (Gongola and Yola basins) has been of great interest to geologists working in the Benue Trough, in the past few years [11], [12]. This study is part of on-going project to understand the depositional environments and petroleum potentials of the region [13], [14], [15], [16]. In the present work, source rock samples from the borehole and outcrop sections of the Dukul Formation in the Yola Basin (Fig. 1) were investigated. The age and paleoenvironment of the Turonian Dukul Formation based on the sedimentological descriptions and fossiliferous analysis of outcrop sections are investigated. Highlighting it's potential as source rock and possible indication of petroleum systems through the measurements on 12 samples from shallow water borehole and outcrop sections.

ISSN 2347-4289

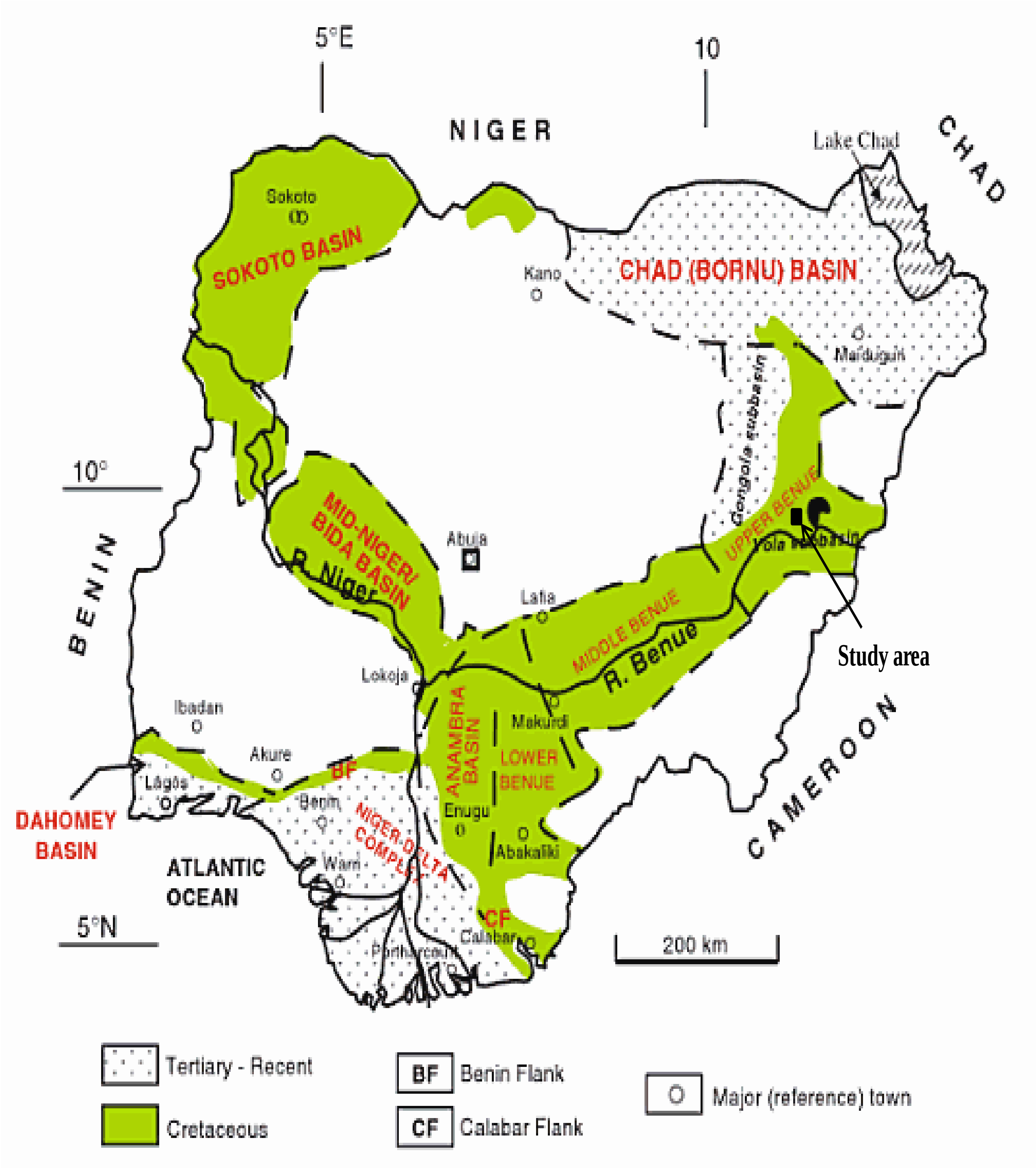

Fig 1: Geological map of Nigeria showing the study location in the Upper Benue Trough (modified from [17]).

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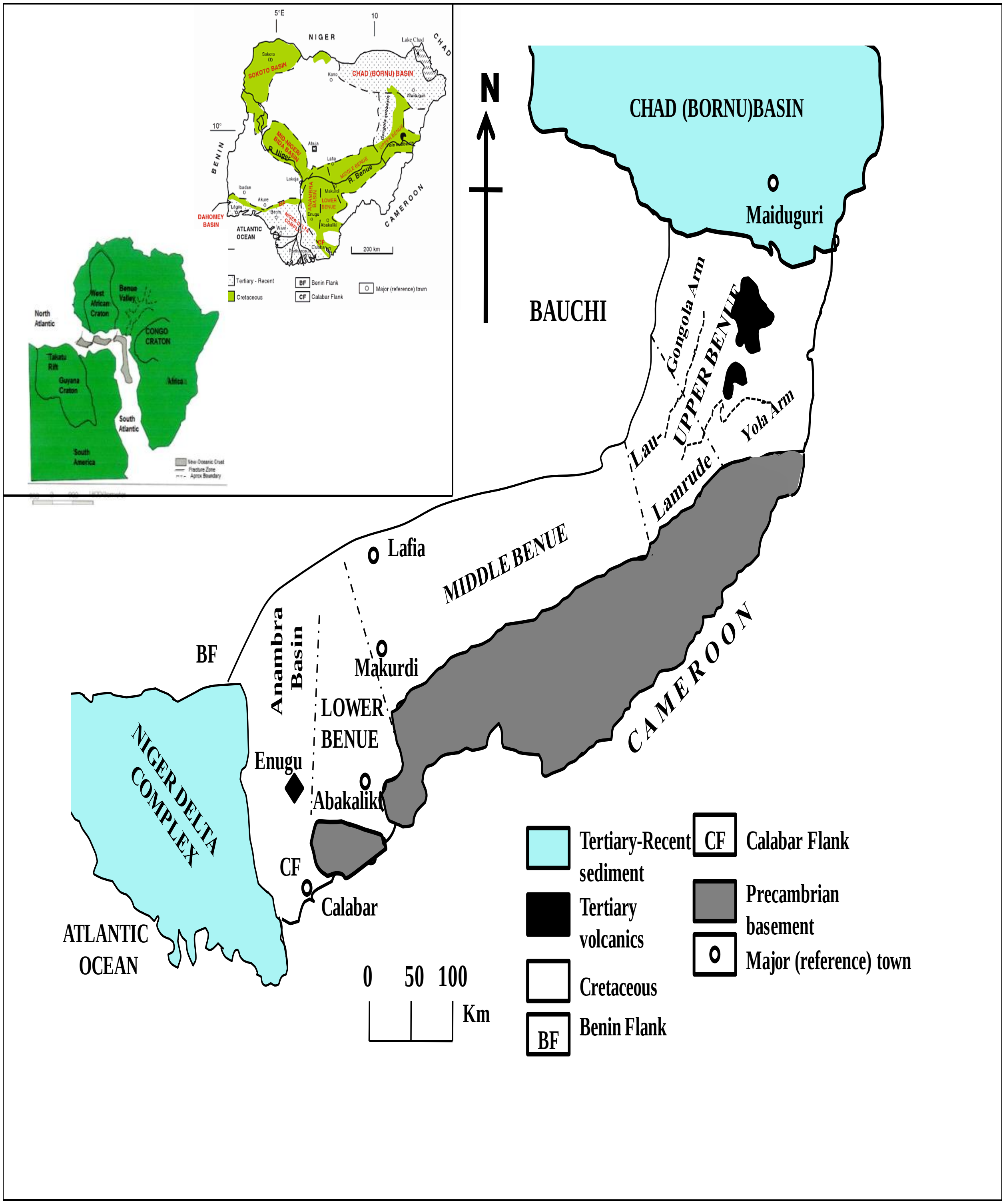

Fig. 2: Geological map of the Benue trough (inset: map of Africa and Nigeria indicating separation of Africa from South America, geological subdivisions of the Benue trough modified from [18]).

REGIONAL STRATIGRAPHIC SETTING

Cretaceous successions in the Upper Benue Trough are flanked by the Precambrian-Late Paleozoic basement gneisses and granite which occur as inlier on occasion (e.g the Kaltungo inlier). The Precambrian basement rocks are overlain by the Albian Bima Sandstone as the oldest

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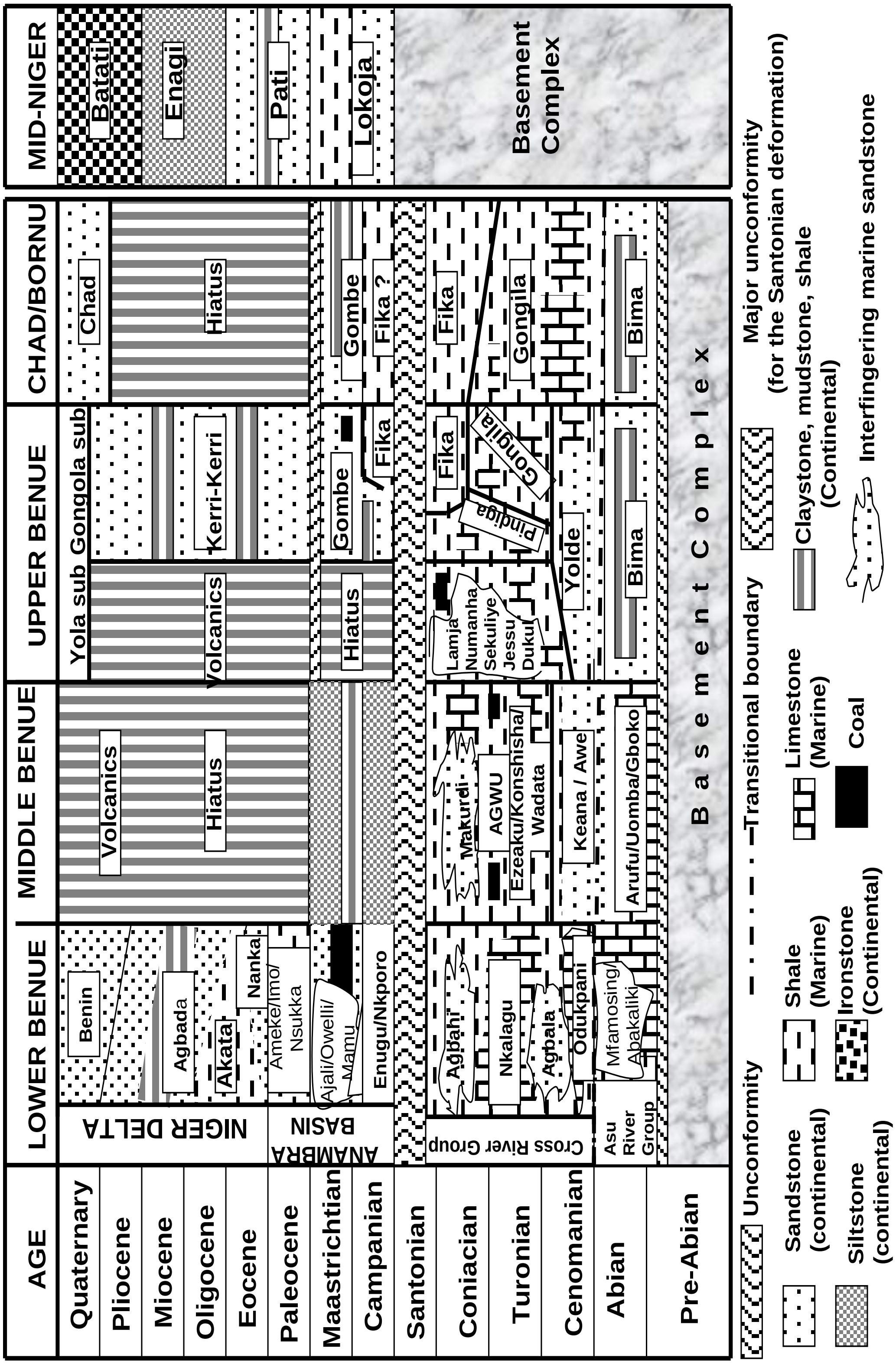

Fig. 3: Stratigraphic succession in the Benue trough, the Nigerian sector of the Chad Basin, the Mid-Niger Basin and relationship to the Niger delta (after Obaje et al., 2006).

Cretaceous sediment in the region. This is overlain by the transitional Yolde Formation (Cenomanian-Turonian), and succeeded by the marine Turonian to Coniacian Pindiga Formation, Gongila Formation in the Gongola Basin and its lateral equivalents; the Dukul, Jessu and Numanha formations in the Yola Basin (Fig. 3). These successions are overlain by the Campanian-Maastrichtian Gombe Sandstone in the Gongola Basin and the lateral Lamja Sandstone (lateral equivalents) in the Yola Basin. The Tertiary Kerri-Kerri Formation capped the succession west of Gombe in the Gongola Basin.

ISSN 2347-4289

MATERIALS AND METHODS

Ten fresh outcrop sections of the Dukul Formation of limestones and shales located at Lakun and Kutari (Fig. 4A) and five shale samples (ditch cutting) from a shallow borehole (GSN BH 1612) located at Numan (Fig. 4B) and penetrating Dukul and Yolde Formations were selected and subjected to sedimentological and paleontological techniques. Care was taking to avoid weathered portions of the outcrop and to obtain material sufficient for various geochemical analyses. The samples were hard, thickly laminated but not fissile, with texture indicative of low permeability. This macro-structure suggests minimum risk of organic matter oxidation. In the laboratory, the samples were reshaped using a rotating steel cutter to eliminate surface that could be affected by alteration. The selected samples were crushed to less than 2 mm and impregnated in epoxy resin for quantitative reflected light microscopy. Kerogen concentrates of the samples with sparse organic constituents were prepared, mounted and polished. Vitrinite reflectance was measured using Reichert Jung Polyvar photomicroscope equipped with Halogen and HBO lamps, a photomultiplier and computer unit at the Bundesanstaft für Geowissenschaften und Rohstofte (BGR), Hannover, Germany. Mean random reflectance of vitrinite using monochromatic (546 nm) non polarized light in conjunction with a x 40 oil immersion objective. About 20 to 25g of each sample was analyzed for microfossil content. The samples were washed and treated with hydrogen peroxide (H_2O_2) and sodium bicarbonate (Na_2CO_3). The treated samples were dried in an oven. The dried samples were further sieved through a 212 µm mesh for easy picking. The picking, counting and identification of microfossils were done using reflected light under a binocular paleontological microscope. The identified microfossils were studied and classified.

RESULTS AND DISCUSSION

The Dukul Formation was defined by [20] as comprising a sequence of shale and thin limestone intercalations with a type locality at Dukul in the north-eastern part of Dadiya syncline. In this study, the formation was found to be composed of grey shales with thin limestone and siltstone beds. The thin limestone beds are evenly distributed in the studied section at Lakun which has a thickness of 30 m (Fig. 4A). The thin siltstone beds occur in the middle and towards the top of the Kutari and Lakun sections respectively. The entire sections at these two localities form part of the Dukul Formation. The overlying Jessu Formation is a marginal marine unit. The upper boundary of the Dukul Formation in the Lakun (Fig. 4A) and Kutari sections was not encountered. At Dukul the formation measures about 60 to 91 m [20] and 80 m [21]. A good section of the unit is also exposed at Jessu. In all these sections, the lithofacies of the unit is composed of shales with thin interbedded limestone, which may measures a few centimeters to a maximum of 1m, and siltstones. The section of the unit described by [22] from Dukul contains thicker beds of limestone when compared with the other sections from the area. They reported a basal limestone which measures about 2.2 m and an upper limestone bed intercalated between shales. The second limestone bed measures about 2.1 m. The limestones are grain supported and rich in bivalves and gastropods. The section at Jessu consists mainly of shale, siltstone and limestone intercalations. The limestone have average thickness of about 0.5 m, they are grey and grain to mud supported. The shales have average thickness of 0.45 m [22]. The siltstone beds occur near the top and at the base of the section. The limestones are rich in macrofossils as demonstrated by the frequency occurrence of bivalve shells and shell fragments. The limestones, shales and siltstones are grey or dark grey in colour, the shales are weathered. Generally, the limestone occurs as two subfacies at Dukul and Jessu. These are shelly and crystalline limestone subfacies. The shelly limestone is highly fossiliferous with macrofossils and occurs more frequently at both localities. The other subfacies is also fossiliferous, indurated and occurs as bands. Oysters, mainly *Exogyra*, constitute the dominant fossils. *Ostrea praelonga* and *Costugyra olisiponensis* are common. Ammonites, other unidentified pelecypods and gastropods are common. Common pelecypods include members of the *Neithea* or *Spondylus* group. Some siphonate gastropods are also common. The associated common ammonites belong to the genera *Vascoceras* and *Hoplitoides.*

Lithostratigraphy

The stratigraphic relationship is well illustrated by the Geological Survey of Nigeria (GSN) borehole N0. 1612 at Numan in the Yola Basin of the Upper Benue Trough (Fig .4). This borehole penetrated the Dukul Formation and it's bounding stratigraphic units the Yolde and Jessu Formations (Fig. 4B). The Dukul Formation occurs at 58-104.9 m. The unit has a total thickness here of 46.9 m and it comprises grey shale with limestone interbeds in upper part (58-89.8 m). The rest of the formation consists of siltstone and grey shale (89.8-104.9 m). The upper and lower boundaries of the formation are placed at the base and top of the sandstone bed respectively. The stratigraphic contacts between the Dukul Formation and its vertically adjacent units are abrupt which is suggestive of changes in depositional environments at the onset and

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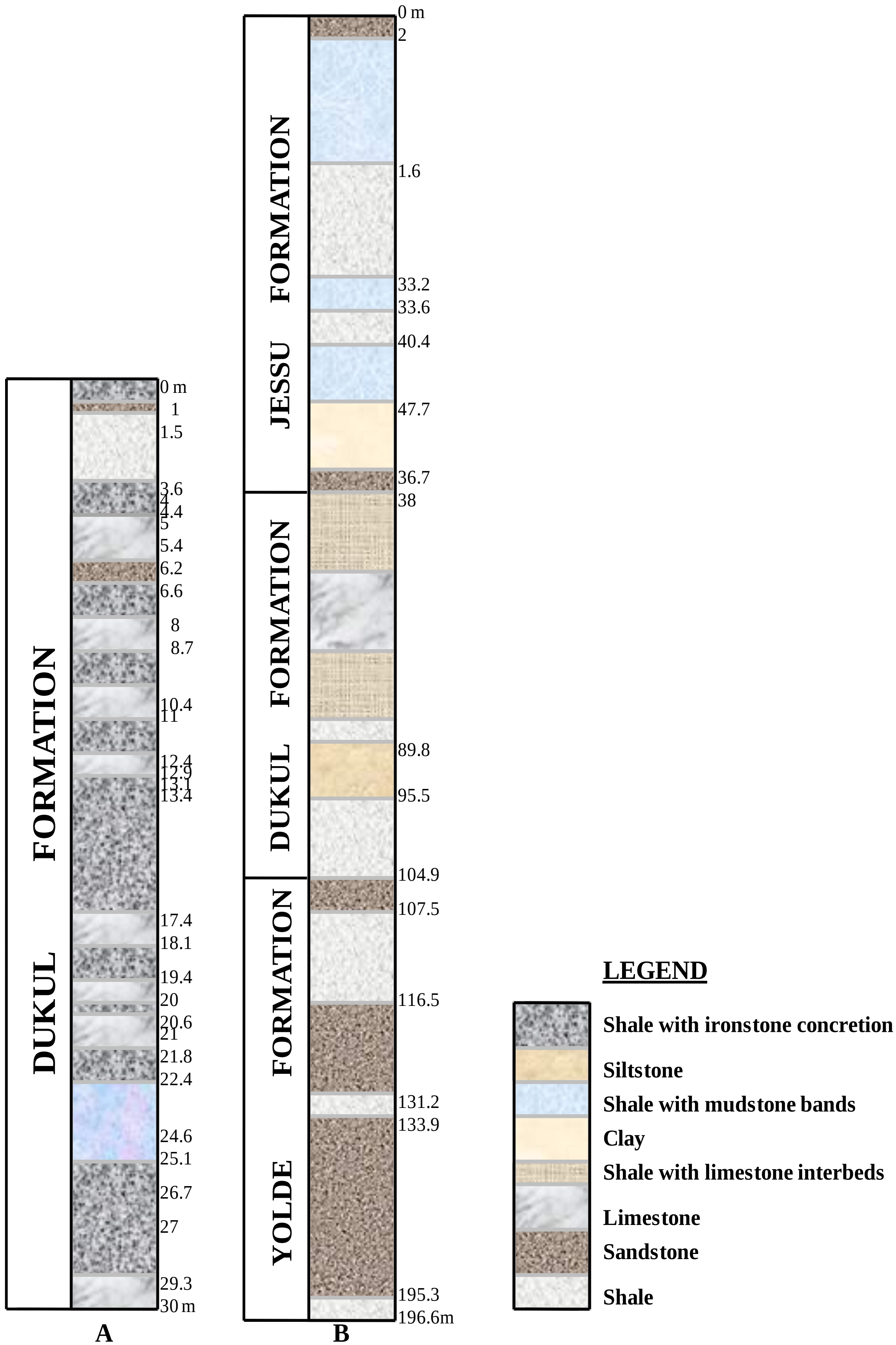


Fig. 4: Lithologic profile of Dukul, Jessu and Yolde Formations at Lakun (A), G.S.N borehole N0. 1612 at Numan (B).

close of its sedimentation. This abrupt character of the lower boundary of the formation is supported by the evidence from a section of the unit described by [23] where the contact between the Dukul and the underlying Yolde Formation is sharp. The above description of the lithofacies of GSN BH 1612 is in agreement with that of [24].

Biostratigraphy

The limestone of the Dukul Formation are highly fossiliferous, the shales contain less fossils. The macrofossils include ammonites, bivalves and gastropods. Ammonites are common in certain horizons in the Upper Benue Trough. This has been documented by previous workers [20], [21], [25], [26], [27], [28], [29], [30], [31], [32]. The following ammonites were found in this study in the limestones of the Dukul Formation at Lakun and Kutari villages: *Vascoceras globosum costatum* (Reyment), *V. globosum* (Reyment), *Pseudovascoceras nigeriense* (Woods), *pseudaspidoceras pseudonodosoides* (Choffat), *Thomasites gongilensis* (Woods), *Wrightoceras wallsi* (Reyment) and *Pseudolissolia nigeriensis* (Woods). The fauna in this location can be subdivided into a lower *Vascoceras* zone and an upper *Hoplitoides ingens* zone. The latter ranges into the Middle Turonian. Other mollusks that occur in the Dukul Formation include oysters commonly represented by *Ostrea* sp and *Exogyra* sp which form the bulk of the fossils of some the limestones [33]. Ostracods and foraminifera were also studied from the formation. The ostracod assemblage is more diverse than that of than that of the foraminifers. The following ostracod species have been identified. *Ovocytheridea apiformis* Aposotlescu, *O. symmetrica* Reyment, *O. ashakaensis* Okosun, *O. reniformis* Van den Bold, *Cythereis gabonesis* Neufvilie, *C. vitilliginosa reticulata* Apostlescu, *Brachcythere ekpo* Reyment, *Hutsonia ascalapha* Van den Bold, *B. sapucariensis* Krommelbein, *Protobuntonia semicostellota* Grekoff, *Cytherella* sp and *Dumontina* sp. Figure 5 shows some of the ostracods found in the Dukul Formation. The foraminiferal assemblage includes the following: *Ammotium nkalagum* Petters, *A. bauchensis* Petters, *A. pindigensis* Petters, *Millamina* sp, *Heterohelix* sp and *Haplophragmoides bauchensis* Petters (Fig. 6). Some

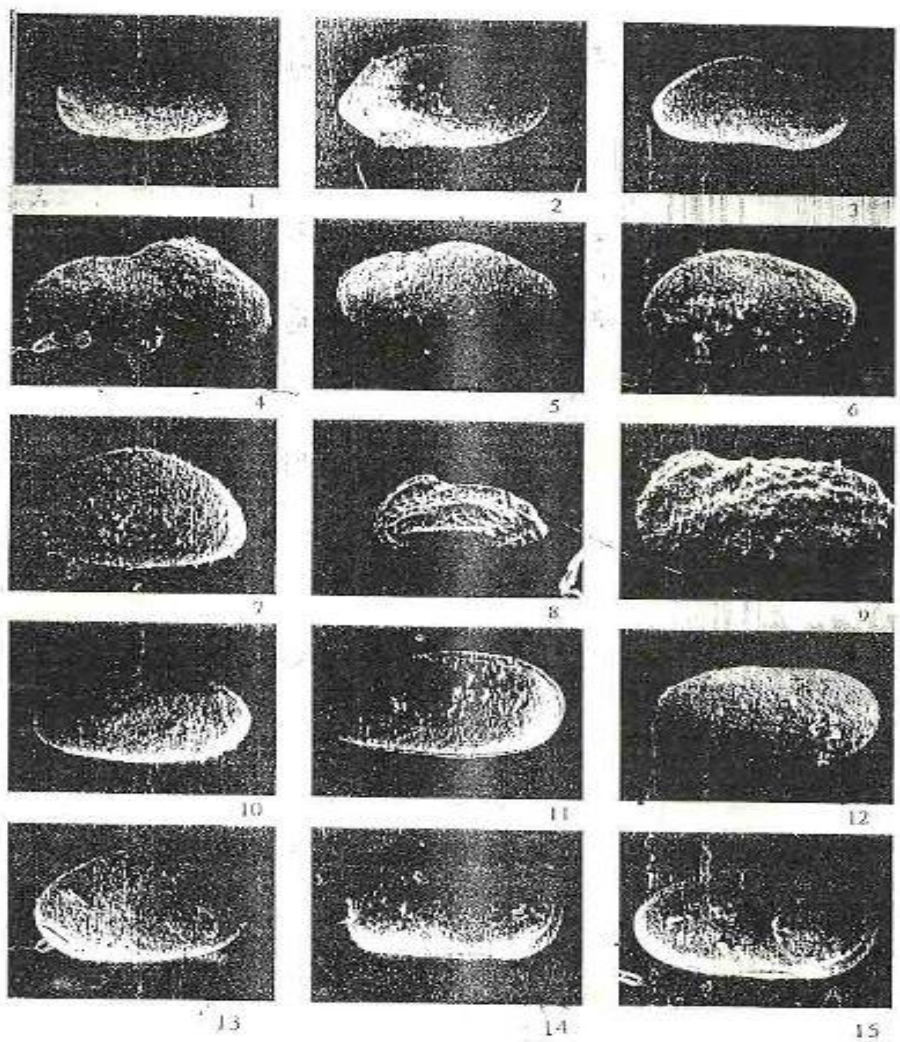


Fig. 5: Some ostracods in the Dukul Formation: 1. *Brachcytheridea* sp.; 2. *Cytherella* sp.; 3. *Ovocytheridea* sp.; 4. *Ovocytheridea* sp.; 5. *Cytherella* sp.; 6. *Cytherella* sp.; 7. *Ovocytheridea* sp.; 8. *Cythereis* sp.; 9. *Cythereis* sp.; 10. *Cytherella* sp.; 11. *Rostrocytheridea* sp.; 12. *Cytherella* sp.; 13 *Ovocytheridea* sp.; 14. *Cytherella* sp.; 15. *Cytherella* sp. (All magnifications x 200) (After [18])

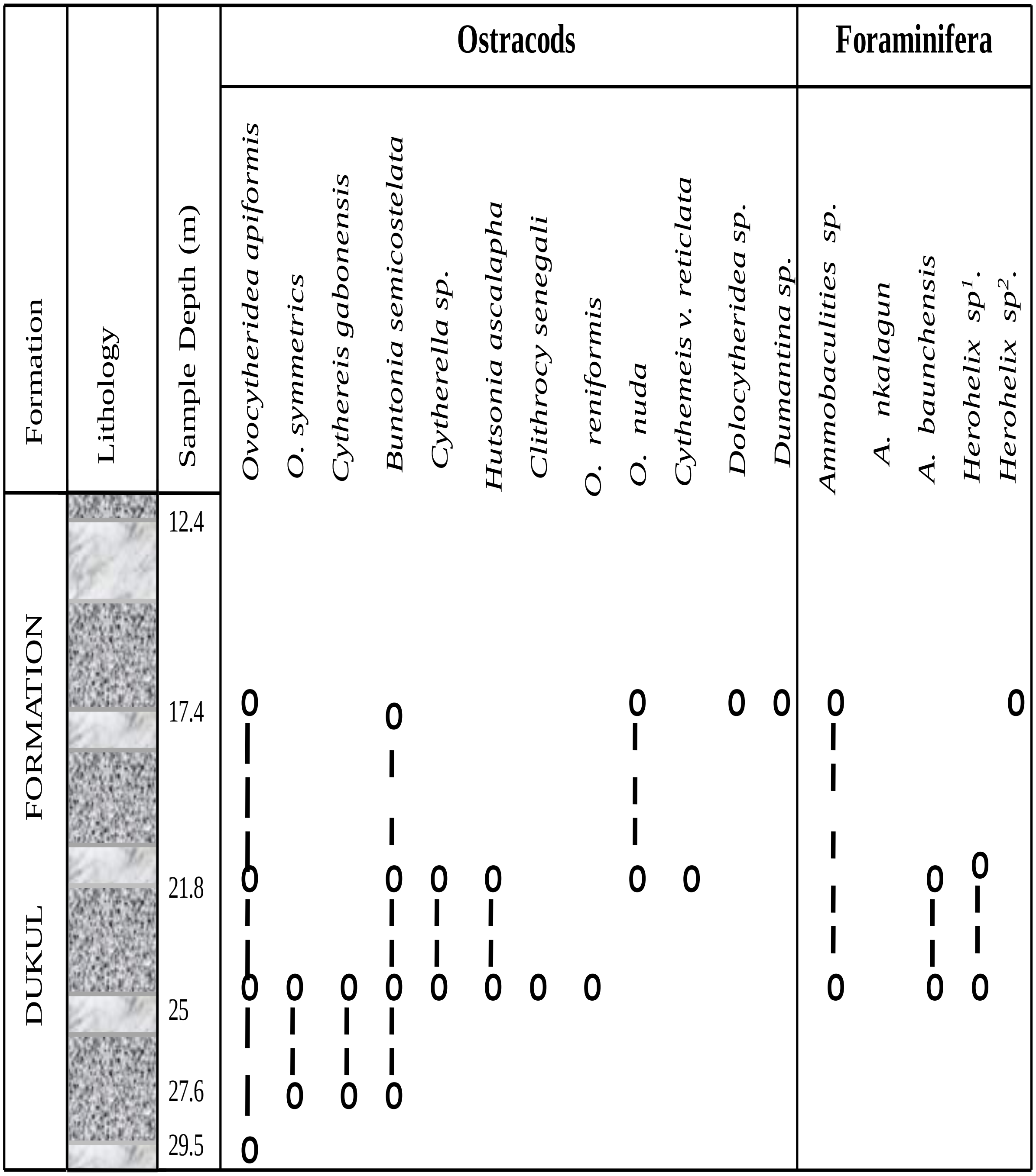


Fig. 6: Distribution of ostracods and foraminifera in Dukul Formation at Lakun, Lithology as in figure 4A.

of the foraminifera found in the Dukul Formation are shown in Figure 7. Some of the benthonic and planktonic foraminifera found in the Upper Benue Trough are illustrated in Figures 8 and 9 respectively. The ostracod and foraminiferal assemblages are similar to those from the Pindiga Formation [34] and the Fika Shale [35]. The ammonite evidence from the Dukul Formation suggests an Early to possibly basal Middle Turonian age [16]. The ostracods have long ranges which indicate a Cenomanian-Turonian age. On the basis of the more age definitive ammonite's evidence, the Dukul Formation can be dated early to basal Middle Turonian.

ISSN 2347-4289

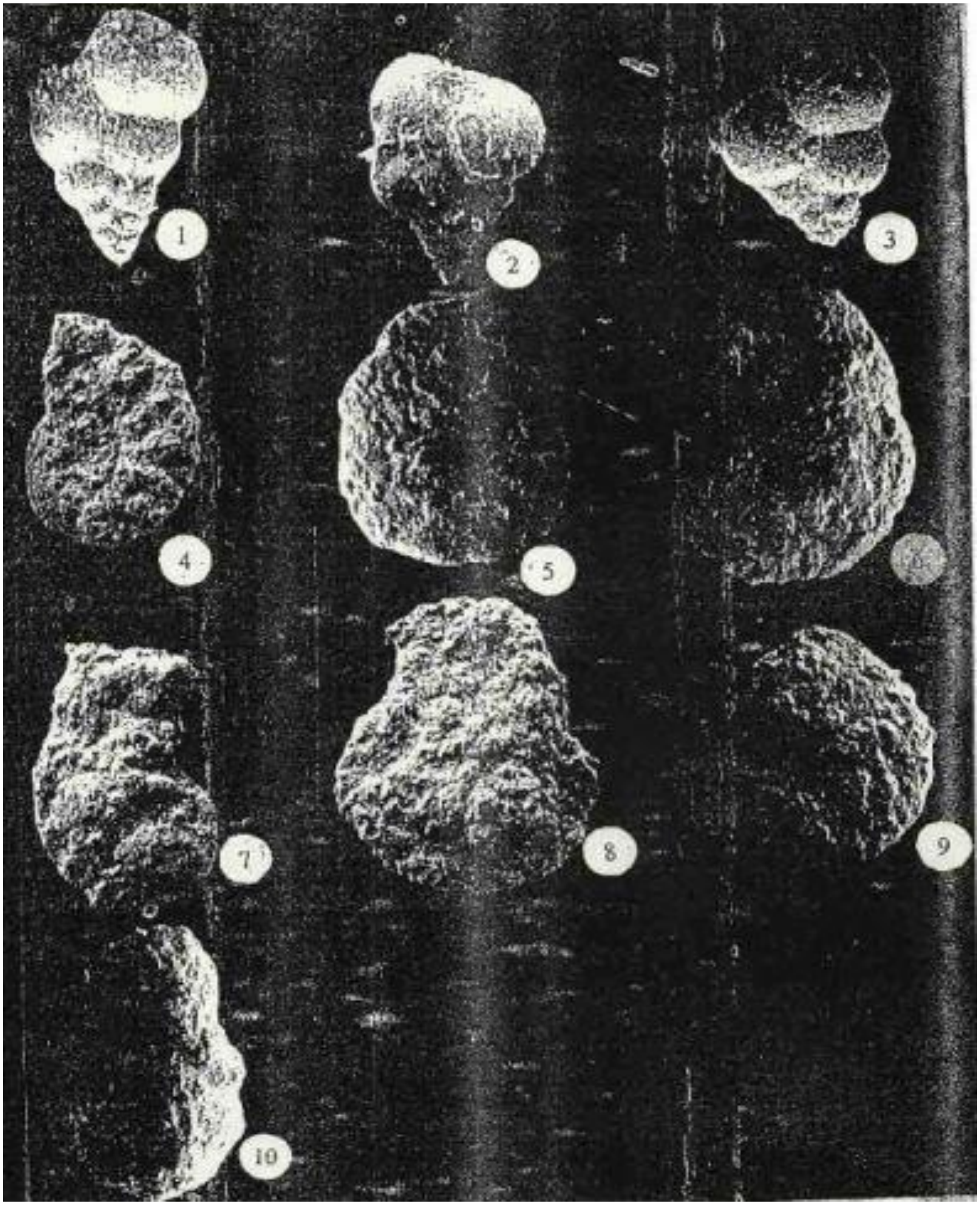
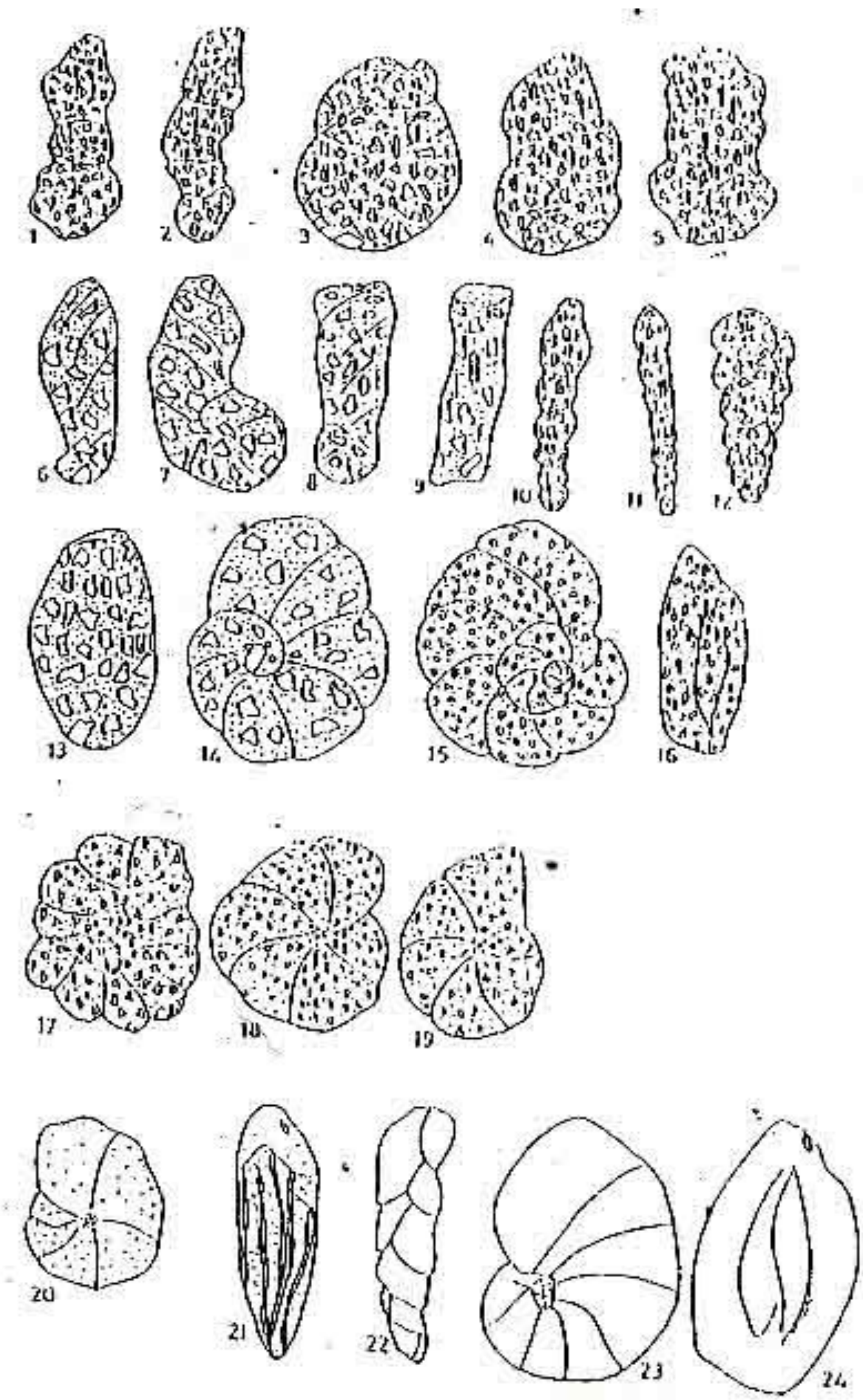


Fig. 7: Some foraminifers in the Dukul Formation: 1. *Heterohelix* sp.; 2. *Heterohelix* sp.; 3. *Heterohelix* sp.; 4. *Haplophragmoids* sp.; 5. *Ammotium* sp.; 6. *Ammobaculites* sp.; 7. *Ammobaculites* sp.; 8. *Ammobaculites* sp.; 9. *Haplophragmoids* sp.; 10. *Ammobaculites* sp. (All magnifications x 350) (After [18]).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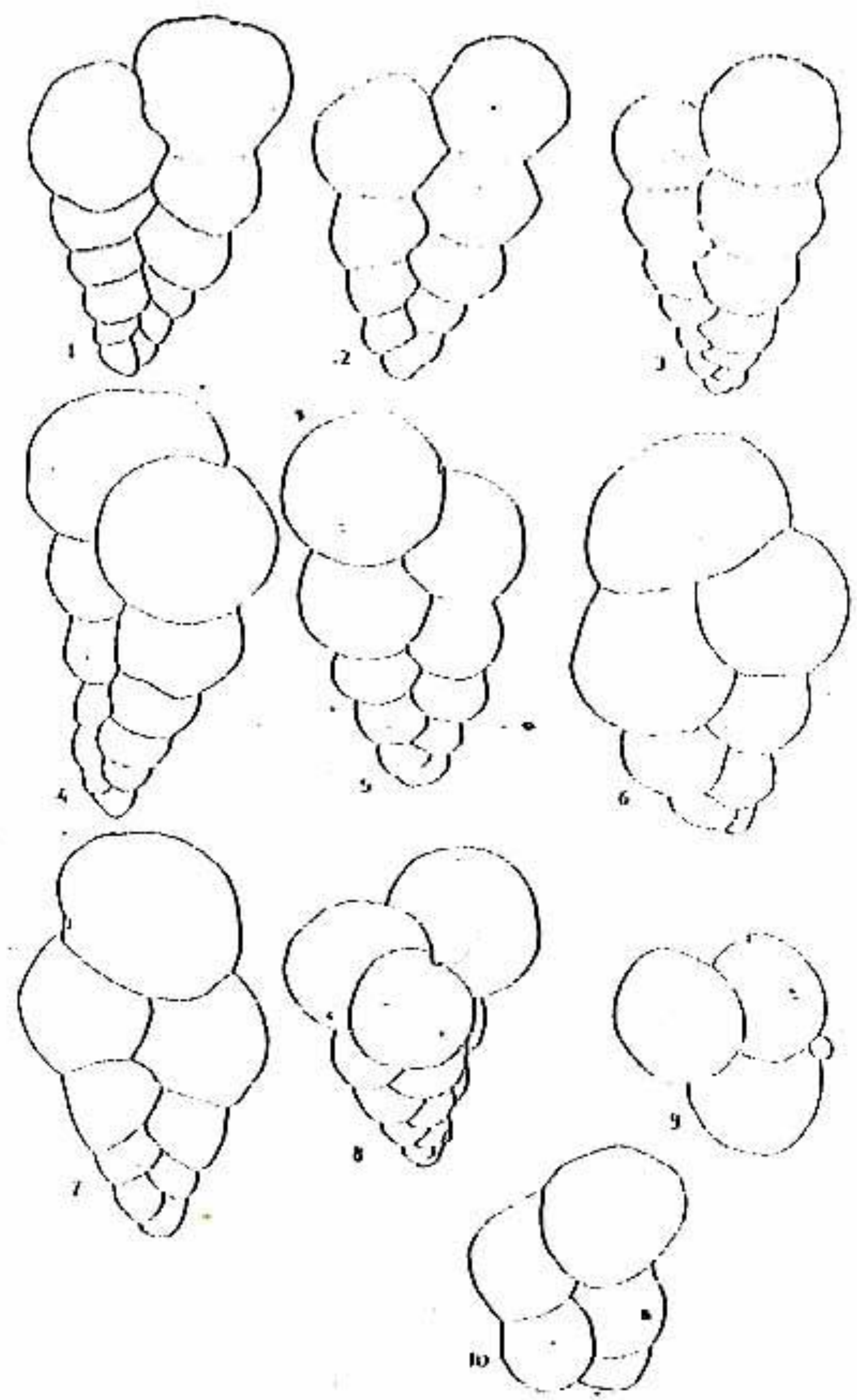

Fig. 9: Some planktonic foraminifera from the Cenomanian – Turonian sequences of the Upper Benue Trough. 1,2,4 *Heterohelix glubulosa*; 3,5 *Heterrohelix reussi*; 6,7 *Heterohelix moremani*; 8 *Guemblitria cenoman*; 9 *Hedbergella cf. delrioensis*; 10 *Hedbergella planispira* (All magnifications x 200 (After [36]).

Paleoenvironment

The paleoenvironment of the Dukul Formation in the study area is inferred based on the lithofacies from the eleven samples, population and diversity of the microfaunas (foraminiferal and ostracods) their assemblages and vertical distribution. The lithofacies (Fig. 4) include fine-grained dark grey fossiliferous limestone (sandy biomicrite) at the base and black shale. Most of the planktonic foraminifers are dwarfed with their last chambers pyritized especially *Heterohelix*. Also the tests of the few arenaceous benthics and the ostracods found in association with the planktonics are dark grey to black due to pyritization. The presence of biomicritic limestone is an indication of deposition under low energy environments (open shelf below wave base or restricted lagoon). Pyrite is an early diagenetic mineral that forms when the overlying sediments is being deposited. The pyritization of the foraminifers and ostracods probably took place shortly after death when individuals were buried a few millimeters of centimeters below the surface, where reducing conditions prevented the complete decomposition of the organic matter [37]. Due to the high amount of pyrite formed, it probably replaced the calcite that originally formed the test, which gave some of the tests their black coloration. Successive units overlying the black shale are alternations of black to dark grey shale with grey marl beds and finally overlain by grey mudstone bed. The sequence in this section shows shoaling-up. The presence of a large number of agglutinated benthic foraminfers supports the shoaling-up sequences. The presence of black shale with a large population of planktonic foraminifers and ostracods with few benthics indicates deposition in deeper marine conditions under an oxygen depleted highly reducing environment. Oertli [37] suggested that anoxic conditions in a basin are indicated by poor benthonic faunas and a large population of planktonic foraminifers [38]. The sediments of Dukul Formation in the study area based on lithofacies and microfaunal association show deposition in littoral to open marine shelf paleoenvironments [16].

Source Rock Quality

Foraminifera, also called foraminifers or forams, phylum of unicellular marine organisms that extrude chitinlike shells, called tests that form rich deposits of sedimentary fossils. It has been reported that foraminifera fossils yield information about the location of petroleum deposits and the history of the earth's climate. With the presence and good number of benthic and planktonic foraminifera found in the Dukul Formation (Fig. 6) supported by other workers such as in [18] [33] and [36] indicates that shale in the Dukul Formation may be a good source rock. A geochemical result by [18] on the contrary, further confirmed that the shale samples of the Dukul Formation plot mainly along the gas prone kerogen evolutionary pathway as indicated by the plot of HI against T_{max}. This confirms that a substantial proportion of the organic matter is of terrestrial origin with gas potential despite their marine environment of deposition. Using [39] classification, [40] plotted HI against T_{max} which indicates that source rocks of the Yolde, Dukul and Jessu formations are dominated by type III (gas prone) kerogen derived from terrestrial plants excepts for the swamp facies of the Yolde Formation with some indication of type II (oil prone) kerogen. The predominance of type III kerogen in the shales is further supported by the of A-factor against C-factor from infrared data and the predominance of vitrinite and inertinite maceral [13] which classified the shales as having gas-prone type III kerogen. With average TOC values of 0.51, 0.58, and 0.53 for the Yolde, Dukul and Jessu formations respectively [40] which met the minimum of 0.5% required for petroleum source beds [41], the source rock units are nevertheless lean in terms of organic matter concentration. This poor organic matter concentrations may be due to deposition under oxic condition in the Cenomanian-Turonian times [36], [42], [43], [44].

Petroleum System, Potential and Reservoir Quality in the Region

The potential source rocks of this possible petroleum system in the Gongola Basin are shales and limestones of the Pindiga and Fika Formations and perhaps the coals of the Gombe Formation, and correlative Dukul, Jessu, Sekuliye, Numanha and Lamja Formations in the Yola Basin (Fig. 3). TOCs from available data in the Yola Basin are in the range of 0.25-1.15wt% (ave. 0.57wt %) for the Dukul Formation, 0.21-0.85wt% (ave. 0.52wt %) for the Jessu Formation and 50.10-51.70wt% (ave. 50.90wt %) for the coals of the Lamja Formation [45]. HIs from these formations are 15-64mgHC/gTOC (ave. 33mgHC/gTOC), 11-49mgHC/gTOC (ave. 25mgHC/gTOC) and 179-184mgHC/gTOC (ave. 182mgHC/gTOC) respectively. These suggest the dominance of type IV OM for the Dukul and Jessu Formations and type II OM capable of generating oil and gas for the Lamja Coals. This however, is inconsistent with coals which generally have terrestrially-derived type III OM. Available data from the Pindiga Formation of the Gongola Basin indicates 0.04-2.45wt% TOCs (ave. 0.59wt %) with 57.95% of the samples having TOCs of? 0.5wt% [45]. HIs are very low (5-180mgHC/gTOC) suggesting poor generating potential, except in the upper part of the formation (Fika Member) where HIs are mostly above 150mgHC/gTOC. The upper part suggests oil and gas generating type II OM. Shale and coaly shale facies of the Maastrichtian deltaic Gombe Formation show TOC range of 0.20-6.87wt% (ave. 1.66wt%) while the shaly coal facies have TOCs of 14.90-23.70wt% (ave. 19.60wt%) [45]. HIs ranges from 2-280mgHC/gTOC with an average of 45mgHC/gTOC in the shale/coaly shale facies and 122-178mgHC/gTOC with an average of 143mgHC/gTOC in the shaly coal facies. This suggests that the shaly coal facies are potential source rocks for gas and some oil locally (where HIs are more than 150mgHC/gTOC). Petroleum type prediction [46] based on data from Open System Pyrolysis Gas Chromatographic runs of Gombe coals, revealed the generation of the paraffinic-naphthenic-aromatic (P-N-A) high wax to paraffinic oil, high wax oil [47]. The Tmax values of the Upper Cretaceous sediments (the Dukul, Jessu and Lamja Formations) of the Yola Basin are mostly above the minimum threshold of 435^{o}C [45], hence are generally mature and capable of hydrocarbon generation. The Pindiga and Gombe Formations of the Gongola Basin, on the other hand, show immaturity. The maturity of the Upper Cretaceous sediments in the Yola Basin may be related to the near-by Tertiary volcanic emplacement of the Longuda Plateau. In the Kerri-Kerri sub-basin, located in the western Gongola Basin, the Pindiga and Gombe Formations are overlain by the Kerri-Kerri Formation, hence may have been buried to greater depth to reach hydrocarbon generation maturity. Possible reservoirs for this system in the Gongola Basin are mainly mid-Turonian sandstones of the middle Pindiga Formation (the Deba Fulani, Dumbulwa and Gulani Members) and the Gombe Formation. The limestones of the Kanawa Member of the Pindiga Formation may also constitute local reservoirs where individual beds are stacked as in the Ashaka cement querry (limestones reach thickness of 10m here) and where porosities and permeabilities are diagenetically and mechanically enhanced. Generally, the middle members of the Pindiga Formation include moderately well sorted, loosely cemented and thickly developed trough and planar cross-bedded, as well as, hummock cross-stratified medium to coarse grained sandstones that are occasionally pebbly and graded bedded [48]. Granulestones are also present. These sandstones show coarsening upward cycles at the base, but are fining upward towards the top. The sandstones represent shoreface and fluvial sedimentation at the lower and upper parts of the members respectively [48]. These sandstones may extend for over 10km and occur over the entire eastern Gongola Basin. The presences of these members in the sub-cropping part of the western Gongola Basin (Kerri-Kerri sub-basin) is possible, but has not been proved. Although porosity and permeability data is lacking, these sandstones constitute excellently reliable aquifers that provide constant supply of a large volume of water needs of the Gombe town from semi-artesian wells at Kwadom. They form also highly productive aquifers in the Kumo area with water yield of 5.80-7.10/sec [49]. These indicate excellent reservoir qualities (high porosity and permeability) for the sandstones. The deltaic Gombe Formation, on the other hand, is made up of thickly developed and fairly extensive distributary mouthbars, and distributary and fluvial channel sandstones. These sandstones are moderately well sorted and mostly very fine grained. Porosity and permeability are likely to be highly variable. However, globally the porosities and permeabilities of deltaic sandstone reservoirs range from 11-35% and 250-8000md respectively [50]. In the Yola Basin, siliciclastic reservoir lithologies are scarce except the Coniacian-Santonian deltaic Lamja Formation. This formation may have similar reservoir qualities as the Gombe Formation but is stratigraphically shallow (the upper-most sedimentation sequence in the Yola Basin) and lacks potential seals. The limestones in the Dukul Formation are thin, hence may not form adequate reservoirs. The shales of the Fika Member could form effective seals for the reservoirs of the middle part of the Pindiga Formation. The potential reservoirs in the Gombe Formation may be sealed by the intercalating silty shales of the formation, but may not be competently and laterally very effective.

CONCLUSIONS

The Turonian Dukul Formation in the Yola Basin contain source rocks that generally have potential less than 2, 000 ppm, suggesting that they cannot generate economic amount of hydrocarbons. The predominance of terrestrially derived organic matter (Type III kerogen) within the various source rock horizons suggests that the Yola Basin region is gas prone. There is predominance of allochtonous type III organic matter and low concentration of organic matter in the middle Cretaceous Dukul shales which suggest prevalence of oxic condition contrary to the earlier proposed mid Cretaceous anoxic model in the Benue Trough based mainly on foraminiferal content. The Dukul Formation can be dated Early to basal Middle Turonian based on definitive ammonite's evidence and it's sediments also showed deposition in littoral to open marine shelf paleoenvironments based on lithofacies and microfaunal associations. The region has a poor natural petroleum system in terms of formational source rock, reservoir, and seal lithologies.

ACKNOWLEDGEMENTS

Gratitude is expressed to Prof. N.G. Obaje for having patiently supervised my M.Sc. work. The Alexander von Humboldt Foundation is gratefully acknowledged for a fellowship award to my supervisor which enabled the analyses of some of my samples at the Federal Institute for Geosciences and Natural Resources in Hannover (Germany).

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