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MICROPALEONTOLOGICAL AND SEDIMENTOLOGICAL ANALYSES OF CARBONATES ROCKS IN PARTS OF SOKOTO BASIN, NIGERIA: IMPLICATIONS FOR PALEOECOLOGICAL INTERPRETATION AND EXPLORATION EFFORTS

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ABSTRACT

This study presents a detailed analysis of the Paleocene and Maastrichtian marine sediments in the Sokoto Basin, Nigeria, using boreholes GSN – BH – 2051 and GSN – BH – 4051, respectively. This study is aimed at integrating sedimentological, micropaleontological and petrographic data in paleoecologic interpretation of depositional environments of the Sokoto Basin. The methods adopted in this research involved the examination of ditch cuttings, carbonate thin sections, and microfossils analyses from the boreholes drilled in Sokoto Basin. The sedimentological data from the borehole showed that the studied stratigraphic unit comprises mainly fine to medium-grained limestone facies, sparitic intraclastic packstone and oolitic-pelmicrite wackestone facies. The microfacies obtained from petrography data revealed micro-fossils abundance and diversity associated with the onset of shallow marine transgression which resulted in the deposition of the Dange and Kalambaina Formations, respectively. The assemblages of the larger foraminifera (Opercullnoides bermudezi) and the larger ostracod (Bairdia iIaroensis) in the borehole sections further suggested marginal marine depositional environment for the Kalambaina and Gamba Shale Formations. The paleoecological interpretation suggests varying salinities and dysaerobic conditions during deposition, with implications for understanding basin evolution. The study concludes by highlighting the importance of integrating multiple methods for a detailed understanding of paleoecological and depositional environment of Sokoto sedimentary basin.

Keywords: Sokoto Basin, ditch cuttings, microfossils, paleoecology and depositional environment

INTRODUCTION

The Paleocene and Maastrichtian marine sediments in the Sokoto Basin constitutes the major units in the southeastern parts of the Iullemmeden Basin (Figs. 1). The marine sediment was mainly deposited as a product of the Tethys Transgression which took place or covered parts of the north and central west African in the Maastrichtian and Paleocene periods (Kogbe *et al.*, 1976; Okosun, 1999). A few number of paper have been published regarding carbonates studies in Sokoto Basin, Nigeria. Most of the published works were on outcrop studies as documented in works of (Obaje *et al.* (2013), Petters, 1977, 1978, 1979, Kogbe, 1991 and Yelwa *et al.*, 2019). Geochemical and petrography results from outcrop studies suggests strongly that the Sokoto sector of the basin has good prospective in terms of hydrocarbon (Obaje *et al.* 2013, 2019; Petters, 1977, 1978and Okosun, 1995).

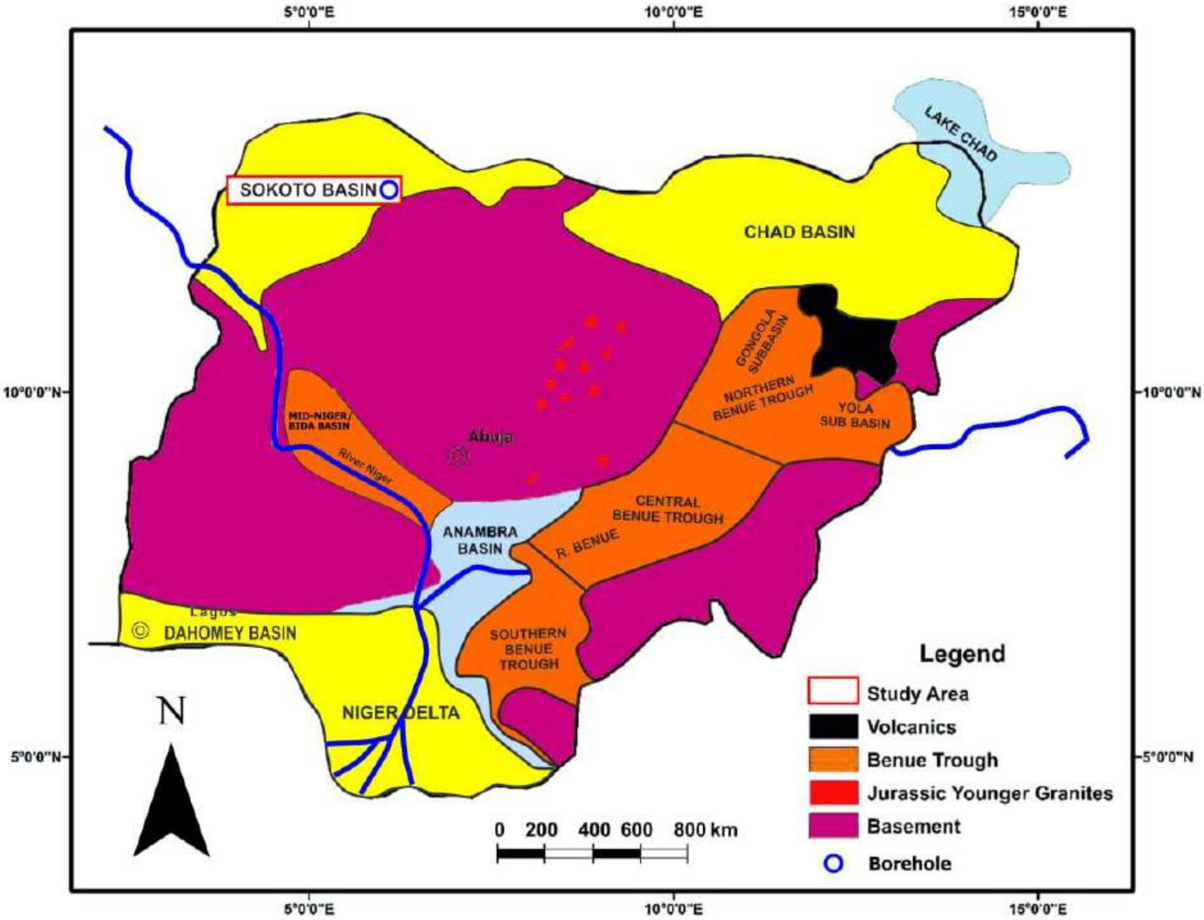

Fig. 1: Geological map of Nigeria indicating study location (modified after Kogbe, 1991; Abubakar *et al.*, 2019 and Aigbadon *et al.*, 2024 c).

Petters (1977, 1978) did an outcrop study and applied micropaleontological method in southeastern part of the Iullemmeden Basin. The fossil and microfacies type results revealed that the carbonate sediments are mainly marine to marginal marine in nature. Their study further revealed that the marine sediments/deposits spanned two depositional cycles ranging from Maastrichtian to Paleocene. This was in tantamount with published works of Okosun (1995) based on Ostracods analysis from boreholes in part of Sokoto Basin, Nigeria. Yelwa *et al.* (2022) carried-out sedimentological and petrographic studies around Gilbedi in Iullemmeden Basin. The recorded limestone samples display medium to coarse grain, ranging from yellow to grey colour. The limestone grains are equipgranular with interstitial quartz cement. The sedimentological results further revealed massive dark grey limestone with intercalations of dark grey shales and mudstones. Within the limestone are evidence of fossils remain (pelecypods, mollusca and little bone of reptiles) reflecting a marginal marine depositional setting.

Few study from boreholes within parts of Iullmedden (Sokoto Basin) are documented in published works by Kogbe *et al.* (1976), Petters (1979), Okosun (1999) and Toyin *et al.* (2015). Toyin *et al*. (2015) integrate sedimentological and facies analysis to deduce carbonate microfacies types as packstone, algae wackestone and bioclastic packstone and with their depositional environment as shallow marine. The lithological and the matrix grain characteristics/relationship including marine gastropods, pelecypods and their remains further reaffirm shallow marine settings. Okosun *et al*. (1999) integrated ostracods and

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foraminifera data from two boreholes in parts of Sokoto Basin, Nigeria and provide a paleoecologic interpretation of the depositional environments. The paleoecologic data revealed a shallow marine environment for the deposition of the stratigraphic units.

The greatest challenges in carbonates sedimentology and facies analysis in Nigeria is due lack of subsurface data. Based on previous studies best to authors knowledge few methods and limited data were employed in evaluating the Sokoto Basin. This study aimed integrating sedimentological, micropaleontology and petrographic data for paleoecology interpretation of depositional environments using boreholes data from Sokoto Basin.

Geological settings in the Sokoto Basin

The Iullemmeden Basin is situated north-western Nigeria and is locally called "Sokoto Basin". It is mainly characterized by a gently undulating plain with average elevation ranging from 250 to 400 m above sea-level. The plain is sometimes interrupted by low mesas which is one of the prominent feature in the basin which is linked to the geology. The initiation of the Iullemmeden Basin is believing to be formed in the late Jurassic (140 Ma) as a result of the break-up of the major supercontinents between the Africa and south America plates (Nwajide, 2022; Obaje *et al.*, 2013; Obaje, 2009). The sediments of the Iullemmeden Basin were accumulated during four main phases of deposition as discussed by Obaje *et al.* (2013), Obaje *et al.* (2019), Yelwa *et al.* (2019) and Nwajide (2022) (Fig. 2): (i) Pre-Maastrichtian phase/Pre-Maastrichtian Deposits: Overlying the Pre-Cambrian Basement unconformably, the Illo and Gundumi Formations which comprises grits and clays, and also known as the Pre-Maastrichtian "Continental Intercalaire" of West Africa. The Gundumi Formation lies unconformably on the basement and comprise basal conglomerates, and gravels with sand and variegated clays increasing upwards; the maximum thickness is about 350 m (Nwajide, 2022). The Illo Formation includes interbedded clays and grits, with an intermediate pisolitic and nodular clay member with thicknesses of about 240 m (Jones, 1948 and Nwajide, 2022). (ii) Maastrichtian Deposits (The Rima Group, Fig. 2): The second phase of deposition of sediments in the Sokoto Basin began during the Maastrichtian, when the Rima Group was deposited unconformably on pre-Maastrichtian continental beds consisting of mudstones and friable sandstones (Taloka and Wurno Formations, respectively), separated by the fossiliferous, shelly Dukamaje Formation. The Dukamaje Formation display mudstone, dark shales, greyish gypsiferous shale with some greyish black horizons. The shales are very rich in reptilian bones with massive gypsiferous and ferruginous altered concretionary limestone capped by lateritic deposits in the basin (Obaje *et al*., 2009, 2013; Yelwa *et al*., 2019). The presence of two horizons of bone beds at the base of the Dukamaje Formation in Gilbedi is significant and supports the view that the bone bed is due to the action of winnowing forces along the strand-line of a transgressive sea during the Maastrichtian (Kogbe, 1981, 1991).

Age	Formation	Group	Environment
Quaternary	Sandy drifts, lateites	–	–
	Unconformity		
Miocene to Upper Eocene(?)	Gwandu Formation	Continental Terminal	Continental
	Unconformity		
Middle Eocene	Primary oolitic ironstone		
to	Gamba Formation		
	Kalambaina Formation	Sokoto Group	marine
Paleocene Late	Dange Formation		
	Unconformity		
Maastrichtian to Campanian	Wurno Formation Dukamaje Formation Taloka Formation	Rima Group	Brackish water with brief marine intercalation
	Unconformity		
Earliest Cretaceous to Late Jurassic	Illo and Gundumi Formations	Continental intercalaire	Continental
	Major unconformity		
Precambrian		Basement complex	

Fig. 2: Various formations in the Sokoto Basin, Nigeria (Kogbe, 1991)

Paleocene Deposit (Group Sokoto, Fig. 2) include the Dange and Gamba Formations (predominantly shales) separated by the calcareous Kalambaina Formation which made up the Paleocene Sokoto Group. The Gamba Formation are mainly grey laminated shale overlying the calcareous Kalambaina Formation. The shales are also folded with presences of slump structures within some beds (Obaje *et al.*, 2013; Okosun, 1995). Except when overlain by the Gwandu Formation, the formation is covered by a mantle of loose sand and laterite. The laterite which is about 1.5 –3 m thick, often passes down into oolitic ironstone 3 – 5 m thick. Post-Paleocene Continental Terminal: The Gwandu Formation forms the Post-Paleocene sediments (Fig. 2). Throughout the sedimentary basin of north-western Nigeria, the Tertiary marine sediments of the Sokoto Group are overlain disconformably by a thick series of deposits consisting predominantly of red and mottled massive clays, with sandstone intercalations (Kogbe, 1972). These sediments belong to the Gwandu Formation, with the type section and the type area in the Gwandu Emirate of northern Nigeria (Kogbe, 1972; Fig. 2).

MATERIALS AND METHODS

35 ditch cuttings samples per boreholes of GSN BH – 2051 and BH – 4051 (at depths 2 – 35 m; Figs. 4 and 5), respectively in the Sokoto Basin, Nigeria were used for this study. Textural parameters such as colour, textures as well as fossil contents, presence of accessory mineral and diagenetic features were examined at specific interval in the boreholes (Aigbadon *et al.*, 2024 a). Carbonate thin section was carried out after (Aigbadon *et al.*,

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2024 b, c). The carbonate thin section slides and textural features were examined with the aid of Olympus BX 41-P polarizing light microscopes. The CorelDraw Graphics Suite update (v25.0) software were used for the plot of the litho-log. The microfossil analysis was carried-out using screen carbonate ditch cuttings samples at particular depth intervals (2 m – 35 m), respectively. For the micro-paleontological analysis, standard procedures were strictly adhered to during preparation of the samples in the laboratory (Armstrong and Brassier, 2005). These stages involved logging of the ditch cutting samples as well as crushing of the samples so as to allow thorough digestion of the carbonate sediments. Two hundred (200) gram mass of each sample was disaggregated by applying hydrogen peroxide, thereby soaking the sample in an aluminum beaker over the night for digestion. Then followed by heating with sodium carbonates for about 2 hours. The retained samples are washed with soap under running tap water with 63µ sieve. Also, the retained samples were poured into a plate for observation and picking of the forams and ostracods into slides. The picked forams and ostracods were further subjected to an Olympus BX61 light microscopes. The selected and representative species of forams and ostracods are digitally photographed.

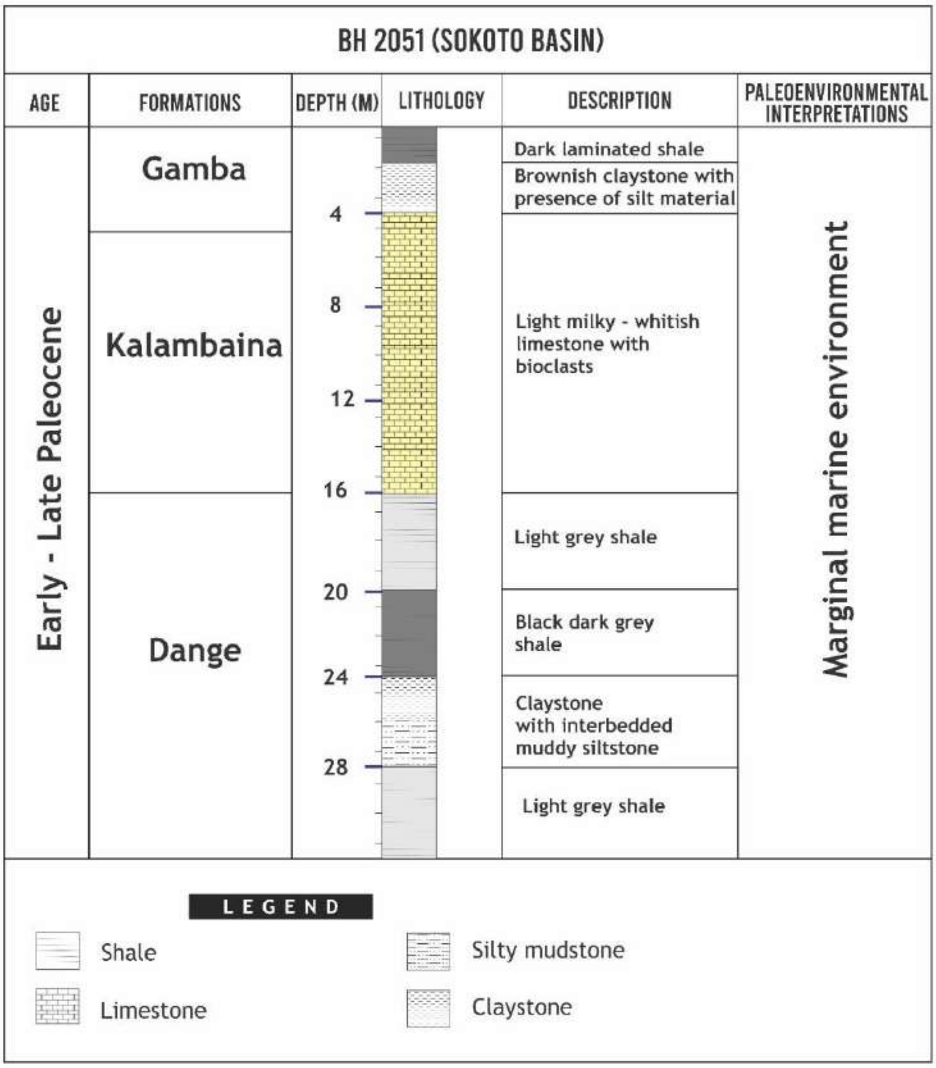

Fig. 3: Lithologic section highlighting various rock facies in borehole 2051

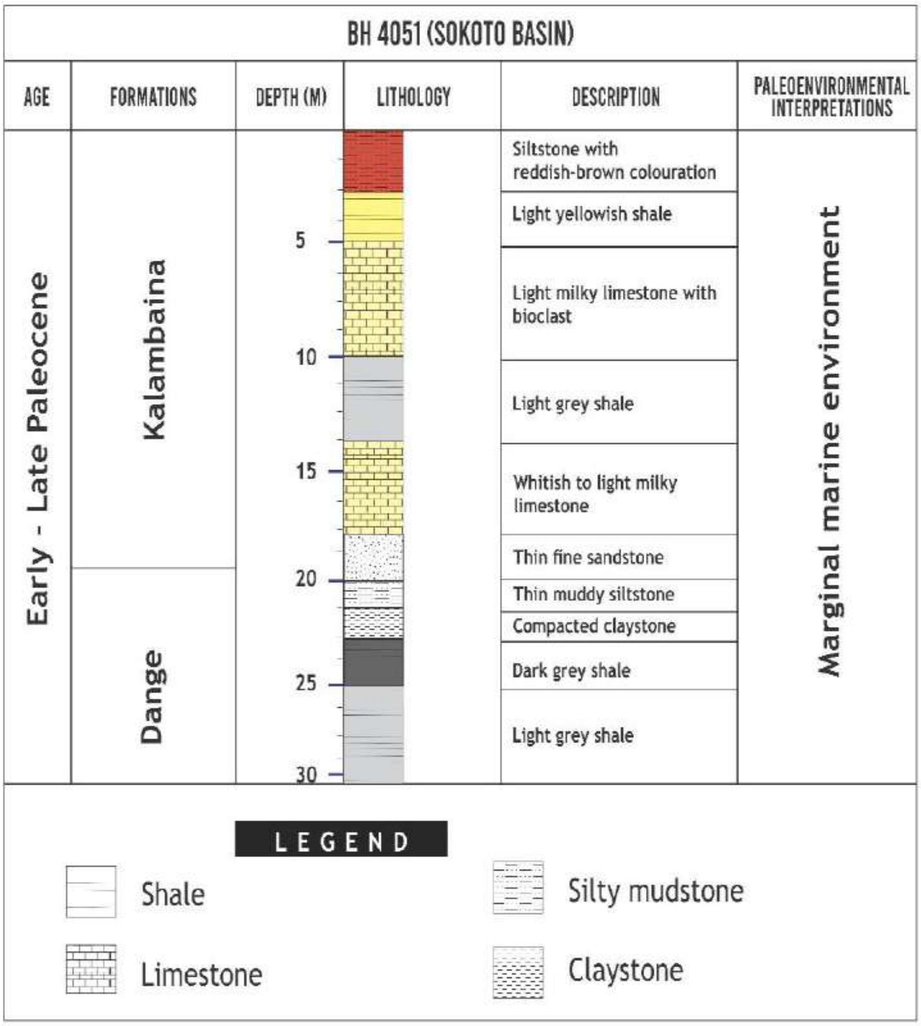

Fig. 4: Lithologic section highlighting various rock facies in borehole 4051

RESULTS AND DISCUSSION

lithological characteristics and facies result

Based on textural features, four descriptive facies are delineated which are described below:

(i) Light milky-whitish limestone facies: The facies is characterized by light milky-whitish limestone with bioclast with thicknesses ranges of 4 m to 16 m (Fig. 3). This facies was also observed that the light milky-whitish limestone facies with thick band of light grey shales with thickness of about 3 m. This facies appears at depths 5 –17 m in BH – 4501 (Fig. 3). The average thickness of limestone in both boreholes range between 10 –12 m.

(ii) Grey shale facies: This lithofacies include light, dark-grey/black shales with compacted claystone. These light, dark/black grey shale facies occur between depths 16 –32 m (Fig.3), and at depth 10 m, 20 – 30 m in BH – 4051(Fig. 4), respectively. There also exists presence of dark laminated shale of thicknesses of about 2 m at BH – 2051. The shale facies display some elements of glauconitic material and authigenic minerals (i.e. kaolinite, hematite) and pyrite. The authigenic minerals and pyrite depicts a low energy environment. The presence of

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glauconitic materials reflects a lacustrine to shallow marine settings.

(iii) Light yellow shale facies: This lithofacies consist of light yellow shale units at depth ranges of 2.5 – 5 m (Fig. 4). This is an indication of fluvial influences.

(iv) Muddy siltstone with claystone facies: This facies includes thin muddy siltstone, siltstone with reddish brown colouration at depths 0.5 – 2 m, 20 – 21.5 m in BH – 4051 (Fig. 4) and 26 – 28 m in BH –205 (Fig. 4), respectively. This also reflects a low energy environment.

Petrography results

Based on petrographic result two microfacies were identified as:

(i) Sparitic intraclastic packstone**:** The photomicrographs in Fig. 5 (a-b) show a significant presence of a sparry calcite cement (sparite) within the matrix of the studied samples in the boreholes. It also revealed the presence of a considerable number of fossils such as bivalves, ostracods and gastropods. It also shows small inclusions of quartz within its matrix.

(i) Oolitic-pemicrite wackestone: The photomicrography in Fig. (5 c-d), show the carbonate rock are characterized by ooids, peloids and micrites. The carbonate grain is produced by mainly inorganic processes and sometimes organic. The carbonate grain is as result of erosion as well as reworking of pre-existing carbonate sediments.

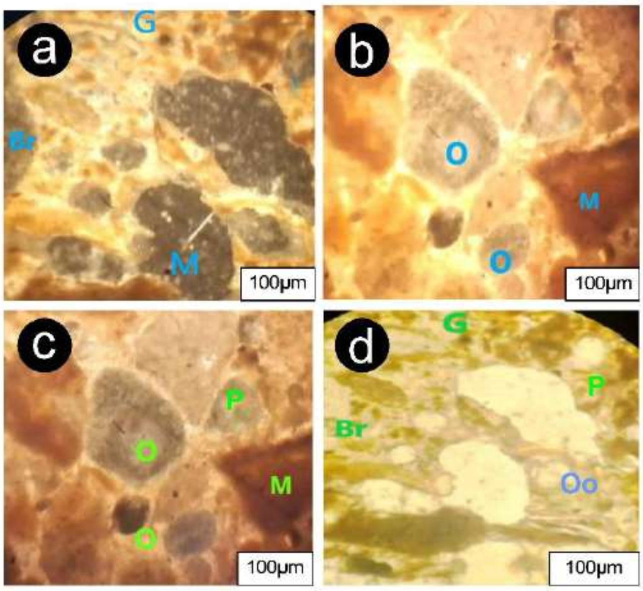

Fig. 5 a - d: Petrographic data depicting carbonate microfacies types. O - ostracod, B - Bivalve, G - gastropod, Oo -Ooids, P - peloid, M - Micrite

Micropaleontological results

The dominant ostracods recovered in both boreholes are *Bardia ilaroensis, Trachyleberis teiskotensis, Paracosta cf warensis, Nucleolina tatteeulensis* and *Xestoleberis tunisiensis,* respectively (Figs. 6 and 7). The predominant benthic and planktonic foraminifera species recovered in both boreholes are *Rosalina cf ystodiensis, amomalinoides umbonifera, haplophragmoides* sp., *Rotalla trochidiformis, Gavelina* sp., *Elphidiella Africana* and *Operculinoides bermudezi* species (Figs. 6 and 7), respectively.

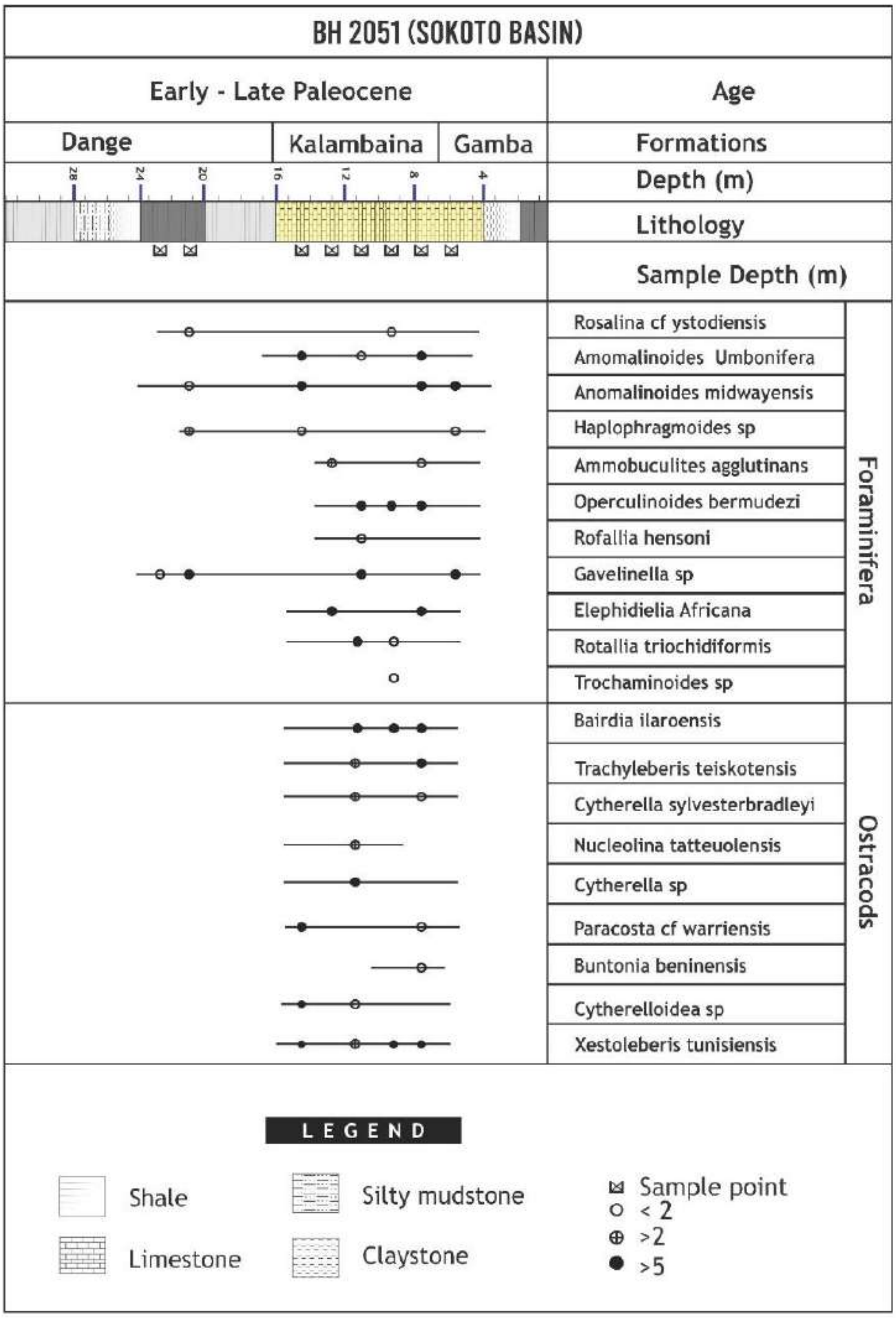

Fig. 6: Microfossil types and formations penetrated by borehole 2051

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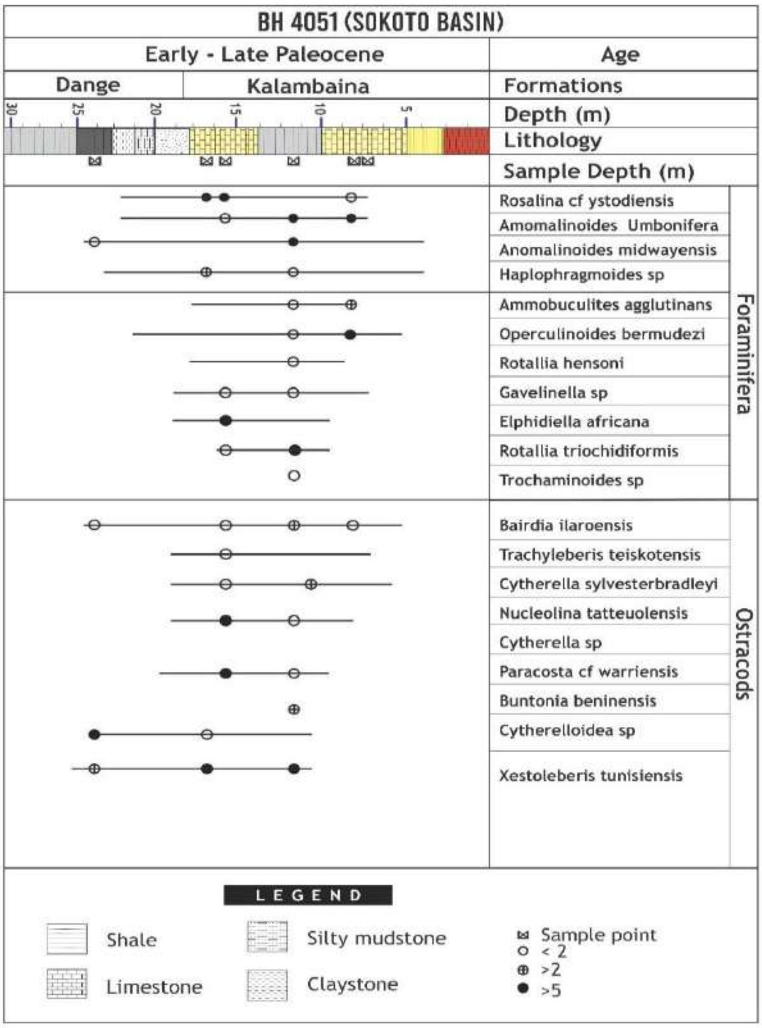

Fig. 7: Microfossil types and formations penetrated by borehole 4051

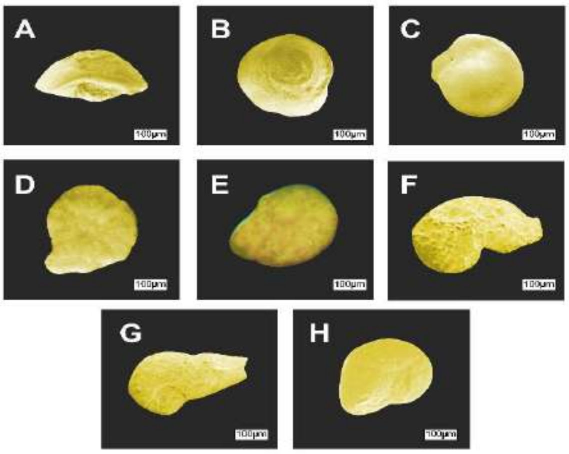

Fig.8: Recovered foraminifera with some of their photomicrography in the studied basin.
a. *Rotalia trochidiformis*, b. *Rotallia hensoni*, c. *Gravelinella* sp., d. *Haplophragmoides* sp., e. *Anomalinoides umbonifera*, f. *Ammobaculite agglutinans*, g. *Operculinoides bermudezi*, h. *Rosalina cf. ystodiensis*

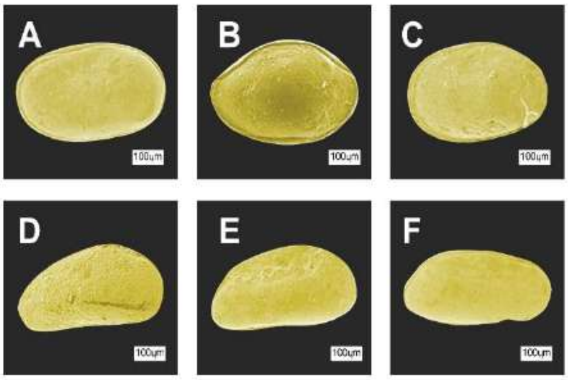

Fig. 9: Recovered ostracods with some of their photomicrography in the studied basin.

a. *Cytherella* sp., b. *Bairdia ilaroensis*, c. *Nucleolina tatteuolensis*, d. *Xestoleberis tunisiensis*, e. *Cytherelloidea* sp., f. *Cytherella slyvesterbradley*

Discussions

Stratigraphy

The Dange and Kalambaina Formations penetrated boreholes (BH – 2051 and BH – 4051), respectively. The Gamba Shale and Claystone facies penetrated BH – 2051 and BH – 4051, respectively (Figs. 6 and 7). The Dange Formation has a thickness of about 11.5m and 16 m in BH – 4051 and BH – 2051, respectively. The Gamba Shale is less than 3 m in BH – 2051 (Fig.3). The Kalambaina Formation are dominantly limestone with thin lenses of gypsums and phosphatic nodule disseminations. The Kalambaina Formation composed of light-milky to whitish limestone, with thin bands of calcareous shale (Figs. 6 and 7). The limestone thicknesses for both boreholes (BH – 4051 and 2051) ranges between 10 – 12 m, respectively. In addition, the limestone is recrystallized in some sections. This corroborate published work of (Nwajide, 2022). The Dange Formation which is the lower portion (Figs. 6 and 7) consists of intercalated beds of muddy siltstone, black to dark grey shale with a thin marl bed in both boreholes. The black to dark grey carbonaceous shale contains some traces of diagenetic pyrite grains. The Gamba Formation at the top caps both formations in the two boreholes, respectively (Nwajide, 2022).

Biostratigraphy

The borehole sections of the basin yielded a total of 11 foraminifera and 10 ostracods species, respectively (Figs. 6 and 7). A similar stratigraphic distribution of species patterns is witnessed in both boreholes (Figs. 6 and 7). The agglutinated test foraminifera are confined within the Dange Formation. The two most stratigraphically significant species in the Dange Formation are *haplophragmoides sp.*, and *Anomalinoides midwayensis*. Stratigraphic marker species found in the Kalambaina Formation include calcareous benthic and planktonic foraminifera, primarily *haplophragmoides sp.*, *Rotalla trochidiformis*, *Gavelinella* sp., *Rosalina cfystodiensis*, *Anomalinoides umbonifera* and *Operculinoides bermudezi* species, which are prevalent in the formation (Figs. 8 a, c, d, e, g and h). The species of *Anomalinoides umbonifera* and *Operculinoides bermudezi* belongs to the "Tethyan carbonate fauna of Berggren and Van Couvering (1974). A low count of *Operculinoides bermudezi* assemblage was witnessed in Gamba Shale (Fig. 4) which mark the last marine unit in the Sokoto Group in the basin (Okosun, 1987, 1995) The ostracods stratigraphic distribution is similar to that of foraminiferas, the dissimilarity is that ostracods has been in existences before the foraminifera in both

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boreholes. The high counts of *Xestoleberis tunisiensis, Bardia ilaroensis, Trachyleberis teiskotensis, Paracosta cf warriensis and Nucleolina tatteeulensis*, respectively was witnessed in both borehole sections (Figs. 9 b, c, d). The *Xestoleberis tunisiensis* and *Trachyleberis teiskotensis* is a well-known zonal index species for the Thanetian age for both north and west African sedimentary basins. This supports published work of (Okosun, 1987 and Van Ittebeeck, 2007). The aforementioned ostracod assemblages possess similar affinities with those from Mali, Niger Republic, north African coastal basins, as well as many other west African coastal basins (Reyment, 1981 and Okosun, 1999; Youssef *et al.*, 2017), respectively.

Paleoecology and depositional environments

Based on the stratigraphic distribution of the ostracods and foraminifera witnessed in both boreholes reflect faunal diversity and abundance in the Kalambaina and Dange Formations (Figs. 6 - 7). This obvious in the upper part of the Dange Formation 17.5 – 30 m (BH – 4051), and 16 to 32 m (BH – 2051) and 5 – 17.5 m (BH – 4051) and 4 to 16 m (BH – 2051) of the Kalambaina Formation, respectively. It is inferred that the Dange Shale was deposited in an environment with varying salinities, such as lagoons and estuaries with limited circulation within these depths in the two boreholes. The dark-grey to black shales within boreholes sections (Figs. 3, 4, 6 and 7) indicates that dysaerobic conditions existed throughout the Kalambaina Formation's deposition. The Kalambaina and Dange Formations were fully deposited under marine conditions. The observed high productivity that resulted in the abundance of the ostracods and foraminifera assemblages in the boreholes as well as the absence of agglutinating foraminifera in the formations further supports this deduction. The Kalambaina contains mainly calcareous fauna with reduced or no agglutinating fauna. The shallow depth of deposition is indicated by the predominance of the bigger foraminifera *Operculiniodes bermudezi* (Palmer) in the Kalambaina Formation (Okosun, 1999 and Nwajide, 2022).

In addition, the Dange Formation and Gamba Shale which both consist of shale lithofacies display moderate count of agglutinating foraminifera. We can deduce that the Sokoto Basin's Paleocene carbonate facies were deposited during times of normal marine salinity and paleo depth comparable to inner neritic. The Dange Formation and Gamba Shale were deposited at shallower depths and during times of varying salinities.

The Dange Formation constitutes the primary habitat of *haplophragmoides sp.*, and *Anomalinoides midwayensis* foraminiferas, which indicates a transitional to marginal marine paleoenvironment of deposition. Based on assemblages of ostracods such as *Bairdía ilaroensis* (Fig. 9 b), *Nucleolina tatteulensis* (Fig. 9 c), and *Xestoleberis tunisiensis* (Fig. 9 d), the Kalambaina Formation and the Gamba Shale's depositional environment is depicted as an inner-outer shelf environment. This corroborates the works of (Okosun, 1999; Morsi and Speijer, 2003; Morsi and Scheibner, 2009 and Youssef *et al.*, 2017). The dysaerobic environment that resulted from restricted circulation during the Dange Formation's deposition at the early stage of the transgression is suggested by the black shale and the diagenetic pyrite crystals that are associated with it. As the Kalambiana Formation is deposited, a freer circulation pattern took effect. Another indication of varying salinities and an arid climate is the intercalation of the gypsiferous layer in the shale facies.

CONCLUSIONS

The Paleocene and Maastrichtian marine sediments constitutes the major units in the southeastern parts of the Sokoto Basin, Nigeria. Detailed analysis of Cretaceous-Paleogene carbonate rock samples from the boreholes in the Sokoto Basin has provided a detailed understanding of the textural, geological and microfossil abundances including the interpretation of the paleoecology and paleo-depositional environment of the limestone facies of the Rima and Sokoto Group in the basin. The study involves the integration of sedimentological, micro-paleontological and petrography methods. The sedimentological and petrographic data showed that the lithology from the litho-log showed that the studied stratigraphic unit comprises mainly fine to medium-grained limestone facies, sparitic intraclastic packstone and oolitic-pelmicrite wackestone facies. The distribution pattern and assemblages of the larger foraminifera (*Opercullnoides bermudezi*) and ostracod (*Bairdia iIaroensis*) in the boreholes further suggested shallow marine depositional environments for the Dange and Kalambaina Formations. The Dange Formation was deposited in environments with fluctuating salinities such as lagoons and estuaries with occasional dysaerobic conditions particularly at the early stages of the basin formation. The presence of reduced circulation during the deposition of the formation also contributed to the dominant occurrence of agglutinated foraminifera in the lower portion of the basin (Figs. 6 - 7). Based on the micropaleontological and sedimentological result, they reflect inner to middle neritic environments of deposition in the basin. This support that shallow marine environments of deposition prevailed during the late Paleocene in the Sokoto Basin. Finally, the microfacies data from petrography and micropaleontological data reflect micro-fossils abundance and diversity associated with the onset of shallow marine transgression which resulted in the deposition of the Dange and Kalambaina Formations, respectively in the Sokoto Basin. Future studies of the carbonate rocks in the Sokoto Basin should utilize geochemical and palynofacies techniques to complement the research already done to improve hydrocarbon exploration in the basin.

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