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Foraminifera and Sequence Stratigraphy Study of the Early Maastrichtian to Paleocene Sediments of Kalambaina Formation, Sokoto Basin, Borth western Nigeria

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Abstract: *Fieldwork was conducted at the Kalambaina Limestone Quarry in Wammako, Sokoto State, to collect samples for a detailed foraminiferal study. The aim was to determine the relative age, paleo-environment of deposition, and the impact of sea level changes on the sediments. A total of eleven samples were collected and analyzed using methods including disaggregation, digestion, washing, and microscopic examination. The results revealed a stratigraphic interval rich in benthic foraminifera, both calcareous and agglutinated, but devoid of planktonic forms. Specifically, the recovered calcareous benthic foraminifera included Rosalina koeneni (12.5% relative abundance), Pararotalia tuberculifera (8.7%), Gavelinella lellingensis (6.3%), Pararotalia perclara (5.2%), Elphidiella africana (4.9%), and Planulina nacatochensis (7.8%). The agglutinated forms identified were Haplophragmoides hausa (9.1%), Trochamina wickedeni (7.4%), Haplophragmoides sp. (6.6%), Miliammina telemaquensis (5.5%), and Haplophragmoides talokaensis (4.2%). Associated fossils included moderate quantities of ostracods and a few echinoderm spines. The foraminiferal assemblage aligns with previous studies that date the sediments from Maastrichtian (Upper Cretaceous) to Paleocene. The paleo-environment ranged from a hypersaline epeiric sea to a lagoonal deposit, suggesting significant sea level fluctuations. This study reaffirms the Maastrichtian to Paleocene age of the Kalambaina Formation, contradicting earlier Paleocene-only attributions and challenging the validity of the "Sokoto Group" nomenclature.*

Key Words: *Calcareous benthic, Agglutinated benthic, Early Maastrichtian to Paleocene, Marginal marine, Lagoonal deposit*

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1.0 Introduction

The Kalambaina Formation, a key unit in the Sokoto Basin of northwestern Nigeria, is situated between the Dange Formation and the Gamba Formation. Despite its significance, the geological age and depositional environment of the Kalambaina Formation remain subjects of debate. Historically, the formation has been attributed a Paleocene age, partly due to its association with the Sokoto Group, which was believed to have been deposited during the Paleocene. However, recent studies, including those by Ola-Buraimo and Mohammed (2024), suggest that the Kalambaina Formation spans from the Early Maastrichtian to the Paleocene. These studies propose that the term "Sokoto Group" may be invalid due to the non-contemporaneous deposition of its constituent formations, challenging previous stratigraphic interpretations.

The existing literature, including works by Petters (1978) and Kogbe (1976), describes the Kalambaina Formation as comprising fossiliferous limestone and shales, with

varied interpretations regarding its depositional environment and age. While the formation has been reported to include a diverse range of invertebrate fossils, including echinoids and gastropods, the foraminiferal content has not been comprehensively analyzed to clarify the age and paleoenvironmental conditions.

This study aims to address these gaps by employing foraminiferal analysis to re-evaluate the stratigraphy and depositional history of the Kalambaina Formation. By analyzing foraminiferal assemblages and their distribution across different lithofacies, this research seeks to provide a more precise age determination and a detailed understanding of the paleoenvironment and sea level changes that influenced the formation.

The study area is Kalambaina Village, located in Wammako Local Government Area, Sokoto State, north-western Nigeria. It lies between 13º 3' 4''N and 5º 9' 21''E with an elevation of 260 m (Fig. 1).

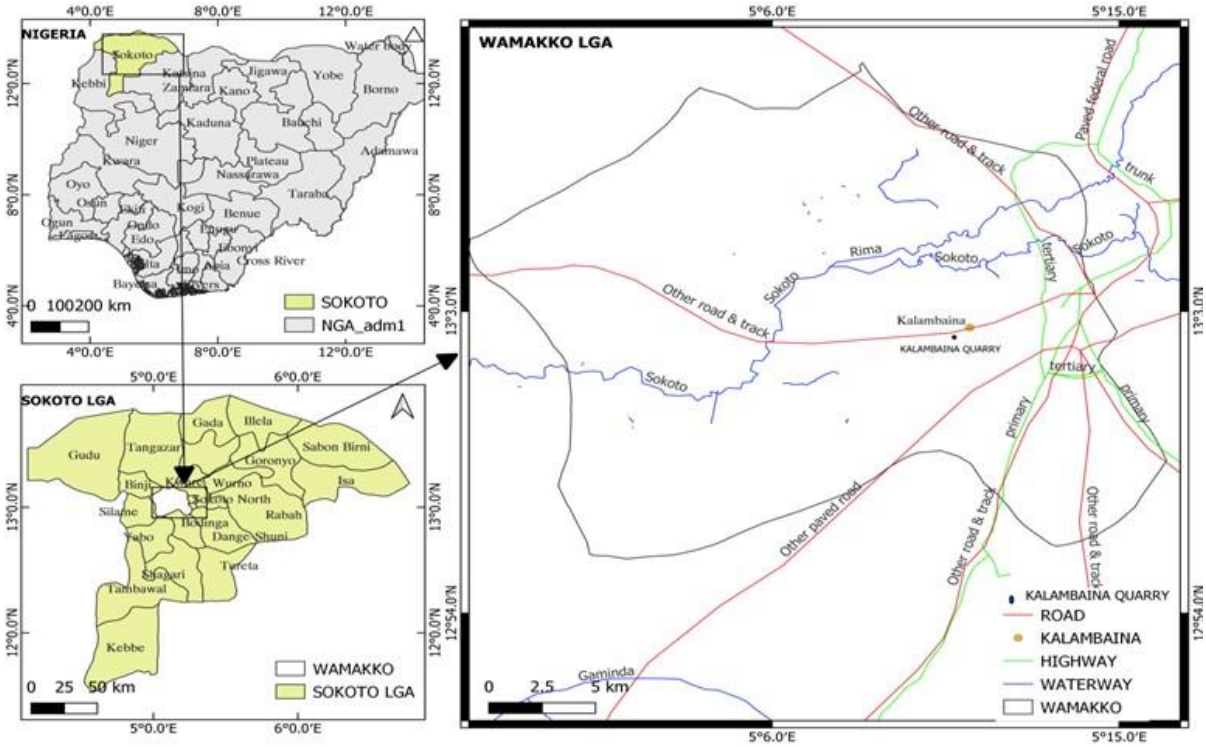


Fig. 1: Map of the Study Area (Kalambaina Quarry)

2.0 Materials and Methods

Eleven samples were collected from the Kalambaina Quarry section. The collected samples were taken from the bottom of the mine section, from different lithofacies at irregular spacing to the top of the Kalambaina Formation. Then, the samples were properly labelled and kept in sample bags. In the laboratory, the samples were arranged in order of depth and were described lithologically.

A measured quantity of about 20 g was taken from each of the eight samples, crushed in a mortar and poured in an aluminium dish. The samples were soaked in liquid soap for 24 hours for a complete disaggregation of the particles. The disaggregated samples were washed with detergent under gently running tap water in a 63 µm sieve till the water coming under the sieve was clean and devoid of clay particles.

The retained particles were poured back into a clean aluminium dish and allowed to dry up in an oven at 80 ^{O}C. Afterwards, the dish was allowed to cool before transferring the particles into a polythene envelop, sealed and labelled appropriately. The foraminiferal, ostracods, shell fragments and any available spines were then picked under the stereo-binocular microscope

The picked microfossils were placed in micro-paleontological slide cavity, covered with cover slip. The foraminiferal and other forms recovered were sorted and mounted with the use of gum. This was followed by the identification of various foraminifera taxa under the zoom microscope by comparing the forms with well-established and identical forms in photomicrographs of previous work of Petters (1982) in order to establish the names of the foraminifera obtained from the samples.

3.0 Result and Interpretation

3.1 *Field and Lithological Description*

Detail observations from the lithological description of the investigated field indicated the location, Kalambaina BUA Cement Quarry (North of the Quarry site) has the following coordinates, namely, 13º 3' 4'' N and 5º 9' 21'' E with elevation of approximately 260 m

3.2 *Litho-description*

The basal bed at the mine is composed of sparsely fossiliferous, whitish coloured limestone. The limestone facie is fairly thick (5 m) and hard. The overlying bed is light grey fissile shale. The light grey fissile shale is overlain by poorly fossiliferous limestone having megafossils. The shale is intercalated in between the upper and lower limestone beds. The shale is overlain by marlstone, characterized by clastic impurities such as quartz and clay. The presence of the classic material influx into the limestone during its formation reduces the amount of calcium carbonate to silicate ratio of the limestone composition, thus, described to be of low grade limestone compared with the whitish basal limestone by the miners.

The middle section of the outcrop is marked by an unconformity where the non-fossiliferous limestone is unconformably overlain by sandstone. The medium grain sandstone is overlain by marlstone. However, the base of the sandstone marks the top of the Paleocene sediment deposit and commencement of Eocene deposits that constitute the Gamba Formation (Ola-Buraimo and Mohammed, 2024). The marine sandstone is successively overlain by marlstone bed, micaceous shale, and at the top by an unconformable conglomeratic ironstone (Fig. 2). The sandstone, marlstone and micaceous shale were deposited.in a shallow marine setting, while the topmost conglomeratic ironstone is possibly of continental origin (Ola-Buraimo and Mohammed, 2024).

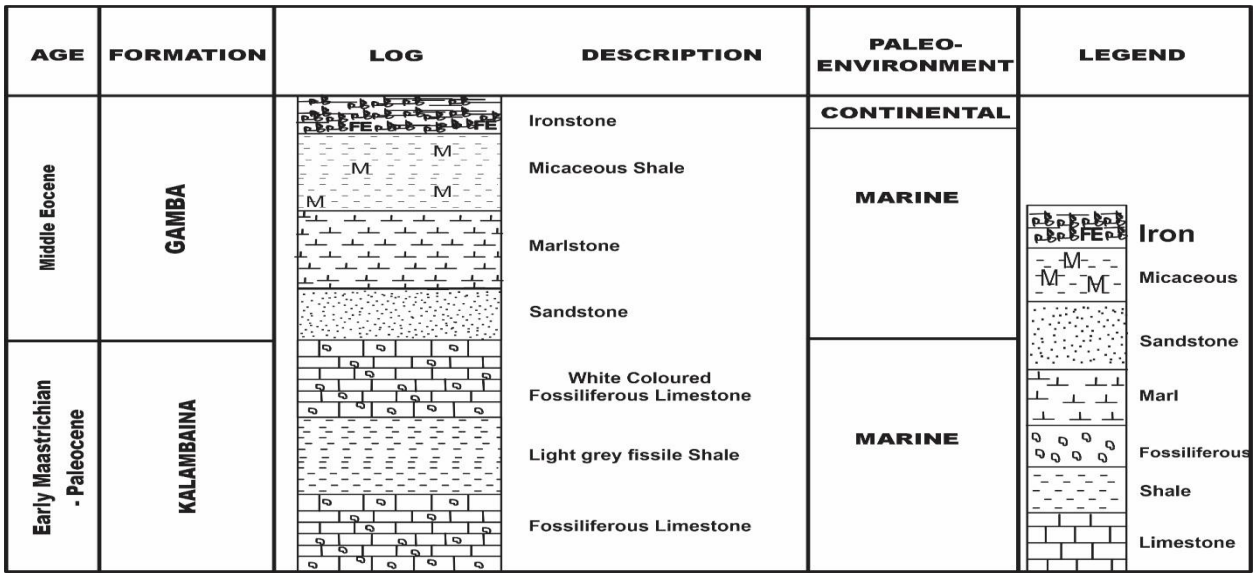


Fig. 2. Lithological description of the Study Area (Kalambaina Quarry site; Not to scale)

Few fossils such as echinoderms and gastropods were seen and recovered from the fossiliferous limestone beds in the quarry, their photographs are presented in Figs. 3 and 4

Fig. 3. Echinoderm

Fig. 4. Gastropod

3.3 Foraminifera

Eleven samples were analysed in all which included samples from the overlying formation. However, only the results of six samples for foraminiferal content of Kalambaina Formation only are contained in Fig. 5. Two samples were analysed for each bed of the Kalambaina Formation but only one of the samples was utilised. The Fig. 5 shows the distribution of the different forms recovered, their abundance and diversity against the different lithofacies present in the Kalambaina Formation. The results of the overlying formation and those of the Kalambaina Formation were utilized in establishing the systems tract, boundaries, and flooding surfaces in relative occurrence to one another. The sample code BQ2B1 represents samples collected from the basal fossiliferous limestone, the BQ2M1 represents samples obtained from the intercalated light grey fissile shale, and the code BQ2M2 represents samples recovered from white coloured fossiliferous limestone which marks the top of the Kalambaina Formation (Fig. 2).

SAMPLE NUMBER.	LITHOFACIES	FORMATION	ROSALINA KOENENI	PLANULINA NACATOCHENSIS	MILIAMMINA TELEMAQUENSIS	GAVELINELLA LELLIGENSIS	HAPLOPHRAGMOIDES HAUSA	TROCHAMMINA WICKENDENI	HAPLOPHRAGMOIDES SP.	PARAROTALIA TUBERCULIFERA	PARAROTALIA PERCLARA	TEXTULARIA PANAMENSIS	HAPLOPHRAGMOIDES TALOKAENSIS	ELPHIDIELLA AFRICANA	OSTRACOD	ECHINOID SPINE	GASTROPOD	TOTAL FOSSIL RECOVERY	TOTAL FOSSIL DIVERSITY	FORAMINIFERAL ABUNDANCE	FORAMINIFERAL DIVERSITY	CHARACTERISTICS	AGE	PALEOENVIRONMENT
BQ2M2	FOSSILIFEROUS LIME-STONE	KALAMBAINA FORMATION	30	4	1	1									5	6		47	6	36	4	The interval is characterized by high occurrence of *Rosalina koeneni* and *Planulina nacatochensis* , *Pararotalia turberculifera* in association with rare occurrence of *Gavelinella lellingensis*, *Miliammina telemaquensis* , *Pararotalia perclara* and *Elphidiella africana*..	MAASTRICHTIAN-PALEOCENE	SHALLOW MARINE
BQ2M1	LIGHT GREY SHALE						1	2	1						1		1	6	5	4	3			LAGOONAL
BQ2B1	BASAL FOSSILIFEROUS LIME-		30	3						4	1	1	1	1	4	2		47	9	41	7			SHALLOW MARINE

Fig. 5. Foraminifera distribution chart of Kalambaina Formation

3.4 *Foraminiferal Zonation*

Foraminifera investigation was carried out on Kalambaina Formation in order to determine the geologic age, the paleo-environment of deposition and the eustatic changes in sea level through the application of sequence stratigraphy. The age determination of the Kalambaina Formation was based on the comparison of the foraminifera assemblages with the work of Petters (1982). The work of Petters (1982) did not recover high abundance of benthic and planktonic a much

as was done here, but it contained some similar foraminiferal assemblages which gave a fair stratigraphic age. The biostratigraphic description of the intervals BQ2B1, BQ2M1, and BQ2M2 would be described one after the other and their sequence stratigraphy shall be considered.

Zonation

The sample interval is BQ2M2 dated Maastrichtian-Paleocene ; lithofacies of the bed is fossiliferous shale of the Kalambaina Formation**.**

3.5 Interval characteristics

This interval marks the top of Kalambaina Formation and it is dominated by calcareous benthic species such as the high occurrence of *Rosalina koeneni* and *Planulina nacatochensis* in very high abundance. The other associated forms recovered are characterized by moderately high abundance of Ostracod and the Echinoid spines. However, forams with rare occurrence are *Gavelinella lellingensis* which is a calcareous benthic foram and an agglutinated foram of *Miliammina telemaquensis* (Fig. 3; Plt. 1).

The foraminiferal assemblage in this interval is similar to those of Petters (1982) recovered from the same Kalambaina Formation, dated Maastrichtian to Paleocene. In this interval, the paleo-environment of deposition is marginal marine of a hypersaline epeiric sea based on the relative abundant recovery of calcareous benthic foraminiferal such as *Rosalina koeneni, Protoeliphidium sublaeve, Planulina spp., Cibicides praecursorius,* and *Nonionella danvillensis* (Petters, 1982). Both the age deduced and paleoenvironment of deposition established in this study are in tandem with the work of Petters (1982). It brings to the fore the idea that the Kalambaina Formation belongs to Sokoto Group which supposedly came up during the third evolution in Paleocene time.

This study is at variance with the Paleocene age ascribed to Kalambaina Formation, and it is also disagreeing with the four evolutionary stages put up for the Sokoto Basin (Kogbe, 1989). The work of Ola-Buraimo and Mohammed (2024) further corroborates this assertion that the evolution of Sokoto Basin was in multifaceted phases and Kalambaina

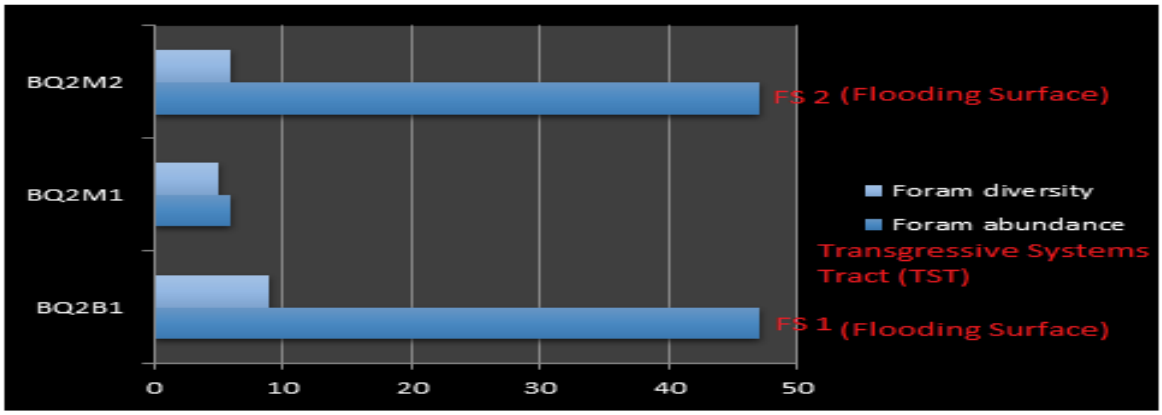


Fig. 6. Histogram abundant and diversity plot of foraminiferal in Klambaina Formation

Formation and other formations such as the underlying Dange and the overlying Gamba Formations do not belong to the Sokoto Group. The basis for this disparity is based on the non-contemporaneous deposition of the formations (Dange, Kalambaina and Gamba) in Paleocene time. Foraminifera abundance at this level is relatively high, which corresponds to a flooding surface (FS). It represents second cycle flooding surface within the Kalambaina Formation. This interval forms part of the transgressive systems tract (TST) of which the Kalambaina Formation belongs (Figs. 5 and 6; Tab. 1).

The sample interval is BQ2M1, dated Maastrichtian-Paleocene; lithofacies of the bed light grey shale of the Kalambaina Formation.

3.6 Interval Characteristics

This interval shows paucity in the population of the foraminiferal recovery. The interval is composed mainly of calcareous agglutinated foraminiferal such as *Haplophragmoides hausa, Trochammina wickedeni* and *Haplophragmoides* sp. (Fig. 5; Plt. 1). Other forms recovered are rare quantitative occurrence of ostracod and gastropod. The interval was dated Maastrichtian to Paleocene age on the basis of it being an intercalated stratigraphic position, characterized by rare occurrence of the agglutinated forams which are similar in assemblage with work of Petters (1982) (Fig. 5). The agglutinated foraminiferal recovered in the interval are *Haplophragmoides hausa, Trochammina wickedeni* and *Haplophragmoides* sp which are indicative of deposition in lagoon environment. However, there is a noticeable shift in environment of deposition from a relatively deeper shallow marine in the lower interval to a shallower lagoonal setting in this interval. This change in environment of deposition also manifested in the coast line shift, whereby, the coastline migrated basin ward in response to the decrease in sea level. However, the interval belongs to transgressive systems tract (TST) (Fig. 5 and 6; Tab. 1).

The sample interval is BQ2B1, dated Maastrichtian-Paleocene; lithofacies of the bed is fossiliferous limestone of the Kalambaina Formation.

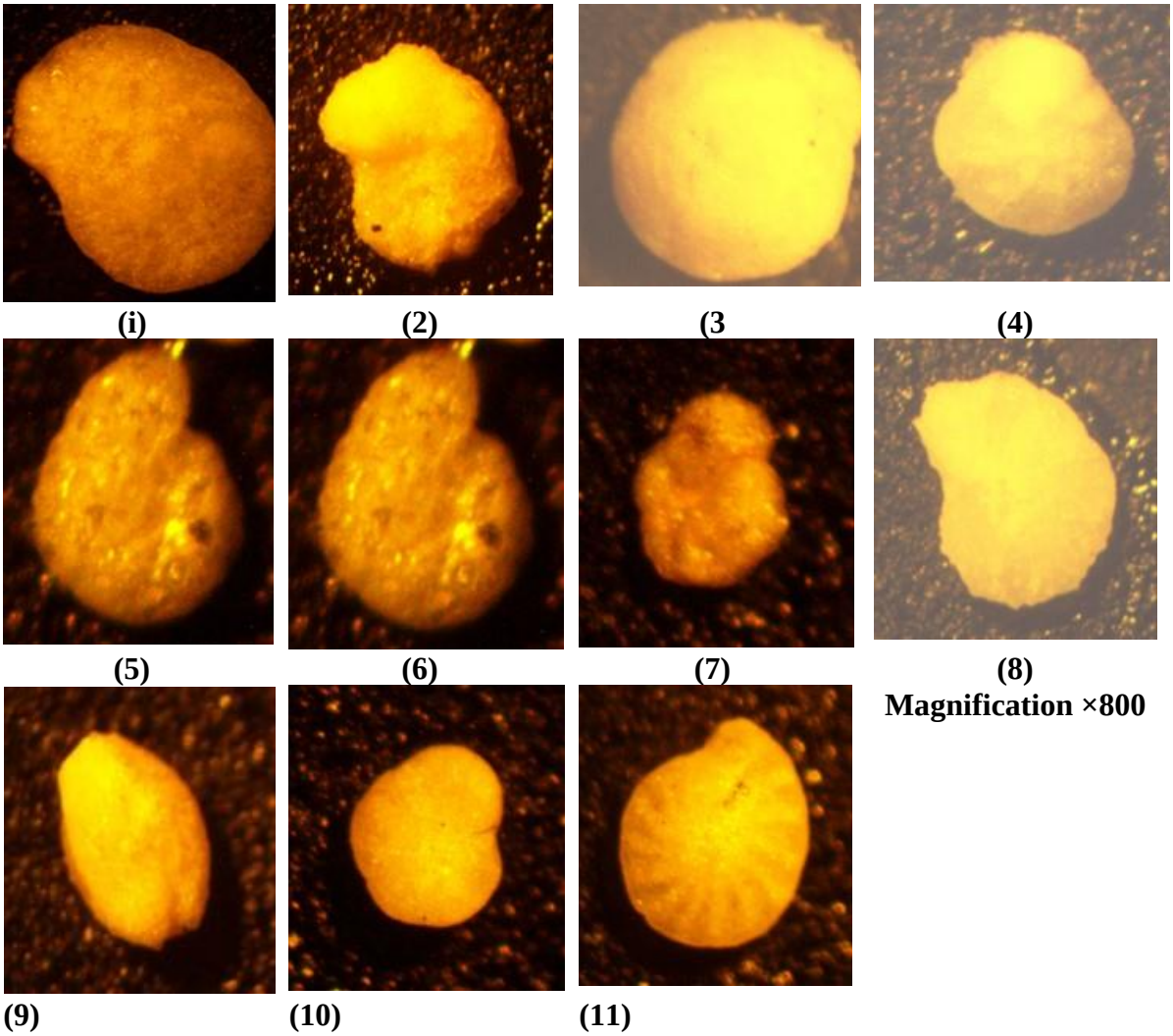
3.7 Interval characteristics

The interval marks the base of Kalambaina Formation in the quarry site. It is composed of whitish fossiliferous limestone facies. The interval is very rich in foraminiferal and the assemblage is dominated by calcareous benthic forams. The important benthic foraminifera present are *Rosalina koeneni*, which occurs in a very high population. It is followed by *Pararotalia turberculifera* and moderate occurrence of *Planulina nacatochensis*. Calcareous benthics with rare occurrence are *Pararotalia perclara* and *Elphidiella africana.* The few agglutinated species encountered are *Textularia panamensis* and *Haplophragmoides talokaensis*, which are rare elements in this interval. Other micro fossils recovered include ostracod in moderate quantity and echinoid spines in few amounts (Fig. 5; Plt. 1).

The foraminiferal assemblage in this interval is similar to those of Petters (1982) from same Kalambaina Formation, dated Maastrichtian to Paleocene. Therefore, this interval is here conveniently dated Maastrichtian to Paleocene age. The age deduction established here is in tandem to palynological age of Early Maastrichtian-Paleocene given in the work of Ola-Buraimo and Mohammed (2024) in the investigation carried out on the same Kalambaina Formation, at the Kalambaina Quarry, Sokoto State, Nigeria. The environment of deposition is indicated to be a hypersaline marine water of a restricted marine environment based on the preponderance of the calcareous benthonic foraminiferal such as *Rosalina koeneni, Pararotalia turberculifera,* and *Planulina nacatochensis*. The age deduced for the Kalambaina Formation corroborates the assertion that the term Sokoto Group is invalid and contravenes the International Stratigraphic Nomenclature based on non-similar depositional ages of the Dange, Kalambaina, and Gamba Formation. The Gamba Formation was dated Middle Eocene and Kalambaina Formation was dated Early Maastrichtian to Paleocene (Ola-Buraimo and Mohammed, 2024) and here, in this study Kalambaina Formation was also dated to be Maastrichtian to Paleocene age.

Table 1. Sequence stratigraphy of Kalambaina Formation, Sokoto Basin

Interval	Lithofacies	Formation	Flooding surface	Bio event	System tracts
BQ2M2	Fossiliferous Limestone	Kalambaina	2nd Cycle Flooding Surface (FS)	*Rosalina koeneni*	Transgressive system tracts (TST)
BQ2M1	Light grey shale				
BQ2B1	Fossiliferous Limestone		1ST Cycle Flooding Surface (FS)	*Rosalina koeneni*	



(i) **(2)** **(3** **(4)**

(5) **(6)** **(7)** **(8)**

Magnification ×800

(9) **(10)** **(11)**

High abundance and relatively moderate diversity of foraminiferal in this interval indicate a flooding surface. The basal limestone is here described to be associated with the first flooding surface (FS) within the Kalambaina Formation. Therefore, the

interval represents a geologic time of relative increase in sea level, whereby, a marine incursion led to a substantial movement of the marine coastline in a landward direction. The onset of the eustatic rise in sea level characterized by high abundance foraminiferal recovery, represents the first cycle of sea level rise in Kalambaina Formation, referred to as first cycle flooding surface (1st Cycle FS). It also represents the first rise in sea level during a period of a transgressive systems tract. The 2nd Cycle of the flooding surface marks the top of the Kalambaina Formation, which is also characterized by high abundance of foraminiferal (Figs. 5 and 6). Therefore, the intervals BQ2B1 – BQ2M2 of the Kalambaina Formation belong to a transgressive systems tract, characterized by bio-events of *Rosalina koeneni* in the two flooding surfaces (Figs. 5 and 6; Tab. 1). The transgressive systems tract (TST) established for Kalambaina Formation on the basis of foraminiferal fossil abundance and diversity is at variance with highstand systems tract deduced for the same formation using outcrop sequence stratigraphy study by Hamidu *et al*. (2024).

3.8 Microphotograph interpretation

The microphographs of the important foraminiferal given above are: *Rosalina kaeneni***,** *Pararotalia perclara***,** *Pararotalia turberculifera***,** *Planulina nacatochensis, Haplophragmoides talokaensis***,** *Haplophragmoides hausa***,** *Trochammina wickendeni***,** *Planulina nacatochensis***,** *Miliammina telemaquensis, Gavelinella lellingensis***,** and *Elphidiella africana*

4.0 Conclusion

The study of foraminifera and sequence stratigraphy of the Early Maastrichtian to Paleocene sediments in the Kalambaina Formation, Sokoto Basin, aimed to determine the relative age, paleo-environment of deposition, and the impact of sea level changes on these deposits. The investigation was conducted at the Kalambaina Limestone Quarry in Sokoto State, where sediment samples were collected and analyzed through a series of laboratory procedures including disaggregation, digestion, and microscopic examination of the recovered microfossils.

The results revealed a rich assemblage of benthic calcareous and agglutinated foraminifera, with no planktonic forms identified. Key calcareous benthic foraminifera included Rosalina koeneni, Pararotalia tuberculifera, and Gavelinella lellingensis, while agglutinated forms included Haplophragmoides hausa and Trochamina wickedeni. These findings indicate a variety of depositional environments ranging from hypersaline epeiric seas to lagoonal settings. The foraminiferal assemblages were comparable to those reported in previous studies, supporting the assignment of the sediments to a Maastrichtian to Paleocene age.

The paleo-environmental analysis suggested that the Kalambaina Formation's depositional environment transitioned from a marginal marine hypersaline sea to a lagoonal setting, reflecting significant changes in sea level. The foraminiferal data indicated two significant flooding surfaces, marking periods of sea level rise. These findings led to the conclusion that the Kalambaina Formation, rather than being restricted to a Paleocene age, spans from the Maastrichtian to the Paleocene. This suggests that the previously used term "Sokoto Group" is invalid due to the non-contemporaneous deposition of the Kalambaina Formation relative to other formations.

The study recommends that future stratigraphic classifications should reflect the Maastrichtian to Paleocene age of the Kalambaina Formation and consider the implications for the nomenclature of the Sokoto Basin formations. Further research is suggested to refine the sequence stratigraphy and to investigate the regional geological implications of these findings.

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Compliance with Ethical Standards Declaration

Ethical Approval

Not Applicable

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Data would be made available on request.

Authors' contributions

Both authors contributed equally to the work.