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Foraminiferal Distribution in the Tertiary Ewekoro Formation, Dahomey Basin, Southwestern Nigeria: Implications for Paleoenvironmental Interpretation and Age Assessment

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Abstract
The Ewekoro Formation, a key stratigraphic unit in Nigeria's Dahomey Basin, is renowned for its rich paleontological record, particularly its diverse foraminiferal assemblages. This study aims to investigate foraminiferal assemblages in the Ibese region of the Dahomey Basin to understand paleoenvironmental conditions, by characterizing species diversity and abundance, reconstructing paleoenvironmental parameters, establishing biostratigraphic relationships, interpreting depositional environments, and correlating paleontological data with existing geological information. This study analyzed twenty-nine core samples from PET-1 well in Ibese region, Ewekoro Formation, Dahomey Basin, Nigeria, employing standard lithologic description and foraminiferal preparation techniques, including kerosene treatment, wet and dry sieving, and microscopic examination, to investigate the formation's microfossil content and sedimentological characteristics. Among these twenty-nine (29) cores samples, only two planktonic species, Acarinina soldadoensis and Morozovella conicotruncata, were identified. The quantitative analysis yielded a total count of 933 benthic foraminifera across 10 species which include Anomalina plummerae, Anomalinoides midwayensis, Anomalinoides umbonifera, Cibicides haperi, Cibicides succedens, Eponides pseudoelevatus, Gavelinella spp., Gavelinella guineana, Florilus spp., and Pararotalia tuberculifera and other Marine Microfauna which include ostracods, gastropods, pelecypods and so on. The foraminiferal assemblages from the PET-1 well, including key species like Acarinina soldadoensis, Gavelinella guineana, and Anomalinoides species, indicate a Paleocene-Eocene age. The Anomalinoides Biozone provides a robust biostratigraphic marker for global correlation. The diverse fossil assemblage, comprising benthic and planktonic foraminifera, bryozoans, ostracods, and echinoids, suggests a shallow to middle neritic marine environment with normal salinity and good oxygenation. This assemblage indicates a warm, humid tropical to subtropical climate and a productive marine ecosystem in an offshore or coastal setting during the Paleocene-Eocene period.

Keywords: Foraminfera, Paleoenvironmental, *Palynomorph*, Paleocene-Early Eocene, Dahomey Basin

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INTRODUCTION

Foraminifera, a diverse group of marine protists, are distinguished by their complex and often ornamented shells, known as tests. These unicellular organisms are a crucial component of marine ecosystems, found in a wide range of environments from shallow coastal waters to the deepest parts of the ocean (Raghukumar, 2017). With over 50,000 species identified, foraminifera are one of the most common and widespread groups of marine organisms (Boersma, 1998). Their shells, primarily composed of calcium carbonate or agglutinated material, are particularly significant in paleontological research due to their abundance and preservation potential in the geological record (Kenneth et al., 1983). The morphology and composition of foraminiferal tests exhibit significant diversity among various species, reflecting their adaptation to a wide range of environmental conditions and ecological niches. Typically, these tests are made of organic material combined with calcium carbonate, although some species construct their tests using agglutinated particles like sand grains or shell fragments, or by secreting organic material themselves (Akande et al., 2005). The tests can range from simple, unadorned shells to intricate chambered structures adorned with a variety of ornamentations, such as ribs, ridges, spines, keels, and perforations. These features may serve various functions, including defence, structural stability, and ecological adaptation, with some species like *Elphidiidae* utilizing spines and keels to stabilize themselves in turbulent conditions and perforations to facilitate the exchange of gases and nutrients (Bandy, 1960).

Foraminifera are of immense importance in geological and paleontological studies, particularly in the field of biostratigraphy. Their small size and durable shells allow for excellent preservation, making them ideal index fossils for correlating sedimentary layers and establishing the relative ages of rock formations (Lipps, 1981). The presence or absence of specific foraminiferal species within sedimentary sequences enables precise dating of geological events and the development of detailed geological maps, which are invaluable for resource exploration, reservoir characterization, and understanding the regional geological history of a basin (Brummer et al., 1986). Beyond their biostratigraphic applications, foraminifera are also sensitive environmental indicators, capturing and preserving records of past marine conditions in their fossilized remains. By analyzing the distribution, diversity, and isotopic composition of foraminiferal assemblages in sedimentary basins, researchers can reconstruct ancient temperatures, decipher oceanographic patterns, and track changes in sea levels and continental configurations over geological time (Châtelet et al., 2004). Isotopic analyses of foraminiferal shells further provide insights into past climate dynamics, including variations in sea surface temperatures, ice volumes, and atmospheric CO_2 concentrations (Frontalini et al., 2011).

The study area lies within Ibese, a town located in Yewa North Local Government Area of Ogun State, Nigeria. This study focuses on investigating the foraminiferal assemblages in core samples from the Ibese region of the Dahomey Basin, with the aim of understanding the paleoenvironmental conditions that prevailed in this area during different geological periods. The specific objectives of this research include characterizing the diversity and abundance of foraminifera species, using foraminiferal assemblages to reconstruct paleoenvironmental parameters, establishing relative age relationships between sedimentary layers, and correlating paleontological data with existing geological and stratigraphic information. By integrating these findings, the study seeks to enhance our understanding of the geological history and paleoenvironmental evolution of the Ibese region within the Dahomey Basin using Foraminiferal assemblages.

GEOLOGIC FRAMEWORK OF THE STUDY AREA

The Dahomey Basin, a significant geological feature along West Africa's Gulf of Guinea, extends from Ghana’s Volta Delta through Togo and the Republic of Benin to southwestern Nigeria, where it is truncated by the younger Niger Delta (Oladimeji, 2016) (Fig 1). Originating in the Late Jurassic-Early Cretaceous due to the separation of the African and South American plates, the basin's formation was influenced by tectonic processes, leading to the deposition of various sedimentary layers during the Mesozoic and Cenozoic eras (Brownfield and Charpentier, 2006). The basin's stratigraphy includes formations from the Cretaceous to Tertiary periods, such as the Abeokuta Group, Ewekoro, Akinbo, and Ilaro Formations, each characterized by distinct lithological compositions ranging from sandstones and shales to limestone (Omatsola and Adegoke, 1981; Nwajide, 2013) (Fig 2).

The Abeokuta Group, the oldest and thickest sequence in the basin, is composed of the Ise, Afowo, and Araromi Formations, representing pre-drift continental sands and marine deposits (Adekeye et al., 2019). Overlying formations like Ewekoro and Akinbo are characterized by limestone and shale respectively, this reflects the basin's complex depositional history, which includes shallow marine environments and deeper marine deposits (Ogbe, 1972; Nton and Elueze, 2005).

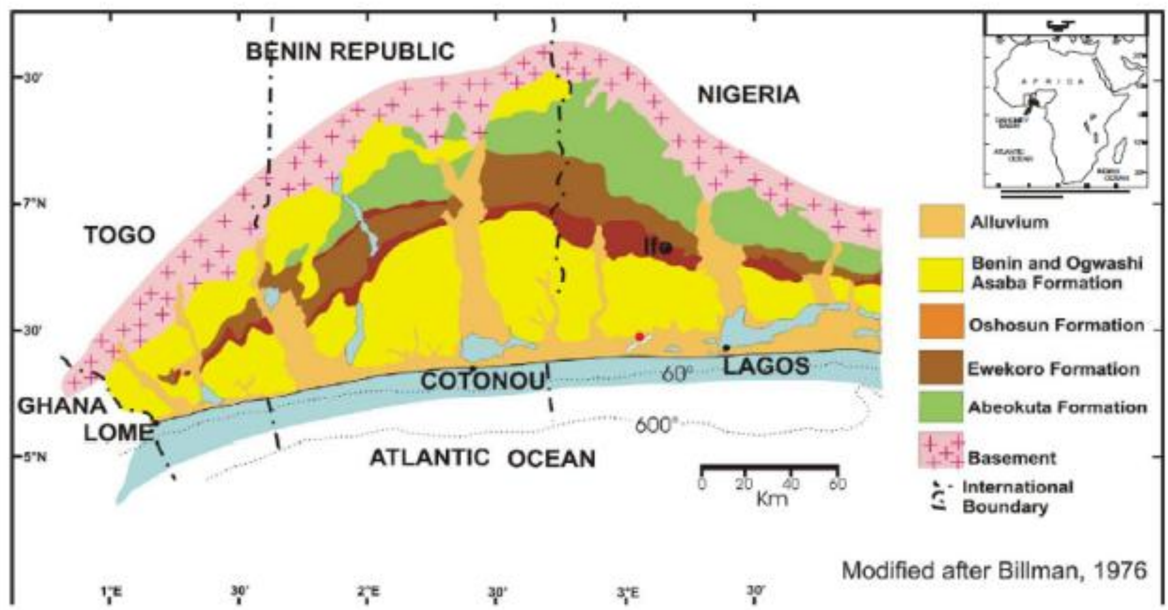

Fig.1: Regional Geology of Dahomey basin (Oladimeji, 2016).

AGE		FORMATION			LITHOLOGY
		Ako et al., 1980	Omatsola and Adegoke, 1981		
TERTIARY	EOCENE	ILARO FORMATION	ILARO FORMATION		SANDSTONE
		OSHOSUN FORMATION AKINBO FORMATION	OSHOSUN FORMATION AKINBO FORMATION		SHALE
	PALEOCENE	EWEKORO FORMATION	EWEKORO FORMATION		LIMESTONE
CRETACEOUS	MAASTRICHTIAN	ABEOKUTA FORMATION	ABEOKUTA GROUP	ARAROMI FORMATION	SHALE
	TURONIAN			AFOWO FORMATION	SANDSTONE AND SHALE
	BARREMIAN			ISE FORMATION	SANDSTONE

Fig.2 : Stratigraphy of Nigerian Eastern Sector of Dahomey Basin (after Omatsola and Adegoke, 1981)

MATERIALS AND METHODS

The study area, Ibese is located in Ogun State, Nigeria. Ibese is situated in the Yewa North Local Government Area of Ogun State (Fig 3). It is bordered by other towns and villages within the state, including Ilaro to the south and Igbogila to the north. The area is primarily rural, with significant agricultural activities, including farming and livestock rearing. Ibese is also known for its cement production industry, with the presence of Dangote Cement Factory, which is a major economic hub to the region. The landscape features typical of southwestern Nigeria, with tropical vegetation and savannah grasslands, characterize the area. In terms of geographical features, it is characterized by hills, rivers, and valleys.

Methods

The procedure of analysis is as follows:
Lithological Description: Through visual inspection, the samples were subjected to lithostratigraphic. Using published lithofacies description models by Webber and Daukoru (1975) and Whiteman (1982), physical attributes such color, texture, hardness, fissility, and rock type were noted.

The study utilized core samples from PET Well at Dangote Cement in the western Dahomey Basin, Nigeria, analyzing 29 samples at 3m intervals for foraminifera content. The methods used for the extraction of microfossils are consistent with the usual approach for preparing micropaleontological samples of (Pessagno, 1967; Zingula, 1968; Brasier, 1980). The procedure is outlined as follows:

Forams Procedure: The laboratory analysis involves three stages; sample preparation, boiling/washing and picking of microfossils. Each sample was carefully cleaned to get rid of field contaminants. 25 g of each sample was weighed out on a weighing balance, crushed into smaller sizes in porcelain mortal and kept in a labeled beaker. Hydrogen peroxide (H_2O_2), Calgon and distilled water were added to the sample in the beaker in sufficient quantity and allowed to stay for a period of 24 hrs, to enable the sample to disaggregates. After soaking for 24 hrs the sample was boiled in an aluminum pan on a hotplate for few minutes, with continuous stirring and then later allowed to cool. The sample was thoroughly washed through 63-micron sieve mesh under a gentle jet of water, to remove mud and sand particles until the muddy water is clear. The residue extract was collected in a filter paper and allowed for few minutes to dry in the sun. The dried residues were sieved into three fractions using different sieve mesh particle sizes of 125 microns, 75 microns and 63 microns. Each fraction of the sieved residues was placed in an envelope dully labeled to ease the picking of the microfossils. On picking, little portion of the residues was evenly spread on the black girded picking tray and examined under the binocular stereomicroscope. A picking brush with a moistened tip was used in picking the microfossils. Identification of microfossils was carried out to generate data for quantitative analysis of faunal abundance and diversity, which were converted to relative percentage frequency distributions, in terms of *Very abundant* (>20 %), *abundant* (15-20 %), *frequent* (10-15 %), *common* (5-10 %) and *rare* (<5 %). The majority of the foraminifera were identified by comparing them to forms that Loeblich and Tappan had previously reported in (1989), and Bolli and Saunders (1985).

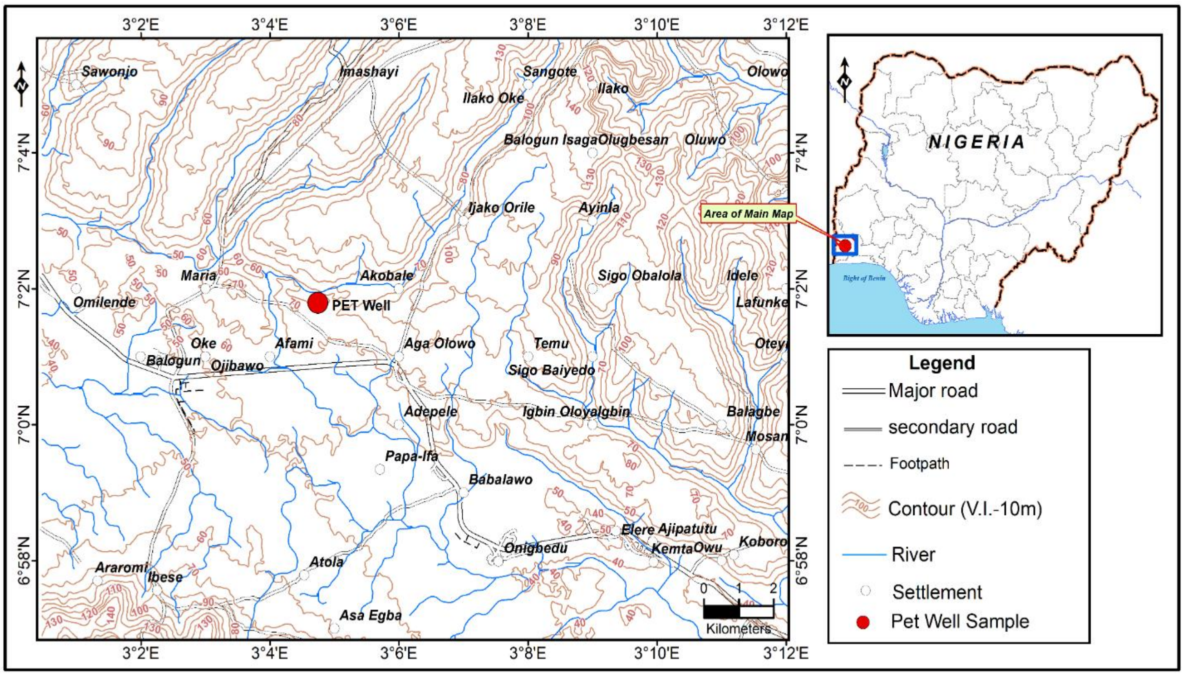

Fig.3: Location map showing the study area.

RESULTS

Lithostratigraphy

The PET well in Ibese, within the Dahomey Basin, reveals a sedimentary sequence marked by alternating clastic and carbonate deposits. It begins with claystone from 1m to 3m, followed by 5m of shale (4m-8m). A substantial 10m limestone layer (9m-18m) suggests shallow marine conditions, transitioning to 5m of marl (19m-23m). Another 4m limestone layer (24m-28m) is followed by marl beyond 29m. This pattern indicates a dynamic depositional environment influenced by changing sea levels and sediment supply (Fig.4).

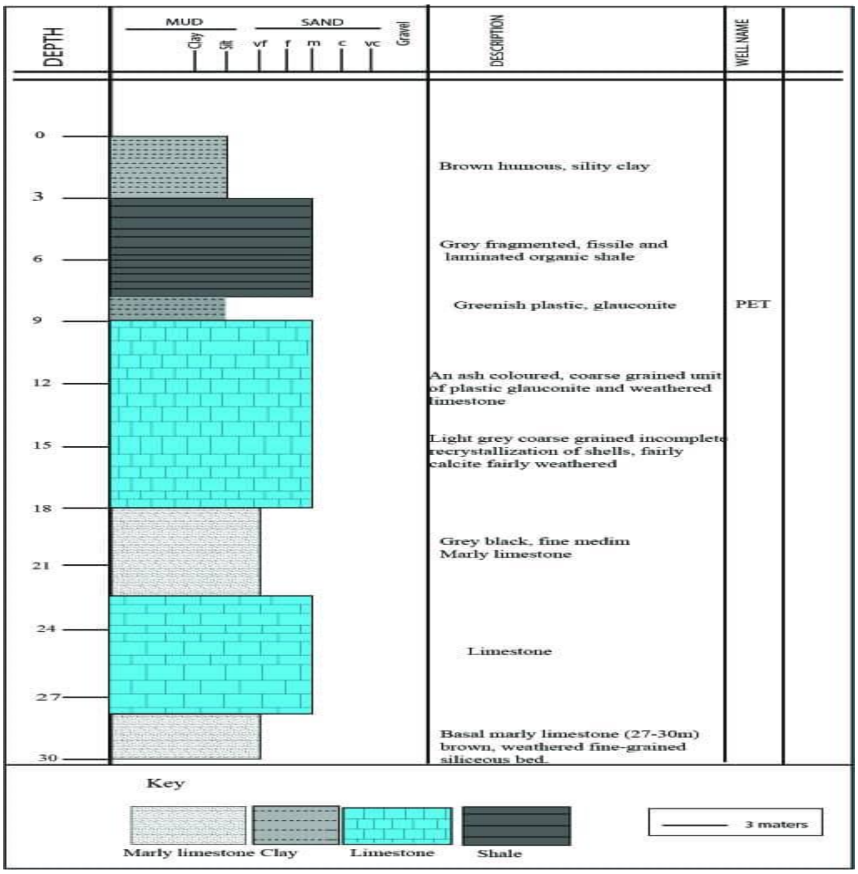

Fig.4: Litholog for PET well. Showing the Ewekoro Formation

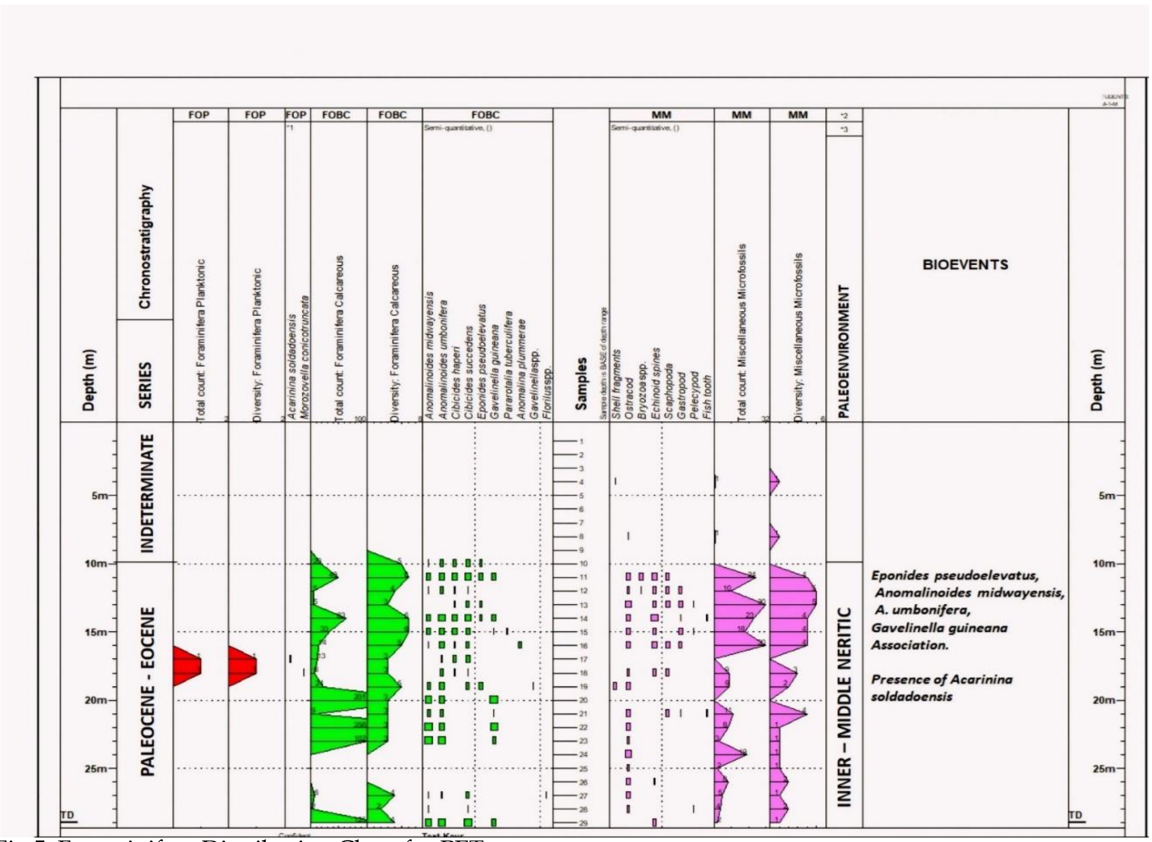

Fig.5: Foraminifera Distribution Chart for PET

Table 1: The occurrence and distribution of palynomorphs species in the studied samples

	EM -10	EM -11	EM -12	EM -13	EM -14	EM -15	EM -16	EM -17	EM -18	EM -19	EM -20	EM -21	EM -22	EM -23	EM -24	EM -25	EM -26	EM -27	EM -28	EM -29
Benthic Foraminifera																				
Anomalina plummerae							2													
Anomalinoides midwayensis	1	5	1		10	5	1			3	40	4	214	85				1	1	35
Anomalinoides umbonifera	3	6	2		15	5	6	1	4	10	6	4	13	15				1		15
Cibicides haperi	2	10	1	1	10	11	1	4	1											
Cibicides succedens	12	15	1	2	20	10	4	8	1	4								3	1	65
Eponides pseudoelevatus	2	5		2	2					6										
Gavelinella spp.										1										
Gavelinella guineana		8			6	1					155	1	29	2						10
Florilus spp.																		1		
Pararotalia tuberculifera						1														
Total	20	49	5	5	63	33	14	13	6	24	201	9	256	102	0	0	0	6	2	125
Planktonic Foraminifera																				
Acarinina soldadoensis								1												
Morozovella conicotruncata									1											
Total	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
Other Marine Microfauna																				
Ostracod .		12	3	15	6	5	13		3	7		7	8	3	19	2	7	5	3	
Bryozoa spp.		5	1																	
Shell fragments										2										
Echinoid spines		5	2	2	15	4	10		3								1			2
Scaphopoda .		2	2	7			5		3			2								
Gastropod .			2	5	1	8	2					1								
Pelecypod .				1		1													1	
Fish tooth					1							1								
Total	0	24	10	30	23	18	30	0	9	9	0	11	8	3	19	2	8	5	4	2

Table.2: Total occurrence of different Microfossil groups recovered from PET well

S/N	Microfossil Groups	Total count	Percentage count
1	Benthic Forams	933	81.1
2	Plantonkic Forams	2	0.2
3	Marine Microfauna	215	18.7
	Total	1150	100

DISCUSSION

Foraminifera Analysis

The analysis of twenty-nine samples from the PET section uncovered a moderately abundant yet low-diversity foraminiferal assemblage, dominated by calcareous benthic species (Table 1). Within the 9-29 meter interval, only two planktonic species, *Acarinina soldadoensis* and *Morozovella conicotruncata*, were identified, with no agglutinated forms detected. The quantitative analysis revealed a total of 933 benthic foraminifera across ten species, along with just two planktonic foraminifera. Notable benthic species identified include *Anomalina plummerae*, *Cibicides haperi*, and *Gavelinella guineana*, providing valuable insights into the depositional environment and paleoecological conditions of the section (Fig 5).

Additionally, the samples revealed 215 marine microfaunal specimens, including ostracods, gastropods, pelecypods, and bryozoans, contributing to the understanding of the marine ecosystem. Other findings, such as shell fragments, echinoid spines, scaphopods, and a fish tooth, further indicate a complex marine environment (Table 2). However, the upper section of the core (1-9 meters) was barren of foraminifera, contrasting with the rich assemblage in deeper intervals, suggesting significant changes in environmental conditions or sedimentation over time.

Description of Different Foraminifera in this study
Anomalinoides midwayensis and ***Anomalinoides*** **umbonifera** are medium-sized benthic foraminiferal species, typically ranging from 0.5 to 1.5 mm in diameter (Fig 6f). They have a spherical or subspherical test (shell) characterized by a thin, perforate calcareous wall, with globular chambers and a single aperture (Olsson et al., 1999; Murray, 2006). The presence of these species indicates warm and humid conditions, suggesting deposition in a tropical or subtropical marine environment (Alegret et al., 2003). Typically found in shallow shelves and coastal areas, their association with other marine fossils provides insights into ancient marine ecosystems, reflecting normal salinity and temperature conditions (Leckie et al., 2002; Alegret & Thomas, 2004).

Cibicides haperi and ***Cibicides succedens*** also display medium-sized, spherical or subspherical tests with rounded peripheries. Their walls are thin, perforate, and have globular chambers with a single aperture (Fig 6c & d) (Murray, 2006; Olsson et al., 1999). These species suggest a warm, temperate climate and are associated with diverse marine life, including both planktonic and benthic organisms (Alegret et al., 2003). Their occurrence in Miocene to Pliocene sediments hints at periods of marine stability and the persistence of warm water masses, providing valuable information about the paleoceanographic and paleoclimatic conditions of that time (Alegret & Thomas, 2004; Koutsoukos & Hart, 1990).

Eponides pseudoelevatus is a small benthic foraminiferal species with a spherical or subspherical test, a rounded periphery, and a thin, perforate calcareous wall (Fig 6b) (Murray, 2006; Olsson et al., 1999). This species indicates a warm, temperate climate, suggesting deposition in a subtropical environment. Its presence in sediments from higher latitudes may indicate a warmer paleoclimate than present-day conditions (Alegret et al., 2003; Leckie et al., 2002). Typically found in shallow marine environments like shelves and coastal areas, this species, along with others, points to a marine setting with stable salinity and temperature conditions (Alegret & Thomas, 2004; Hart & Koutsoukos, 2015).

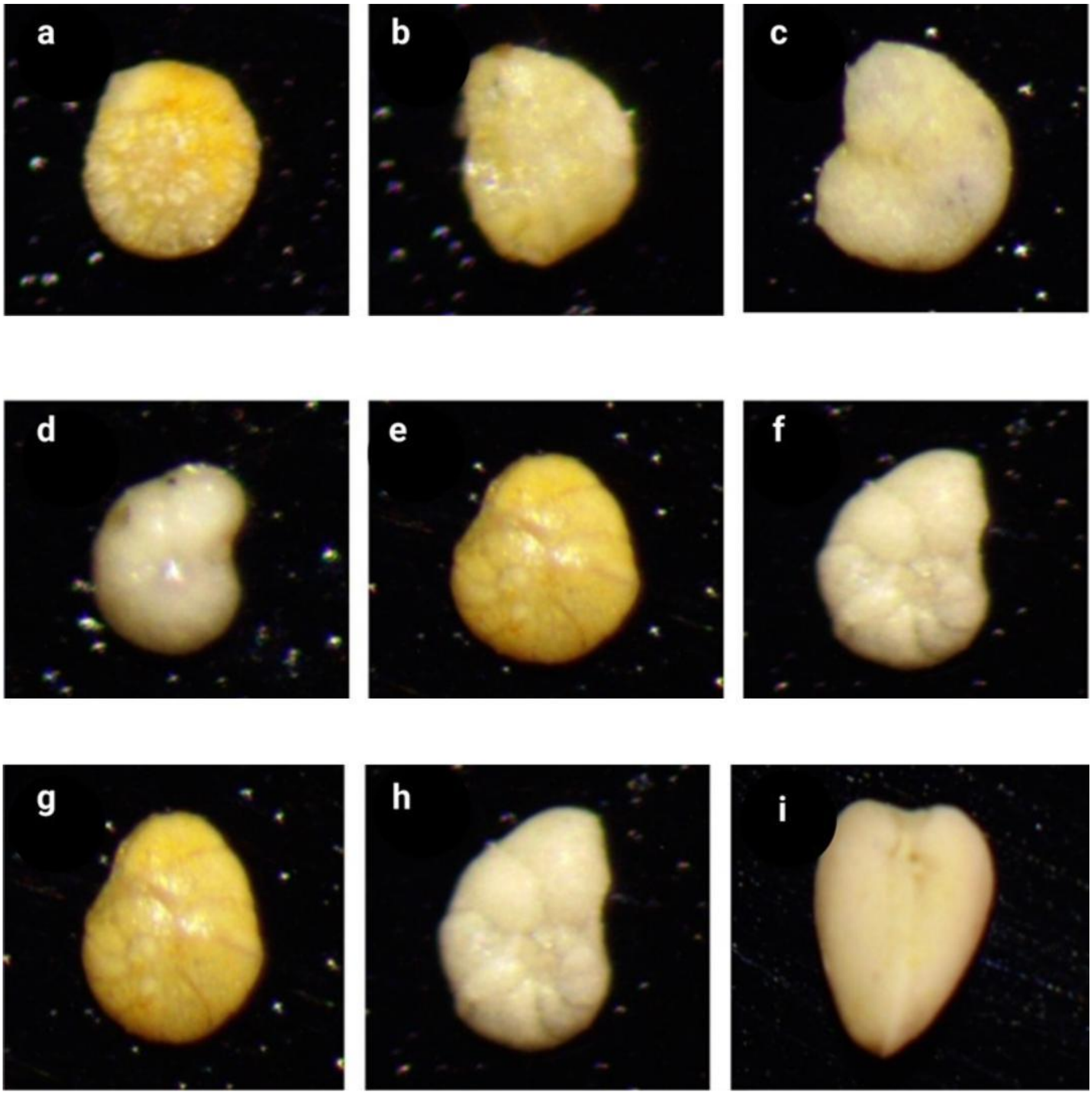

Fig.6: Photomicrographs of some Foraminifera species recovered from the studied samples. (a) *Gavelinella guineana; (b) Eponides pseudoelevatus; (c) Cibicides haperi; (d) Cibicides succedens; (e) Anomalinoides umbonifera; (f) Anomalinoides midwayensis; (g) Planorotalites sp.; (h) Acarinina soldadoensis; (i) Pelecypod.*

Gavelinella guineana is distinguished by its trochospiral test, which is asymmetrical and rounded, featuring four to five inflated chambers in the final whorl and a large proloculus (initial chamber) (Fig 6a). The test surface is smooth with depressed sutures, and the diameter typically ranges from 0.3 to 0.6 millimeters. The presence of *Gavelinella guineana* in Jurassic and Cretaceous rocks, particularly from the Late Cretaceous, suggests a warm, shallow marine environment with normal salinity and temperature conditions.

Pararotalia tuberculifera has a trochospiral test with a rounded periphery and a small umbilicus. The test diameter typically ranges from 0.5 to 1.5 millimeters, with a smooth wall surface adorned with small tubercles (Murray, 2006; Hart & Koutsoukos, 2015). This species indicates a warm, temperate climate, suggesting deposition in a subtropical environment. Its association with marine settings like shallow shelves and coastal areas reflects normal marine salinity and temperature conditions, indicative of a calm environment with minimal terrigenous input.

Anomalina plummerae features a trochospiral test with a rounded periphery and a small umbilicus, with a diameter typically ranging from 0.5 to 1.5 millimeters (Fig 6e). The test surface is smooth, often with small tubercles (Murray, 2006; Olsson et al., 1999). The presence of this species suggests a warm, temperate climate, likely in a subtropical marine setting with normal salinity and temperature conditions.

Acarinina soldadoensis is a planktonic foraminiferal species characterized by a trochospiral shell and a rounded periphery, with a muricate wall texture, featuring surface projections known as "muricae" (Olsson et al., 1999; Pearson et al., 2006). Typically, it has 5 to 7 chambers in the final whorl, with a small, rounded aperture (Fig 6h). This species indicates a warm, temperate climate, suggesting deposition in a subtropical marine environment, possibly during a period of marine transgression with increased oceanic productivity.

Morozovella conicotruncata is another planktonic foraminiferal species, recognized by its low to moderately high spired test shape and spinose wall texture, with surface spines (Olsson et al., 1999). The chambers are globular, and the aperture ranges from low to high arched (Pearson et al., 2006). This species indicates a warm, temperate climate, often associated with subtropical marine environments. It serves as a key species in paleoclimate research, used to reconstruct ancient ocean temperatures and circulation patterns, providing insights into Earth's climate history.

*Gavelinella spp***.** are typically Plano convex or slightly biconvex benthic foraminifera, with chambers arranged in a trochospiral manner. The test surface can be smooth or ornamented with fine ribs or grooves, depending on the species. The aperture, located at the base of the final chamber, is often a low to high arch, sometimes with a lip or flap. These species, with their finely perforate calcareous walls, are indicative of warm, temperate marine conditions, commonly found in shallow shelves and coastal areas, suggesting normal salinity and temperature levels in the ancient marine environment.

Florilus spp. are characterized by their planispiral, biconvex test, with chambers symmetrically coiled around a central axis. The test surface is usually smooth, though some species may exhibit fine ornamentation. The aperture is located at the periphery of the final chamber and is typically a low to high arch, sometimes featuring a lip or flap. The presence of Florilus spp. in sedimentary deposits indicates a warm, temperate climate, suggesting a subtropical marine environment with stable salinity and temperature conditions. These species are important in paleoclimate research, as they are sensitive to changes in ocean temperature and chemistry, making them valuable for reconstructing ancient ocean conditions and climate patterns.

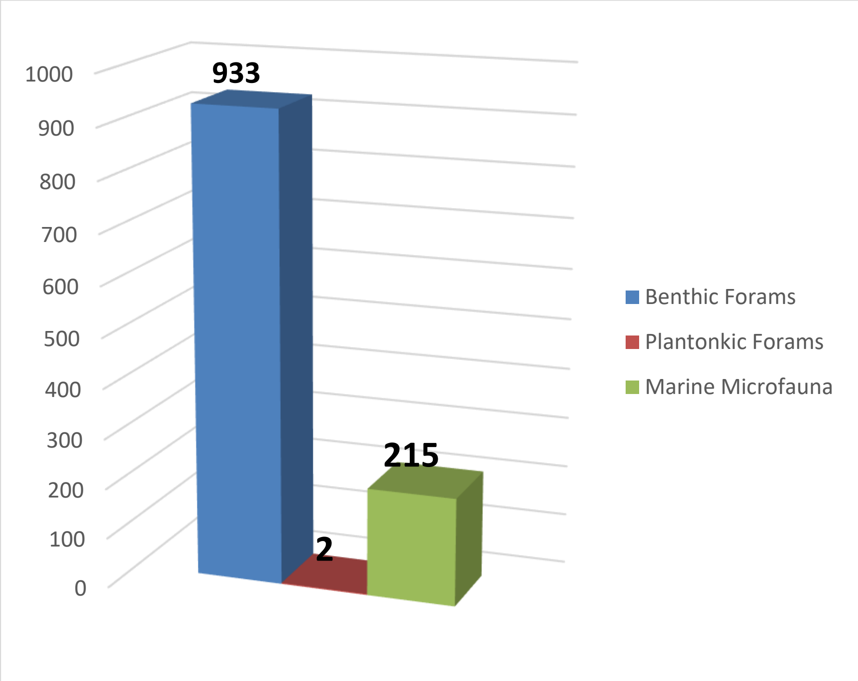

Fig.7: Histogram chart showing the total count of Benthic, Planktic and other marine microfauna.

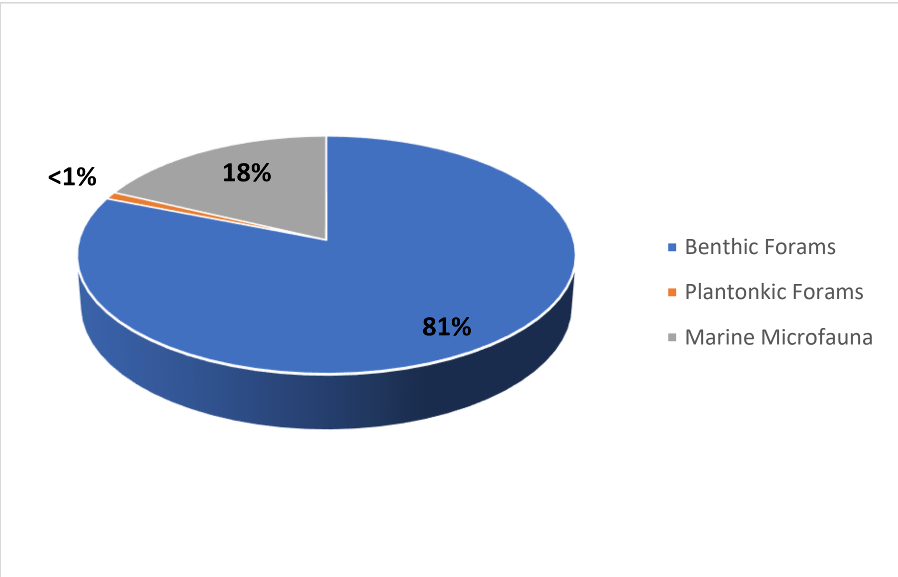

Fig.8: Pie chart representing the Percentage count of Benthic, Planktic, and other marine microfauna.

Scaphopoda, commonly known as tusk shells, are marine mollusks characterized by their elongated, curved shells resembling elephant tusks (Cattaneo-Vietti, Doneddu & Trainito, 2016). The soft body is long and slender, with a foot and tentacles. Scaphopod fossils are valuable indicators of past climate conditions, reflecting sensitivity to changes in ocean temperature and chemistry. Their presence in sedimentary rocks suggests a warm, temperate paleoclimate, and their shell morphology offers insights into paleoceanographic conditions, including ocean currents and circulation patterns. Scaphopods likely fed on small invertebrates and detritus, indicating their role in ancient marine ecosystems and providing clues about paleoenvironmental conditions such as water depth and sedimentation rates (Steiner, 1992, Reynolds, 2002).

Gastropods are a diverse class of mollusks, including snails, slugs, limpets, and abalone. Their shells are typically spiral, but can also be conical, cylindrical, or irregular. The soft body is unsegmented, with a distinct head, foot, and mantle. Gastropod fossils are essential for studying past climate conditions due to their sensitivity to temperature, salinity, and ocean chemistry changes. The presence of certain gastropod species can indicate warm or cold temperatures, reflecting their distribution and tolerance levels (Barker, 1999). Additionally, gastropod shell morphology and ornamentation provide information about paleoceanographic conditions, such as ocean currents and circulation patterns. These fossils also offer insights into past marine ecosystems and food webs, indicating the presence of other marine species and contributing to the understanding of paleoecological relationships (Dodd and Stanton, 1991).

Ostracods are small, shrimp-like crustaceans with a long fossil record dating back to the Ordovician period. They have a two-part hinged shell composed of calcite, typically oval or egg-shaped, with a distinctive hinge and muscle scars. Ostracod fossils are valuable indicators of paleoclimate conditions due to their sensitivity to changes in temperature, salinity, and water chemistry (Horne et al., 2002). The presence of specific ostracod species indicates warm or cool temperatures based on their modern-day distribution and tolerance levels. Ostracod fossils also provide significant insights into ancient marine ecosystems and food webs. Likely detritivores or filter feeders, their presence suggests a diverse marine environment and contributes to the understanding of paleoecological relationships and community structures (Mesquita-Joanes et al., 2012).

Taxonomy

The examination of 29 samples from the PET section uncovered a diverse assemblage of foraminifera and other marine microfossils, totaling 1150 counts across 10 benthic species, 2 planktonic foraminifera species, and 8 other marine microfauna (Fig.7 and Fig. 8). Notably, samples EBS-22, EBS-20, and EBS-23 exhibited the highest foraminiferal counts, with Anomalinoides midwayensis emerging as the most abundant species at 406 counts. This species' prevalence, along with Gavelinella guineana and Cibicides succedens, suggests these taxa were particularly well-adapted to the prevailing paleoenvironmental conditions, which likely included optimal salinity levels and nutrient availability, indicative of a stable, marine environment (Fig 6a & d) (Ideozu et al., 2019). In addition to foraminifera, other marine microfossils such as ostracods, echinoid spines, scaphopods, and gastropods were identified, further enriching the paleoenvironmental reconstruction. Ostracods were especially abundant, with a total count of 119, predominantly in specific samples. The varied assemblage, particularly in the interval from EBS-10 to EBS-29, suggests a well-oxygenated, nutrient-rich marine setting, likely on a continental shelf or upper slope, characterized by a dynamic ecosystem with a complex food web.

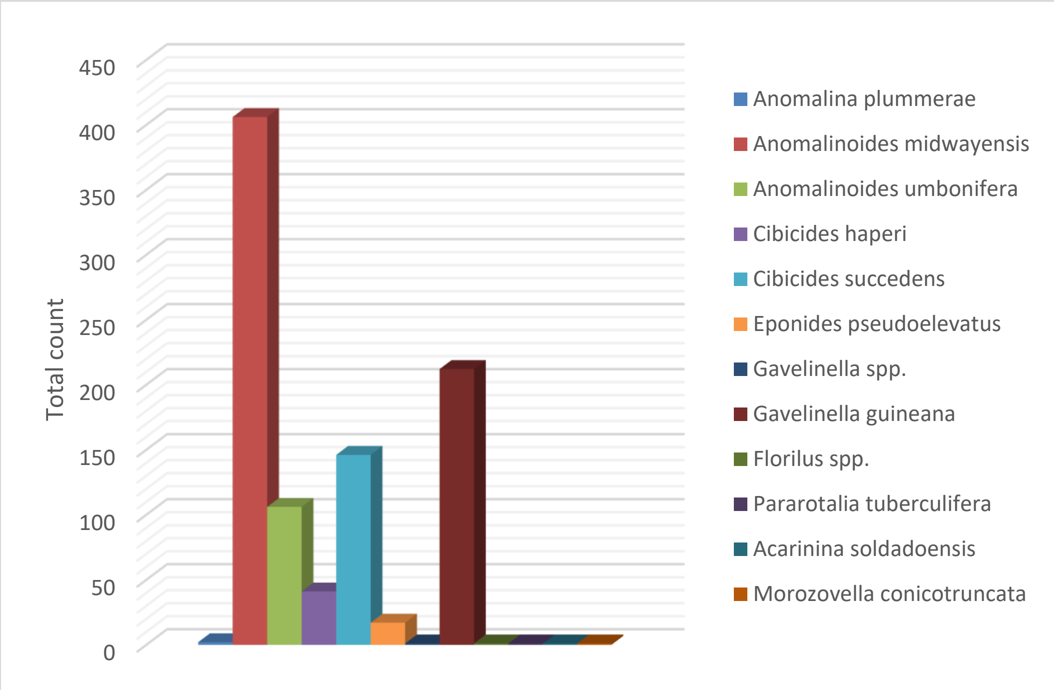

Fig. 9: Histogram chart representing the distribution of the foraminifera across PET well

Age Determination

The foraminiferal assemblages comprising Acarinina soldadoensis, Gavelinella guineana, Anomalinoides midwayensis, Anomalinoides umbonifera, and Cibicides succedens are indicative of Paleocene-Eocene sections in the eastern Benin Basin, as noted by various studies (Adegoke et al., 1970; Okosun and Alkali, 2012; Adebambo et al., 2022). Biostratigraphy, which uses fossil organisms with limited stratigraphic ranges, plays a key role in determining the relative age of sedimentary rocks. Acarinina soldadoensis, recognized as a biostratigraphic marker for the late Paleocene to early Eocene (approximately 58.7 to 54.8 Ma), along with other diagnostic species, provides strong evidence for dating the sedimentary sequences in this region.

The presence of Gavelinella guineana and Cibicides succedens, despite their longer stratigraphic ranges, alongside Acarinina soldadoensis, helps to narrow down the age determination. Anomalinoides midwayensis and Anomalinoides umbonifera, known for their occurrence during the late Paleocene to early or middle Eocene, further support the conclusion that the sedimentary sequences in the eastern Benin Basin were deposited during this transitional period.

Biostratigraphy

The Anomalinoides Biozone, spanning the Paleocene to Eocene epochs, is characterized by the co-occurrence of Anomalinoides umbonifera (Schwager) and Anomalinoides midwayensis (Galloway and Heminway). This zone is defined by the presence of these species, which mark the Paleocene period, and is bounded at its top by their disappearance. This biozone includes all sedimentary units from the Paleocene epoch represented in the study's samples. Key species in this biozone include Anomalinoides midwayensis, Anomalinoides umbonifera, Cibicides succedens (Brotzen), Gavelinella guineana (Petters), Cibicides haperi (Bermudez), Eponides pseudoelevatus (Leroy), Acarinina soldadoensis (Brönnimann), and Morozovella conicotruncata (Subbotina). The presence of Acarinina

soldadoensis and Morozovella conicotruncata, along with these Paleocene foraminifera, supports the Paleocene age of the sedimentary sequences (Fig.9).
However, Eponides pseudoelevatus, formerly considered a Paleocene index fossil, has also been found in Eocene sediments, which means its presence does not disprove the Paleocene age determined by other diagnostic foraminifera. Overall, the Anomalinoides Biozone offers a robust framework for correlating the Paleocene sequences globally, establishing a clear biostratigraphic context for the samples studied.

Paleoenvironment
The diversity of benthic foraminifera, including Anomalinoides midwayensis, Anomalinoides umbonifera, Cibicides haperi, Cibicides succedens, Eponides pseudoelevatus, Gavelinella spp., Gavelinella guineana, Florilus spp., and Pararotalia tuberculifera, indicates a marine depositional environment with normal salinity and well-oxygenated conditions. These species suggest a stable marine environment, likely in a shelf or upper slope setting due to the relatively low abundance of planktonic foraminifera, such as Acarinina soldadoensis and Morozovella conicotruncata, which are more common in outer shelf and slope settings (Wade et al., 2004).

The presence of bryozoans, though in low abundance, supports a shallow water environment, typically up to around 80 meters deep, with calm water conditions suggested by delicate forms and a higher-energy environment indicated by robust encrusting types (Flügel, 2004). The absence of significant terrigenous input and low bryozoan abundance suggest a more offshore or coastal marine setting, away from major sediment sources.

Additionally, the presence of ostracods, echinoid spines, scaphopods, gastropods, pelecypods, and fish teeth reinforces the marine environment and its diverse ecosystem. The distribution of these fossils implies a productive and well-established ecosystem, with moderate energy conditions indicated by shell fragments and echinoid spines, potentially influenced by bottom currents or wave action (Leckie et al., 2002). This suggests a tropical to subtropical climate with well-oxygenated, nutrient-rich waters suitable for diverse marine life.

CONCLUSION
The foraminiferal analysis of the PET section provides significant insights into the paleoenvironmental conditions and depositional history of the study area. The assemblage, dominated by calcareous benthic foraminifera and characterized by moderate abundance but limited diversity, indicates a stable and relatively shallow marine environment with minimal ecological variation. This suggests a consistent habitat with little change in environmental conditions. The presence of only two planktonic species, Acarinina soldadoensis and Morozovella conicotruncata, within the 9–29-meter interval reinforces the interpretation of a primarily benthic habitat with restricted planktonic input. The absence of agglutinated foraminifera further supports the notion of a shallow marine environment.

The foraminiferal assemblages, including species such as Acarinina soldadoensis, Gavelinella guineana, Anomalinoides midwayensis, Anomalinoides umbonifera, and Cibicides succedens, are indicative of the Paleocene-Eocene era. The Anomalinoides Biozone, marked by the concurrent presence of Anomalinoides umbonifera and Anomalinoides midwayensis, covers the entire Paleocene epoch, providing a solid biostratigraphic framework for global correlation. The diverse fossil assemblage, featuring benthic and planktonic foraminifera along with bryozoans, ostracods, echinoids, and other microfossils, points to a shallow to middle neritic marine environment with normal salinity and well-oxygenated conditions, suggesting a warm, tropical to subtropical climate and a productive, well-established marine ecosystem.

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