DOI: https://dx.doi.org/10.4314/gjgs.v22i1.6

GLOBAL JOURNAL OF GEOLOGICAL SCIENCES VOL. 22, 2024: 67-77
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PALEOCENE OSTRACODS OF THE EASTERN DAHOMEY BASIN OF NIGERIA: IMPLICATIONS FOR PALEOENVIRONMENTAL, PALEOBIOGEOGRAPHIC AND HYDROCARBON EXPLORATION EFFORTS

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(Received 25 June 2024; Revision Accepted 12 August 2024)

ABSTRACT

This study investigates the paleoenvironmental conditions, paleo-biogeographic affinities, and paleoecological significance of Paleocene ostracods from the Ewekoro Formation in the eastern Dahomey Basin, Nigeria. Less attention has been given to ostracods study in Nigeria. The research aimed at understanding the paleoecological and paleobiogeographic distributions of the ostracods from borehole data in the eastern Dahomey Basin of Nigeria and their relationship to other African basins. The carbonates samples were analysed using sedimentological and micropaleontological methods. Eleven carbonates samples that were carefully collected from borehole BH-22 and processed based on Nagy et al. (1988) procedure were used for this study, yielding 18 well-preserved ostracod species. These species include *Soundanella laciniosa triangulata*, *Bardia ilaroensis*, *Nigeroloxoconcha acgyptiaca*, *Paracosta kefensis*, *Xestoleberis tunisiensis*, and others. The identified assemblages reflect a heterogenous neritic zone, ranging from high-energy nearshore to low-energy outer neritic settings. Species such as *Bardia ilaroensis* and *Nigeroloxoconcha aegyptiaca*, indicate shallow marine or estuarine environments, while *Cytherella* species suggest deeper, low-energy conditions. The paleobiogeographic distribution supports a Trans-Saharan Seaway connection during the Paleocene–Eocene, linking the Southern Tethys and West African provinces. Ostracod species between the eastern Dahomey Basin and regions in North Africa, the Middle East, and other parts of West Africa indicate significant faunal interchange. For hydrocarbon exploration in the basin, the limestone units and interbedded light grey sandstone of the Ewekoro Formation suggest potential reservoirs, while black shales indicate potential source rock. The identified ostracods provide biostratigraphic markers enhancing the predictability of reservoir and source rock distribution in the basin.

KEYWORDS: Paleocene ostracods, eastern Dahomey Basin, Tethys sea, paleoenvironment, paleobiogeography, West African province, Trans-Saharan Seaway, neritic zone.

INTRODUCTION

Ostracods are sensitive environmental indicators that provide important insights into past ecosystems and paleoclimate changes. Their fossil records help reconstruct past biogeographic provinces by highlighting significant trends in species migration and distribution (Reyment, 1960). Hydrocarbon exploration also benefits greatly from an understanding of the depositional settings of these microfossils, as it aids in the identification of possible reservoir and source rocks.

Apostolescus (1961) and Reyment (1960, 1963) investigated the paleontology of ostracods and the stratigraphy of the western Dahomey Basin. Their research was the first published works on ostracod assemblages ranging from the upper Cretaceous to Paleogene period of the Nigerian sedimentary basin. Building on these pioneer efforts, other studies have been conducted on the basins in the region (Foster et al., 1983; Okosun, 1987; Sarr, 2012; Adebambo et al. 2023).

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Assemblages of ostracods are useful indicators of many ecological and paleoecological parameters, comprising water depth, dissolved oxygen content, temperature, and turbulence (Youssef et al., 2017). Moreover, these microfossils are highly useful for identifying historical sea routes (Morsi et al., 2011). Research has established a connection between the North African and West African ostracod assemblages. According to Barsotti (1963), the Trans-Saharan Seaway provided a Paleogene link between the coastal basins of West Africa and Sirte and Libya. Reyment (1980) discovered several different ostracod taxa in the Dahomey and Iullemeden Basins. The Trans-Saharan and North African basins share a number of species, he pointed out. Based on these faunal similarities, a notion was proposed that Paleogene ostracods migrated across the Trans-Saharan Seaway from the Gulf of Guinea to southern Tethys basins (including the Sirte Basin). Carbonnel et al. (1990) observed ostracod species in Mali and Niger that are comparable to those in the Dahomey and Sirte basins, supporting the concept that there is a Trans-Saharan migration path. Adebambo et al. (2023) studied ostracods within the Dahomey Basin. They revealed that Paleogene ostracod assemblages share close affinities with those in North and West African basins and the species indicative of shallow neritic and marine upwelling conditions were found, and many also appear in the Iullemeden and southern Tethys basins, suggesting migration via the Trans-Saharan Seaway.

This study seeks to expand on these foundational works by focusing specifically on Paleocene ostracods, which have been less studied in this region. By analyzing these microfossils, we aim to infer paleoenvironmental conditions and evaluate their implications for paleobiogeographic patterns and hydrocarbon exploration.

Geologic Setting

The Dahomey Basin (Fig. 1) spans southeast Ghana, Togo, Benin, and southwest Nigeria. Due to the rifting and eventually splitting of the African and South American plates, which resulted in the opening of the South Atlantic Ocean, its geologic evolution started during the Late Jurassic to Early Cretaceous period (Adediran and Adegoke, 1987). Major fracture zones such the Romanche, Chain, and Charcot were formed as a result of this tectonic activity, and numerous horst and graben structures were created, which had a substantial impact on sediment deposition (Brownfield and Charpentier 2006). The horst and graben characteristics of the Jurassic basement complex, which were further modified by wrench motions of the basement blocks, are what structurally define the Dahomey Basin. These features resulted from basement fragmentation, block faulting, and subsidence. These structural features controlled the deposition patterns within the basin (Adekeye et al., 2019).

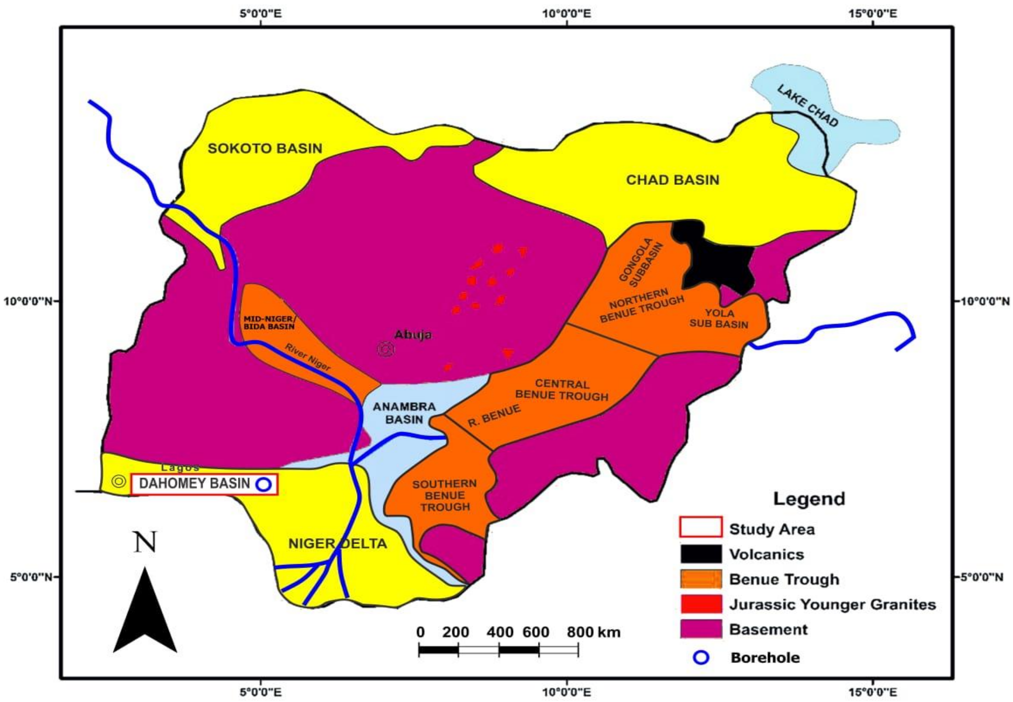

Fig.1: Geological map of Nigeria indicating the study location (After Abubakar et al., 2019 and Aigbadon et al., 2024 a).

The stratigraphy of the Nigerian sector, known as the eastern Dahomey Basin, is controversial because different stratigraphic names are used for the same formations in different places. This problem is exacerbated by the lack of sufficient outcrops and borehole data for in-depth research (Jones and Hockey, 1964). Three chronostratigraphic units comprise the sediments of the basin: pre-lower Cretaceous folded sediments, Cretaceous sediments, and Paleogene sediments (Omatsola and Adegoke, 1981). The Abeokuta Group, which is further separated into the Ise, Afowo, and Araromi Formations, is a part of the Cretaceous period. Comprising of coarse conglomeratic sediments, the Ise Formation lies unconformably on the basement complex. Sandstone and transitional to marine sands with siltstone and shales interbedded are found in the Afowo Formation. The top-most section, the Araromi Formation, is made up of limestone and sand interbeds between shales and siltstone. The Ewekoro, Akinbo, Oshosun, Ilaro, and Benin Formations make up the Paleogene-Neogene deposits (Omatsola and Adegoke, 1981). The Akinbo and Oshosun Formations are distinguished by hazy grey and black shales, whereas the Ewekoro Formation is renowned for its fossiliferous, well-bedded limestone. Five lithostratigraphic units were documented by these authors. Glauconitic rock bands and phosphatic beds delineate the Ewekoro-Akinbo Formation boundary. Most of the coarse sandy estuarine, deltaic, and continental sands are found in the Ilaro and Benin Formations (Ako et al., 1980; Okosun, 1990; Adekeye, 2004; Adekeye et al., 2006).

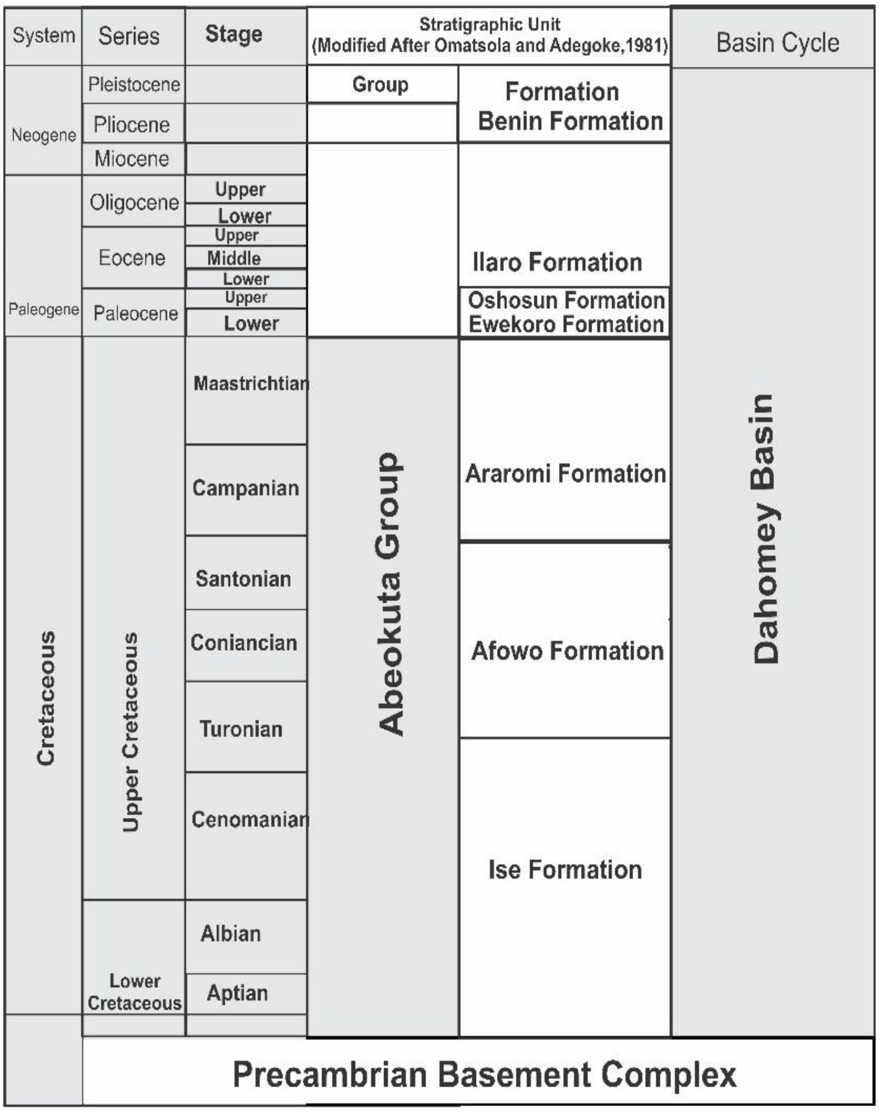

Fig. 2: Stratigraphic successions within the eastern Dahomey Basin, Nigeria (Omatsola and Adegoke, 1981; Aigbadon et al., 2024)

MATERIALS AND METHODS

Within BH 22 eleven carbonate and one shale core samples (Fig. 3) were collected and screened from the Ewekoro Formation, a well-known stratigraphic unit in the eastern Dahomey Basin, Nigeria. The sample preparation and procedures were all established after Nagy et al. (1988). For the purpose of disaggregation, a 35 g part of each sample was soaked in soapy water after being treated with kerosene. Subsequently, a 63 µm filter was used to filter the samples, and the residue was placed in an oven that is temperature controlled at 60^{0}C for about 30 minutes to dry the residue. The next stage is to place these residues on a slide, and examined with an Olympus BX 45 binocular reflected light microscope, and photographed. These photomicrographs were compared with published studies by Youssef et al. (2017) and Morsi and Speijer (2003), respectively.

RESULTS AND DISCUSSION

Lithostratigraphy

The BH-22 borehole penetrated the Ewekoro Formation (Fig. 3). It has a depth of 140 meters, and is primarily characterized by a limestone sequence, indicative of a stable, marine carbonate depositional environment. This limestone predominates from 70 to 210 meters with intercalations of shale units at 90-94 meters, 135-160 meters and 180-196 meters as well as fine sandstone interval at 125-135 meters, respectively. Limestone units in the study borehole possess granular texture with interbedded laminated shale units. The limestone constituent grains range in sizes greater than 0.001 mm. They colour of the limestones ranges from milky to dark grey. In addition, there is presence of bioclasts and intraclasts held together by grains through cementation, though with a little amount of mud. The sandstone units at (128-138m) and (195 -200m), respectively possess very fine to fine texture. Furthermore, the presence of black/grey laminated shale within the formation indicates periods of low-energy, anoxic conditions suitable for the preservation of organic material, likely reflecting deeper marine settings or restricted circulation. The unit also contain Paleocene ostracod assemblages (Fig. 3).

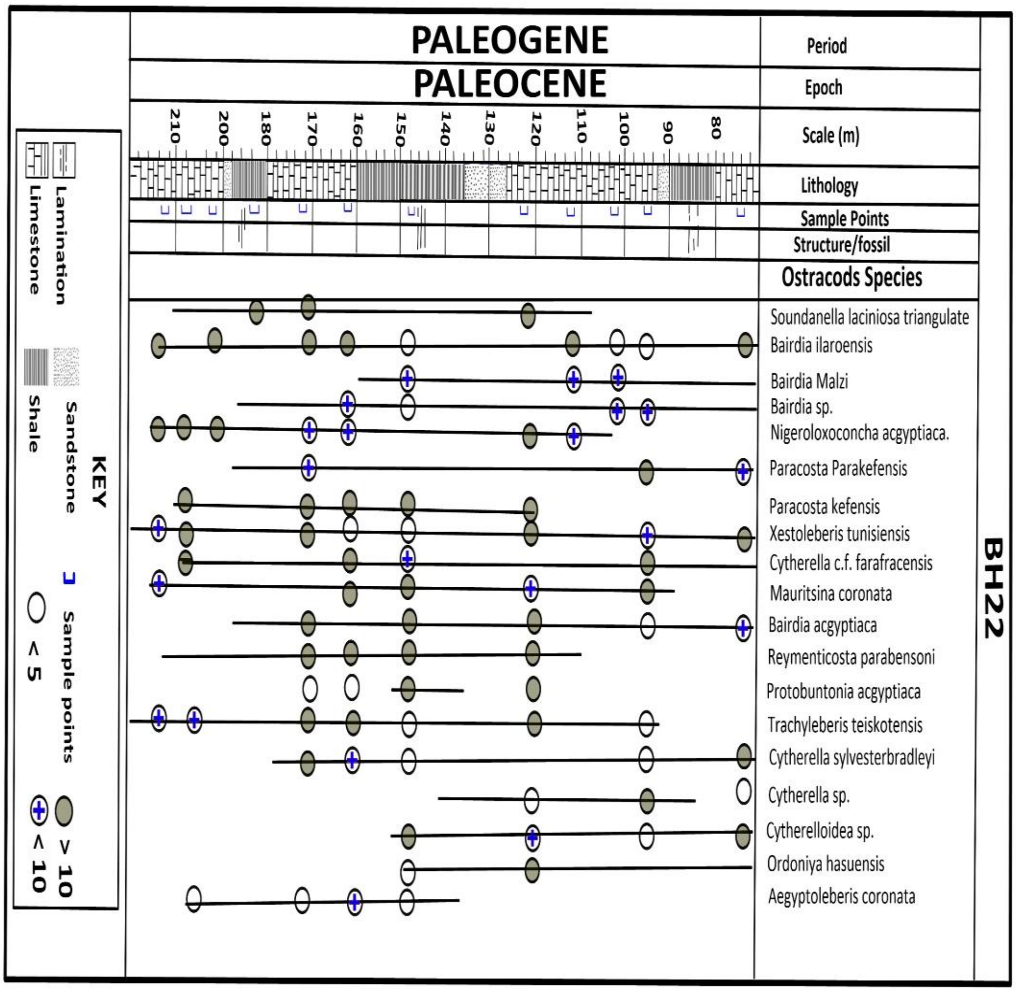

Fig. 3: Paleocene ostracod assemblages of BH-22

Ostracods

The analyses of the samples extracted from various intervals in the studied area yielded well-preserved ostracods and allowed us to recognize 18 species belonging to 13 genera and 7 families. The identified species include: *Soundanella laciniosa triangulate*, *Bardia ilaroensis*, *Bardia malzi*, *Bardia sp*, *Nigeroloxoconcha aegyptiaca*, *Paracosta parakefensis*, *Paracosta kefensis*, *Xestoleberis tunisiensis, Cytherella cf farafraensis, Mauritsina coronata, Bairdia aegyptiaca*, *Reymenticosta parabensoni, Protobuntonia aegyptiaca*, *Trachyleberis teiskotensis*, *Cytherella sylvesterbradleyi*, *Cytherella sp*, *Ordoniya hasaensis*, and *Aegyptoleberis coronata*. The aboved ostracod species will be discussed in relation to their paleoecology, paleoenvironments and paleobiogeographical distributions across basins in Nigeria, West Africa, Middle East and northern Africa, respectively (Figs. 3 and 4).

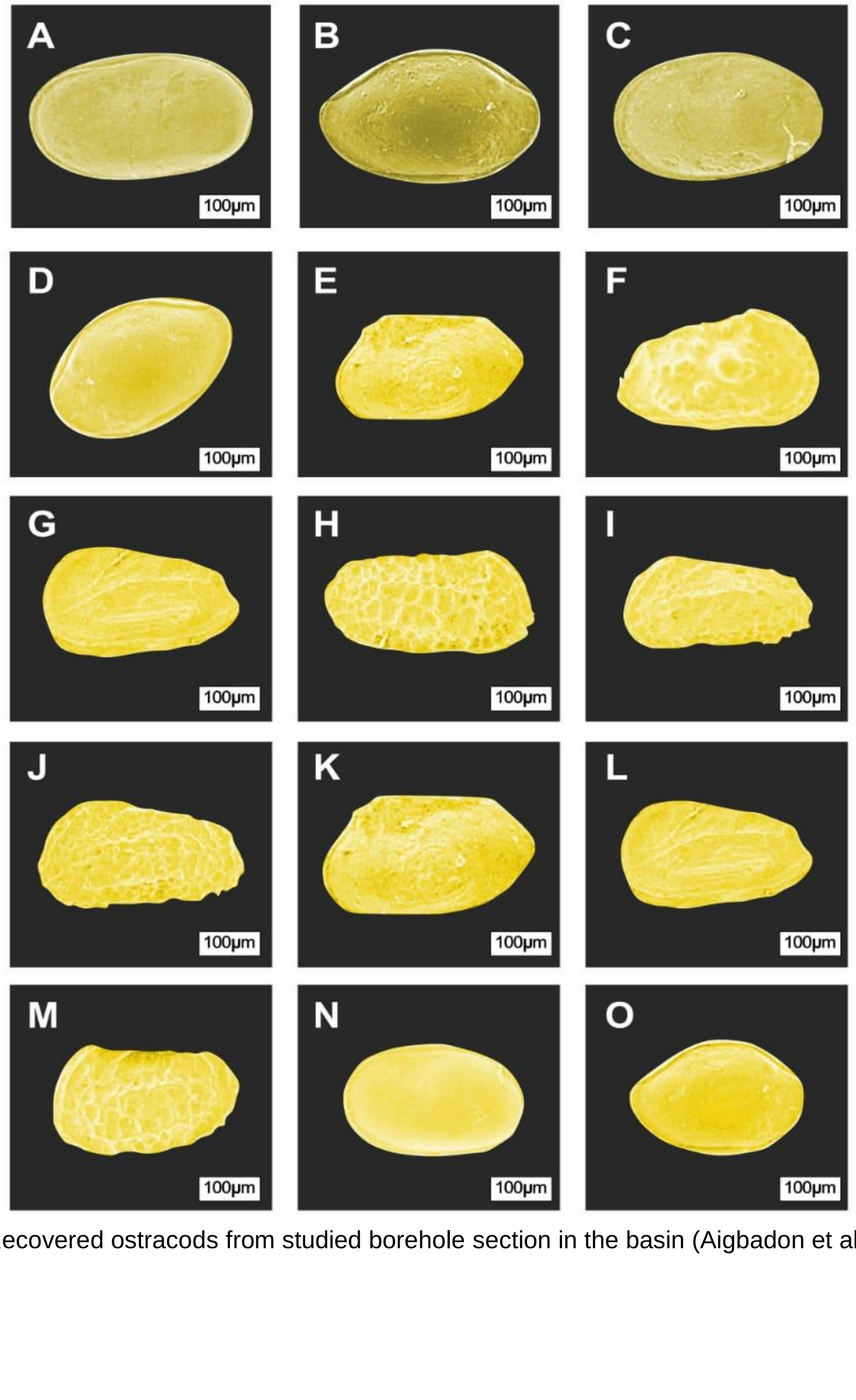

Fig. 4: Recovered ostracods from studied borehole section in the basin (Aigbadon et al., 2024 b).

a. *Cytherella sp.*, b. *Bairdia ilaroensis, c. Xestoleberis tunisiensis, d. Cytherella sylvesterbradleyi,* e. *Nigeroloxoconcha acgyptiaca*, f. *Aegyptoleberis coronata*, g. *Ordoniya hasuensis*, h-i. *Paracosta Parakefensis*, j. *Paracosta kefensis*, k. *Protobuntonia acgyptiaca*, i. *Sundanella laciniosa triangulate*, m. *Reymenticosta parabensoni*, n. *Cytherella c.f. farafracensis*, o. *Bairdia* sp.

DISCUSSIONS

Paleoecology

Investigation of the ostracod species discovered in sedimentary deposits yields important information about ancient ecosystems. Due to their unique tolerances and preferences for certain environments, these micro crustaceans function as ecological markers (Maddocks, 1991). Species such as *Cytherella cf. farafraensis* and *Cytherella sylvesterbradleyi* (Figs. 3 and 4 d, 4 n) suggest the presence of stable, low-disturbance benthic ecosystems, where they likely played roles as detritivores or micro-predators, feeding on microorganisms and organic detritus (Gertsch, 2010). *Nigeroloxoconcha aegyptiaca* (Fig. 4 e) exhibits a broad ecological tolerance, thriving in environments with fluctuating salinity, indicative of its generalist feeding strategy (Peypouquet et al., 1986). *Soundanella laciniosa triangulate* (Fig. 4 i) points to dynamic settings with nutrient influxes, possibly participating in the detrital food web and contributing to nutrient cycling (Morsi et al., 2011). *Bairda ilaroensis* (Fig. 4 b) is adapted to variable salinity and sedimentation, likely processing organic material and influencing sediment stability (Reyment, 1980). *Trachyleberis teiskotensis* and related species suggest complex, biodiverse communities, possibly reef-associated, where they maintained ecological balance by feeding on microorganisms and algae (Said, 1990). Collectively, these ostracods highlight the diverse ecological roles and interactions within their communities, reflecting the richness and complexity of the ancient ecosystems they inhabited.

Paleoenvironment

Particularly in marine environments, ostracods are sensitive markers of paleoenvironmental conditions. The species listed offer important insights into the paleoenvironmental conditions of the neritic zone, which is generally defined as shallow marine environments down to a depth of approximately 200 meters. Numerous paleoenvironmental elements, such as water depth, temperature, turbulence, and dissolved oxygen content, affect the distribution of ostracod assemblages in sedimentary deposits. These factors shape the composition and distribution of ostracod species, allowing for the differentiation of assemblages indicative of specific environmental conditions (Morsi and Speijer, 2003). The identified species encompass a range of families, reflecting diverse ecological niches (Munef et al., 2012). Species such as *Bardia ilaroensis* and *Nigeroloxoconcha aegyptiaca* (Fig. 4 b, 4 e) are indicative of marine or brackish environments, suggesting deposition in shallow marine settings or estuarine environments influenced by seawater influx (De Deckker, 1981). *Paracosta kefensis*, and *Reymenticosta parabensoni* (Fig. 4 j and 4 m) indicates an inner-middle shelf environment (Morsi and Speijer, 2003). *Cytherella* species, including *Cytherella cf. farafraensis* and *Cytherella sylvesterbradleyi* (Fig. 4 d and 4 n) which are present in the studied area, inhabit reduced oxygen water and it indicates low-energy, deeper neritic to outer shelf environments (Bergue et al., 2007; Elewa, 2002). *Xestoleberis tunisiensis* is typically found in marine or brackish environments and is most likely found in the upper part of the neritic zone. Its presence implies deposition in shallow marine settings with variable salinity conditions. *Mauritsina coronata* and *Protobuntonia aegyptiaca* (Fig. 3) suggest fine-grained sediments of outer neritic environments, indicating lower energy conditions (Whatley and Coles, 1987). *Trachyleberis teiskotensis* is indicative of sandy, high-energy nearshore settings (Kontrovitz, 1976), while *Ordoniya hasuensis* and *Aegyptoleberis coronata* (Fig. 4 f and 4 g) reflect lagoonal or estuarine conditions with fine-grained sediments (Dingle and Hendry, 1984; Whatley and Coles, 1987). The diversity and ecological preferences of these ostracods indicate a heterogeneous neritic zone, ranging from high-energy nearshore environments to low-energy outer neritic settings with varying sediment types and salinity levels, reflecting a dynamic and complex marine ecosystem (Van Morkhoven, 1963). The main factors influencing the change were not origination or extinction within the analyzed lineages, but rather the studied species' tolerance of environmental change or lateral migration (Youssef et al., 2017).

Paleobiogeography

Significant implications regarding the ostracods' marine link, potential migration routes, and facies associations can be inferred from their paleobiogeographic distribution (Speijer and Morsi, 2003). The Southern Tethys province and the West African province are the two primary Paleogene biogeographic provinces for ostracods (Youssef et al., 2017). The Trans-Saharan Seaway connected these two provinces during the Paleocene–Eocene (Adebambo et al., 2023) The South Tethys Province, includes parts of North Africa and the Middle East. The study area which is in the Dahomey Basin belongs to the West African province which also covers areas along the Gulf of Guinea. Several ostracod species from BH-22 (*Soundanella laciniosa triangulata*, *Bardia ilaroensis*, *Nigeroloxoconcha* aegyptiaca, *Paracosta kefensis*, *Xestoleberis tunisiensis*, *Cytherella cf. farafraensis*, *Cytherella sylvesterbradleyi*, *Ordoniya hasaensis*, *Cytherella* sp., *Mauritsina coronata*, *Protobuntonia aegyptiaca* and *Trachyleberis teiskotensis*, and *Bardia* sp., Figs. 3 and 4 a - 4 o;

Table 1) exhibit a broad paleobiogeographic distribution tracing their evolutionary history from the coast of West Africa to Mali, Egypt, and the Southern Tethys region, indicating potential faunal interchange between these two geographical regions (Bassiouni and Luger, 1990; Keen et al., 1994; Elewa, 2002; Table 1).

Middle East

In the Middle East, specifically in Isreal and Jordan, several ostracod species such as *Cytherella cf. farafraensis*, *Cytherella sylvesterbradleyi*, *Ordoniya hasaensis* and *Trachyleberis teiskotensis* have been documented (Table 1). These species are also noted in BH-22, indicating a shared paleoenvironmental history between these regions. The linkage between the ostracods of the Middle East and the eastern Dahomey Basin indicates a marine connection and faunal migration between the two areas and lies in their historical connection to the Tethys Sea, which provided extensive shallow marine and lagoonal habitats during the Cretaceous and Paleogene periods. This ancient sea created similar ecological conditions across these geographically separated areas, facilitating the spread and evolution of similar ostracod assemblages. The comparable sedimentary environments, characterized by calm, nutrient-rich waters and dynamic salinity conditions, allowed these species to thrive, highlighting the widespread influence of the Tethys Sea on marine biodiversity in both the Middle East and West Africa (Said, 1990; Honigstein and Rosenfeld 1995; Gertsch, 2010; Youssef et al., 2017; Table 1).

Table 1: Ostracod species common to both the eastern Dahomey Basin and North Africa, the Middle East, and other parts of West Africa regarding their trans-Saharan seaway connection.

S/N	Ostracod species	Middle East	North Africa	West Africa	Eastern Dahomey Basin (This study)
1	*Aegyptoleberis coronata*				X
2	*Bairdia ilaroensis*			X	X
3	*Bardia malzi*			X	X
4	*Bairda aegyptiaca*			X	X
5	*Bairdia sp*			X	X
6	*Cytherella sp*				X
7	*Cytherella sylvesterbradleyi*	X	X	X	X
8	*Cytherella c.f. farafracensis*	X	X		X
9	*Mauritsina coronata*				X
10	*Nigeroloxoconcha acgyptiaca*			X	X
11	*Ordoniya hasuensis*	X		X	X
12	*Paracosta Parakefensis*			X	X
13	*Paracosta kefensis*			X	X
14	*Protobuntonia acgyptiaca*				X
15	*Reymenticosta parabensoni*		X	X	X
16	*Sundanella laciniosa triangulate*		X	X	X
17	*Soudanella fusa*				
18	*Trachyleberis teiskotensis*	X	X		X
19	*Xestoleberis tunisiensis*		X		X
20	*Loxoconcha lagosensis*				

X- Present

North Africa

Several ostracod species, including *Cytherella cf. farafraensis*, *Cytherella sylvesterbradleyi*, *Trachyleberis teiskotensis*, *Xestoleberis tunisiensis*, *Soudanella laciniosa triangulata* and *Reymenticosta parabensoni*, are found in North Africa, particularly in Egypt and Libya (Table 1). These species also appear in the study area, suggesting a strong paleoenvironmental link between these regions. These species' similarity suggests that the Tethys Sea, which formerly spanned portions of West and North Africa, had a significant impact on the environment, producing similar circumstances that were advantageous for ostracods (El-Sogher, 1996). During the Cretaceous and Paleogene periods, these ostracods were found in both North Africa and the Dahomey Basin due to the extensive dispersal of marine species across the oceans of the world (Table 1). The thriving populations of these species were supported in both regions by similar sedimentary settings characterized by nutrient-rich waters and varying salinity conditions (Said, 1990; Reyment, 1980).

West Africa

Some of the ostracod species found in the study area, such as *Soundanella laciniosa triangulate*, *Bairda aegyptiaca*, *Nigeroloxoconcha aegyptiaca*, *Paracosta kefensis*, *Bardia ilaroensis*, *Bardia malzi*, *Bardia sp.*, *Xestoleberis tunisiensis, and Reymenticosta parabensoni*, also occur in other parts of West Africa, including regions like Ghana, Senegal, and the Ivory Coast (Table 1). These species reflect a shared paleoenvironmental history across West African coastal basins during the Cretaceous and Paleogene periods. The linkage between these ostracods lies in the similar depositional environments characterized by extensive shallow marine, deltaic, and lagoonal settings that dominated West Africa's coastal regions. These environments provided stable and nutrient-rich conditions that supported diverse ostracod communities. The widespread presence of these species across West Africa indicates that the marine transgressions and sedimentary processes during these geological periods created interconnected habitats, facilitating the dispersal and evolution of similar ostracod assemblages throughout the region (Reyment, 1960, 1963, 1980; Okosun, 1987, 1989; Table 1).

Implications for Hydrocarbon Exploration

The study of Paleogene ostracods in the Dahomey Basin reveals crucial insights for hydrocarbon exploration, highlighting depositional environments and potential reservoirs. The Ewekoro Formation's well-bedded limestone and interbedded sandstone strata suggest high reservoir quality due to favorable porosity and permeability (Adekeye et al., 2019; Jones and Hockey, 1964). Black shales indicate anoxic conditions suitable for source rocks, enhancing hydrocarbon potential (Omatsola and Adegoke, 1981). The ostracod assemblages, such as *Cytherella cf. farafraensis* and *Cytherella sylvesterbradleyi*, reflect low-energy environments conducive to organic matter preservation (Elewa, 2002), while species like *Xestoleberis tunisiensis* indicate shallow marine settings with variable salinity, suggesting both source and reservoir rock potential (Munef et al., 2012). Biostratigraphic frameworks established from ostracod species such as *Bardia ilaroensis* and *Nigeroloxoconcha aegyptiaca*, are indicative of marine or brackish environments, provide markers for correlating similar depositional environments across the basin, enhancing the predictability of reservoir and source rock distribution (De Deckker, 1981; Morsi and Speijer, 2003). Additionally, the basin's horst and graben structures, formed by tectonic activities, play a crucial role in controlling sediment deposition and hydrocarbon migration and trapping (Adekeye et al., 2019). Thus, the paleoenvironmental and paleoecological analyses of these ostracods provide a comprehensive understanding of depositional environments, enhancing hydrocarbon exploration strategies within the Dahomey Basin (Adebambo et al., 2023).

CONCLUSION

Significant insights into paleoenvironmental conditions, paleobiogeographic patterns, and implications for hydrocarbon exploitation in the region can be gained from the research of Paleocene ostracods from the Ewekoro Formation in the eastern Dahomey Basin. 18 different species of ostracods from different time periods were identified in the study, indicating a wide variety of ecological niches within high-energy nearshore settings to low-energy outer neritic settings. These microfossils reveal a dynamic and varied marine ecosystem.

These ostracods were found to have flourished in a variety of habitats, including dynamic environments with nutrient inflows and stable, low-disturbance benthic ecosystems, according to the paleoecological study. Their ecological roles point to rich, intricate, and highly diverse ancient ecosystems. The idea that a Trans-Saharan Seaway facilitated faunal interchange between the Southern Tethys and West African provinces during the Paleocene–Eocene is supported by the paleobiogeographic distribution of these species. The common ostracod species found in the Dahomey Basin and other parts of West Africa, the Middle East, and North Africa clearly shows this connection.

The study also highlights the potential of the Ewekoro Formation as a potential reservoir for hydrocarbon development, owing to its interbedded sandstone beds and well-bedded limestone. Black shales imply anoxic conditions that serve as potential sources rock. The discovered ostracod assemblages offer biostratigraphy indicators that can improve the basin-wide prediction of reservoir and source rock distribution. The *Bairda aegyptiaca*, *Xestoleberis tunisiensis*, and *Protobuntonia aegyptiaca* are good indicators of the inner to outer shelf neritic environments of deposition. The *Reymenticosta parabensoni* and *Paracosta kefensis* reflects an inner to middle shelf environments of deposition. These taxa could serve as environmental indicators for these depths in exploration work. Furthermore, knowledge of sediment deposition, hydrocarbon movement, and trapping depends on the horst and graben structures of the basin. By providing relevant information for reconstructing depositional environments and guiding hydrocarbon development efforts in the study basin. The ostracod study will further broaden our understanding of Paleocene ostracod assemblages in the eastern Dahomey Basin, Nigeria.

ACKNOWLEDGEMENTS

Both authors acknowledged the Geological Survey Agency, Kaduna for making the core data available for this research.

Conflict of interest

Both authors declared there is no conflict of interest between them.

Authors Contribution

Both authors were involved in the research design, megascopic examination and laboratory analysis of the core samples as well as drafting and proof reading of the manuscript.

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