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Facies and Geochemical Characteristics of the Igumale Formation, Lower Benue Trough, Nigeria

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Abstract: *This research examines the carbonates textures, chemical composition, and depositional settings of carbonate rocks collected from the Igumale region in the Lower Benue Trough, Nigeria. This approach integrates X-ray Diffraction (XRD) for mineralogical identification, X-ray Fluorescence (XRF) for geochemical characterization, and thin section petrographic examination for microfacies analysis, this research aimed to unravel the compositional attributes and interpret the paleoenvironmental conditions within these Cretaceous carbonate sediments. The petrographic analysis of the Igumale samples revealed two distinct carbonate microfacies: a sandy bioclastic wackestone, indicative of a lower energy setting with detrital siliciclastic input and significant fossil accumulation, and a micritic bioclastic packstone, suggesting a slightly higher energy environment with closely packed bioclastic grains within a fine-grained carbonate matrix. The XRD analysis revealed a substantial presence of calcite as the dominant mineral phase, underscoring the primary carbonate composition of the Igumale Formation. The XRF analysis revealed that calcium oxide (CaO) and its constituent element, calcium (Ca), as the most abundant oxide and element, respectively, further corroborating the calcitic nature of these rocks. Petrographic interpretations, based on the textural and compositional characteristics of the identified microfacies and their fossil content, strongly suggest that the Igumale Formation was deposited within a shallow marine environment, potentially transitioning into tidal flat settings, influenced by both biological activity and terrigenous input. The findings offer valuable insights into the geological history of the Lower Benue Trough, highlighting the mineralogical makeup, textural diversity, and dominant depositional environments of the carbonate rocks in the Igumale Formation, thereby enhancing the understanding of the basin's Cretaceous sedimentary development.*

Keywords: *carbonates, Facies, Geochemistry, Lower Benue Trough, Formations*

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1.0 Introduction

The Lower Benue Trough, a prominent geological feature situated between 6°N to 9°N latitude and 7°E to 10°E longitude in Nigeria, constitutes a significant segment of the Benue Rift System. The study area falls within this coordinate (Fig. 1). This intra-continental sedimentary basin, formed during the separation of the African and South American plates in the Early Cretaceous, is characterized by a substantial accumulation of Cretaceous to Tertiary sediments, reaching thicknesses of up to 6,000 meters (Kogbe, 1989; Benkhelil, 1989). The tectonic evolution of the lower Benue Trough involved phases of rifting, subsidence, and subsequent compressional deformation, resulting in the complex structural architecture observed today. Within this geological framework, the Asu River Group represents a key lithostratigraphic unit of Albian age, known for its diverse lithologies, including sandstones, shales, and limestones, deposited under varying paleoenvironmental conditions (Reyment, 1965; Ojoh, 1992).

The focus of this research is specifically on the carbonate members of the Asu River Group exposed in the Igumale area of the lower Benue Trough. These carbonate rocks provide a valuable study of the paleoenvironmental conditions that prevailed during their formation in the Cretaceous period (Akanni, 2024). Understanding their microfacies characteristics, mineralogical composition, and geochemical signatures is crucial for reconstructing the depositional history of this part of the basin.Earlier research has provided insights into the carbonate deposits within the Lower Benue Trough. Aigbadon et al. (2024) examined the carbonate facies in the Yandev region, identifying a diverse assemblage of marine microfossils, suggesting a shallow marine environment. Agumanu (2009) conducted a comprehensive study on the carbonate microfacies and geochemistry of Cretaceous limestones in the southern Benue Trough, aiding in the interpretation of their depositional settings. Additionally, Priceton and Okwara (2016) assessed the lithofacies and depositional environments of carbonate deposits in the southeastern Lower Benue Trough, offering valuable insights into sedimentary processes and paleoenvironments.

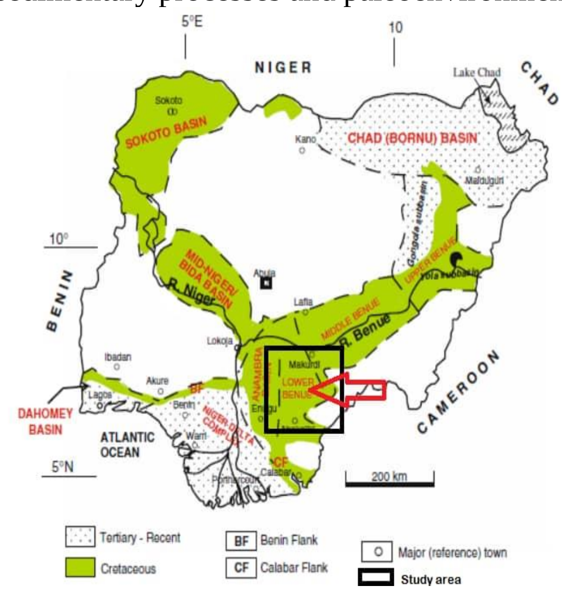

Fig 1: presents a geological map of Nigeria, highlighting the locations examined in this study (Obaje, 2009)

Building upon this existing literature, this study aims to provide a more detailed and integrated analysis on the limestone facies of the Igumale Formation within the lower Benue Trough. By employing a combination of high-resolution petrographic analysis of thin sections, precise mineralogical determination using X-ray Diffraction (XRD), and detailed geochemical characterization through X-ray Fluorescence (XRF), this research tends to: (i) identify and describe the distinct carbonate microfacies present in the Igumale samples; (ii) determine their bulk mineralogical composition; (iii) analyze their major elemental geochemistry; and (iv) integrate these data to develop a refined interpretation of the depositional environment(s) under which these carbonate sediments accumulated. The study of this research enhance current knowledge of the Cretaceous paleoenvironmental conditions and sedimentary development within the Lower Benue Trough, with a focus on the origin and features of its carbonate formations.

2.0 Materials and Methods

Carbonate rock samples were systematically collected from the Igumale locality, situated within the Asu River Group in the southern Benue Trough, for a comprehensive geological analysis. To investigate their petrographic characteristics, selected specimens were converted into polished thin sections using established laboratory protocols (referencing Tucker, 2011; Aigbadon et al., 2024). These sections were examined under a BXL-41 Olympus polarizing microscope to identify and describe key components such as skeletal and non-skeletal grains (allochems), the surrounding fine-grained matrix, binding cements, and void spaces. The carbonate facies were classified using Dunham's (1962) depositional texture framework, which organizes carbonates based on their fabric and grain support. High-quality photomicrographs were taken to visually document distinct features and textures observed during microscopic analysis.

For the mineralogical component, 500 grams of each rock sample were ground to a uniform powder using an agate mortar and pestle to ensure consistency. These powdered samples underwent X-ray diffraction (XRD) analysis using a Bruker D8 Advance diffractometer, fitted with a Cu Kα radiation source. The scan covered a 2θ angle range from 5° to 70°, with a step increment of 0.02° and a data collection time of one second per step. The diffraction results were analyzed using Bruker DIFFRAC.EVA software and compared against reference patterns from the International Centre for Diffraction Data (ICDD) to identify the mineral constituents and estimate their relative quantities based on peak intensities.

For geochemical analysis, separate portions of the powdered samples were prepared as pressed powder pellets. These pellets were then analyzed using a Xenemetrix XRF spectrometer to determine the major elemental oxide and elemental composition of the bulk rock. The XRF analysis was calibrated against international rock standards to ensure accuracy and precision of the elemental concentrations. The results were reported in weight percentages for the major oxides (e.g., SiO_2, Al_2O_3, CaO) and elements (e.g., Ca, Si, Al). The integration of the petrographic, mineralogical, and geochemical data was done for the characterization of the Igumale Formation carbonates and interpretation of their depositional environment.

3.0 Results and Discussion

At the top in Fig. 1 consist of sandstone units. The lithosection was capped at the top by cross-bedded sandstone units (Fig.1). At depths 60-70 m display light grey limestone pelycypods and similar lithological units with pelycypods was observed at depths 175-178m, though with a dark grey shale. Within depths 84-90m are mainly sandstone and siltstone units. The dominant lithology is light-dark grey limestones with interbeds of sandstones and siltstone units (Fig. 2). The base at depths of 190-220m is capped by dark laminated grey shale with gypsum-mineralization to dark grey shaley limestone (Fig. 2)

The mineralogical composition of the Igumale Formation, as determined by X-ray Diffraction (XRD) analysis, revealed that calcite ($CaCO_3$)

is the dominant mineral phase, constituting a significant 56-65 % of the bulk mineralogy. Subordinate mineral phases identified include quartz (SiO_2) at 24-27%, chlorite (a hydrous phyllosilicate) at 4.9 -11%, and albite (a sodium-rich plagioclase feldspar, $NaAlSi_3O_8$) at 3.1-9 % (Table 1, Fig. 3). The high proportion of calcite confirms the classification of these rocks as predominantly limestone. The presence of quartz indicates a contribution of siliciclastic material, likely derived from adjacent terrestrial sources or through the reworking of pre-existing siliciclastic sediments within the depositional basin (Osumanu et al., 2024; Odoma et al., 2023). Chlorite, a common clay mineral, may have originated as a detrital component or formed as a result of diagenetic alteration of other silicate minerals. Similarly, the presence of albite suggests a feldspathic input, potentially from the weathering of igneous or metamorphic source rocks.

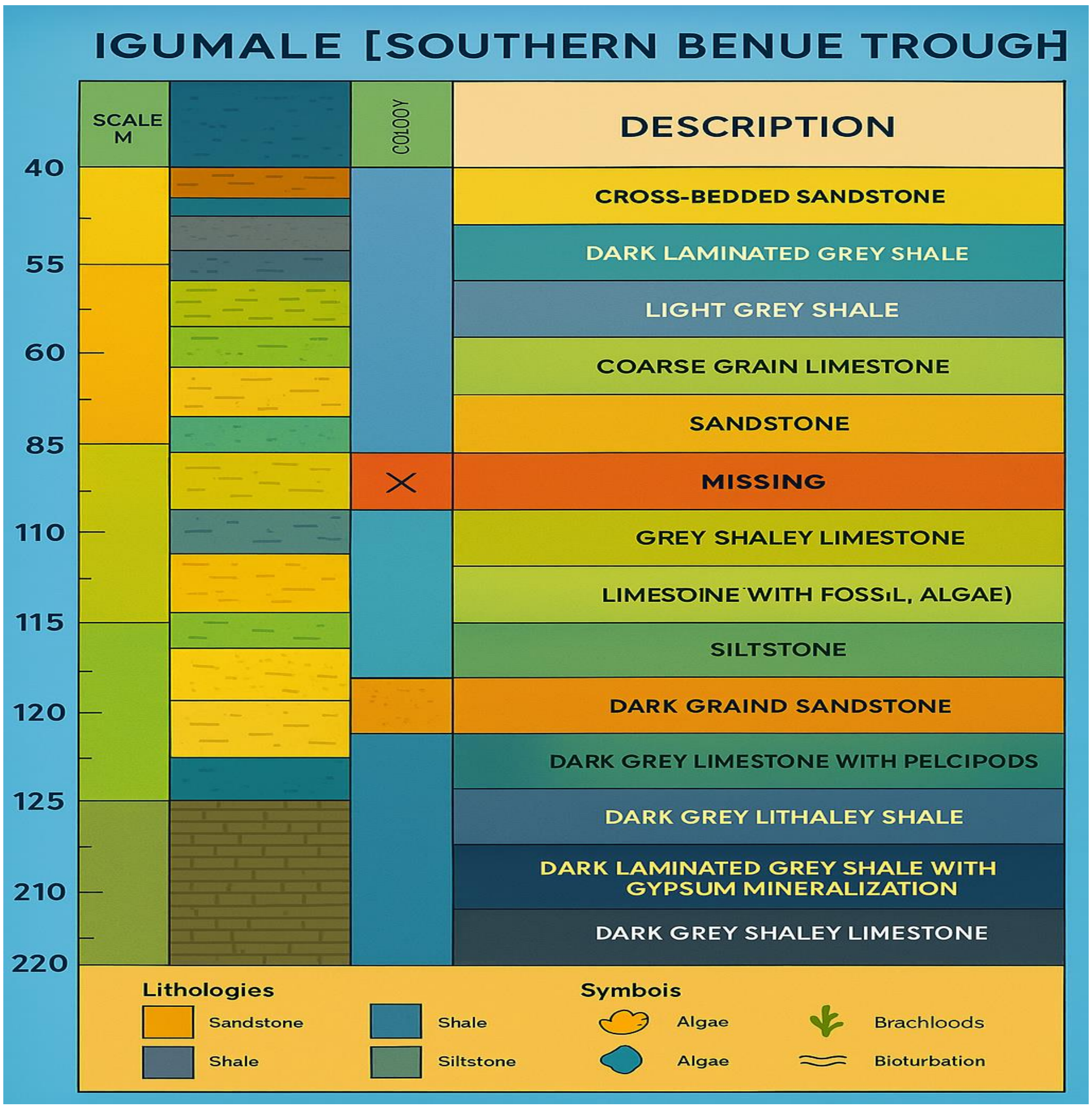

Fig 2: Lithologic section of studied well

Table 1: Mineralogical composition of limestone samples from Lower Benue Trough

Basin	Formation	Sample Location	Calcite (wt.%)	Quartz(wt .%)	Chlorite (wt.%)	Albite (wt.%)
Southern Benue trough	Asu-river group	Igumale (65-70 m)	65	27	4.9	3.1
Southern Benue trough	Asu-river group	Igumale (174-178m)	56	24	11.0	9.0

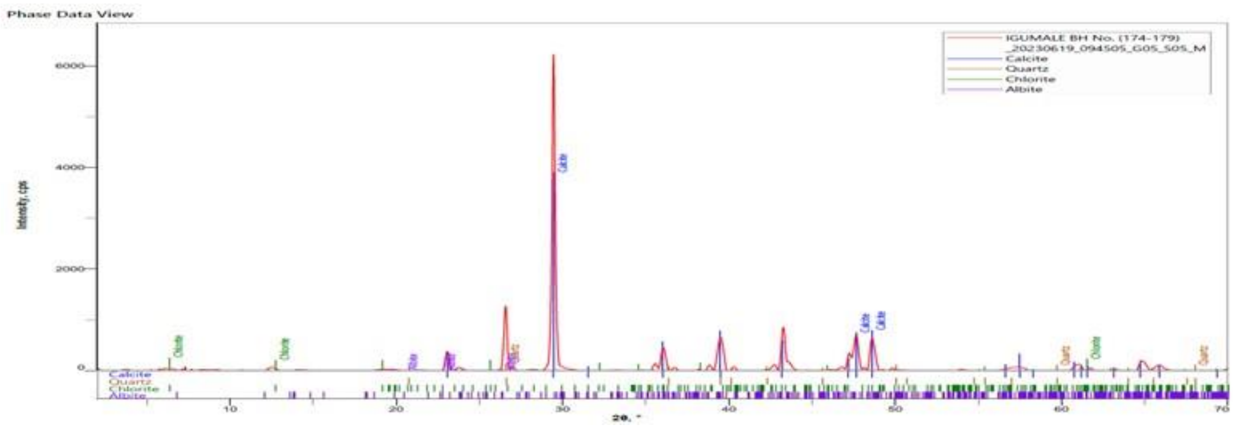

Fig. 3: XRD diffractogram of carbonate samples at depths 174-178m

X-ray Fluorescence (XRF) analysis provided a quantitative assessment of the major elemental oxides and elemental composition of the Igumale samples. The most abundant oxide was calcium oxide (CaO) at a substantial 74.032 weight percent, which corresponds to a calcium (Ca) mineralogicalconcentration of 60.05 weight percent. This exceptionally high concentration strongly supports the XRD finding of calcite dominance. Other significant oxides, although present in much lower concentrations, include silica (SiO_2) at 4.892 weight percent, alumina (Al_2O_3) at 3.041 weight percent, and iron oxide (Fe_2O_3) at 4.345 weight percent. Minor oxides such as manganese oxide (MnO) at 0.359 weight percent, magnesia (MgO) at 0.054 weight percent, and tin oxide (SnO_3) at 0.49 weight percent were also detected. The elemental analysis (Table 2) showedthe presence of oxygen (O) at 29.683 weight percent, silicon (Si) at 2.28 weight percent, aluminum (Al) at 1.609 weight percent, iron (Fe) at 3.039 weight percent, manganese (Mn) at 0.278 weight percent, and potassium (K) at 0.218 weight percent, with sodium (Na) being below the detection limit.

Table 2: Average oxide elemental composition for Igumale sample

Oxides	Concentration (wt%) Igumale	Elements	Concentration (wt%) Igumale
SiO_2	4.892	O	29.683
V_2O_5	0.025	Na	0
Cr_2O_3	0	Mg	0.032
MnO	0.359	Al	1.609

Fe_2O_3	4.345	Si	2.287
Co_3O_4	0.053	P	0.212
NiO	0.009	S	0.436
CuO	0.027	Cl	0.232
Nb_2O_3	0.018	K	0.218
WO_3	0	Ca	60.058
P_2O_5	0.485	Ti	0.153
CaO	74.032	V	0.014
MgO	0.054	Cr	0
K_2O	0.263	Mn	0.278
BaO	0.186	Fe	3.039
Al_2O_3	3.041	Co	0.039
Ta_2O_5	0.071	Ni	0.007
TiO_2	0.255	Cu	0.022
ZnO	0.006	Zn	0.005
Ag_2O	0	Zr	0.050
Cl	0.232	Nb	0.014
ZrO_2	0.067	Ag	0
SnO_2	0.490	Sn	0.386
Na_2O	0	Ba	0.167
		Ta	0.058
		W	0

The petrographic examination of thin sections from the Igumale Formation samples revealed two distinct carbonate microfacies, each providing key insights into the depositional environment:

- Sandy bioclastic wackestone (Fig. 4)**:** This microfacies is characterized by a significant presence of sand-sized grains, which may be composed of quartz or fragmented carbonate material, dispersed within a fine-grained micritic matrix (wackestone texture). A notable component of this microfacies is the abundance of fossil fragments (bioclasts), including recognizable remains of bivalves and ostracods, indicating a marine fauna. The lack of clear boundaries between the cementing micrite and the larger carbonate grains suggests a relatively low-energy depositional setting where fine-grained carbonate mud accumulated alongside coarser siliciclastic and bioclastic material. The presence of quartz grains within the matrix further underscores the influence of siliciclastic input into this carbonate depositional environment.

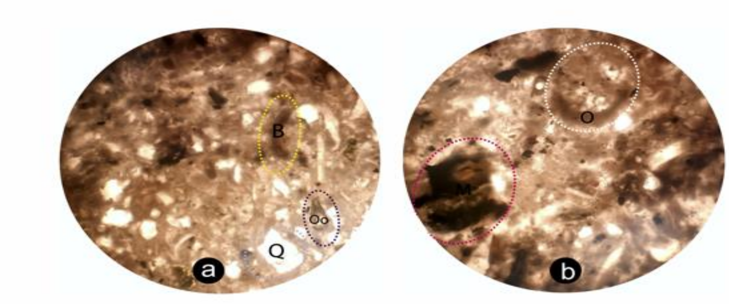

Fig. 4: Shows a sandy bioclastic wackestone

Micritic bioclastic packstone (Fig.5)**:** This microfacies exhibits a grain-supported texture (packstone) where bioclasts, consisting of fragmented shells of ostracods, brachiopods, and bivalves, are closely packed together. The interparticle spaces are primarily filled with sparite cement, indicating post-depositional recrystallization and cementation. The presence of micrite, although subordinate to the bioclasts, suggests that fine-grained carbonate mud was also a component of the original sediment. Some bioclasts show evidence of internal micritization, a process where micrite fills the internal cavities of shells. The occurrence of small fragments of quartz crystals within this microfacies again points to a degree of siliciclastic influence.

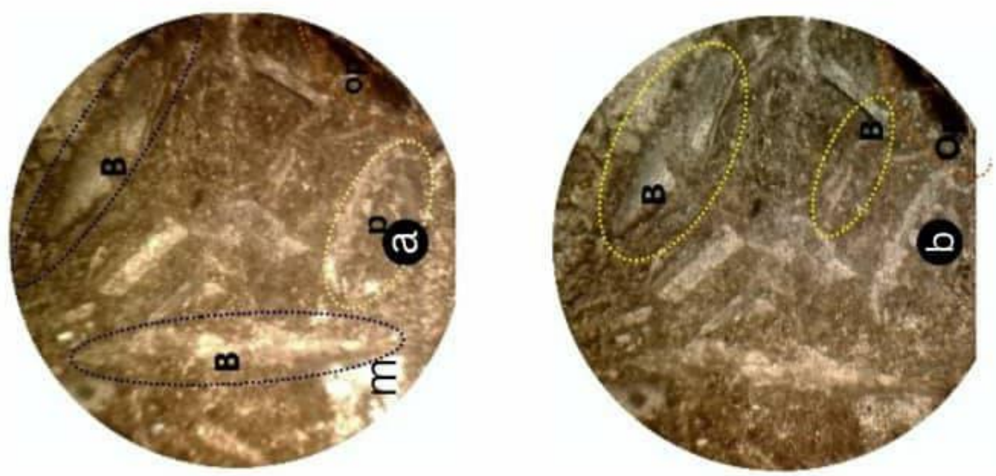

Fig.5: Shows a micritic bioclastic packstone

The mineralogical composition of the Igumale Formation, dominated by calcite (56--65%) as revealed by XRD, firmly establishes these rocks as limestone with a high degree of carbonate purity. This is further supported by the exceptionally high CaO content (74.032 wt%) identified through XRF analysis. The subordinate presence of quartz (24 -27%), chlorite (4.96 -11.0%), and albite (3.1-9.0%) indicates a consistent, albeit minor, influx of siliciclastic material into the carbonate depositional system (Reineck and Singh, 1973; Aigbadon et al., 2024). This detrital input could be attributed to the proximity of terrestrial source areas or the influence of processes such as fluvial discharge or tidal currents transporting siliciclastic sediments into the shallow marine environment where carbonate precipitation and accumulation were occurring (Syum et al., 2025).

The two distinct microfacies identified in the Igumale Formation provide crucial insights into the paleo environmental conditions. The sandy bioclastic wackestone suggests deposition in a relatively low-energy shallow marine or possibly a transitional environment such as a tidal flat. The mud-supported texture (wackestone) indicates deposition from suspension in quiet waters, while the presence of sand-sized grains and quartz points to periods of increased energy or proximity to a siliciclastic source (Reading, 1986). The presence of marine fossils (bivalves and ostracods) confirms a marine influence, although the admixture of siliciclastic material might suggest a nearshore setting.

The micritic bioclastic packstone, on the other hand, indicates a slightly higher energy shallow marine environment where bioclastic material (ostracods, brachiopods, bivalves) accumulated and became closely packed, resulting in a grain-supported texture (packstone). The presence of sparite cement suggests post-depositional diagenetic alteration in a relatively open pore system. The micritic component likely represents periods of lower energy sedimentation of fine-grained carbonate mud (Agboola & Hashemi, 2024). The occurrence of quartz fragments within this microfacies further supports the pervasive influence of siliciclastic input in the broader depositional setting of the Igumale Formation (Tucker, 2011; Aigbadon et al., 2024).

The overall interpretation of the microfacies and mineralogical data suggests that the Igumale Formation was deposited in a dynamic shallow marine environment that experienced fluctuations in energy levels and was consistently influenced by the input of siliciclastic material. This environment supported a diverse marine biota, as evidenced by the variety of bioclasts observed. The characteristics of the sandy bioclastic wackestone might indicate deposition in a more nearshore or tidally influenced setting, while the micritic bioclastic packstone could represent slightly more offshore or higher energy shoals or banks where bioclastic debris accumulated. The significant calcite content throughout both microfacies underscores the overall carbonate-dominated nature of the depositional system, albeit with a notable siliciclastic component.

4.0 Conclusions

The detailed petrographic, mineralogical, and geochemical analysis of the Igumale Formation within the Lower Benue Trough has revealed two distinct carbonate microfacies: sandy bioclastic wackestone and micritic bioclastic packstone. The mineralogical composition is overwhelmingly dominated by calcite, with subordinate amounts of quartz, chlorite, and albite indicating a consistent influx of siliciclastic material. The high CaO content further confirms the carbonate-rich nature of the formation. Petrographic evidence suggests that the Igumale Formation was deposited in a dynamic shallow marine environment characterized by fluctuating energy conditions and a persistent influence of terrigenous input. The sandy bioclastic wackestone likely formed in a lower energy, nearshore or tidal flat setting with mixed carbonate and siliciclastic sedimentation, while the micritic bioclastic packstone suggests a slightly higher energy shallow marine environment with significant bioclastic accumulation and subsequent diagenetic cementation. These findings provide valuable insights into the paleoenvironmental conditions and sedimentary processes that shaped the carbonate deposits of the Igumale Formation during the Cretaceous period within the lower Benue Trough, contributing detailed understanding of the basin's geological evolution.

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Declaration

Consent for publication

Not applicable

Availability of data

Data shall be made available on demand.

Competing interests

The authors declared no conflict of interest

Ethical Consideration

Not applicable

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