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MICROFACIES ANALYSIS OF CRETACEOUS SEDIMENTS OF DUKUL FORMATION, YOLA SUB-BASIN, NORTHERN BENUE TROUGH, NIGERIA: PALEO-ENVIRONMENTAL IMPLICATIONS

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ABSTRACT

Carbonate microfacies analysis was conducted on the exposed sediments of Dukul Formation from Yola Sub-basin of the Northern Benue Trough with an objective to reconstruct the paleodepositional environment. The study revealed four (4) major microfacies; oyster wackestone, ostracod oyster wackestone-packestone, bioclastic wackestone and bioclastic packestone microfacies. The microfacies assemblages indicate and affirm that the Dukul Formation sediments were deposited in shallow marine (mid-inner ramp) environment under suboxic to relatively anoxic conditions due to sea-level drop. This is further supported owing to the occurence of *corals, brachiopods, bivalves* and *ostracods* immediately below the mean fair-weather wave base (FWWB).

Keywords: Sedimentary; Carbonate; Shallow Marine; Facies Model; Ramp Setting

INTRODUCTION

Carbonate sedimentary successions are formed in one of the three main depositional settings; the carbonate shelves, the carbonate platforms and/or the carbonate ramps (Tucker, 1985). One type of the depositional setting may perhaps develop into another setting through either sedimentologic or tectonic processes (Nichols, 2009). More so, there are a lot of significant variations in the mineralogy of carbonates especially in the skeletons, ooids and syn-sedimentary cement through geologic time (Tucker, 1985; Anan, 2014). Moreover, carbonate deposition involves a complex process more than the other sedimentary types.

The Benue Trough is an intra-continental rift sedimentary basin (Sarki Yandoka et al., 2014; Abubakar, 2014). It was divided into Southern (Lower), Central (Middle) and Northern (Upper) Benue basins (Zaborski, et al., 1997; Nwajide, 2013; Sarki Yandoka et al., 2014; Sarki Yandoka, 2015). (Fig. 1). The Northern Benue Trough consists of the Gongola Sub-basin and the Yola Sub-basin (Fig. 1). The study area falls within the Yola Sub-basin. The Cretaceous Dukul Formation (the subject of this study) was earlier recognized as sequences of "Limestone – Shale Series" and assigned to the Lower Turonian (Falconer, 1911; Carter et al., 1963; Kogbe, 1976: Guiraud, 1990, 1992). It consists of clays, shale, siltstones and thick limestone (Ojo and Akande, 2000; Nwajide, 2013; Sarki Yandoka, 2015).

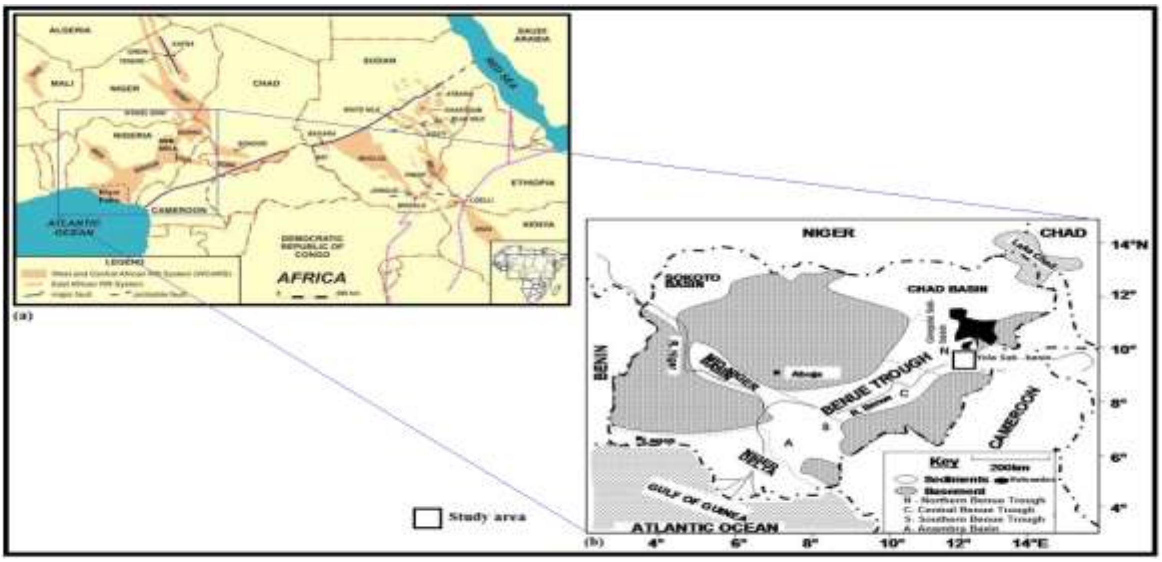

Figure 1: : (a) Regional tectonic map of west and central African rift basins showing (b) the Nigerian Benue Trough and study area (from Sarki Yandoka et al., 2016).

Carbonate microfacies analysis and models on the Cretaceous sequences of Dukul Formation are lacking. This study however, attempts to present the carbonate microfacies and other diagenetic characteristics of Dukul Formation with an objective of describing and interpreting the paleodepositional environment and reconstruct the paleodepositional model. It is expected that findings from this research could be used for future studies related to sequence and tectonostratigraphic reconstruction of the Northern Benue Trough for petroleum exploration and resource assessment of the region.

2. Geology and stratigraphy

The Nigerian Benue Trough was formed during the Early Cretaceous rifting and strike-slip faulting or movement of the Central West African Basement Complex (Carter et al., 1963; Grant, 1971; Kogbe, 1976; Genik, 1993; Benkhelil, 1983; 1989; Obaje, et al., 2000; Abubakar, 2014). The Benue Trough trends northeast-southwest and about 1000 km in length and about 150 km in its width. It is bounded in the south by the Niger Delta Basin and the Chad (Bornu) Basin in the north (Zarborski et al. 1997; Abubakar, 2014; Sarki Yandoka et al. 2014). The NE-SW trend of the Benue Trough can be seen from the geological map of Northern Benue Trough (Fig. 2), indicating the Gongola and Yola Sub-basins. The area where lithostratigraphic sections were logged is shown in Figure 2.

The geology and stratigraphy of the Northern Benue Trough were described in detail by earlier workers such as Carter et al., (1963), Abubakar, (2014), Sarki Yandoka et al., (2014), Ojo and Akande (2000), Sarki Yandoka, (2015) and among many others. The stratigraphic succession of the Yola Sub-basin (Fig. 3) comprises of the Berremian-Aptian to Albian continental sediments of Bima Formation (Carter et al. 1963; Sarki Yandoka et al. 2014)). The Bima Formation consists of main cobbles, gravels, sandstones and shales/clays. Recent authors (e.g. Tukur et al., 2015) sub-divided the Bima Formation into two end-members; the Lower Bima (B1) and the Upper Bima (B2) members.

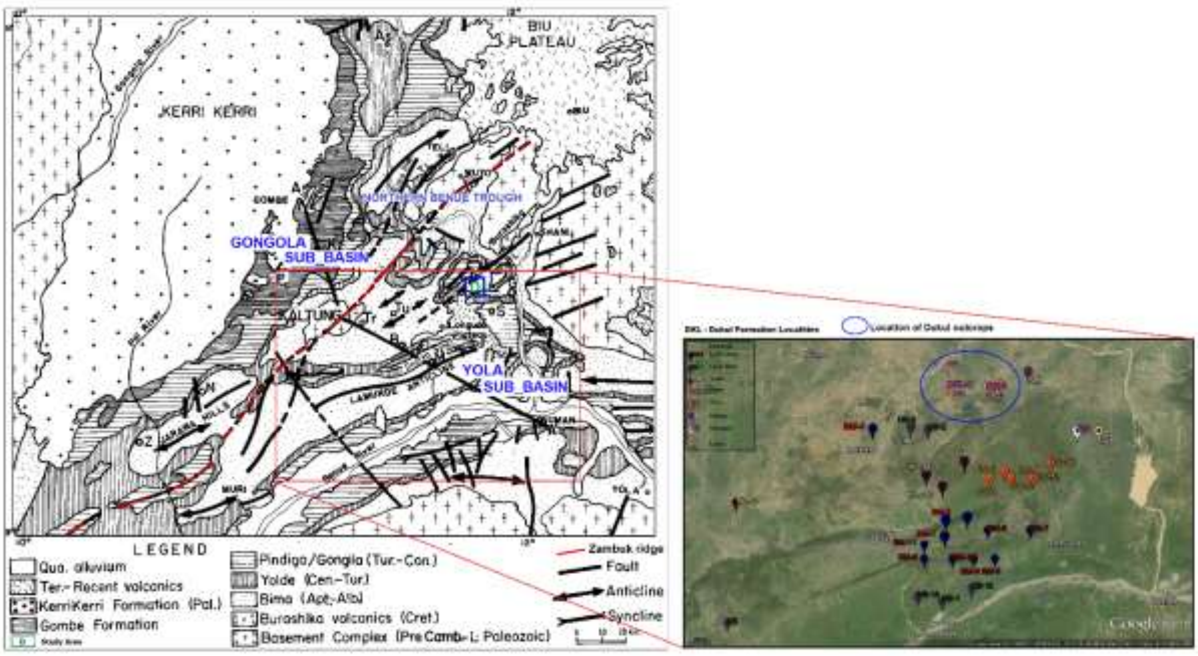

Figure 2: (a) Simplified geological map showing the study area (modified after Akande et al., 1998) and (b) Google Earth Map showing the studied localities

The Bima Formation is overlying by the Cenomanian transitional coastal and shallow marine sediments of Yolde Formation. The Cenomanian Yolde Formation consists of sandstones, clays and occasionally calcereous materials (Sarki Yandoka et al., 2015). The sediments were succeeded by the marine Late Cenomanina – Turonian – Coniacian sequences of the Dukul, Jessu and Sekuliye Formations and Numanha Shales (Sarki Yandoka et al., 2019). These shallow marine sediments are the lateral equivalents of Pindiga and Gongila Formations in the Gongola Sub-basin (Abubakar, 2014). The Dukul Formation generally consists of bedded shales and fossiliferous limestone (Carter et al., 1963). Its type locality is at Dukul village and the formation is also exposed at Cham, Lakun and Kutari areas.

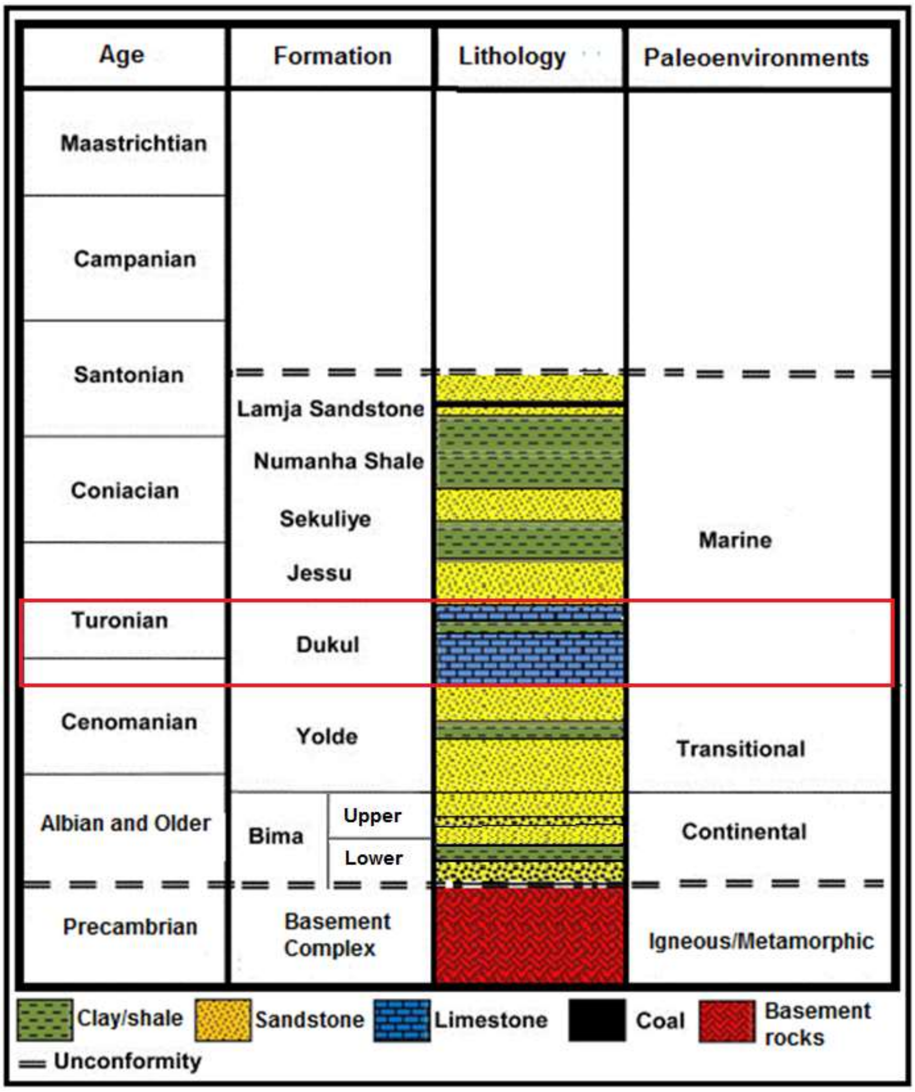

Figure 3: Stratigraphy of Yola Sub-basin successions (from Sarki Yandoka, 2015)

MATERIALS AND METHODS

Fieldwork was conducted on the exposed outcrops of Dukul Formation around Cham, Lakun and Kutari areas in the Yola Sub-basin. Lithostratigraphic sections were measured. Description of lithology and facies analysis covering silicilastic lithofacies and carbonate microfacies was conducted. Sedimentological features such as color, texture, trace or body fossils and thicknesses of beds were studied. Macrofossils that were found in some of the sections were collected. Samples of limestones were obtained at different stratigraphic intervals of about 3-4m. The limestone samples were grounded to smaller sizes 8-10mm for slides preparation. The samples were mounted on a glass slide and smoothen using finer abrasive grit until the samples are 30µm thick. Petrographic examination of carbonate microfacies and classification were carried out based on Dunham (1962) classification. The procedures were repeated for all the studied samples.

4. Results and discussions

4.1 Lithostratigraphy

The sediments in the study areas are composed of mainly sandstones, siltstones, clays and shales and are widely distributed in all the lithostratigraphic sections (Fig. 4). The sediments vary in colour from grey, black, greyish-yellow, gypsiferous, calcareous, occasionally glauconitic and perhaps fossiliferous with a thickness of about 6m. The shale and sandstones are interbedded with fossiliferous limestone facies (Fig. 5). The quality of the rocks differs from one location to another as some samples were hard, thickly laminated but feasible with texture. The mudstones are generally intercalated with sandstone and siltstones that are calcareous and glauconitic with a thickness ranging from 3m and are laterally extensive.

4.2 Microfacies analysis

The carbonates constitute the major part of Dukul Formation in the Yola Sub-basin. Thickly bedded limestones of the FL lithofacies were studied using the Dunham classification (1962) for carbonatic rocks. The carbonate microfacies analysis enabled us to sub-divide the carbonates into four (4) facies types. Silicification and dolomitization were also observed in the study area.

Bioturbations are generally uncommon in most of the logged sections. Body fossils are rare but are found as sparse fragments within the logged sections. Microfacies analysis revealed the following:

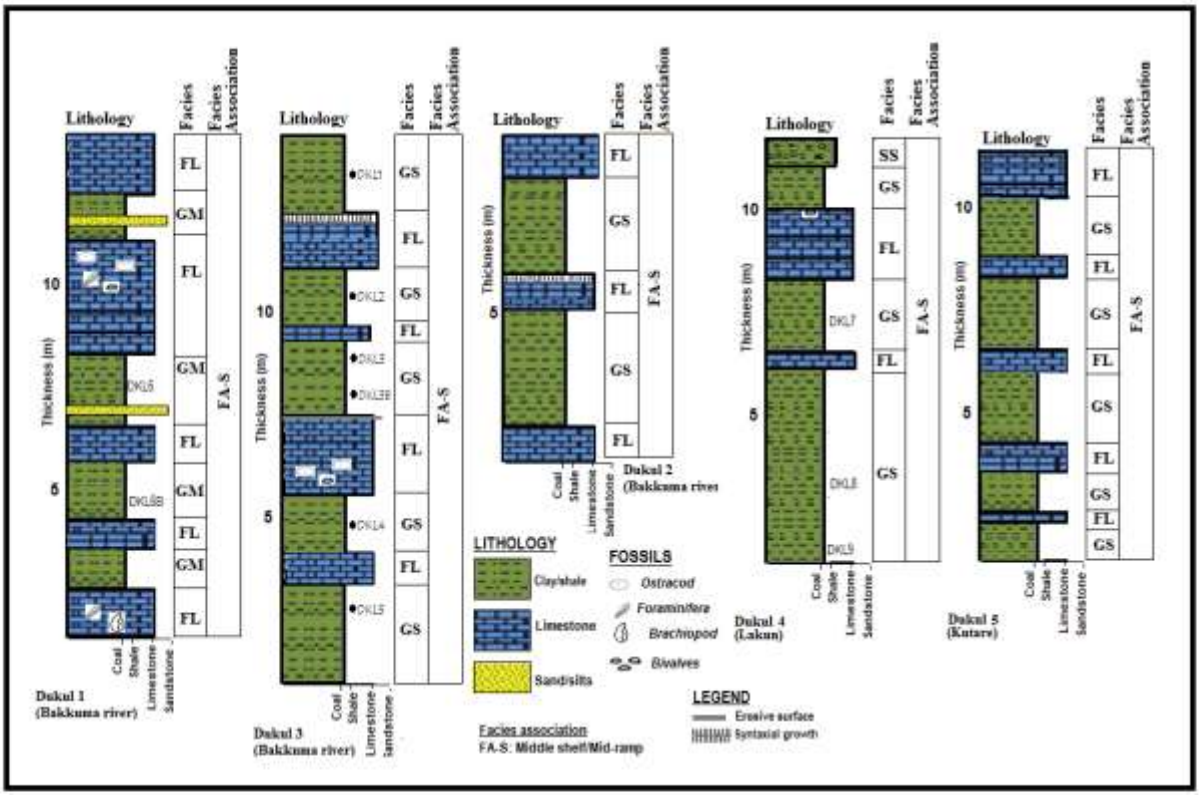

Figure 4: Lithostratigraphic sections of Dukul Formation based on this study

Microfacies OW: Oyster Wackestone

These microfacies are composed of the oyster fragment (almost 40%) (Figs. 5 and 6) including ostracods and gastropods with some scattered calcareous materials. However, diagenetic features are the replacement of the oyster fragments. Minor to moderate bioturbation was encountered in these microfacies. In the African sub-region, the oysters inhabit shallow water depositional environment (e.g. Dhondt et al., 1999). Oysters are abundant in the geologic record from the Cenomanian to around the Middle Turonian (Bauer et al., 2003).

Microfacies OWP: Ostracod oyster wackestone–packestone

The ostracod oyster wackestone-packestone microfacies are found in samples collected from almost all the logged sections; Bakkuma River, Lakun and Kutare. The facies are composed of ostracods (30%, Figs. 5 and 6) with fragments of oysters, gastropods and unidentifiable foraminifera and echinoderm. Allochems are generally moderately parked and sorted, ranging in sizes from coarse to fine embedded in carbonate matrix. Diagenetic alterations are the replacement of oyster fragments and ostracod filled with calcite.

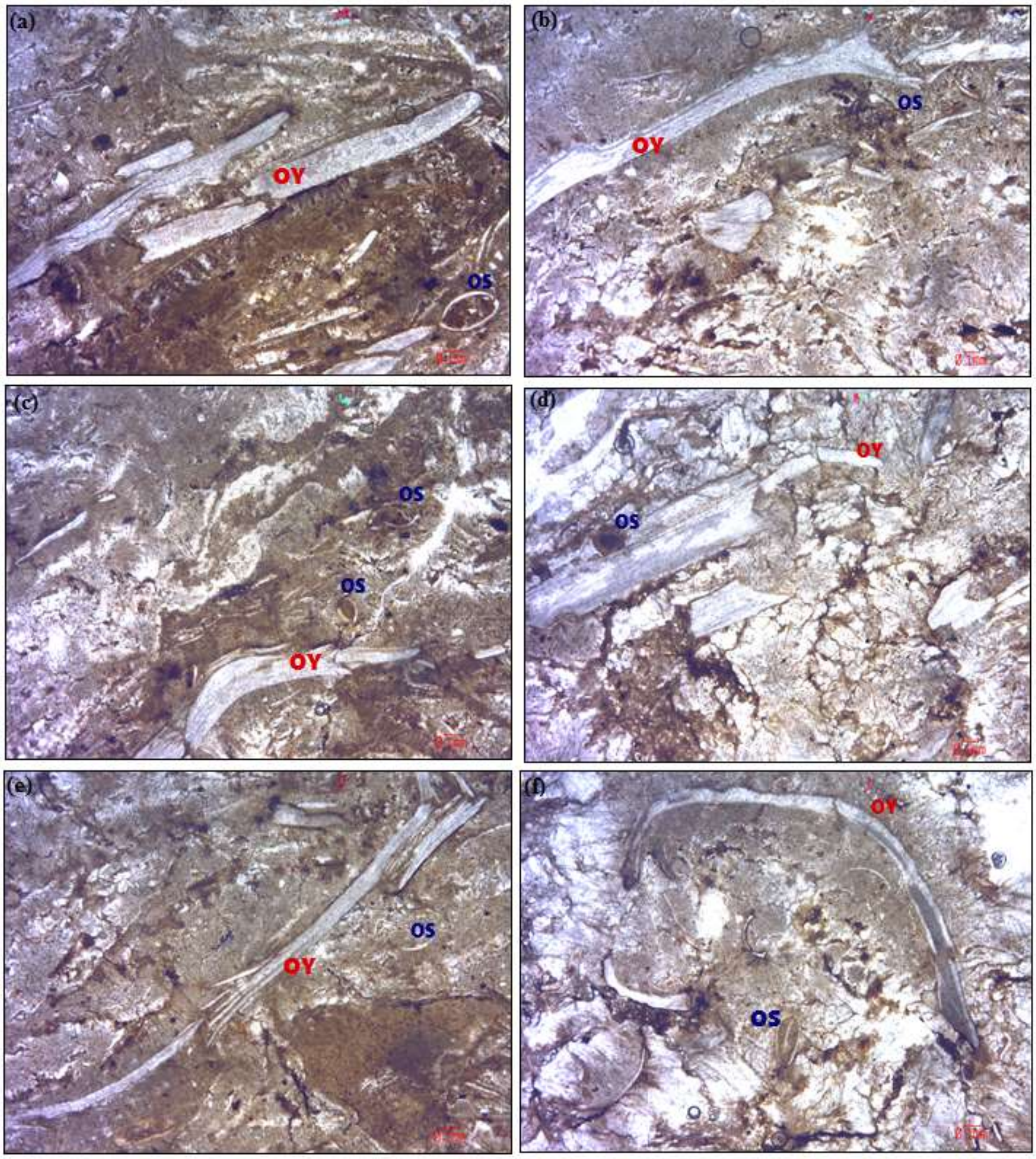

Figure 5: Photomicrograph of carbonate microfacies showing (a-f) oyster wackestone with oyster fragments (OY) and ostracod oyster wackestone–packstone with other fossils encountered in low distributions (magnification 0.1mm).

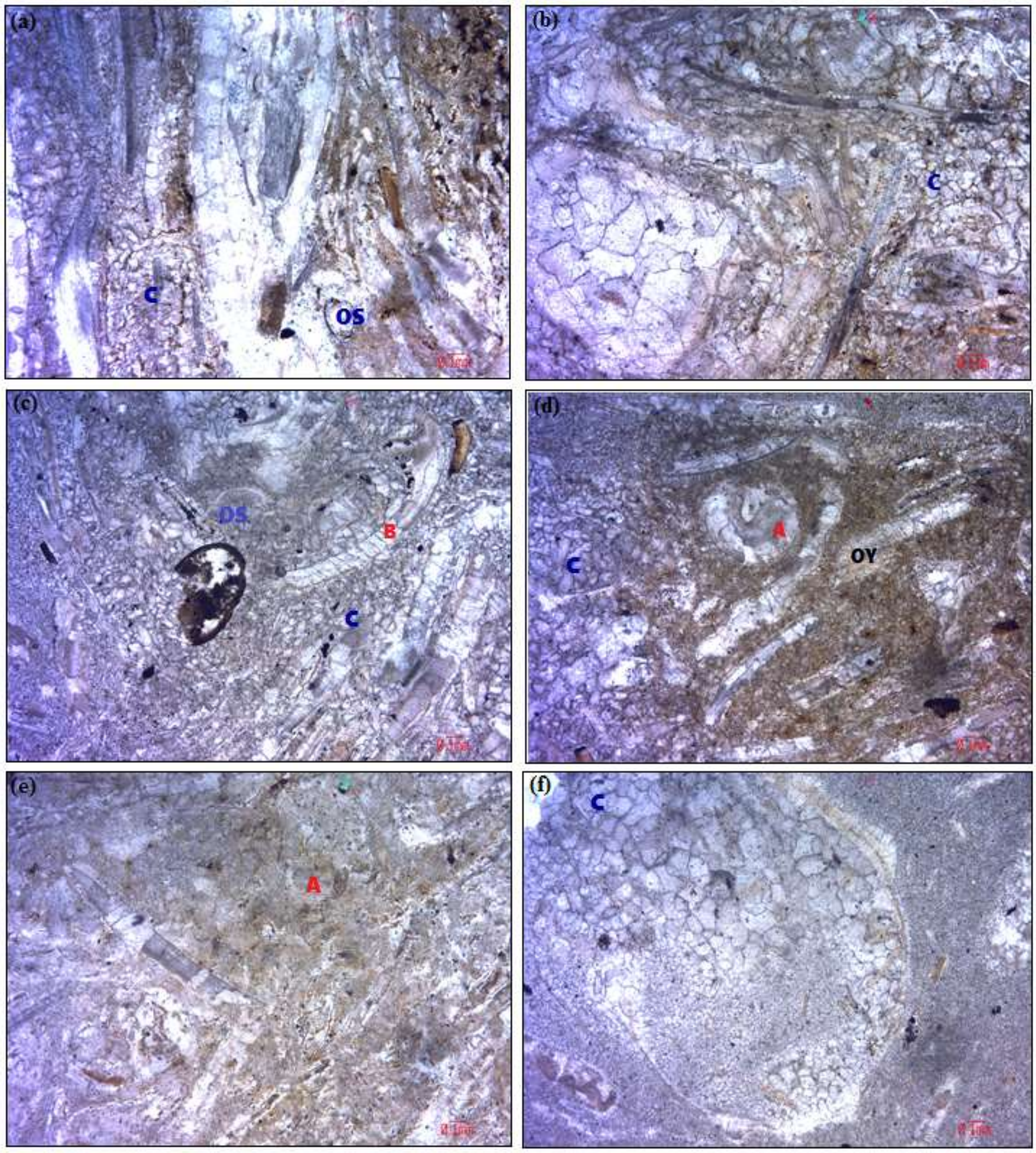

Figure 6: Photomicrograph of carbonate microfacies showing (a-f) bioclastics wackestones, packestones and fossils such as corals (C), ostracods (OS), oysters (OY) and ammonite (A) with other fossils encountered in low distribution (mag. 0.1mm)

Microfacies BP: Bioclastic packestone

In these microfacies, the clasts components may include corals, brachiopods, peloids in various proportions. It shows several shell fragments but has been replaced by sparry calcite. The predominant texture here is the packstone but peloidal and non-fossiliferous grainstone may also be present. Some of the fractures vugs in the shell fragments and the crystalline pores of the microspar are filled with pyrobitumen.

4.2.4 Microfacies BW: Bioclastic wackestone

Bioclastic wackestone microfacies are dark to medium gray having a micrite matrix. It consists of marine fossil bioclasts. Important components are bivalves, brachiopods, intraclasts embedded in a micrite matrix. Original micrite has been recrystallized. The bivalve fragments have been replaced by sparry calcite leading to the preservation of the shells. This facies is partially dolomitized and shows a lenticular to wedged-shape geometry.

4.3 Paleoenvironmental implications

Carbonate microfacies analysis of the studied Dukul Formation allows interpretation of the depositional environment as mid-inner ramp facies succession. The paleoenvironmental interpretation of the microfacies are based on sedimentological and paleontological features observed. Structural features and textural analysis of the studied carbonates indicate that the samples were affected by many diagenetic processes e.g. micritization, cementation, dissolution and compaction (Tucker and Wright, 1990; Anan, 2014). The fine-grained carbonatic materials were largely derived from shallow water areas.

The oyster wackestone (OW) microfacies indicate deposition in shallow water or marine carbonate environment just below the mean fair-weather wave base (FWWB). Bioturbation and micrite also support low energy depositional condition (e.g. Nichols, 2009; Anan, 2014). However, oysters tolerate several paleodepositional environmental conditions during formation and deposition. They are usually present in shallow but restricted environments under high energy and lower salinity stratified column (Pufahl and James, 2006).

The presence of oysters in almost all the samples further confirms a shallow marine environment. Although, this type of environment is unfavorable for benthic foraminifera. So some microfacies may indicate deposition in a relatively shallow marine environment where large fragments of shell were abraded by the action of waves (Nichols, 2009). Heckel, (1977) interpreted bioclastic packstone as part of the upper limestone series in the cyclothem model. This microfacies is however, interpreted as deposition in a moderate energy environment immediately below the mean fair-weather wave base (FWWB).

Textural combination coupled with the presence of fauna also suggests deposition in marine or perhaps moderate energy shallow environment (Heckel, 1977; Nichols, 2009). Evidence of micrite matrix in bioclastic wackestone facies is also an indication of a low energy depositional environment as demonstrated by Heckel, (1977). Similar of these facies were interpreted as low energy shallow marine deposits below the fair-weather wave base (FWWB) based on well-preserved body fossils. Bioclasts disarticulation may be due to storm activity or moderate bioturbation within the shallow marine depositional complex.

An idealized model summarizing the distribution of the encountered microfacies in a ramp that developed during the Cenomanian–Turonian in Yola Sub-basin is given in Figure 7. This model provides an inference for the interpretation of vertical facies changes in terms of Walther's Law of the succession of facies. The depositional model of the studied successions indicates ramp depositional facies. The ramp consists of limestone, sandstone, shale, mudstone and the oyster wackestone whilst other lithologies are siltstones, shale, mudstone and ostracod oyster wackestone– packstone including other fossil assemblages.

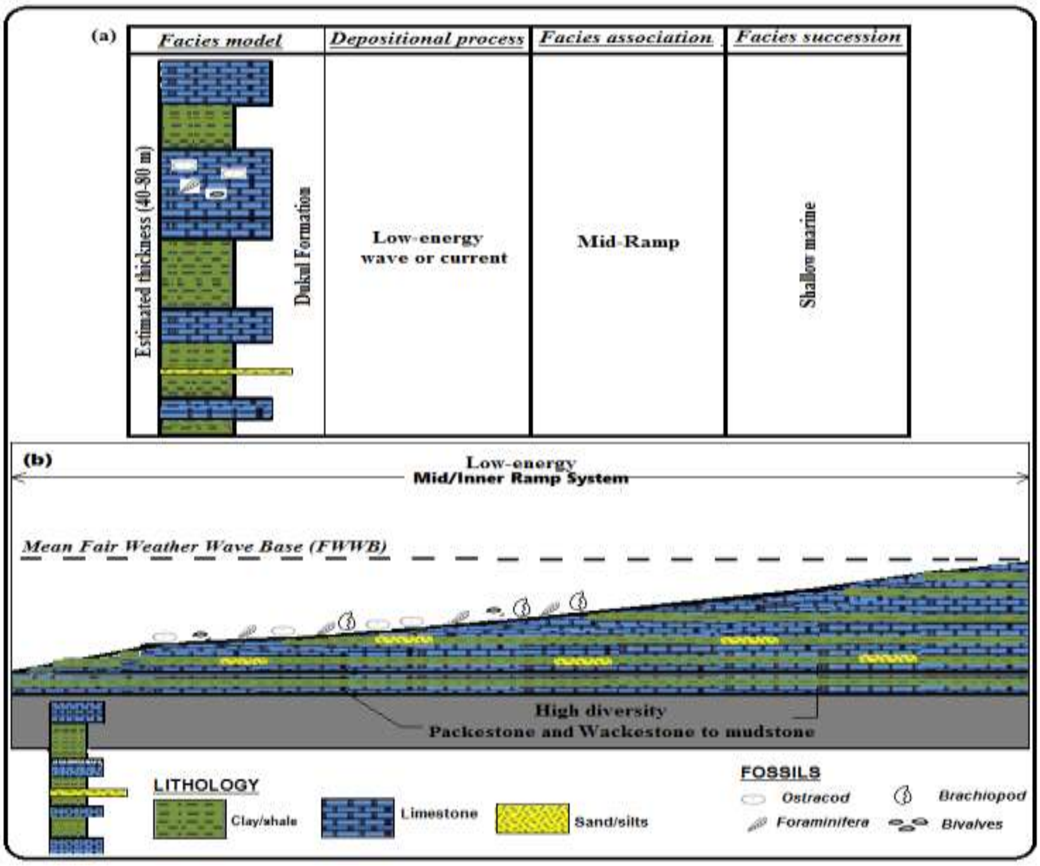

Figure 7: Depositional and facies model showing the summary of facies succession of Dukul Formation based on this study

However, the proposed depositional model with a summary of lithofacies and microfacies distributions were inferred as deposition in the shallow marine ramp. Carter et al. (1963) Genik, (1993), Guiraud, (1993) Sarki Yandoka et al. (2014) and many others reported that during the Cenomanian, major marine transgression affected the entire Benue Trough. The transgression also matched with the regional and global sea-level rise (Haq et al., 1987). Thus, the Cenomanian marine transgression was responsible for the deposition of transitional Yolde Formation conformably on the continental Bima Formation (Sarki Yandoka, 2015).

The coastal-shallow marine siliciclastic facies of the Cenomanian Yolde Formation gradually transformed into a Carbonate dominated depositional environment, most probably due to the relative sea-level rise which continued resulting in the development of a deeply entrenched carbonate shallow marine (ramp) environment of the Dukul Formation. The abundance of low to moderate energy facies and lack of marine turbidite deposits indicate their development in such a setting. Occurrence of carbonate-silicilastic facies indicates that the sediment influx from land has significantly reduced.

The facies model should be regarded as a predictive tool and not as a paleogeographic reconstruction for a certain time interval. The facies distribution as well as the presence of larger oysters, corals and ostracod assemblages suggest that the depositional profiles of the studied sediments is consistent with a ramp model. Burchette and Wright (1992) sub-divided ramp depositional systems based on the fair-weather wave base (FWWB) and the storm wave base (SWB). According to the microfacies distribution, a distal inner ramp/middle ramp transitional setting represented by carbonate microfacies types is located under constant wave-agitated environments across the FWWB (Fig. 7).

CONCLUSIONS

Carbonate microfacies analysis of the Cretaceous sequences of Dukul Formation from Yola Sub-basin, Northern Benue Trough, northeast Nigeria has revealed the following;

- The sediments were deposited in a ramp environment (coastal-shallow marine depositional complex) just below the mean fair-weather wave base, where the facies of the inner/mid-ramp are dominated by sandstones, shale, mudstone, oyster wackestone, ostracod oyster wacke–packstone and the outer ramp facies are not represented and thus, not present in the study areas,
- The sediments are interpreted as deposits of the shallow marine (ramp) depositional environment. This confirms that the coastal-shallow marine Cenomanian Yolde Formation was gradually transformed into a Carbonate dominated setting due to the relative rise in sea-level which results in the development of carbonate ramp environment of the Cretaceous Dukul Formation in the Yola Sub-basin.

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