SPSBIC 2024 21ST-24TH APRIL, 2024 MINNA NIGERIA

Proceedings of the 4th School of Physical Sciences Biennial International Conference

Outcrop and petrographic lithofacies analyses of the Kanawa Member of Pindiga Formation, Northern Benue Trough, Nigeria: Implications for environment of deposition

Isah Aliyu Goro
Department of geology, Federal university of Technology, PMB 65 Minna, Nigeria
isahgoro@futminna.edu.ng

Abstract

Understanding the depositional history of carbonate rocks is key to successful resource exploration and exploitation. The Kanawa Member of Pindiga Formation in the Gongola sub-basin of the northern Benue trough is a limestone-shale succession which has been a subject of research especially on the macro and micro fossil contents based on which the open marine environment of deposition has been inferred. However, the existing literature lacks clarity on the nature of the carbonate platform upon which the Kanawa Member was deposited. There are two primary aims of this study: 1) To investigate the macro (outcrop) and micro (thin-section) facies and 2) To ascertain depositional environment based on integrated macro and micro facies analyses. The method employed is detailed outcrop studies combined with thin-section microfacies analyses of the Ashaka quarry and Pindiga stream sections. Results reveal the presence of dark grey to black, fissile mudstone facies and limestone facies. The limestone facies is in turn divisible into three sub-facies including mudstone-wackestone, wackestone-packstone and packstone microfacies. The lithofacies are organised into two associations, namely 1) outer ramp and mid-ramp facies associations. The facies architecture depicted by these associations suggests deposition in homooclinal carbonate ramp setting. This study demonstrates that the combination of detailed outcrop and microfacies analyses leads to a better understanding of paleogeography of carbonate rocks which is relevant to resource exploration and exploitation.

Keywords: Benue trough, Gongola basin, Kanawa Member, Pindiga Formation, Carbonate ramp

1.0 Introduction

Apart from serving as raw materials for the manufacturing and construction industries, reservoirs and aquifers in the petroleum and groundwater industries as well as host to several ore minerals, limestones (and dolostones) aid in understanding the geological history of the earth. Their depositional environment control the large scale facies architecture and several models have been used to explain their depositional processes (e.g., Ginsburg, 1953; Folk, 1973; Wantland & Pusey, 1975; Hardie, 1977; Harris, 1979). The Kanawa Member of the Pindiga Formation (Zaborski et al., 1997) is a shale-limestone unit that is about 200 m thickin the Gongola sub-basin of the northern Benue trough, Nigeria. The limestones are utilised for the manufacture of Portland cement (Ashaka Cement) among other uses and has the potentials as good reservoir rocks in the subsurface.

Currently our understanding of the depositional environment of the limestones of the Kanawa Member is based on biostratigraphy content especially ammonites (e.g., Zabosrki, 1995; Popoff et al., 1986) and palynological attributes (Aliyu et al., 2016). Despite a plethora of work on these sediments, gaps still exist concerning the documentation of the detailed microfacies of the limestone and lithofacies associations of the unit. The present work intends to document the outcrop lithofacies, microfacies, lithofacies associations and broad environment of deposition of the limsetones- mudstones of the Kanawa member of Pindiga Formation. This will give important insights on their stratigraphic architecture which is relevant for resource exploration and exploitation.

2.0 Geologic setting

The origin of the Gongola sub-basin of the northern Benue trough is related to the breakup of the Gondwana land in the late Jurassic to early Cretaceous when the West and Central African Rift System was initiated (Genik, 1992; Fig. 1). The sub-basin contains more than 6000 m of Cretaceous and tertiary sedimentary succession (Fig. 2). Marine conditions were established during the Cenomanian to Turonian which led to the deposition of the limestones and shales of the Kanawa Member of the Pindiga Formation (Fig. 2; Zabosrki et al. 1997, 1998, Aliyu et al., 2016). Even though the name Kanawa Formation was first proposed for the unit around Gongola basin, the name is now restricted to the lower part of Pindiga Formation (Zaborski et., 1997: Fig. 2). This unit is the stratigraphic equivalent of Gongila Formation in the Chad basin but has been used interchangeably used (e.g., Popoff et al., 1986; Covelli et al., 1992) before the work of Zaborski et al. (1997). This member was deposited during the late Cenomanian to early Turonian times (Aliyu et al., 2016). Several works have shown that the Tethys and the south Atlantic were connected via the Benue trough at the peak of this marine transgression (Collignon and Lefranc, 1974; Reyment, 1987; Reyment and Dingle, 1987; Courville et al., 1991; Zaborski, 2000).

Fresh samples of this unit commonly appear grey but weathers to light blue to green-grey colours; not commonly well exposed or used for settlement due to their swampy nature during the rainy season rather they are often cultivated (Zarborski et al., 1997). The most complete sections occur at the Ashaka quarry (27 m) and Pindiga section (80 m). Earlier works on this unit concentrated on ammonite biostratigraphy due to its rich ammonite content (e.g., Barber, 1957; Carter et al., 1963; Wonzy and Kogbe, 1981; Poppof et al., 1986; Meister, 1989; Oti, 1990; Courville, 1994; Zaborski, 1995). Molluscs, echinoids, sepulid, pynodont plates occur with the molluscs being the most dominant fossils while brachiopods and corals are absent (Zaborski et al., 1997). Petrologic works of Ojo (2004) at Pindiga section and Uti (1990) at Ashaka section inferred open marine depositional environments for the limestones. Ojo (2004) identified micritization, compaction, dissolution, neomorphism dolomitization and stylolitization as the diagenetic reactions.

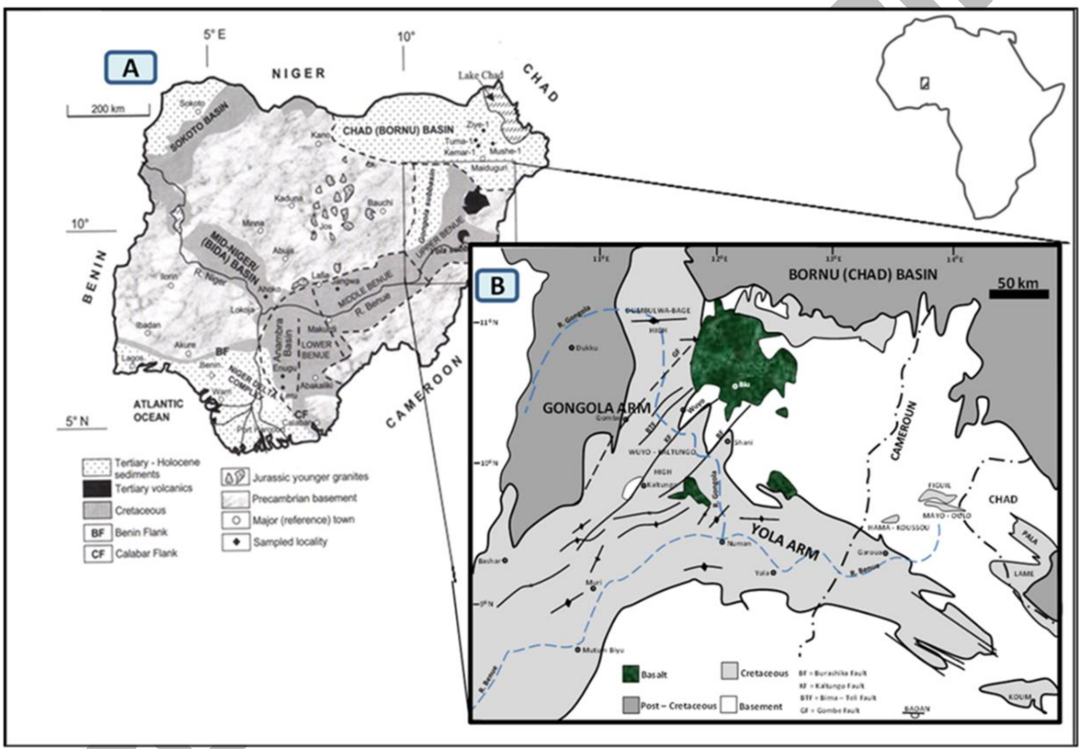

Figure 1. Simplified geological maps showing [A] Cretaceous basins of Nigeria (From Obaje et al., 2004; [B] the main features of the Northern Benue Trough (modified from Zaborski, 1998

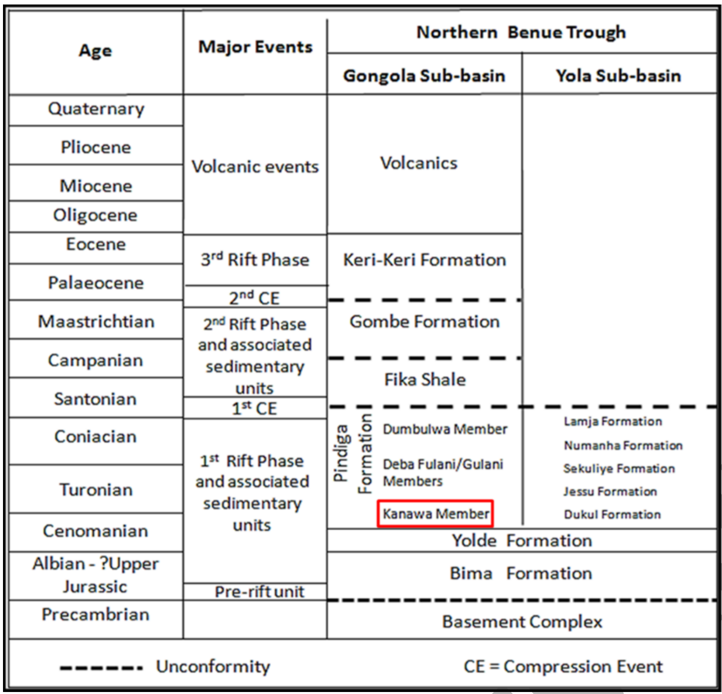

Figure 2. Lithostratigraphic successions in the Northern Benue Trough (Data from Genik, 1992; Guiraud, 1993; Zaborski et al., 1997; Zaborski, 1998; Abubakar et al., 2014).

3.0 Method

Field outcrop studies, laboratory and data analysis and interpretation stages were involved in the research. The Field outcrop studies was undertaken through examination of well exposed parts of Ashaka quarry face and Pindiga stream sections. The examination took account of the lithology, thickness, texture and structures of each bed, construction of sedimentologic graphic logs and sampling of each limestone bed for petrographic analysis.

Laboratory studies involved limestone thin section preparation and examination, documentation of framework grains, micrite and sparry calcite and their percentages as well as classification of the limestones using Dunham (1962) scheme. The Dunham scheme was used because it takes account of depositional textures which is vital to depositional facies analysis.

4.0 Results and Discussion

4.1 Lithofacies

A total of two major outcrop lithofacies were identified including the: 1) Dark grey to black fissile mudstone facies (K1) and 2) Limestone lithofacies (K2).

4.1.1 Dark grey to black fissile mudstone facies (K1)

This facies consists predominantly of dark grey to black fissile mudstones. The mudstones are interbedded with thin to thickly bedded limestones of facies K2 within the Kanawa Member (Fig. 3A, B). The facies is differentiated from similar facies of the Fika Shale in the basin by its lower stratigraphic position and the intimate association (inter-bedding) with beds of limestone (K2) facies (Fig. 4). Very thin lenses of diagenetic gypsum are abundant within this facies. Glauconites as well as phosphatic materials are sporadically concentrated near the contact with some of the associated limestone beds (Figs. 3 and 4). Bioturbation tend to be concentrated within the limestone beds with the mudstones generally not bioturbated.

4.1.2 Limestone facies (K2)

This facies consists mainly of bioclastic limestones in form of lime mudstones (marl), wackestones and packstones. The beds are typically bedded, laterally extensive and characterized by lack of primary depositional structures such as lamination or cross bedding. This facies occur as either 5 - 20 cm beds inter-bedded with the mudstones of K1 facies or as stacked limestone beds of up to 9 m thick (Fig. 3). Three sub-facies have been differentiated based on their petrography and field outcrop expression. The sub-facies include: 1) mudstone-wackestone (K2a); 2) wackestone-packstone (K2b); 3) packstone (K2c). The three sub-facies may grade into one another in a single limestone bed. In some parts, they form coarsening upwards cycle starting from K2a at the base, through K2b and capped by K2c (Fig. 3). Identifying features of the sub-facies are presented below.

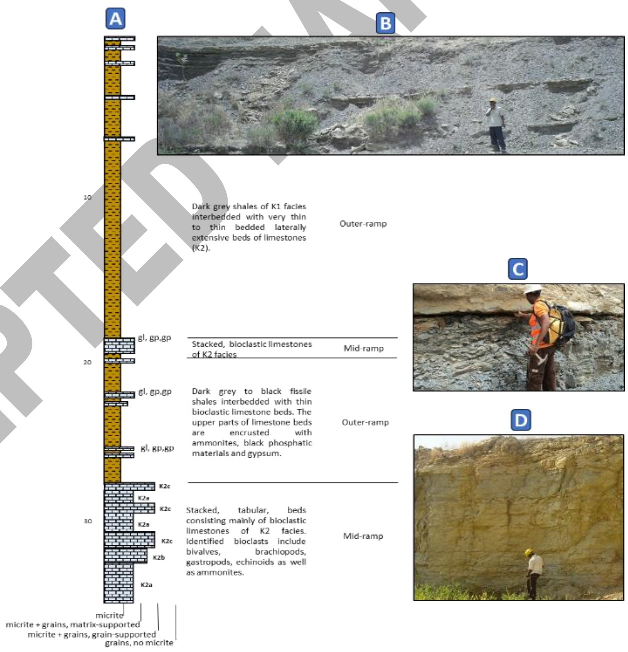

Figure 3. [A] Graphic log of the Kanawa Member exposed Ashaka Cement quarry: [B] upper part of the Kanawa Member; [C] middle part of the Kanawa Member; [D] Loower part of the Member. K2a - Mudstone-Wackestone with flaser texture, K2b - Wackestone – Packstone with fitted texture K2c - Packstones with nodular structure. Note: gl=glauconites, ph=phosphates, gp=gypsum

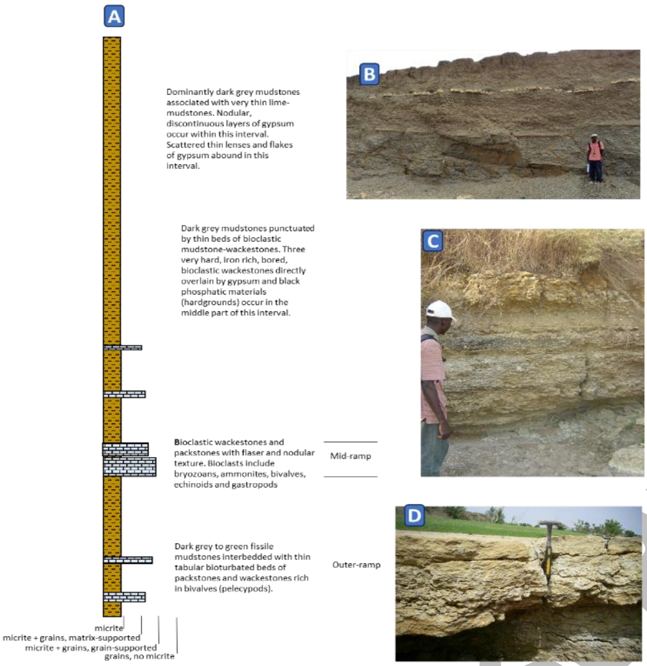

Figure 4. [A] Graphic log of the Kanawa Member exposed Pindiga steam: [B] upper part of the Kanawa Member; [C] 2m thick bryozoan, echinoderm and bivalve rich limestone unit in the middle part of the Kanawa Member; [D] Lower part of the Member

4.1.2.1 Mudstone-Wackestone Sub-facies (K2a)

This sub-facies comprises mainly of dark grey, bioclastic lime-mudstones and wackestones. It occurs inter-bedded with other sub-facies or may form the lower part of coarsening upward cycles comprising K2a, K2b and K2c (Fig. 5A). On the outcrop, the limestones are characterized by nodular bioclastic mudstones to wackestones surrounded by very thin dark grey clay layers giving them a flaser look (Fig. 5D).

The wackestones consist of pelecypod, and other bioclasts with floating contacts set in a matrix of micrites (Fig. 6A & B). Some of the bioclasts were replaced by sparry calcite, whereas parts of the micrite were replaced with microsparite. The microsparites appear patchy (Fig. 6 A). Sparry calcite was only observed as filling dissolved grains. Porosity may be poor due to the predominance of micrite. Though compaction effects were noted between nodules on the outcrop (i.e., flaser structure, Fig. 5D); this effect was not observed in thin sections of the nodules.

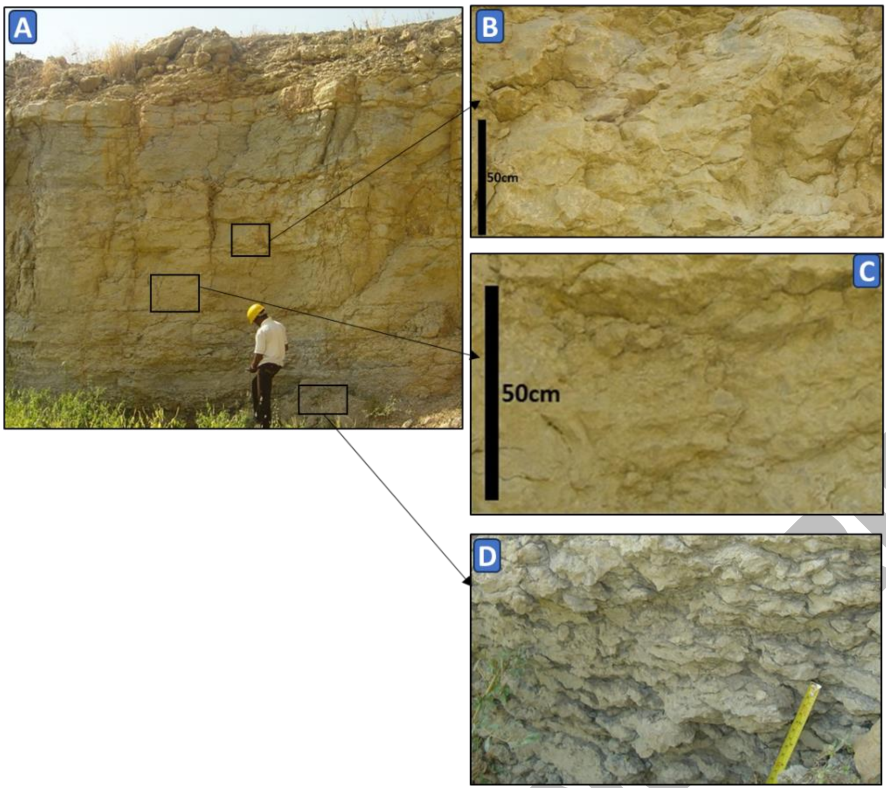

Figure 5: Photographs illustrating outcrop expressions of limestone lithifacies. A] stacked limestone lithofacies: [B, C, & D] close-up view of K2a, K2b and K2c subfacies.

4.1.2.2 Wackestone – Packstone sub-facies (K2b)

On the outcrop, this facies typically display 2-5cm thick and 3-10cm wide nodules of wackestones and packstones with sutured or curved contacts (Fig. 5C). It is differentiated from K2a sub-facies by lighter grey colour, decrease or absence in clay content and torching contact between the elongate nodules (Fig. 3). Silt sized materials may be concentrated along the contacts of the nodules (Fig. 6D).

Petrographically the facies consist of bioclasts of bivalves, gastropods and minor ostracods with floating, torching and sometimes suture contacts set in matrix of micrite, microsparite and calcite spar (Fig. 6C & D). Coarse silt to fine sand sized quartz, feldspar and glauconite grains commonly occur between the nodular limestones (Fig. 6D). Broken fragments are sometimes seen. Calcite spars usually occur as void filling cements in dissolved bioclast grains (Fig. 6C & D).

4.1.2.3 Packstone sub-facies (K2c)

This sub-facies consists of greenish, light to dark grey, wavy, nodular packstones. It is grain-supported and commonly possess little micrite. It is very hard and occurs inter-bedded with

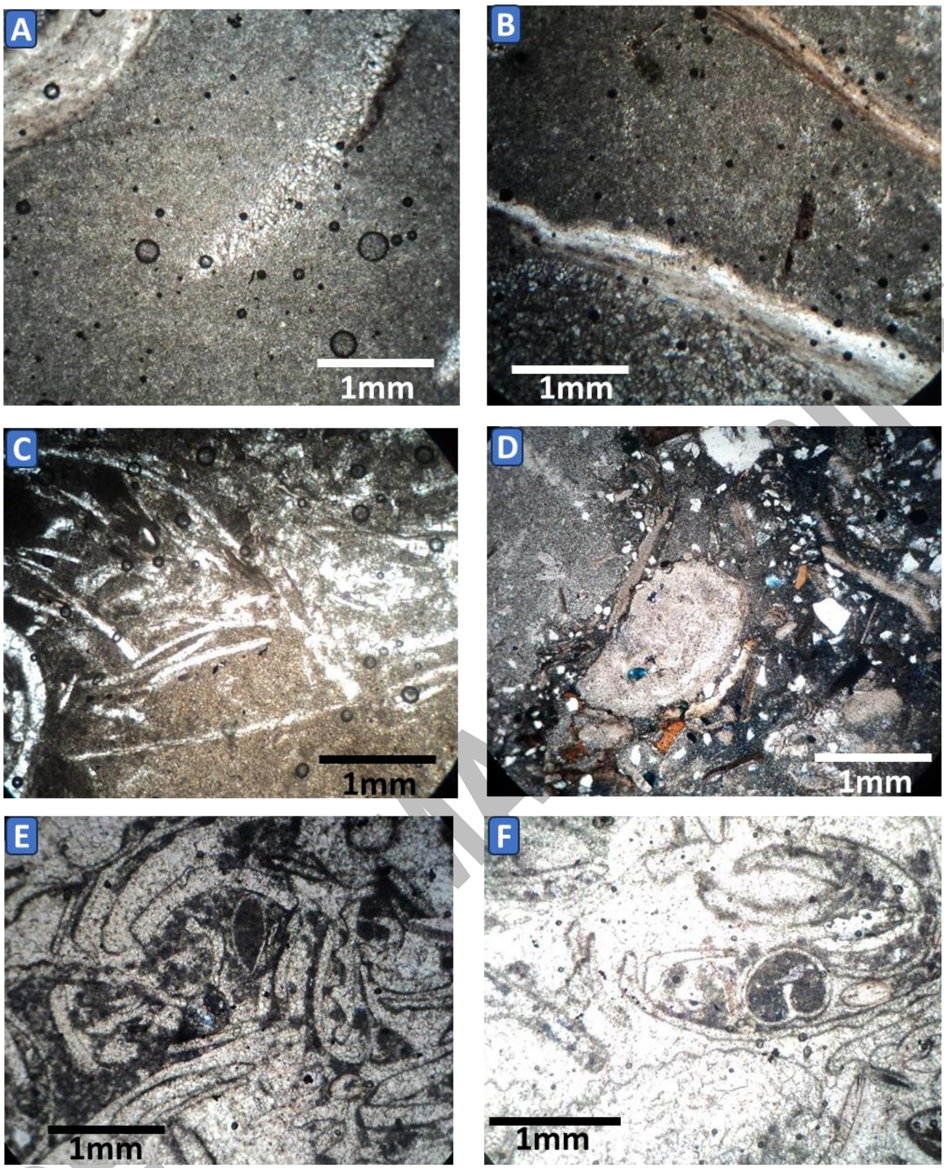

Figure 6: Photomicrographs illustrating typical features of the Limestone microfacies [A&B] Mudstone-Wackestone sub-facies (K2a); [C&D] Wackestone-Packstone sub-facies; [E&F] Packstone sub-facies.

other sub-facies, usually overlying sub-facies K2a or K2b (Figs. 3, 6B). Usually it stratigraphically occurs on top of coarsening upward units starting from K2a at the base and K2b in the middle. This coarsening upward character is well observed in the thickest limestone unit in the Ashaka quarry section (Fig. 3A). It is further differentiated from other sub-facies in the field by its larger, sub-rounded nodules showing torching contacts with often little or no compaction effects and lacking mud/silt layers between the nodules (Figs. 5A, 6E & F).

The framework grains consist of bioclasts of pelecypods, gastropods (e.g., Fig. 6E & F), and ammonites appear to be more abundant than in other sub-facies. The biolascts are set in matrix consisting of micrite, microspar and sparite.

4.2 Lithofacies associations

The Kanawa member display two main facies associations (FA): a) outer ramp, and 2) mid ramp.

4.2.1 Interbedded mudstone and limestone (Outer-ramp) facies association (FA1)

This association is composed mainly of thick dark grey to black mudstones of K1 facies that are punctuated at some intervals by thin beds of limestone (K2 facies). The association is well illustrated at upper part of the Ashaka quarry section (Fig. 3A, B), where it directly overlies the thickest mid-ramp limestone unit (FA2). The basal part of this association at the Ashaka locality is made-up of the most fissile and darkest (nearly black) mudstone interval (Fig. 3C). The associated thin limestone beds may be represented by any of the limestone sub-facies but the mudstone-wackestone sub-facies predominate. In the Pindiga stream section; this association occurs below and above the mid-ramp facies association as interbedded units (Fig. 4). Bioturbation is sparse within the mudstones but more on the limestone beds. Glauconites, black phosphatic materials as well as fibrous and nodular diagenetic gypsum occur on top of some the limestone beds (Figs. 3 and 4).

Interpretation

The identified bioclasts as well as the occurrence of glauconites suggest deposition in open marine outer ramp environment below storm wave base. The thick clastic mudstones were deposited out of suspension during fair-weather periods and the wackestone to packstones are inferred to be storm products (Tucker, 1994). Modern analogue of outer ramp facies association are represented in the Shark-Bay of Western Australia (Tucker and Wright, 1990). Well documented outer ramp facies associations occur in the Upper Cambrian to Middle Ordovician of the Appalachians in Virginia (Markello & Read, 1981).

4.2.2 Lime-mudstone and limestone (Mid-ramp) facies association (FA2)

This facies association consists of stacked beds of limestones (K1 facies) comprising the three sub-facies with or without shale partings. It ranges in thickness from about 20 cm to approximately 9 m. This facies association directly overlies the Yolde Formation (Fig. 3) in the Ashaka area in the northern part of the study area where the thickest development is recorded. However, the thickest development of this facies association is only about 2 m in the Pindiga stream section where it occurs as predominantly carbonate mudstones and wackestones (Fig. 4). Sedimentary cycles containing K2a sub-facies at the base through K2b and K2c at the top are well developed in the thickest limestone unit at Ashaka (Fig. 3A). These cycles are also visible in some thinner limestone beds.

Interpretation

The predominance of muddy limestones (mudstones and wackestones) interbedded with lesser amount of packstones suggests deposition in generally, low energy environment (below fair-weather wave base) that was affected by episodic storm events (Mathey et al., 1993; Tucker, 1994; Frugel, 2004). These characteristics suggests deposition between fair-weather wave base and storm wave base within mid-ramp zone (Burchette and Wright, 1992). The coarsening-up cycles from mudstone to wackestone to packstones are indicative of shallowing-up profiles within this zone (Burchette and Wright, 1992).

4.3 Discussion

The studied succession shares many similarities with the better studied, age equivalent (lower Cenomanian to early Turonian) carbonate successions of the east Niger basins which were generally deposited on carbonate ramps (e.g., Pascal et al., 1993). The development of the carbonate ramps has been explained to result from tectono-eustatic sea level rise which led to the connection between the Tethys and the southern Atlantic through the Benue trough (Greigert, 1966; Reyment, 1980; Reyment and Dingle, 1982; Courvelli et al., 1991 and Mathey et a., 1991). During this time, the Ashaka area was close to a paleo-high (i.e., Dumbulwa-Bage High) which separated the Benue trough from the Chad basin (Zaborski et al., 1997; Zaborski, 1998). Goro et al. (2021) also indicated the presence of a coast during this time which all together suggests the proximal paleogeography of the Ashaka area relative to the Pindiga area. The identified lithofacies associations of the Kanawa Member and the lack of any evidence of paleo-high between the proximal (Ashaka area) and the distal (Pindiga area) parts further suggests a homoclinal rather than distally-steepened carbonate ramp existed at that time. Therefore, the homoclinal ramp depositional model depicted on Figure 7 better summarises the conditions of deposition of the study interval.

Carbonate ramps are platforms that consist of gentle slope, commonly less than 1^o. They are characterized by lack of steep slopes and carbonate margins near slope breaks and many ancient carbonate successions were deposited in this setting (Ahr, 1973; Murray et al., 1973). Owing to these characteristics, carbonate ramps are commonly divisible in to inner ramp (nearshore), mid ramp (shoreface) and outer ramp (offshore) based on the dominant documented depositional processes (Reading, 1996).

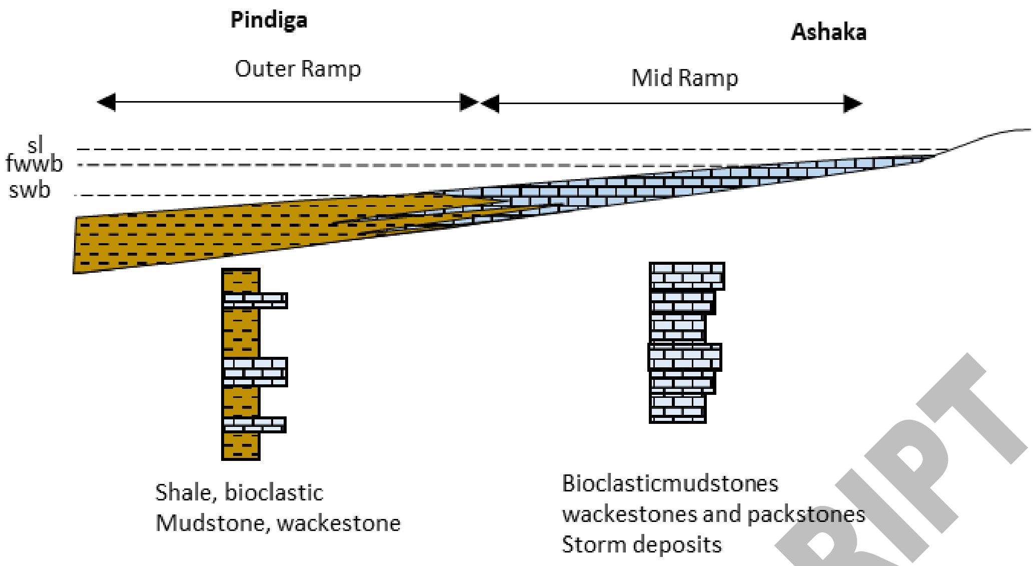

Figure 7: Proposed schematic summary of carbonate ramp of the Kanawa Member of Pindiga formation, NBT Nigeria. Abbreviations: sl, sea level; fwwb, fairweather wave base; swb, storm wave base.

Deposition in inner ramp zones are characterized by identification of lithofacies associations indicating sub-environments that occur above fairwater wave base such as shoreline, shoreface, tidal flat, beach and lagoon. In the present study, the absence of lithofacies associations depictive of these sub-environments such as the absence of grainstones, ooids, cross-beddings and the presence of micrites in all the studied samples indicate the absence of strong energies characteristic of deposition in inner ramp zones where shoals may occur. This scenario has been well noted by Mathy et al. (1995) on the east Niger ramp carbonates deposited at the same time with the study interval. However, micritic limestones like the ones described herein have been shown to characterize deposition in mid and outer ramp settings or mixed silisiclastic-carbonate settings in the ancient record (Aigner, 1984; Calvert and Tucker, 1988). The bioclasts found within the limestones especially pelecypods (bivalve), ~~brachiopods~~ and ammonites are good indicators of open marine environment of deposition (Frugel, 2004; Scholle and Ulmer-Scholle, 2003; Rebelle, 1990); which are typical of mid to outer ramp carbonate ramp platform (Frugel 2004; Tucker and Wright, 1990).

Mid ramp zones lie between fair-weather and storm wave base and is dominated by storm processes (Reading, 1996). In this part, Aigner (1984), Burchette (1987) and Faulkner (1988) have shown that amalgamated storm beds formed in ancient successions. The thickest limestone unit in Ashaka area perhaps record stacked storm beds deposited in mid ramp setting. These beds were later affected by bioturbation (due to the prevailing low energy conditions), early cementation and compaction which led to the nodular nature of the limestones (Tucker and Wright, 1990). The mudstone-wackestone facies (K2a) that form the lower parts of upward coarsening cycles in the mid-ramp facies association suggests deposition of argillaceous limestones during fair-weather periods while the capping packstone sub-facies indicate deposition by storm events.

The outer ramp setting is generally a low energy region occurring below fair-weather base wave up till the basin floor (Reading, 1996). However, storm beds are commonly deposited by very strong storms. The outer-ramp facies association therefore, indicates deposition below storm wave base in an offshore environment where only the heaviest storm events were able to deposit the muddy limestones. These limestones are commonly present as thin layers within thick shales. The upper portion of the Ashaka section and the entire Pindiga stream section shows typical characteristics of deposition in this zone. Here, the thick shale units representing lower energy deposition and the thin limestones recoding storm deposits.

In the upper part of the Ashaka section, the thinly laminated, dark grey to black mudstone interval that occurs at the base of this association is interpreted as product of pelagic accumulation in oxygen poor offshore environment with the dark grey to black colour indicating accumulation of organic matter within the mudstones. Obaje et al. (2000), based on identification of heterohelicids (non-keeled foraminifers) and high planktic to benthic ratios (predominantly 80 - 90 %) interpreted this interval as sediments deposited under shallow water anoxic conditions. They also correlated this unit with the Global Cenomanian-Turonian Oceanic Anoxic Events (CTOAE). The echinoderm and byozoan rich limestone unit which is the thickest limestone bed in the Pindiga section may represent site of isolated offshore carbonate bank (Reading, 1996). Similar carbonate banks have been interpreted from wackestone-packstone intervals of the stacked mid-outer ramp facies of the ferrous limestones of southern Britain (Burchette and Wright, 1985). The abundance of byozoans may be attributable to their sedentary and colonial life style. Similar isolated platforms have been shown to develop during transgressive systems tracts (Reading, 1996). Apart from the analogous limestone-shale units of the nearby Chad and Iullemmeden basins (Pascal *et al.*, 1993; Mathey *et al.*, 1995), similar cyclic facies were described and interpreted as outer ramp carbonates from the Triassic upper Muschelkalk Limestones of Catalan Basin, Spain and the intra-cratonic German Basin (Calvet and Tucker (1988); Tucker and Wright 1990).

5.0 Conclusions

Resource exploration and exploitation as well as reservoir and aquifer prediction and characterization within limestone-shale successions is controlled by their depositional environment. Evidence from previous studies indicates that detailed lithofacies and microfacies analyses of limestones is needed to better understand the nature of the carbonate platform upon which limestone-shale successions are deposited. This study conducted a combined outcrop lithofacies and thin section microfacies analyses of the Kanawa Member of Pindiga Formation exposed in the Ashaka quarry and Pindiga stream within the Gongola sub-basin of the Northern Benue Trough, Nigeria.

Field outcrop results reveal the presence of dark grey to black, fissile mudstone and limestone lithofacies. The limestone facies is in turn divisible into three microfacies including mudstone-wackestone, wackestone-packstone and packstone microfacies. The lithofacies are organised into two associations, namely outer ramp and mid-ramp facies associations. The facies architecture depicted by these associations suggests deposition in homooclinal carbonate ramp setting. This model does not consider sequence stratigraphic constraints which is one of the key limitations to this study. This perhaps may affect the accurate prediction of lithofacies within the study interval. In future studies, it will be important to consider integration of high resolution biostratigraphy, palynology and chemostratigraphy to erect a sequence stratigraphic model which will aid better lithofacies prediction for exploration and exploitation purposes.

References

Aliyu, A.H., Mamman, Y.D., Abubakar, M.B., Babangida, M.S.Y., John, S.J., Shettima, B. (2016). Paleodepositional environment and age of Kanawa member of Pindiga Formation, Gongola sub-Basin, northern Benue trough, NE Nigeria: sedimentological and palynological approach. J. Afr. Earth Sci. 134, 345–351.

Boggs, S. (1995). **Principles of Sedimentology and Stratigraphy**. New Jersey, Prentice Hall, 774p.

Courville, P. (1992). Les Vascoceratinae et les Pseudotissotiinae (Ammonitina) d Ashaka (NE Nigeria); relations avec leur environment biosedimentaire. *Bulletin Centres Reserches Exploration-Producion Elf-Aquitaine*, **16**: 407-457

Flügel, E. (2004). **Microfacies of Carbonate Rocks**. Berlin Heidelberg, Springer–Verlag, 976p.

Guiraud, M. (1990). Tectono-sedimentary framework of the Early Cretaceous continental Bima Formation (Upper Benue Trough, NE Nigeria). *Journal of African Earth Science*, **10**: 341–353.

Guiraud, M. (1993). Late Jurrasic rifting – Early Cretaceous rifting and Late Cretaceous transpressional inversion in the upper Benue basin (NE Nigeria*). Bull. Centres Rech. Explor – Prod. Elf Aquitaine*, **17**(2): 371 – 383.

Genik, G. J. (1992). Regional framework, structural and petroleum aspects of rift basins in Niger, Chad and Central African Republic (C.A.R). *Tectonophysics*, **213**: 169-185.

Marino, M. & Santantonio, M. (2010). Understanding the geological record of carbonate platform drowning across rifted Tethyan margins: Examples from the Lower Jurassic of the Apennines and Sicily (Italy). *Sedimentary Geology*, **225**: 116–137.

Nichol, G. (2009). **Sedimentology and Stratigraphy.** Oxford, Wiley-Blackwell, 419p.

Obaje, N. G., Ulu, O. K., Maigari, S. A. & Abubakar, M. B. (2000). Sequence stratigraphy and paleoenvironmental interpretation of Heterohelicids from the Pindiga Formation, Northeastern Benue Trough, Nigeria. *Jour. Min. Geol*., **36**(2): 191-198.

Ojo, O.J. (2004). Microfacies, depositinal environments and diagenetic history of the limestone facies of the Pindiga Formation, Gongola basin, Nigeria. Journal of mining and geology, vol. (40)2, pp 127-132.

Oti, M. N. (1990). Lower Turonian carbonates on the Zambuk Ridge, southeastern Chad Basin, and the Ashaka Limestone. In C. O. Ofoegbu (Ed.); *The Benue Trough, structure and evolution (pp* 287-320). Braunchweig. Vieweg and Sohn.

Popoff, M., Wiedmann, J. & De Klasz, I. (1986). The Upper Cretaceous Gongila and Pindiga Formations, Northern Nigeria: Subdivisions, Age, Stratigraphic Correlations and Paleogeographic Implications. *Eclogae Geol. Helv.*, **79**: 343-363.

Reading, H. G. (1996). **Sedimentary Environments: processes, facies and stratigraphy**. Oxford, Blackwell Science, 688p.

Reading, H. G. and Collinson, J. D. (1996). Clastic Coasts. In H. G. Reading (Ed.); *Sedimentary Environments: Processes, Facies and Stratigraphy (pp 154–231)*. Oxford. Blackwell Science.

Rebelle, M. (1990). The marine transgression in the Benue Trough (NE Nigeria): A paleogeographic interpretation of the Gongila Formation. *Journal of African Earth Sciences*, **10**: 643-665.

Reyment, R. A. (1965). New Turonian (Cretaceous) Ammonite genera from Nigeria. *Colon. Geol. Miner. Resour.*, **4**: 149-164.

Tucker, M. E. & Wright, V. P. (1990). **Carbonate Sedimentology**. Oxford, Blackwell Scientific Publications, 482p.

Tucker, M. E. (1994). **Sedimentary Petrology**. Oxford, Blackwell Scientific Publications, 260p.

Tucker, M. E. (2003). Sedimentary Rocks in the Field. Oxford, Blackwell scientific publications, 260p.

Zaborski, P. M. (1990). The Cenomanian and Turonian (mid-Cretaceous) Ammonite Biostratigraphy of North eastern Nigeria. *Bulletin of British Museum of Natural History (Geology)*, **46**: 1-18.

Zaborski, P., Ugodulunwa, F., Idornigi, A., Nnabo, P. & Ibe, K. (1997). Stratigraphy and structure of the Cretaceous Gongola basin, northeast Nigeria. *Bulletin Centres Recherches Exploration Production Elf-Aquitaine*, **21**(1): 153-185.

Zaborski, P. M. (1998). A Review of the Cretaceous System of Nigeria. *Africa Geoscience Review*, **5**(4): 358-483.