REGIONAL AND LOCAL CONTROL ON LIMESTONE FACIES IN THE CRETACEOUS PINDIGA FORMATION (KANAWA MEMBER), NE NIGERIA.

BY

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A THESIS SUBMITTED TO THE DEPARTMENT OF GEOLOGY, FACULTY OF SCIENCE AHMADU BELLO UNIVERSITY, ZARIA IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF MASTER OF SCIENCE DEGREE IN GEOLOGY (PALEONTOLOGY AND STRATIGRAPHY)

MAY, 2008

DECLARATION

I declare that in the project thesis entitled “REGIONAL AND LOCAL CONTROL ON LIMESTONE FACIES IN THE CRETACEOUS OF PINDIGA FORMATION (KANAWA MEMBER) NE NIGERIA” has been performed by me in the Department of Geology. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this project thesis was previously presented for another degree or diploma at any university.

_____	_____	_____
Name of student	**Signature**	**Date**

CERTIFICATION

This thesis entitled " REGIONAL AND LOCAL CONTROL ON LIMESTONE FACIES IN THE CRETACEOUS OF PINDIGA FORMATION (KANAWA MEMBER) NE NIGERIA" by Saleh Yamta Grace, meets the regulation governing the award of the degree of master of science in Geology (Paleontology and Stratigraphy) of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This research work is dedicated to Mrs. Habiba Fain with love.

ABSTRACT

The Kanawa Member of the Pindiga Formation at Ashaka Quarry, Pindiga stream and Deba Habe stream (Northeast Nigeria) was studied using Shaw's graphic correlation method. coupled with sequence stratigraphic data. For the former method, the first and the last appearances of ammonites species common to the two sections were utilized. For the latter parasequence boundaries were used. The ammonites occur only in the limestones; they do not occur in the shales possibly due to anoxic bottom conditions at that time. The line of correlation suggested that some of the limestones at Ashaka and Pindiga are continuous and contemporaneous, namely units D, F and R at Ashaka and units A, H, and R at Pindiga respectively. The crossed- bedded limestone units G-J at Ashaka correlate with shales in the Pindiga section and are local developments. Sequence stratigraphic data can, in some cases, is shown to produce correlation that matches that based on biostratigraphic data. In particular, the ammonite *Pseudaspidoceras paganum* is uniquely found upon a marine flooding surface. The closely – related genus *Burroceras* sp is also confined to marly, relatively deep-water limestones.

Eustatic sea-level fluctuation is the most likely central over the development of regionally continuous limestones though climatic factors could also be important. Local tectonics affected the Ashaka area, these factors often being more important than the regional controls.

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CHAPTER ONE

INTRODUCTION

1.1 LOCATION, EXTENT AND ACCESSIBILITY OF THE AREAS

The areas investigated are in Gombe State north eastern Nigeria. Two locations were studied, where there are exposures of the Kanawa Member of the Pindiga Formation.

The first is in the Pindiga stream south – west of Gombe, within the Federal Survey of Nigeria 1:50,000 sheet 172 Futuk NE. It lies between latitudes 09º 57' 30E and 10º 58' N and longitudes 10º 57' 30'' E and 10º 58' E (Fig.1). Detailed work was carried out within a total area of about 4km^2.

The second locality is along the Gombe Deba Habe road, 1 km north of Deba Habe town {Deba Habe stream section (Fig 1)}. It lies within Federal Survey of Nigeria 1:50,000 Sheet 152 (Gombe) SE. It lies between latitudes 10º 12^1 50'' N and 10º 14' N and longitudes 11º 21' E and 11º 22' E (Fig. 1).

The area around Pindiga is accessible by means of a tarred road and numerous foot paths linking the villages around. The major motorable road in the area is tarred and passes through Tumu from the junction to Pindiga on the Gombe - Yola road. The Deba Habe area is accessible by means of a tarred road and numerous foot paths linking villages around the area. Stream channels and foot paths in the area, served as access routes during the field work.

1.2 RELIEF AND DRAINAGE

Pindiga village lies on flat low lying land which is liable to flooding in the eastern part of the studied area. The western and southwestern parts of the

studied area are made up of hills of the Gombe Formation which forms the watershed region.



Fig. 1: General map of Gombe area with location ◍ Deba Habe ● Pindiga village After Zaborski et al; 1998.

The drainage pattern is dentritic with the seasonal streams flowing in a northwest to southeast direction.

Deba Habe village lies on flat low lying land which is also liable to flooding in the western part of the studied area. The drainage pattern is also dentritic.

1.2 CLIMATE

The studied areas fall within the humid tropical climatic zone of northern Nigerian, with average precipitation between 76cm to 100cm per year.

The rainy season lasts for five months (April to September). The annual average temperature ranges between 70ºF to 80ºF having a maximum at the beginning of the wet season.

1.4 VEGETATION AND SOILS

The areas studied fall within the Sudan Savannah vegetation zone, which is characterized by short trees, sparse shrubs and feathery grasses.

The Pindiga Formation is overlain by dark coloured clayey soil. The Gombe Sandstone is overlain by medium – grained white to pinkish or grayish sandy soils while the Kerri – Kerri Formation produces medium to fine – grained brownish or reddish sandy soils.

1.5 SETTLEMENT AND LAND USE

The settlement pattern in the Deba Habe and Pindiga area is dispersed with small scattered villages. This makes it possible for the inhabitants to have

sufficient farmland and grazing land as most of the inhabitants indulge in the mixed farming.

The villages around the Pindiga area include Tumu, Sumbe, Sudinge, Sindingo, Rigiya and Garin –Kale with the eastern part having more settlement. Those around Deba Habe are Tangwayel, Gokaru, Garin Baraya, Zamfarawa, Wuro Mado and Kufa.

1.6 AIM OF THE PRESENT STUDY

The present work was in intended to investigate the paleo- environmental, paleogeographical and paleoecological implications of the shale – limestone member of the Pindiga Formation (Pindiga stream section and Deba Habe stream section). This was achieved by carrying out a detailed study of the macro faunal content of the clastic and limestone facies and attempts to correlate the individual limestones.

Aerial photographs were interpreted by use of a stereoscope before the commencement of the field work. A systematic mapping of the area was carried out with the aid of a global positioning system (GPS). It involved profiling along stream courses so as to determine mode of facies succession, and also logging the exposed sections. Fossils (ammonites) were collected for macrofossil identification.

CHAPTER TWO

GENERAL ACCOUNT OF THE BENUE TROUGH

2.1 INTRODUCTION

The Benue Trough of Nigeria is a rift- like basin that extends NNE – SSW for about 800 km and overlies the Pan – African mobile belt of West African. It stretches from the Niger Delta in the south west to the Chad Basin in the north east (Fig. 2). The trough contain up to 6000 metres of Cretaceous to Tertiary sediments of which those predating the mid – Santonian have been compressionally deformed, faulted and uplifted with over 100 anticlinal and synclinal structures produced through out the Benue Trough (Benkhelil, 1989). Major deformational structures include the Afikpo syncline, Abakaliki anticlinorium, Giza anticline, Lamurde anticline, Dadiya syncline and Obi syncline. However, the Lamurde anticline and Dadiya syncline are thought by some authors like Benkhelil (1989) to be Maastrichitian in age.

Conventionally, the Benue Trough is subdivided into the Lower, Middle and Upper Benue Trough (Fig.3). In the upper Benue Trough the lithostatigrahic sequence includes a lower continental unit, with the Bima group deposited in lacustrine / fluvial environments. Above is Formation). The Cretaceous succession terminates with the regressive Gombe Sandstone of Maastrichtain age. The Tertiary is represented by the continental deposits of the Kerri – Kerri Formation which are restricted to the western part of the upper Benue Trough.

agreement on a connection between the initiation of the Benue Trough and the opening of the south and equatorial Atlantic Oceans, its exact nature has been debated. Authors have sought to explain its fundamental crustal structures and mainly a marine sequence of shales with interbedded carbonates (Pindiga).

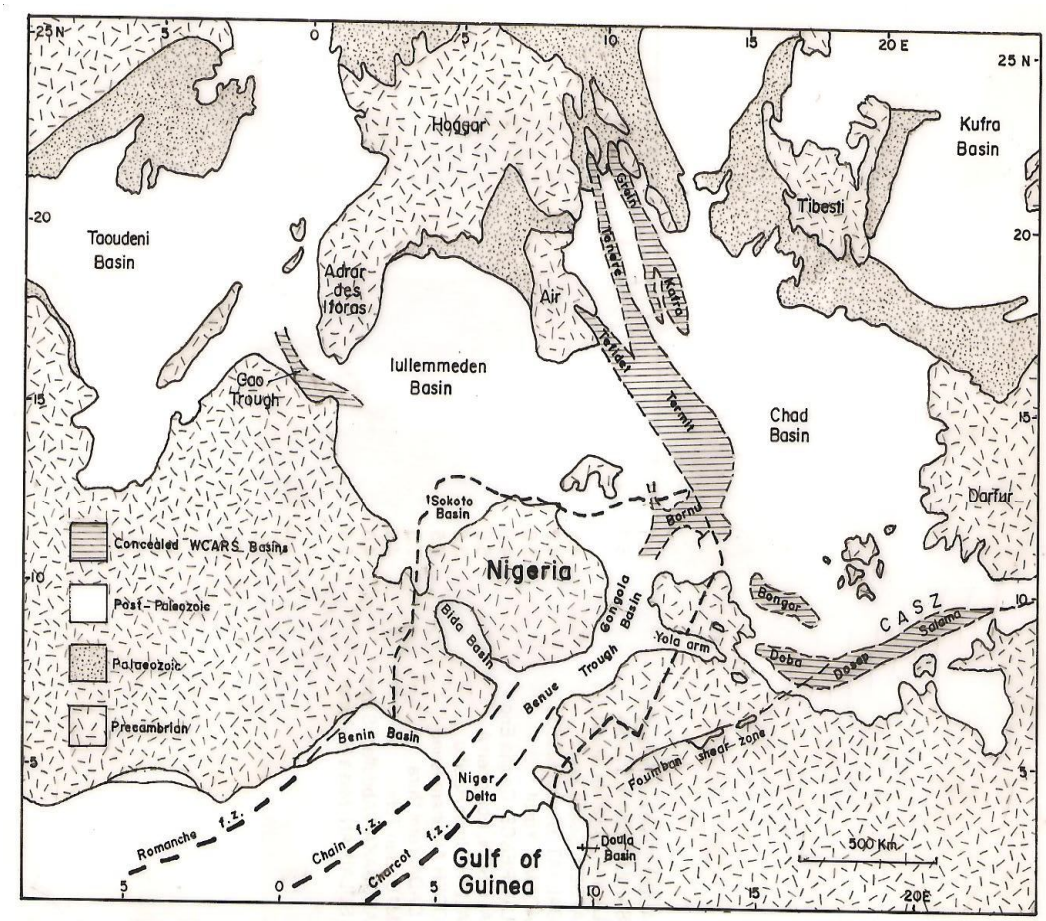


Fig. 2: Simplified geological map showing the sedimentary basins of Nigeria and neighbouring areas. After Zaborski, 1998

2.2 NATURE OF THE BENUE TROUGH

The origin and evolution of the Benue Trough have received much the folding that occurs parallel to its length.

Lees (1952) considered the Benue Trough to be a compressional downwarp with folding being induced by deep- seated basement contraction King (1950) regarded the Benue Trough / Bida Basin and Gao Trough as extensions of the rifts which produced the equatorial and South Atlantic Oceans respectively. Cratchely and Jones (1965) and Stonely (1966) were in support of attention in the last five decades. Although there is a general

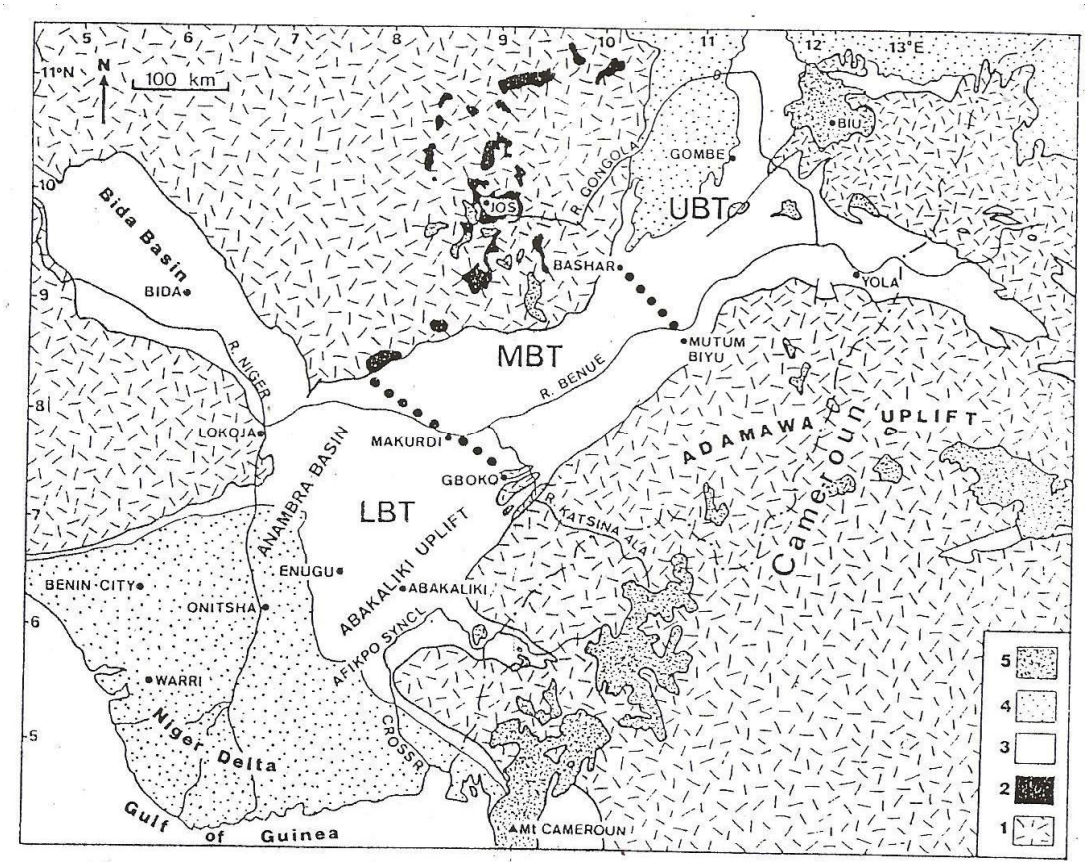


Fig.3: Outline geological map of Benue Trough and adjacent areas; LBT, lower Benue Trough; MBT, middle Benue Trough; UBT, upper Benue Trough. 1, Precambrian 2. Jurassuc" Younger Granites"; 3 Cretaceous; 4 Post - Cretaceous sediments;5 Cenozoic – Recent basalt (including those of the Cameroun line). After Zaborski 1997.

a rift origin for the Benue Trough. Burke *et al.* (1971; 1972), Burke and Whiteman (1973) and Burke and Dewey (1974) believed the Benue Trough to be an arm of a rift- rift –rift triple junction developed over a Cretaceous hot spot located below the present – day Niger Delta. They thought the Benue Trough developed into a true ocean floored by oceanic crust, but which was destroyed by subduction. Olade (1975; 1976; 1979) developed a rift model as well; he interpreted the Benue Trough as an aulacogen related to intermittent mantle upwelling during the Albian (Fig. 4). The mantle plume, he believed, fell dormant during Cenomanian time which produced minor folding but was reactivated during the Turonian. The activity of the mantle plume finally ceased or moved

else where during the Santonian, bringing about a collapse of the trough, the main folding episode and a broad symmetrical downwarp. Wright (1981) believed the Trough to be a tensional feature containing numerous normal faults which was never floored by oceanic crust. Benkhelil (1989) believed that the Benue Trough is not a tensional feature but contains sinistral strike – slip faults connected to oceanic Trans current and that the trough is a collection of pull apart basins and uplifted blocks. He regarded the Benue Trough as always having being floored by continental crust and noted that the marginal faults have not been demonstrated. He said that a system of NE – SW trending sinistral strike – slip faults was thought to exist within the axial zone of shallow basement; these faults are exposed in the Wuyo - Kaltungo high. The axial zone was identified as one of persistent structural instability characterized by the greatest intensity of igneous activity Fairhead (1986, 1988) and Fairhead and Green (1989) related crustal extension for the West and Central African Rift System (WCARS) basins to large extensional stresses developed rapidly during mid – Cretaceous times with crustal thinning and ultimately sedimentation (Fig. 4). Freeth (1978; 1979; 1990) returned to the subdcuction model. He believed the present day lower Benue Trough to be floored by oceanic crust. Benkhelil (1989) slightly modified the strike – slip model, regarding the evolution of the Benue Trough as best explained by a combination of extensional and strike slip movements.

2.2.1 THE UPPER BENUE TROUGH (NE NIGERIA), STRUCTURE AND STRATIGRAPHY

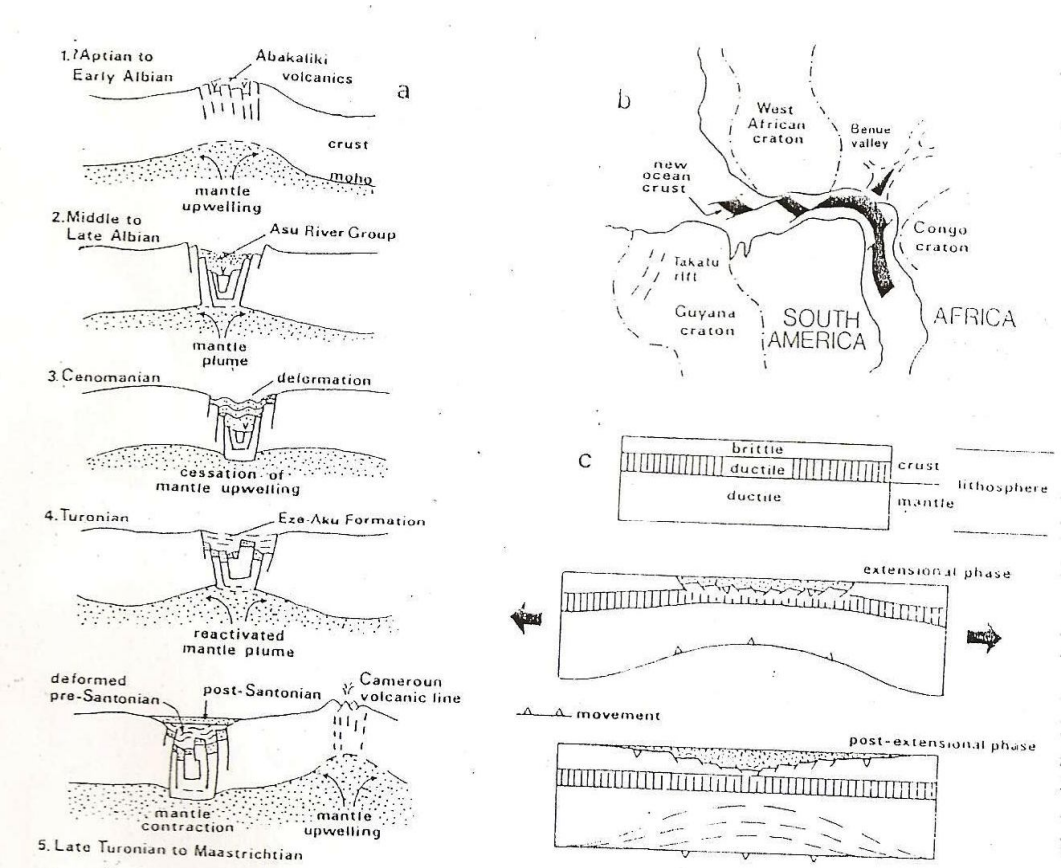


Fig. 4: a, Proposed stages in the tectonic evolution of the Benue Trough involving active mantle upwelling (after Olade, 1975). b, Sketch map of the Gulf of Guinea area in the Early Cretaceous with the lower Benue Trough floored by oceanic crust (after Burke *et al.*, 1971, 1972). c, Lithospheric model for the WCARS basins involving extension and passive upwelling (after Fairhead, 5

2.2.1.1 STRUCTURE

The upper Benue Trough covers the area from the Bashar – Mutum Biyu line to the "Dumbulwa – Bage High" of Zaborski *et al.* (1998). This anticlinal structure separates the upper Benue Trough from the Bornu (Chad) Basin (Zaborski, 1998). The floor of the basin is Precambrian crystalline basement reactivated during the Pan – African thermotectonic phase (Guiraud, 1993).

Structurally, the upper Benue Trough splits into an east – west trending Yola Arm and a north – south trending Gongola Basin. The Yola arm terminates against the Cameroun basement while the Gongola arm is continuous with the

Chad Basin (Fig. 5). Between these two branches of the upper Benue Trough lies an area that is structurally dominated by four major strike– slip faults; the Gombe, Bima – Teli, Kaltungo and Burashika faults. This median zone was described as the partially exposed basement high characterizing the axis of the Benue Trough {Benkhelil, (1986; 1989), Carter *et al.* (1963)} termed it the "Zambuk ridge", Guiraud (1998) adopted the name "Wuyo-Kaltungo basement," while Zaborski (2000) used the name "Wuyo-Kaltungo high".

The overall trend of the Gongola Basin according to Zaborski *et al*. (1997) is controlled by a series of N-S to NNE – SSW trending faults. The trend of the Yola arm is characterized by deep seated E -W trending fractures (Benkhelil, 1988). The eastward extension of the Yola arm in Cameroon is the Garoua Basin which is bounded at its eastern extremity by NW – SE trending strike-slip faults (Zaborski *et al.* 1997., Fig. 5).

The major ENE – WSW trending folds of the Yola arm including the Lamurde anticline and Dadiya syncline have generally been attributed to terminal Maastrichtian compression but they may be Santonian, as suggested by Guiraud (1993) and more tentatively by Allix (1983).

Fold axes in the Gongola arm show dominantly E – W to N – S trends. The former are in accord with the regional pattern while the latter folds are deviations of the stress directions in the domain of the N – S transpressional faults (Zaborski *et al.,* 1997)

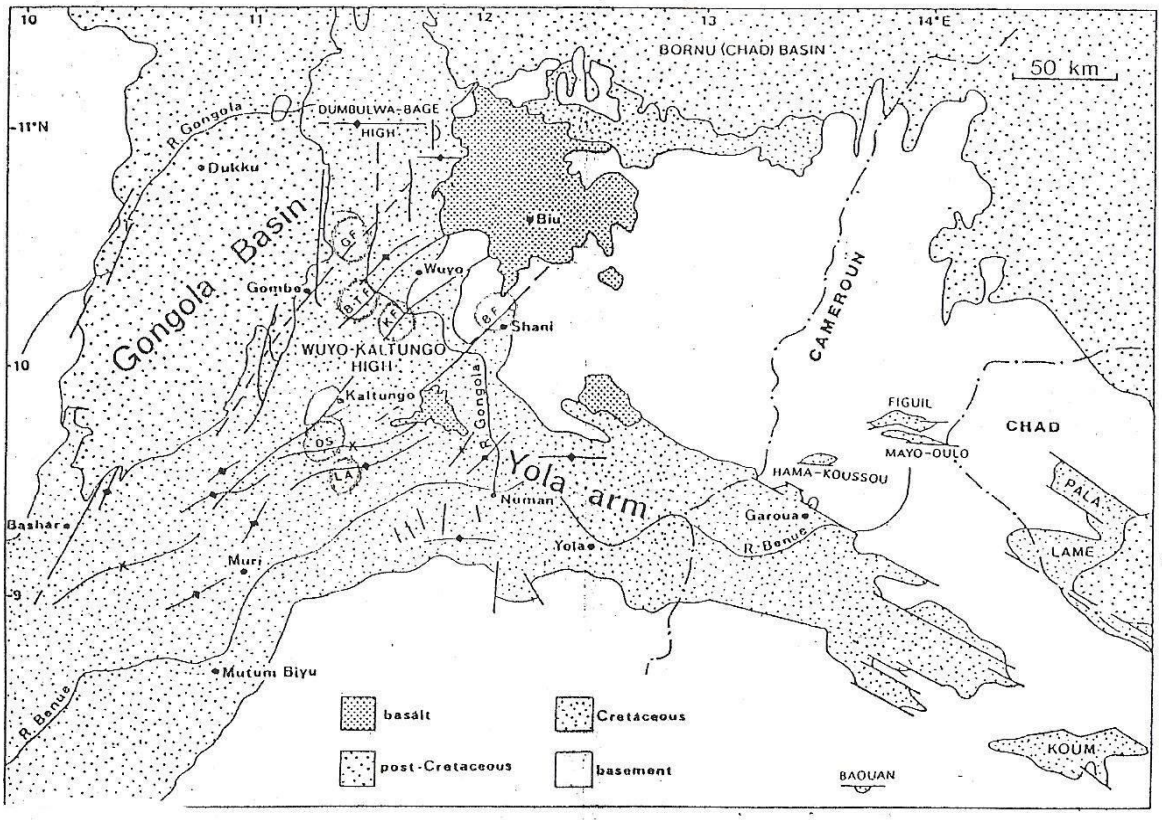


Fig. 5: Outline geological map showing the main features of the upper Benue Trough region; GF, Gombe Fault; B-TF, Bima-Teli Fault; KF, Kaltungo Fault; BF, Burashika Fault; DS, Dadiya syncline; LA, Lamurde anticline.

Based on Benkhelil 1985; Guiraud 1989; Zaborski et al; 1998.

2.2.1.2 STRATIGRAPHICAL SUCCESSION

The main rifting in the evolution of the Benue Trough was immediately followed by sedimentation. Sedimentation took place from at least Aptain to early Cenozoic times in the Upper Benue Trough. Guiraud (1990) was of the opinion that sedimentation might have started as early as late Jurassic. Allix and Popoff (1983) indicated that sedimentation started during the active rifting with deposition of the continental Bima Group. Zaborski *et al.,* (1997) concluded that Late Cretaceous sedimentation was controlled by transgressive- regressive events during thermotectonic sag conditions.

The lithostratigraphical succession in the upper Benue Trough comprises the Early Cretaceous continental clastics of the Bima Group, and a dominantly

marine Late Cretaceous succession. The Upper Cretaceous may be divisible into discrete pre- Santonian and Campano-Maastrichitian parts, the later deposited during a renewed phase of rifting (Zaborski, 1998; Fig. 6).

2.2.3 THE BIMA GROUP

The term “Bima sandstone” was first used by Falconer (1911) for beds occurring at the type locality, Bima Hill, and including the Yolde Formation of later authors. It is a continental clastic unit and its thickness is in excess of 4000 metres in some places with its thickest outcrops occurring in the Lamurde anticline (Carter *et al.* 1963; Allix, 1983). The Bima Group directly overlies the basement complex. Guiraud (1990, 1991) sub divided it into three siliciclastic “members” “the Lower Bima” (“B1”), “Middle Bima” (“B2”) and “Upper Bima” (“B3”) members, which were also informally referred to as formations. As a whole, the Bima Group is made up of conglomerates and alluvial fan / debris/ flow braided river sandstones with interbedded clays, fine - grained sandstones and calcareous sandstones which were derived from granitic sources and deposited within continental (fluviatile, deltaic and lacustrine) environments. It shows an upward maturation sequence reflecting a change from periods of tectonic activity to more stable conditions (Guiraud, 1990; 1991) that is a change from an active rifting to an early thermotectonic sag stage. The “Lower Bima Formation” is separated from the Middle and Upper Bima by a regional unconformity. Fossils are very rare in the Bima Group but a late Jurassic to Berriasian age has been suggested for its basal part by Guiraud (1990) based on radio metric ages from intercalated lavas.

2.2.4 YOLDE FORMATION

The Yolde Formation lies conformably on the Bima Group. It is a transitional unit between the continental Bima Group and the succeeding marine Pindiga Formation representing the beginning of a marine incursion into the upper Benue Trough. The name Yolde Formation was proposed by Carter *et al.* (1963) for the "transitional beds" earlier recognized by Falconer (1911) and Barber *et al.* (1954). The type section is found in the Yolde stream. The Yolde Formation is made up of sandstone, calcareous sandstones, shales, clays and mudstones. Lawal (1982), Alix (1983) and Lawal and Moullade (1986) suggested an age between Albian and late Cenomanian on the basis of pollens.

2.2.5 PINDIGA FORMATION

The first marine transgression into the upper Benue Trough took place during the Late Cenomanian to Early Turonian. The deposits associated with this in the Yola arm are referred to as the Dukul Formation (Carter *et al.,* 1963). In the "Wuyo – Kaltungo High" Carter *et al.* (1963) referred them to the lower part of the Pindiga Formation and included them in the lower part of their "Gongila Formation". In the Gongola Basin the name Gongila Formation which was first proposed by Carter *et al.* (1963) was considered by Popoff *et al.* (1986) and Zaborski *et al.* (1997) to be synonym of the Pindiga Formation. Zaborski *et al.* (1997) subdivided the Pindiga Formation into five members in the Gongola Basin as follows:

V. Fika Member

Vi. Dumbulwa Member

iii. Deba – Fulani Member

ii. Gulani Member

i. Kanawa Member

2.2.5.1 THE KANAWA MEMBER

The name “Kanawa Formation” was proposed by Thompson (1958) for a sequence of shales and intercalated limestones outcropping around Kanawa to the east of Gombe. It was thought to be distinct from the Pindiga Formation since it contains ubiquitous limestone intercalations. This misconception stemmed from a failure to recognize that the overlying sandstones around Kanawa belong not to the Gombe Formation but to the Deba Fulani Member. The “Kanawa Formation” therefore corresponds to only the lower (shale – limestone) member of the Pindiga Formation. The Kanawa Member has a very wide spread occurrence in the upper Benue Trough. Its age equivalent in the Yola arm, the Dukul Formation, has similar lithology of a shaly mudstone with intercalated limestone (Carter *et al.,* 1963; Zaborski, 1990).The most complete sections occur in the Pindiga stream and at the Ashaka quarry. This work is primarily concerned with sections found at Pindiga, Ashaka and Deba Habe.

The Gulani, Deba Fulani and Dumbulwa members are arenaceous deposits formed under regressive conditions during the mid- Turonian. The Fika Member comprises mainly shales, siltstones and fine- grained sandstones with carbonate beds at some levels. It has an age range from mid –Late Turonian to Campanian\Early Maastrichtian.

2.2.6 GOMBE FORMATION

The term “Gombe sandstone” areas was proposed by Carter *et al.* (1963) for the “Gombe grits” and clays previously identified by Falconer (1911). The

Gombe sandstone which may ultimately prove divisible into separate members (Zaborski *et al.,* 1997); namely

3. The “red sandstone facies”

2. The bedded facies

1. Rapidly alternating units of siltstone, sandstones and iron stones.

The basal part of the Gombe Sandstone comprises rapidly alternating of siltstones, sandstones and ironstones with *Thalassinoides* burrows indicating a pro – deltaic environment. The bedded facies was deposited in a deltaic environment while the “red sandstone facies” was deposited in a fluvial environmental (Zaborski *et al.*, 1997).

Occurrences of coal in the upper part of the Gombe sandstone have been reported (Dike, 1995; Petters, 1978a). There is a decrease in marine fossils (foraminifers, dinoflagellates and acritarchs) at the boundary of the Pindiga Formation and the Gombe Sandstone (Lawal, 1982). A Maastrichtian age has been suggested by Allix. (1983) and Lawal and Moullade (1986) for the Gombe Sandstone.

2.2.7 KERRI – KERRI FORMATION

An angular unconformity separates the Kerri – Kerri Formation from the Gombe Sandstone. The Kerri – Kerri Formation is made up of whitish grey sandstones, siltstones and clay stones. In the Gongola Basin the continental Kerri –Kerri Formation represents the Paleocene, at least in part. Age data for the Kerri – Kerri is scanty. Paleocene pollen has been recovered (Adegoke *et al.,* 1978) but Eocene beds may occur (Adegoke *et* al*..,* 1986).

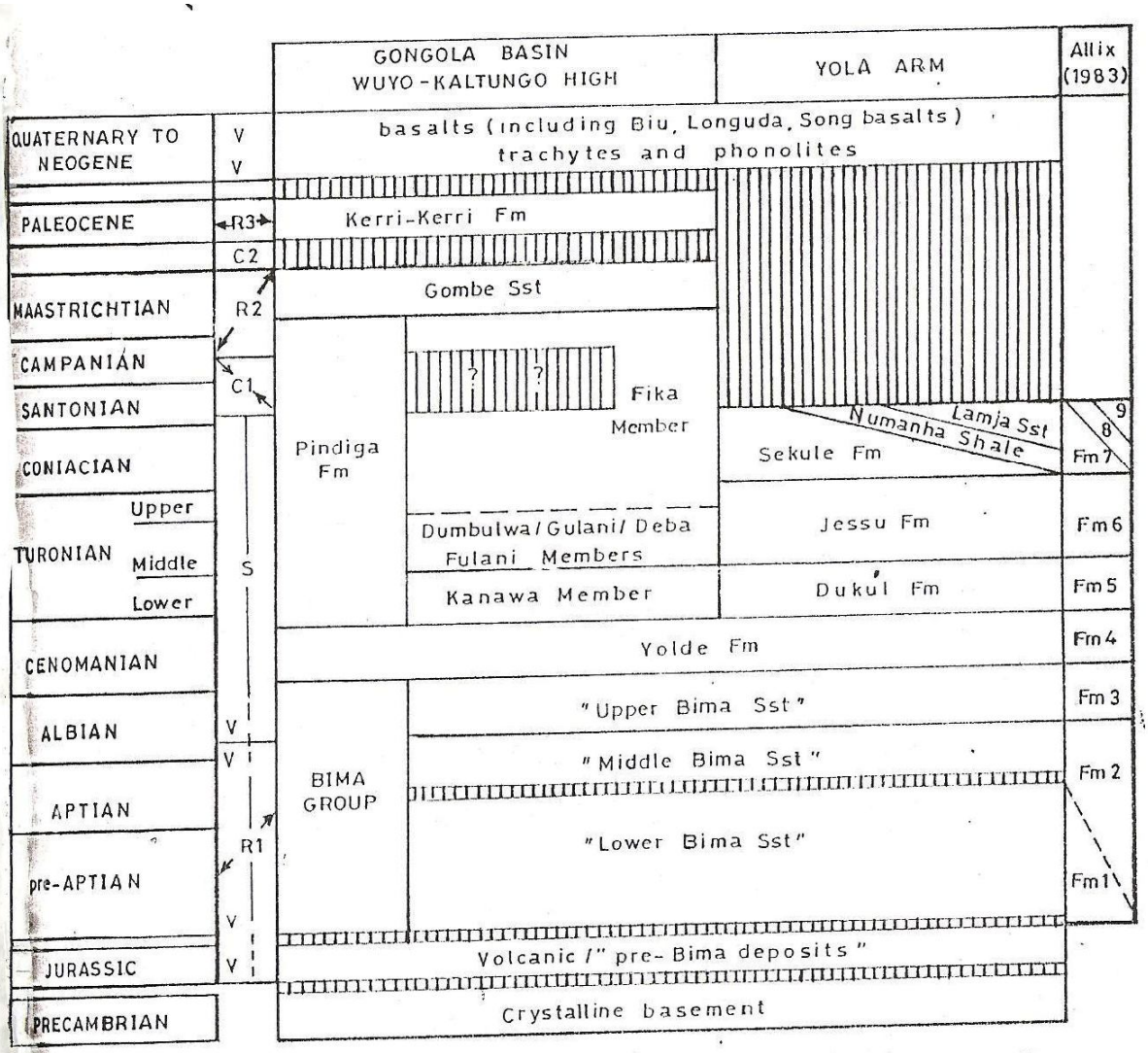


Fig.6: Lithostratigraphical successions present in the upper Benue Trough region [subdivision of the Bima Group after Guirand (1990 ,1991)]. V, volcanic episodes; R1, Early Cretaceous strike-slip related rifting; S, thermo-tectonic sag phase; C1, first compressional phase, associated with strike-slip movements; R2, Compano Maastrichtian rifting; C2, terminal Cretaceous compression, associated with strike-slip movements; R3, Paleocene rift stage.

2.3 GEOLOGICAL HISTORY OF THE UPPER BENUE TROUGH

The transgressions and regressions that took place in the Benue Trough are though to be a reflection of the rhythmic growth of the south Atlantic ridge

and sea floor spreading (Offodile, 1976). Transgressive and regressive phases dominated the environments of deposition of the upper Cretaceous sediments.

During the terminal Jurassic to earliest cretaceous there was a “pre – rift” stage when local depressions were though to have developed in association with distortation along NE – SW trending faults (Popoff, 1988). Subsequently “basal conglomerates” and sandstones several hundreds of meters thick and including boulders of very large size were deposited as a result of a N-S extensional phase which may have produced the E – W Yola Arm structures and those of the small Cameroun basins during a Neocomian to Barremian “eo – rift” stage (Popoff, 1988). This stage was accompanied by magmatism in the Burashika area where lavas flows yield ages close to the Jurassic - Cretaceous boundary (Popoff, 1988).

From Barremian to Middle Albian there existed a “syn – rift” stage whereby the rate of subsidence due to crustal extension increased giving rise to a larger elongate basin (Popoff, 1988).

According to Popoff (1988) a “syn – rift II” phase took place during the later part of stretching giving way to a sag stage of basin development during the Cenomanian. Then rates of subsidence were greatly reduced and crustal extension ceased.

2.3.1 ALBIAN TRANSGRESSION

The final continental separation of Africa and South America occurred along the Ivory Coast – Guinea transform margin during the Albian to early Cenomanian (Mascle *et al.,* 1988). The sea invaded the Benue Trough for the first time during the Albian, though the first marine influence, may have reached the Gulf of Guinea without an established connection with the waters of the

North Atlantic (Benkhelil, 1986). According to Zaborski (2000) the first marine penetration of the Benue Trough coincided with or immediately preceded the establishment of a through- going seaway between the South and Equatorial Atlantic oceans. Current evidence indicates that during the late Albian the sea shoaled in the poorly understood area south of Bashar (Zaborski, 2000; Fig. 7). It has been suggested that it extended north, where it is represented by argillaceous beds in the lower parts of the Bima Group. (Carter *et al.,* 1963; Cratchley and Jones 1965; Ayoola, 1981) but Allix, (1983) considered these shale – dominated horizons to be of lacustrine origin and to have ages ranging between Late Aptian to Middle Albian. In the upper Benue Trough, the Middle and Upper Albian is represented by the “Middle” and “Upper” Bima S

andstone of Guiraud (1990, 1991) which were deposit in fluvial systems discharging into the Benue sea (Jones 1961; Ayoola, 1981; Allix, 1983; Guiraud, 1990; 1991).

2.3.2 LATE ALBIAN TO CENOMANIAN REGRESSION

The Late Albian to Cenomanian regression was characterized by extensive deltaic development (Carter *et al.,* 1963). A gradual regression from the interior of the Benue Trough forming a large part of the Cenomanian is represented by the Yolde Formation which contains dinoflagellates and arenaceous foraminifers at various stratigraphic levels (Lawal, 1982). The Yolde formation contains bioturbated sandstones and oyster-rich calcareous beds. The upper part of the Yolde Formation is related genetically to the late Cenomanian transgression (Zaborski, 2000). It is possible that intermittent marginal marine conditions affected the upper Benue Trough during the early and middle

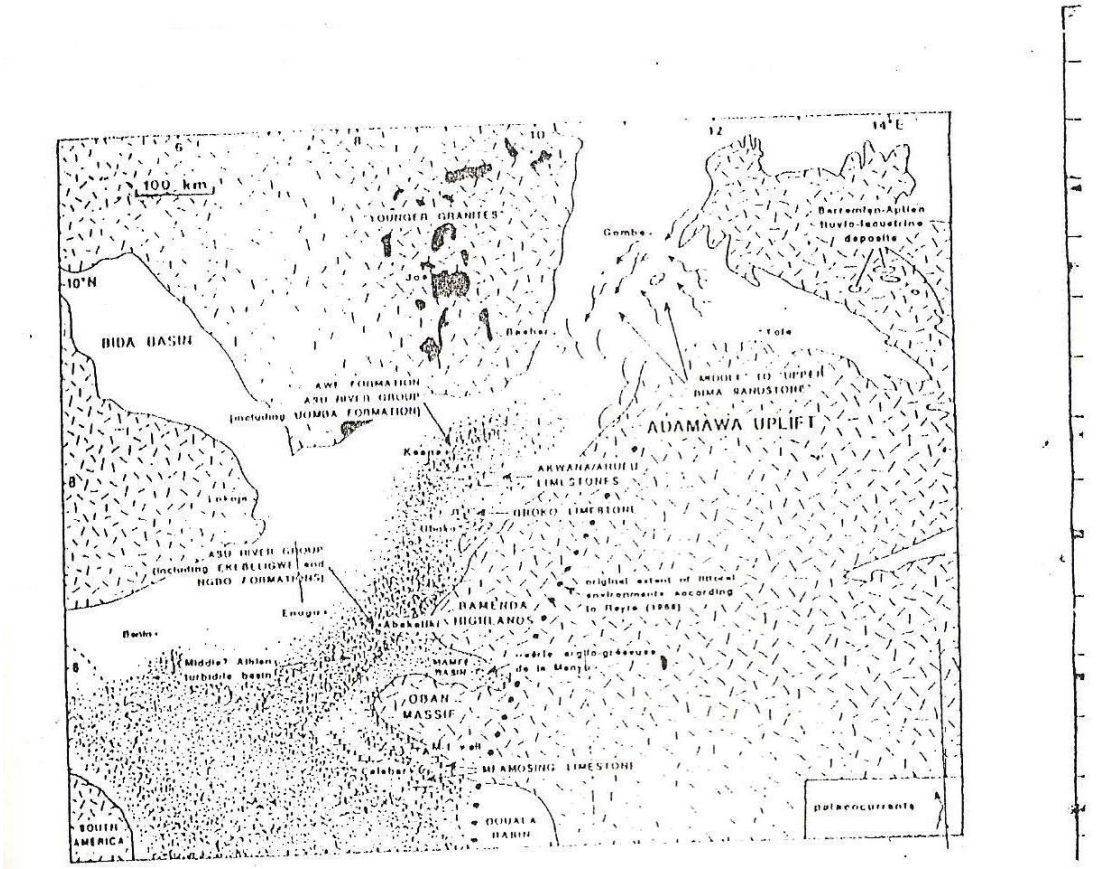


Fig.7: Map showing the extent of the late Middle Albian transgression in the Benue Trough. Marine areas stippled with stipple density being related to water depth. Also indicated are Albian lithostratigraphical units (note that direct correlation of this is not implied). After Zaborski (2000).

Cenomanian, where the sea was advancing into the region from the north through the east Niger rifts (Zaborski, 2000).

2.3.3 LATE CENOMANIAN TO EARLY TURONIAN TRANSGRESSION

This transgression was the most extensive in Nigeria and Niger (Figs. 8 & 9). Marine upper Cenomanian to lower Turonian occurs through out the Benue Trough but is unknown on the Calabar flank at least in out -crop (Zaborski, 2000). This transgressions is represented

in the upper Benue Trough by the Dukul Formation in the Yola arm and the Kanawa Member of the Pindiga Formation in the Gongola arm (Carter *et al.,* 1963; Zaborski *et al.,* 1997). The Kanawa Member and Dukul Formation comprise shales and limestones horizons.

In the Iullemmeden and Chad basins the upper Cenomanian lower Turonian deposits (Iguellala mountains, Bérérié and Zoo Baba formations are exclusively marine (Table 1). They are of equivalent age with Kanawa Member and Dukul Formation.

In Niger and the Tinrhert region of Algeria there are four important ammonite faunas, successively characterized by *Neolobites*

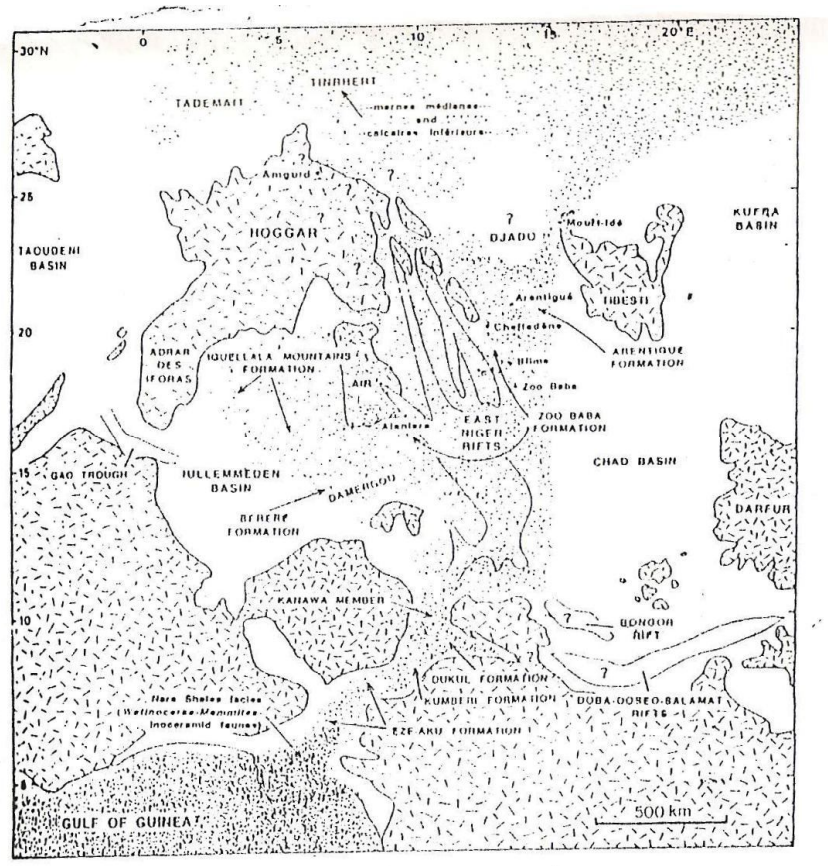


Fig.8: Map showing the maximum extent of the sea (stippled) in Nigeria, Niger and Southern Algeria during the late Cenomanian to early Turonian transgression. Also indicated are lithostratigraphical units deposited during this events. After Zaborski (2000).

vibrayeanus (d'Orbigny) *Nigericeras gadeni* (Chudeau). *Paravascoceras cauvini* (Chudeau) and *Pseudotissotia nigeriensis* (Woods). The last three occur in the upper Benue Trough (Table 2), demonstrating direct faunal exchange with areas to the north (Zaborski, 2000).

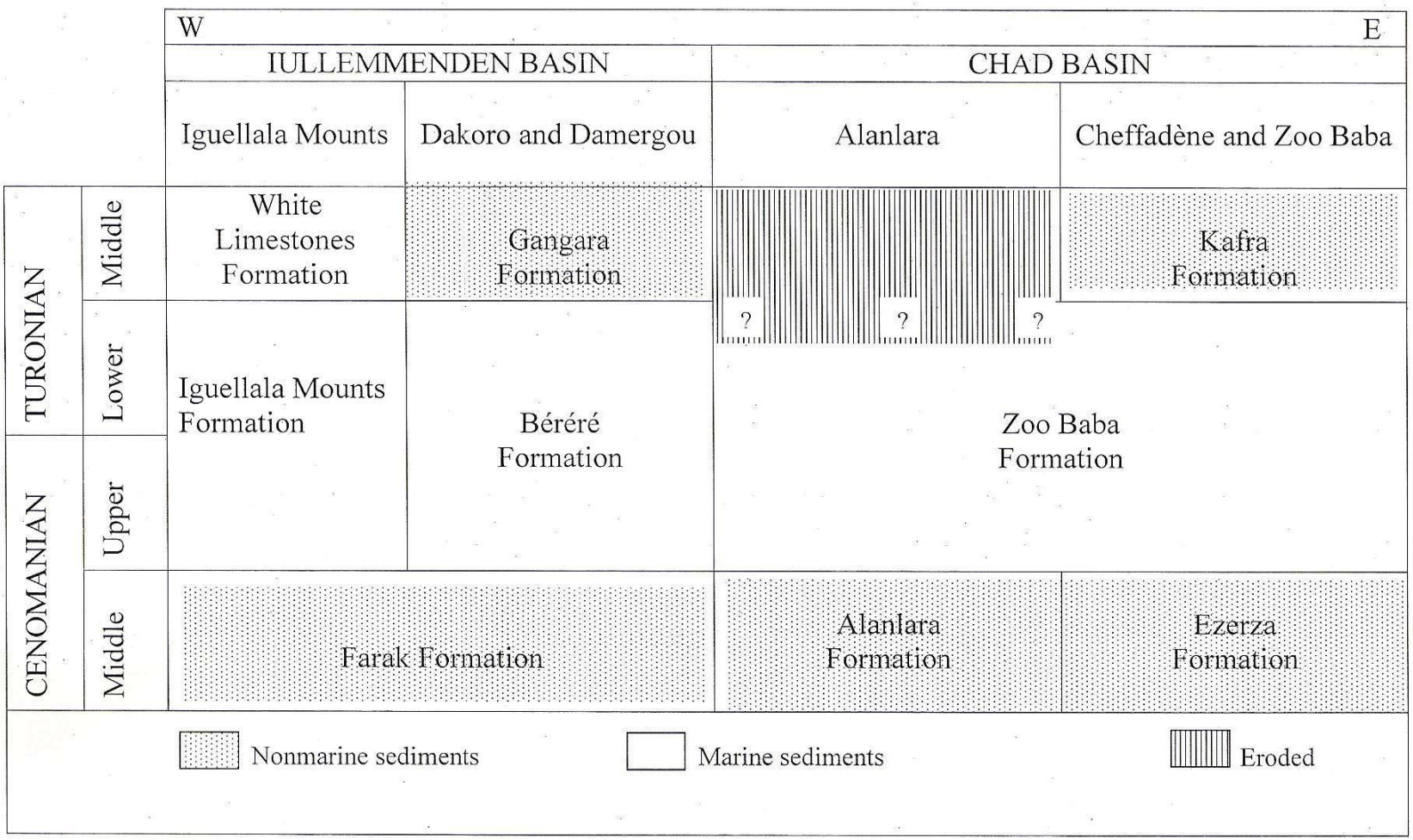


Table 1: Stratigraphic correlation chart of the middle Cretaceous formations in lullemmenden basin and northern Chad basin. (Modified from Greigert, 1966, and Faure, 1966.)

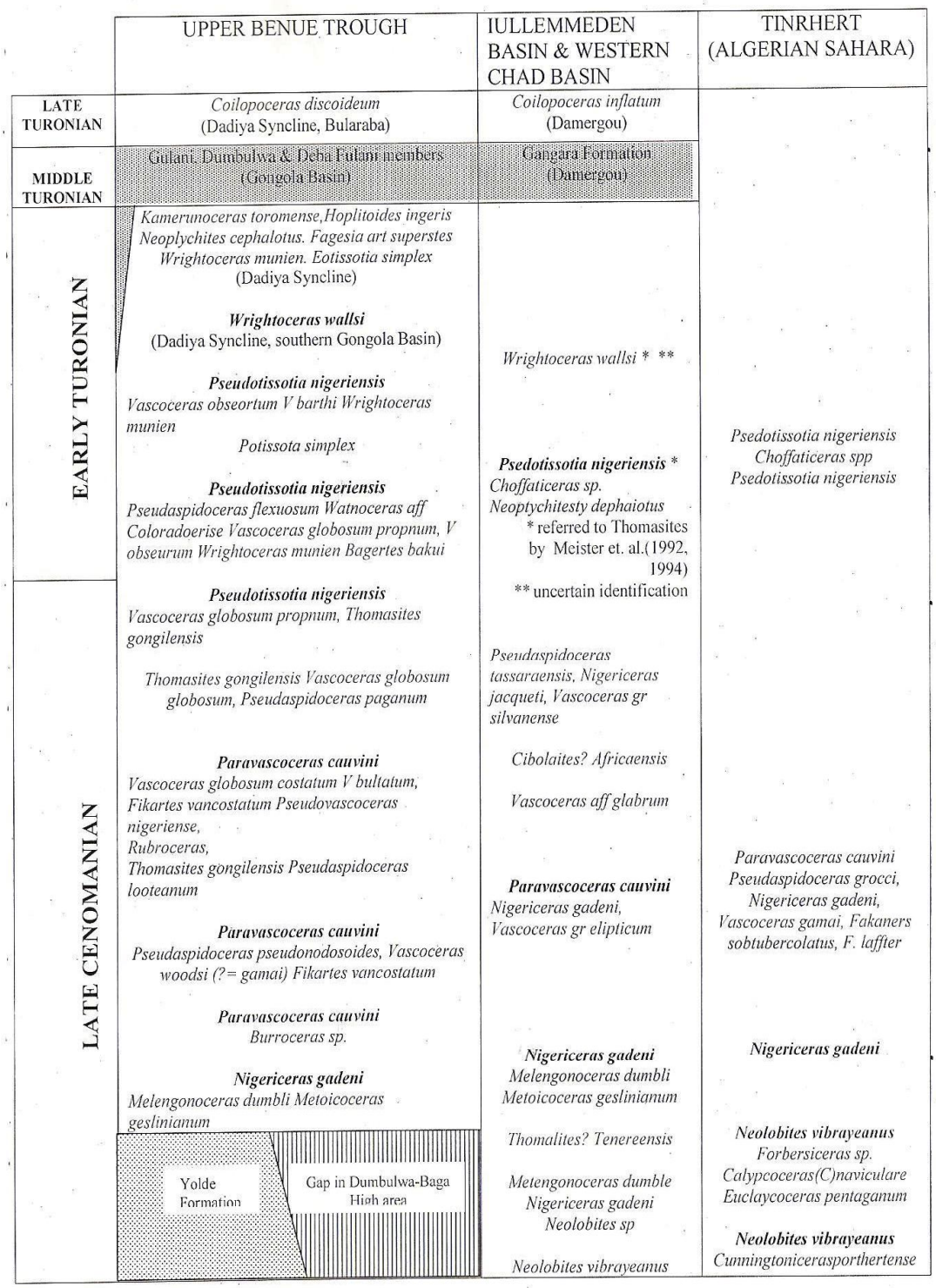


Table 2. Table showing the Late Cenomanian to Turonian ammonite sequences in the upper Benue Trough (Nigeria), Iullemmenden Basin and Western Chad Basin (Niger) and the Tinrhert region (Algeria). Exact correlation of the faunas indicated is not implied, formal biozones are not indicated nor are the faunas necessarily present throughout each area. Data from Zaborski (1990a, 1996), Meister et. al. (1992, 1994), Amédro et. al. (1996).

2.3.4 LATE TURONIAN TO CONIACIAN TRANSGRESSION

Marine Coniacian beds occur through out the Benue Trough and in the Calabar flank. In the upper Yola arm, the Sekuliye (Sekule) Formation and Numanha Shale represent open and more restricted marine Coniacian conditions respectively while in the Gongola Basin

marine Coniacian occurs in the lower part of the Fika Member of the Pindiga Formation (Carter *et al.,* 1963; Zaborski *et al.,* 1997; Fig. 10). Molluscs and ammonites are known from these units.

2.3.5 SANTONIAN BASIN INVERSION

The first compressional phase associated with strike **–** slip movement was during the Santonian when the Benue Trough proper was inverted at about 85 – 83 Ma as a result of global plate reorganization. Erosion followed in the Benue Trough where lower and middle Campanian beds are unknown (Zaborski, 2000).

2.3.6 LATE CAMPANIAN TO MAASTRICHITIAIN TRANSGRESSION

In the late Campanian sedimentation resumed in the Benue Trough when a renewed phase of rifting took place (Popoff *et al*., 1988, Zaborski, 1998) and also in the east Niger rifts (Genik, 1993). Depocentre were shifted to the west into western Gongola Basin. In the Gongola Basin, the Fika Member contains Campanian beds with dinoflagellates and arenaceous foraminifers (Lawal, 1982; Allix, 1983). A juvenile *Libycoceras* was described from near Gombe (Reyment, 1955; 1980)

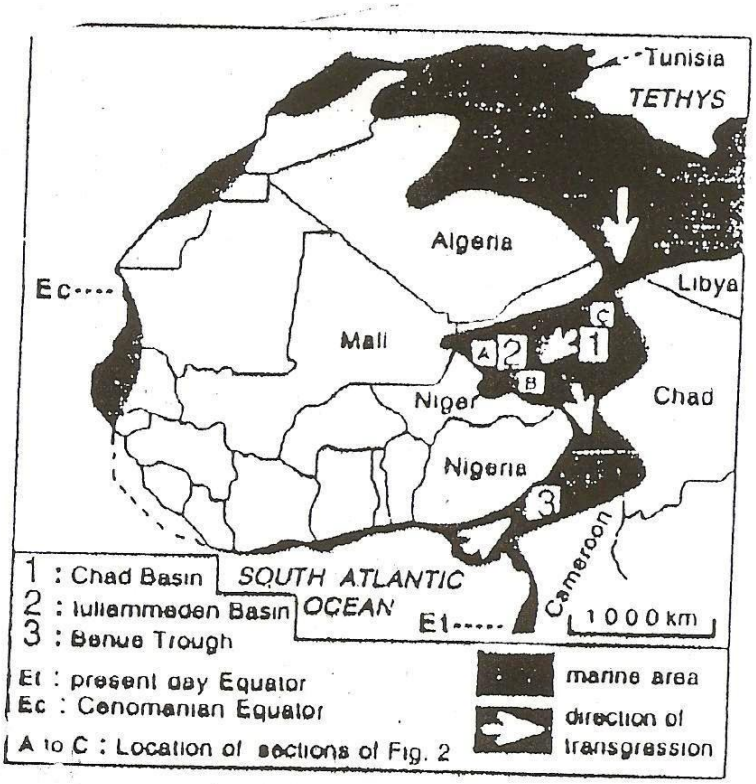


Fig. 9: Maximum extent of southern Tethys in West Africa during the late Cenomanian (ammonite horizon IV). Shown are the connection of the Iullemmeden and Chad basins with the marine domain, the approximate distance of sections *A*, *B* and *C* of Fig. 2 from the shoreline, and the inferred Tethys-South Atlantic link through the Benue Trough (after Reyment, 1980, 1989; Kogbe, 1981; Reyment and Dingle, 1987; Pascal et al., 1993).

The Campano – Maastrichitian cycle began with transgression which created a trans – Saharan migration route for *Libycoceras* flooded the Benue Trough and allowed the genus to colonize south Nigeria from the north (Zaborski, 2000)

Terminal Cretaceous compression in the upper Benue Trough, Iullemmeden and Chad Basin accompanied the switching of the trans – Saharan seaway from the east to the west of the Hoggar massif (Avbovbo *et al.,* 1986; Benkhelil 1989; Olugbemiro, 1997; Zaborski *et al.,* 1997)

2.3.7 PALEOCENE CONTINENTAL SEDIMENTATION

After the termination of Cretaceous sedimentation in the Gongola Basin, the area was affected by a compressional episode before the onset of Cenozoic sedimentation. The Kerri –Kerri Formation which is continental in origin (fluviale to lacustrine) represents Cenozoic sedimentation in the Gongola Basin. It comprises sands, grits and clays. A Paleocene age has been assigned to it based on pollens (Adegoke *et al.,* 1978).

CHAPTER THREE

3.1 THE LATE CENOMANIAN EARLY TURONIAN BENUE AND SAHARAN SEAS

During the late Cenomanian to early Turonian the most extensive transgressive event affected the Benue Trough. The sea spread in a narrow tongue from the coastal Nigerian basin via the north eastern “Chad Route” and into the Sahara. Marine upper Cenomanian to lower Turonian that is representative of this transgression is found in the upper, middle and lower Benue Trough. Faure (1966) concluded that the sea encroached gradually from the north over a subdued forested landscape. By early in the late Cenomanian, the sea had spilled out over a large part of the northern Iullemmeden Basin, introducing the *Neolobites* fauna there; marginal marine environments existed in the upper Benue Trough represented by the upper part of the Yolde Formation which contains bioturbated sandstones and oyster – rich calcareous beds. In the lower and middle Benue Trough the relevant beds are referred to the Eze Aku Formation, the Ezillo Formation and Nara shales of Ojoh (1990). In the upper Benue Trough they belong to the Dukul Formation in the Yola arm and the Kanawa Member of the Pindiga Formation in the Gongola Basin (Carter *et al.,* 1963; Zaborski *et al.,* 1997).

In the Iullemmeden and Chad Basin, the upper Cenomanian – lower Turonian deposits (Iguellala Mountains Béréré and Zoo Baba formations are exclusively marine (Table 1) they are of equivalent age with the Kanawa Member and Dukul Formation.

Transgression from the Tethys penetrated into the eastern part of the Iullemmeden Basin during the late Cenomanian. It resulted in the creation of shallow furrow – shaped marine environments where bottom conditions were alternately oxic and anoxic in response to the combined effects of general (eustatic) and regional (climatic) factors according to Mathey *et al.* (1991). At the peak of this transgression, a temporary seaway linked the Tethys and the south Atlantic via the Benue Trough (Fig. 10). By mid-late Cenomanian times open marine conditions reached the upper Benue Trough area marked by the *Nigericeras gadeni* fauna (Zaborski, 2000). At the time the sea was advancing through the Benue Trough from the Gulf of Guinea' The Gracile zone species *Euomphaloceras septemseriatum* (Cragin) an Atlantic immigrant occurs in the middle Benue Trough (Offodile, 1976; Offodile and Reyment, 1957). The merger of the two seas near the junction of the middle and upper Benue Trough completed the trans Saharan seaway.

In the upper Benue Trough, the faunas are mainly of Saharan origin, with two sub- families the Turonian Pseudotissotia and the mainly Cenomanian Vascoceratinae (Courville, 1992).

In the lower Benue Trough, the ammonite content includes Cenomanian-Early Turonian assemblages dominated by Atlantic Mammitinae.

The control of the composition of the ammonite assemblages depends on ecological factors such as salinity and water depth as mentioned by Zaborski (1985). Therefore the composition is related to the local tectonic frame work and to its impact on the paleobathymetry (Courville, 1992).

The southern ammonite assemblages are nearly identical to the European and North –American ones; these taxa are used for the "standard" biostratigrahic framework. In the lower Benue Trough where deeper water conditions prevailed,

the Nara Shales contain Early Turonian faunas including *Watinoceras* and *Mammites* which have virtually nothing in common with those of the upper Benue Trough but which share many elements with the western interior of the USA, NW Europe and, notably, Venezuela (Zaborski, 1987; 1990).

In Niger, the upper Cenomanian to lower Turonian shale – limestone successions outside the east Niger rifts contain abundant Vascoceratid ammonites *gryphaeid* and *ostreid* biralves (Zaborski, 2000). In contrast, the Tethyan platforms to the north are rich in brachiopods, corals, rudists and larger benthic foraminifers.

The middle Benue Trough and the northern part of the lower Benue Trough are characterized by vascocoratid ammonites (Offodile, 1976; Offodile and Reyment, 1976; Zaborski; 1987)

The conditions that might have characterized the sea includes: -

i. Negligible tidal range

ii. Cyclic sedimentation

iii. Tendency towards stagnation

iv. High temperatures

v. High freshwater influx

The alternation of shale and limestone lithologies has been attributed to episodes of alternation of normal marine oxic conditions (limestones) and dysoxic sometimes brackish bottom water conditions (shales) that prevailed in the area. The deposition of the grey to black shales which are very poor in benthic faunas could also have been due to water deepening in the area.

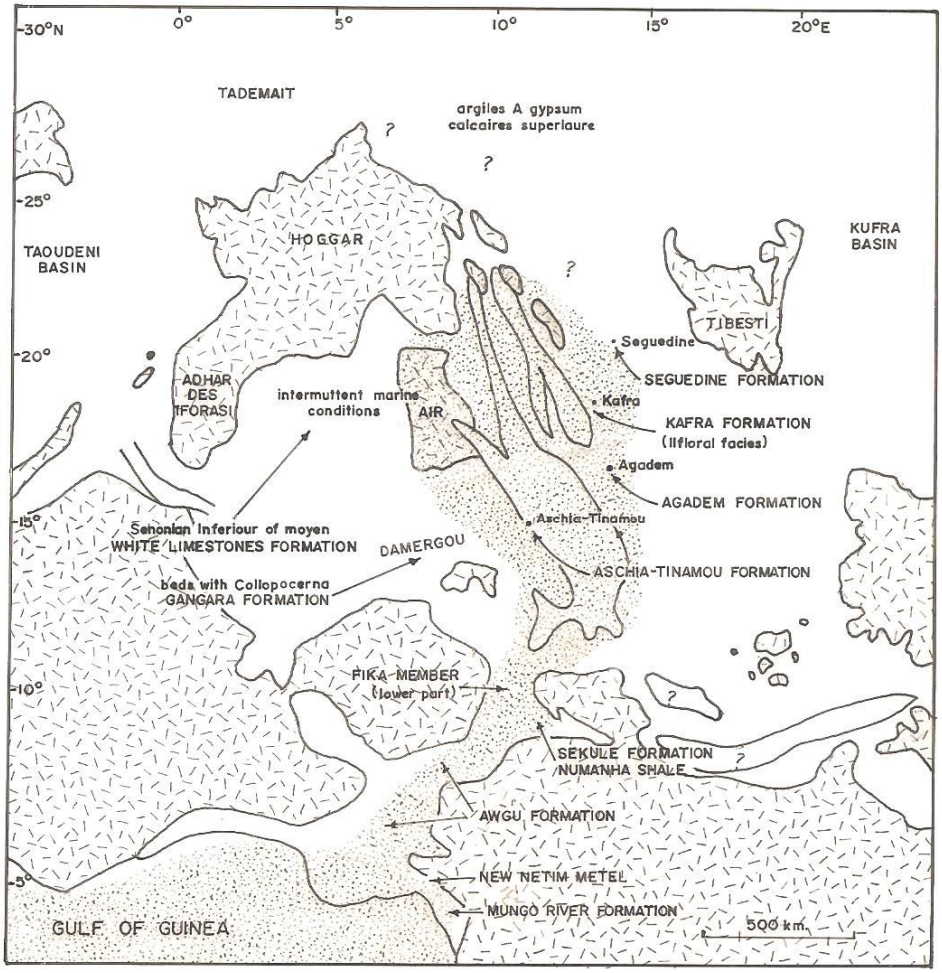


Fig. 10: Map showing the extent of the sea (stippled in Nigeria, Niger and southern Algeria the Coniacian. After Zaborski (2000).

In Niger the upper Cenomanian to lower Turonian shale – limestone successions outside the east Niger rifts were regarded by Pascal *et al.* (1993) as having formed under a humid tropical climate on a large ramp inclined gently and lacking shoal areas. Mathey *et al.* (1991) and Pascal *et al.* (1993) attributed the Iguellala Mountains and Bérérê Formation limestone horizons to regional control. For the former authors, they represent intervals of low rainfall and clastic influx when an absence of density stratification allowed oxic bottom conditions to develop. For the latter authors, the limestones coincided with the peak of transgressive pulses when effective water circulation precluded bottom anoxia.

3.2 PREVIOUS WORK

The Pindiga Formation was previously described by Barber *et al*. (1954) under the name “Calcareous Beds” and “clay shales” was used by Reyment (1957) for the lower part of the Formation .The Pindiga Formation was divided into the Kanawa Formation and Pindiga Shales by Thompson (1958).

Barber (1957) studied 195 meters of the Pindiga Formation at Pindiga made up of 75m of fossilferous beds below overlain directly by 120 m of shales (Fig .11). He observed that the shales do not contain ammonites. He subdivided the fossilferous beds into three zones based on the 24 species of ammonites he recognized from them.

iii Zone of *Pseudotissotia (Bauchioceras*) *nigeriensis* (Woods) above;

ii. Zone of *Parvascoceras costatum* Reyment in the middle; and

i. Zone of *Vascoceras bulbosum* (Reyment) below.

Barber (1954) assigned a (Cenomanian to Turonian) age to the Pindiga formation based on ammonites.

The name Pindiga Formation was proposed by Carter *et al,* (1963) for the greater part of the marine rocks in the “Zambuk ridge” area and this according to them corresponds to the Dukul, Jessu, Sekule and Numanha Formations of the Yola Arm (Benue Basin). They described 195 m of strata of this Formation at its type section at Pindiga, noting that the lower 75m contains a number of limestone beds ("limestone – shale member ") and the upper part is made up of 120 m of blue – black shales ("shale member ").

They observed that the limestone shale member yielded 24 species of ammonites, 16 species of bivalves and 2 species each of gastropods and echinoids. This in their opinion represented a typical Salmunian (lower Turonian)

fauna Based on the ammonites of the limestone – shale member; they recognized 3 zones:

iii. Zone of *Pseudotissotia (Bauchioceras) nigeriensis* (Woods) above.

ii. Zone of *Paravascoceras costatum* (Reyment) in the middle and

i. Zone of *Vascoceras bulbosum* (Reyment) below

At Kanawa, Carter *et al.* (1963) collected 11 species of ammonites 6 species of bivalves and 2 species each of gastropods and echinoids, They also encountered 14 species of ammonites and 2 species of bivalves at Gulani while at Bularafa they collected 13 species of ammonites, and 1 species each of bivalves and echinoids. They reported that the shale member at Gombe has yielded *Libycoceras ismaeli* (Zittel), an ammonites said to be typical of the Maastrichitian.

Carter *et al.* (1963) proposed the name “Gongila formation” for a sequence of continental and marine strata in the Gongola Basin and observed that it was a lateral equivalent of the Pindiga formation. They recognized a limestone bearing unit below and an upper sandstone – shale member. They recognized 23 species of ammonites, 6 species of bivalves and 4 species of gastropods from both the type locality (the hill near Gongila village and a reference section at Chole. They regarded the fauna as early Turonian in age.

Wozny and Kogbe (1983) observed that the lower part of the Pindiga Formation as represented in the type locality along the Pindiga stream corresponds lithologically and faunistically to the lower part of the “Gongila formation” exposed at the Ashaka quarry(Figs. 12 &13). They described a 27m thick section within the Gongila formation at the Ashaka quarry, and proposed four bio – stratigraphic zones based on ammonites.

iv. Zone of *Pseudotissotia (Bauchioceras) nigeriensis* (woods) above,

iii. Zone of *Gombioceras gongilensis*

ii. Zone of *Paravascoceras costatum* Reyment.

i. Zone of *Vascoceras bulbosum* Reyment below

They emphasized that the basal beds of the Pindiga and Ashaka sections (Figs. 12 & 13) contained an upper Cenomanian fossil assemblage including *Exogyra olisiponensis* (Sharpe)' *Exogyra columba* (lamarck); *Hemiaster Pseudofourneli* (Peron and Gauthier) *Kanabiceras Septemseriatum.* They proposed a late Cenomanian age for the basal limestone at Ashaka and Pindiga (Fig. 12) with upper Cenomanian and lower Turonian fossils occurring along the Pindiga stream. They identified three ammonites zones.

iii Zone of *Pseudotissotia (Bauchioceras) nigeriensis* above

ii. Zone of *Paravascoceras costatum* in the middle

i. Zone of *Vascoceras bulbosum* below.

Popoff *et al.* (1986) studied the lower parts of the Gongila and Pindiga Formation equivalent to the "limestone shale" Members of the Gongila and Pindiga Formations of Carter *et al.* (1963). They based their work on sub – divisions, age and stratigrahic correlations of these Formations. They described 42m and 46m thick section for the Gongila and Pindiga Formations respectively, observing

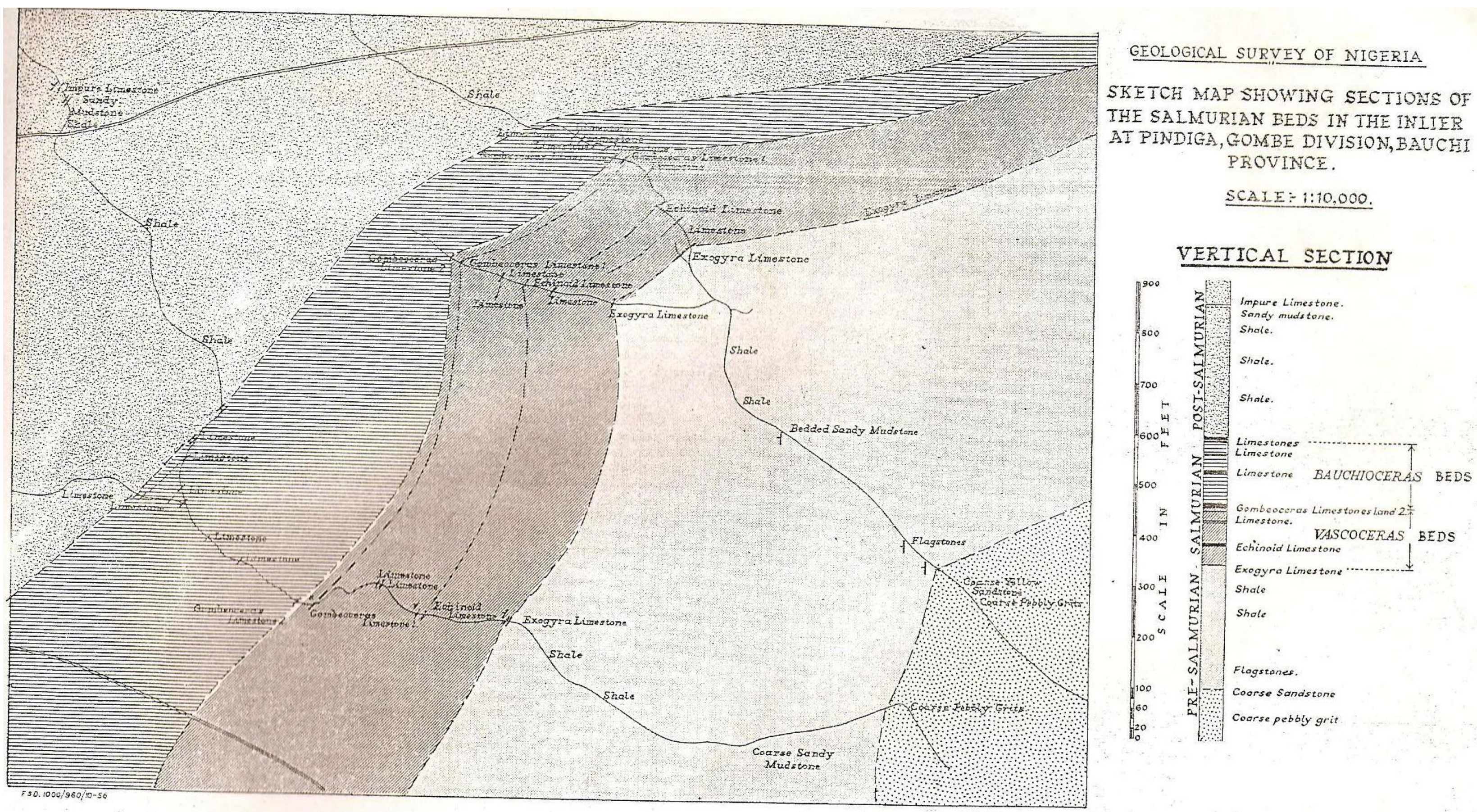
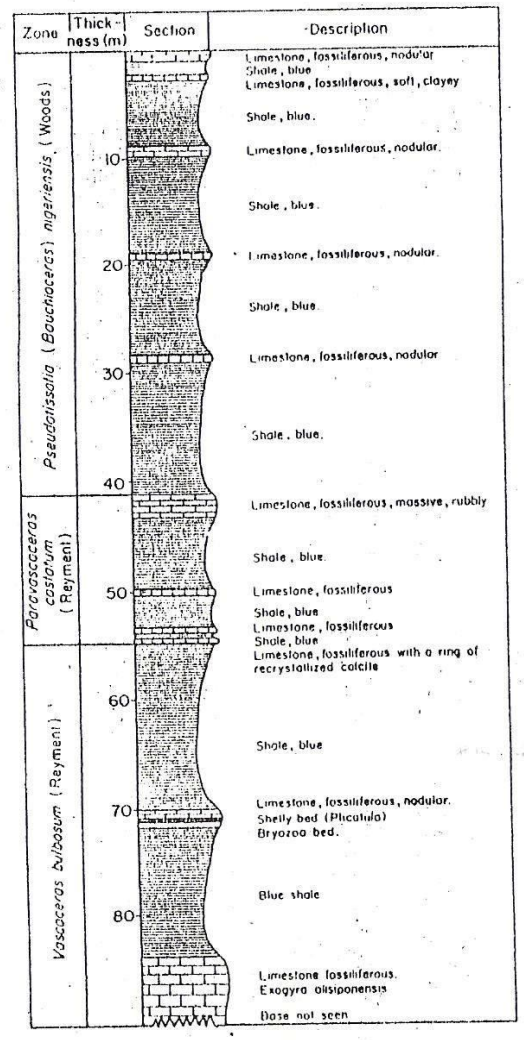


Fig.11: (Pindiga Section after Barber 1952)



. Pindiga section.

Fig.12: (After Wonzy and Kogbe 1983)

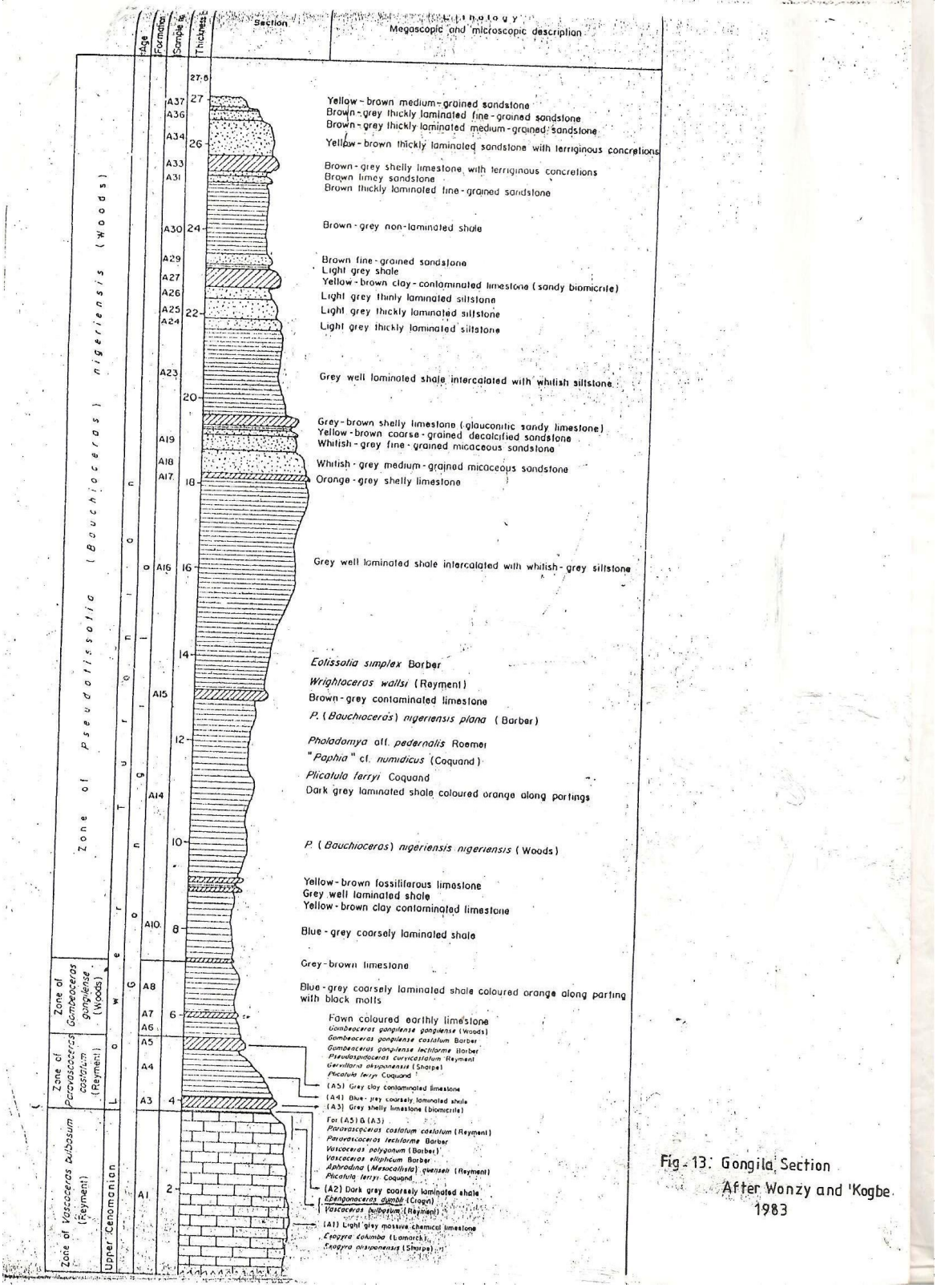


Fig. 13: Gongila Section
After Wonzy and 'Kogbe. 1983

that the two sections consist of alternations of limestone and shale \mud stone(Figs.14 & 15).

They subdivided the Gongila and Pindiga formations into 18 and 32 units respectively (Figs.14&15). Based on ammonite's biostratigraphy they assigned a

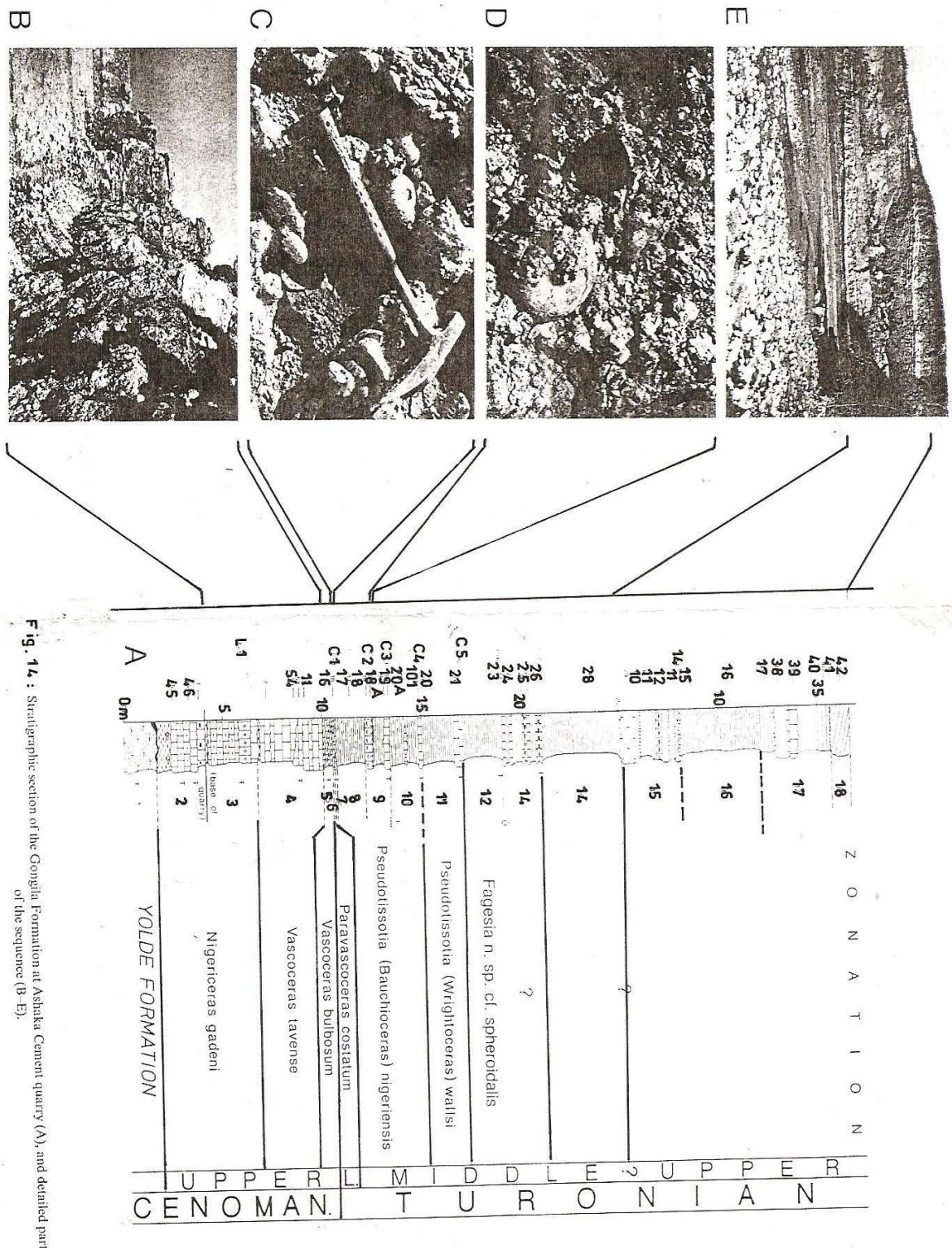


Fig. 14 : Stratigraphic section of the Gongila Formation at Ashaka Cement quarry (A), and detailed parts of the sequence (B–E).

After popoff et al, 1986

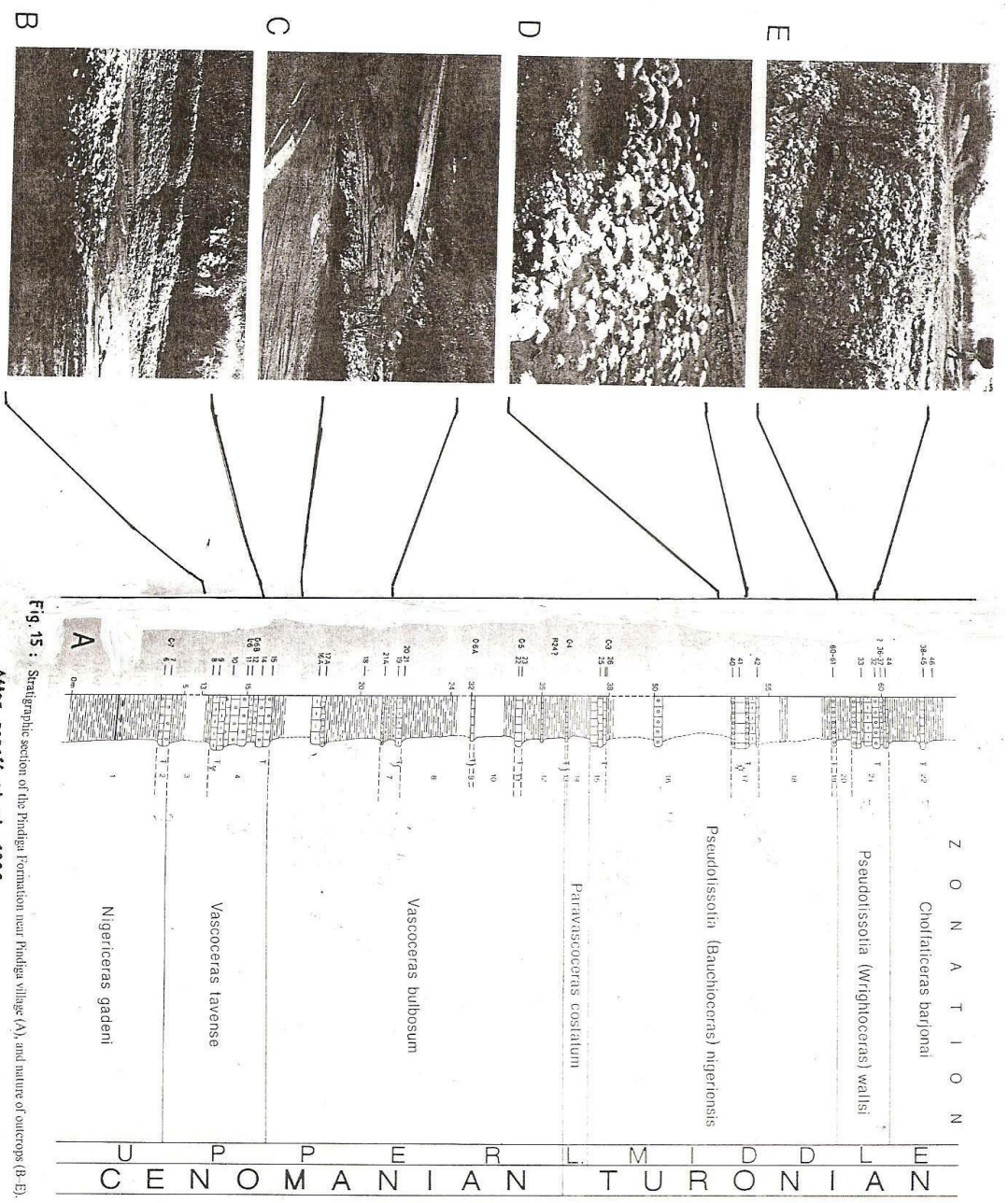


Fig. 15 : Stratigraphic section of the Pindiga Formation near Pindiga village (A), and nature of outcrops (B–E).
After popoff et al., 1986

late Cenomanian to middle Turonian age for beds 2 to 13 of the Gongila Formation while a late- middle and late Turonian age was proposed for beds 14 to 18. Popoff *et al.* (1986) put the Cenomanian -Turonian boundary at the top of unit 5 (Fig. 14). Popoff *et al.* (1986) put the Cenomanian – Turonian boundary at the top of unit 12 (Fig. 15) for the Pindiga Formation. Meister, (1989) studied the Ashaka section which enabled him to establish the vertical distribution of 28

Cenomanian – Turonian ammonites. The results he obtained enabled him to differentiate 10 biozonations.

Rebelle (1990) investigated the Sedimentogical characteristics of the Gongila formation at the Ashaka quarry. He studied the lower 15m of the formation and lithostratigraphically subdivided the section into 22 limestone – shale units which he noted were dominantly wackestones and packstones (Fig.16).

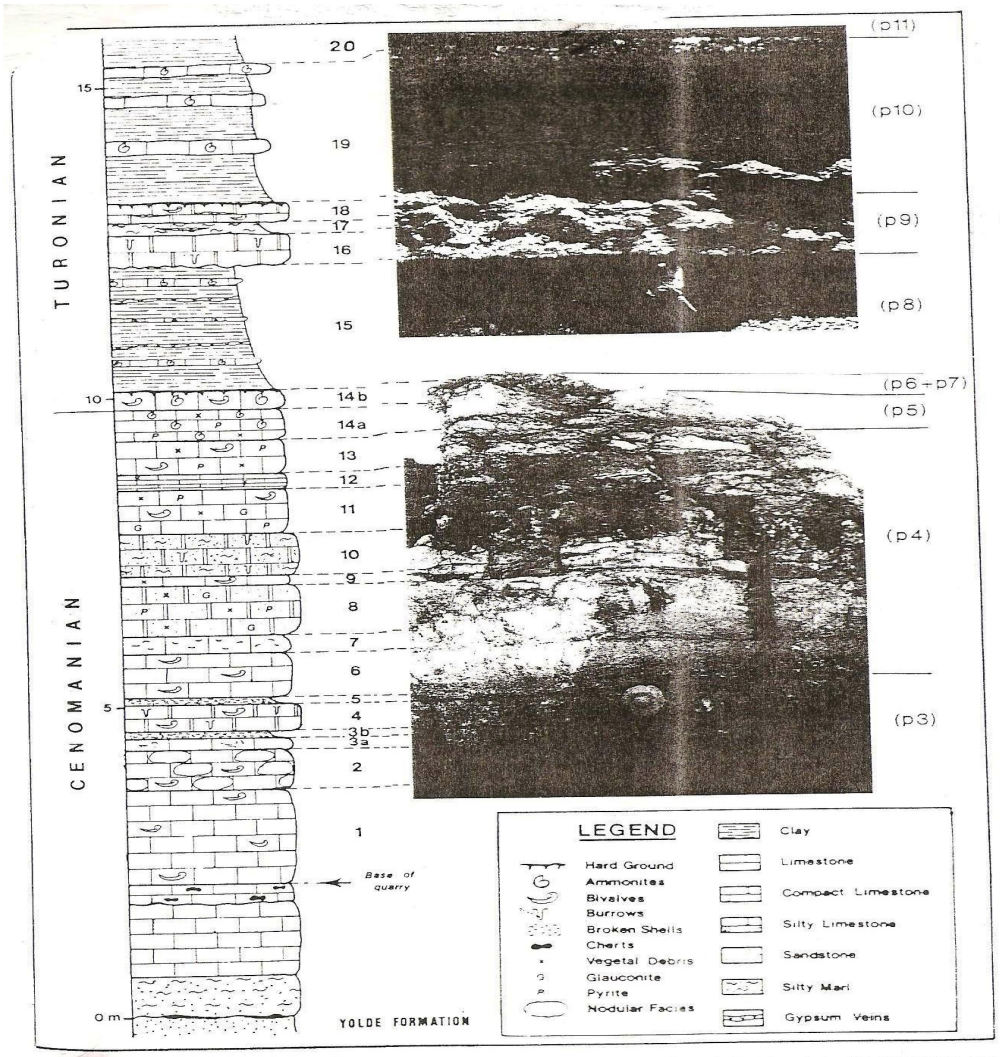


Fig.16: Stratigraphic log of the Gongila Formation at Ashaka quarry, with subdivision into 20 lithologic levels. On the right side, correlation with the lithologic subdivisions by Popoff et al (1986) is given by the number between brackets.

Courville, (1992) studied the Vascoceratinae and Pseudotissotinae from Ashaka and tried to relate them with the biosedimentary environment. He adopted a multi disciplinary approach involving sequence stratigraphy to interpret the marine section of the “Gongila formation” at the Ashaka section. He concluded that the Ashaka section is made up of a single sequence with a transgressive systems tract (TST) below and hightstand systems tracts (HST) above (Fig. 17).

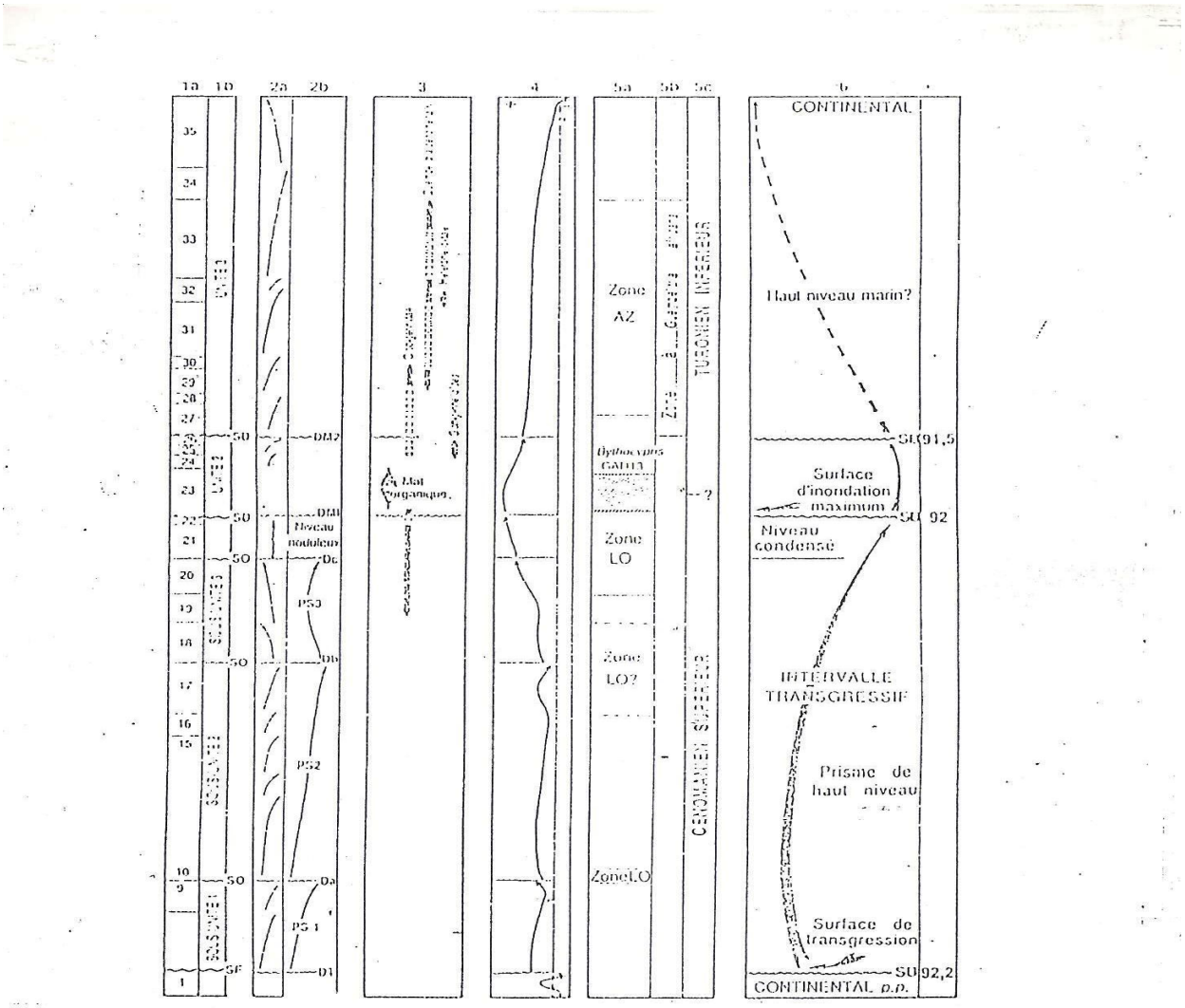


Fig. 17: Sequence stratigraphic interpretation of Gongila Formation at Ashaka, after Courville (1992)

Definition of the lithostratigraphic units and interpretation according to the concepts of the sequential analysis. Column 1a : numbering of the section; 1b : position and nature of the discontinuities; SD : undulating surfaces; SD : hardgrounds; SF : ferruginous surfaces. Column 2a : first order parasequences; 2b : second order parasequences (PS1, PS2, PS3); D1, DM1, DM2, Da, Db, Dc : discontinuities. Column 3 : occurrence of planktonic foraminifera and organic matter (Wonders et al., 1989). Column 4 : relative fluctuations of the water section thickness. Column 5 : microbiostratigraphic setting (Wonders et al., 1989). 5a : reduced biozonation; 5b : biozonation of planktonic foraminifera. Column 6 : sequential stratigraphic interpretation.

Zaborski *et al.* (1998) were of the opinion that the Gongila Formation is a synonym of the Pindiga formation. They subdivided the Pindiga Formation into five members: the Kanawa member, being the “Kanawa Formation” of Thompson (1958) and the lower shale – limestone members of the “Pindiga Formation” and Gongila Formation of Carter *et al.* (1963); three sandstone members namely the Gulani Member, the Deba – Fulani Member and Dumbulwa Member are lateral lithofacies equivalents occurring in the middle part of the Pindiga Formation. With a probable age limit within the range of late – early Turonian and late Turonian; and at the top the Fika Member, being the equivalent of the Fika Shales of *Carter et al.* (1963).

Using the distribution of ammonites in the Kanawa Member, Zaborski (1990; 1993; 1995; 1996) constructed a detailed biostratigraphy proposing 5 regional biozones (from top to bottom).

v. Zone of *Wrightoceras wallsi* (woods)

iv. Zone of *Pseudotissotia nigeriensis* (Reyment)

iii. Zone of *Vascoceras globosum* (Reyment)

ii. Zone of *Paravascoceras cauvini* (Chudeau)

i. Zone of *Nigericeras gadeni* (Chudeau)

Zaborski , (1998) interpreted this unit as belonging to the upper part of the late Cenomanian and most or all of the middle Turonian, based on ammonites. Zaborski (1993) concluded that the Cenomanian – Turonian boundary coincides with the base of the *Nigeriensis* zone. He fixed the boundary in the middle of his limestone unit T (Fig 18) having identified *Vascoceras Proprium* (Reyment) and *Pseudaspidoceras flexuosum* which have been proposed as a marker species for the base of the Turonian immediately above the level.

Suleiman, (2004) interpreted the sequence stratigraphy of Ashaka quarry section. He concluded that the Ashaka quarry comprises

a single sequence made up of a transgressive systems tract but without the lowstand systems tract since the lower sequence boundary (SB) corresponds with the transgressive surface (TS). The transgressive systems tract in the Ashaka quarry therefore comprises units C-T1 (Fig. 19). The highstand systems tract (HST) includes unit T2-X. He identified the parasequences which are separated by minor flooding surfaces marked by encrustation, bioturbation and nodular limestone surfaces (Plate 1).

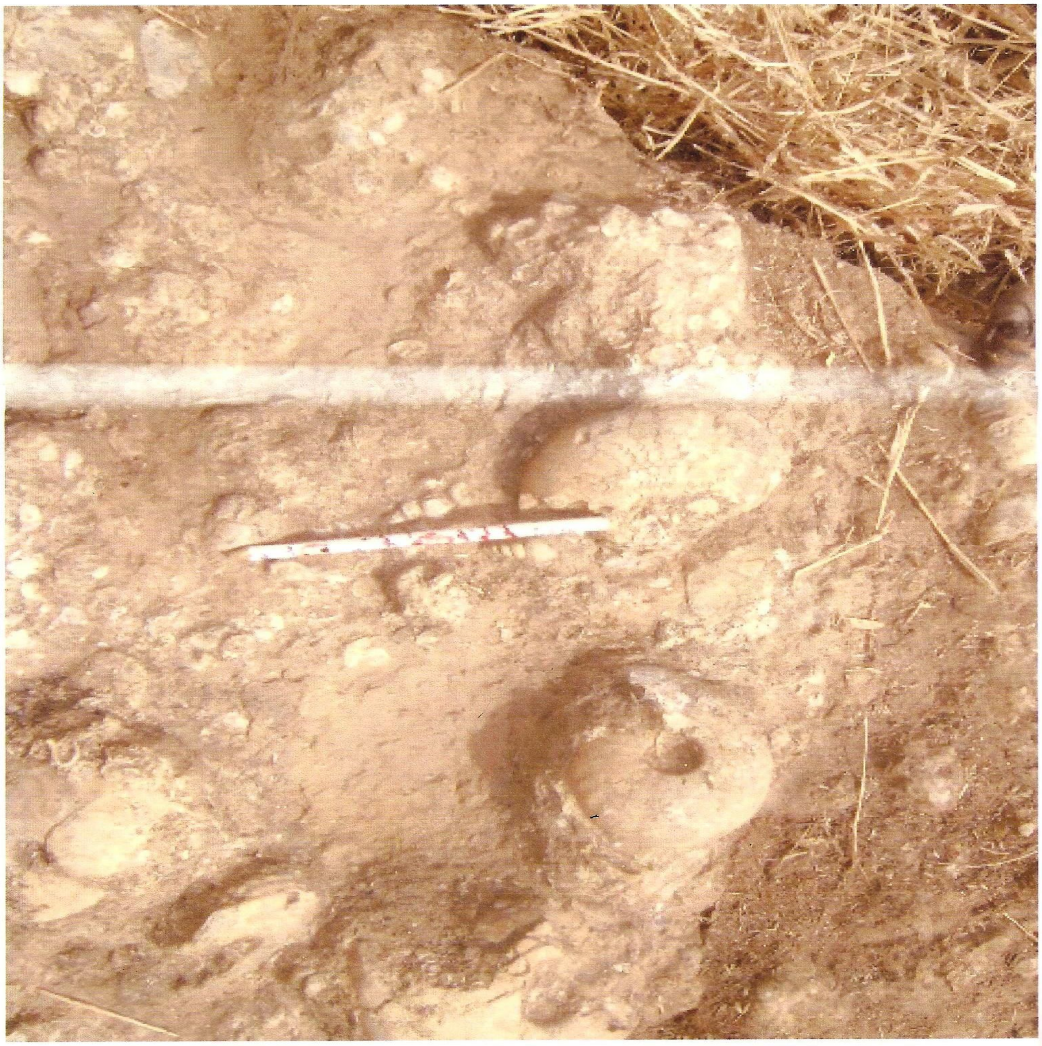


Plate 1: Marine flooding surface top of unit R Ashaka section with Pseudaspidoceras paganum and other mollucs

BARBER(1957)	WOŻNY&KOGBE(1983)	POPOFF et. al. (1986)	ZABORSKI(1990)
Pseudotissotia (Bauchioceras) nigerienesis	*Pseudotissotia (Bauchioceras) nigerienesis*	*Choffaticeras Barfonae Fagesia n.sp*	*Wrightoceras wallsi*
		wrightoceras wallsi	
		Pseudotissotia nigerienesis	*Pseudotissotia nigerienesis*
	Gombeoceras gongilense		
Paravascoceras costatum	*Paravascoceras costatum*	*Paravascoceras costatum*	*Vascoceras globosum costatum*
Vascoceras bulbosum	*Vascoceras bulbosum*	*Vascoceras bulbosum*	*Paravascoceras canvini*
		Vascoceras tavense	
		Nigericeras gadeni	*Nigericeras gadeni*

Fig. 18: Previous proposal for a biostratigraphical subdivision of the Upper Cenomanian and Lower Turonian in North-eastern Nigeria based on ammonites. Adapted from (Zaborski, 1990)

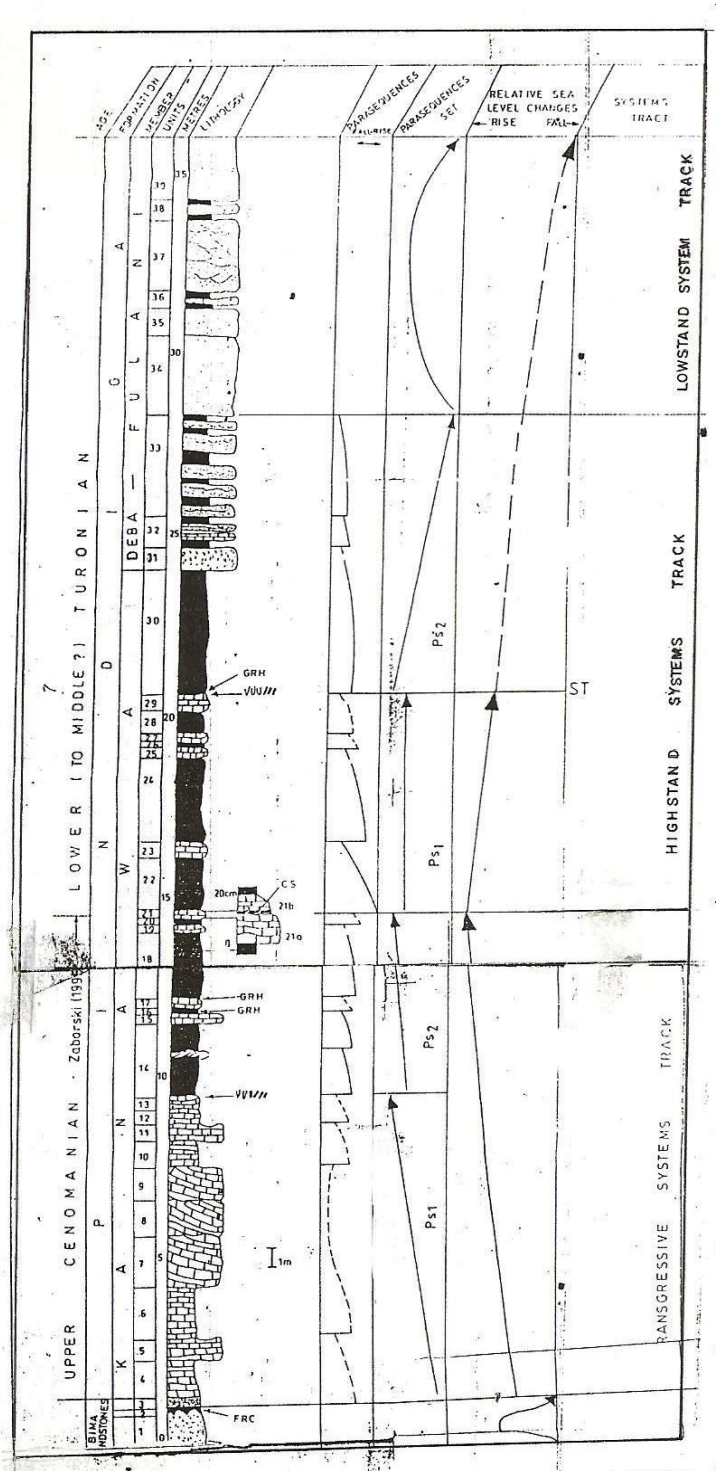


Fig 19; Sequence Stratigraphic interpretation of Pindiga formation at Ashaka quarry. Legend; SB = sequence boundary, TS = Transgressive surface, FRC = ferrogenious crust, Icc = Inferred correlative comformity, MFS = maximum flooding surface, CS = Condensed section, ST = Standstill, Ps1 = Parasequence sets, Ps2 = Parasequence set, GRH = Glauconitic rich horizone, vvv = bioturbative horizone, ''' = Nodular surface, χχ = Bivalves bed. After Sulaiman

CHAPTER 4

LITHOSTATIGRAPHY AND BIOSTRATIGRAPHY OF THE BASAL PINDIGA FORMATION (KANAWA MEMBER) AT ASHAKA, PINDIGA AND DEBA HABE

4.1 INTRODUCTION

The Kanawa Member has a very wide spread occurrence in the upper Benue Trough. (Carter *et a*l., 1963; Zaborski, 1990). The greater part of the Kanawa Member consists of shaly mudstones, dark grey in colour when fresh, weathering to light blue to green colours. There are also intercalations of limestones. The limestones weather to white, cream and brownish colours. The Kanawa Member was deposited during the late Cenomanian to early Turonian transgression, which affected the entire Benue Trough and the Saharan region to the north (Zaborski, 2000). The two best known sections are the Ashaka quarry and Pindiga stream sections.

4.2 The Ashaka, Quarry Section of the Kanawa Member

The Ashaka section is located some 80 km north of Gombe town. It is located within the N – S aligned Gongola Basin of the upper Benue Trough. The Gongola Basin is bounded to the south by the “Wuyo Kaltungo High “which is the median zone of the upper Benue Trough separating it from the Yola Arm (Fig.20). northern border of the Ashaka area is the “Dumbulwa - Bage High” which is also the northern border of the Gongola Basin (Fig. 21) separating it from the Bornu/ Chad Basin. The “Dumbulwa -Bage High” was described by Zaborski *et al.* (1998) as a shoal area during the late Cenomanian to early

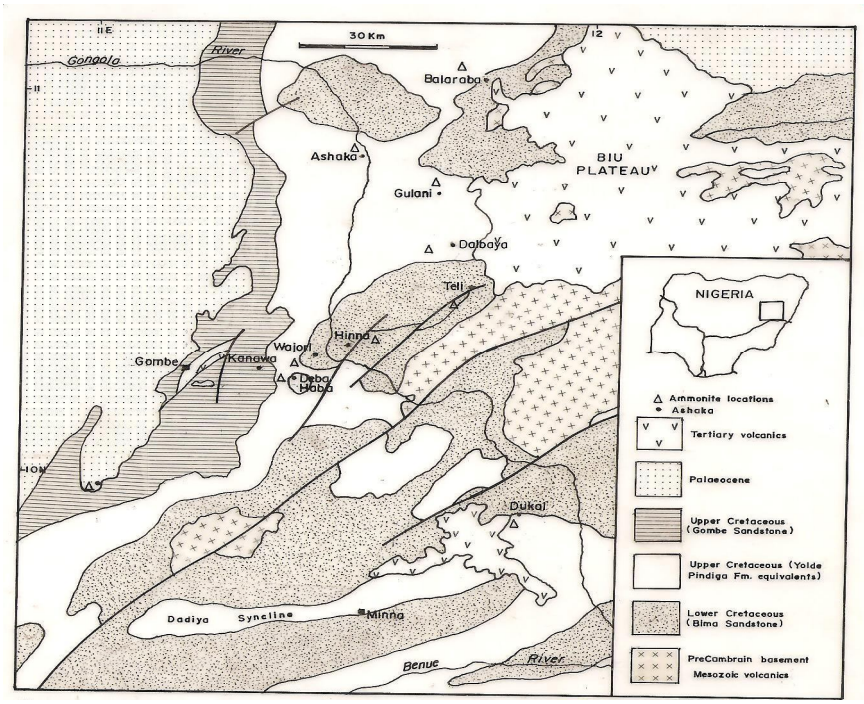


Fig. 20: Simplified Geological map of part of north eastern Nigeria showing the location of Ashaka area. (Zaborski (1990)

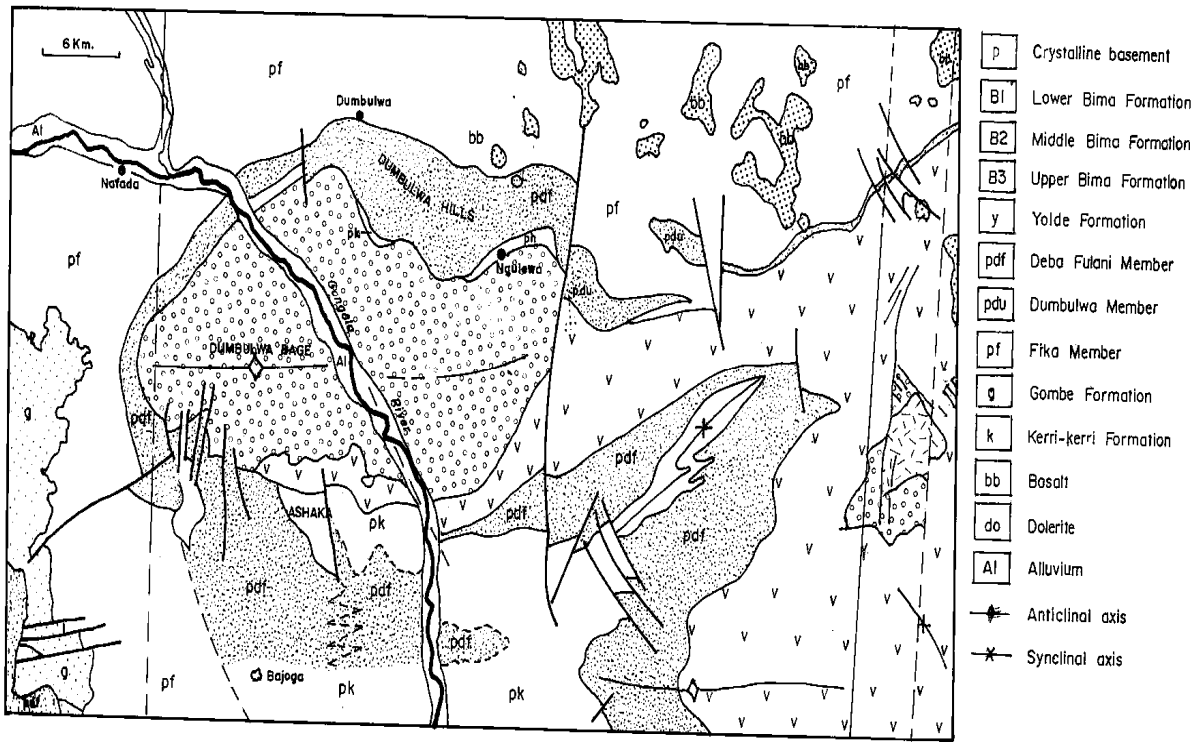


Fig 21: Geological map of the northern portion of the Gongola Basin including Dunbulwa Bage High, after Zaborski *et al* (1997)

Turonian and they indicated that it was an area of persistent uplift subsequent to the deposition of the lower Bima Sandstone. To the east and west of the Ashaka area are the Biu Plateau and the Kerri- Kerri plateaus respectively. The Kanawa Member exposed at the Ashaka Quarry is overlain by the Deba- Fulani Member and rests uncomformably on the red to light brown medium- grained sandstone of the upper Bima Sandstone (Zaborski *et al.,* (1998). A detailed description of the Ashaka section was given by (Zaborski *et al.,* Fig .22).

The Ashaka cement quarry is the best known geological locality in the Gongola Basin (Zaborski, 2003). The rich diverse

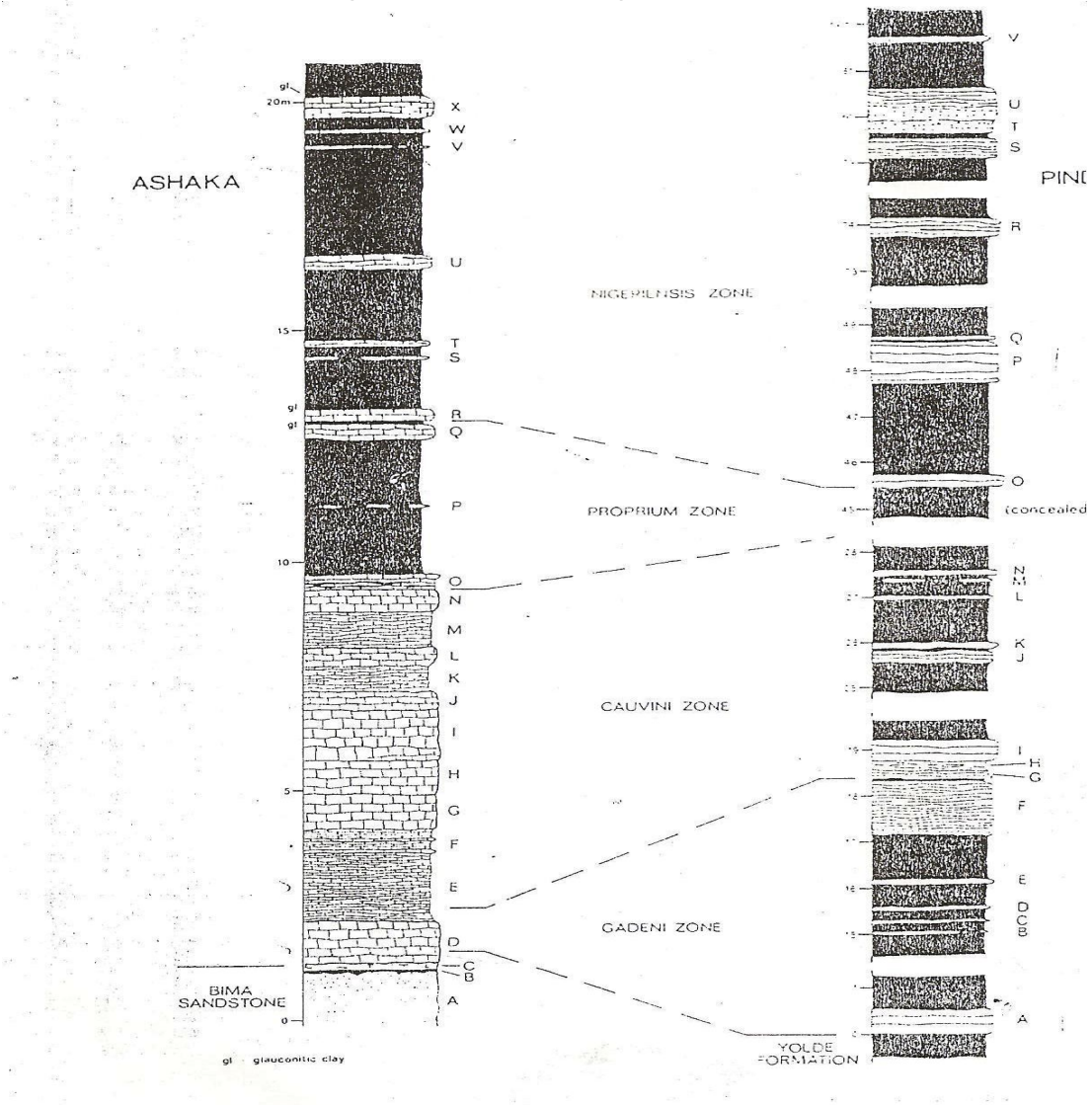


Fig. 22: Stratigraphical sections in the Pindiga formation exposed at Ashaka Quarry and in Pindiga stream. After Zaborski (1995).

macro –fauna, especially the ammonites in this section have led to detailed descriptions by former workers: (Wozny and Kogbe; 1983,
Rebelle et al; 1986; Meister, 1989; Oti, 1990; Rebelle, 1990; Courville, 1992; Zaborski, 1995; 2003).

The floor of the quarry is formed by unit D of Zaborski (1995) in the Kanawa Member (Fig .22), a sandy limestone rich in bivalves, notably *Exogyra* and *Pinna.* The ammonite *Nigericeras gadeni* occurs as an extreme rarity (Zaborski, 2003). The Bima Sandstone was subaerially exposed prior to the onset of the late Cenomanian transgression. Initially, deposition of the Kanawa Member involved reworking of the underlying sandstones (Zaborski, 2000). Units E and F are rubbly limestones hosting *Paravascoceras cauvini,* the latter also with echinoid *Mecaster*. Units G – J form the workable limestone body, they are cross- bedded in places. Units K – N are alternating marly and hard limestones. The marly limestones K and M are rich in poorly preserved examples of *P cauvini, Vascoceras woodsi* Zaborski and *Pseudaspidoceras pseudonodosoides (Choffat)*. Unit O is a rubbly limestone with shale partings and a nodular limestone above, hosting numerous burrowing and encrusting bivalves, especially *Plicatula fourneli*. It's Ammonite fauna includes *P. cauvini, Vascoceras globosum globosum,, (Reyment) V globosum costatum,*Reyment *V. bullatum* (ISchneans), *Thomasite gongilensis* (Woods)*, , Fikaites varicostatum (*Zaborski)*, Pseudaspidoceras footeanum* (Stoliczka) *and Ruboceras.* Units Q – R are rich in *Thomasites gongilesis* in and the later also hosts *Vascoceras globosum globosum and Pseudaspidoceras paganum.* Unit T is composed of two parts: T1, a lower hard limestone with *V. globosum proprium* (Reyment)and *Pseudotissotia nigeriensis* separated by a discontinuity surface marked by black phosphate pebbles and a thin layer of diagenetic gypsum, from T2, an upper

deeper – water glauconitic marl with following ammonite fauna; p. *nigeriensis* and *Vascoceras globosum proprium, V. obscurum* (Barber). *Thomasite gongilensis, Bageites bakui* (Zaborski)*, Wrightoceras munieri* (perrinquiere) *Watinoceras coloradoense (*Henderson) and *Pseudaspidoceras flexuosum* (Powell)*.* The latter fauna correlates with early Turonian faunas in the USA and *P. flexuosum* has been regarded as a marker species for the base of the Turonian (Zaborski, 2003). Units U – X host the ammonites *Pseudotissotia nigeriensis* and *Eotissotia simplex* (Barber).

According to Gebhardt, (1997) planktonic foraminifers are restricted to the limestone horizons with the exception of the shales between O and Q. They are non- kneeled heterohelicids with subordinate hedbergelids of low diversity and of little use in correlation.

According to Suleiman (2004; Fig. 19) the Kanawa Member some Deba Fulani at Ashaka quarry comprise a single sequence made up of a transgressive systems tract and highstand systems tract but without the lowstand systems tract since the lower sequence boundary (SB) corresponds with the transgressive surface (TS). The transgressive systems tract in the Ashaka Quarry. The highstand systems tract (HST) includes unit T2-X. The overlying part of Deba Fulani Member, represents regressive conditions (at least in part).The Maximum flooding surface of the Ashaka sequence is found at unit T2 (Fig. 19). Parasequences are commonly separated by minor marine flooding surfaces marked by encrustation, bioturbation and nodular limestone surfaces (Plate 1 above)

The Kanawa Member in the Pindiga stream section embraces the strata between the base of unit A and the top of unit V in the section provided by Zaborski, (1995 ; Fig. 22). It is about 89 m thick. Unlike the Ashaka section that

is fully exposed, the Pindiga section is discontinuous and partly subject to burial and re-exposure during the rainy season. Ammonite species in the Pindiga section common to the Ashaka section are presented in Table 3. The limestones are grey in colour when fresh but weather to whitish cream orange / brownish colour. The limestones occur as shelly, marly laminated, biostromal and decalcified types (Zaborski, 1995). The shales are generally laminated. Unit A lies conformably upon the Yolde Formation. Zaborski, (1995) identified the following macrofossils from the Pindiga stream section apart from ammonites:

Costagyra olisiponesis (Shape)

Plicatula fourneli (Coquand)

Gyrostrea deletrei (coquand)

Mecaster pseudofourneli (Peron & Gauthier)

Plicatula auressensis (Coquand)

Micropedina olisiponesis (Forbes)

Heteroconopeum janieresiense (Canu)

4.3 DEBA HABE STREAM SECTION

The Kanawa Member is exposed in the Deba Habe stream about 1km north of Deba Habe town. The Kanawa Member here consists of shales and intercalations of limestones. The limestones rarely reach 1 metre in thickness. The exposed section has a total thickness of about 15 m (Fig. 23). The limestones are generally grey when fresh but weather to white cream and brownish colours. The exposed section contained limestones labeled (A – G units). The limestones are separated by shales. The limestones are crystalline, nodular/ shelly /

marly with thin gypsum lenses. The marly limestones host ammonites, bivalves and gastropods. The upper surfaces of the limestones often show *Thalassinoides* burrows. The upper surfaces of the nodular

limestones are highly bioturbated. The shales are dark blue – grey in colour when fresh. From the earlier work provided by Zaborski (1990; 1995) and Zaborski *et al*.(1997) most of the ammonite fossils common to Ashaka and Pindiga sections presented in Table 3, are found in the Deba Habe stream section. Only *Pseudotissotia nigeriensis* was collected by the author. The exposed section of Deba Habe stream comprises limestones units A – G (Fig .23)

G	2.00m	dark grey shales
	0.30m	brownish - grey fossilferous limestone with gastropods.
	2.00m	dark grey shales.
F	0.40	grey – brownish limestones with *Thalassinoides*
	0.10m	shale – parting dark grey shales
E	0.20m	grey highly bioturbated limestones.
	3.00m	dark – grey shales.
D	0.22m	brownish – grey limestones with ammonites *Pseudotissotia nigeriensis*
	0.04	dark grey shales with gypsum.
C	0.04	grey – brownish limestones
	0.75	dark grey shales
B	1.50m	hard nodular massive grey- brown limestones with ammonites *Pseudotissotia nigeriensis* *Exogyra* and *Thalassinoides* burrows
	1.00m	dark grey shales
A	0.10m	crystalline limestone
	0 5.0	dark grey shales.

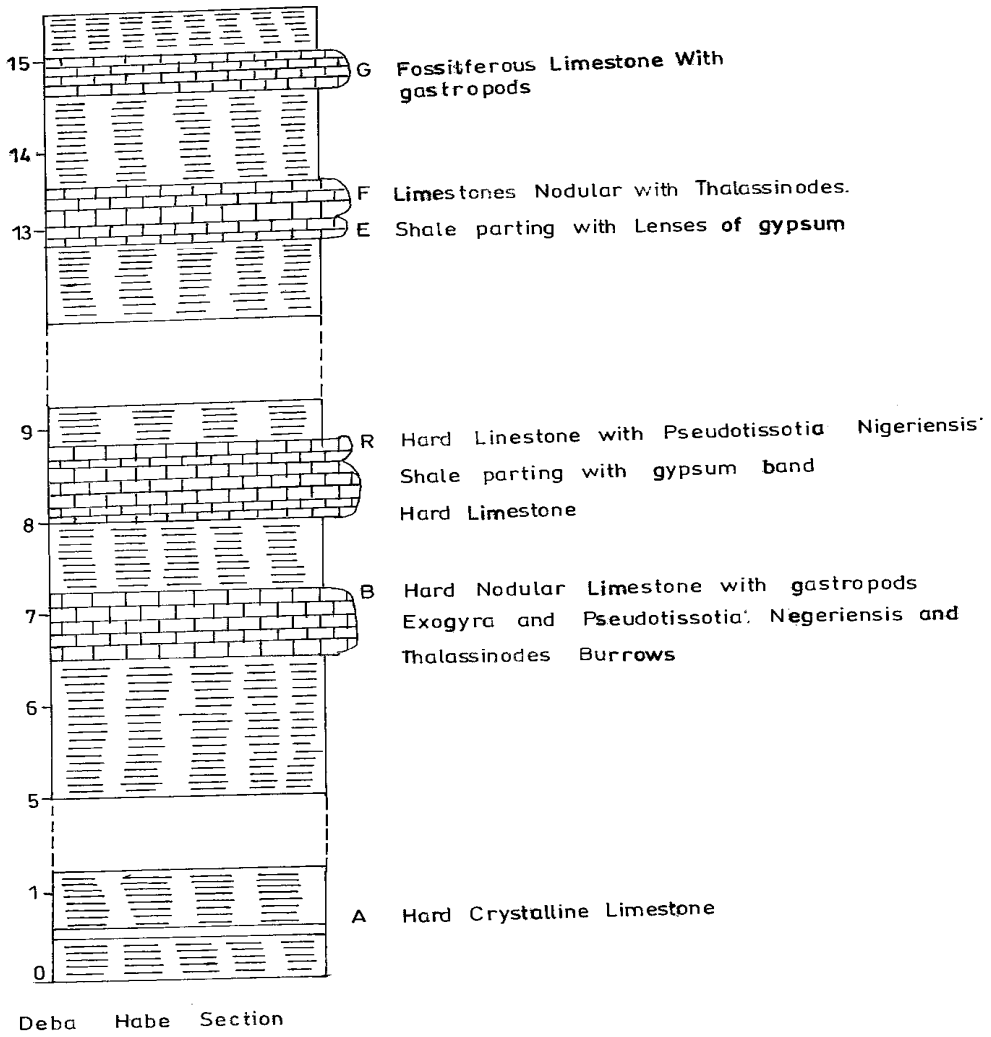


Fig.23. Pindiga Formation(Kanawa Member) Stream Section in Unit Exposed at Deba Habe Stream.

CHAPTER FIVE

CORRELATION OF THE ASHAKA, PINDIGA AND DEBA HABE SECTIONS

5.1 BIOSTRATIGRAPHY

The following ammonite biozones were proposed for main part of the late Cenomanian – early Turonian limestone bearing sequences in north – eastern Nigeria by Zaborski (1990):

5 Zone of *Wrightoceras wallsi* Reyment (youngest)

4 Zone of *Pseudotissotia nigeriensis* (Woods)

3 Zone of *Vascoceras proprium* (Reyment)

2 Zone of *Paravascoceras cauvini* (Chudeau)

1 Zone of *Nigerienceras gadeni* (Chudeau)

He referred to zones 1 – 4 as interval zones, defined at their bases by the appearances of the index species, zone 5 is a range zone based on the local occurrence of *Wrightoceras wallsi.* The *wallsi* zone is locally overlain by beds with *Hoplitoides.* Their relationship with earlier schemes is presented in Fig. 18.

5.2 SHAW'S GRAPHIC CORRELATION METHOD

5.2.1 INTRODUCTION

Zonal intervals can be used to define units of strata deposited during relatively short periods of time but they do not actually yield precise correlation. Organisms may migrate laterally and appear in other areas at somewhat later times than their first time appearance, or they may migrate out of a local area

before their final extinction elsewhere. This behavior tends to make the boundaries between zones “fuzzy”. The exact boundaries between biozones can never be known because such boundaries are determined empirically. Collection of additional species in a new area always holds the probability of extending the known range of previously defined species or taxa, due to the fact that they may have appeared earlier or persisted longer in the new area than in the originally defined areas. To overcome this come “fuzziness” of zonal boundaries, fossil ranges can be treated using the first and last appearances of all species present in a stratigraphic section rather than ranges of just one or two species.

Shaw in (1964) proposed a correlation technique that utilizes the first appearances and last disappearances of all the species which two stratigraphic sections have in common. First, the ranges of common species are carefully established and measured. Then the bases and the tops of the ranges of common species are plotted on a graph (Fig .24)

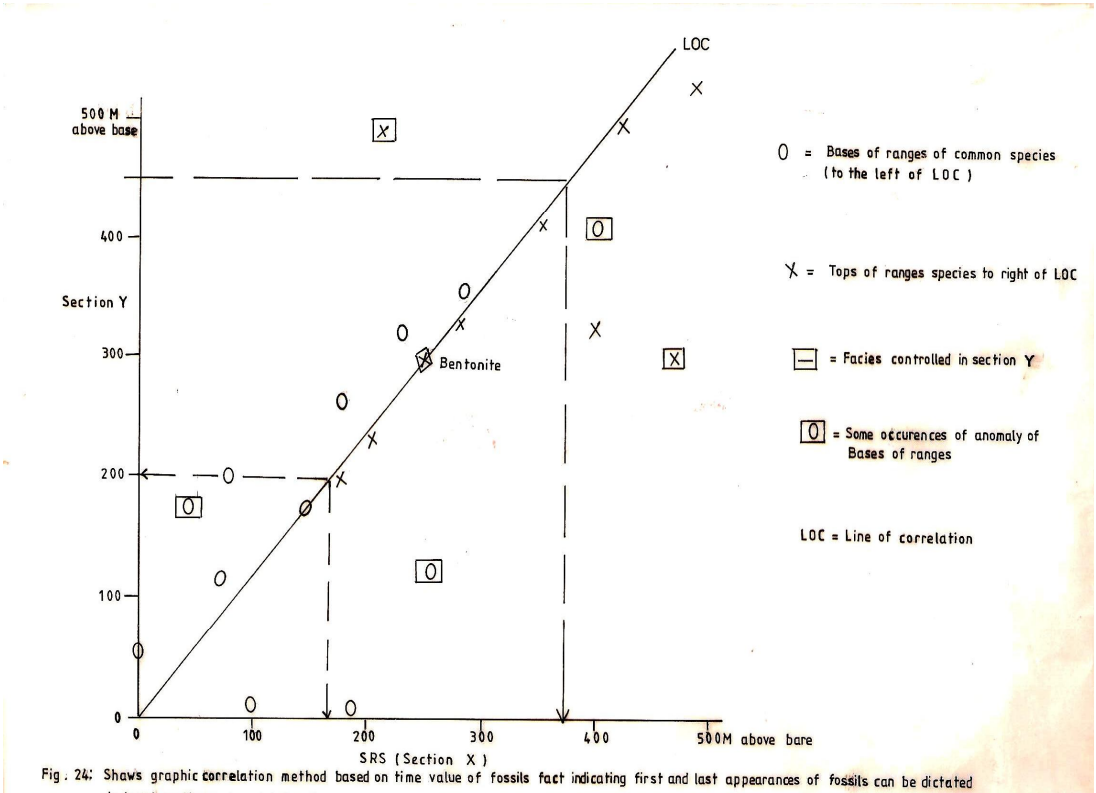


Fig. 24: Shaws graphic correlation method based on time value of fossils fact indicating first and last appearances of fossils can be dictated in local sections - by plotting the common ammonite fossils to the two sections concerned.

using section A as the horizontal axis and section B as the vertical axis. These points tend to cluster around a line of correlation (LOC) like that shown in Fig. 24, whose intercepts depict a precise correlation between the two sections. This kind of diagram is thus a good stratigraphic tool because it takes into account every potentially time- significant biostratigraphic event in the two sections. In applying it one needs to have no concern for the often arbitrary selection of zonal boundaries.

The points in Fig. 24 that fall off the correlation line represent species which appear or disappear in one section much earlier than in the other. Such species are strongly facies controlled. Physical events can also provide points for the correlation line. A bentonite bed, for example that occurs in both sections represents identical time level. This helps greatly in locating the correlation line which should pass directly through it.

Changes in slope of the correlation line tell much about the geological history of an area. If the rate of sedimentation at one section increased or decreased significantly, the result is an expanded or condensed interval and this shows up as a dog- legged correlation (Fig .25). A hiatus appears as a horizontal or vertical segment in the line (Fig. 26).

5.2.2 STANDARD REFERENCE SECTION (SRS)

A single standard reference section is selected; ideally it should have a large and varied fossil content and should be the thickest section, complete and unfaulted. These facts help to determine the ranges of the fossils in the SRS and establish the chronological scale

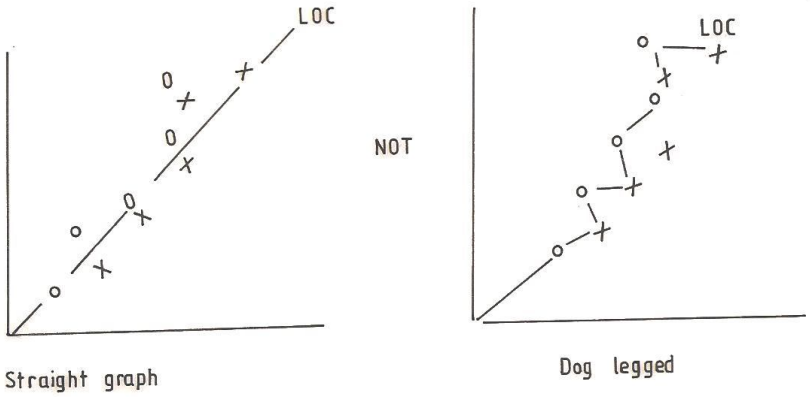


Fig. 25; Illustrating LOC as a straight line and not Dog legged

Reveal diastems hiatuses

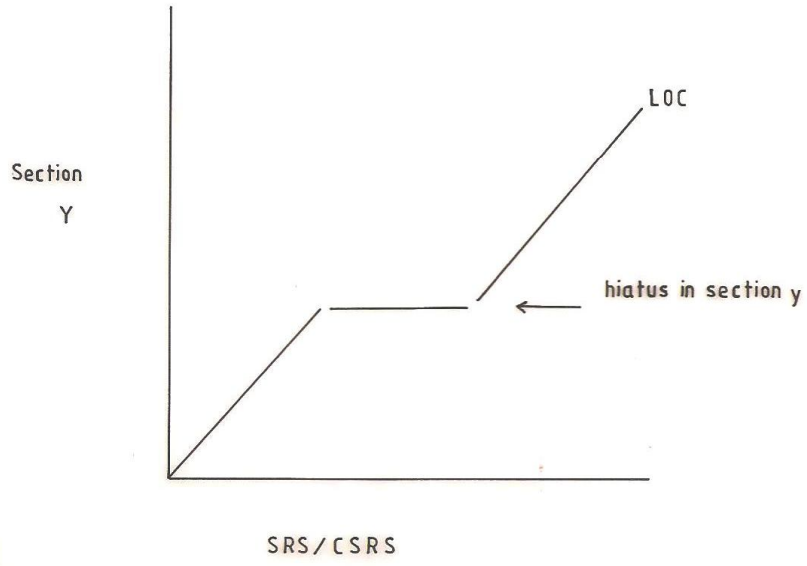


Fig. 26; Rate of sedimentation indicating a hiatus or a diastem in section y

for the SRS. A second outcrop or well is chosen to compare with the SRS. An attempt is made to correlate on the basis of overall ranges of all fossils common to both sections (Table 3). A good SRS produces bases to the left and tops to the right of the line of correlation (LOC).

5.2.3 LINE OF CORRELATION (LOC)

Since the SRS is meant to have something like the total ranges of species concerned, this fact helps to determine where the line of correlation LOC should be plotted. Palaeontological knowledge, environmental control, fossil relationships, details of stratigraphic section and the fossil sequence all help to plot the best LOC as do key beds e.g. a common bentonite bed represents an identical time level.

5.2.4 COMPOSITE STANDARD REFERENCE SECTION(CSRS)

A fossil taxons composite standard range is equal to its total stratigraphic range. If the range of a fossil in the SRS coincides with the composite standard range then its range here is equal to sum of local ranges in other sections, and in this situation anomalies will not occur. For anomalous ranges in the SRS, the LOC can be used to detect their more “correct” position in the SRS. Also for species only found in the SRS or section Y (Fig. 27), we can do the same thing to find where

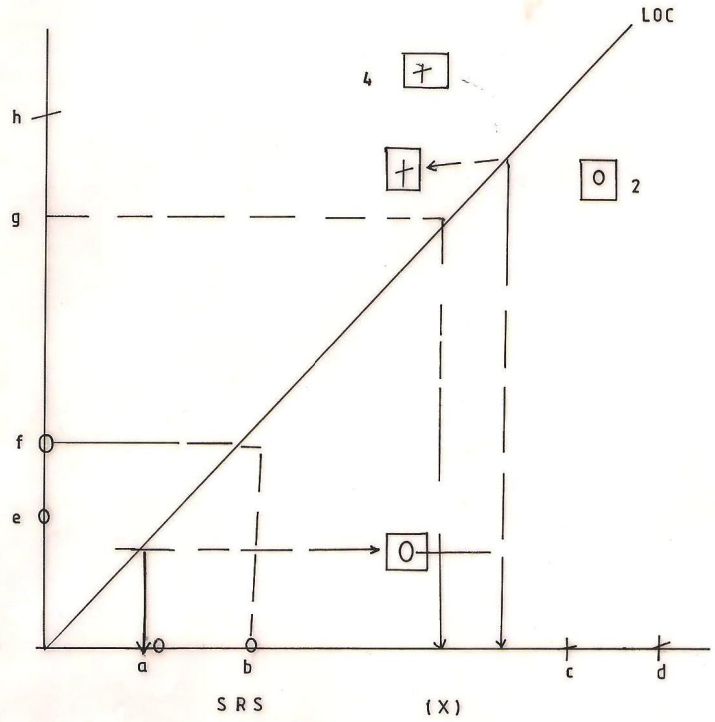


Fig. 27: Adjustment for anomalous species in one section only. If S R S coincides with composite standard range then its range there = sum of local ranges in other sections. Anomalies will not occur.
*Anomalous ranges in S R S (L O C can be use to detect their more correct possition in S R S.)

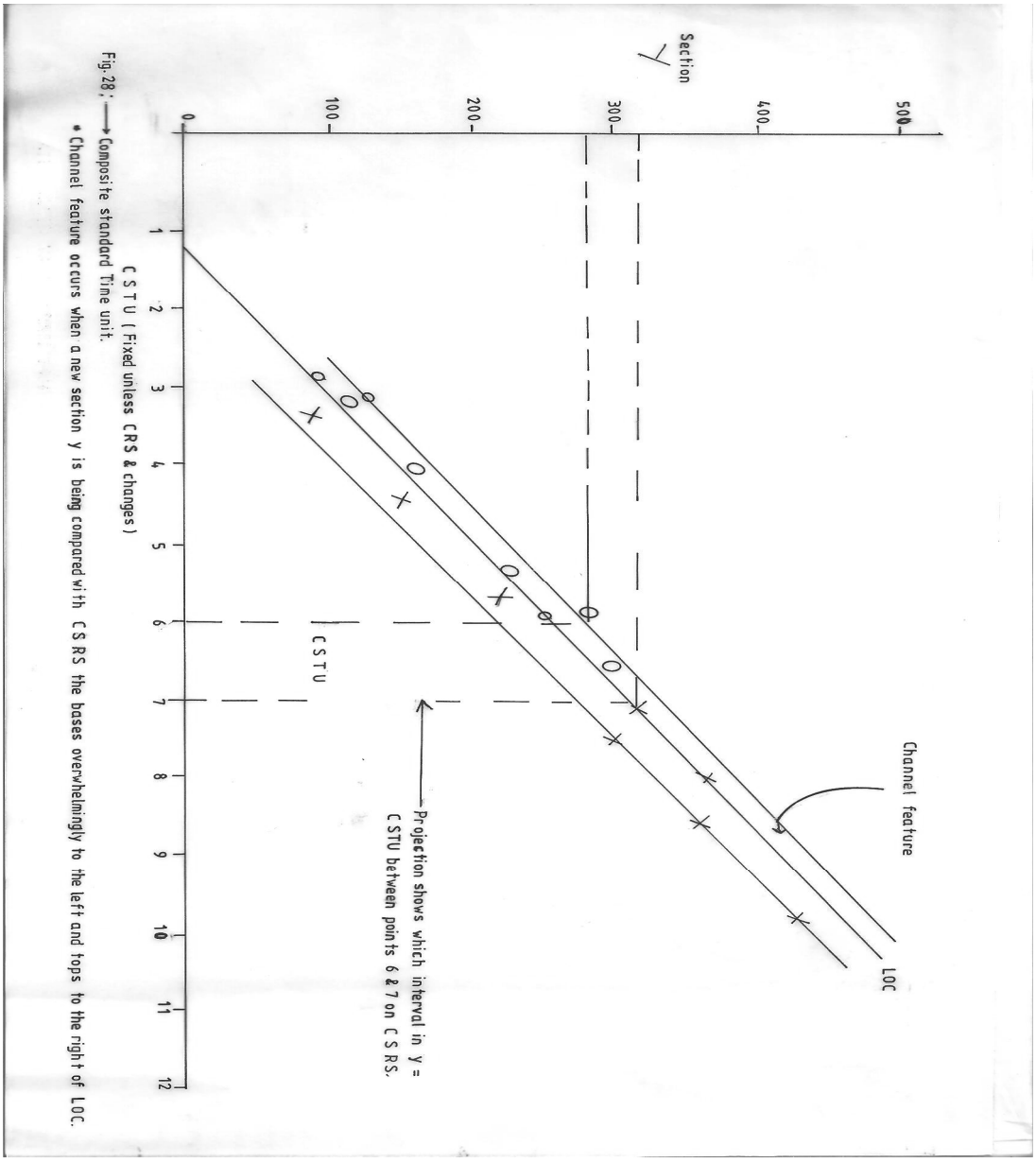


Fig. 28 ;

they ought to occur in SRS or section Y. Now the SRS is being changed into a composite standard reference section (CSRS) using composite standard ranges. As more and more sections are compared with the SRS, the total ranges of species concerned are being detected more correctly. Facies control for example is being eliminated and does not interfere with correlations. Many graphs may be needed before a CSRS is arrived at.

5.2.5 COMPOSITE STANDARD TIME UNITS (CSTU)

To scale the CSRS, series of equivalent points are established in the CSRS. These are composite standard time units (CSTU). These are projected into sections to be compared with the CSRS. The CSTU is the equivalent of time in the equation

D = R x T, not years but an alternative where D = distance i.e. thickness in the second section, T = time i.e. division of the Y axis/division of the SRS, then R = rate of sedimentation, i.e. the interpolated line on the graph (Fig. 28). A “channel” feature is often found in comparing CSRS with new section (Y) because now the bases should be overwhelmingly to the left and tops to the right of LOC. A channel may be defined by these points. CSTUS now are time units. These time intervals are not known in absolute terms or whether they are of the same length. The graph may reveal diastems or hiatuses.

5.3 BASIC CONCEPTS OF SEQUENCE STRATIGRAPHY

Sequence stratigraphy is the study of rock relationship within a chronostratigraphic framework of repetitive genetically related strata bounded by surfaces of erosion or non –deposition or correlative conformities. A sequence is a relatively conformable succession of genetically related strata bounded by unconformities and their correlative conformities'' (Mitchum, 1997).An unconformity is a surface separating younger from older strata along which there is evidence of subaerial erosional truncation (and in some areas; correlative submarine erosion), or subaerial exposure, with a significant hiatus. Within a sequence, three systems tracts are normally recognized these are the lowstand systems tract (LST), transgressive systems tract (TST) and highstand

systems tract (HST). Sequences their stratal components are interpreted to form in response to relative falls and rises in sea level brought by one or more factors: eustacy, tectonics (subsidence and upliftment) and the rate of sediment supply. Within a sequence, many smaller scale units produced by relative sea level changes on a shorter time- from 10,000-100,000 years, known as parasquences, occur (Tucker, 1993).

Parasequence may be grouped into packets to produce parasequence sets. A parasequence is a relatively conformable succession of genetically related beds or bed sets bounded by marine flooding surfaces (Van Wagoner, 1985). A parasequence starts at a flooding surface and contains both deeper water (below) and shallower water (above) units.

The boundaries of sequences, parasequence sets and parasequences provide a chronostratigraphic framework for correlating and mapping of sedimentary rocks. The top of the lowstand system tract is a marine flooding surface called the transgressive surface. The maximum flooding surface occurs at the boundary of the LST and HST and marks the change from a retrogradational to aggradational Parasequences set and commonly indicated by a condensed section. Suleiman (2004; Fig.18) gave a detailed sequence stratigraphic interpretation of the Ashaka quarry section.

5.4 **APPLICATION OF SHAW'S GRAPHIC METHOD**

Shaw's graphic correlation technique was applied for the purpose of the present work with the Ashaka section being plotted against the Pindiga section. The first and last appearances of ammonites were documented in terms of their position in the stratigraphic section (Fig. 29). The Ashaka section was chosen as

the standard reference section (SRS) due to the fact that the section is continuous, has a varied fossil content and is unfaulted.

The Ashaka section as the standard reference section was the vertical axis while the Pindiga section was on the horizontal axis (in standard work, SRS should be along the horizontal axis). The first and the last appearances of ammonite taxa in the Ashaka section were plotted against the first and last appearances of the same taxa in the Pindiga section. Table 3 indicates the common ammonite species in the two sections. A line of correlation LOC was drawn from the plots of data in Table 3. Three special points were plotted where both the bases and tops fall on the same point .These special points indicate biostratigrahpic "events" being represented by the occurrences of *Nigerienceras gadeni, Burroceras* and *Pseudaspidoceras paganum.*The LOC was drawn between the tops and the bases but directly through the special points. The bases predominate to the right indicating that the SRS was good choice (Fig. 29). The LOC constructed was close to a straight line but there was slight dog-leg at about 4m in the Ashaka section. The dog –legged pattern could indicate that there was a relative increase in the rate of sedimentation in the Ashaka section. The thickness of Pindiga section was reported by previous workers as 89 m but this may not be the true thickness as the amount of dip measured varied. The implication of this is that the thickness of the interval from unit O to unit G at Pindiga is estimated and may be less than 19 m shown in Fig .29.

5.5 DRAWBACKS OF SHAW'S GRAPHIC CORRELATION METHOD

In the situation where bases predominate to the right and tops predominate to the left of the LOC, the ranges in the CSRS may not be accurately known. For the CSRS to be constructed many more sections/graphs are needed to be

compared with the SRS and in this present work only two appropriate sections are available.

Sources of error that may occur in Fig.29) are: a) because when limited numbers of ammonite species have been correlated, or b). because environmental control of species might not have been determined, c) because the thickness of the Pindiga section is largely concealed and can not be logged fully and d) because ammonites are found only within the limestones so their chronostratigraphic ranges are unknown. Parasequences are by definition controlled only by changes in relative sealevel-that is by marine flooding events. Parasequence boundaries are marked by marine flooding surfaces. Which may be indicated by encrustation, bioturbation and nodular limestone surfaces (Plate 1). Parasequence boundaries in the Pindiga stream section were identified using the same criteria as Suleiman (2004) for the Ashaka section (Table 4; Fig .29).

5.6 LIMESTONE/SHALE BOUNDARIES

The upper surfaces of the limestones frequently coincide with marine flooding surfaces as they show encrustation, bioturbation, nodular surfaces, condensed ammonite faunas, phosphatic grains and glauconite concentrations. Flooding surfaces represent water deepening and mark parasequence boundaries. They can be important in chronostratigraphy since parasequence boundaries can often be matched from place to place having been formed synchronously, being of the same age they can therefore be correlated.

5.7 THE PRESENT LOC

The LOC derived from the data presented in Table 3 can be use to determine facies relations and equivalents between the Ashaka and Pindiga sections.

S/NO.	SPECIES	SP UNIT	RANGE	RANGE	METRES
		ASHAKA	PINDIGA	ASHAKA	PINDIGA
1.	*Nigericeras gadeni* (chudeau)	D	A	0.90	0.42
2.	*Paravascoceras cauvini* (chudeau)	E–D	G–N	2.10 – 8.44	18.30 – 27.50
3.	*Burroceras Sp.* (chudeau)	F	H	2.80	18.70
4.	*Vascoceras woodsi*	K–M	M–N	6. 44 – 7.62	27.00 – 27.50
5.	*Pseudaspidoceras pseudonodosoides*	K-M	M–N	6.44 – 7.62	27.40 – 27.50
6.	*Pseudaspidoceras paganum*	R	O	11 – 9.6	45.70
7.	*Vascoceras globosum globosum*	Q–R	O	8.44 – 13.55	45.70 – 47.70
8.	*Thomasites gongilensis*	Q–T	O–P	8.44 – 13.53	45.70 – 47.70
9.	*Pseudotissotia nigeriensis*	T–X	O–V	13.47 -18.92	45.70 – 81.60
10.	*Eotisssotia sinplex*	U–X	S–V	15.38 – 20.2	79.50 – 81.60

Table 3: common ammonites species occuring in both Ashaka and Pindiga sections modified after Zaborski (1995)

Drawing the LOC directly through the "special points'' (biostratigraphic events) causes correlation of the limestone horizons in the Ashaka and the Pindiga sections. There is the danger of a circular argument as only the limestones contain ammonites; the ammonites do not occur in the shales. In order to circumvent this problem an independent, non-biostratigrahic, method of correlation was incorporated into the LOC, namely, an attempt to match parasequence boundaries which as mentioned above, may be correlatable Table 4.

Parasequence boundaries at Ashaka section after Suleiman, (2004).	Corresponding parasequence boundaries at Pindiga section.	Reasons for correlation
D	A	Phosphatic grains, faum: *Nigericeras gadeni*
F	H	Encrustation, biosturbation *Burroceras SP*
G		
H		
O		
P		
Q		
R	O	Shelly Limestone, *P. paganum V proprium globosum, P. Nigeriensis.*
S		
T		
U	S, V	Nodular limestone surfaces
V		
W	V	Encrustation bioturbation and nodular surfaces
X		

Table 4: Corresponding parasequence boundaries of Pindiga section with Ashaka section based on marine flooding surfaces.

CHAPTER SIX

6.1 DISCUSSION

A line of correlation (LOC) was constructed using the first and last appearance of common ammonite species in the Ashaka and Pindiga sections. A non biostratigrahic method, sequence stratigraphy, was incorporated into the correlation technique. Here parasequence boundaries were plotted on both axes.

The ammonites are found only in the limestones, they do not occur in the shales. The persistent limestones of the lower Ashaka section and their faunas indicate normal marine conditions in which oxygen levels were sufficient for the benthics to thrive at that time. Rebelle (1990) and Suleiman (2004) attributed the deposition of the shales which are very poor in benthic faunas to water deepening in the area while the limestones indicate shallowing of water depths with their upper surfaces marking marine flooding surfaces in most cases.

The Ashaka quarry section of the Kanawa Member and Deba Fulani Member was considered by Suleiman (2004) to comprise a single sequence made up of a transgressive systems tract but without lowstand systems tract. Within this sequence, parasequence and parasequence set also occur (Suleiman, 2004) .The thin ferruginous crust on the top of upper Bima sandstones is the lower type 1 boundary of the sequence.

The Yolde Formation is not seen at the Ashaka quarry. An unconformity surface coincides with the transgressive surface marking the onset of the late Cenomanian to early Turonian marine incursion that deposited the Kanawa Member of the Pindiga Formation .Minor marine

flooding surfaces represent water deepening and mark parasequence boundaries. Parasequence would have been deposited at the same time and can be correlated, if the water deepening resulted from regional or eustatic factors.

6.2 CORRELATION OF THE LIMESTONES HORIZONS USING THE LOC

The LOC can be used to attempt to correlate individual limestones horizons to determine if they are persistent between the Ashaka and the Pindiga sections.

Some of the limestones in of the Ashaka section do not obviously correlate with the limestones of the Pindiga section, these limestones includes:

i). Units G-J which correlate, at least mainly, with shales at Pindiga. Limestones G-J are cross-bedded grainstones deposited in shallow, well agitated water. Local tectonics could have been responsible for the non continuity of limestones G-J. Zaborski, (1998) described the Dumbulwa – Bage High as a shoal area during the late Cenomanian –early Turonian and indicated that it was an area of persistent uplift subsequent to the deposition of the lower Bima Sandstone. This uplift is shown by the wedging out of the middle Bima, upper Bima and Yolde Formation and the attenuation of the Kanawa Member in the Dumbulwa Bage High (Fig . 21).

On the other hand, certain limestones do appear to correlate:

i) Unit D at Ashaka section can be correlated with unit A at Pindiga on the basis of the ammonite *Nigericeras gadeni.* The marine flooding surface at the top of each bed is marked by encrustation.

ii). Unit F at Ashaka correlates with unit H at Pindiga as both the units contain the ammonite *Burroceras sp.*

iii). Unit R at Ashaka can be correlated with unit O at Pindiga, as both contain *Thomasite gongilensis* .The upper surfaces of units are parasequence boundaries .It is upon these surfaces that *Pseudaspidoceras paganum* is uniquely present , introduced into the Pindiga \ Ashaka area by a regional (eustatic) rise in sea level. In this case correlation of parasequence boundaries acts as a check upon and agrees with the biostratigraphic evidence.

Units D|A, F|H and R|O discussed above could be continuous and contemporaneous. If so, regional factors would be responsible for their formation.

6.3 RATE OF SEDIMENTATION

The LOC provides a powerful tool for evaluating differences in the rates of sedimentation between the areas of study. Shaw (1964) stated that an abrupt change of slope of the LOC suggests a sudden relative increase or a decrease in sedimentation rate in one of the sections. The most noticeable change occurs at about 4.0 m in the Ashaka section and 19.0 m in the Pindinga section. There is an apparent increase in the rate of sediment accumulation in Ashaka section compared to that at Pindiga. But, as mentioned earlier, this change in the slope as indicated by Suleiman between units A and B at Pindiga has been correctly estimated, LOC could be a straight line with sediment accumulation in the Pindiga section being consistently a little greater than four times that of Ashaka. The rate of sedimentation at Deba Habe cannot be ascertained as the

ammonite species collected were not enough for comparism with the SRS since at least 6 varied species are needed for the comparism.

6.4 EUSTATIC AND REGIONAL CLIMATIC EFFECT

In Niger, the late- Cenomanian mid -Turonian shale – limestone successions outside the east Niger rifts contain abundant *Vascoceratid* ammonites gryhaeid and ostreid bivalves (Zaborski, 2000). In the Iullemmeden and western Chad basins the Iguellala Mountain, Béréré and Zoo Baba Formations are of equivalent age to the Kanawa Member. They too consist largely of shales but include ammonite - bearing limestones and calcareous sandstones (Zaborski, 2000). In Niger and the Tinhert region, there are four important ammonite faunas characterized by *Neolobites vibrayeanus* (d'Orbigny) *Nigericeras gadeni (*Chudeau) *Paravascoceras cauvini* (Chudeau) and *Pseudotissotia nigeriensis* (Woods). The last three occur in the upper Benue Trough (Table 2), indicating direct faunal exchange with the areas to the north. Mathey *et al.* (1991) and Pascal *et al.* (1993) attributed the Iguellala Mountains, Zoo Baba and Béréré lithologies to regional control. For the former authors the limestones represent intervals of low rainfall and low clastic influx when an absence of density stratification allowed oxic bottom conditions to develop. For the latter authors the peak of transgressive pulse was when effective water circulation preclude bottom anoxia. For these authors, flooding surfaces are the bases of limestones. Marine flooding surfaces are considered to occur at the tops of the limestones at Ashaka and Pindiga. Regional factors notably eustacy, were possibly the main control in this area, with water deepening bringing limestone deposition to an end.

Climatic factors, however, may also have been important notably the effect that those periods of high rainfall and freshwater influx might have had on salinity levels in the upper Benue Sea, along with the possibility of density stratification.

6.6 CONCLUSION

The limestones /shale alternations in the Kanawa Member are responses to alternating normal marine oxic (limestones) and dysoic / anoxic (shales) bottom water conditions. Such alternations could be attributed to stratification resulting from fresh water influx from the hinterland. Global change in sea level (eustacy) could equally have contributed to this shale –limestone intercalation. This latter factor is especially indicated where parasequence boundaries can be correlated

The ammonites are vascoceratid dominated. They are known to be shallow water dwellers and thrive in oxic environments. Benthics (bivalves, gastropods and bryozoans) also occur in the studied sections, indicating oxygenated bottom conditions as does the frequent bioturbation on the surfaces of some of the limestone units. Cross- bedded limestones without ammonites were formed under shallow well agitated water conditions. Cross- bedded limestone units (G-J) are found in the Ashaka section because traction currents prevailed in the area at that time the limestones were being deposited. The water was of high energy locally due to the persistent upliftment of the '' Dumbulwa Bage High'' creating shoal condition.

A line of correlation was constructed by plotting the first and the last appearances of ammonites in the Ashaka section against the first and last appearances of the same species in the Pindiga section. Parasequence boundaries at Ashaka were compared with those at Pindiga.

Marine flooding surfaces represent water deepening and are indicated by encrustation, bioturbation and nodular limestone surfaces. Facies equivalents were determined for the Pindiga and Ashaka from the LOC (Fig. 29). Units G-J at Ashaka correlate with shales at Pindiga. These limestones at Ashaka are cross-bedded in places. The non- continuity of these limestone units could have been due to local tectonics, namely gentle uplift in the '' Dumbulwa Bage High'' area. Unit D at Ashaka correlates with unit A at Pindiga, on the basis of the ammonite *Nigericeras gadeni.* Unit F at Ashaka correlates with H at Pindiga based on the presence of the ammonite *Burroceras sp and Paravascoceras cauvini* .Marly limestones indicate slight water deepening. Unit R of Ashaka correlates with unit O at Pindiga based on the following fauna: *Pseudaspidoceras paganum, Vascoceras proprium globosum* (Reyment) *Thomasites gongilensis and Pseudotissotia nigeriensis*. Importantly *Pseudaspidoceras paganum* only occurs on the upper surfaces of these units which are marine flooding surfaces. Units U-X at Ashaka generally correlate with units S-V at Pindiga but inadequate data is available to confidently match parasequence boundaries here.

The above mentioned biostratigraphic and non biostratigraphic methods indicate that some of the limestones are regionally controlled and continuous, while others of the limestones are locally controlled and discontinuous.

The standard reference section (SRS) constructed is presented for further comparism when many more sections and graphs are made available for the construction of a composite standard reference section (CSRS) and composite standard time unit (CSTU) respectively.

REFERENCES

Adegoke, O.S., Jadu Cheˆne, R.E., Agumanu, A.E., and Ajayi, P.O. 1978 Palynology and age of the Kerri Kerri formation, Nigeria. *Revisita Espanola Micro- palaeontogia.* **10**: 267 – 283.

Adegoke, O.S., Agumanu, A. E., Benkhelil, J and Ajayi, P O. 1986. Stratigraphy, sedimentologic and structural data on the Kerri-Kerri Formation, Bauchi and Borno States, Nigeria. *Journal of African Earth Science* **5**, 249-277.

Allix, P. 1983. Environments mésozoigues de la partie nord- Orientale du fossé de la Bénoué (Nigéria). Stratigraphie, sédimentologie, évolution géodynamique. *Travaux Laboratoire Sciences de laTerre St Jérôme, Marscille (*B), **21**, 1 – 200.

Alix, P. and Popoff, M., 1983. Le crétacé Inférieur du la Partie Nord –Orientale du fossé de la Bénoué (Nigeria). *Bulletin de centres de Recherches exploration Production Elf –Aquiaine*, **7**, 349-359.

Ayoola, E. O., 1981. Paleocurrent and sedimentological studies in the Benue Trough. Nigeria. *Sedimemtological Geology* 288. 28. pp. 153-162.

Avbovbo, A.A., Ayoola, E. O and Osahon, G. A., 1986. Depositional and structural styles in Chad Basin of North Eastern Nigeria *Bulletin American Association Petroleum Geologists* **70**, 1787 - 1798.

Barber, W.1957. Lower Turonian ammonites from North – Eastern Nigeria. *Bulletin Geological Survey Nigeria* **26**, 1 – 86.

Barber, W; Tait, E. A and Thompson, J.O. 1954. The geology of the Lower Gongola. *Annual Report Geological Survey Nigeria,* 1952 – 1953, 18 – 20.

Benkhelil, J. 1988. Structure et évolution géodynamique du baSin intra – continental de la Bénoué (Nigéria) *Bulletin de Centres dse Recherchés Exploration Production Elf.- Aquitaine* **12**, 128.

Benkhelil, P. 1989. The origin and evolution of the Cretaceous Benue Trough (Nigeria). *Journal of African Earth Science.* **8**, 251 – 282.

Burke, K. Dessauvagie, T. F. J. and Whiteman, A.J. 1971. Opening of the Gulf of Guinea and geological history of the Benue depression and Niger Delta. *Nature* **233**, 51 – 55

Burke, K. Dessauvagie, T. F. J and Whiteman, A.J. 1972. The geological history of the Benue valley and adjacent areas. *(African Geology (*edited by Dessauvagie, T. F. J and Whiteman, A.J.), pp 187 – 205, Ibadan University Press, Ibadan.

Burke, K., Whiteman, A.J., 1973. Uplift rifting and breakup of Africa. In implication of continental drift to the earth sciences.(Edited by Tarling, D .H. And Runcom S.K.) 735-755.pp . *Academic press London*

Burke, K. and Dewey, A. J., 1974. Two plates in Africa during the Cretaceous *Nature* **249**, 313 -316.

Carter, J.D., Barber, W., Tait E.A. and Jones, G. P. 1963. The geology of parts of Adamawa, Bauchi and Borno provinces in north eastern Nigeria. *Bulletin Geological Survey Nigeria.* **30**, 1 – 99

Courville, P. 1992. Les Vascoceratinae ae les Pseudotissotinae (Ammonitina) d 'Ashaka (N.E. Nigeria); relations avec leur environment biosédimentaire. *Bulletin des Centres Recherchés Exploration – Production Elf Aquitaine,* **16**: 407 – 457, pls 1 – 14.

Cratchley, C. R and Jones, G.P. 1965. An interpretation of the geology and gravity anomalies of the Benue valley, Nigeria. *Oversea Geological Surveys Geophysical Paper* **1**, 1-26.

Dike, E. C.1995. Stratigraphy and structure of the Kerri - Kerri Basin, north – eastern Nigeria. *Journal of Mining and Geology* **29** (for 1993), 77 – 93.

Fairhead, J. D. 1986. Geophysical controls in sedimentation within the African rift systems. Sedimentation in the African Rifts. Edited by L. E. Frostic R. W. Renauts et al; (Editors) *Geological society London Special Publication* **25**, 19-27.

Fairhead, J. D. 1988. Mesozoic plate tectonic reconstructions of the central South Atlantic Ocean: The role of the west and the central African rift system. *Tectnopphysics* **155**, 181-191

Fairhead, J. D. and Green, C. M. 1989. Controls on rifting in Africa and the regional tectonic models for the Nigeria and Niger rift basins. *Journal African Earth Science* **8**, 231-249.

Falconer, J.P. 1911. *The geology and geography of Northern Nigeria.* Macmillan, London. 286pp.

Freeth, S.J. 1978. A model for tectonic activity in West Africa and the Gulf of Guinea during the last 90 Ma based on membrane tectonics. *Geologj*che, Rundschan **67**, 67-87.

Freeth, S .J. 1979. Deformation of the African plate as a conquence of membrane stress dominantly generated by post Jurassic drift. *Earth and planet Science letters* **38**, 298-300.

Faure, H. 1966. Reconnaissance géologique des formation Sedimentaires. Post- paléoeoiques du Niger Oriental Direction. De Mines et de la Geologie (Niger). *Publication Bur Rech Geologuigues et. Miniéres Paris.*629pp

Gephardt, H. 1997. Cenomanian to Turonian foraminifera from Ashaka (N.E. Nigeria): quantitative analysis and palaeo-environmental interpretation. *Cretaceous Research* **18**, 17 -36

Genik, G.J. 1993. Petroleum geology of Cretaceous – Tertiary rift basins in Niger, Chad and the Central African Republic. *Bulletin American. Association of Petroleum Geologists* **77**, 1405 – 1434

Gregert, J. T. 1966. Description des Formations crétacées Tertiares dú Bassin des Iullemmenden (Afrique occidentale) *Mémoire Bureau Recherches Géologiqres Minieres* **36**, 1-234.

Guiraud, M. 1990. Mecanisme de formation du baSin sur décrochements multiplies de la Haute – Bénoué (Nigéria) Facies et géometric des corp sedimentares, microtectonicque et déformations synsedimentaire *Memoir d' Habilatation, Unversite de Montpelier,.* 445 pp

Guiraud, M. 1991. Mécanisimé du formation du baSin crétacé sur dećrochements multiples de la Haute – Bénoué (Nigéria). *Bulletin des centre de Recherchés Exploration Production Elf – Aquitaine* **15**, 11 – 67.

Guiraud, M. 1993. Late Jurassic rifting- Early Cretaceous rifting and Late Cretaceous transpressional inversion in the Upper Benue Basin (NE Nigeria) *Bulletin de Centres de Recherché Exploration – Production Elf – Aquitaine* **17**, 371 – 383.

Jones, G.P. 1961. Sedimentary structures in the Bima sand stones. *Record Geological Survey, Nigeria* 1959, 5-14.

Kogbe, C. A., 1981. Createceaus and Tertiary of the Illummenden Basin in Nigeria (West Africa) *Creataceous Research* **2**, pp 129-186

King, L. 1950. Speculations upon the outline and the mode of distruption of Gonduwanaland. *Geological magazine* **87**, 353-359.

Lawal, O. 1982. Biostratigraphie, palynologie et paléoenvironments des formations crétaceés de la haute Bénoué, Nigéria nord orientale *These 3e Cycle Universit*é *Nice,* 198.pp.

Lawal, O. and Moullade, M. 1986 – Palynological biostratigraphy of Cretaceous, sediments in the upper Benue Basin *Revede de micro-paléontologie* **29**, 61 – 83

Lees, G. M. 1952. Foreland folding Q-Journal Geological Society of London. 108. 1-34.

Mathey, B. Lang, J. Pierre, C and Alizouma, K. 1991. Effects empledes premieres transgression du crétacé supervieur dans de le Basin du lullunenden (Niger) CD. *Acad sci* (Paris ii) **312**, 523 – 523

Mascle, J., Blarez, E. & Marinho, M. 1998. The shallow structures of The Guinea and Ivory Coast – Ghana transform margins; their bearing on the Equatorial Atlantic Mesozoic evolution. *Tectonophysics* **155**, 193 – 209.

Maurin, J. C. Benkhelil, P. and Robineau, B. 1986.Fault rocks of the Kaltungo lineament NE Nigeria and their relationship with Benue Trough tectonics. *Journal of the Geological Society of London* **3**, 587-597.

Meister, C. 1989. Les ammonites du crétacé superienr d'Ashaka (Nigéria) *Bulletin des Centres de Recharchés Exploration Production Elf Aquitaine*, **13** (Suppl) 1 – 84.

Mitchum, R. M. 1977. Seismic Stratigraphy and global changes of sea level, part 1: Glossary of terms used in seismic Stratigraphy. In Payton. C. E., ed., Seismic stratigrahy – Application to Hydrocarbon Exploration: American Association of Petroleum Geologists Memoir, **26**, 205-212

Offodile, M.E. 1976. A review of the geology of the Cretaceous of the Benue valley. *In: Geology of Nigeria* (edited by Kogbe, C.A.), pp. 319 – 330 Elizabethan Publishing Co, Lagos.

Offodile, M.E. and Reyment, R.A. 1976. Stratigraphy of the Keana Awe area of the middle Benue region of Nigeria. *Bulletin of Geological Institute University Uppsala* (N.S.) **7**, 37 – 66.

Ojo, O.M. and Pinna, P. 1982. Palaeogeographical and structural evolution of the Benue Trough of Nigeria. *Cretaceous Research* **3**, 195 – 207.

Ojoh, K. A., 1990. Cretaceous geodynamic evolution of the Keana Awe area of the south Atlantic, stratigraphy basin analysis and palaeo-oceanography. *Bulletin des Centre Recherchés Exploration Production. Elf Aquitaine* vol .**14***, 419* – 44

Olade, M. A. 1975. Evolution of Nigeria's Benue Trough (aulacogen); a tectonic model. *Geological Magazine* **112**: 575 – 583

Olade, M. A. 1976: On the genesis of lead -zinc deposits in Nigeria's Benue rift (Aulacogen), a re- interpretation *Journal Mining and Geology)* **13.** 20 – 27.

Oti, M. 1990. Lower Turonian carbonate on the Zambuk ridge, S.E. Chad Basin; The Ashaka limestone.

Olugbemiro, O. R. 1997. Hydrocarbon potential, maturation and paleoenvironments of the Cretaceous (Cenomanian – Santonian) series in the Bornu (Chad) Basin, N. E Nigeria. *Tùbrger micro palaeontology MiH*, 14, viii + 150p

Pascal, A.F., Mathey B.J. Alzouma, K., Lang. T. and Meister, C. 1993. Late (Cenomanian – Early) Turonian shelf ramp, Niger West Africa. *Memoir American Association of Petroleum Geologists*, **56**, pp 145 – 154.

Petters, S.W. 1978a. Mid – Cretaceous palaeoenvironments and biostratigraphy of the Benue Trough, Nigeria, *Geological Society of America Bulletin* **89**, 151 – 154.

Petters, S.W. 1978b. Stratigraphic evolution of the Benue Trough and its implications for the Upper Cretaceous paleogeography of Nigeria. *Journal of Geology* **86**, 311 – 322.

Petters, S.W. and Ekweozor, E.M. 1982 .Origin of mid-Cretaceous Black shales in the Benue Trough, Nigeria, *Palaeogeography Paleoclimatology Paleoecology.* **40**, 311 – 319.

Popoff, M. Wiedmann, J. and deKlasz I 1986. The Upper Cretaceous Gongila and Pindiga Formations, Northern Nigeria subdivisions, age, Stratigraphic correlations and paleogeographic implication. *Ecologa Geologica Helvetine* **79**, 343 – 363.

Popoff, M. (1988) – Du Gonduwana á Í Allantique sud: les connexious du fosse de la Bénoué avec les basins du nord Est bre-siliecu jusqua Í ouverture du golfe de Guinee au Cretacee inferieur . *Inferieur Journal African Science* **7**, 409 – 431.

Rebelle, M. 1990. The marine transgression in the Benue Trough (NE Nigeria) a palaeogeographic interpretation of the Gongila Formation. *Journal of African Earth Sciences* 10, 643 – 655.

Reyment, R A. 1954a. Notes on fossils from the northern and eastern region. *Annual Reports of the Geological Survey of Nigeria.*52-53, 20-22.

Reyment, R. A. 1955. The Cretaceous Ammonoidea of southern Nigeria and the southern and the southern Camerouns. *Bulletin Geologica Survey Nigeria* **25** 1- 112.

Reyment, R.A. 1957. On the occurrence of Santonian in north-eastern Nigeria Stockholm. *Contributions in Geology,* (NS) **1**. 35 – 40.

Reyment, R. A. 1969. Ammonite boistatigrahpy, continental drift and oscillatory transgression, *Nature.* **224**, 137-140.

Reyment, R. A. 1980. Biogeography of the Saharan Cretaceous epicontinental transgression. *Cretaceous Research* **1**, 299-327.

Reyment, R. A., Dingle, R. V.1987. Paleogeography of Africa during the Cretaceous period. *Palaeoclimatology, Palaeoecology* **5**. 93-116.

Shaw, A.B. 1964. *Time in Stratigraphy McGraw* –New York 365pp.

Stoneley, R. 1966. The Niger Delta region in light of the of the theory Of continental drift .*Geological Magazine* 103, 386-397.

Suleiman, U.A.2004. A sequence Stratigraphy interpretation of the Cretaceous Pindiga Formation at Ashaka Quarry, NE Nigeria. *Unpublished M.Sc Thesis. Geology Dept A.B.U.* Zaria.89pp

Thompson J.H. 1958. The Geology and hydrology of Gombe, Bauchi Province. *Records geological Survey Nigeria* 1956, 46 – 65.

Tucker, M. E. 1993. Carbonate diagenesis and sequence stratigraphy *Sedimentology Review* **1**, 51-72.

Vacoutere, T.L., Mullins, H.T., Mc Dougall, K & Thompson, J.B 1987. Sedimentation across the central California oxygen minimum zone an alternative coastal upwelling sequence. *Journal of sedimentary Petrology,* **57**, 709 – 72

Van Wagoner, J.C. 1985. Reservoir facies distribution as controlled by sea level change: *Abstract and poster session. Society of Economic Paleontologists and mineralogists mid – year meeting (Golden – Colorado),* 91 – 92.

Whiteman, A. 1982. Nigeria it's Petroleum Geology Resources and Potential. Vol.1 *Publications Graham and Trotman Ltd.* pp 104-155. Vol 2. pp 232-235.

Wozny, E. and Kogbe C.A. 1983. Further evidence of marine Cenomanian, Lower Turonian and Maastrichitian in the Upper Benue Basin of Nigeria (West Africa). *Cretaceous Research* **4**, 95 – 99.

Wright J.B. 1981. Review of the origin and evolution of the Benue Trough in Nigeria. In Kogbe, C.A. (ed). *Geology of Nigeria* (second Edition), 359 – 364. Rock view (Nigeria), Jos,

Zaborski, P.M.B. 1982. Campanian and Maastrichitian sphenodiscid ammonites from southern Nigeria. *Bulletin of the British Museum of Natural History. London (Geology)* **36** (4): 303 – 332.

Zaborski, P. M. P. 1985. Upper Creataceous ammonites from the Calabar region , south –east Nigeria. Bulletin British meseum Natural History, London. (Geology)**36** (4): 303-332 .36 figs.

Zaborski, P.M.P. 1987. Lower Turonian (Cretaceous) ammonites from south -east Nigeria. *Bulletin of the British Museum (Natural History. London (Geology)* **36** (4): 303 –

Zaborski, P.M.P. 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.M.P. 1990. Some Upper Cretaceous ammonites from southern Nigeria. *Journal of African Earth Scienc* **10**, 365 – 581.

Zaborski, P.M.P. 1995. The upper Cretaceous ammonites *Pseudaspidoceras* Hyatt 1903 in north –eastern Nigeria. *Bulletin of the Natural History Museum London.* (Geology). **52**, 61 – 89.

Zaborski, P.M.P. 1996. The Upper Cretaceous ammonite *Vascoceras* choffat, 1898 in north – eastern Nigeria, *Bulletin of Natural History Museum London, (Geology)* **52**, 61 – 89.

Zaborski P.M.P. 1998. A review of the Cretaceous System in Nigeria. *Africa Geoscience Review* 385 – 483.

Zaborski, P.M.P 2000. The Cretaceous and Paleocene transgressions in Nigeria and Niger, *Journal of Mining and Geology,* **36**, 153 – 173

Zaborski, P.M.P. 2003. Guide to the Cretaceous System in the upper part of the Upper Benue Trough, north – eastern Nigeria. *Africa Geoscience Review* 2pp 13 – 32.

Zaborski, P, Ugodulumwa, F., Idorngie, Nnabo, P. and Ibe, K., 1997. Stratigraphy and structure of the Cretaceous Gongola Basin, north eastern Nigeria. *Bulletin desCcentres des Recherches Exploration Production Elf. Aquitaine* **21**. 153 – 185.