Did the Benue Trough connect the Gulf of Guinea with the Tethys Ocean in the Cenomanian? New evidence from the Palynostratigraphy of the Yola Sub-basin

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Abstract

The Yola Sub-basin represents the lower portion of the bifurcated Upper Benue Trough, whose origin has been linked to the opening of the Atlantic Ocean in the Mesozoic. The sub-basin fill consists predominantly of siliciclastic and carbonate deposits, the ages of which have remained controversial until now. This work employs field observations integrated with palynostratigraphy to refine the stratigraphy of these Upper Cretaceous deposits. We delineate five palynozones, spanning the upper Albian–Cenomanian, middle Cenomanian, upper Cenomanian, Turonian and Coniacian–Santonian. This palynology indicates that rocks previously thought to be Turonian are in fact Cenomanian. Further, the species *Florentinia berran*, *Florentinia khaldunii*, and *Subtilisphaera senegalensis* are all low latitude dinocysts that previously have only been reported from the Tethyan realm. Their presence here, together with the sedimentology, implies that there was an influx of Tethyan waters into the epeiric sea of the Benue Trough in the Cenomanian. The collective sedimentary and palynological evidence indicates that the Cenomanian transgression was well established in the Yola Sub-basin, and more broadly in the Upper Benue Trough, connecting Tethys with the Gulf of Guinea.

Keywords: Trans-Sahara; Late Cretaceous; Palynomorphs; Biostratigraphy; Benue Trough; Nigeria; Failed rift

1. INTRODUCTION

The Benue Trough owes its origin to the opening of the Atlantic Ocean, driven by rifting as Africa separated from South America in the Mesozoic (Genik, 1993). The basin extends for about 800 km into the African continent, with a more or less continuous width of 150 km (Abubakar et al., 2011). The Benue Trough is filled with continental to marine deposits of siliciclastic sandstone and mudstone, plus some limestones. The deposits are about 6000 m thick at the centre of the basin (Benkhelil, 1989). The Benue Trough is divided into the Upper, Lower and Middle Benue Trough sectors (Carter et al., 1963) based on geographical location. The Lower Benue Trough at the southern end is bounded by the Anambra Basin, whereas the Upper Benue Trough at the northern end is bounded by the Chad Basin (Fig.1). The Upper Benue Trough is itself divided into two sub-basins, named the Gongola and Yola sub-basins.

Tectonic and palaeogeographic studies of Upper Cretaceous rocks have previously suggested the existence of a seaway linking the Atlantic and Tethys Oceans during that timeframe (Scotese, 2014), with a link via the Trans-Sahara seaway purported to be active from the early Cenomanian to Maastrichtian (Scotese, 2014). Goswami et al. (2018) presented a global bathymetry of the Cenomanian, which suggested a link between the two seas. Attempts to define the path taken by such a Trans-Sahara seaway have been hampered by poor stratigraphic control in the oldest marine deposits of the Benue Trough (Zaborski, 2000; Edegbai et al., 2019).

Previous stratigraphic schemes for the Yola Sub-basin are contradictory (Carter et al., 1963; Petters, 1978b; Lawal and Moullade, 1986; Mamman, 2007). Carter et al. (1963) proposed that these strata were deposited during the Cenomanian to Maastrichtian based on evidence from

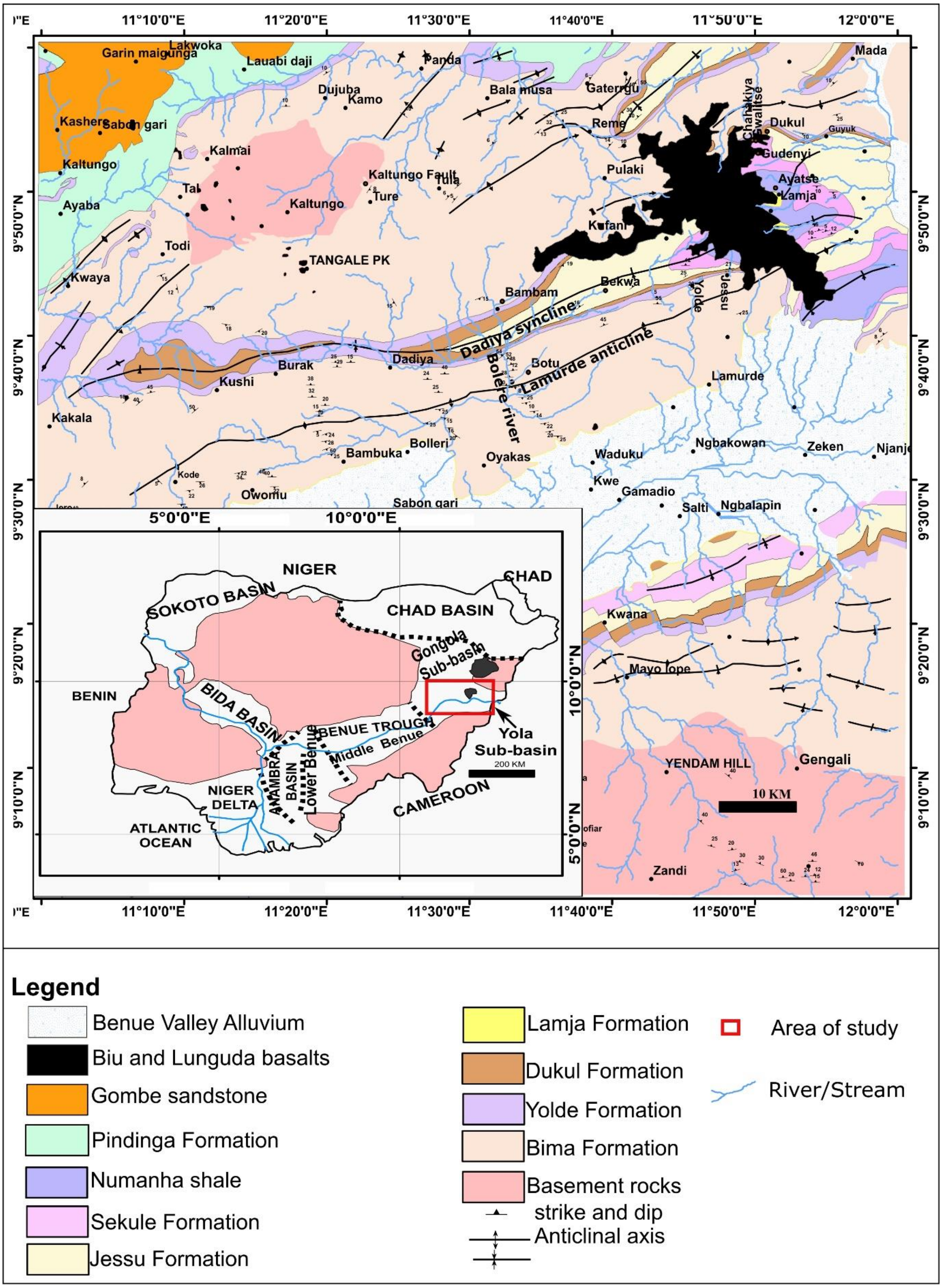

Figure 1. Geological map showing the study Area (modified after Carter et al., 1963)

bivalves and lithostratigraphy. The first attempts at sub-surface palynostratigraphy of the Benue Trough were presented by Lawal and Moullade (1986) and Abubakar et al. (2011). These authors based their work on three shallow boreholes, and the Nasara-1 well in the Upper Benue Trough. Of their three shallow boreholes, only the Mona borehole was from the Yola Sub-basin. An attempt to revise the stratigraphy of the Benue Trough was presented by Popoff et al. (1986) based on ammonites. Conducted on rock units from the Gongola Sub-basin, six Ammonite zones were proposed ranging in age from Cenomanian to Turonian. They extrapolated their erected zones into the Yola Sub-basin.

Petters (1978b; 1979) studied the foraminifera of the Upper Benue Trough and concluded that the foraminiferal assemblages were not age diagnostic. However, Mamman (2007) recorded *Heterohelix moremani, H. reussi, H. globulosa, Hedbergella, Haplophragmoides, Ammobaculites, Globigerinnelloides, Trochammina, Ammotium, Reophax, Bathysiphon, Miliammina, Bigenerina* and *Rhizammina* planktonic and benthic forms. These occurrences led the authors to assign the Dukul and Jessu formations (Fig. 2) to the upper Cenomanian to upper Turonian interval (Mamman, 2007).

Except for studies by Carter et al. (1963), none of the previous works covers the stratigraphy of the Yola Sub-basin. The studies (Fig. 2) were carried out in the Gongola Sub-basin but were also extrapolated to the Yola Sub-basin. A challenge in the correlation between the Yola and Gongola sub-basins is their dissimilar lithofacies. The Gongola Sub-basin consists dominantly of sandstones whereas the Yola Sub-basin is dominated by shales interbedded with limestones or mudstones. Correlation of these heterolithic deposits has also been hindered by the absence of age-diagnostic foraminifera. Until now there have been no published palynostratigraphic analyses of the Yola Sub-basin despite lithofacies favourable to the preservation of organic-

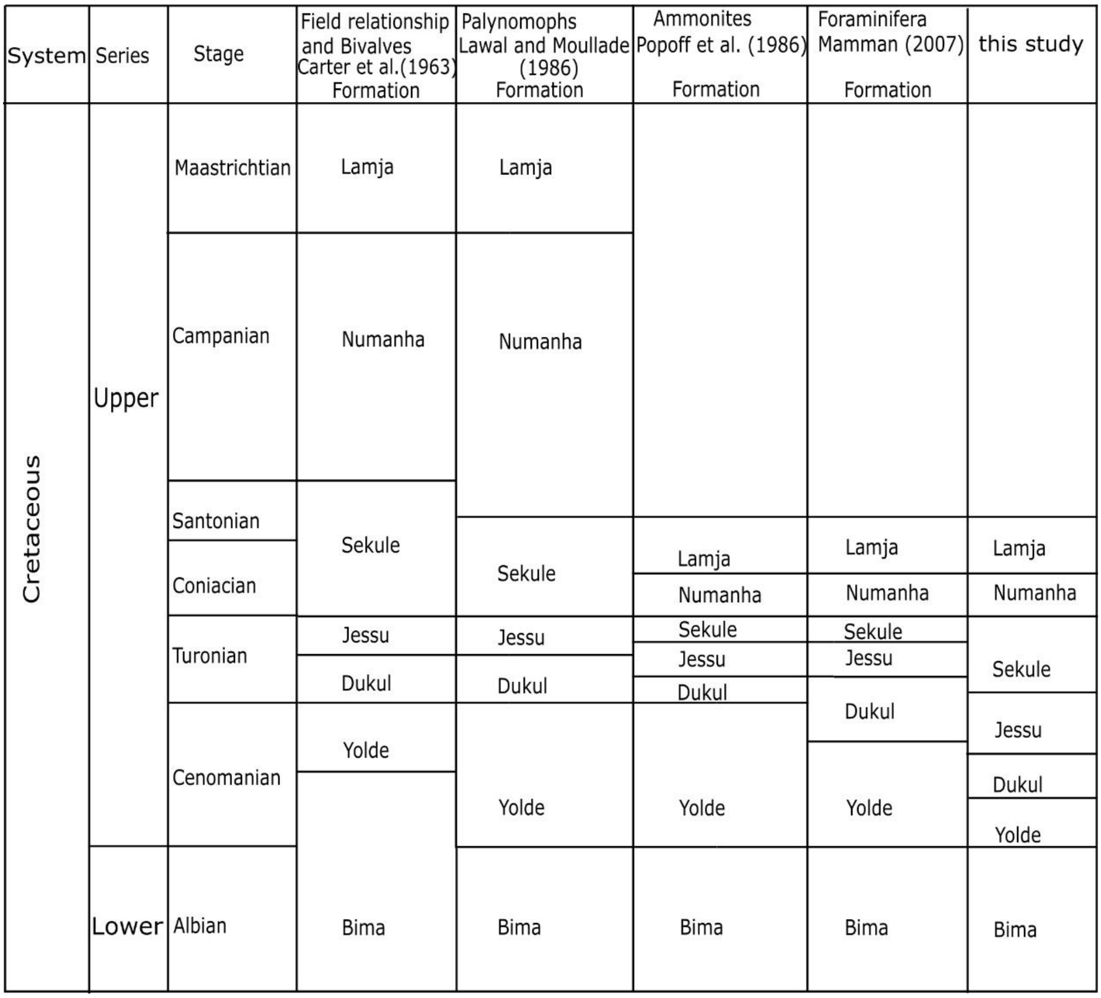

Figure 2. Correlation of the relative ages assigned to various formations in the study area by previous researchers.

walled microfossils. This paper aims to provide a detailed palynostratigraphic zonation of the Yola Sub-basin sedimentary rocks to establish the ages of the formations and members present, and place them in a global stratigraphic context. To our knowledge this is the first attempt to carry out a palynological study of Upper Benue Trough deposits from outcrop sections that include all the formations present.

2. STRATIGRAPHY

2.1 The Bima Formation

The stratigraphically lowest formation in the Yola Sub-basin is the Bima Formation (Fig. 3), which lies unconformably on the Basement Complex. It is composed of partly clast-supported, partly matrix-supported, coarse to fine-grained sandstone and mudstone (Carter et al., 1963). The apparently continental Bima Formation was informally divided into lower, middle, and upper members based on lithologies by Carter et al. (1963). This subdivision was upheld by subsequent authors (Guiraud, 1990; Shettima et al., 2018). The lower Bima Member was inferred to have been deposited in an alluvial fan environment, whereas the middle and upper members were deposited in a braided river system (Carter et al., 1963; Guiraud, 1990; Shettima et al., 2018). Sarki Yandoka et al. (2014) proposed a lacustrine facies model in which they divided the Bima Formation into lacustrine, proximal braided river and standard braided river successions. However, Tukur et al. (2015) argued that the earlier subdivision was not practical. They subdivided the Bima Formation into a lower and upper Bima Formation.

2.2 *The Yolde Formation*

The Yolde Formation incorporated a transition between the continental and marine environments. It is characterised by interbedded sandstone and shale. The formation forms low-lying outcrops and is exposed in the Gongola and Yola sub-basins with its type locality being in Yolde village. The formation was initially interpreted as a fluvial to marine deposit (Zaborski et al., 1997), and subsequent work interpreted it as a coastal deposit (Sarki Yandoka et al., 2015). The formation was considered late Cenomanian in age based on occurrences of *Classopollis brasiliensis* and *Triorites africaensis* (Lawal and Moullade, 1986).

2.3 The Dukul Formation

The Dukul Formation of the Yola Sub-basin (Fig. 3) consists of interbedded limestones and shales. Fossils in the limestones include bivalves, gastropods, and ammonites, which together have been considered as evidence for a marine incursion into the sub-basin (Carter et al., 1963). The ammonite genera *Voscoceras, Paravascoceras* and *Gombeoceras* were recognised at the base of the formation with *Pseudotissotia* (Bauchioceras) and *Pseudotissotia* (Wrightoceras) higher up the stratigraphy (Carter et al., 1963). These macrofossils indicate an early Turonian age for the formation. The formation is interpreted as a shallow marine deposit based on the observed planktonic foraminifera (Mamman, 2007).

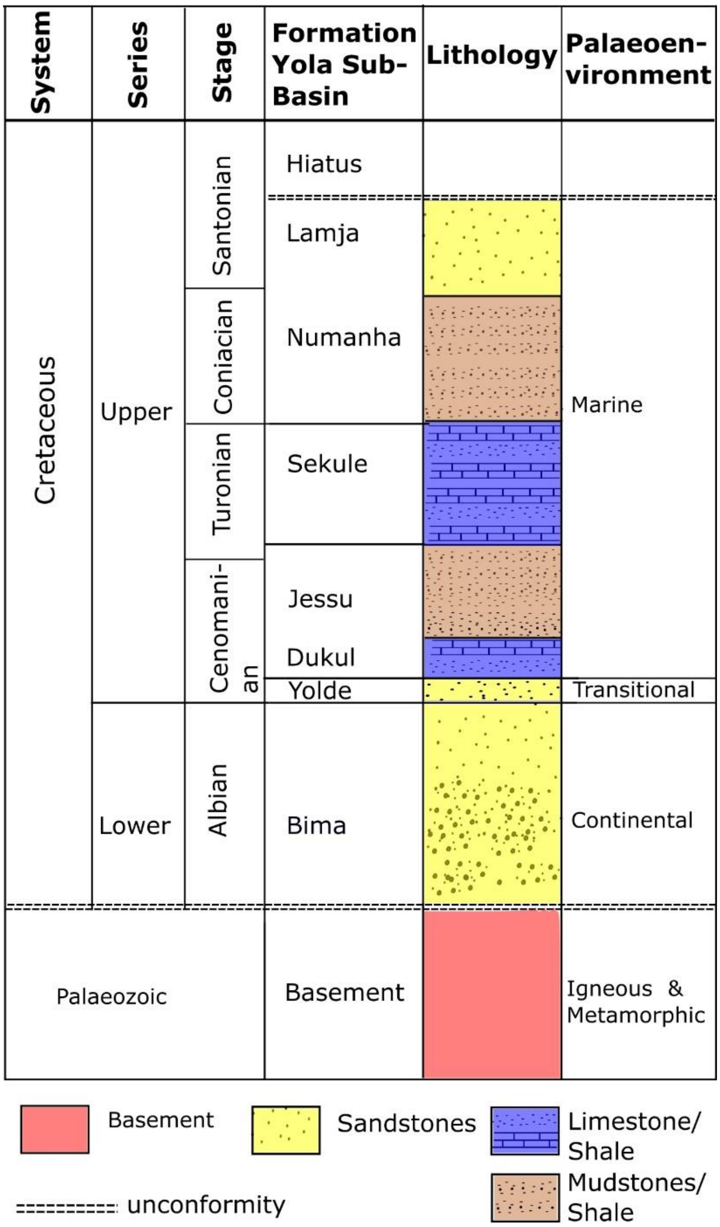

Figure 3. Stratigraphic chart of the Yola Sub-basin.

2.4 The Jessu Formation

The Jessu Formation (Fig. 3) consists of sandstones overlain by dark shales and mudstones (Carter et al., 1963). The formation was earlier termed "Mudstone Shale" (Barber et al., 1954) because of its grey, dark grey and brown mudstones. From the basal part of the formation, a sandstone unit was reported by Carter et al. (1963) at Dukul, Cham and Dong villages. Within the Reme Syncline, this sandstone attains a thickness of three metres and comprises fine-grained sandstone with subordinate claystone. The dominant lithology is shale/claystone interbedded with bioturbated mudstone. This formation was interpreted as marine by Carter *et al*. (1963), but later attributed to a regressive shoreface (Sarki Yandoka et al., 2019).

2.5 The Sekule Formation

The 274-m-thick Sekule Formation (Fig. 3) overlies the Jessu Formation conformably, and it is lithologically similar to the Dukul Formation. It consists of thin beds of fossiliferous limestone and thick shales. The claystone facies are poorly exposed, but Carter et al. (1963) recorded 21 limestone beds exposed in the Numanha Stream. The formation was dated as late Turonian to Santonian based on records of *Plicatula auressinsis, Lopha semiplana,* and *Ostrea vatonnei* (Carter et al., 1963).

2.6 The Numanha Formation

The 200-m-thick Numanha Formation (Fig. 3) consists of shale, nodular mudstone, and limestone (Carter et al., 1963). The formation was interpreted as a deposit of shallow to deeper marine environments (Opeloye, 2002).   Fossils of fish and bivalves were recorded by Carter et al. (1963).

2.7 *The Lamja Formation*

The sub-basin is capped by the Lamja Formation which consists of a succession of fine-grained but upward-coarsening sandstones, claystones, limestones, and a coal seam (Carter *et al*., 1963). The formation has been considered to be Maastrichtian in age based on occurrences of *Pycnodonte vesicularis* (Carter et al., 1963). This formation is overlain by the Lunguda Basalt near Lamja village (Fig.1). It is not exposed in other parts of the Sub-basin, so the true thickness of the formation is unknown.

3. METHODOLOGY

The Yola Sub-basin of the Upper Benue Trough was affected by Santonian tectonism, which folded the pre-Santonian strata, and by Cenozoic volcanism. The nature of the lithofacies, which comprise weathered interbeds of claystone, limestone, and mudstone (Fig. 4), make it difficult to establish a continuous stratigraphic section. The shales are generally weathered to black cotton soil, with strata being exposed only in topographically high areas close to the limbs of anticlines. However, there are some well-exposed sections, including those studied here from the Dadiya Syncline and Lamorde Anticline (Fig. 1).

The materials used for this study were samples collected from outcrops and from one shallow borehole (35 m). Seventeen outcrop sections were logged across the Dadiya Syncline and Lamorde Anticline (Fig. 1). Samples of about 70 g of clay, shale and mudstone were collected for palynological studies. The samples were collected at intervals ranging between 50 cm to 100 cm in shale-dominated sections. The basal Bima and Yolde formations (sandstones) were sampled where possible. The lithofacies data were recorded as graphic logs (Fig. 4).

One hundred and four samples were analysed using the standard method described by Stukins et al. (2013), which involved the use of 40% HF to oxidise silicate minerals, and 60% HCl. The samples were immersed in 40% HF for three days and then neutralised. They were subsequently sieved through a nylon 7µm mesh, after which HCl was added to the residue. The sample was boiled in HCl for 20 minutes to remove precipitated CaF_2. The residue was then centrifuged for thirty minutes in 2.2 g/cm^3 of sodium polytungstate (SPT) to remove heavy minerals. Two slides were prepared using a permanent epoxy mounting medium from each sample, and these were studied under an Olympus biological, transmitted light microscope

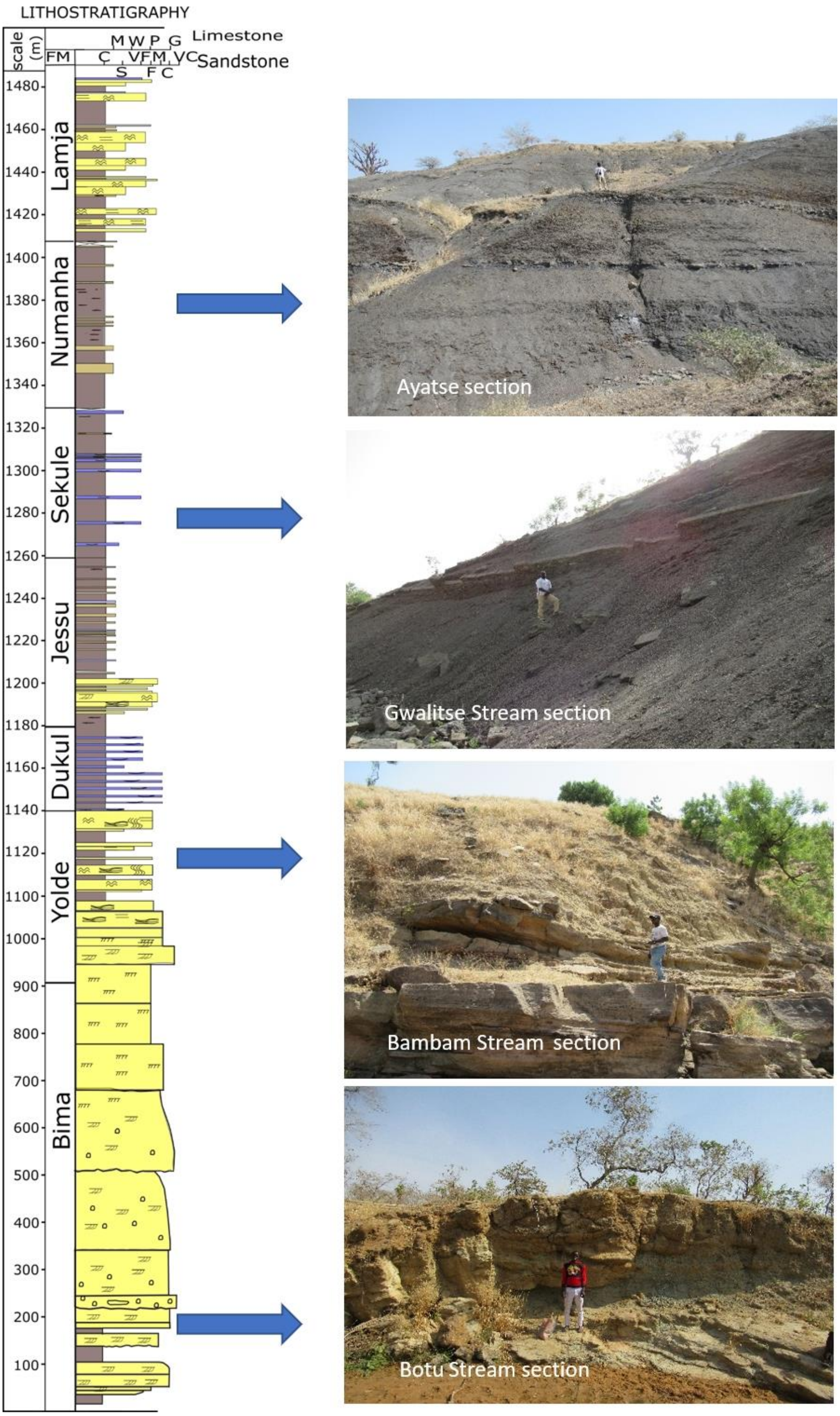

Figure 4. Composite stratigraphic section of Yola Sub-basin; photographs show the nature of the outcrops

(Model BX53), mounted with an Olympus camera (Model SC50). The slides were examined for palynomorphs, with two hundred and fifty specimens counted from each sample where possible, with the remainder of the slide scanned for additional taxa.

4. RESULTS

The samples collected yielded diverse and abundant palynomorphs. However, their preservation differs through the stratigraphy. The Bima, Yolde and Dukul formations (Fig. 3) are characterised by poor recovery of palynomorphs, their assemblages being dominated by spores and pollen with rare dinocysts. The Jessu, Sekule and Numanha formations (Fig. 3) yielded abundant and diverse palynomorphs. Dinocysts and foraminifera linings are the most abundant palynomorphs in this interval, with subordinate freshwater algae, spores and pollen. The average dinocyst recovery from the Bima Formation to the Dukul Formation is 24%, being mostly from the Dukul Formation. Spores and pollen are the dominant palynomorphs constituting an average of 73% of the total assemblage. Sedimentary rocks of the younger Jessu, Sukule, Numanha, and Lamja formations (Fig. 3) preserved an increase in frequency of marine palynomorphs. The average proportion of dinocysts increased to a maximum of 65% in these units, whereas spores and pollen decreased to 35%.

One hundred and thirteen species of spores and pollen were identified within the stratigraphic succession. The lower interval spanning the Bima to Yolde formations contains specimens of *Sofrepites legouxae*, *Cicatricosisporites* spp., *Deltoidospora* sp. 1, other trilete spores, and the gymnosperm pollen *Classopollis*, *Ephedripites* spp., *Elaterosporites klaszi*, *Afropollis* spp and *Klukisporites* sp. The upper interval, from the Jessu to Lamja formations, preserved a record dominated by angiosperm pollen, incorporating triporates, tricolpates, polyporates, and monosulcates. These spores and pollen from the Yola Sub-basin are considered here in the framework of a previously published palynozonation of the Gongola Sub-basin (Abubakar et al., 2011).

One hundred and five dinocyst taxa were identified from the Yola Sub-basin. The dinocyst recovery was generally good except from the sandy parts of the succession. This is considered to be attributable to taphonomic biases in separate depositional facies. Abundant and diverse dinocyst assemblages were recovered from the Jessu, Sekule and Numanha formations. The dinocysts are mostly cosmopolitan with few Tethyan dinocysts (*Florentinia berran*, *F. khaldunii* and *Xenascus plotei*). The dinocyst assemblage is similar to that of the Sergipe and Santos basins of Brazil (Masure and Arai, 2003; Santos et al., 2019), Mazagan Plateau of Morocco (Below, 1984) and Cyrenaica, northeast Libya (Batten and Uwins, 1985).

The spores, pollen and dinocysts recovered here are characteristic of the African and South American province (ASA) (Herngreen et al., 1996). To establish zones from outcrop sections of the Yola Sub-basin, the stratigraphic ranges of index taxa from Africa, South America and North America were used (Fig. 5, Appendix A and B). The zones proposed in the current study were correlated with local palynozones and the ASA province (Fig. 6). Representative images of the spores, pollen, and dinocysts, are presented in figures 7–9.

5. DISCUSSION

5.1 *Elateroplicites africaensis-Elaterosporites klaszi Zone*

This zone is an assemblage zone (Fig. 10) proposed by Abubakar et al. (2011) for the Gongola Sub-basin of the upper Benue Trough. In order to follow the rules of standard biostratigraphic nomenclature, the name of the *Elateroplicites africaensis-Elaterosporites klaszi-Elaterosporites protensus* Zone (Abubakar et al., 2011) is here modified to the *Elateroplicites*

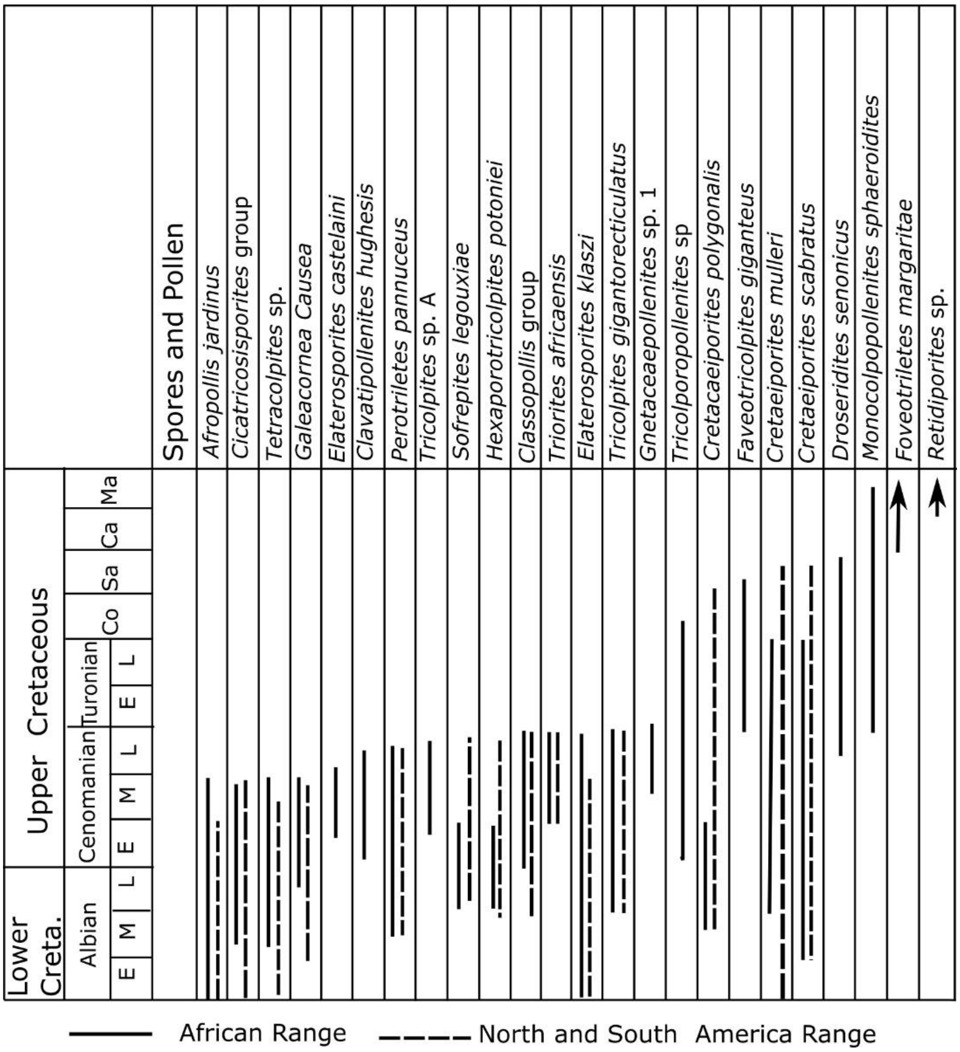

Figure 5. Range of some selected taxa within Africa and North and South America Cretaceous Co, Coniacian, Sa, Santonian, Ca, Campanian, Ma, Maastrichtian, E = early, M = middle, and L= late (Jardiné, 1967; Herngreen, 1974; Regali et al., 1974; Doyle, 1982; Salard-Cheboldaeff, 1990; Deaf et al., 2014)

africaensis-*Elaterosporites klaszi* Zone. The base of the zone could not be determined due to poor preservation. The top of the zone is defined by disappearance of *Klukisporites* sp., *Elaterosporites klaszi*, *Araucariacites* cf. *australis*, and *Ephedripites brasiliensis*. Index species of the zone include *Ephedripites*, *Cicatricosisporites* sp. 2, *Ruffordiaspora ludbrookiae*, *Sofrepites legouxae* and *Elaterosporites* spp.

Spores and pollen identified in this zone include *Elaterosporites klaszi*, *Afropollis* spp., *Araucariacites* cf. *australis*, *Galeacornea causea*, *Klukisporites* sp., *Cicatricosisporites* spp., *Perotriletes*, and *Classopollis* pollen from xerophytic cheirolepidiacean conifers. Spores and pollen are rare from the overlying Dukul Formation. The latter formation contains a low

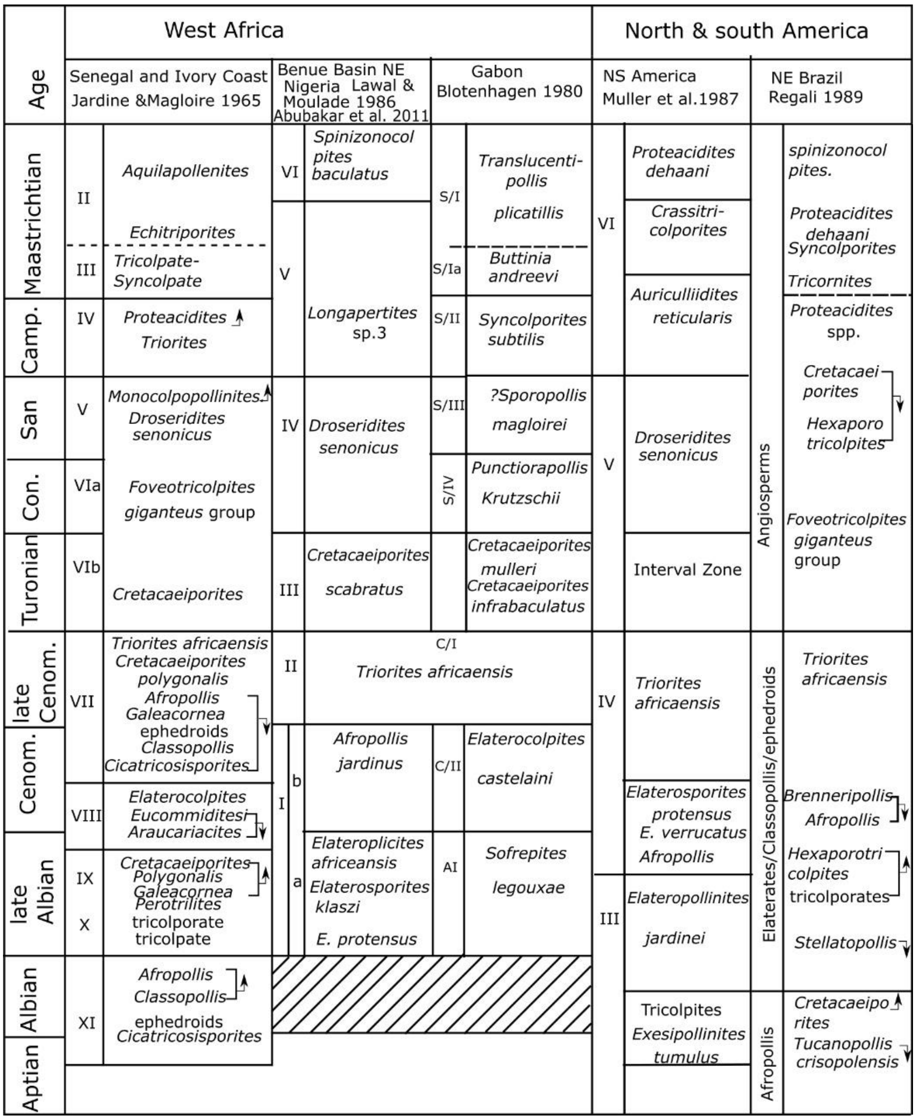

Figure 6. Correlation of the middle to Late Cretaceous palynozonation in West Africa and Eastern South America (modified after Schrank 1992)

diversity assemblage including *Paleohystrichophora infusorioides, P. cheit*, and *Cribroperidinium* spp. The upper limit of this zone is, therefore, placed below the base of the Dukul Formation. The zone reaches the upper part of the Yolde Formation because *Classopollis*, *Perotriletes pannuceus*, *Elaterosporites klaszi* and *Perotriletes* were recorded from the Yolde section at Bambam (Fig. 1).

Elaterosporites species are of importance in the definition of the ASA province. *Elaterosporites klaszi* was reported from lower Albian to upper Cenomanian strata in the Maranhão Basin that were dated using ammonites and foraminifera (Jardine, 1967 and

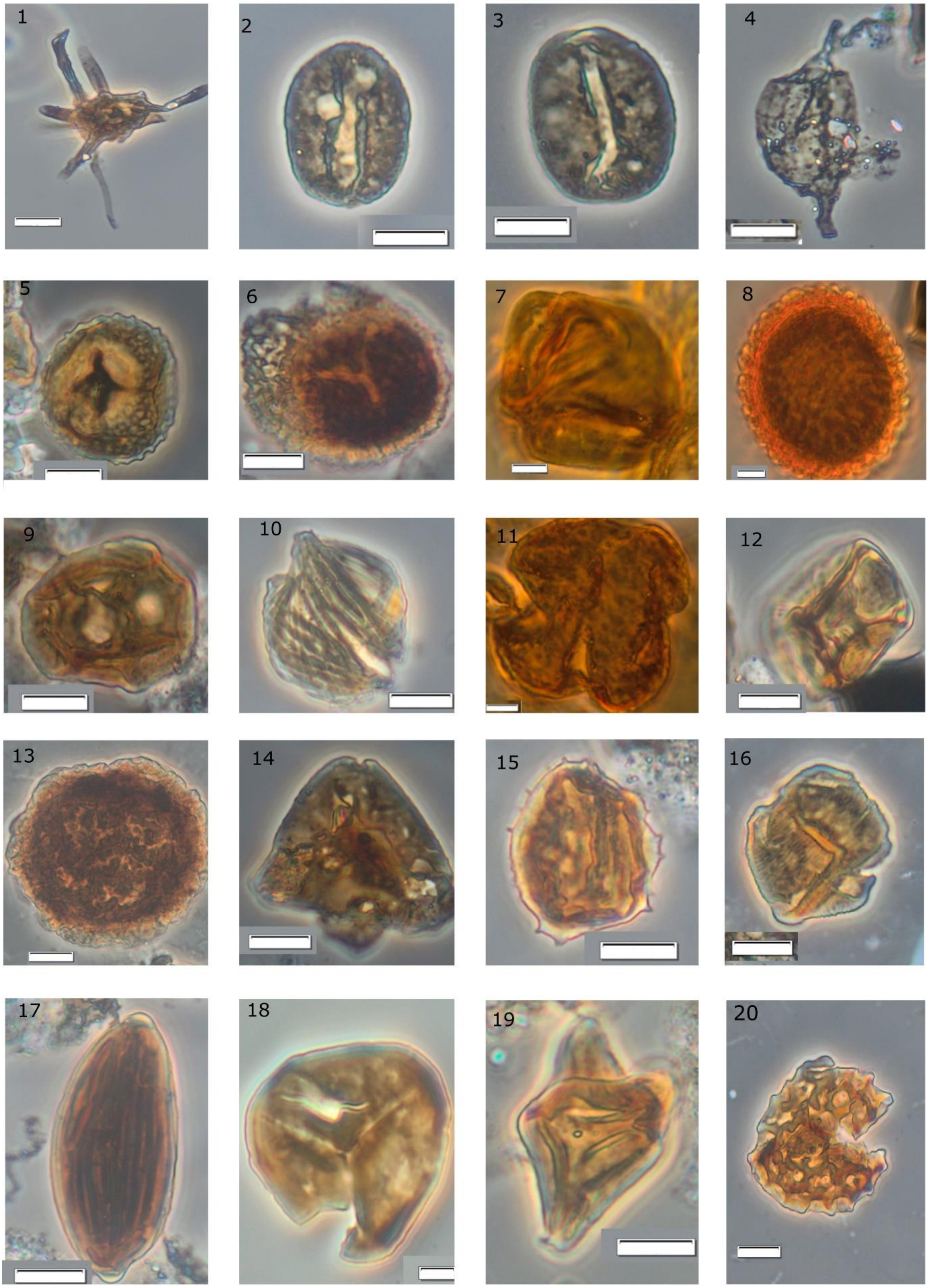

Figure 7. Selected palynomorphs from Yola Sub-basin, the scale bar represents 10 µm. 1, *Elaterosporites klaszi* (Jardiné and Magloire) Jardiné, 1967, BBR3 G35. 2, 3, *Clavatipollenites hughesii* DKD5 H45-2 and E32-4. 4, *Sofrepites legouxae* Jardiné, 1967,

BBR3 M35, 5,6. *Afropollis jardinus* S8 H41-2 and DKD5 P54-3. 7, 19, *Glaecornea causea* Stover, 1963, BEJ1 J39 and S5 G39-4. 8, *Perotriletes pannuceus* Brenner, 1963, BY4 L39-4 9. 12, *Cretaceaiporites polygonalis* (Jardiné and Magloire), Herngreen, 1973 S10 Q45-2 and S7 G31-4. 10, *Gnetaceaepollenites* cf. *clathratus* Stover 1964 S8 N41-3, 11. *Tetracolpites* sp. 2 S2A H28-4. 13, *Gabonisporis vigourouxii* Boltenhagen 1967, GWS1 B53, 14. *Triorites africaensis* Jardiné and Magloire, 1965, S10 C34-4, 15. *Hexaporotricolpites emelianovi* Boltenhagen 1967, S7 F38-2. 16, *Tricolpites microstriatus* Jardiné and Magloire, 1965, GUN2 H50-2. 17, *Steevesipollenites binodosus* Stover 1964 S5 F39-3, 18. *Deltoidospora* sp. 1 Couper 1953 KFS2 N52. 20, *Klukisporites* sp. KFS2 K39-4.

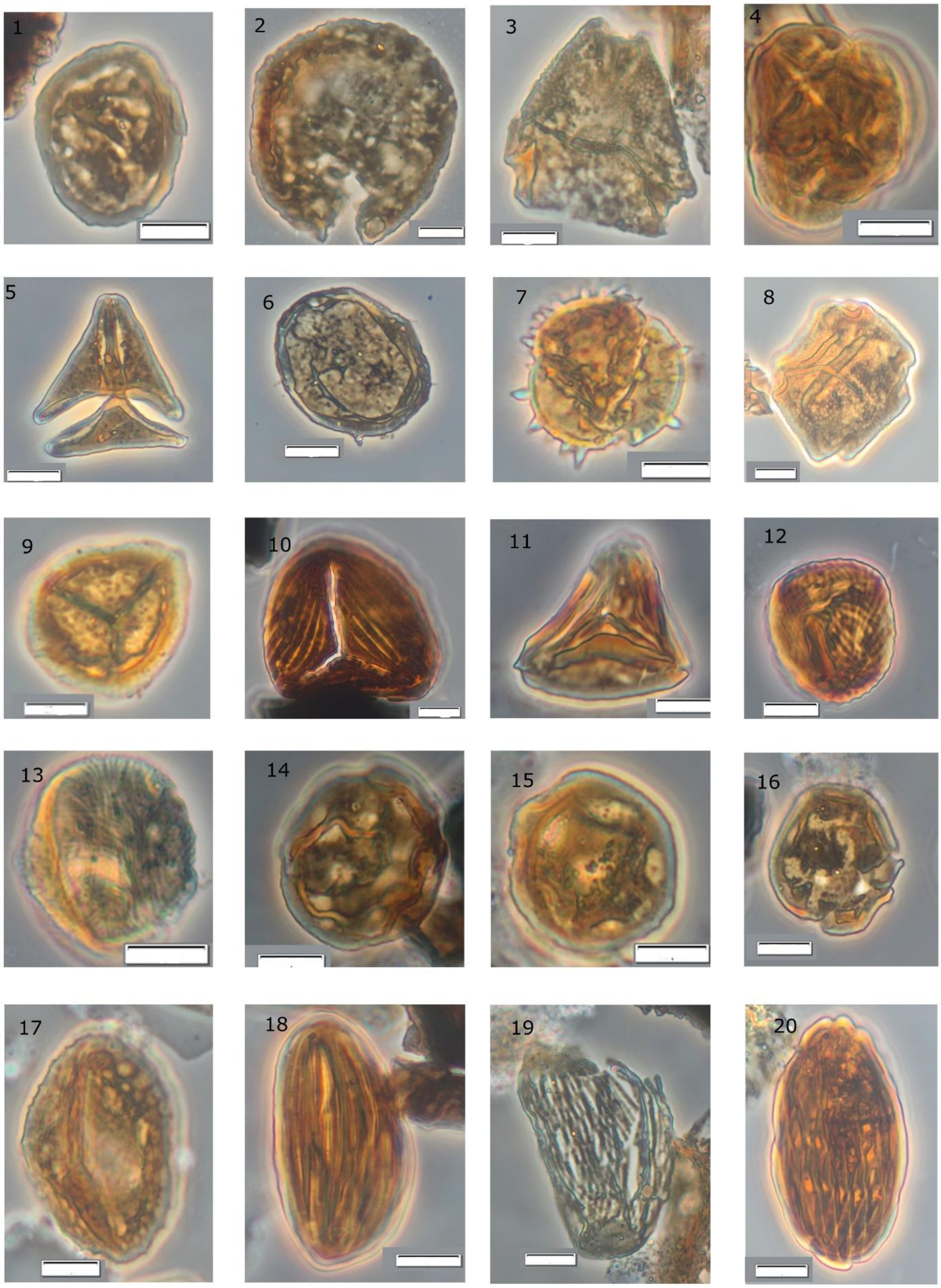

Figure 8. Selected palynomorphs from Yola Sub-basin, the scale bar represents 10 µm.

1, *Classopollis* sp.1 KFSO1, F30. 2, *Araucariacites* cf. *australis* Cookson 1947, KFS01 F51-1. 3, *Tricolporopollenites* sp. 1 LL6 F44-1. 4, *Tetradopollenites* sp., LL6 M48. 5, *Tricolporopollenites* sp. S. 152 in Jardiné and Magloire, 1965. 6, *Classopollis jardinei GUN21 K51*. 7, *Droseridites senonicus* Jardiné and Magloire, 1965, S7 G43. 8, *Tetracolporopollenites* sp., LAL13 E36-3. 9, Triletes spore BY4 Q44-4. 10, *Ruffordiaspora ludbrookiae* KFS., 11, *Cicatricosisporites* sp. 2 DKD5 E46-1.12, *Cicatricosisporites minutaestriatus*, KFS2 F50-2. 13, *Classopollis brasiliensis* Herngreen, 1975, CHY3 D40-4. 14, *Cretacaeiporites krutzchi* Boltenhagen 1975, S10 Q45-4. 15, *Cretacaeiporites scabratus* Herngreen, 1973, BEJ5 M40-1. 16, *Cretacaeiporites mulleri* Herngreen, 1973, S7 H45-2. 17, *Retimonocolpites* sp. 1 LZN8 E44-2. 18, *Ephedripites multicostatus*, S7 D44-2. 19, *Gnetaceaepollenites* sp. 1 in Lawal and Moullade, 1986 BEJ9 P51. 20, *Ephedripites* sp. 11 in Herngreen, 1973, S7 C46.

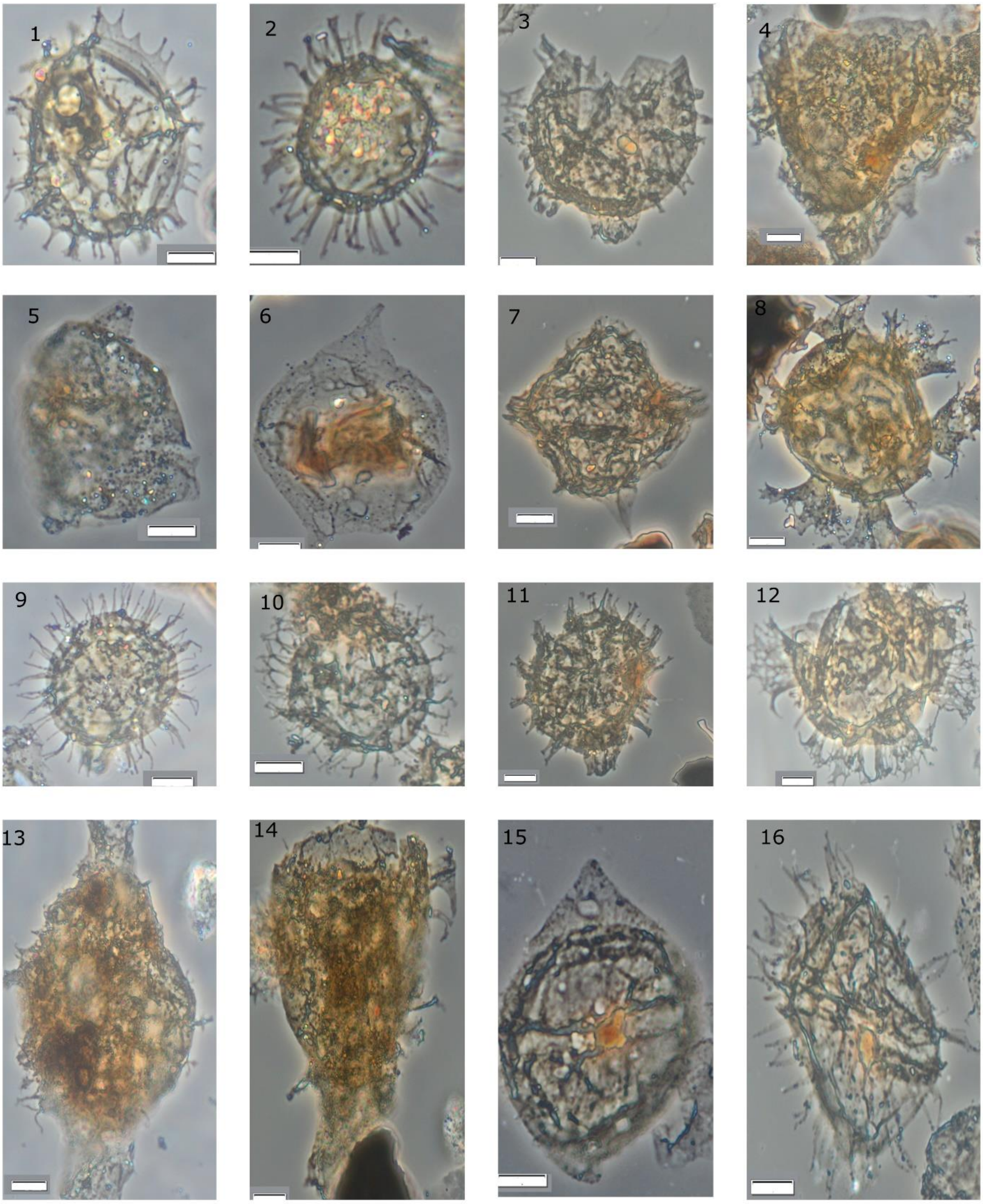

Figure 9. Selected palynomorphs from Yola Sub-basin, the scale bar represents 10 µm. 1, *Spiniferites lenzii*, S7 H36. 2, *Impletosphaeridium clavus*, S7 M44-2. 3, *Florentinia khaldunii*, AY2 F41-1. 4, *Phoberocysta neocomica,* S7 G39-4. 5, *Endoceratium dettmanniae,* S7 F31-1. 6, *Altertibidinium* sp. 3, S7, T39. 7, *Xiphophoridium alatum,* CHY7 F51. 8, *Oligosphaeridium* sp. 2, 2A R27. 9. *Florentinia berran* Below 1982, 10, *Achomosphaera triangulata*, AYS25 P44. 11, *Florentinia radiculata* Davey and William 1966 emend Davey and Verdier 1976, AY2 C52-2. 12, *Achomosphaera danica*, AYS25 D35-

1. 13, *Xenascus plotei* ,S5 D30. 14, *Xenascus ceratioides*, S5 X36-2. 15, *Subtilisphaera perlucida*, DKD S45-4. 16, *Hystrichodinium pulchrum* Deflandre 1935 AYS18, P47.

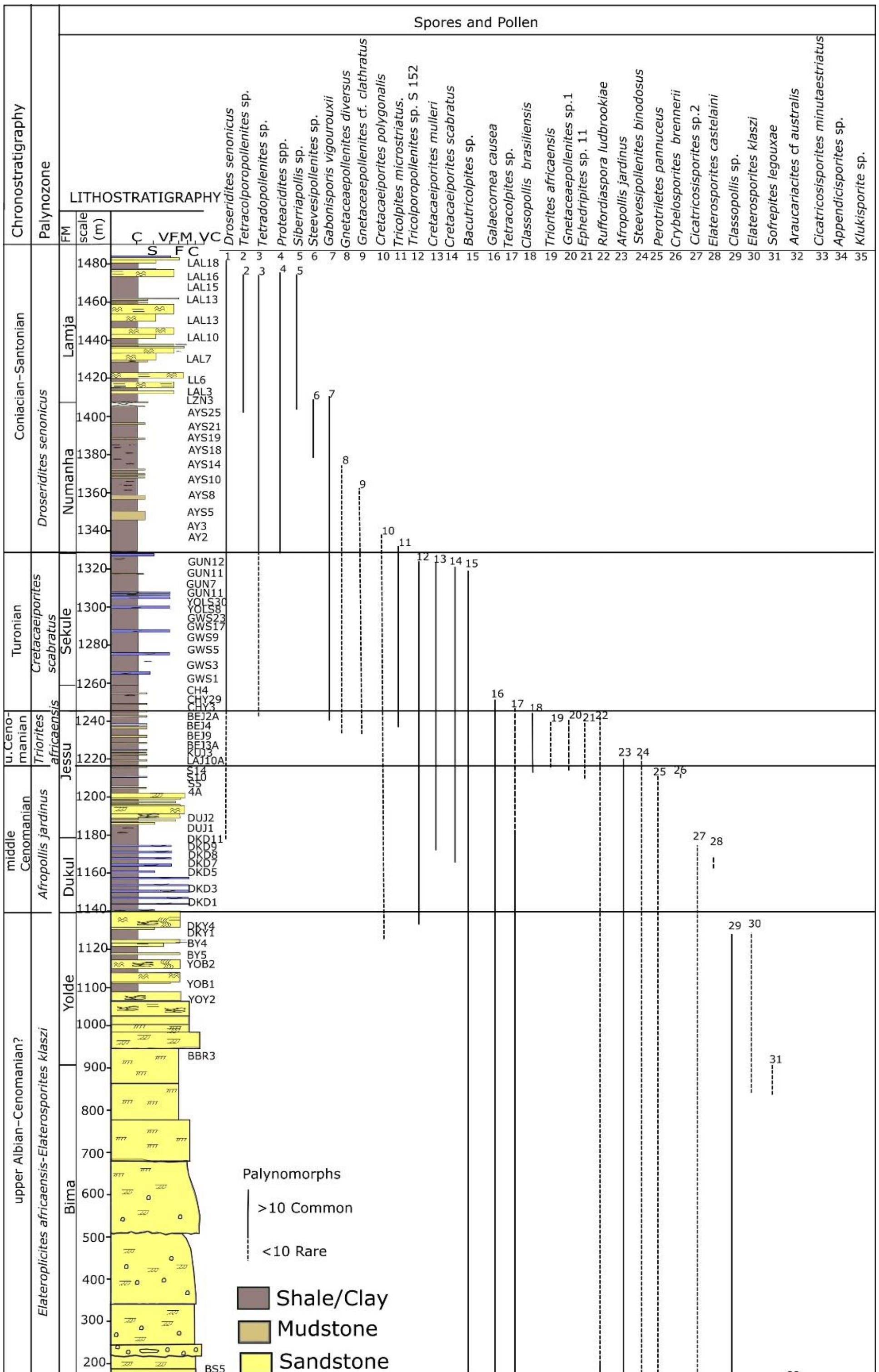

Figure 10. Stratigraphic distribution of selected taxa biozones of Yola Sub-basin; letter-number combinations next to the log represent sample numbers (for more detail check appendix A and B)

references therein). The Albian age also corresponds with rocks containing this species dated using ammonites and foraminifera from the Ivory Coast, plus foraminifera- dated rocks of Nigeria (Jardine, 1967) and Angola (Morgan, 1978). Finally, *E. klaszi* was also recorded in upper Albian to lower Cenomanian strata of Senegal (Jardine, 1967).

Small *Classopollis* species were first identified by Hengreen (1974) from upper Albian to lower Cenomanian rocks of Brazil. There, *Classopollis* sp. was recorded within zones I and II, but absent from zone III, which was dated as Albian to late Cenomanian based on ammonites and foraminifera (Herngreen, 1974). Deaf et al. (2014) compiled the range of *Cretacaeiporites polygonalis* within the ASA province, defining stratigraphical ranges from late Albian to late Cenomanian in Africa, and early Albian to early Cenomanian in northern and southern America. Specimens of *Perotriletes pannuceus* have been reported from Albian sedimentary rocks of the ASA province by Herngreen (1974). Examples of this spore were recorded from the upper Albian of Brazil (Herngreen, 1974) and the upper Albian of Nigeria (Lawal and Moullade, 1986).

Sofrepites legouxae of Jardine (1967) was observed in the present study in one sample (Bbr3) of the Bima Formation. It has previously been reported from upper Albian to lower Cenomanian (foraminifera dated) rocks of Senegal and Gabon (Jardine, 1967), in Brazilian upper Albian to lower Cenomanian strata, (Herngreen, 1974), and in upper Albian deposits of Nigeria (Abubakar et al., 2011).

This palynological assemblage is, therefore, considered to be of late Albian–Cenomanian age. This zone was found within the Bima and Yolde formations of the Yola Sub-basin (Fig.10). It can be correlated with zone I of Nigeria (Lawal and Moullade, 1986), zone II of Brazil (Herngreen, 1974), zone I of Egypt (Deaf et al., 2014), zone IX and X of Senegal, zone AI and C/II of Garbon, zones III and IV of North and South America (Fig. 6 & 10; Schrank, 1992).

5.2 *Afropollis jardinus Zone*

This zone was suggested by Lawal and Moullade (1986) as a subzone of the PO-304 Assemblage Zone but, was later modified by Abubakar et al. (2011) to a full assemblage zone. The lower limit of the zone is defined by the last appearance of *Klukisporites* sp., *Elaterosporites klaszi*, and *Araucariacites* cf. *australis*, whereas the upper limit of this zone is defined by the last appearance of *A. jardinus* and the first occurrence of *Gnetaceaepollenites* sp. 1.

This zone is defined by the co-occurrence of *Afropollis* spp., *Tetracolpites* spp., *Classopollis brasiliensis*, *Steevesipollenites*, *Ephedripites* sp. 4, pollen POP-304 (Lawal and Moullade, 1986) and *Crybelosporites brennerii*. This zone is found within the Dukul Formation and lower part of the Jessu Formation. *Afropollis jardinus* has been used as a marker for Aptian to lower Cenomanian strata within the ASA province (Herngreen and Duenas Jimenez, 1990), and has been observed in Albian to middle Cenomanian rocks in Gabon (Doyle et al., 1982). In Senegal, *Afropollis* has a stratigraphic range from upper Albian to lower Cenomanian (Morgan, 1978; Doyle et al., 1982). Doyle et al. (1982) indicated that the taxon became extinct within the lower Cenomanian of the Ivory Coast, Ghana, Algeria, Congo and Brazil. This extinction occurred before the appearance of the *Triorites africaensis* in the Gongola sub-basin (Abubakar et al., 2011) and in other ASA province basins (Herngreen and Duenas Jimenez, 1990).

However, we recorded *Afropollis jardinus* occurring with *Triorites africaensis* in the lower parts of the Jessu Formation in the present study.

Other palynomorphs associated with this zone are *Tetracolpites, Cretacaeiporites polygonalis, Deltoidospora* spp.*, Cicatricosisporites* spp.*, Classopollis* spp.*, Cretacaeiporites scabratus, Galeacornea causea*, *Clavatipollenites hughesii*, *Tricolpites* sp. A, *Elaterocolpites castelainii*, and *Cretacaeiporites mulleri*.

Associated dinocysts are *Senegalinium* spp., *Subtilisphaera perlucida*, *Spiniferites lenzii*, *Florentinia berran, Florentinia laciniata*, *Achomosphaera triangulata*, *Palaeohystrichophora infusorioides*, *P. cheit*, *Dinopterygium cladoides*, *Muderongia perforata*, *Isabelidinium* spp., *Xenascus plotei*, and *Xenascus ceratioides.* Similar assemblages have been reported from the Aptian–Cenomanian rocks of South America (Arai et al., 2000), Morocco (Below, 1981; Below, 1984), Nigeria (Lawal, 1991) and Australia (Cookson and Eisenack, 1968).

This zone can be correlated with zone II of the Maranhão Basin northern Brazil (Herngreen, 1974). In short, the palynomorph suite of this zone suggests that the Dukul and lower Jessu formations are not younger than middle Cenomanian (Fig. 10).

5.3 Triorites africaensis Zone

This zone was proposed by Lawal and Moullade (1986). It is an assemblage zone defined by the co-occurrence of *Triorites africaensis*, *Galeacornea causea*, *Lilliacidites*, *Bacutricolpites*, *Gnetaceaepollenites* sp. 1, *Classopollis brasiliensis*, *Cretacaeiporites scabratus*, *Cretacaeiporites mulleri* and *Cretacaeiporites polygonalis.* The lower limit of the zone is defined by the appearance of *Gnetaceaepollenites* sp. 1 and *Triorites africaensis.* whereas the upper limit of the zone is defined by the disappearance of *Gnetaceaepollenites* sp. 1, *Galeacornea causea*, and *Triorites africaensis*.

The angiosperm pollen taxon *Triorites africaensis* was reported from the upper Cenomanian of the Maranhão Basin (Herngreen and Duenas Jimenez, 1990), from the upper Cenomanian of the Angola Basin (Morgan, 1978), from the lower to upper Cenomanian of the equatorial Atlantic (Moullade et al., 1998), and upper Cenomanian deposits of the Ivory Coast (Jardine, 1967). Salard-Chebolddaeff (1990) compiled the range of the *Triorites africaensis* from African basins, surmising that the taxon indicated late Cenomanian strata in Senegal and the Ivory Coast, with a range from Albian–Cenomanian in rocks from Gabon and Congo, and from upper Cenomanian to Turonian in Togo, Nigeria, Niger, and Mali.

A second important species of this zone is *Galeacornea causea*, considered one of the key pollen taxa of the upper Albian–Cenomanian interval of the African - South American province (Hochuli, 1981). *Galeacornea causea* was first reported by Stover (1963) from Albian–Cenomanian rocks of Senegal, Portugal, and Guinea. It was recorded in ammonite-dated upper Albian–Cenomanian formations of the Maranhão Basin, Brazil (Jardine, 1967 and references therein), as well as from Albian–Cenomanian rocks of Gabon (Jardine, 1967), and Cenomanian rocks of the Gongola Sub-basin (Lawal and Moullade, 1986; Abubakar et al., 2011).The dinocysts of this zone are similar to those of the *Afropollis jardinus* Zone.

The zone can be correlated with zone III of Herngreen (1974), and with upper Cenomanian rocks of the equatorial Atlantic (Moullade et al., 1998), as well as the *Triorites africaensis* Zone of the Gongola Sub-basin (Lawal and Moullade, 1986; Abubakar et al., 2011). This zone is considered to be of upper Cenomanian age, being recorded within the middle part of the Jessu Formation.

5.4 *Cretacaeiporites scabratus Zone*

This is an acme zone proposed by Lawal and Moullade (1986). The palynofloras of this zone are composed of *Cretacaeiporites scabratus, Cretacaeiporites mulleri*, *Tricolporopollenites* S 152, *Tricolpites giganteus*, *Bacutricolpites*, *Tricolpites microstriatus*, *Syncolpites* sp. 1, *Ephedripites ambiguus*, *Foveotriletes giganteus* and *Ephedripites multicostatus.* The zone is characterised by an abundance of gymnosperm pollen. It was recorded from strata of the upper Jessu Formation to Sekule Formation interval.

This zone is not defined on the basis of the high frequency of *C. mulleri* and *C. scabratus* as outlined by Lawal and Moullade (1986), because similar abundances were observed within the *Triorites africaensis* Zone. We propose that the zone should be defined as an interval zone, between the last occurrence of *Classopollis brasiliensis, T. africaensis Gnetaceaepollenites* sp. 1 and *G. causea* at the base, and the extinction of *C. mulleri, C. scabratus* and *Tricolporopollenites* sp. S 152 Lawal and Moullade, 1986 at the top of the zone. High frequencies of *Tetradoporopollenites* and *Droseridites senonicus* also characterise the upper boundary of this zone.

Both *Classopollis*, *C. scabratus* and *C. mulleri* have been reported from many African and South American basins (Ibrahim et al., 2017). They were recorded in Cenomanian–Turonian rocks of Nigeria (Lawal and Moullade, 1986) and middle Cenomanian–Turonian rocks of Egypt (Ibrahim et al., 2017). In South America they were reported from Albian–Cenomanian intervals (Herngreen, 1974), plus Cenomanian–Turonian rocks of Brazil (Ibrahim et al., 2017). They have been found in many African basins from the late Albian–Turonian, with the exception of the Angola Basin where they were reported from Turonian–Coniacian sections (Morgan, 1978).

Associated dinocysts are *Oligosphaeridium djenn*, *O. porosum*, *O. albertense*, *O. pulcherrimum*, *Florentinia radiculata*, *F. berran*, *F. mantellii*, *Achomosphaera verdieri A. triangulata* and *A. danica*. This palynomorph association suggests an age younger than Cenomanian. This zone can be correlated with many palynozones from the ASA province (Fig. 6). Therefore, the zone is assigned to the Turonian, occurring within the upper Jessu and Sekule formations including from the Gwalitse Stream section (Fig.1 Appendix A. 5)

5.5 *Droseridites senonicus Zone*

This is an acme zone proposed by Lawal and Moullade (1986). The zone was defined in the Gongola Sub-basin by the high frequency of *Droseridites senonicus* (Lawal and Moullade, 1986), with its upper limit defined by the last occurrence of *D. senonicus*. The lower limit of this zone is defined by last occurrence of *Cretacaeiporites mulleri*, *C. scabratus*, *Tricolporopollenites* sp. S 152 and *Tricolpites microstriatus* at the top of the preceding *Cretacaeiporites scabratus* Zone. The zone here is composed of *Tetradopollenites*, *Foveotriletes*, *Proteacidites*, *Tricolporopollenites* sp. SCI 428 (in Jardiné and Magloire, 1965), *Ephedripites multicostatus*, *Deltoidospora minor*, *Monocolpopollenites sphaeroidites*, *Longapertites, Microfoveolatus, Gabonisporis vigourouxii* Boltenhagen 1967, and *Milifordia jardinei*. The zone is recorded within the Numanha and Lamja formations. The top of the zone is not identified since the sample collected from the top of the section yielded abundant *Droseridites senonicus*.

Associated dinocysts of this zone are *Deflandrea*, *Chatangiella*, *Isabelidiniun, Andalusiella*, *Achomosphaera danica*, *Achomosphaera triangulata, Eucladinium*, *Eurydinium, Xenascus*, *Downiesphaeridium aciculare* and *Hystrichodinium* sp. cf. *H. pulchrum.*

Droseridites senonicus has been reported from zone VIII of Egypt and dated there as Turonian–Santonian (Schrank, 1992 and references therein), and as Coniacian–Santonian in the Gongola Sub-basin of Nigeria (Lawal and Moullade, 1986).

Droserdites senonicus is widely accepted as a marker species of the Coniacian–Santonian of African and South American provinces, and in Senegal and the Ivory Coast zone V where it has been dated as Santonian (Jardiné and Magloire, 1965). However, Ibrahim (1996) indicated that *Droseridites* has a stratigraphical range from the Turonian to Cenozoic. This zone is here assigned to the Coniacian–Santonian, occurring within the Numanha and Lamja formations.

5.6 The Cenomanian Transgression

The Benue Trough was formed by reactivation of NE-SW trending faults during the early Albian (Benkhelil, 1989). The basin fully developed during the early Cenomanian to late Turonian. This time was marked by the first marine transgression into the Benue Trough, which also coincided with a significant Cenomanian eustatic sea level rise (cf. Haq et al., 1987). Foraminifera-based dates on rocks from the lower and middle Benue Trough indicate that the marine Odukpani Formation was deposited during the Cenomanian (Petters, 1978a), suggesting a Cenomanian transgression at least into the lower and middle Benue Trough. Similarly, palynological dating of the marine Eze-Aku Formation from the middle Benue Trough suggests a Cenomanian age (Lawal, 1991), which would be consistent with this. However, the foraminifera assemblages recovered from the Upper Benue Trough were not age diagnostic (Petters, 1978b, 1979).

Palynological studies from boreholes and well cuttings (Lawal and Moullade, 1986 and Abubakar et al., 2011) suggest a Cenomanian age for the Yolde Formation. The Yolde Formation has been recently interpreted as shoreface to offshore marine, indicating shallow marine conditions (Sarki Yandoka et al., 2015). The palynomorph recovery of the samples of the upper Bima and Yolde formations for this present study is poor. However, age diagnostic palynomorphs have been identified. These diagnostic palynomophs include *Elaterosporites klaszi*, *Classopollis* sp. 1, *Sofrepites legouxae*, *Afropollis jardinus*, and *Perotriletes pannuceus*, suggesting a Cenomanian age for those formations. *Odontochitina costata* and *Pediastrum* sp. are present, suggesting brackish conditions during deposition of the Yolde Formation.

Petters (1978b, 1979) proposed a Turonian age for the Dukul and Jessu formations, in which the author suggested a connection between the Tethys Ocean and the Gulf of Guinea. The age diagnostic spores and pollen grains identified from the formations include *Afropollis jardinus*, *Perotriletes pannuceus*, *Galaecornea causea*, *Triorites africaensis*, *Cicatricosisporites*, *Elaterocolpites castelainii*, and *Tetracolpites* sp. These palynomorphs are mainly restricted to the Cenomanian in the ASA. The diverse dinocysts recorded include *Muderongia perforata*, *Subtilisphaera* spp., *Palaeohystrichophora infusorioides*, *Florentinia* spp., *Spiniferites* spp., *Coronifera* spp., and *Phoberocysta neocomica*. This association has been reported from the Cenomanian in the ASA province (Batten and Uwins, 1985). Batten and Uwins, (1985) reported a similar association collected from Cenomanian rocks in Libya. An abundance of *Subtilisphaera* has been reported from the Lower Cretaceous, though this abundance was evidently related to environmental conditions and lacks global stratigraphic significance (Arai et al., 2000). Nevertheless, it was assigned to Aptian–Albian in Brazilian marginal basins. Batten and Uwins (1985) reported abundant *Subtilisphaera* spp. and *Palaeohystrichophora infusorioides* in Cenomanian rocks of Libya. The Dukul Formation, which marks a major marine influx into the Yola Sub-basin, is characterised by abundant *Subtilisphaera* and *Palaeohystrichophora infusorioides* abundance. This suggests that there was indeed a marine incursion extending into the Upper Benue Trough during the Cenomanian. The species *Florentinia berran*, *Florentinia khaldunii*,and *Subtilisphaera senegalensis* are low-latitude dinocysts. They have previously been reported only from the Tethyan realm. Their presence also implies that there was an influx of Tethyan waters into the epeiric sea of the Benue Trough in the Cenomanian. Cenomanian marine rocks have been reported from the Chad Basin that were deposited during the influx of the Tethys Ocean (Petters, 1981). Together, this all indicates that the Gulf of Guinea and the Tethys Ocean were in communication during the Cenomanian.

6. CONCLUSIONS

This work has for the first time provided a palynostratigraphical framework within which the lithostratigraphic units of the Yola Sub-basin of the Benue Trough can be constrained and dated (Fig.11). The palynomorphs recovered from the Yola Sub-basin are assigned to five palynozones that range from upper Albian to Santonian. The zones are *E. africaensis-Elaterosporites klaszi* Zone (upper Albian–Cenomanian), *Afropollis jardinus* Zone (middle Cenomanian), *Triorites africaensis* Zone (upper Cenomanian), *Cretacaeiporites scabratus* Zone (Turonian) and *Droseridites senonicus* Acme Zone (Coniacian–Santonian). The index species employed allowed correlation of the palynozones with other zones from the ASA province.

The Bima and Yolde formations contain the characteristic *E. africaensis-Elaterosporites klaszi* Zone which is of upper Albian to Cenomanian age. Palynofloras recovered from Dukul Formation to lower Jessu Formation rocks are assigned to the *Afropollis jardinus* Zone. This lithostratigraphic unit is here dated as middle Cenomanian. The middle part of the Jessu Formation hosts *Triorites africaensis* and is dated as late Cenomanian. The upper part of the Jessu Formation and the Sekule Formation are Turonian (*Cretacaeiporites scabratus Zone*) in age. The *Droseridites senonicus* Zone is found within Numanha and Lamja formations. These rock units are dated as Coniacian–Santonian.

This study has found that the transgressive thick dark shale of the Jessu Formation was deposited at a time not later than Cenomanian. The Jessu Formation was previously erroneously assigned to the lower Turonian (Carter et al., 1963; Petters, 1978b, 1979). These strata can now be correlated with the marine Eze-Aku Formation in the Lower Benue Trough and the Pindiga Formation of the Gongola Sub-basin, which were palynologically dated as Cenomanian (Lawal and Moullade, 1986; Lawal, 1991; Abubakar et al., 2011). Therefore, the Cenomanian transgression was not restricted to the Lower Benue Trough as proposed by the earlier studies. This palynostratigraphic correlation together with sedimentological data indicates that the Tethys Ocean was indeed connected with Gulf of Guinea through the Benue Trough in the Cenomanian.

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Appendix A: Stratigraphic range of the selected palynomorphs and their spatial distributions in outcrop sections

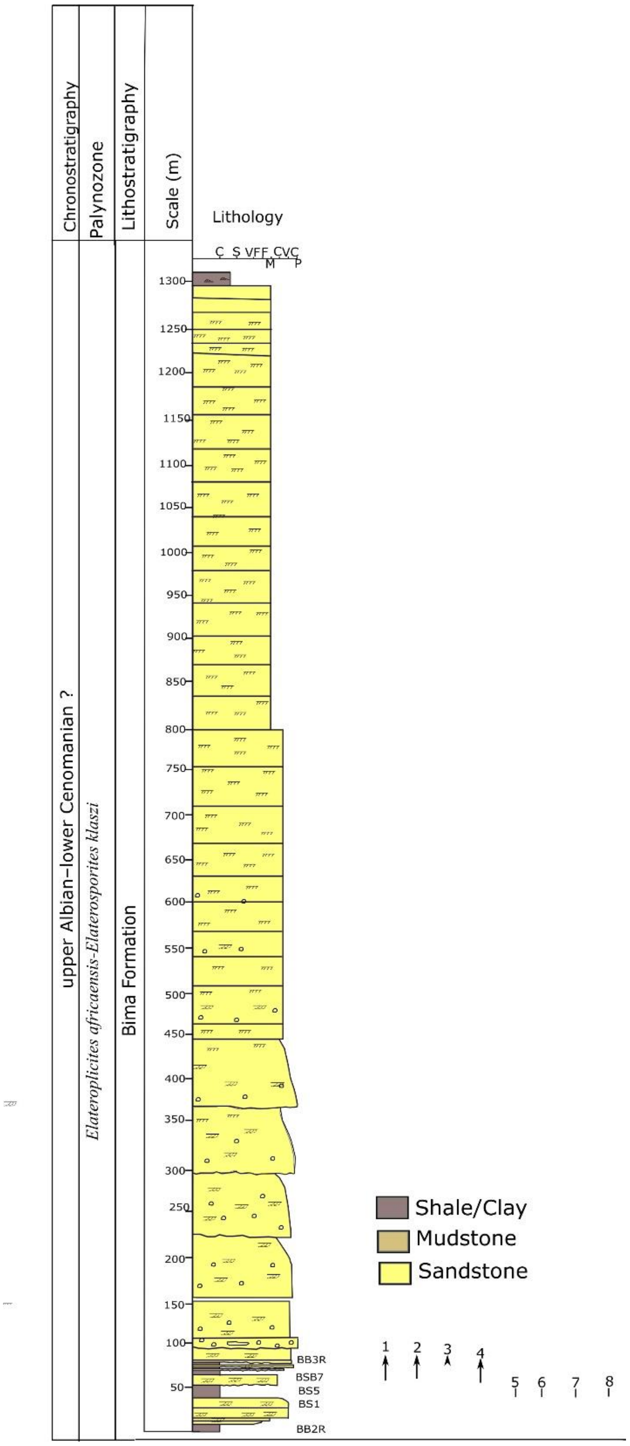


Figure A. 1, Stratigraphic range of some selected palynomorphs at Bolere River section. 1, *Galeacornea causea*. 2, *Classopollis* sp. 3, *Steevesipollenites binodosus*. 4, *Araucariacites* cf. *australis*. 5, *Ruffordiaspora ludbrookiae*. 7, *Klukisporite* sp. 8, *Perotriletes pannuceus*. letter-number combinations next to the log represent sample numbers.

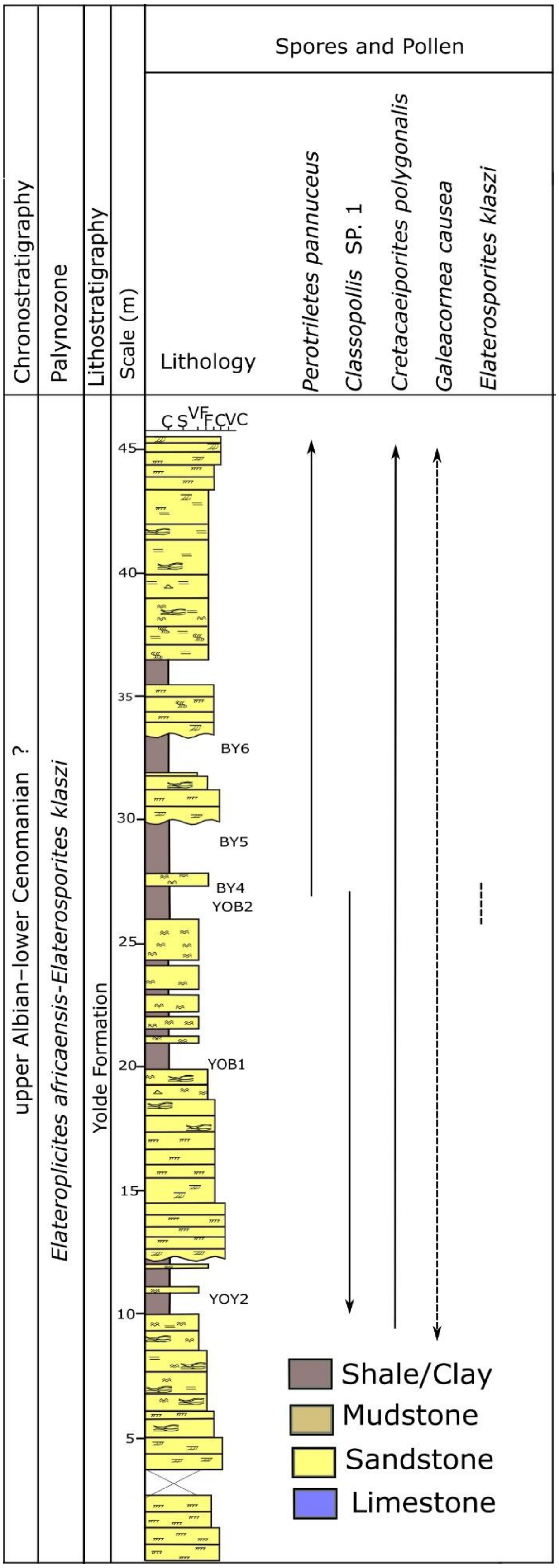
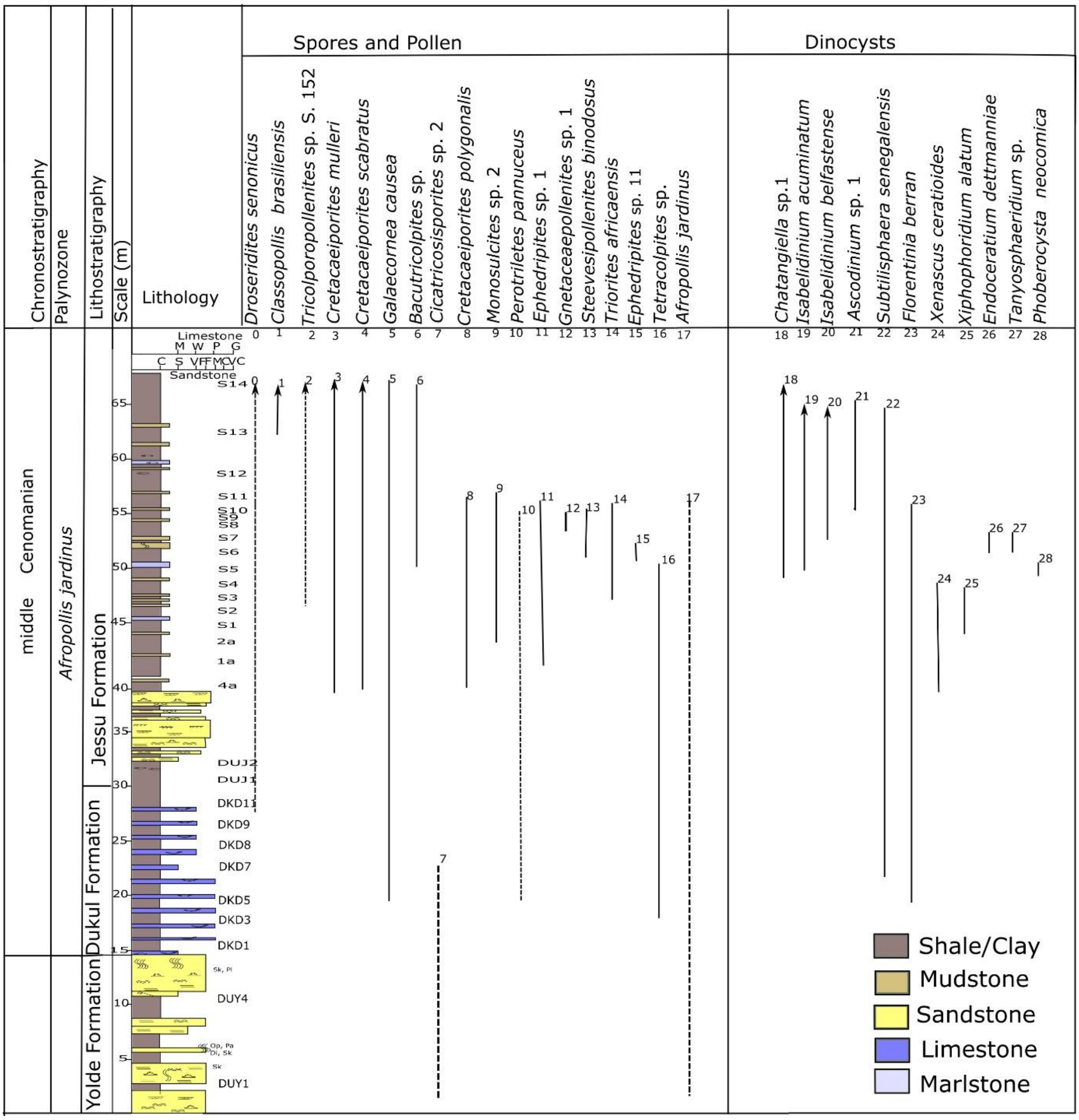


Figure A. 2, Stratigraphic range of some selected palynomorphs at Bambam section; letter-number combinations next to the log represent sample numbers.



726

727 Figure A. 3, Stratigraphic range of some selected palynomorphs at Dukul village section;
728 letter-number combinations next to the log represent sample numbers.

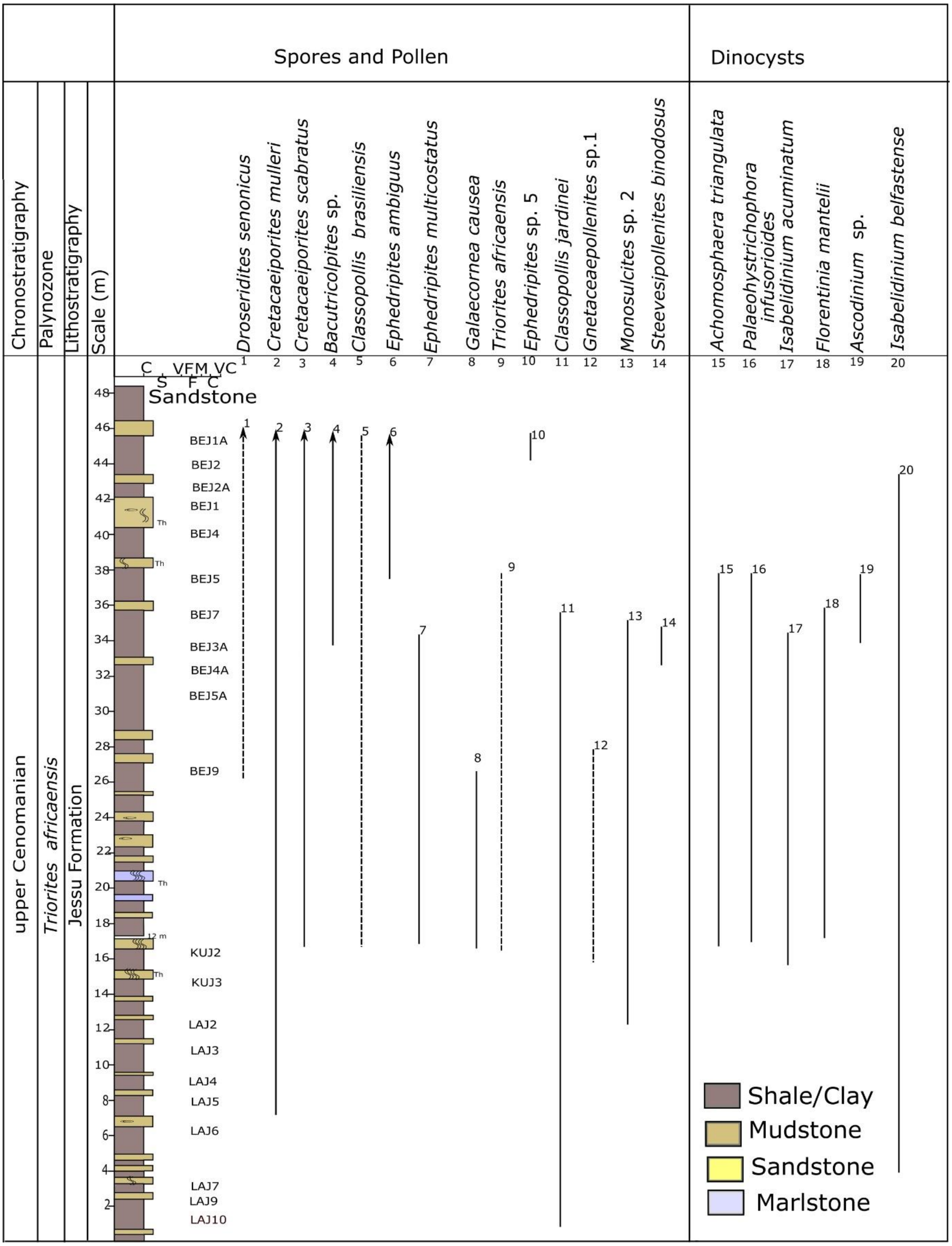


Figure A. 4, Stratigraphic range of some selected palynomorphs at Bekwa Stream section; letter-number combinations next to the log represent sample numbers.

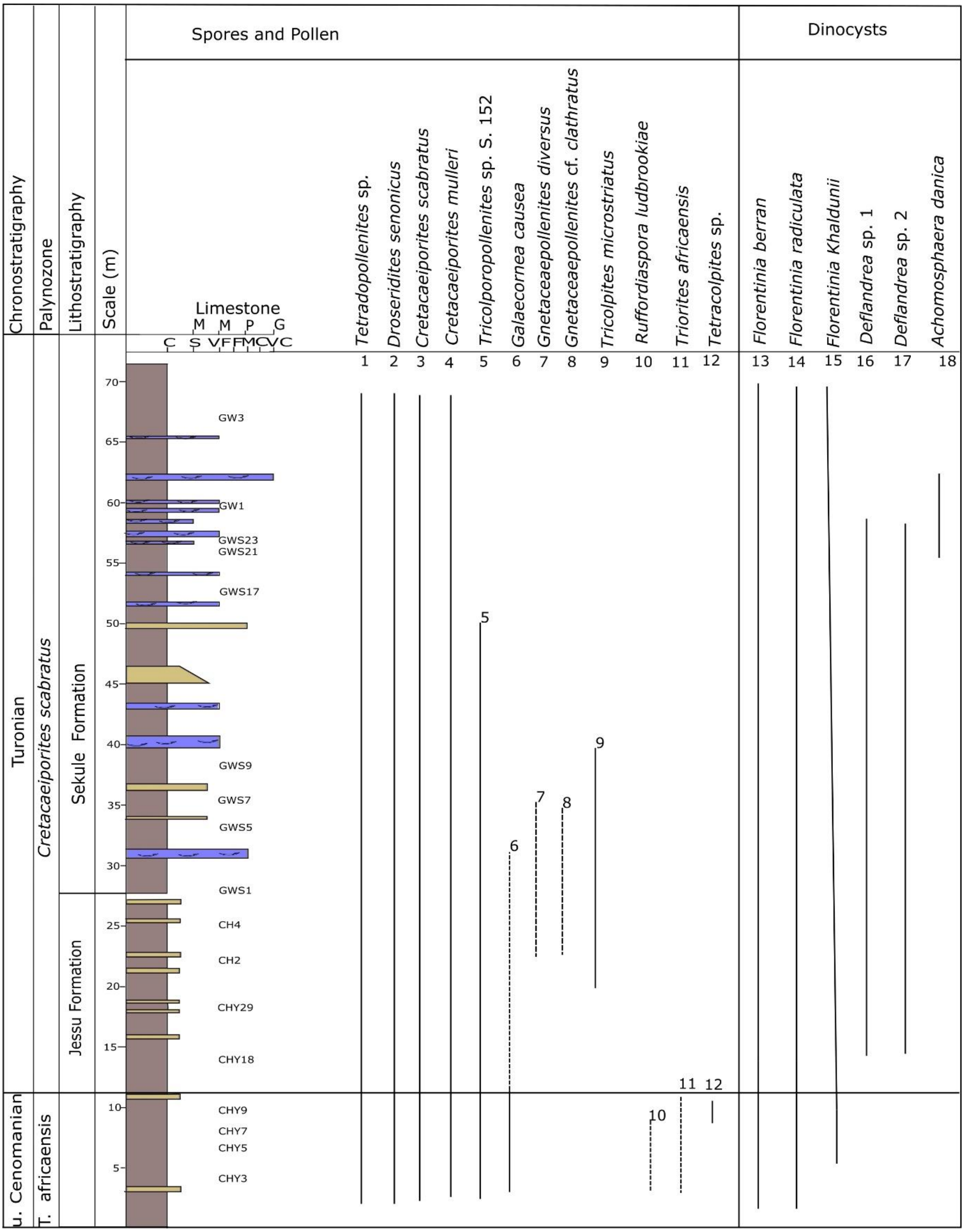


Figure A. 5, Stratigraphic range of some selected palynomorphs at Gwalitse Stream section; letter-number combinations next to the log represent sample numbers.

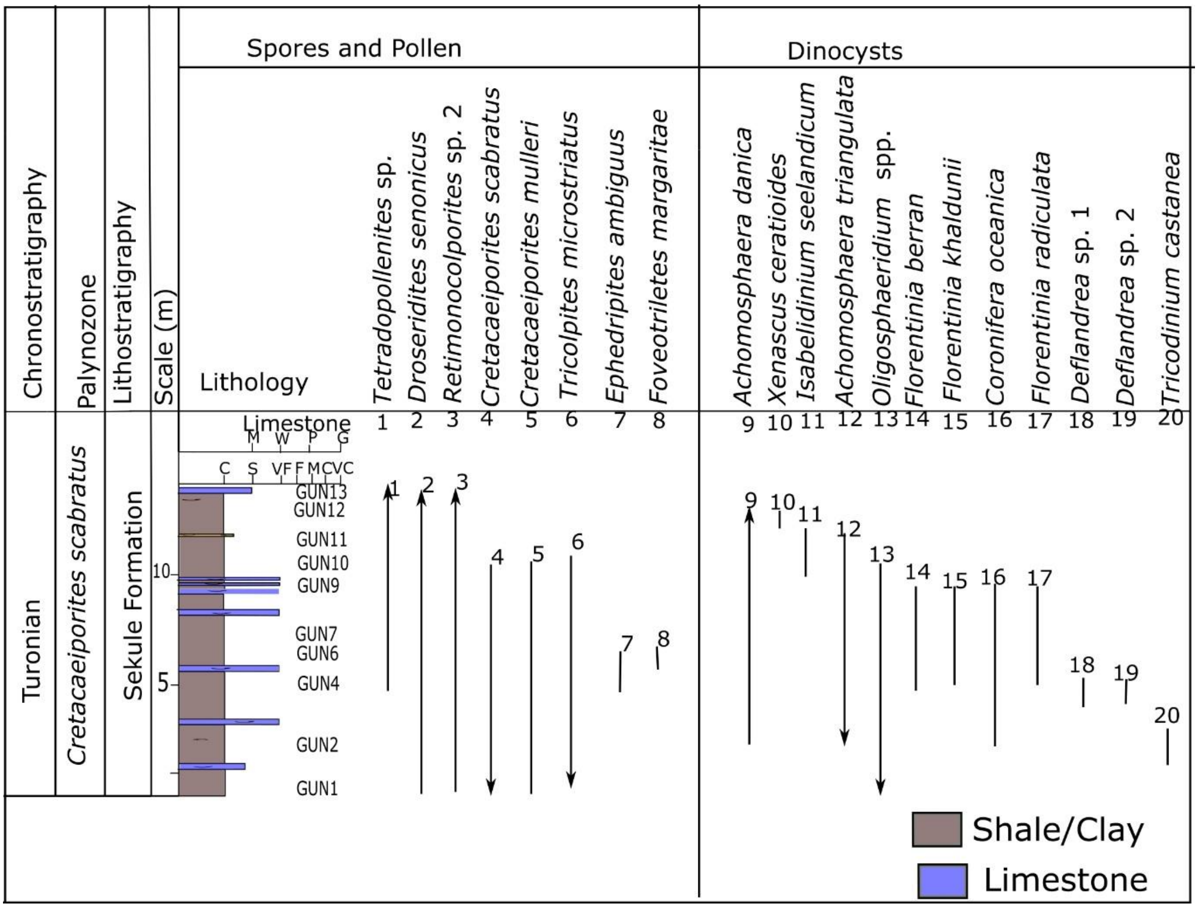


Figure A. 6, Stratigraphic range of some selected palynomorphs at Gudenyi Stream section; letter-number combinations next to the log represent sample numbers.

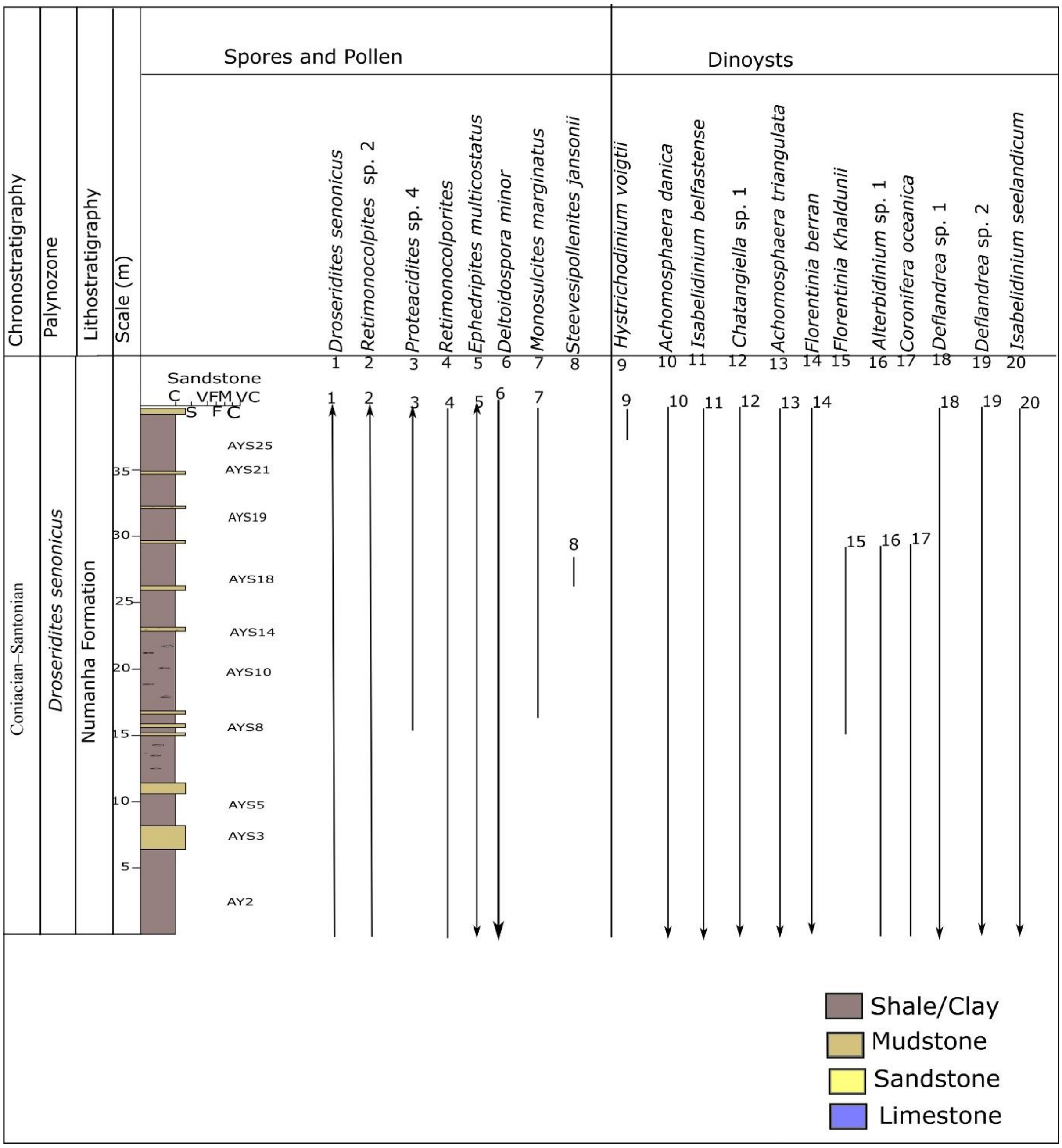


Figure A. 7, Stratigraphic range of some selected palynomorphs at Ayatse section; letter-number combinations next to the log represent sample numbers.

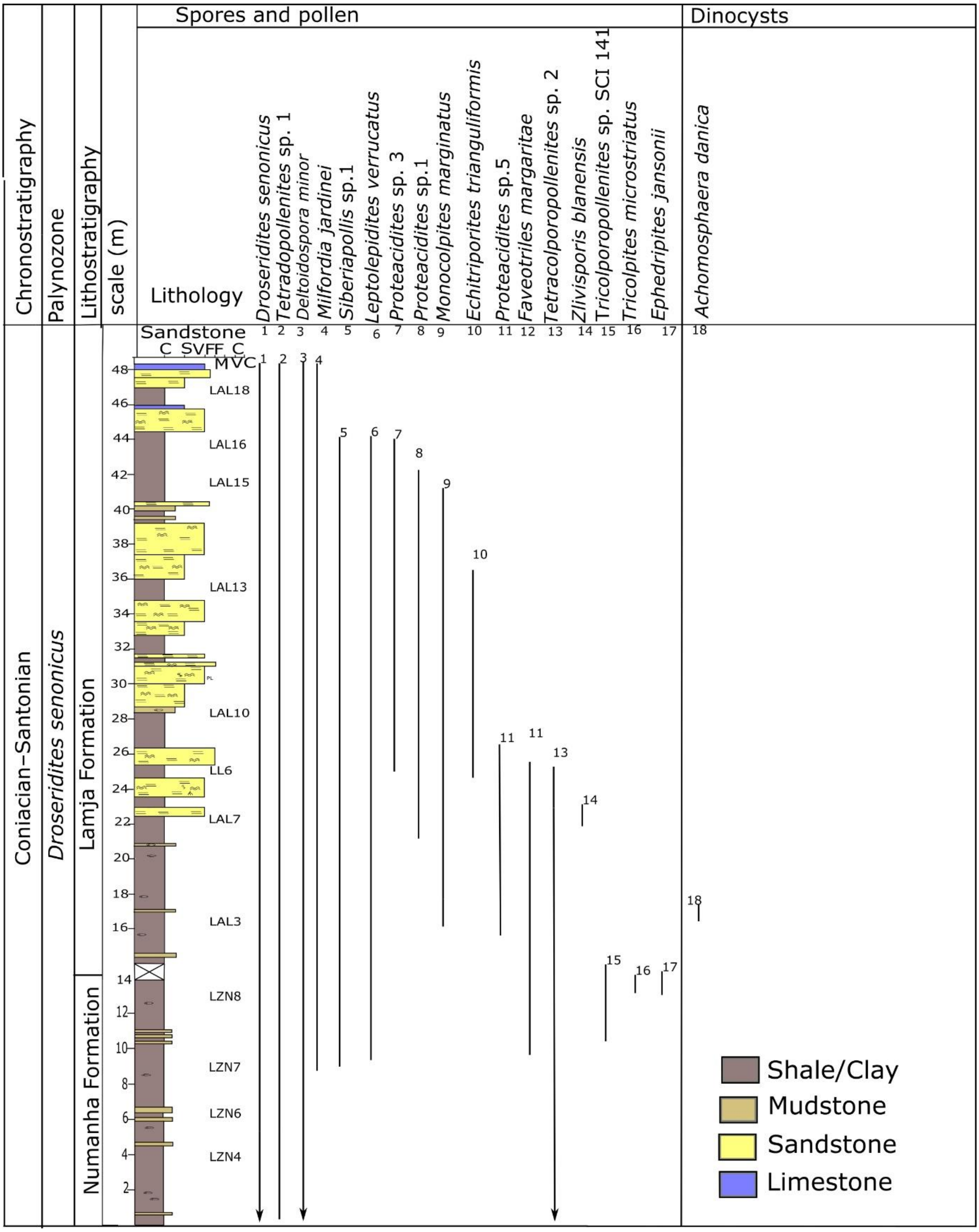


Figure A. 8, Stratigraphic range of some selected palynomorphs at Lamja village section; letter-number combinations next to the log represent sample numbers.