Stratigraphic Palynology, Palynofacies and Reservoir-Scale Palaeoenvironment Framework of Selected Neogene Clastic Deposits, Niger Delta Basin: Serravallian Sea Level Changes, and Palaeoclimate Synchronicity

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Abstract

Palynomorph and palynofacies distributions from the Alakiri Field wells X and Z, Coastal Swamp Depobelt, onshore Niger Delta, were investigated to interpret stratigraphic successions and reservoir-scale palaeoenvironment variations in order to understand the impact of sea level change and palaeoclimate synchronicity during the deposition of Serravallian aged sediments. The resulting observed climate and eustacy changes supported by the notional absence of marine dinoflagellate cysts, during a period of 2.19 m.y. within the Serravallian enables key proxies to be interlinked better to understand a dynamic depositional system for the key hydrocarbon producing Agbada Formation across the Niger Delta basin.

Terrestrial pollen and spores *in lieu* of the noted absence of dinoflagellate taxa in the wells were used to delineate two (2) palynozones per well based on the following bioevents, namely: Top Consistent Occurrence (TCO) of *Verrutricolporites rotundiporus* and Top Regular Occurrence (TRO) of *Belskipollis elegans*. These bioevents corresponded to boundaries between well-established biozones used across the Niger Delta and demonstrate that the studied intervals penetrate two biozones, namely the P770 and P750 zones of Evamy et al. (1978) and zones F to G of Legoux (1978). The palynostratigraphic framework shows that *Verrutricolporites rotundiporus, Belskipollis elegans, Verrucatosporites usmensis, Zonocostites ramonae, Brevitricolporites molinae, Crassoretitriletes vanraadshooveni,* and *Retibrevitricolporites obodoensis*, in association with other palynomorphs suggest a Middle Miocene (Serravallian) age linked to a relative age range between 13.82 Ma (within the P750 Zone) to approximately 11.63 Ma within the P770 Zone for the studied Agbada Formation based on recent calibration with the Global Time Scale 2020 of Gradstein et al. (2020). Palynofacies distributions for the Alakiri-Z Well show a dominance of Palynomaceral type 2, low recoveries of Palynomaceral type 4 debris and Palynomaceral type 3, while the palynofacies assessment of the Alakiri-X Well reflects an overwhelming dominance of Palynomaceral type 4 with associated Palynomaceral type 1 *sensu* Whitaker (1982, 1984). This palynomaceral scheme was initiated to elucidate the palynomorph and palynomaceral microflora hydrodynamic controls of the Niger Delta basin for the first-time. Palynomaceral provenance mechanics in the palynological analysis of the Agbada Formation sediments substantiates the depositional environment and fluctuating marine realm dynamics.

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The palynomorph and palynofacies microfloral evidence reflects variable palaeoenvironmental settings suggestive of fluvio-deltaic systems transgressing coastal swamps with other low energy fluvial settings consistent with swamps, marshes and crevasse splays suggestive of a coastal plain domain. The high abundance and diversity of pollen and spores with the non-occurrence of marine taxa indicates continued regression suggesting a causal link between climate change and eustasy during the Serravallian. The wet and warm climate events linked with marine sequence stratigraphy signature are characterised by arid savannah, and humid/ever-wet mangrove taxa, with a well-developed intermediate canopied rain forest as sourcing terrane for many of the sub-tropical terrestrial composition types; indicating a strong connection between mean sea-level changes, variable inferred sequence stratigraphy and sedimentary distributary facies and palaeoclimate-linked palynostratigraphic events across the Niger Delta basin.

Key Words: Niger Delta, Serravallian, Palynostratigraphy, Palynomacerals, Palaeoenvironments, Palaeoclimates, Sequence Stratigraphy.

1. INTRODUCTION

In structurally diverse sedimentary basins such as the Niger Delta (Figure 1), complex geological deformational processes can alter the stratigraphic succession across the basin. The structural complexities of the Niger Delta basin are inherent in the deep-rooted faults (Short & Staüble, 1967; Weber & Daukoru, 1975; Whiteman, 1982; Nwajide, 2013) which then in turn affect other sedimentary process across the region. Palynomorphs and palynofacies studies (Evamy et al., 1978; Whitaker 1982, 1984; Tyson, 1993, 1995; Okeke, 2014) are dynamic in allowing reconstruction of the key deformational geological processes due to the potential link between biostratigraphy, climate change, depositional facies, sequence stratigraphy and other geologic events. High impact biostratigraphy studies may narrow down inferences on depositional settings, climate and sea-level changes which will ultimately refine existing depositional models and enhance the understanding of the depositional history of an area. In turn, this can be linked to the development of existing hydrocarbon fields and subsequent exploration campaigns across the basin.

Palynostratigraphy (the study of terrestrial spores and pollen along with marine indices such as algae and dinoflagellate cysts) is undertaken as one of the key tools for understanding the stratigraphy of the Niger Delta basin. Previous key reference studies reviewing both the terrestrial components, but less so, the marine elements are documented (Germeraad et al.,1968; Legoux, 1978; Poumot, 1989; Oboh, 1992; Oboh et al., 1992; Biffi & Grignani, 1993; Morley & Richards, 1993; Sowunmi, 1995; Morley, 2000; Adeonipekun et al., 2017; Fajemila et al., 2022). The palynostratigraphy and sporomorphs attributes of the downdip and updip Niger Delta basin illustrates the age and depositional settings of the sedimentary sequences ranging from Palaeocene through to Recent ages. However, the biostratigraphic details of the Cenozoic Danian stage is regarded as a component of the Cretaceous-linked Nsukka Formation (Van Hoeken-Klinkenberg 1964, 1966; Umeji, 2000; Umeji & Edet, 2008). Nevertheless, the analysis of the Cretaceous-Palaeogene (K-PG) boundary events fall short of the objective of this research. Okeke (2014) indicated that integrated geological application of palynostratigraphy and palynofacies provides a very reliable tool for correlation of coeval geologic sequences, determination of depositional environments, and derivation of source rock potential linked with high resolution sequence stratigraphy events. Lithostratigraphic successions are relatively thick and complex, deposited during fluvio-deltaic and eustatic sea level oscillations (Mitchum et al., 1994). The field-scale palynological studies on the onshore Kolo Creek Field (Oboh, 1992) illustrated Middle Miocene successions and but linked depositional conditions at that geologic time with similar Recent environmental models driven by the notion of drier climate conditions based on the abundance of Gramineae (grass pollen).

Sequence stratigraphy is the systematic subdivision of sedimentary successions (sandstone, shale, coal and limestone facies) into packages (i.e., TST, MFS, HST, SB) relating to sea-level changes while eustasy explains the global synchronous sea-level change (Simmons, 2012) and associated impacts substantiated by climate change. Climate change is seen as a product of weather dynamics, where average wetness and dryness in tropical and subtropical domains is the determinant factor of climate (Shepherd, 2005; Planton, 2013). In the Niger Delta, nine (9) climate driven "palynocycles" were used to demonstrate wet and dry events within the Miocene as well as depositional cycles which indicate variable polynomial sequences, vegetation changes and sea level dynamics (Onema et al., 2015). In contrast, when evaluating for tropical ever-wet conditions, review of high abundance levels of brackish-marine mangrove pollen taxa such as *Zonocostites ramonae* (aka *Rhizophora* spp.) and *Psilatricolporites crassus* from the Paleocene in Brazil, Cameroon and Nigeria (Pares Regali et al., 1974; Salard-Cheboldaeff, 1978; Adegoke et al., 1978; respectively) has often been emulated in more recent Niger Delta studies to balance the wet-dry climate equation.

Located within the Coastal Swamp depobelt, the Alakiri Field (Well-X and Well-Z) were analysed through application of standard palynostratigraphy and palynofacies techniques, to allow the microfloral assemblages be systematically assessed in terms of chronostratigraphic age, through application of known biozonal schemes for the Niger Delta (after Evamy et al., 1978). For the palynofacies, since the advent of the pioneering work of Combaz (1964), many researchers (Parry et al., 1981; Tyson, 1993, 1995) have devised classification schemes but in the course of this work, the development-scale classification scheme proposed by Whitaker (1982, 1984) has been used in the palynofacies interpretation work, primarily in line with the nature of the anticipated deltaic sediments.

The work thus offers the opportunity to embed the application of palynology including palynofacies in strengthening a paradigm shift in reservoir scale age dating, determination of Palaeoenvironments, sea-level and climate changes in coastal geological sequences. The palynomorph indices indicate a Serravallian age range (Middle Miocene) for the appraised wells. The microflora and palynomaceral palynostratigraphic and reservoir scale palaeoenvironmental arrays illustrate a series of depositional mechanisms within the hydrocarbon prone domain of the Agbada Formation. The paleoclimate and sea-level change model deduced from this study allows for the reconstruction of non-marine and intermittent marginal marine mechanisms during the time interval of study.

2. NIGER DELTA GEOLOGY

The hydrocarbon-rich economic significance of the Niger Delta basin emphasises it as one of the most widely researched major sedimentary basins in sub-Saharan Africa. Several authors (Burke et al., 1971; Murat, 1972; Evamy et al., 1978; Ejedawe, 1981; Stacher, 1995; Nwajide & Reijers, 1996; Reijers et al., 1997; Reijers, 2011; amongst others) have summarised the tectonic setting and stratigraphy of the Niger Delta basin. The origin and development of the Niger Delta basin was associated with the first deltaic sediment deposition towards the southern and eastern sections of the older Cretaceous coastline, in the 'Northern Delta depobelt' during the Eocene (Reijers, 2011). The key sub-surface lithostratigraphic units of the Niger Delta basin consists of the Akata, Agbada, and Benin formations (Figures 1 & Figure 2). The lateral equivalent of these formations landwards consists of the Imo, Ameki, Ogwashi and Benin formations (Okeke & Umeji, 2016). However, the top of the subsurface Agbada and base of the Benin formations correlate with the surface outcropping Ogwashi Formation. The onshore delta complex which runs from the base of the Imo Formation to the shoreline is assumed larger than the present-day Niger Delta (Nwajide, 2013). The offshore part of the delta extends into the lower part of the continental shelf of the Gulf of Guinea (Whiteman, 1982). Fine-grained sediments forming the lower part of the deltaic complex extend to the abyssal plain on the lower part of continental rise. According to Nwajide (2013) the delta complex is defined onshore by the contact between the Imo and Nsukka formations, in the offshore by the Cameroon Volcanic Line in the southeast, the Okitikpukpa Ridge to the west, and Guinea Abyssal Plain in the southwest.

The marine mudrock dominated Akata Formation is the oldest unit in the Niger Delta basin. It is composed of dark grey shales and siltstones with rare streaks of sands of possible turbidite origin (Doust & Omatsola, 1990). It occurs in diapirs along the continental slope and is over-pressured where deeply buried. The Akata Formation grades upwards/laterally into the Agbada Formation with abundant plant remains and micas in the transition zone (Doust & Omatsola, 1990).

The Agbada Formation is the main hydrocarbon bearing unit of the Niger Delta basin petroleum system. It represents the actual deltaic portion of the succession that accumulated in the delta front, delta top set and fluvio-deltaic environments. The Agbada Formation ranges in age from Eocene to Pleistocene (Nwajide, 2013) although this younger age is not as yet defined or proven. The top of the Agbada Formation is characterised in hydrocarbon exploration wells by the first down-hole occurrence of marine mudrocks with associated marine fauna while the base is characterised by the deepest sandstones recorded in subsurface wells. The formation has been informally divided into upper, middle and lower units in some publications with limited biostratigraphic indices cited. The Agbada Formation is correlative with the outcropping Ameki Formation (at times referred to as the Ameki Group (Figure 1 & Figure 2). It predominantly consists of sandy lithologies with the notable Nsugbe and Nanka sandstones as lateral equivalents (Nwajide, 1979). Landwards, the Ameki Formation and basin wards the Agbada Formation overlie the Imo and Akata formations respectively (Avbovbo, 1978). Short & Staüble (1967) established the contact between the Agbada and Benin formations basin-ward at the highest mudrock bearing marine fauna in the Agbada Formation. However, the contact is more practically defined at the base of the massive sandstones depicting the onset of the Benin Formation and generally corresponds to the base of fresh water bearing strata (Reijers, 2011). In wells drilled in relatively shallow water located in the Shallow Offshore Depobelt, sediments that suggest analogy to the Benin Formation are strongly interbedded with marine sediments, with high numbers of planktonic foraminifera associated with the mudrocks.

The Benin Formation is the uppermost unit of the Niger Delta basin. It consists of Late Eocene to Recent deposits of alluvial and upper coastal plain clastic wedge deposits (Avbovbo, 1978). The sediment wedge developed from Benin-Onitsha in the North and extends beyond the present coastal line (Short & Staüble, 1967). This formation is relatively barren of microplankton, microfauna and microflora in onshore wells. Nevertheless, the age of the formation is estimated to range from Oligocene to Recent (Short & Staüble, 1967). However, recent studies would suggest that age control for some mud-prone sequences do yield marine assemblages, thus suggesting a dynamic coastal interface can be expected even in the “Benin Formation”. Very young time-coeval sequences of marine mudrocks and sandstones have been studied in gravity cores by Adojoh et al. (2020) supporting Late Pleistocene to Holocene ages based on foraminifera and calcareous nannoplankton age dating.

3. LITHOLOGICAL DESCRIPTIONOF THE STUDIED INTERVALS

The studied sections of the Alakiri-X and -Z wells penetrated the Agbada Formation with abundant cyclical sandstone, shale and siltstone alternations with thin mud-rock intercalations within the blockier sandstone lithofacies units as defined on the suite of wire line logs shown on Figure 2. In the absence of core, lithological descriptions of ditch cutting samples was necessitated with the aid of a petrographic microscope, whereas the presence or absence of carbonate sediments was determined with the aid of hydrochloric acid (HCL).

3.1 Alakiri-Z Well (Interval: 7500ft – 9150ft)

3.1.1 Main lithologies: Sandstone and shale with sandstone lenses within the shales.

Palynological sample interval 7480ft to 8620ft is characterised by dominant sandstones with shale intercalations. The sandstones are described as coarse- and fine-grained, friable and argillaceous. Towards the top and persistent within the interval, dark-grey shales with minor streaks (lenses) of sands and shale heteroliths occur. This is similar to the interpreted sedimentary units of the Alakiri-X Well over the studied interval 9750ft-10100ft (associated with the 9727ft-9831ft palynological sample). The shales are dark grey with minor streaks (lenses) of sandstones and non-reactive to HCl application suggesting a possible non-marine sedimentary sourcing. However, on further inspection, the shales are well preserved, micaceous, dense and associated with rich microfaunas as well as being slightly to moderately indurated. The medium-to fine-grained sandstone layers are unconsolidated. These sandstones and mudrock facies are equally suggested by the gamma ray wireline motif.

3.2 Interval: 9150ft – 12000ft.

3.2.1 Main Lithology: Shale with minor siltstone bands and sandstone streaks.

Over this interval the Ditch Cutting samples are defined primarily as shales with sandstone streaks and minor siltstones. The shales are dark-grey with minor siltstone layers, streaks (lenses) of sands and heteroliths which are non-reactive to HCl response. The sedimentary attributes of this intervals are characteristically similar to the Alakiri-X Well interval 10100ft-11500ft (associated with 10338ft-11625ft sample depths), where increased vertical thickness of sandstone with associated heterolithics is noted. In Alakiri-Z Well, palynological interval samples 9280ft to 12050ft have been assessed. The sandstones are medium- to very fine-grained with white siltstone intercalations. The shales presumably act as hydrocarbon top seals for the sandstone reservoirs units.

4. MATERIALS AND METHODS

A total of 39 samples were studied for palynology and palynofacies. The palynological analysis utilised a systematic standard inductive technique in ditch cutting sample collection and laboratory analysis along with relative deductive model engineered in the stratigraphic principles of uniformitarianism geology concept. The samples were prepared by adopting a standard palynological acid maceration technique, using hydrofluoric (HF) acid. Since the samples were not overtly calcareous, HCl treatment was not necessary. After cleaning and crushing, each 10 grams of sample was allowed to digest, immersed in hydrofluoric acid for removal of silicates. The samples were sieve-washed with a 10µm mesh and the extract was divided into two 5 grams equivalent aliquots, one for palynomaceral analysis and the other for oxidation used in palynological analysis. The 5-gram equivalent aliquots for palynofacies analysis were dispersed in polyvinyl alcohol before being mounted on glass slides and analysed with the aid of Motic B300 microscope. The palynomaceral particles were counted in each slide referencing the well-established in-country SPDC type-collection photograph atlas, with interpreted results against the palynological zonation schemes of (Germeraad et al.,1968; Evamy et al.,1978; Legoux,1978). A new zonation scheme was not integrated in the study due to the dynamic quantity and occurrences of terrestrial microflora where palynomorph abundances and occurrences are most likely linked to environmental mechanisms, depositional facies and oxygen related productivity criteria. The Quantitative Top (QT) and Quantitative Base (QB) zonal terminology approach of Adeonipekun et al. (2017) was also applied in the palynozonal assessment per interval. The zones are associated with occurrences of quantitative and qualitative palynofloral assemblages triggered by biological evolution, extinction, along with palaeoclimatic and ecological factors influenced directly (coastal settings) and indirectly by sea level change (eustacy).

The palynofacies study of the two Alakiri wells was undertaken adopting the palynomaceral classification schemes of Whitaker (1982, 1984), Whitaker et al. (1992) to aid interpretation of the key depositional environment processes influencing palynomaceral distributions. The important aspect of the application of palynofacies analysis lies in detailed consistent observation, description and classification of the palynomaceral particles during the period of microscope study. The palynofacies occurrences of the two Alakiri wells indicates the presence of Whitaker-styled Palynomaceral 1, Palynomaceral 2, Palynomaceral 3 and Palynomacerals 4, designated as P1, P2, P3 and P4 respectively herein.

4.1 Palynological Assemblages Descriptions

Figures 3 & 4 illustrate the percentage distribution of palynomorph and palynomaceral components identified in this study. The palynomaceral model description and interpretation of the Nigerian sedimentary basins studies is systematically utilised for the first time in the Palaeoenvironment and sequence stratigraphy concepts for the Niger Delta Basin. Palynomorphs recovered include fungal, algal, pteridophyte and bryophyte spores, gymnosperm and angiosperm pollen (Figure 3) with a notable non-occurrence of dinoflagellate cysts taxa and other marine algal species (Plate 1 & Plate 2). As suggested in the discussion section, the non-recovery of marine indices does not automatically discount a marine setting (noting the high microfaunal recoveries from some of the mudrocks) but maybe a potential bias when applying the standard palynological processing techniques used predominantly in the Niger Delta. The analysed Alakiri-Z Well interval 9280ft-12050ft has an abundance and diversity of *Verrucatosporites alienus*, *V. usmensis*, *Crassoretitriletes vanraadshooveni* (0.2%), *Psilatricolporites crassus*, *Pachydermites diederixi*, *Zonocostites ramonae*, *Verrutricolporites rotundiporus*, *Belskipollis elegans*, *Retibrevitricolporites obodoensis*, rare occurrence of *Magnastriatites howardi* (0.4%), *Corsinipollenites jussiaensis* (0.1%), *Retitricolpites irregularis* (0.8%) and other subdominant species listed in Figure 3 and selectively shown on Plate 1 & Plate 2). The species recovery from this interval of the well has the same percentage distribution characteristics with results of the palynological data illustrated for interval 11415ft-11625ft of the Alakiri-X Well.

The recorded palynomorph groups from the upper interval 8620ft-9380ft of Alakiri-Z Well by close association, can be suggested corresponding with Alakiri-X Well interval 9727ft-11315ft. These include fungal/algal spores (13.8%), pteridophyte and bryophyte spores (35.5%) with subdominant gymnosperm and angiosperm pollen. Palynomorphs recovered include *Laevigatosporites ovatus*, *Psilastephanocolporites laevigatus*, *Zonocostites ramonae*, *Verrutricolporites rotundiporus*, *Belskipollis elegans*, *Psilatricolporites ifeensis*, *Longapertites marginatus*, *Margocolporites vanwijhei* and other species occurrences as shown in Plates 1 & Plate 2.

The palynofacies interpretation of the two wells was undertaken using the palynomaceral classification scheme for deltaic settings as devised by Whitaker (1982, 1984) with an attempt to determine depositional processes and dynamics. Palynomaceral 1, Palynomaceral 2, Palynomaceral 3 and Palynomaceral 4 are designated as P1, P2, P3 and P4 respectively within the descriptive section supplied as Figure 4. The Early Serravallian interval (9280ft to 12050ft) of the Alakiri-Z Well was dominated by well-preserved brown Palynomaceral 2, opaque Palynomaceral 4 (equant) and Palynomaceral 3 (Figure 4). Also recorded are Palynomaceral 1 with low numbers of both Palynomaceral 4 (lath and particulate morphologies). The overlying Late Serravallian and non-age diagnostic interval (7480ft to 8620ft) has a similar palynofacies characteristic with the underlying interval (9280ft to 12050ft). The palynofacies and palynomorphs recovered from the Alakiri-X Well are also similar with that studied in Alakiri-Z Well. There is an overwhelming presence of opaque Palynomaceral 4 (equant and lath morphologies), abundance of dark and light brown Palynomaceral 2 and Palynomaceral 1 with subordinate recoveries of Palynomaceral 3 and Palynomaceral 4 (particulate).

4.2 Palynozonation

The pollen and spore species recovered from the two Alakiri wells portrays abundant and diverse groups of taxa categorised to assign appropriate palynozones following an integration of Germeraad et al. (1968), Evamy et al. (1978) and Legoux (1978) palynozonation schemes. The more recently published palynozonation of Adeonipekun et al. (2017) does not cover the stratigraphic interval assigned herein, but useful inferences from that publication have been adopted in terms of zonal description qualifiers. The concept of base regular occurrence (BRO) and top continuous occurrence (TCO) of palynomorphs similar with base (Last Downhole Occurrence and First Appearance Datum (LDO/FAD) and top (First Downhole Occurrence/Last Appearance Datum (FDO/LAD) were systematically applied in the biozonation noting that sample materials are ditch cuttings and thus will not clearly show a precise FDO due to potential sample winnowing and even less likely accurate LDO due to prevalence of down-hole cavings.

The evolutionary appearances and quantitative abundancies of palynomorph taxa were also utilised. The microflora diversity of the Alakiri wells indicated two palynological zones characterised by Base Regular Occurrence (BRO) of *Belskipollis elegans* at 12050ft and Continuous Occurrence of *Verrutricolporites rotundiporus*; Top Regular Occurrence (TRO) of

Belskipollis elegans (Figure 6) at 9280ft and Continuous Occurrence of *Verrutricolporites rotundiporus* at 8380ft corresponding to the P750 and P770 zones of (Evamy et al.,1978) respectively linked to the F and G zones of Legoux (1978) and *Crassoretitriletes vanraadshooveni* Pantropical Zone of Germeraad et al. (1968) along with defined K1 and K2 zones of this study. Further discussion relating to these two key taxa can be found more recently in Mkpong et al. (2019) where the ranges of the key taxa are highlighted, and further stratigraphic relationships described.

The biozones are assigned as follows:

4.2.1 P750 Zone *Belskipollis elegans*

4.2.1.1 Stratigraphic Interval: 9280ft -12050ft TD

TOP biohorizon: **9280ft** (FDO/LAD/TCO) ***Verrutricolporites rotundiporus***

BASE biohorizon: **12050ft** (BRO) ***Belskipollis elegans***

This is the deepest penetrated interval of the Alakiri-Z Well which is considered correlative with the 11415ft-11625ft interval of the Alakiri-X Well. The Zone is characterised by Regular Occurrence (RO) of *Belskipollis elegans* in association with highest relative abundance of *Verrutricolporites rotundiporus, Zonocostites ramonae, Crassoretitriletes vanraadshooveni Retibrevitricolporites obodoensis, Verrucatosporites alienus, Brevitricolporites molinae, Cyathidites australis* and *Verrucatosporites usmensis* (Figures 3 and 5).The stratigraphic inception of *Belskipollis elegans* was encountered during the Middle Miocene (Langhian) but stratigraphically is believed to range up to the Recent (Salard–Cheboldaeff, 1990). However, its stratigraphic abundance here is key in assigning the palynozones, as also suggested by Mkpong et al. (2019).

4.2.2 P770 Zone *Verrutricolporites rotundiporus*

4.2.2.1 Stratigraphic Interval: 8380ft– 8620ft

TOP biohorizon: **8380ft** (LDO/FAD**) Non-diagnostic**

BASE biohorizon:**8620ft** (CO) ***Verrutricolporites rotundiporus***

This is the shallowest penetrated interval of Well-Z characteristically similar with the penetrated interval 9727ft-11315ft of Well-X. The Zone is characterised by the base occurrence (Top Continuous Occurrence (TCO) of *Verrutricolporites rotundiporus* in association with relative abundance of *Brevitricolporites molinae, Laevigatosporites discordatus, Leiotriletes* spp*., Retibrevitricolporites obodoensis* and *Zonocostites ramonae* and few *Belskipollis elegans* occurrence events (Figures 3 and 6).

4.3 Palynostratigraphy

The palynological interpretation of the two Alakiri wells in line with their sedimentary facies were largely built from pollen and spores due to non-recovered occurrence of marine dinoflagellate cysts, algal or acritarch taxa in the recorded data. The species distribution data and stratigraphic range chart of some key diagnostic palynomorph taxa are illustrated in Figures 3, 5 and 6 respectively. These data are in general accordance with other parts of the Agbada Formation as studied by earlier authors. More than 50 well-preserved individual microfloral species were identified. These mostly fall into the land-derived categories of pteridophytic-bryophytic spores, gymnosperm and angiosperm pollen. The interval 9280ft-12050ft of the Alakiri-Z Well is assumed correlative with the 11415ft-11625ft interval of the Alakiri-X Well and was deposited during the Middle Miocene (Early Serravallian) based on the regular occurrence of age diagnostic type *Belskipollis elegans* in association with highest abundance *of Verrutricolporites rotundiporus*, *Zonocostites ramonae* and presence of *Crassoretitriletes vanraadshooveni*, *Verrucatosporites* *alienus*, and *V. usmensis*. Other episodic pollen and spore events included localised abundances of *Brevitricolporites molinae*, *Retibrevitricolporites obodoensis*, and *Cyathidites australis* (Plates 1 and 2). These palynomorph species of angiosperm, gymnosperm and spores were previously documented by Clarke (1966), Germeraad et al. (1968), Jan du Chêne et al. (1978), Legoux (1978), Morley & Richards (1993) and more recently Mkpong et al. (2019), amongst others across the Niger Delta region. The *Crassoretitriletes vanraadshooveni* Pantropical Zone of Germeraad et al. (1968) in Nigeria, Borneo and the Caribbean and the regular occurrence of the taxa was instrumental in the Miocene (Serravallian) chronostratigraphic age assessment of strata in India (Kar and Jain, 1981), Venezuela (Lorente, 1986), Taiwan (Li & Huang, 1990), Nigeria (Oboh et al., 1992; Bankole et al., 2014; Okeke, 2014) and in other tropical and subtropical regions.

The presence of *Belskipollis elegans*, defining the P750 Subzone of Evamy et al. (1978) and Zone F of Legoux (1978) shows that the studied interval is not older than Early Serravallian consistent with a Middle Miocene age. *Belskipollis elegans* taxa was initially documented in Nigeria by Salard–Cheboldaeff (1990) as a Middle Miocene to Recent taxon while a Late Eocene age was also reported in Cameroon for the taxa. Palynomorph and foraminifera studies of E2.0 reservoir well (Oboh-Ikuenobe, 1990) indicated earliest Middle Miocene with the presence of *Ephedripites* spp., *Cycadopites* spp., *Zonocostites ramonae* and *Verrutricolporites rotundiporus* as well as foraminiferal types *Ammoscalaria pseudospiralis*, *Texutularia elegans*, and *Bolivina* spp. This is in agreement with the stratigraphic age of *Belskipollis elegans* and other microflora recorded in this study.

The occurrence and diversity of palynological assemblages the Alakiri-Z Well interval 8380ft-8620ft is suggested correlative with the interval 9727ft-11315ft interval in the Alakiri-X Well and is associated with the assigned P770 Zone *sensu* Evamy et al. (1978) and G Zone of Legoux (1978) suggesting a Late Serravallian (Late Middle Miocene) age. This is upheld by the First Downhole Occurrence (FDO) / Last Appearance Datum (LAD) of *Verrutricolporites rotundiporus* in association with *Brevitricolporites molinae, Laevigatosporites* cf. *discordatus*, *Leiotriletes* spp., *Retibrevitricolporites obodoensis* and *Zonocostites ramonae* and rare occurrences of *Belskipollis elegans* (Figures 3, 5 and 6). It is important to note that the boundary between the *Cicatricosisporites dorogensis* and *Verrutricolporites rotundiporus* Pantropical zones is marked by the decrease in *Cicatricosisporites dorogensis* and increase in *Verrutricolporites rotundiporus* and *Zonocostites ramonae* (Germeraad et al.,1968). The Atlantic zonal microflora (op. cit.) corresponds with the *Magnastriatites howardi* and *Crassoretitriletes vanraadshooveni* (Oligocene to Early Miocene) Pantropical Zone of (Germeraad et al.,1968). The *Verrutricolporites rotundiporus* and *Belskipollis elegans* palynozones correlate with the top of the F9500 and base of F9600 foraminiferal biozones of the SPDC (2010) zonation scheme and NN9/NN8 and NN6 global nannofossil biozones of Martini (1971) respectively, calibration of which can be found in Adegoke et al. (2017) and Ukpabi et al. (2021). The palynostratigraphy of the studied intervals thus suggests a Serravallian (Middle Miocene) age which is not younger than 11.63 Ma and presumably not older than 13.82 Ma.

5. PALAEOENVIRONMENT RECONSTRUCTION

The development of a Palaeoenvironment interpretation model for the Alakiri wells was based on palynomorph and palynofacies distributions and interpretations of gamma ray wireline motifs as well as the lithofacies attributes of the studied intervals due to the non-availability of other geological data. Available nannofossil and foraminiferal occurrences were integrated to help understand the environments of deposition although diagnostic work related to those disciplines were not within the scope of the study. The botanical and ecological quantification of the recovered pollen and spore taxa delivers palaeoecological patterns, qualifying parent plant vegetation patterns that can be reversed engineered to those of modern-day settings. Thus, the depositional systems, dynamic mechanisms and the hydrodynamic implication of phytoclasts derived from the progradational Agbada Formation has been interpreted primarily from the palynomorphs and palynomaceral distributions suggesting marginal to non-marine settings systems interspersed with fluvial environments dominated by low and intermediate fluvial energy and crevasses play features of the coastal swamp environment (Figure 8)

The absence of any dinoflagellate cysts, acritarchs or marine algal components would suggest the absence of any marine influence but the integrations of both nannofossil and foraminiferal data from the investigated intervals suggests intermittent marine influences. The caveat to the non-recoverable aspects of any marine palynomorphs is potentially linked to local processing techniques employed by in-country laboratories that may be unwittingly prejudicing the preservation of thin-walled dinocysts and Leiosphaerid-type algal components. Recent publications such as Ikegwuonu et al. (2020) describe coincident recovery of marine and non-marine palynomorphs from older Palaeogene sequences, whilst Bankole et al. (2014) describe marine microplankton recovery in their review of well-sections equivalent to the Neogene Agbada Formation, as do Durugbo and Olayiwola (2017) in their assessment of Middle Miocene sequences of the M1 Well, also located in the Niger Delta. A review of the many short papers submitted and supported by the oil industry operations across the Niger Delta often fail to discuss marine elements, supporting the premise that the recovery issue may relate to processing techniques rather than just geology.

The presence of *Cyathidites australis, Leiotriletes adriensis* and *L. maxoides* fern spores (Figure 8) reflect local pteridophyte vegetation of coastal swamp deposits growing on wetlands (Schrank & Mahmoud, 1998), whereas the *Araucariacites australis* conifer vegetation grows on a relatively dry hinterland ecological space of the Middle Miocene araucariacean forest (Schrank & Mahmoud, *op cit*.).

Pachydermites diederixi is suggested to related to vegetation developed in coastal swamp areas likewise *Magnastriatites howardi,* an inhabitant of alluvial plain and coastal swamps where the parent plants grow in shallow waters alongside lakes and riverbanks (Germeraad et al., 1968). *Verrutricolporites rotundiporus* and *Zonocostites ramonae* are very abundant in coastal swamp and marine settings associated with fluvial – estuarine deltaic environment. In modern-day equivalent coastal mangrove settings types with a botanical affinity with Rhizophoraceae dominate. Occasional abundances of *Zonocostites ramonae* preserved in progradational sediments (dry climate) suggests pro-deltaic palaeoenvironments with remobilisation of shore-line sediments (Morley, 1995). The presence of Gramineae / Poaceae pollen as *Monoporites annulatus* suggest open coastal savannah vegetation associated with drier climate periods (Figure 7 & Figure 8) and marked rainy seasons which favours extensive seasonal grass growth rather more than presumed ever-wet humid climate intervals.

The presence of *Longapertites marginatus*, *Racemonocolpites racematus*, *Psilamonocolpites* spp. and other monocolpate microflora of the Palmae group (Figure 2) suggest the potential for a Palmae Province origin for the angiosperm-dominated sporomorphs of the Agbada Formation which is akin to the Late Cretaceous Palmae Province microflora attributes of Herngreen & Chlonova (1981), Herngreen et al. (1996). Other key elements of this province, *Echitriporites trianguliformis* and *Ephedripites* spp., were also recovered. These species are phytoecological relatives of *Nypa*, an index element of the mangrove environments of the humid tropics (Herngreen, 1996; Digbehi et al., 1996). The presence of these pollen in the Serravallian of Agbada Formation strata indicates availability of *Nypa* vegetation along the coastline of the fluvial dominated shallow marine settings of the study.

The abundance and diversity of microflora taxa with their respective climatologic significance in the Niger Delta strongly suggest that the fluvial processes are responsible for the bulk of sediments deposited in the basin. For example, hydrodynamic distribution dictates the microflora recorded from Recent sediments of Black Sea which indicated that fungal remains were an index of terrigenous sediment influx and transport by large rivers (Mudie et al., 2002). This is because most fungal sporomorphs are derived from soils in the watershed and fringing marshlands given that there are no marine fungi that can produce spore fossils (Batten, 1999). This is true of the Agbada Formation sediments where high abundance and diversity of fungal and algal spores in association with other terrestrial palynomorphs is suggestive of Low Stand Systems Tracts with the bulk of the sediment fed by a "proto-River Niger" and its tributaries. Other notable types recovered in this study are the spore type Alternaria that were inhabitants of saltwater marshes while the presence of *Multicellaesporites* spp. and *Tetraploa* spp. indicate warm and humid climates in the Cenozoic (Elsik, 1969). The paleoenvironment quality of the fluvial coastal settings of the study reflects three vegetation zones/model of a seaward mixed *Nypa* and *Rhizophora* mangrove zone, a palm vegetation induced wet lowland forest and a relatively arid zone of the warm tropical to subtropical Africa.

The high abundance of small and medium sized Palynomaceral 4 (equant), Palynomaceral 1 and Palynomaceral 2 in association with other palynomaceral assemblages large size ranges of Palynomaceral 4 (lath), Palynomaceral 4 and Palynomaceral 3, along with palynomorphs demonstrate that the sediments of the studied intervals were deposited relatively close to the parent plants.

The high abundance of lateral, equidimensional and other irregularly shaped Palynomaceral 4 debris types are suggestive of a mixed intermediate environment. The opaque debris in the study has dark brown edges under the microscope which suggests that they are immaturely opaque. The characteristic of these Palynomaceral 4 components in the studied wells suggests that they are in their late diagenetic stage of transformation from brown - black brown - opaque particle grading. This supports that they are of plant origin and their unique opaque nature is as a result of natural sedimentological diagenesis and not necessarily as a result of wildfires and other mechanisms as suggested by Tyson (1993) and Whitaker et al. (1992) but do retain some characteristics suggesting sporadic bush burning. Morley & Richards (1993) suggest that the consistent first appearances of Charred Gramineae Cuticle related to savannah fires was during the earliest Middle Miocene, associated with their palynological Zone G. The record of Charred Gramineae Cuticle by Durugbo and Olayiwola (2017) in their Middle Miocene assessment of the M1 Well, Niger Delta may provide supporting evidence for this premise. Although Oboh-Ikuenobe (1996) and Batten & Stead, in Koutsoukos (2005) linked the abundance of opaque particles to high energy conditions, the palynofacies associations (Figure 2) of the studied wells illustrate low to intermediate environments. In the Oboh-Ikuenobe (1996) study of Upper Cretaceous rocks of Book Cliff of central Utah, she suggested that cuticle fragments are more prominent in sediments of Low stand System Tracts with higher percentages in fluvial channel deposits. This is similar to the inferred sequence stratigraphic package associated with the Agbada Formation in the current study. The abundance of variable sizes of high buoyancy Palynomaceral 2 (well preserved structured phytoclasts, cuticle and relatively structureless light brown phytoclasts) were dominated by medium to large particles despite the fact that their fragile nature makes them susceptible to fragmentation, indicating deposition of sediments close to the parent vegetation. Notwithstanding that cuticles can be transported offshore out into pro-delta systems (Oboh-Ikuenobe, 1996; Okeke & Umeji, 2018) and submarine fan lobes described by Cross et al. (1966) can be counter-proposed to suggest that a high percentage of cuticles are deposited near river mouths and in near-shore settings.

The presence of low buoyant Palynomaceral 1 (black brown, yellowish brown and fluffy Amorphous Organic Material (AOM), resin particles and algal remains) in the study favours a near-shore to non-marine environment. The presence of resins is suggestive of Lowstand Systems Tracts (Oboh-Ikuenobe, 1996), while Oboh (1992) advocated previously that they are more common in non-marine and near shore environments. Therefore, it is suggested that Palynomaceral 1 is characteristic of a terrestrial origin. The scale of degradation can be well observed from poorly degraded-degraded phytoclasts-amorphous organic matter of partly marine and non-marine origin. Palynomaceral 1 colour range is from brown to dark brown through to black brown which also points to a potential terrestrial origin. This is in general agreement with Staplin (1969) who suggested that they are products of alteration other than primary products. Masran & Pocock (1981) suggested that the yellowish amber colour suggests derivation from terrestrial material as opposed to the grey coloured marine variant. The nature of the AOM shows that bacteria is the principal physical activity responsible for phytoclast biodegradation or possible breakdown by fungi in some cases. Nevertheless, there are some occurrences of yellowish brown to black-brown coloured AOM of aquatic origin suggesting marine influences.

Taking all elements into consideration, namely the palynological and palynofacies analysis, foraminifera and nannofossil intermittent recoveries, and gamma ray wireline log data indicates that the sediments of the studied interval of the Alakiri wells were deposited in low to intermediate fluvial energy environments with episodic direct and indirect (water-table change) marine influences.

6. MEAN SEA-LEVEL CHANGE AND PALAEOCLIMATE SYNCHRONICITY

Sea-level change/eustacy is the most relevant dynamic natural process which successively subdivides sedimentary successions into sequential packages which are generally linked with sequence stratigraphy and palaeoclimate change. This synchronicity relationship is the backbone of sequence stratigraphic interpretation and derivation of the apparent cyclic nature of the sedimentary rock record of the Niger Delta coastal swamp domain.

The abundance, diversity, quality and quantity of palynomaceral particles, angiosperm and gymnosperm pollen assemblages, taxa, algal and fungal spores, pteridophyte/bryophyte spores, along with the Gamma Ray wireline motif have been integrated in support of attempting to build a palaeoclimate-inferenced sea-level and climate change synchronicity of events during the Serravallian stage of the Middle Miocene. This is to ultimately understand and interpret the sea-level change and relative climate impact during the Serravallian stage. The palaeoclimate dynamics of the Serravallian stage, Agbada Formation is made up of series of “wet and dry cycles” with dominant wet climates substantiate by the ever-wet vegetation and coastal swamp prevalent microflora. However, earlier palynoflora analysis of the sedimentary packages in the Niger Delta basin, has further denoted eustatic sea-level change, climate and systems tracts of the Niger Delta basin (Poumot, 1989; Morley, 1995; Adojoh et al., 2015).

The palynofloral applications of Poumot (1989), Morley (1995), Bankole et al. (2014), Adojoh et al. (2015), and a significant number of other workers have documented elements referencing sea-level, climate and systems tracts of the Niger Delta basin in a fairly disparate fashion, but in this work the Serravallian age eustasy, tectonics and sediment supply of the basin was harnessed through a practical and pragmatic approach. The occurrence and diversity of *Belskipollis elegans*, *Verrutricolporites rotundiporus*, *Zonocostites ramonae*, *Crassoretitriletes vanraadshooveni*, *Verrucatosporites alienus*, *Verrucatosporites usmensis*, *Brevitricolporites molinae*, *Retibrevitricolporites obodoensis* and *Cyathidites australis* (Plates 1 & 2) along with absence of dinoflagellate taxa with limited episodic occurrences of foraminifera and nannofossils as well as the respective depositional mechanisms substantiates the palaeoclimate interpretations of the Serravallian in this study. These episodic and microflora hydrodynamics implications, substantiates the palaeoclimatic dimensions of the Serravallian stage of the study (Figure 7 & Figure 8). The hinterland “upland” type Podocarpidites spp., along with *Belskipollis elegans*, and other saccate pollen can be interpreted as monsoon wind-blown products. This may account for the unique relationship of *Belskipollis elegans* described by Mkpong et al. (2019) possibly relating to wind-blown source direction change. *Zonocostites ramonae* (Mangrove Swamp palynomorph taxon) and *Cyathidites australis* (Montane pollen) indicates warm humid climate influences during the Serravallian. Dry palaeoclimates with associated warm-hot and hot temperatures are indicated by the presence of *Monoporites annulatus* and *Retibrevitricolporites obodoensis* (Rubiaceae, savannah species) with lowland forest type *Polypodiaceoisporites retirugatus* as well as swamp and hinterland taxa (Figure 8) suggestive of distinct short dry periods, interspersing longer periods of persistent wetness (warm climate).

Previous palaeoclimate analysis and interpretations of the Niger Delta basin has documented two (2) series of dry climate periods with intermittent wetness in the Miocene. Morley & Richards (1993) suggested that the ‘climates became increasingly dry and particularly arid from the latest Early Miocene and Late Miocene’, with an ever-wet regime from ‘the earliest Early Pliocene, the Late Pliocene and Pleistocene’ while Oboh (1992) indicated that the ‘climatic conditions were somewhat drier in the Middle Miocene’. More recently, a “carbonate crash” event was documented as a prevalent Serravallian low marine oxygenation crisis event in the Niger Delta (Fadiya & Salami, 2012). All these confirm the lack of a dominant water system-an ocean, rainfall and low fluvial transportation mechanism of the water realm, diagnostic of the Miocene dry climate cycle. Summarily, the Miocene period was a dry climate regime with a dominant non-marine expansion, which portrays the entire Miocene Epoch as a dry time period associated with a non-marine regime illustrated in this study through the miospore assessments.

This substantiates that the origin and existence of the Trans-Saharan Seaway along with the Atlantic Ocean has offered up a scenario of faunal mixing between the two water masses which has been previously mooted by Carter et al. (1963), Rayment & Tait (1972), Petters (1978) and Okosun (1990).

Evidence for the dry savannah style episodes within the dry pollen and spore spectra is suggested by *Monoporites annulatus* and *Retibrevitricolporites obodoensis* which are regarded as prevalent due to the dynamic fluvial nature of the “proto-Niger River” style fluvial systems bringing more inland mudrock style vegetation derivative products across the more coastal elements and into the near-shore basins. These dry climate Saharan Desert styled palynomorphs would have been transported through proto-Niger and Benue rivers from a sub-Saharan origin, along pre-developed routes and through long migratory distances. The palynomorph assemblages and palynofacies components of the Serravallian Coastal Swamp Depobelt architecture suggests those proto river systems as the most dynamic principal fluvial mechanism responsible for the majority of terrestrial palynomorph transport and deposition in the direction of the Niger Delta basin.

Although the age of those river system developments and origin are unknown/undocumented, the geologic ages of the build-up of the Adamawa Plateau (Bamenda Massif) of Northern Cameroon and Guinea Highlands with many mountains, ranges and plateaus has been documented as part of the Pan-African orogeny (Ekwueme & Kroner, 2006; Mefire et al., 2016), which sporadically reactivated during Mesozoic and Cenozoic with the end Eocene (38.22 ± 0.80 Ma) and Oligocene (28.88 ± 0.61 and 28.60 ± 0.60Ma) K–Ar ages of the volcanic activities (Mefire et al., 2016). The mountains and highlands are the known originator of the many streams, spring and fluvial system makeup of proto-Niger and Benue rivers. The sporadic originating volcanic events of the Guinea Highlands mountains and plateaus recognised by reset age zircon dating was documented by Thiéblemont et al. (2004) and Lebrun et al. (2016). This supports the high occurrence and diversity of savannah driven (dry episode) palynomorphs within some mangrove and rainforest prevalent Cenozoic intervals of the Niger Delta basin as reported by Oboh (1992), Morley & Richards (1993), amongst others. The high abundance of the savannah-related palynomorph taxa recorded within the studied Serravallian intervals suggests an adverse dryness, drought or desertification (Desert extension) towards the north reflecting Sahel Fringe - Sub-Sahara vegetation belts across the northern part of present-day Nigeria (Sub-Sahara) similar to Recent environmental and climate events where the southward movement of the “desert” eco-system has been well documented. However, the evolution and origin of *Monoporites annulatus* and other dry climate prone species have also been previously associated with the distant afromontane and savannah terranes of Cameroon and Congo Mountain ranges (Bankole et al., 2014). It could be argued that both models are interchangeable and more data / studies, aligned with the Miocene temperature proxy data suggested by Pound et al. (2012) may further help rationalize. This substantiates the origin of savannah desertification regions with fluvial system migration over significant distance of the proto-Niger and Benue rivers as the major savannah pollen and vegetation fluvial influence of the shallow marine prone Agbada Formation sediments.

The dry or warm climate affecting the Niger Delta depobelts were linked closely with associated gramineae pollen by Morley & Richards (1993) suggestive of a pro-deltaic palaeoenvironment dominated with savannah-linked vegetation recoveries mobilised with associated dry climate intervals (Poumot, 1989; Morley, 1995). The palynomorphs associations of Well-X and Well-Z wells, supported by *Peregrinipollis nigericus* (hinterland species), *Verrucatosporites usmensis*, *Perfotricolporites digitatus,* (Lowland Rain Forest), *Verrutricolporites rotundiporus* (Coastal

Swamp) and *Pachydermites diederixi*, (Fresh-Water Swamp), confirm periods of high rainfall and humidity prevalent during periods of the deposition. For the Niger Delta basin (Germeraad et al., 1968) indicated that *Magnastriatites howardi* is a product of alluvial plain and coastal swamp settings where the parent plants grow as aquatic ferns in shallow waters adjacent to lakes shores and low energy riverine systems. The coastal swamp deposits depict saltwater swamps sediments deposited next to tropical and subtropical coastlines linked to Agbada Formation of Niger Delta basin depositional system. The microflora paleoecology systems of wet - dry climate is indicative of current and wave energy in the fluctuations of the sea level. Mangrove swamp, savannah-style species, coastal swamp, lowland rain forest, along with components derived from more proximal settings suggests Low stand Systems Tract (LST), with intermittent marine minor transgressions. However, fresh and salt-water swamps have water input originating from a diversity of sources including tides, freshwater flooding, rainfall precipitation and groundwater outflow.

The sea-level drop during the LST, is responsible for subsequent up-dip recalibration of the flood plain, with incipient erosion and incision occurring across the coastal plain suggesting potential, but difficult to assign, sporomorph reworking. The intermittent marine transgressive systems tracts (TST) is substantiated by nannofossil and foraminiferal records (Oboh, 1992; Fadiya & Salami, 2012; Okeke, 2017; Ukpabi et al., 2021). The dominant LST with intermittent TST are a reflection of the modern/Recent morphology of the Niger Delta, the genesis which of commenced during the Eocene regressive phase of the onshore Nanka Formation after the Paleocene transgressive episode (Okeke & Umeji, 2016; Okeke, 2017; Okeke et al., 2021). Conversely, it should be noted that many of the key changes affecting representation of the sequence stratigraphic dynamics of the Niger Delta are products of 'tidal dynamics responsible for sediment transport and deposition, tectonic-induced changes' as suggested by (Kvale, 2012). This would suggest that there are many levels of coastal onlap changes and strong inputs of tidal dynamics, driven by the shifting monsoon winds linked to the seasonal movements of the Intertropical Convergence Zone (ITCZ). Onuoha (1981) suggested that the subsidence of the rifted Atlantic type continental margin resulted from thermal contraction of the lithosphere. It was this subsidence that induced the major marine transgression of the Danian and Selandian-Thanetian (Paleocene) which began the filling of the new basin. The establishment of Niger Delta sedimentary regime from the Paleocene must have taken advantage of a continued thermal sag (Nwajide, 2013).

Palynomorph and palynofacies sequence stratigraphic interpretation illustrates large scale angular terrigenous fragments as associates of Low Stand System Tracts. Leopold et al. (1982) indicated that palynofacies constituents do not necessarily reflect the biologic environment of the area near the basin of deposition but are a product of a variety of geological and geochemical taphonomic processes associated with sedimentation. The palynomacerals of the two Alakiri wells indicates the presence of large, small to intermediate sized Palynomaceral 4 (Equant), Palynomaceral 1 and Palynomaceral 3, Palynomaceral 2 (Plate 1 & Plate 2). The interrelationship of palynomaceral groups suggest a more dynamic environment consistent with low energy fluvial input in association with a narrow higher energy coastal margin. These palynomaceral diversity and abundances (Figure 4) strongly suggest proximity of the parent vegetation consistent with Low stand System Tracts (LST) previously indicated for the Agbada Formation. Generally, the presence, abundance and diversity of *Fusiformisporites crabbii*, *Laevigatosporites* cf. *discordatus*, *Leiotriletes maxoides*, *Monoporites annulatus*, *Perfotricolporites digitatus*, *Polyadopollenites indecorus*, *Psilatricolporites ifeensis* and *Verrucatosporites alienus* suggest continued dominance of a generic ever-wet palaeoclimate. The fungal spores associated with influx and transport of terrigenous sediments by rivers thrive in soil found around watersheds and fringing marshes (Mudie et al., 2010). The palm pollen taxa represented by *Longapertites marginatus* and *Racemonocolpites racematus* are all products of a mangrove swamp domain associated with wet climates. The palaeoclimate intricacies of this study supports the premise that the bulk of the sediments deposition across the Niger Delta are product of fluvial processes associated of Low stand Systems Tracts (LSTs) with intermittent Transgressive Systems Tracts (TSTs) indicated by the nannofossil and foraminiferal occurrences.

Shoreline transgressive systems tracts (TST) progradational packages are products of sea level rise, substantiated by mudrock facies similar to the brackish, coastal or mangrove swamp dominated deltaic settings consistent with tidal estuary development (Morley, 1995; Dalrymple et al., 2012). Onema et al. (2015) suggested nine climate-driven palynocycles during the Miocene indicating increased periods of dryness and wetness as well as depositional cycles with variable palynological sequences, vegetation changes and sea level dynamics of the Niger Delta basin. Modern geographic environmental perceptions indicate that dry climates are associated with savannah, montane pollen and spores while wet climates are synonymous with development of mangrove vegetation and the expansion of lowland rainforests. This phenomenon is substantiated by beach vegetation, brackish water swamp, freshwater swamp forest, Guinean lowland rainforest, Southern and Northern Guinea savannah, Sudan savannah and Sahel savannah vegetation belts inherent in palynofloral assemblages of the West African Domain (Leroy and Dupont, 1994; Morley, 2000; Adeonipekun et al., 2017) recovered in the Alakiri wells. The observed Middle Miocene (Serravallian) events of the Agbada Formation strongly indicate that synchronous sea level change/eustacy, depositional environment and climatic change are the imprints of variable sedimentary packages and long-term average weather archetypes of those seen throughout the Miocene. The principal geologic synchronicity events in this study triggered the sandstone depositional processes, sea level oscillations, climate and palynomorphs interdependencies associated with an active hydrodynamic system across the Niger Delta basin.

7. **CONCLUSIONS**

The diversity and abundance of palynomorphs and palynofacies recovered from the two studied Alakiri wells illustrates that the sediments of the studied intervals were deposited during the (Mid-Miocene) Serravallian. The palynomaceral scheme of Whitaker (1982, 1984) were initiated to understand the detailed palynomorph and palynomaceral microflora hydrodynamics of the Niger Delta basin. The prime palynomceral and palynomorph analysis of the Agbada Formation sediments were investigated to interpret the stratigraphic successions and reservoir-scale palaeoenvironment dynamics inherent in sedimentary rock and microflora provenance. This is geared towards the productive exposé to understand the impact of sea level change and palaeoclimate synchronicity during the deposition of the Serravallian. The microflora, palaeoenvironment and palaeoclimate synchronicity of the wells data, illustrates sea level oscillation cycles and natural climate interdependencies. Two palynozones for the Agbada Formation deduced from the study consists of the principal assemblage zones: P750 (*Belskipollis elegans* - RO) and P770 (*Verrutricolporites rotundiporus*). Palynomaceral and palynomorph inferred depositional palaeoenvironments reflect marginal to non-marine fluctuating fluvial dominated swamps, marches, crevasse splays of a coastal swamp setting. The absence of dinoflagellate cysts could suggest an exclusive non-marine mechanism of sediment deposition, however, the integration of nannofossil and foraminifera data from the investigated intervals supports marine influences. The oscillating imprint of *Zonocostites ramonae*, *Belskipollis elegans*, *Verrucatosporites usmensis*, *Magnastriatites howardi* palynomorph species can be aligned with substantiated variable sandstone grain sizes and microenvironment parameters inherent in sediment stacking packages and palaeoenvironment indices. The palynological data suggests distinct short-term dry-periods, interspersing longer periods of persistent wetness (aka warmer climate) consistent with the higher abundances of *Monoporites annulatus, Retibrevitricolporites obodoensis* with *Zonocostites ramonae*, and *Verrutricolporites rotundiporus* respectively. The wet - dry climate model of the study portrays the shallow to relatively deep marine oscillation of sea level.

The sequence stratigraphic events which are products of the Middle Miocene Sea level changes of the studied Coastal Swamp Depobelt wells indicate Low stand Systems Tracts (LST) are responsible for the erosion and incision along the coastal plain as well as sporadic transgressive systems tracts (TST) substantiated by the occurrences of nannofossil and foraminiferal species. The cyclic nature of the sedimentary rocks/successions, with the palynological and other micropaleontologic taxa strongly confirm the sea level changes, sequence stratigraphy and climatic change synchronicity of the coastal Niger Delta basin. These findings also confirmed the practical value of the acid maceration techniques in palynology studies and the authenticity of the approach in the collection of palynomorph and palynomaceral plant remains for effective age, palaeoenvironment, sequence stratigraphic and palaeoclimate clarification. The sequence stratigraphic packages and eustatic models, all dynamic sedimentary successions are the bed rock of palaeoclimate driven factors because vegetation diversity arrays are dependent on the aforementioned.

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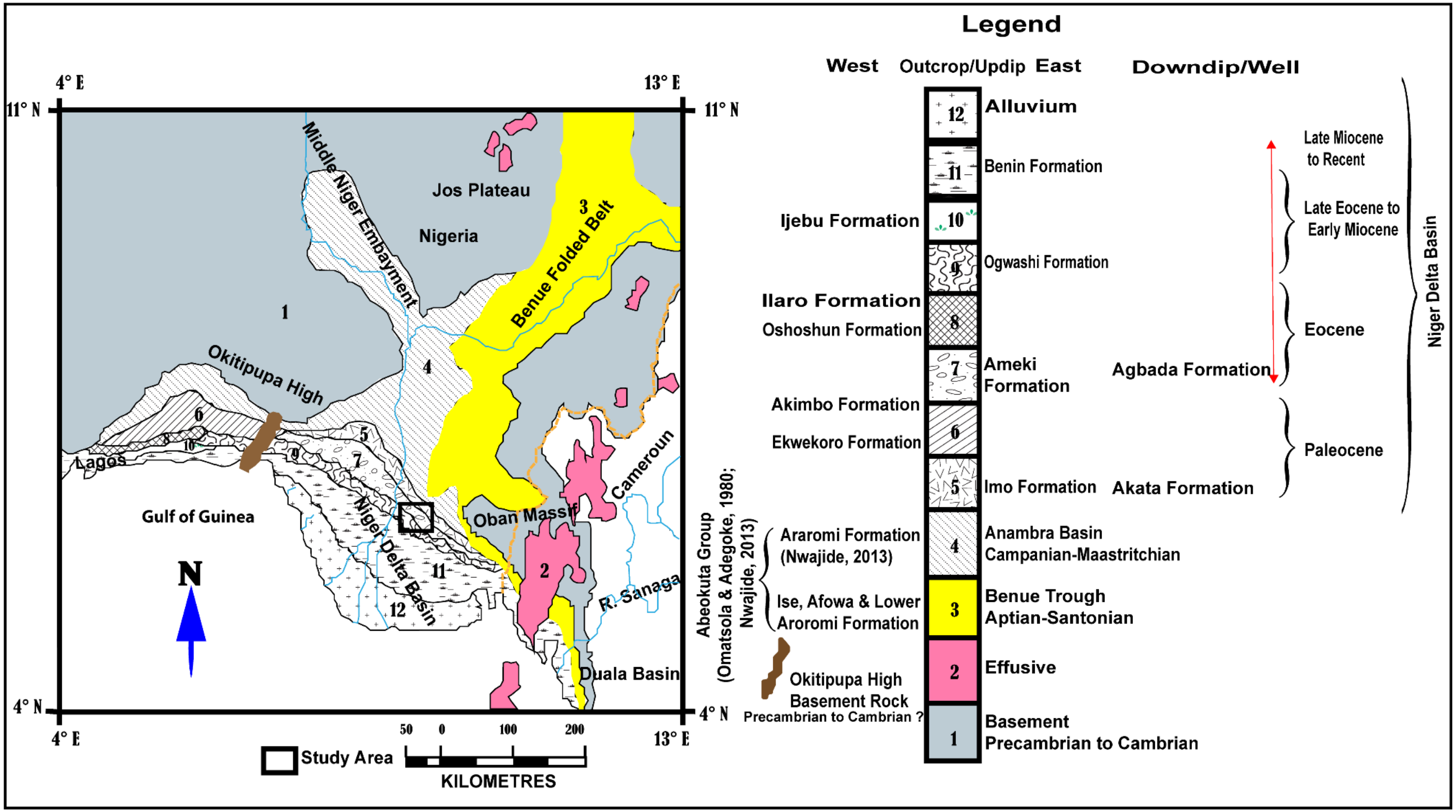


FIGURE 1: The regional geology of southern Nigeria showing the Niger Delta basin compared with updip outcrop locations and subsurface downdip well lithostratigraphy (Modified after Okeke & Umeji, 2018).

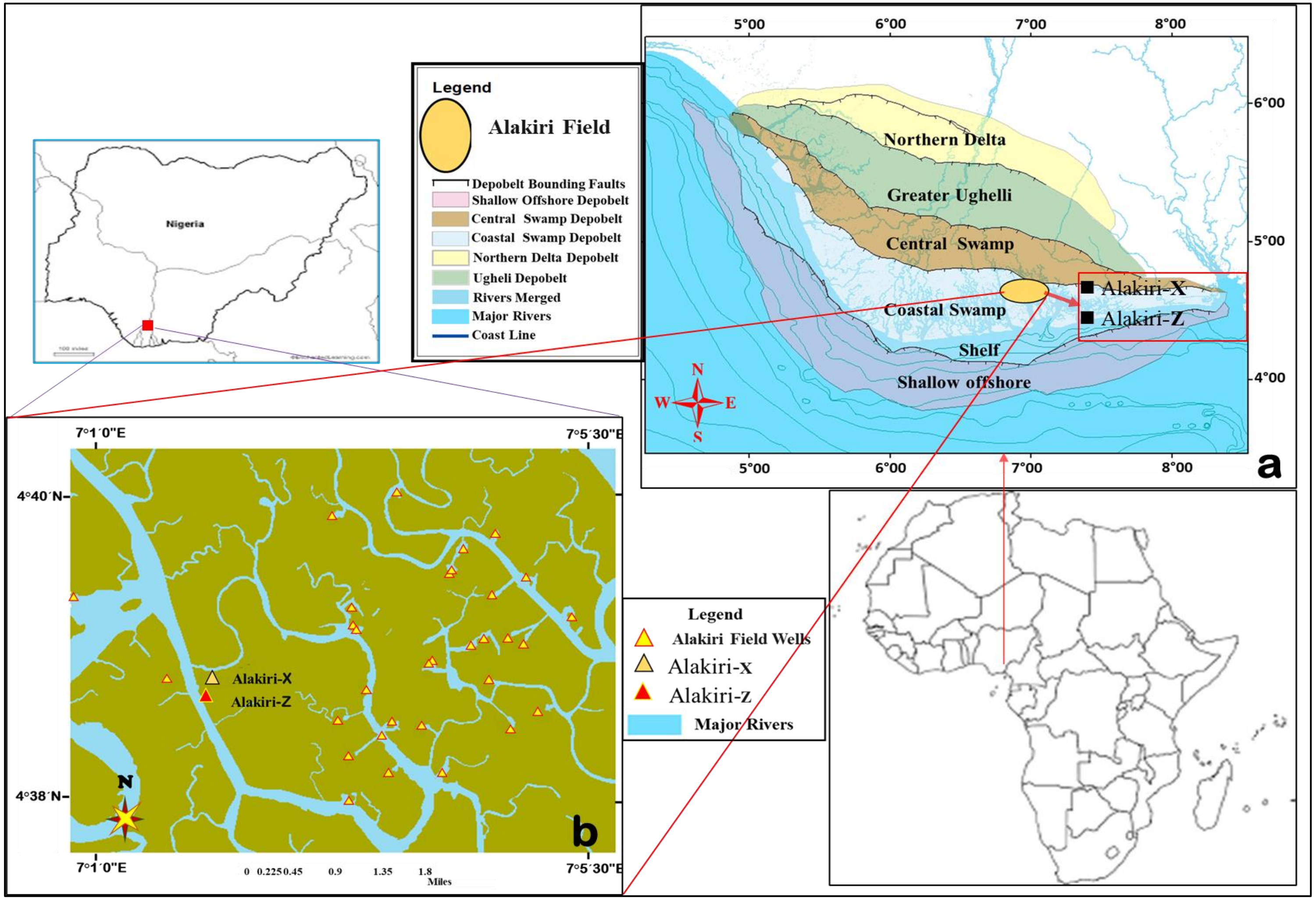


FIGURE 2A: The regional geologic map of Niger Delta basin showing the Niger Delta Depobelts and the location of the studied wells in the Coastal Swamp **B:** The location map for Alakiri-X and Alakiri-Z wells of the Alakiri Field, Coastal Swamp Depobelt, Nigeria Depobelts. Insert is the map of Africa and Nigeria showing the location of the study area in southern Nigeria.

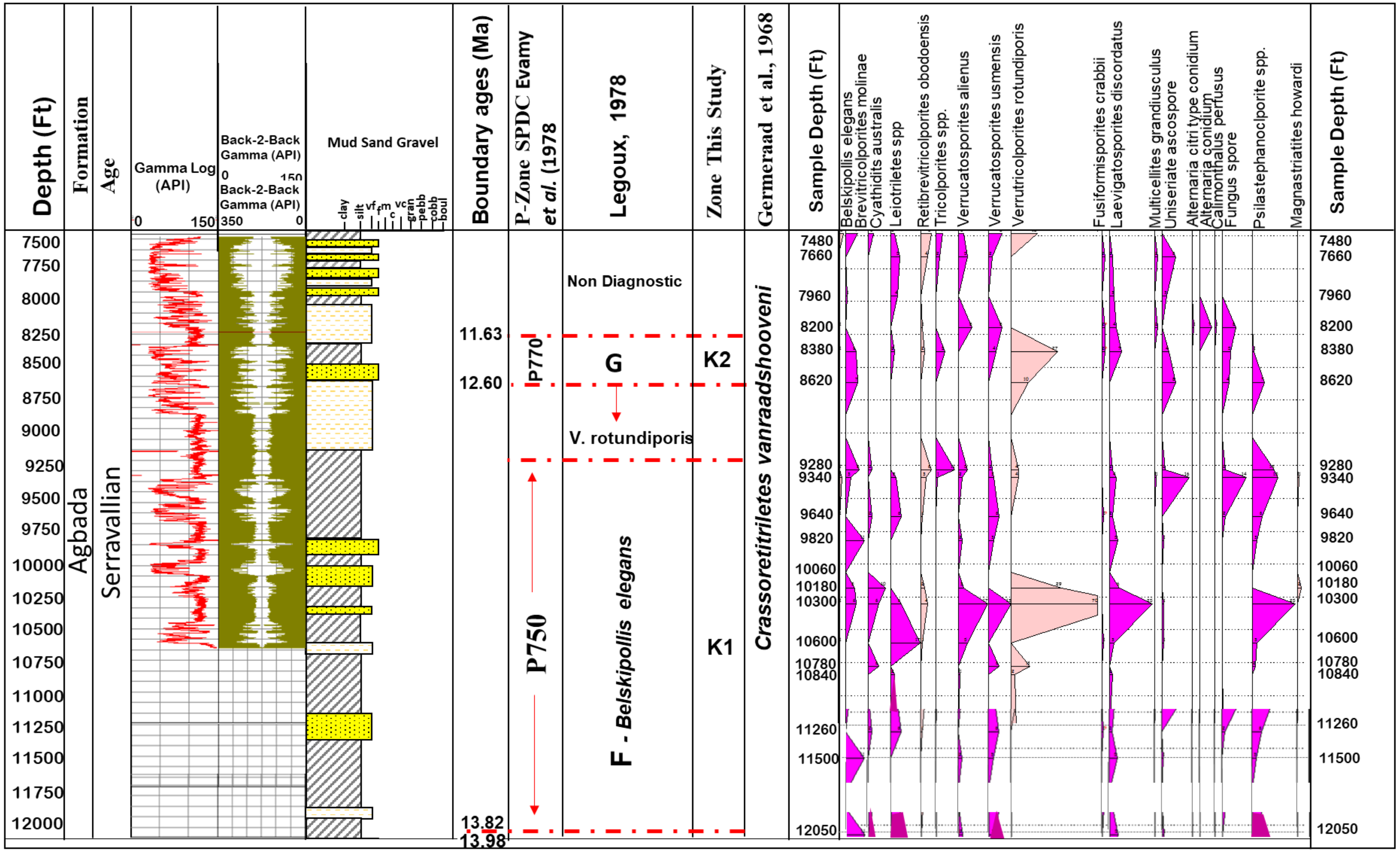


FIGURE 3: Zonal scale biostratigraphy of microfloral distributions for the Alakiri-Z well. Columns shown are as follows: Column 1 Depth Scale; Column 2-3formation and age; Column 4 Standard Gamma Ray wire-line; Column 5 Back-to-Back Gamma Ray wireline log showing relative position of sandstone units and mud-rock dominated intervals of coulum 6; Column 7-12, palynological zonation schemes, Relative frequencies of some selected palynomorphs and finally Sample Depths analyzed in the Alakiri-Z well (all ditch cuttings).

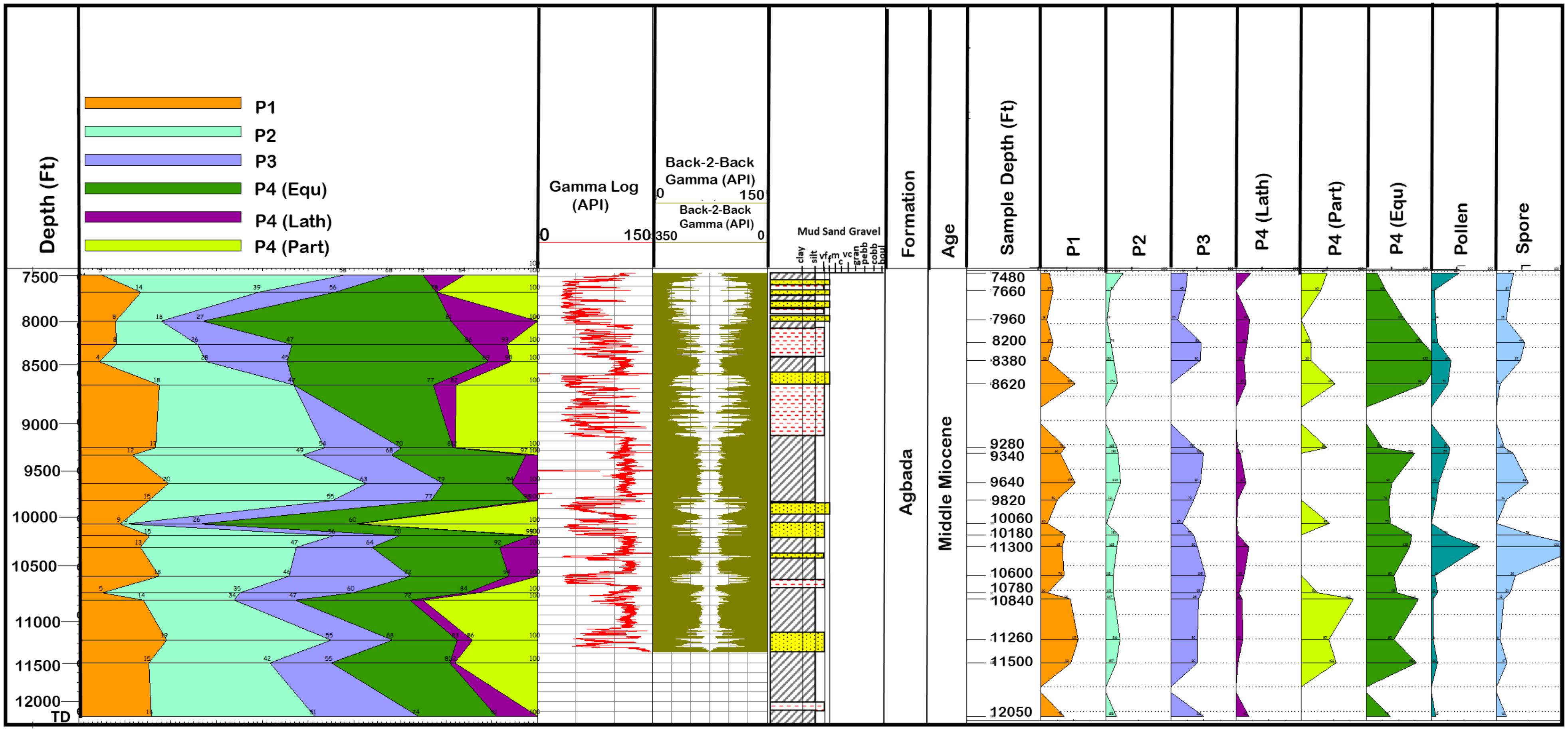


FIGURE 4: Palynomaceral distributions for the Alakiri-Z. Columns shown are as follows: Column 1 Depth Scale; Column 2 Proportional distribution of palynomacerals as defined in Whitaker (1984); Column 3 Standard Gamma Ray wire-line; Column 4 Back to Back Gamma Ray wireline log showing relative position of sandstone units and mud-rock dominated intervals in Column 5; Column 6 Sample Depths analysed in the Alakiri-35 well (all ditch cuttings); Columns 7-12 Relative frequencies of main palynomacerals as defined in Whitaker (1984), columns 12 and 13 pollen and spore respectively.

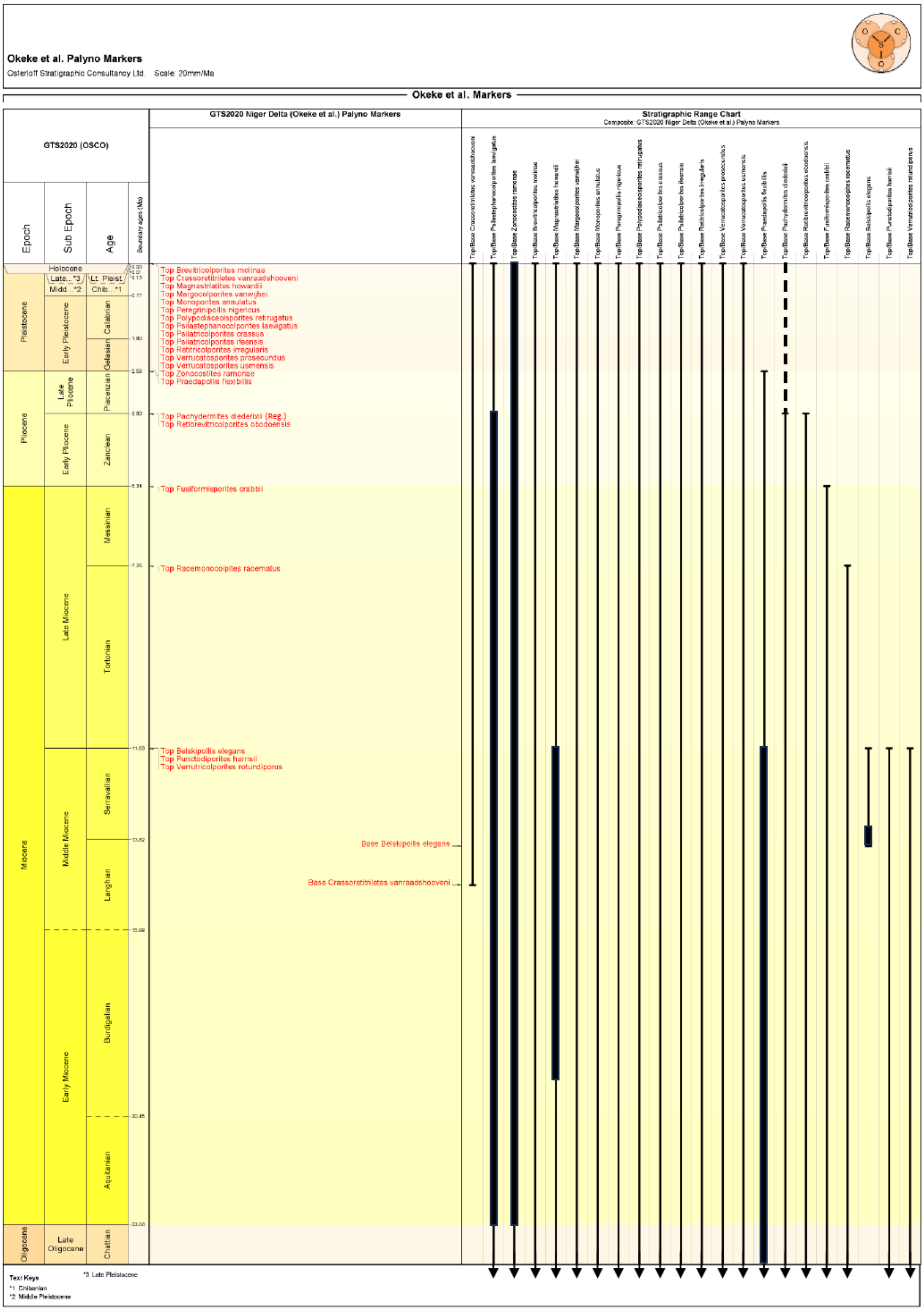


FIGURE 5: Previous records of stratigraphic ranges of some selected palynomorphs in the studied wells. (After Sah, 1967; Germeraad et al., 1968; Sowunmi, 1995; Eisawi & Schrank, 2008; Bankole et al., 2014). All the species occur in Alakiri-X and Alakiri-Z wells.

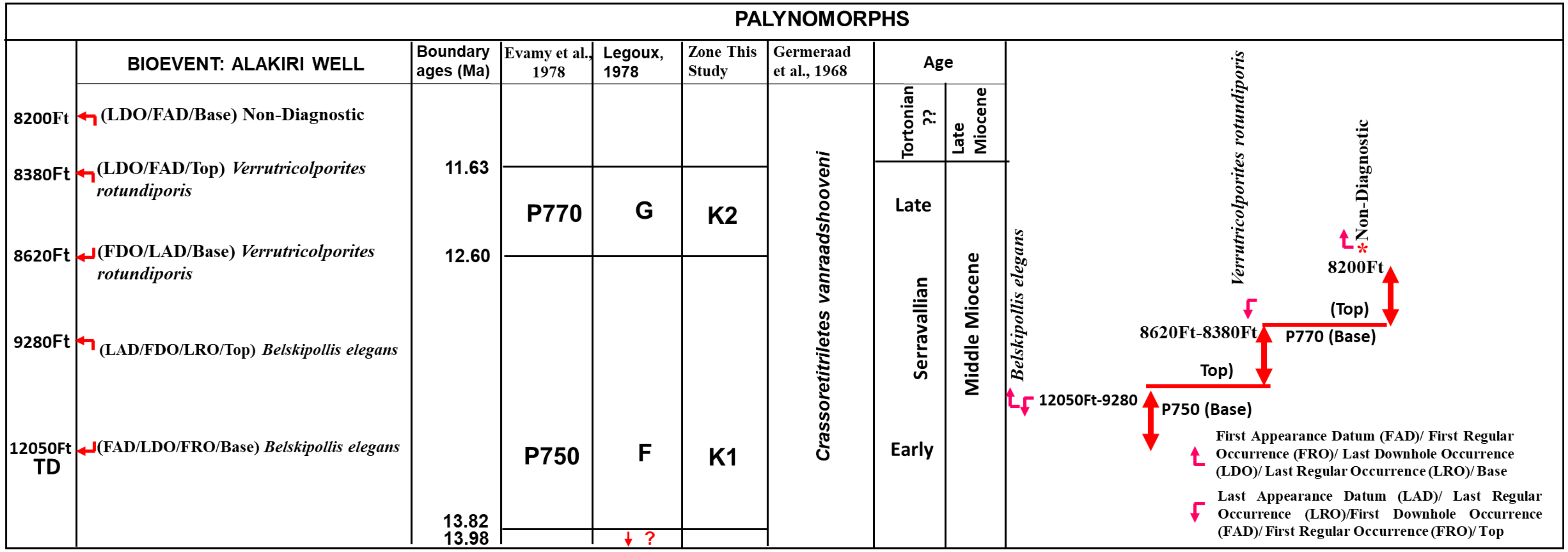
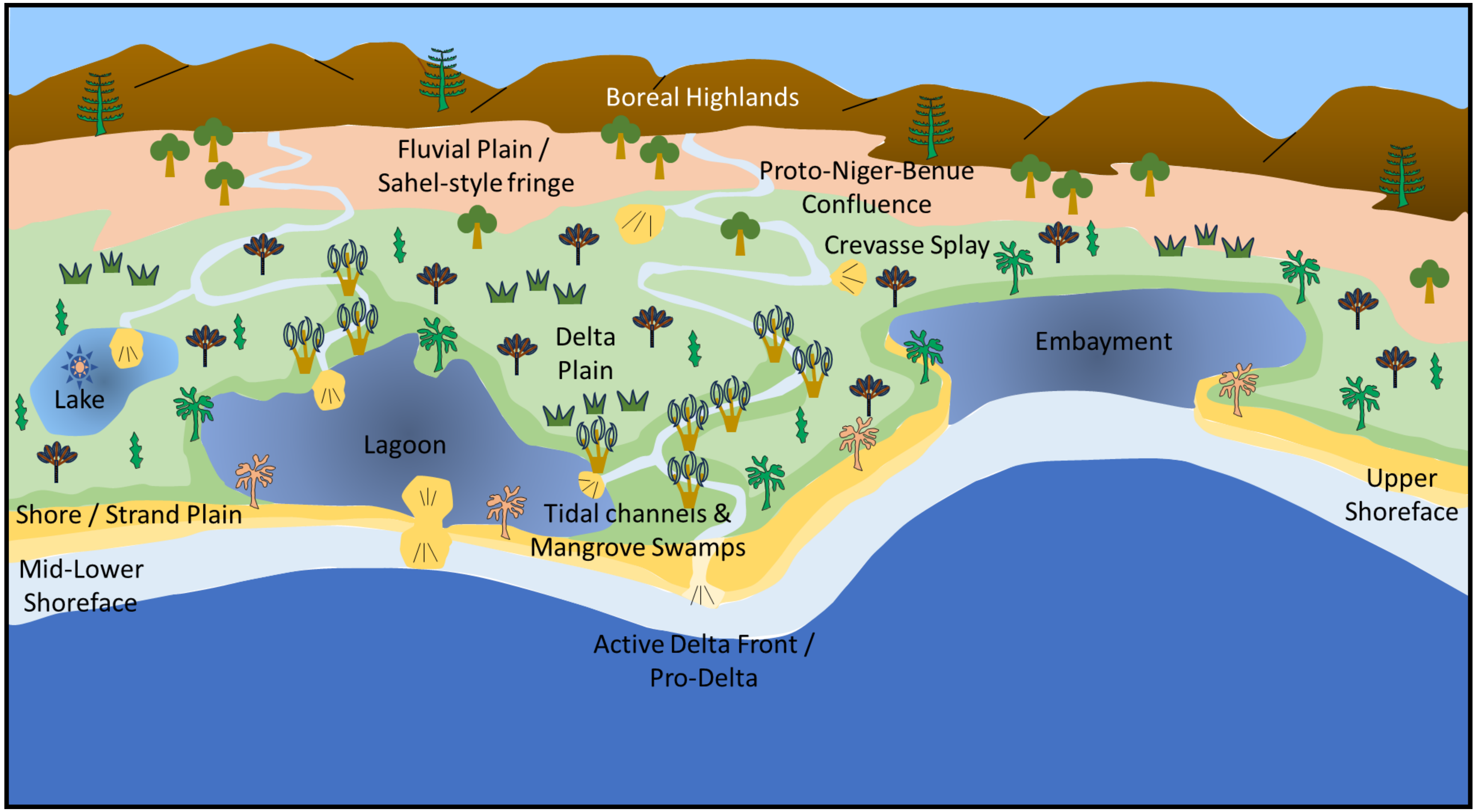


FIGURE 6: Palynostratigraphy Chart showing palynomorph zones and subzones indicating identified biohorizons with depths and stratigraphic significance as recognized in Alakiri wells based on the frameworks of Germeraad et al., (1968), Evamy et al. (1978) and Legoux, (1978).

Ecology	Microflora Species	Botanical Afinity	Palaeoclimate
Brackish Water Swamp	*Pachydermites diederixii*	Guttiferae-Symphonia globulifera	Wet
Mangrove Swamp	*Zonocostites ramonae*	Rhizophoraceae-Bruguiera type	Wet
	Psilatricolporites crassus	Euphorbiaceae	Wet
Coastal Swamp/Alluvial plain	*Magnastriatites howardi*	Parkeriaceae-Ceratopteris	Wet
	Margocolporites vanwijhei	Fabaceae (Leguminosae)-Caesalpinia type	Wet
	Margotricolporites spp.		Wet
	Margortricolporites spp.		Wet
	Verrutricolporites rotundiporis	Lythraceae-Crenea	Wet
	Verrutricolporites spp.		Wet
Fresh Water Swamp	*Retibrevitricolporites obodoensis*	Rubiaceae	Wet
	Retitricolporites irregularis	Euphorbiaceae-Amonoa	Wet
	Verrucatosporites ornatus	Polypodiaceae	Wet
	Verrucatosporites spp.		Wet
	Verrucatosporites prosecundus		Wet
	Verrucatosporites usmensis		Wet
	Laevigatosporites haardti	Polypodiaceae	Wet
	Laevigatosporites ovatus		Wet
	Laevigatosporites javanicus		Wet
	Crassoretitriletes vanraadshooveni	Lygodium microphyllum	Wet
Lowland Rainforest	*Polypodiaceoisporites* spp.	Adiantiaceae-Pteris	Wet
Savanna	*Monoporites annulatus*	Gramineae (Poaceae)	Dry
	Peregrinipollis nigericus	Caesalpinioides-Brachystegia cf. peltophorum	Dry

FIGURE 7: Palaeoecology and palaeoclimatic indicators of the microflora taxa and the botanical affinity dimensions of the Serravallian coastal swamp depobelt, Niger Delta Basin. (Botanical affinity and paleoecology after Germeraad et al. (1968), Onema et al. (2015) and Olayiwola & Bamford (2016).



Palmae ecological grouping

Boreal conifer ecological grouping

Mixed closed-canopy rainforest, i.e., Dipterocarp ecological grouping

Mixed grasslands, i.e., Poaceae ecological grouping

Fresh-water swamps ecological grouping, e.g., *Stenochlaena palustris*

Lake system prasinophyte algae ecological grouping, e.g., *Pediastrum* spp.

Nypa-style brackish riverine ecological grouping

Rhizophora-style brackish mangrove ecological grouping

Mixed beach/strand-plain ecological grouping

FIGURE 8: Idealistic depositional setting and palaeoenvironmental inference model for the Cenozoic proto-Niger Delta (Adapted after Fjellanger et al., 1996).

Plate 1: Microflora assemblages from the Alakiri Wells, Alakiri Field, Agbada Formation. (Magnifications: (x40). Scale bar represents 20µm.

1. *Araucariacites australis* (Cookson) ex Couper, 1953
2. *Belskipollis elegans* Legoux, 1978.
3. *Corsinipollenites jussiaensis* Nokaman, 1965.
4. *Crassoretitriletes vanraadshooveni* Potoȋie et Gelletich, 1933.
5. *Cyathidites australis* Couper ,1953.
6. *Leiotriletes adriennis* Krutzsch, 1962.
7. *Echiperiporites* spp cf. *minor* ? Salard-Cheboldaeff, 1974
8. *Dictyosporites morularis* Salard-Cheboldaeff and Locquin,1980.
9. Chenopodiaceous type Muller, 1981.
10. *Longapertites marginatus* Van Hoeken-Klinkenberg, 1964.
11. *Fusiformisporites crabbii* Rouse, 1962;
12. *Laevigatosporites discordatus* Krutzsch, 1959.
13. *Latosporite rotundus* Takahashi & Jux, 1989.
14. *Magnastriatites howardii* Germeraad, Hopping & Muller, 1968.
15. *Margocolporites vanwijhei* Germeraad, Hopping and Muller, 1968.
16. *Monoporites annulatus* (Van der Hammen) Potonié, 1960

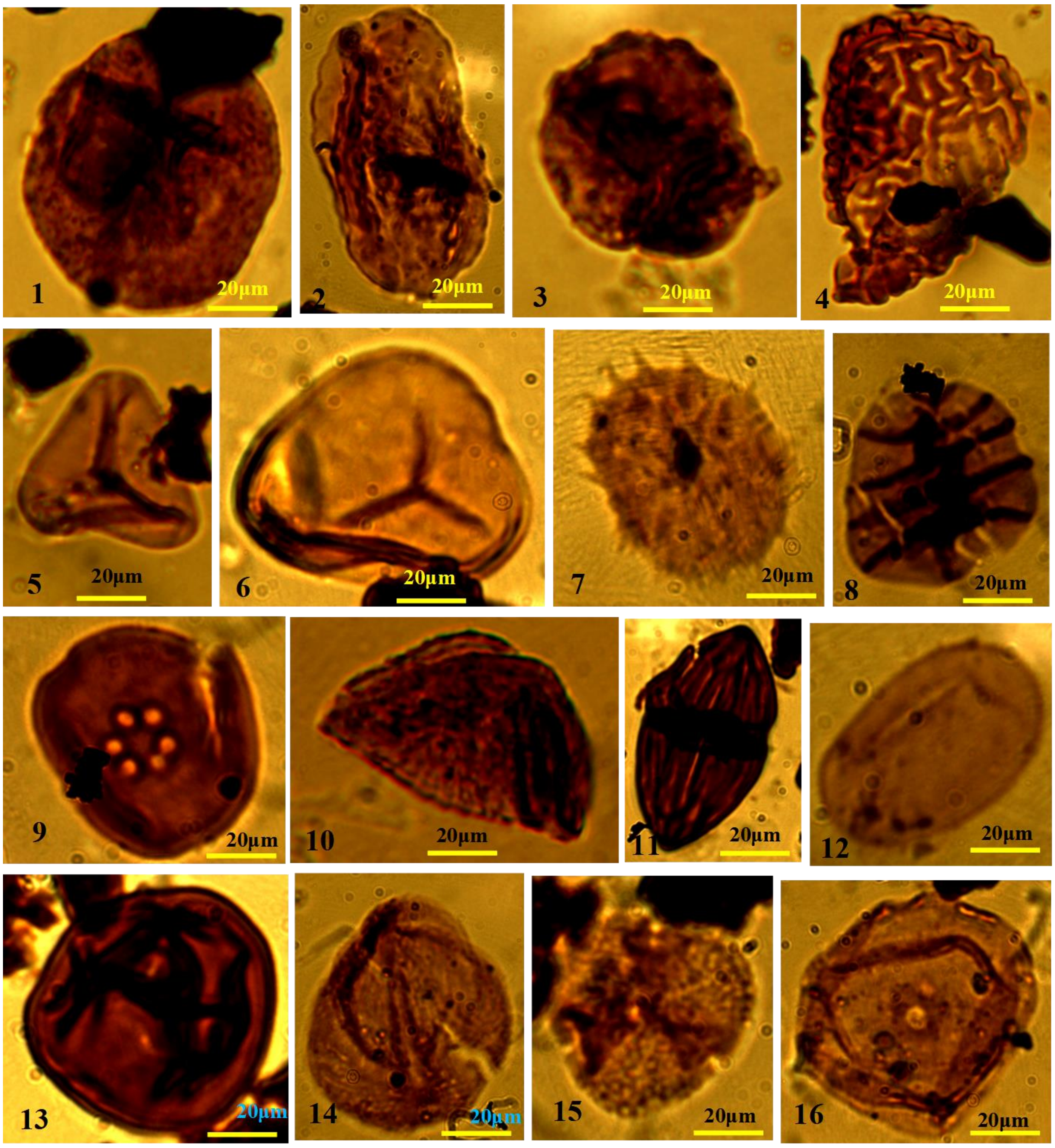


Plate 1: Palynomorph taxa assemblages from the Alakiri wells, Alakiri Field, Agbada Formation.

Plate 2: Microflora assemblages from the Alakiri Wells, Alakiri Field, Agbada Formation. (Magnifications: (x100). Scale bar represents 20µm.

1. *Pachydermites diederixii* Germeraad, Hopping & Muller, 1968.
2. *Peregrinipollis nigericus* Clarke, 1966.
3. *Perfortricolporites digitatus* González Guzmán, 1967.
4. *Brevitricolporites molinae* Schuler and Doubinger, 1970.
5. *Verrutricolporites rotundiporis* Van der Hammen & Wymstra, 1964.
6. *Podocarpidites* spp.
7. *Polyadopollenites indecorus* Takahashi & Jux, 1989.
8. *Psilatricolporites ifeensis* Jan Du Chêne, Sowunmi and Onyike, 1978.
9. *Verrucatosporites usmensis* Van Der Hammen, 1956.
10. Palynomaceral 3.
11. Palynomaceral 2
12. Palynomaceral 4 (Equant)
13. Palynomaceral 1
14. *Zonocostites ramonae* Germeraad et al., 1968.
15. Palynomaceral 2
16. Palynomaceral 1

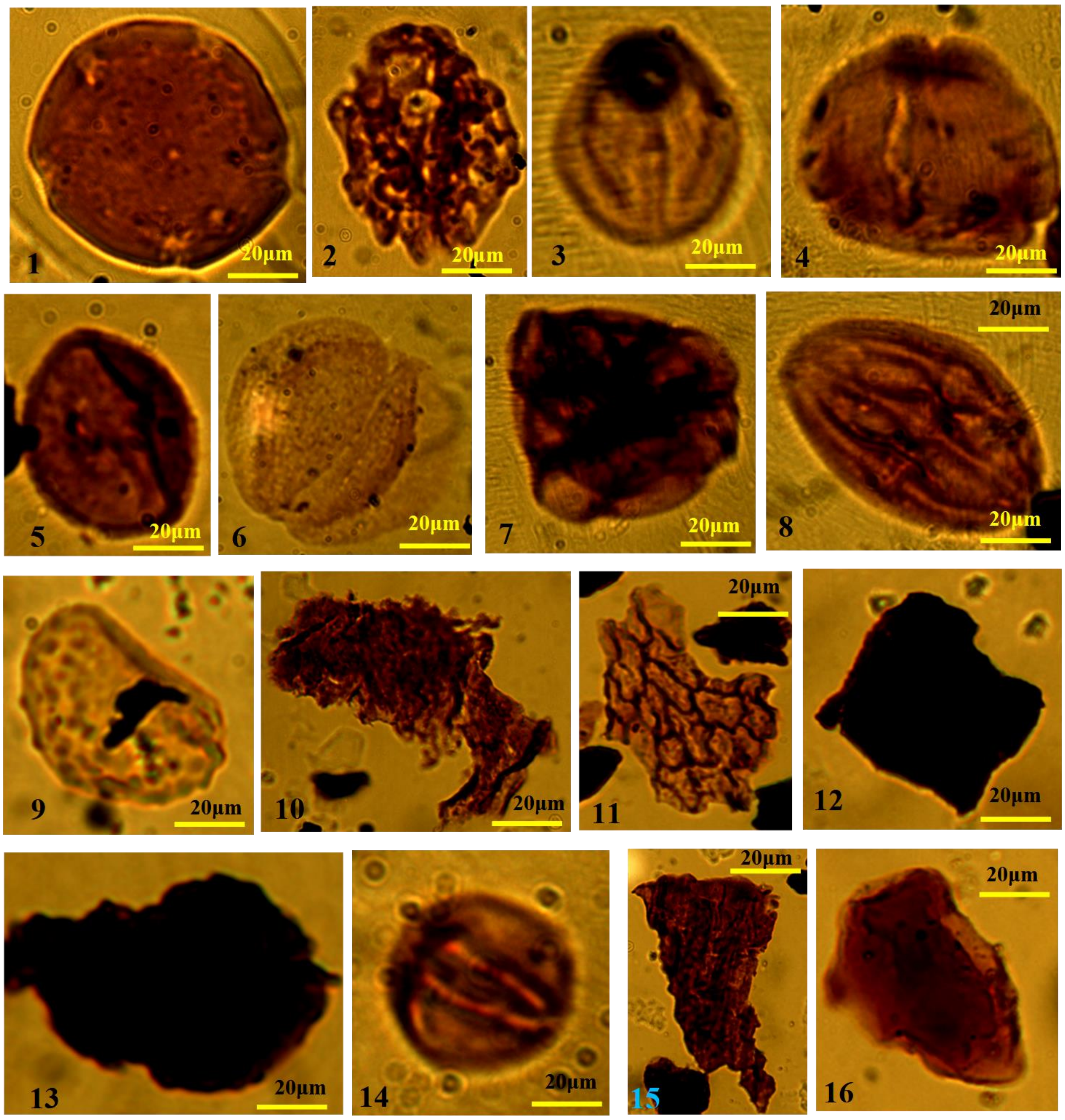


Plate 2: Palynomorph and palynomaceral taxa from the Alakiri Wells, Alakiri Field, Agbada Formation Niger Delta basin.