Research article

Age and paleo-environmental evolution of the Douala Basin (Cameroon) during the Cenozoic: insights from palynology and sequence analysis

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\textbf{ABSTRACT}

The Douala basin in Cameroon is one of the West African basins created during the opening of the South Atlantic Ocean after the break-up of the Gondwana superstructure. Until now, no detailed studies of age and paleo-environmental evolution of this basin during the Cenozoic have been carried out, especially on outcrops sections. Palynological and sequence analyses have been performed on the outcrops in the Missole I and Dibamba localities in the central part of this basin. This integrated approach allows us to propose a new age and paleo-environmental evolution of the Douala Basin. Three palynomorph assemblages have been identified: (i) the Paleocene-Eocene palynomorph assemblage (A) from the Missole I deposits; (ii) the Oligocene palynomorph assemblage (B) from the lower part of the Dibamba deposits; and (iii) the Lower to Middle Miocene palynomorph assemblages (C) from the upper part of the Dibamba deposits. Sequence analysis indicates four depositional sequences with a vertical succession, characterized by major transgressive depositional sequences (depositional sequence “A”, “B”, and “C”), and a minor regressive depositional sequence (“D”). The transgressive sequences were deposited in lagoon or marginal marine environments during Paleocene-Eocene, while the regressive sequence was deposited in prograding continental shelf during the Oligocene-Middle Miocene. The recognized depositional sequence and associated depositional environments were controlled by spasmodic subsidence, margin uplift and climatic variations. Climate evolved from a wet-dry subtropical to tropical during the Paleocene-Eocene and a warm humid subtropical during the Oligocene up to Lower Middle Miocene with overall shift of the Douala basin from the Southern to the Northern hemisphere. This study reveals the existence of Oligocene deposits (Souellaba Formation) in the outcrops and could be useful for future correlation with the offshore part of the Douala Basin.

1. Introduction

The Gondwana break-up and the opening of the South Atlantic Ocean created a series of E-W distension sedimentary basins along the West African margin, which has been known to have evolved in three phases namely: (i) the rifting phase; (ii) post-rift transitional phase (iii) and drift phase (Belmonte, 1966; Reyre, 1966; Njike Ngaha and Eno Belinga, 1987a; Edwards and Bignell, 1988; Brownfield and Charpentier, 2006). Biostratigraphy, seismic stratigraphy and structural studies provided an overview of the paleoenvironmental evolution of this margin during Mesozoic and Cenozoic (Reyre, 1966, 1984; Logar, 1983; Ngueue et al., 1992; Loule et al., 1997). However, most of these studies are highly generalized and do not take into account the specificity of each basin linked to progressive opening of the South Atlantic Ocean. For example, the progressive opening of the South Atlantic from the South to the North during the Late Jurassic to the mid Cretaceous makes the Douala Basin the youngest of the series from the edge of the Niger Delta (Nigeria) to the Walvis Ridge (near the Angola-Namibian border) (Le Pichon and Hayes, 1971; Reyre, 1984). Therefore, the paleoenvironmental evolution of the Douala Basin is critical for better understanding of the evolution of the West African margin especially during the Cenozoic, where many petroleum fields have been discovered.

Up to now, geological information concerning the Cenozoic in the Douala Basin is still very scanty although offshore data concerning this period have been accumulated (cuttings, cores, well logs, seismic sections, etc.) by petroleum companies. Cenozoic formations are generally

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poorly exposed in many parts of the Douala Basin (Figure 1) and have been reported by Reyre (1966); Belmonte (1966); Dumort (1968), Regnoult (1986); Njike Ngaha (2005). The ages assigned to these formations by these authors still remains a subject of debate. Whereas a Paleocene-Eocene age has been assigned to the deposits of the Dizangue outcrop at the Southern part of the basin (Dumort, 1968; Regnoult, 1986), a Maastrichtian to Paleocene age were assigned to those cropping out at the Kompina, Miang, and Fiko localities in the North of the basin (Kenfack et al., 2012). The ages of deposits in the central part of the basin in the Missole I and Dibamba localities remains uncertain. The knowledge of the stratigraphy and depositional sequence of these formations is critical for the reconstruction of the geological history and the depositional environment of the Douala Basin during the Cenozoic. This present work constitutes the first study of environmental data using palynology as biostratigraphic proxy integrated with sequence analysis.

In this paper we present a synthesis of the palynological and sequence analyses performed on the deposits cropping out in the Missole I and Dibamba localities in order to, (1) refine the ages of these formations, (2) propose vertical evolution of depositional sequence and interpret their corresponding depositional environments, and (3) draw a paleoenvironmental evolution of the Douala Basin during the Cenozoic and
integrate it to the regional paleogeographical context of the West African margin during the Cenozoic.

2. Tectono-stratigraphic framework

The Douala basin is one of the three Cameroonian coastal basins located in the central part of the Gulf of Guinea (Figure 1). The basin was formed during the break-up of the Gondwana and the separation between Latino American and African blocks (Reyre, 1966; Njike Ngaha, 1984; Salard-Cheboldaeff, 1990). The Douala basin is characterized by three major tectono-stratigraphic phases (Salard-Cheboldaeff, 1977, 1978, 1979; Nguene et al., 1992; Robertson, 1992; Loule et al., 1997; Benkhelil et al., 2002; Manga, 2008 and Mbesse et al., 2012, Figure 2a).

(I) The Aptian-Albian syn-rift phase: the deposits of this early stage evolution of the Douala Basin consist of a terrigenous proximal alluvial fan sediments as conglomerates coming from igneous and metamorphic rock of the basement, associated with fluviolacustrine sediments as channelised sandstones and foodplain to lacustrine shales (Reyre, 1966; Dumort, 1968, Njike Ngaha, 1984; Regnoult, 1986) (Figure 2a). The vertical organisation and structural characteristic of these deposits with composite gravity sediment at the bottom, follow by a layer of coarse grains forming the grain flow, and at the top finer lacustrine facies correspond to fluxoturbidites (Njike Ngaha, 1984). These syn-rift deposits was named as the "Basal sandstones” or Mundeck Formation (Nguene et al., 1992; Pauken, 1992; Meyers et al., 1996; Ntamak-Nida et al., 2010).

(II) The Albian-Eocene drift (phase I): this phase started with a discrete drift stage linked to the regional tectonic event. It was characterised by a first marine incursion in the Douala Basin with the deposition of marine sediment which is consist of fossiliferous shales and marl (Njike Ngaha, 1984; Nguene et al., 1992). These first marine sediment are different to those identified from Kribi/Campo to Angola Basins which consist of salt series accumulation (Benkhelil et al., 2002). During this phase, the Douala Basin recorded episode of marine transgression during Cenomanian-Turonian and late Cretaceous to lower Cenozoic which correspond to the period of deposition of Logbadjeck (Cenomanian-Campanian), Logbaba (Maastrichtian) and N’kapa (Paleocene-Eocene) Formation (e.g. Reyre, 1966; Dumort, 1968; Regnoult, 1986; Nguene et al., 1992; Coward et al. (1999). The sediments are mainly consist of coarse-grained sandstones, fossiliferous shales, marl, and limestone (Figure 2a). The late Eocene was marked by the interruption of sedimentation due to a major episode of uplift associated to intense erosion in the Douala Basin (see Nguene et al., 1992; Pauken, 1992; Meyers et al., 1996; Ntamak-Nida et al., 2010).

(III) The Eocene-Actual drift (phase II): it was marked by the deposition of the Souellaba (Oligocene) and Matanda (Miocene)
The fossil presented in this study were dated using glycerin jelly and examined with a Leitz ORTHOPLAN microscope equipped with a Leica/Leitz photographic device. Only 9 out of the 22 samples analyzed proved to contain palynomorph. Identifications of the species were made by comparing our results to preexisting work in the tropical regions of Africa (e.g. Germeraad et al., 1968) and the South America (Regali et al., 1974b; Lorentz, 1986; Muller et al., 1987). The ages of the most important taxa were assigned on the basis of data related to the Cameroon basins (Salard-Chlobař, 1977, 1978, 1979; Mbsese, 2013), and comparison with the neighboring basins in Nigeria, Benin and Ghana (Van Hoeken-Klinkenberg, 1966; Germeraad et al., 1968; Bio-Lokoto et al., 1998; Atta-Peters and Salami, 2004b; Chiagham et al., 2012) as well as the North and South American basins (Fiel, 1969; Jaramillo et al., 2011). The fossil presented in this study were not collected from a protected area.

4. Results

4.1. Palynology

Palynological analysis reveals the presence of well-preserved palynomorphs in the Missolé I and Dibamba deposits. All taxa identified in each sample and their counts are presented in Table 1.

The palynomorph assemblages in sample 3SPK17 and 5SPK17 from Missolé I deposits constitute pollen grains, which represents 60% of the total palynomorph count (408), followed by dinoflagellate cysts (21%), spores (17.5%), and tectinous foraminferal test lining (1.5%). The dominant species are Spinizonocolpites baculatus (21%), Proxapertites cursus (15.8%), Striatopollis bellus (13.6%), Biretisporites triglobosus (12.8%), Verrucatosporites usmensis (12.4%). These species are associated with other species such as Psalmonocolpites (monocolpites) medius, Nyssapolloites sp., Monosoricites rarispinosus, Foroecopites pseudoreticulatus, Sabalpollenites sp., Leiotriletes maxoides maxoides, Deltoiopsis sp. Deflandrea sp. 1, Gonyaulacysta sp., Cordosphaeridium sp., Trochamminidae (Figure 4).

The Palynomorphs found in the 11SPK17, 13SPK17, 40AL84, and 41AL84 samples from the lower part of the Dibamba deposits is dominated by continental materials with 38% (pollen) and 14% (spores) of the total palynomorph count (383). In this assemblage, there is overall increase in the percentage of dinoflagellate cysts (48%) whereas tectinous microforaminiferal test lining is absent. Significant taxa of this assemblages include Chiropteridium sp. (31.25%), Polysphaeridium sp. (16%), Creticosporites doroensis (12.5%), Longipollis sp. (6.9%), and Monocollopollenites Groupe C (6.2%), which is associated with other species such as Retihosphorbites striatoaoides, Salixpollenites Groupe B, Hysrichosphaera sp., Phragmothrytes sp., Hysrichosphaeridium sp. 1 (Figure 5).

In the upper part of the Dibamba deposits, palynomorphs were identified in the 52AL84, 49 sup AL84, and 42/42 AAL84 samples. The assemblage is dominated by pollen with 57% of the total palynomorph count (430), followed by the spores (27%), and dinoflagellate cysts (16%). The dominant taxa in these assemblages are Verrucitricolporites rotundiporis (19.6%), Crassoretitites sp. cf. C. vanraadhoveleni (16.28%), Leiotriletes aplehe (13%), Microreticulatisporites densus (10.8%), Schizosporis parvus (8.6%). These taxa are associated with other taxa such as Ephedra sp., Archaeopteris sp. cf. A. Groupe C, Nymphaeapollenites neogenicus, Psilastephanoctinvillea sp., Retitrites sp. aff. R. pseudocalavatias, Hysrichosphaeridium sp. 2, Hysrichosphaeridium sp. 3 (Figure 5).

4.2. Sequence analysis

Several studies about to sequence analysis in continental margin deposits have been focused on sequence stratigraphy and have been based on analysis of stratigraphic base-level fluctuation (Wheeler, 1964; Cross et al., 1993). This assumes that accommodation space should be combined with sediment supply (Cross, 1988; Jervey, 1988; Galloway, 1989; Galloway and Williams, 1991; Muto and Steel, 2002). In this study we focus our attention on the vertical evolution of lithofacies and their, bounding surfaces.

In the Missolé I and Dibamba localities, three main facies associations were recognized in the previous study by (Mfayakou Chavom et al., 2014). The summary of these facies are presented in Table 2. The vertical evolution of these facies allowed us to define two virtual sequences that correspond to the paleoenvironment and paleogeographic evolution of a passive continental margin basin similar to those previously described by (Cogan and Renard, 2006). These includes (i) the transgressive virtual sequence, characterized by conglomerates, coarse-grained sandstone, fine-grained sandstone, siltstone, claystone, marlstone, limestone and shale, and (ii) the regressive virtual sequence includes claystone, limestone, marlstone, siltstone, fine-grained sandstone and coarse-grained sandstone. The vertical succession of these lithofacies in the studied formations were compared to these virtual sequences (Figure 6). Detailed description of these sequences are presented below.
Table 1. Taxonomic list and palynomorph counts of the species found in the Missole and Dibamba deposits.

| Palynomorphs                  | Samples |
|-------------------------------|---------|
|                               | 52AL84  | 49 Sup AL84 | 42/42 AL84 | 41AL84 | 40AL84 | 13SPK17 | 11SPK17 | 5SPK17 |
| Fungal spores                 |         |             |            |         |        |         |         |        |
| Schizosporis parvus           |          |             |            |         |        |         |         |        |
| (this paper)                  |          |             |            |         |        |         |         |        |
| Phragmuthrytes sp             | 12       | 10          |            |         |        |         |         |        |
| Pluricellaasperites sp. cf. P. pailatus |          | 2           | 3          | 2       | 2       | 6        | 5        | 4      |
| Spores                        |         |             |            |         |        |         |         |        |
| Biretisporites triglobosus    |          |             |            |         |        |         |         |        |
| Sah and Dutta (1966)          |          |             |            |         |        |         |         |        |
| Baculatisporites sp. cf. B. primarius |          | 14          | 8          | 7       | 41      | 35       | 26       |        |
| Cicatriciosporites dorogensis |          |             |            |         |        |         |         |        |
| Potonié and Gelletich (1933)  |          |             |            |         |        |         |         |        |
| Crassoretirites sp. cf. C. vanradshooveni Germeraad et al. (1968) | 11 | 13 | 5 | 7 | 7 | 8 | 7 | 8 |
| Detoldaspore sp.              |          |             |            |         |        |         |         |        |
| Fiveasporesites pseudoreticulatus Sah and Dutta (1966) | 8 | 7 | 4 | 28 | 22 | 11 | 22 | 11 |
| Faviricolporites sp. cf. F. baculeferus (in Salard-Cheboldaeff, 1977) | 8 | 7 | 4 | 28 | 22 | 11 | 22 | 11 |
| Gleicheniidites Kerguelensis |          |             |            |         |        |         |         |        |
| (this paper)                  |          |             |            |         |        |         |         |        |
| Laevigatosporites aff. L. discordatus | 0 | 5 | 3 | 3 | 3 | 3 | 3 | 3 |
| Leiotriletes apheres Krutsch (1962) | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 |
| Leiotriletes maxoïdes maxoïdes (this paper) | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 |
| Leiotriletes sp. cf. L. triangulus (in Salard-Cheboldaeff, 1977) | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 |
| Lycopodiumsporites sp. aff. L. discordatus | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| Microreticulatisporites denius (this paper) | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| Pollen grain                  |         |             |            |         |        |         |         |        |
| Araliaeicopollenites sp.      |          |             |            |         |        |         |         |        |
| Acanthorities sp. cf. A. trigonus (in Salard-Cheboldaeff, 1977) | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| Aquilapollenites sp. cf. A. reticulatus (in Salard-Cheboldaeff, 1977) | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| Arecites sp. cf. A. Groupe G. Wodehouse (1933) | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| Auriculapollenites sp. cf. A. reticulatus (in Salard-Cheboldaeff, 1977) | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| Décolpolli sp. cf. D. Groupe C (in Salard-Cheboldaeff, 1977) | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| Ephedra sp.                   |          |             |            |         |        |         |         |        |
| Ephedra sp. n. (type pollen) (this paper) | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| Inaperturopollenites Groupe B. (in Salard-Cheboldaeff, 1977) | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| Inaperturopollenites magnus (this paper) | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Inaperturopollenites sp.      | 5        | 5          |            |         |        |         |         |        |
| Inaperturopollenites sp. cf. I. Groupe C (in Salard-Cheboldaeff, 1977) | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Intriraporollinates sp. cf. I. minimus (in Salard-Cheboldaeff, 1977) | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| Liliacidites sp. cf. L. microreticulatus (in Salard-Cheboldaeff, 1977) | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Longapertites sp. Van Hooken-Klinkenberg, 1964 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 |
| Longapertites sp. B. (in Salard-Cheboldaeff, 1977) | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| Longapertites sp. C. (in Salard-Cheboldaeff, 1977) | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 |
| Longapertites sp. cf. L. brasiliensis (in Salard-Cheboldaeff, 1977) | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 |
| Mauritiidites lehmanii Salard-Cheboldaeff (1977) | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 |
| Monocolpapollenites Groupe C (in Salard-Cheboldaeff, 1977) | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| Monocolpapollenites sp.      | 10       | 10         |            |         |        |         |         |        |
| Monocolpapollenites sp. cf. M. Groupe A (in Salard-Cheboldaeff, 1977) | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Monoporites sp.              | 8        | 8          |            |         |        |         |         |        |
| Monoporpollenites sp.        |          |             |            |         |        |         |         |        |
| Monosulcites aff. Brevispinosus (in Salard-Cheboldaeff, 1977) | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Monosulcites raripinnosus (this paper) | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Monosulcites sp. 2 (in Salard-Cheboldaeff, 1977) | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Monosulcites sp. cf. M. borassoides (in Salard-Cheboldaeff, 1977) | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Multiporтратrate sp. C. (in Salard-Cheboldaeff, 1977) | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| Nymphaceapollenites neogenicus (this paper) | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 |

(continued on next page)
4.2.1.1. Depositional sequence “a”. This sequence is a fining-upward lithofacies succession of about 50 m-thick, characterized at the base by a sharp erosional surface. This erosional surface is over lain by clayey, fine to medium-grained sandstone bed that ranges in thickness between 2 to 15 m here in described as facies Sm (Figure 6). This unit is followed by 5 m-thick bed, characterized by rounded, clayey sandstone, which is greyish in color with shining quartz fragments and described as facies Sg (Figure 6). This unit is interpreted as channel-fill deposit under low energy condition in shallow water environment. Facies Sg is overlain by about 30 m-thick, claystone and clayey siltstone termed facies Fl. Facies Fl show a gradual transition from sandstone to grey/black claystone termed facies FsF (Figure 6). The top of this sequence, is characterized by marlstone that contains marine fossils such as bivalves and gastropod shell fragments as well as terrestrial organic matter. We also identified in the grey to black claystone (Samples 3SPK17 and 5SPK17) some palynomorph assemblage including Angiosperms, pollen grains, Pteridophytes, fungal spores and dinoflagellate cysts. These fine-grained materials are interpreted to have settled out of suspension in a low energy environment.

4.2.1.2. Depositional sequence “b”. Depositional sequence “b” is organized as fining-upward succession of approximately 45 m-thick ferruginous, cross-stratified coarse-grained sandstone with rounded quartz pebbles (facies Gt), which passes vertically to a fine to medium-grained sandstone facies Sg (Figure 6). The cross-stratification are rarely multi-storied with pebbles as lag deposits at base. These lithofacies succession are interpreted as channel-fill deposits setting up by progressive decreasing of the transport energy. The shale and limestone observed at the top of this sequence respectively indicate deep and shallow marine incursions represented by the low thickness (50 cm) of limestone deposit (facies Fc; Figure 6). However, the relative increase in the thickness of shale (Fml) deposit rich in marine fossils (bivalves, gastropods and
Nautilus shell fragments), and organic matter indicates overall deepening in water depths. Some spores as Schizeacea family and dinoflagellate cysts as Hytrichosphaeridaceae and Peridinium family have been observed in these fine-grained facies association (Samples 11SPK17, 13SPK17, 40AL84, and 41AL84).

4.2.1.3. Depositional sequence “c”. This sequence is characterized by clayey sandstone (facies Fmlc, Figure 6) that reaches a thickness of about 45 m-thick. The presence of Angiosperm pollen and a few dinoflagellate cysts (52AL84, 49 sup AL84, and 42/42 AL84) in this sequence are interpreted to represent the transition between transgression to early regression.

4.2.2. Minor regressive sequence

4.2.2.1. Depositional sequence “d”. Depositional sequence “d” comprises continental deposits, characterized by coarse to medium-grained sandstone that exhibit cross stratification (facies St, Figure 6). Depositional sequence “d” is associated with kaolinitic-claystone at the base. The entire sequence reaches a thickness of 45 m with an overall a coarsening-upward trend.

5. Discussion

5.1. Age assignment and paleoenvironmental significance

Despite the poor palynomorphs counts in samples that we studied, the assemblages contained important palynostratigraphic taxa that enabled us to assign relative ages to the Missole I and the Dibamba deposits. The stratigraphic distribution of the palynomorph assemblages A, B, and C that were used in age assignment are shown (Figure 7). We correlated these taxa using the palynostratigraphic zonations proposed by Germeraad et al. (1986) for the tropical regions, Regali et al. (1974) for the Brazilian coastal regions, Lorente (1986) for Venezuela, and Müller et al.
We also compared our results to the existing works in Cameroon (e.g. Salard-Chbolfaeff, 1977, 1979, 1981; Mbesse et al., 2012; Mbesse, 2013; Ngon et al., 2015; Kwetche et al., 2018), neighboring basins e.g. Nigeria, Benin and Ghana (Germeraad et al., 1968; Van Hoeken-Klinkenberg, 1966; Atta-Peters and Salami, 2004b; Bio-Lokoto et al., 1998; Chiaghanam et al., 2012; Okechukwu and Obianuju, 2016), as well as in the northern and southern American basins (e.g. Piel, 1969; Jaramillo et al., 2011).

5.1.1. Missole I deposits

The sediment was deposited in delta plain environment (Mfayakouo Chavom et al., 2014). The palynomorph assemblages identified in the samples from this unit are Paleogene in age (see Ngon et al., 2015; Kwetche et al., 2018). Among the fossil assemblages in this unit, the dominant are Spinizonocolpites baculatus, Proxapertites cursus, Striatopollis bellus, Biretisporites triglobosus, Verrucatosporites usmensis and Gonyaulacysta sp, that are globally known to be associated with sediments of Paleocene to Eocene age (Germeraad et al., 1968; Salard-Cheboldaeff, 1977; Bio-Lokoto et al., 1998; Atta-Peters and Salami, 2004; Chiaghanam et al., 2012). For example although Spinizonocolpites baculatus has been reported with Spinizonocolpites echinatus (absent in the samples that we studied), in the previous study by Salard-Cheboldaeff (1979), who used it to date the Paleocene and Lower Eocene sediments recovered from Kwa-Kwa well in the Douala Basin. Furthermore, Spinizonocolpites baculatus has been used to date the Maastrichtian to Lower Eocene deposits in Benin (Bio-Lokoto et al., 1998); in Ghana (Atta-Peters and Salami, 2004); in Nigeria (Germeraad et al., 1968; Chiaghanam et al., 2012), and in the South American basins (Muller et al., 1987).
Cameroon, *Spinizonocolpites baculatus* was reported by Salard-Cheboldaeff (1979) to the Paleocene and Lower Eocene in the Kwa-Kwa well (Douala Basin). *Proxapertites cursus* has been reported within the Maastrichtian to the Middle Eocene interval in Ghana (Atta-Peters and Salami, 2004), in Nigeria (Van Hoeken-Klinkenberg, 1966; Germeraad et al., 1968), in Cameroon (Salard-Cheboldaeff, 1978, 1979, 1979), whereas Mbesse (2013) assigned Paleocene age to this taxa in the Moulongo, Mamiwater and North Matanda wells in Douala Basin. Jaramillo et al. (2011) fixed the LAD (Last Appearance Datum) of *Spinizonocolpites baculatus* at 61.87 Ma while the FAD (First Appearance Datum) of *Proxapertites cursus* and the LAD were fixed at 65.09 Ma and 41.15 Ma respectively in south and North American basins.

Considering the age of these taxa as Paleocene from the foregoing examples and also their associations with those reported as Eocene e.g. *Biretisporites triglobosus* (Sah and Dutta, 1966), *Verrucatosporites usmensis* (Germeraad et al., 1968) and *Striatopollis bellus* (Sah, 1967), which is considered as Thanetian age in the Missole I deposits (Ngon et al., 2015), we propose Paleocene-Eocene age for the Missole I deposits. This interpretation support the presence of N’Kapa formation in the studied outcrop according to Nguene et al. (1992) stratigraphical scheme.

The Missole I sediments were deposited in delta plain environment (see Mfayakouo Chavom et al., 2014). The association of palynomorph including continental and marine species with the dominance of monocotyledonous plant materials such as *Spinizonocolpites baculatus* and...
Proxapertites cursus indicate a mangrove biome (see Germeraad et al., 1968). These taxa associated with polypodiaceas such as Verrucatosporites usmensis, acritarch and Dinoflagellate cysts e.g. Deflandrea sp. 1, Gonyaulacysta sp., and tectinous foraminiferal test linings represented by Trochamminidaceae, generally characterize lagoon environment which is a transition between continental freshwater and shallow marine salinity water (Figure 10).

### 5.1.2. Dibamba deposits

The palynomorph assemblages recognized in the sample from the Dibamba sediments have two palynomorph assemblages (B and C) that formed the basis of the Upper Paleogene to Lower Neogene, which we propose for this deposits. Precisely, we propose Oligocene age to the Dibamba deposits based on the occurrence of the palynomorph assemblages B, represented by an important taxa (Chiropteridium sp.), which has been previously identified in Oligocene formations (see Gocht, 1960; Dybkjaer, 2004). Furthermore, the Chiropteridium sp., was reported in association with Polyphaeriaidum sp., in the Kwa Kwa well by Salard-Cheboldaef (1979), who assigned Oligocene age to this fossil. Moreover, Cicatricoisporites dorogenis in association with other species such as Monocolopollinite Groupe C, Longapertites sp. C, Retitricolporites striatoides, have been used in dating the Oligocene sediments in the Nigeria (Germeraad et al., 1968), Brazil (Regali et al., 1974), and in other basins in south America (Muller et al., 1987). In the north and South American basins, the LADs and LADs of these species were fixed at 48.61 Ma and 23.03 Ma respectively (see Jaramillo et al., 2011). In Cameroon, this specie has been reported as Oligocene taxa in the Kwa Kwa well sediments by Salard-Cheboldaef (1978).

Based on the palynomorph assemblages C, characterized by Verru- tricolporites rotundiporis along side with Leiotrilites apheres, Schizosporis parvus, Microreticulatisporites densus, and Nymphacepellinotes neogenicus that have been previously reported as Lower Miocene species. In Cameroon, Salard-Cheboldaef (1979) assigned to this species a Lower...
Miocene age in the Kwa Kwa well sediment (Douala basin). Similar interpretation have been made elsewhere in Nigeria (e.g. Gemeraad et al., 1968) and South American basins e.g (Muller et al., 1987).

The Oligocene to Lower Miocene age has also been assigned to the Dibamba deposits according to the age of these taxa. In addition, the presence of *Crassoretitriletes* sp. cf. *C. vanraadshooveni*, whose FAD and LAD were fixed at 14.18 Ma and 3.40 Ma respectively by Jaramillo et al. (2011), permitted us to suggest Oligocene to Middle Miocene age to the Dibamba deposits.

The presence of an Oligocene formation, which corresponds to the Souellaba Formation of Nguene et al. (1992) in the outcrops has been revealed by this palynological analysis. Up to now only the Paleocene, Lower to Middle Eocene and the Lower Miocene have been reported in outcrops studies in the Doula Basin (Regnoult, 1986; Nguene et al., 1992). Although Salard-Chebolaeff (1981), using Dinoflagellate cysts such as *Chiropteridium* sp., *Polysphaeridium* sp., and *Hystrichosphaeridium* sp., interpreted the Dibamba sediments as shallow marine, we propose progradational continental shelf environment based on the presence of Schizaeaceae spores such as *Cicatricosiaporites dorogensis*, *Crassoretitriletes* sp. cf. *C. vanraadshooveni* that are typical of sub-littoral to littoral environment (see Salard-Cheboldaeff, 1981, Figure 11). Our interpretation is also supported by the observed lithofacies succession.

5.2. Paleoclimatic and paleogeographic evolution

According to Reyre (1966), the Late Mesozoic was marked by a warm-dry climatic condition in most part of the West African region. In the Douala Basin, this climatic condition is characterized by the occurrences of certain pollen assemblages such as Ulmaceae, Proteaceae, Restionaceae and also Monocotyledonous like palm ancestors (Nypa). The K/T transition indicates a palynofloral change marked by a progressive climate humidification up to the Early Paleocene (Ojjike Ngaha, 2005). This change could be linked to global cooling observed during the Paleocene Period (Salard-Cheboldaeff, 1981). During the Paleocene-Eocene period, the Douala Basin appears to have been under a wet-dry subtropical to tropical climate attested by the presence of the Palm tree pollen grains in the palynomorph assemblages identified in the

![Figure 6. Sequence analysis of the Missole I and Dibamba localities and inferred depositional environments.](image-url)
Missole I deposits (*Spinisonocolpites baculatus*, *Foveosporites pseudoreticulatus*, *Proxapertites cursus*, *Psilamonocolpites (monocolpites) medius*, *Nyssapollenites* sp., *Monosulcites rarispinosus*). Similar paleoclimatic conditions have been documented during the Paleocene-Eocene period in the adjacent African, South American and Indian sedimentary basins (Morley, 2000; Bankole et al., 2006; Ojo et Akande, 2006; Jaramillo et al., 2007; Garcia et al., 2008; Sahay, 2011). This paleoclimatic condition has also been proposed on the African continent based on its location with respect to the palaeoequator during the Cenozoic (Louvet and Magnier, 1971). The present day Missole I Formation in the Douala basin was located in the southern hemisphere, at the 5° south of latitudes during the Paleocene-Eocene (Figure 9). During this period, especially in the Early Paleocene, the separation of the South American and African blocs in the Late Maastrichtian (Njike Ngaha, 2005), was favored the extension of the equatorial portion of the south Atlantic. The sedimentary basin of this equatorial margin was controlled by frequent subsidence which was spasmodic in the Douala Basin (Reyre, 1966; Lawrence et al., 2002). It is thought to have initiated the installation of oxidizing floodplain environment probably due to rising regional base level (Mfayakouo Chavom, 2016) following the Paleocene to Middle Eocene marginal transgression. Similar marine transgression has been documented by Kenfack et al. (2012) and Mbess et al. (2012) in the northern part of the Douala Basin and in the North Matanda, Moulongo and Mamiwater well, respectively.

The Missole I sediment have been deposited during this transgression phases. The depositional environment has evolved from floodplain to delta plain or lagoon (marginal marine?) environment according to palynological data (Figure 10A and B). In the Missole I locality, subsidence favored the accumulation of the depositional sequence “a” but was interrupted by the margin uplift during the Upper Eocene (Nguene et al., 1992; Lawrence et al., 2002; Benkhelil et al., 2002; Dickson et al., 2003).

This could explain the flexural features that occur on most of the basins along the West African margin (Reyre, 1984). This margin uplift was followed by extensive erosion of the basement and Cretaceous deposits of the late Eocene with regional unconformity (e.g. Manga, 2008). Although, we did not formally identify this unconformity, the 8-10 m-thick, oxidized conglomerates, identified at the top of the Missole I deposits, is interpreted as gravity flow deposits linkable to the late Eocene marginal uplift (Figure 10B).

According to Salard-Cheboldaeff (1981, 1990), the Oligocene and the Lower Middle Miocene were marked by the progressive diversification of palynoflora across the West African coastal regions. However, we note that in the palynomorph assemblages identified in the sample from the Dibamba deposits, the percentages of Pteridophytes fungal spores, and Dinoflagellate cysts decreased, while the angiosperm palm tree and other angiosperm species increased. This suggest that climate evolved from wet dry subtropical to tropical condition during the late Eocene to warm humid subtropical condition during the Oligocene up to the Lower Middle Miocene. This paleoclimatic deductions are on the African continent present position compared to the palaeoequator during the Cenozoic (Louvet and Magnier, 1971). The present-day Dibamba locality in the Douala Basin was located in the northern hemisphere during the Oligocene up to Lower Middle Miocene, approximately between 3° and 5° North latitude (Louvet and Magnier, 1971, Figure 9). During this period, the basin deepening renewed after the late Eocene margin uplift contributing to the installation of the marginal littoral environment (Figure 11A). The marginal littoral environment is supported by the cm-thick limestone facies observed within the depositional sequence “b” dominated by the shale facies with low organic matter content (Figure 6). Nonetheless this environment continues to receive from the surrounding regions flora, spores and pollen grains that suggest the development of the tropical rainforest in the Cameroon littoral margin.
| Zone   | Author                  | TROPICAL AREAS | BRAZIL | VENEZUELA | NORTHERN SOUTH AMERICA | DOUALA BASIN | DOUALA BASIN Present paper |
|--------|-------------------------|----------------|--------|-----------|------------------------|--------------|-----------------------------|
|        |                         | Caribbean zone| Atlantic Zone | Pantropical Zone |                        |              |                             |
| Pleistocene | A. venus               |                |          | Alnigollenites    | A. venus               |              |                             |
| Pliocene | E. meneelyi             |                |          | F. longispinosus  | E. meneelyi            |              |                             |
|        |                         |                |          | Asteraceae       | Echitricolporites      |              |                             |
|        |                         |                |          | Grimsdalea       | spinosus               |              |                             |
|        |                         |                |          | Crassoretiriletes|                         |              | Crassoretiriletes           |
|        |                         |                |          | Palladiporites   |                         |              | sp. cf. C. vanraadhooveni  |
| Miocene | P. ochotleri         | Echitricolporites spinosus |          | C. vanraadhooveni | Crassoretiriletes     |              |                             |
|        | F. ameghini         |                |          | E. marteilla     | E. marteilla           |              |                             |
|        |                         |                |          | P. minimus       |                         |              | Crassoretiriletes           |
|        |                         |                |          | Verraticolporites | Verraticolporites      |              |                             |
|        |                         |                |          | Verraticolporites | spinosus               |              | Verraticolporites           |
|        |                         |                |          | Verraticolporites | /                     |              | Verraticolporites           |
|        |                         |                |          | Verraticolporites | /                     |              | Verraticolporites           |
|        |                         |                |          | Verraticolporites | /                     |              | Verraticolporites           |
|        |                         |                |          | Verraticolporites | /                     |              | Verraticolporites           |
|        |                         |                |          | Verraticolporites | /                     |              | Verraticolporites           |
|        |                         |                |          | Verraticolporites | /                     |              | Verraticolporites           |
|        |                         |                |          | Verraticolporites | /                     |              | Verraticolporites           |
|        |                         |                |          | Verraticolporites | /                     |              | Verraticolporites           |
|        |                         |                |          | Verraticolporites | /                     |              | Verraticolporites           |
|        |                         |                |          | Verraticolporites | /                     |              | Verraticolporites           |
|        |                         |                |          | Verraticolporites | /                     |              | Verraticolporites           |
|        |                         |                |          | Verraticolporites | /                     |              | Verraticolporites           |
|        |                         |                |          | Verraticolporites | /                     |              | Verraticolporites           |
| Oligocene | Cicatricostiporites dorogensis |                |          | Magnastratiates/ Cicatricostiporites | Magnastratiates/ |              |                             |
|        |                         |                |          |  | Cicatricostiporites | Cicatricostiporites | Magnastratiates/ Cicatricostiporites dorogensis | Cicatricostiporites dorogensis |
|        |                         |                |          |  |  |  |  |  |
| Eocene | Late | F. guianensis |                |          |  |  |  |  |
|        |        | P. Operculatus |                |          |  |  |  |  |
|        |        | P. Crassus |                |          |  |  |  |  |
|        |        | Retibrevitriclet |                |          |  |  |  |  |
|        |        | Prosauropites operculatus |                |          |  |  |  |  |
|        |        | Prosauropites operculatus |                |          |  |  |  |  |
|        |        | Prosauropites operculatus |                |          |  |  |  |  |
|        |        | Prosauropites operculatus |                |          |  |  |  |  |
| Paleocene | F. Perforatus |                |          |  |  |  |  |
|        |        | C. Iraeae |                |          |  |  |  |  |
|        |        | Retidipites magdalenensis |                |          |  |  |  |  |
|        |        | Prosauropites operculatus |                |          |  |  |  |  |
|        |        | Prosauropites operculatus |                |          |  |  |  |  |
|        |        | Prosauropites operculatus |                |          |  |  |  |  |

**Figure 8.** Correlation of different palynozone with the present study.

**Figure 9.** Proposed Paleoposition of the West African margin basin during Cenozoic showing different position of the study area compared to paleoequator (modified from Louvet and Magnier, 1971 “All right reserved”).
Figure 10. Paleoenvironmental reconstruction of the Missole I formation in the Douala basin during Paleocene-Eocene period: A) Fluvial to Flood plain environment, B) Delta plain environment.

Figure 11. Paleoenvironmental reconstruction of the Dibamba formation in the Douala basin during Oligocene up to Middle Miocene period: A) Marginal littoral environment, B) Regression of the shoreline.
6. Conclusions

Palynology and sequence analyses of the deposits cropping out in the Missoloe I and Dibamba localities at the central part of the Douala basin allows identification of:

Three Palynomorph assemblages which have been correlated to those defined for the tropical areas and permit us to assign relative ages to these deposits. The Paleocene-Eocene age has been assigned to the palynomorph assemblages A from Missoloe I deposits, while the Oligocene age was assigned to the palynomorph assemblages B from the lower part of the Dibamba deposits. The Lower to Middle Miocene age was assigned to the palynomorph assemblages C from the upper part of the Dibamba deposits. Contrary to the existing knowledge, Oligocene deposits (Souellaba Formation) exist in the outcrops within the Douala Basin.

A predominantly major transgressive and a minor regressive events, represented by lagoon and progradational continental shelf environment occurred during the Paleocene-Eocene and the Oligocene up to the Lower Middle Miocene respectively. These depositional sequence were put in place under the spasmodic subsidence and margin uplift, but probably record a palaeoclimate uplift.

Our study shows that the paleo-geographical evolution of the Douala Basin can be integrated to the regional paleo-geographical evolution of the West African margin during the Cenozoic, considering the position of the basin in relation with the paleo-equator and tectonic plate orientation (Figure 9). However, the impact of the Mount Cameroon uplift in the geodynamic evolution of the Douala Basin still requires further investigation.

Declarations

Author contribution statement

B.C. Mfayakouo: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed resources, materials, analysis tools or data; Wrote the paper.

P.R.N. Ngaha: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

D.L. Bitom: Performed the experiments; Wrote the paper.

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The authors declare no conflict of interest.

Additional information

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