Facies, depositional environment,geodynamic setting, and climatic implications of the Como Formation (lower Aptian) from the Gabonese interior basin

Abstract:

This work presents a sedimentological and palaeoenvironmental study of the Como Formation (early Aptian) in the Gabonese interior basin, based on five outcrop sections and two boreholes (NKG1, WE1). Fourteen elementary lithofacies were identified and grouped into seven Facies Associations (FA1-FA7), encompassing alluvial fans, braided and meandering fluvial systems, vegetated floodplains, deep anoxic lacustrine deposits with bituminous mudstones, cyclic anoxic/mesoxic alternations, deltaic progradation, and terminal evaporitic confinement. Rock-Eval data (TOC 0.45-25.5 wt.%; HI 270-764 mg HC/g TOC; Tmax 427-448 °C) confirm the source-rock potential of the anoxic lacustrine facies within a complete lacustrine petroleum system. Sequence stratigraphic analysis reveals two complete third-order cycles. The first comprises a degradational phase (alluvial fans, braided rivers), a transitional tract (isolated channels, fining-upward conglomerates), and an aggradational anoxic lacustrine phase (black shales, varved dolomitic argillites). The second culminates in a lacustrine maximum flooding surface represented by anoxic bituminous varved argillites at the Cocobeach Landing Stage, and terminates with forced regressive deposits (composite sequence L8). Major erosional surfaces act as sequence boundaries recording pronounced falls in the accommodation-to-supply ratio. This cyclic architecture is superimposed on second-order regional thermal subsidence and modulated by high-frequency climatic forcing and coastward eustatic propagation during the Aptian South Atlantic opening. Regional comparisons with coeval formations on conjugate West African and South American margins (Bucomazi, Mundeck, Lagoa Feia, Itapema) confirm the Pan-Atlantic character of this lacustrine-to-evaporitic episode, driven by post-rift thermal subsidence under a warm, semi-arid palaeoclimate.

Keywords: Early Aptian, Gabonese interior basin, post-rift deposits, lacustrine palaeoenvironments, sequence stratigraphy, South Atlantic.

1. Introduction

The fragmentation of the Gondwana supercontinent and the opening of the South Atlantic Ocean during the Early Cretaceous led to the formation of several intracontinental sedimentary basins along the conjugate West Africa and South America margins. The geodynamic evolution of these basins provides a succession of the primary stages in the formation of an ocean, encompassing active rifting (Neocomian-Barremian), post-rift thermal subsidence (early Aptian), evaporitic confinement (late Aptian), and marine transgression (Albian-Cenomanian) (TeisserencandVillemin, 1990; Moulin et al., 2010; Torsvik et al., 2009).

Among these basins, the Gabonese interior basin is noteworthy as one of the most well-preserved segments of the equatorial West African margin, offering a comprehensive record of the tectonosedimentary evolutionary sequence (e.g. Brice et al., 1982;MbinaMounguenguiand Guiraud, 2009).

Within this sequence, the Como Formation represents the lithostratigraphic unit of the lower Aptian Substagein the Gabonese interior basin (Chevalier et al., 2002; MbinaMounguengui et al., 2006). The transition between the sedimentary materials is recordedby the transition between the syn-rift conglomerate-dominated deposits of the Neocomian-Barremian, controlled by basin-margin normal faults, and the post-rift deposits. These latter are characterised by an architecturecausedby the diffuse thermal subsidence of a sag-type basin (McKenzie, 1978; Carroll andBohacs, 1999) andare regarded as the continental equivalent deposits of the Gamba Formation, a major petroleum reservoir in the southern coastal sub-basin of Gabon (Teisserencand Villemin, 1990; Brink, 1974). The Gamba Formationis also a counterpart of the Bucomazi Formation inAngola and Congo (Brognonand Verrier, 1966) and the Lagoa Feia Formation of the Campos Basin inBrazil (Guardado et al., 1989). These treeformations serve as source rocks for the major petroleum systems of the southern South Atlantic margins. Furthermore, the bituminous mudstones in theseformations exhibit total organic carbon (TOC) values of up to 25.5 wt.%, with Type II kerogen (MbinaMounguengui et al., 2003)suggesting a significant source-rock potential (Peters and Cassa, 1994; Bohacs et al., 2000).

Despite the palaeogeographic and petroleum significance of the Como Formation, its lithofacies,depositional architectures, and palaeoenvironments remain poorly known, as previous studies focused particularly on the Neocomian–Barremian syn-rift series (MbinaMounguengui et al., 2008) and theupper Aptian evaporites (Teisserencand Villemin, 1990).

The present study aims to characterise the lithofacies, the depositional architectures, and the palaeoenvironment conditions of the Como Formation through the analysis of five outcrop sections: MadukuMembo river, Southern Lighthouse, Cocobeach beach, Cocobeach landing stage, Bisséghé river,and cores from two boreholes (NKG1, WE1) located in the Cocobeach, Bifoun, and Lambaréné regions (Fig. 1). This study is focused on three main subjects:1) to describe and interpret the lithofacies of the fluvio-lacustrine succession using classification schemes from previously published work; 2) to reconstruct the palaeoenvironmental evolution within a lacustrine sequence-stratigraphic framework; 3) to integrate the obtained results within a regional Atlantic perspective. Thiswill contributeto improving the understanding of the geological conditions of the post-rift lacustrine petroleum systems of the West African passive margin. This study is also based on stratigraphic data from MbinaMounguengui et al. (2003), MbinaMounguengui et al. (2006), and MbinaMounguenguiand Guiraud (2006).

2. Geographical and geological setting

The Gabonese interior basin (Fig. 1) is extended over approximately 200 km in length and 70 km in width, trending NW-SE and is located between the Cristal Mountains to the north-east and the Lambaréné horst to the south-west (MbinaMounguengui et al., 2002). Structurally, theGabonese interior basin is an intracontinental basin within the province of Central Africa, which emerged through the extension of the Cretaceous rift zones (Guiraud and Maurin, 1992; Genik, 1993). The basin is infilled by a thick sedimentary sequence that spans the temporal range from the Precambrian to the Albian, as evidenced by previous studies by Hudeleyand Belmonte (1970), Chevalieret al. (2002), and MbinaMounguengui et al. (2003, 2008).

The Gabonese interior basin has been identified as a key region in which the primary stages of South Atlantic opening can befound. In this basin, three main lithostratigraphic unitshave been distinguished (e.g., MbinaMounguengui et al., 2003): The first unit of a pre-rift stageis considered to be of Precambrian to Jurassic age; the second of a syn-rift stageis considered to be of Neocomian to Barremian age; andthe latest one of a post-rift stageis considered to be of Aptian-Albianage (Fig. 2).

The structural framework is controlled by three principal categories of seismic fault orientations(see MbinaMounguengui et al., 2003), which are: longitudinal N130-160, transverse N20-60, and N-S faults. The occurrence of E-W faults is comparatively infrequent. A major longitudinal fault with a steep westward dip,called the axial fault, subdivides the basin into two distinct parts: an upstream part and a downstream part (MbinaMounguengui et al., 2002). To the South of Kango, the basin adopts a half-graben configuration, distinguished by an asymmetric synclinal structure, with the Madiela Formation occupying its axial part. There, the Madiela Formation is crossedin its axial plane by a fault. To the North of Kango, the succession exhibits a more or less complex monocline (MbinaMounguengui et al., 2002, 2006).

Within the post-rift unit of the Gabonese interior basin, the Como Formation (Fig. 2) is considered as a lithostratigraphic unit representative of the lower Aptian (Chevalier et al., 2002; MbinaMounguengui et al., 2006). The stratum under consideration here is approximately 50-100 m thick and comprises an alternation of sandstones, dolostones, mudstones, and organic-matter-rich horizons (MbinaMounguengui et al., 2006; MbinaMounguenguiand Guiraud, 2006). It rests in angular unconformity above the Neocomian-Barremian schist series, and is overlain by the evaporite deposits of the Ezanga Formation (Fig. 2), which constitute the regional impermeable seal of the petroleum system (Teisserencand Villemin, 1990; Davison, 1999).

3. Materials and methods

3.1. Field and subsurface data

The present study is based on the sedimentological analysis of five outcrop sections located in three distinct areas of the Gabonese interior basin (Fig. 1; Table): the MadukuMembo river (Fig. 1; Fig. 3a), and the Cocobeach landing stage (Fig. 1; Fig. 3c) sections, in the Cocobeach region on the Atlantic coast; Southern Lighthouse (Fig. 1; Fig. 3b), and Cocobeach beach (Fig. 1; Fig. 3d) sections, in the South ofthe CocobeachQuay Lighthouseregion; and the BisséghéRiver section (Fig. 1; Fig. 3e), in theLambaréné region in the Ogooué valley (BisséghéRiver section (Fig. 1; Fig. 3e), in addition of some cores from two cored boreholes: NKG1 (Fig. 1; Fig. 3f) and WE1 (Fig. 1; Fig. 3g), whose lithostratigraphic features have been descripted byMbina Mounguengui et al. (2006), and MbinaMounguenguiand Guiraud (2006).

3.2. Facies Associations

Lithofacies analysis was conducted according to a two-tier hierarchical approach. At the elementary scale, the lithofacies were classified according to the nomenclature of Miall (1978, 1985, 1996) and the classification of Bohacset al. (2000) for lacustrine and evaporitic facies. At a larger scale, the lithofacies were grouped into facies associations (FA) on the basis of their vertical stratigraphic relationships, sedimentary structures, and sedimentary body geometries. This approach was adopted from the architectural-element analysis approach of Miall (1985, 1996).

The palaeoenvironmental interpretation of each facies association is based on a systematic comparison with established facies models for analogous environments, including alluvial and fluvial systems (Miall, 1996; Blairand McPherson, 1994), alluvial plains and deltaic systems (Galloway, 1975; Postma, 1990), deep anoxic and carbonate lacustrine environments (Kelts andHsü, 1978; Plattand Wright, 1991), and confined evaporitic environments (Warren, 2006).

3.3. Stratigraphic framework and regional comparisons

The vertical stratigraphic organisation of the facies associations was interpreted within the conceptual framework of lacustrine sequence stratigraphy, as developed by CarrollandBohacs (1999), Bohacs et al. (2000), and Keighleyet al. (2003). This framework was then applied to continental successions from comparable post-rift basins.

Finally, the Como Formation was placed in its regional and intercontinental context through systematic comparison with equivalent lower Aptian formations on the conjugate South Atlantic margins, notably the Bucomazi (Angola and Congo), Mundeck (Cameroon), Lagoa Feia, and Itapema formations (Brazil), as well as with Aptian deposits from the Atlantic basins of western Morocco.

4. Results

A detailed examination of five outcrop sections (Bisséghé River, MadukuMembo River, Cocobeach Southern Landing Stage, Southern Lighthouse, and Cocobeach Beach) and cores from two boreholes (NKG1 and WE1) enabled the recognition of fourteen elementary lithofacies, encompassing great conglomeratic facies, sandstone facies with varied sedimentary structures, fine argillaceous and heterolithic facies, and specific evaporitic and carbonate facies (anhydrite, dolostone). These lithofacies are organised into seven facies associations (FA1-FA7), reflecting a complex palaeoenvironmental evolution from proximal fluvial environments to deep anoxic lacustrine settings, deltaic transition zones, and confined evaporitic environments.

4.1. Facies Association 1 (FA1)

- Description

The FA1 (Alluvial fans and proximal braided-river system) is applied to the facies of levels 1 and 2 of the Bisséghé River section. Level 1 (L1) comprises great polymictic grey conglomerates with clasts of granitic and gneissic basement, up to 80 cm in diameter. These clasts are angular to rarely rounded in shape, clast-supported, and locally arranged in imbricated fans. A sparse microconglomeratic matrix and clasts of 0.5 to 10 cm in diameter are also present. Lenticular and channelised structures on a metric scale (0.4 to 2 m) are visible towards the top of the level, particularly in the sandier beds. These conglomerates can be traced along theBisséghé River for several hundred metres and are disposed in terraced steps that rise progressively upstream, suggesting a pronounced palaeoslope. Level 2 (L2) is characterised by the presence of relatively fine polymictic conglomerates, comprising crystalline basement clasts, a sparse coarse matrix, and sandstone with coarse quartz grains,and microconglomeratic elements. These sandstones exhibit localised channelised structures. These facies are organised into fining-upward sequences that are locally well expressed, with clast imbrication (clusters) in places.

- Interpretation

Level 1 (L1). The great polymictic conglomerates with large angular clasts (up to 80 cm) from the crystalline basement, sparse matrix, lenticular and channelised structures, and a stepped arrangement suggestive of a palaeoslope, are characteristic of proximal alluvial-fan deposits (Blairand McPherson, 1994; Postma, 1986). The angularity of theclasts and their exceptional size are indicative of minimal transport by gravity-driven flows, most likely debris flows or mud-rich torrential floods associated with intense tectonic activity (Leeder, 1999; Gloppen and Steel, 1981). The fan-shaped clast arrangement is consistent with traction transport during ephemeral floods on steep proximal fans (Nemecand Steel, 1984).

Level 2 (L2). The presence of relatively fine conglomerates exhibiting clast imbrication and fining-upward sequences, in association with channelised structures within sandstone with very coarse quartz grains, is indicative of a high-energy braided-river system of the Scott or Donjek types (Miall, 1977; Rust, 1978; Miall, 1985). Clast imbrication has been shown to provide a direct palaeohydraulic indicator of current direction (Brayshaw, 1984). The fining-upward sequences record the infilling of active channels by progressive flow-energy waning, a characteristic of bed-load-dominated braided fluvial systems (Miall, 1996).

4.2. Facies Association 2 (FA2)

- Description

The FA2 (Meandering fluvial system and alluvial plain)is represented principally by levels 1 and 2 of the MadukuMembo section, levels 2 and 3 of the Southern Lighthouse section, and levels 1 and 2 of the Cocobeach Beach section. The coarse facies are characterised by the presence of coarse to very coarse sandstones, with sporadic conglomeratic elements. These sandstones exhibit trough and planar cross-bedding structures, with palaeocurrent measurements ranging from N250° to N295° (MadukuMembo,L2). The assemblage is further characterised by the presence of stacked channels (Cocobeach Beach,L2) and polymictic conglomeratic beds with clasts from crystalline basement (5-12 cm), silicified algal-laminated microcrystalline dolostones, and argillaceous sandstone. These are supported by a poorly sorted, very coarse sandstone matrix. These coarse facies gradually transition to medium-grained sandstones exhibiting trough cross-bedding, followed by fine-grained sandstones characterised by centimetric amplitude and horizontal lamination. This sequence signifies a decrease in depositional energy from the base to the top of the succession. The associated fine facies (MadukuMembo,L1) are constituted of grey-blue coarse sandstones with scattered conglomeratic elements (0.2-8 cm), including conglomeratic beds with a coarse sandstone matrix supporting carbonaceous plant debris.

- Interpretation

Large-scale trough cross-bedding in coarse to conglomeratic sandstones, associated with channelised structures and stacked channels, is characteristic of moderate- to high-sinuosity meandering fluvial channel fills, with lateral migration of point bars (Allen, 1970;Miall, 1985; Cant and Walker, 1976). The predominant palaeocurrent direction N250°-N295° suggests a westward to north-westward transport trajectory, which is consistent with the sediment supply from the eastern Congo-Gabon shield (Teisserencand Villemin, 1990). The presence of clasts of silicified algal-laminated microcrystalline dolostone in the conglomeratic beds attests to the reworking of earlier lacustrine carbonate deposits (Gierlowski-Kordeschand Kelts, 1994). The presence of associated carbonaceous plant debris indicates the presence of abundant riparian vegetation along the channel banks (Retallack, 2001). The fining-upward sequence from base to top (conglomerates, coarse sandstones with cross-bedding, fine sandstones with ripples) is indicative of a fluvial channel-fill model (Miall, 1996).

4.3. Facies Association 3 (FA3)

- Description

The FA3 (Floodplain and distal settling zones)has been identified in the level 3 of the Bisséghé River section;the levels 3 and 4 of the MadukuMembo section;the level 4 of the Southern Lighthouse section; and the levels 1 and 4 of the Cocobeach Beach section. The succession comprises grey, locally carbonated, very fine argillaceous sandstones that are very finely laminated and rich in plant debris, interbedded with dolomitic, locally silty, varved mudstones displaying ripple-mimicking undulations (Bisséghé,L3). These facies manifest as minor pluridecimetric sequences characterised by coarsening-upward trends. The associated facies include dark to black paper shales (laminites) that exhibit a tendency to split into thin slabs (MadukuMembo,L3), very fine grey argillaceous sandstones that are characterised by a high plant debris content, with horizontal lamination, intercalated with locally bioturbated fine sandstones (burrows) and organic-matter-rich black-grey varved mudstones (Lighthouse,L4). In the Cocobeach Beach (L1), these facies are characterised by the presence of very fine to fine grey argillaceous sandstones, exhibiting locally undulating horizontal lamination and trough cross-bedding. These sandstones are interbedded with dark grey-green, finely laminated mudstones, which form thinning-upward beds.

- Interpretation

The presence of very fine sandstones with horizontal and undulating lamination, alternating with varved mudstones rich in plant debris in small coarsening-upward sequences, is indicative of deposition on an alluvial plain by suspension settling during flood events and channel overbank spills (Leeder, 1978; Farrell, 1987). Paper shales with fine lamination and organic-matter enrichment have been found to record preservation under conditions of low oxygenation in floodplain depressions (oxbow lakes, crevasse splays) (Smith, 1983; Nanson and Croke, 1992). The presence of bioturbation (burrows) in the more argillaceous sandy beds of level 4 of the Lighthouse section indicates phases of subaerial exposure and biological colonisation (Pemberton et al., 2001). The vertical transition from horizontal to trough cross-bedding observed at Cocobeach Beach reflects a localised increase in depositional energy within a generally low-energy, settling-dominated environment, which is compatible with crevasse splays prograding into the floodplain (Mjøset al., 1993; Smithet al., 1989).

4.4. Facies Association 4 (FA4)

- Description

The FA4 (Deep lacustrine environment under anoxic conditions) is found in two distinct sections of the Cocobeach Southern Landing Stage, specifically in levels 1 and 4. Additionally, it is present in levels 3 and 5 to 7 of the Cocobeach Beach section. The sedimentary succession is characterised by the presence of dark grey to black, unbioturbated, dolomitic varved mudstones with abundant bitumen traces (Landing Stage,L1), black unbioturbated bituminous mudstones impregnated with hydrocarbons (Landing Stage,L4), and dark grey to black paper shales (laminites), fissile (5-10 mm maximum), more or less dolomitic (Cocobeach Beach,L5 andL7). Levels 3 and 5 to 7 of the Cocobeach Beach section also contain more or less dolomitic bituminous mudstones, which split into thin slabs, with bioclasts comprising plant debris and fish remains.

- Interpretation

Black, unbioturbated, varved mudstones enriched in organic matter, impregnated with hydrocarbons, and paper shales with fish remains represent lake-floor deposits in deep, anoxic-to-euxinic conditions (KeltsandHsü, 1978; Bohacset al., 2000). The complete absence of bioturbation and the exceptional preservation of organic matter (bituminous impregnations) are indicative of permanent stratification of the water column (thermocline or chemocline) that prevented any re-oxygenation of the bottom waters (Talbotand Livingstone, 1989; Eugster and Kelts, 1983). Millimetric lamination (varves) has been demonstrated to reflect seasonal variability in detrital input or rhythmic algal blooms (Calvert, 1990). The phenomenon of early dolomitisation is commonly associated with sulphate-reducing bacterial activity in the anoxic sediments of closed alkaline lakes (Warren, 2000; Kelts and Talbot, 1990).

4.5. Facies Association 5 (FA5)

- Description

The FA5 (Shallow lacustrine environment under mesoxic and carbonate conditions)is represented by levels 2, 3, 5, and 6 of the Cocobeach Southern Landing Stage section, and level 1 of the Southern

Lighthouse section. The succession comprises bioturbated dark grey to black dolomitic varved mudstones with tubular burrows (Landing Stage,L2), silty dolomitic mudstones with calcarenitic–carbonate nodules (Landing Stage,L3 and L5), and bioturbated black argillaceous dolostones with abundant burrows (Landing Stage,L6). Level 1 of the Southern Lighthouse section comprises laminated and varved grey to black mudstones, with ahigh or low degree of carbonation, and thin beds of grey-green to grey-blue argillaceous-carbonate, locally dolomitic, siltstone to very fine sandstone. At the base of this level, a black dolomitic breccia with clasts (2 to 6 cm in size) of finely sandy dolostones and varved mudstones, locally rich in plant debris, is present. Argillaceous-dolomitic very fine grey-green sandstones forming 35-70 cm thick beds without visible internal structure (Cocobeach Beach,L4) are also included in this association.

- Interpretation

The presence of tubular bioturbation in varved mudstones and dolostones (Landing Stage,L2 and L6) indicates episodic partial re-oxygenation of the bottom waters, consistent with a shallow,mesoxic lacustrine environment subject to seasonal ventilation (Droserand Bottjer, 1986; Savrdaand Bottjer, 1989). Calcarenitic-carbonate nodules in dolomitic mudstones are interpreted as early diagenetic concretions formed in zones of organic-matter production (Colemanand Raiswell, 1981). The dolomitic breccia at the base of the Southern Lighthouse, level 1 records a gravitational reworking event (i.e., slumping or lacustrine tempestite) of a carbonate-dolostone platform at the margin of the lake (Plattand Wright, 1991). The substantialargillaceous-dolomitic very fine sandstones present in thick beds at Cocobeach Beach,L4 correspond to distal turbidite or storm-suspension deposits in a shallow, semi-confined lake (Gierlowski-Kordeschand Kelts, 2000). Collectively, these facies mirror cyclic bathymetric variations in an alkaline carbonate lake, a phenomenon typical of warm, arid intracontinental basins (Eugster and Hardie, 1978; Bohacs et al., 2000).

4.6. Facies Association 6 (FA6)

- Description

The FA6 (Deltaic and fluvio-shoreline system)is developed in the levels 5 to 8 of the Southern Lighthouse section and levels 6 to 8 of the Cocobeach Beach section. In the Southern Lighthouse section, the sedimentary layers are composed of polymictic conglomerates (L5), which contain rounded clasts (2 to 30 cm) of granite, gneiss, mudstone, and coarse quartz grains. These clasts are supported by a matrix of sand, with rare trough structures. Overlying these conglomerates are coarse to very coarse siliceous compact sandstones that are locally ferruginous, which transition abruptly to a grey-blue mudstone (L6). This is then followed by very coarse siliceous sandstones with large-scale planar cross-bedding (dip 20-35°, amplitude 15-35 cm) that contain rounded to subspheroidal clasts (1 to 6 cm) from the basement, quartz, and algal-structured grains. These grains are locally laminated over 6-8 cm (L7). At Cocobeach Beach, the level 6 comprises laminated grey-green, siliceous, argillaceous-carbonate very fine to fine sandstones, which are locally bioturbated, exhibiting small current ripples, and containing conglomeratic clastsof 10to20 cm in size, along with milky quartzite pebbles measuring between 3 and 4 cm, as well as carbonaceous debris. Load casts and water-escape structures are present at the base. Level 8 exhibits a composite vertical succession from base to top, characterised by blue-green laminated very fine sandstones with minor ripples (0.5 m), followed by blue medium-grained sandstones with trough cross-bedding (1 m), coarse sandstones with planar cross-bedding (1.5 m), massive blue coarse sandstones (0.4 m), and at the summit there are polymictic conglomerates with crystalline basement clasts (0.5 m).

- Interpretation

The polymictic conglomerates with rounded clasts and abundant sandy matrix of Southern Lighthouse, level 5, are interpreted as distributary channel deposits of a delta front or proximal Gilbert-type delta, characterised by high hydraulic competence (Postma, 1990; Massari and Colella, 1988). The siliceous sandstones, characterised by their very coarse texture, exhibit substantial planar cross-bedding (dip 20-35°) at the Southern Lighthouse, level 7. These deposits are interpreted as representing subaqueous sandy bar or high-energy delta-plain channel deposits, exhibiting well-developed foresets(Harms et al., 1982; Allen, 1982). The presence of clasts exhibiting algal structures (i.e.,oncoids or intraclasts with silicified stromatolitic laminations) in level 7, facies indicates reworking of lacustrine carbonate bioconstructions at the basin margin (Cohen, 2003; Platt and Wright, 1991). At Cocobeach Beach, load casts and water-escape structures at the base of level 6 record the destabilisation of water-saturated sediments during rapid deposition (Lowe, 1975; Owen, 1987). The coarsening-upward composite sequence of level 8 (ripples, trough cross-bedding, planar cross-bedding, massive conglomerate) is indicative of a lacustrine transgressive sequence generated by the erosion of prograding distributary channels (Galloway, 1975; Postma, 1990). Local bioturbation in fine sandstones of Cocobeach Beach, level 6, may indicate shallow-water conditions with sporadic benthic colonisation (Pemberton et al., 2001).

4.7. Facies Association 7 (FA7)

- Description

The FA7 (Confined evaporitic and carbonate environment)has been documented exclusively in cores from the boreholes NKG1 and WE1. In borehole NKG1,level 1 corresponds to dolomitic limestone and level 2 to very fine sandstones with beds of crystalline anhydrite. Borehole WE1 exhibits alternations of clay and sandstone in level 1, accompanied by crystalline anhydrite beds. These evaporitic facies are not visible in surface outcrops, most likely due to their solubility and susceptibility to meteoric weathering.

- Interpretation

The presence of crystalline anhydrite in repeated beds within fine-grained sandstones and clay-sandstone alternations indicates an evaporitic precipitation environment under confined, hydrologically negative conditions (i.e., where evaporation exceeds inputs) (Warren, 2006; Kendall, 1992). Crystalline anhydrite ($CaSO_4$) has been observed to precipitate in hypersaline settings, typically in sabkhas or hypersaline intracratonic lakes, when temperatures and evaporation rates are high (Schreiber and El Tabakh, 2000; Hardieand Eugster, 1970). In the context of the Gabonese interior basin during the Aptian, these evaporitic deposits form part of the phase of progressive desiccation of the Gabonese interior basin, preceding or accompanying the Aptian marine transgression of Central West Africa, by analogy with the saliferous deposits (Loeme Salt) of the Lower Cretaceous of West Africa (Davison, 1999; Brownfield and Charpentier, 2006). The dolomitic limestone of NKG1, level 1, is indicative of a shallow, hypersaline or organo-sedimentary carbonate platform (microbialites), which is consistent with the carbonate lagoonal-to-lacustrine environments that were recognised during the Aptian in the Gabonese interior basin (Brice et al., 1982; Kelts andHsü, 1978).

5. Discussion

5.1. Palaeoenvironmental synthesis and basin evolution in a post-rift context

Analysis of the seven facies associations (FA1-FA7) has revealed a complexpolyphasicpalaeoenvironmental evolution during the early Aptian in the Gabonese interior basin. This evolution is entirely inscribed within a phase of post-rift thermal subsidence (sag basin), which is consequent upon the cessation of the Neocomian-Barremian crustal extension. This geodynamic framework exerts a decisive control over the accommodation space generation and the nature of detrital inputs (Leeder and Gawthorpe, 1987; SchlischeandWithjack, 2009).

The stratigraphic succession delineates an evolution in three principal stages, characteristic of intracontinental sag basins at incipient passive margins:

Stage 1, which corresponds to the phenomenon of residual syn-rift inheritance, along with the transition to the post-rift regime (FA1-FA2), is of particular interest in this study. At the base of the lithostratigraphic sequence, alluvial-fan and proximal braided-river deposits (FA1) are indicative of residual activity of rift-margin faults, with pronounced relief and direct sediment supply from the crystalline basement of the Congolese craton (Teisserencand Villemin, 1990). The exceptionallygreat-sized clasts (up to 80 cm) and angularity of the clastic material suggest short-distance gravitational transport, characteristic of proximal alluvial fans developed at the foot of normal faults (Blairand McPherson, 1994; Leeder, 1999). The transition from these proximal facies to a meandering fluvial system (FA2) is indicative of a progressive diminution of differential tectonic subsidence and the establishment of an organised drainage system in a basin whose topography was being homogenised by diffuse thermal subsidence (Gawthorpeand Leeder, 2000).

Stage 2corresponds to a Lacustrine flooding maximum and bathymetric fluctuations (FA3-FA5). The formation of a vegetated alluvial plain (FA3) is indicative of the structuring of a fluvio-palustrine system within a gradually subsiding plain. The subsequent development of a deep lake under anoxic conditions (FA4) represents the lacustrine flooding maximum (lacustrine flooding surface sensu CarrollandBohacs,1999), conditioned by the progressive deepening of the sag basin and a positive hydrological budget favouring permanent water-column stratification (Bohacset al., 2000). The alternations between anoxic (FA4) and bioturbated mesoxic (FA5) conditions are interpreted as reflecting high-frequency orbital lake-level fluctuations (Milankovitch cycles of 21 ka or 100 ka), inducing variations in the accommodation-to-sedimentation ratio (A/S ratio sensu CarrollandBohacs, 1999) and episodes of partial re-ventilation of the deep waters.

Stage 3 is characterised by regression and evaporitic confinement (FA6-FA7). The progression of deltaic systems (FA6) marks a regressive phase accompanied by an increase in detrital inputs, most likely related to a decrease in the rate of thermal subsidence or to an intensification of climatically driven fluvial supply. The evaporitic facies (FA7), documented exclusively from boreholes, attests to a phase of extreme confinement and partial desiccation of the basin, consistent with the underfilled lake basin context (Carroll andBohacs, 1999) preceding the Aptian marine transgression of Central West Africa (Brownfieldand Charpentier, 2006; Davison, 1999).

This vertical evolution from coarse fluvial systems (FA1-FA2) through anoxic organic-matter-rich lacustrine stages (FA4) to evaporitic deposits (FA7) is characteristic of intracontinental rift basins in the phase of post-rift thermal subsidence (Leeder and Gawthorpe, 1987; SchlischeandWithjack, 2009), a model consistent with the geodynamic setting of the Gabonese passive margin during its individualisation in the Aptian (Brice et al., 1982; Teisserencand Villemin, 1990).

5.2. Palaeocurrent analysis and post-rift drainage organisation

Palaeocurrent measurements derived from directional sedimentary structures (trough cross-bedding, and clast imbrication) range from N240° to N340°, with a dominant NW-NNW trend (N315° at Bisséghé; N250°-340° at MadukuMembo; N240°-300° at Southern Lighthouse; N320° at Cocobeach; and N250°-340° from borehole data). This convergence indicates a regionally organised sediment-transport system directed towards the north-western sector of the basin, controlled by palaeogeographic relief inherited from the eastern cratonic margin. The low angular dispersion of flow directions is indicative of an axial to sub-axial drainage system, which is characteristic of post-rift basins. In such cases, sediment routing is linked to topographic gradients, established during earlier rifting phases rather than active tectonic segmentation (Allenand Allen, 2013; Leeder, 1999). The absence of multimodal dispersion, which would indicate control by active normal faults generating transverse relief, confirms the post-rift nature of the materials of the Como Formation.

5.3. Structural framework and control of post-rift sedimentation

A structural analysis was conducted, which revealed polyphase deformation affecting the Como Formation. This analysis highlights the prominent role of inherited structures in the basin architecture. At MadukuMembo, the stratification displays a N20°E and N180° orientation, exhibiting a gentle westward inclination of 10°-15°, intersected by N80°-100°E faults dipping southward at 50°-60°. At the Southern Lighthouse, a significant N160°-170°E fault dipping at 70° towards the SW places the Como Formation in tectonic contact with the Neocomian-Barremian schist series, indicating late tectonic reactivation along the pre-existing structures.

Secondary fault systems (N125°-145°E), dipping NE (~65°), locally generate early synsedimentary deformation structures, notably drag folds in argillaceous facies, which can be attributed to differential compaction and moderate tectonic reactivation. The variability of structural orientations suggests a complex stress field, consistent with the reactivation of basement structures during the post-rift evolution (Guiraud and Maurin, 1992; Genik, 1993).

Nevertheless, despite this evident structural inheritance, the sedimentary architecture of the Como Formation exhibits no compelling evidence of active synsedimentary tectonic control.There are no major intraformational unconformities, and facies associations demonstrate lateral continuity over tens of kilometres. Sedimentation in this region appears to be dominated by diffuse post-rift thermal subsidence, with tectonic structures playing a passive role in controlling basin geometry and sediment routing (Cloetingh et al., 1990). The angular unconformity observed in boreholes between the Como Formation and the underlying formations is indicative of a tectonic phase predating deposition, corresponding to the initial structuration of the basin during the Neocomian-Barremian rifting.

5.4. Geochemical characterisation and petroleum implications

The geochemical characterisation of the Como Formation is based on Rock-Eval analyses performed on bituminous mudstones from the Cocobeach region. These analyses yield total organic carbon (TOC) values ranging from 0.45 to 25.5 wt.%, Tmax values from 427 to 448 °C, and hydrogen index (HI) values from 270 to 764 mg HC/g TOC.

The data indicate the presence of organic-matter-rich intervals dominated by Type II to mixed Type II/I kerogen (sensu Tissotand Welte, 1984), derived from lacustrine algal and continental inputs, with maturity ranging from immature to early mature (early oil window, Tmax 427-448 °C; Petersand Cassa, 1994). The high TOC values (up to 25.5 wt.%) and HI values (up to 764 mg HC/g TOC) are indicative of lacustrine source rocks of exceptional quality, comparable to the best Aptian lacustrine source rocks described from South Atlantic basins (Briceet al., 1982; Teisserencand Villemin, 1990).

The sedimentological context of these bituminous mudstones, associated with stratified deep-lake (FA4), and shallow-to-mesoxic lacustrine transition environments (FA5) confirms their interpretation as effective source rocks formed under reducing to euxinic conditions (Bohacset al., 2000; Katz, 1990). The restriction of geochemical data to the single Cocobeach region limits the evaluation of lateral variability in petroleum potential at the basin scale.

From a petroleum systems perspective, the Como Formation exhibits the fundamental components of a functional system. The source rocks are represented by organic-matter-rich lacustrine mudstones (FA4-FA5); potential reservoirs correspond to fluvial and deltaic sandstones (FA2, FA6); and the seal is provided by evaporitic and fine lacustrine facies (FA7), as well as by the evaporites of the overlying Ezanga Formation. This stratigraphic organisation is indicative of the lower Aptian post-rift lacustrine petroleum systems of West Africa, which are distinguished by their high hydrocarbon potential (Teisserencand Villemin, 1990; Brownfield and Charpentier, 2006).

5.5. Comparisons with reference facies models

5.5.1. - Fluvial facies models

The architectural-element analytical framework of Miall (1985, 1996, 2006) enables a precise characterisation of the fluvial facies of the Como Formation. The FA1, which is characterised by the GB (Gravel Bars and Bedforms) and SG (Sediment Gravity Flows) elements of Miall, corresponds to the bed-load-dominated braided-river stage (braided, Donjek to Scott type). The presence of conglomerates exhibiting clast imbrication, channelised structures (element CH), and fining-upward sequences with erosional bases is fully consistent with the Donjek-type braided-river model of Miall (1977, 1985), characterised by an alternation of active channels and gravel bars with longitudinal migration.

The FA2, characterised by substantial large-scale trough cross-bedding and stacked channels, is congruent with the meandering-river model proposed by Miall (elements LP: Lateral Accretion Macroforms and CH: Channel fills), exhibiting moderate to high sinuosity and lateral point-bar migration. The dominant palaeocurrent direction (N250°-N295°) is consistent with an organised axial drainage system, which conforms to the Miall (2006) model for post-active rift basins. The FA3, distinguished by its fine facies with horizontal and undulating lamination, corresponds to the Floodplain Fines (FF) element of Miall, with intercalations of Sandy Bedforms (SB) elements in the crevasse-splay levels. The complete vertical succession (FA1, FA2, and FA3), from braided coarse facies to fine settling-dominated alluvial plains, reproduces the post-rift fluvial basin-fill model described by Miall (2006) for passive margins in the process of formation.

5.5.2. - Lacustrine basin classification

The tridimensional genetic model of Carroll andBohacs(1999), and Bohacs et al. (2000) distinguishes three fundamental types of lacustrine basin according to the ratio between available accommodation space (A) and total input volume (water + sediment, S). The overfilled lake ($A/S < 1$) is characterised by a preponderance of fluvio-deltaic facies, which renders it suboptimal for hydrocarbon generation. The balanced-fill lake ($A/S \approx 1$) is distinguished by substantial bathymetric fluctuations and is conducive to the preservation of organic matter. Conversely, the underfilled lake ($A/S > 1$) is dominated by evaporitic facies within a negative water-balance context.

The succession of the Como Formation, from FA2 toFA5 and FA7, provides a clear illustration of the transition from a state of overfilling (FA2-FA3: fluvio-deltaic facies, shallow lake) through a balanced-fill phase (FA4-FA5: stratified anoxic deep lake with cyclic bathymetric fluctuations) to an underfilled state (FA7: evaporites, lacustrine sabkha) during the Early Cretaceous. This evolution corresponds to a progressive decrease in the A/S ratio, linked to the reduction of thermal subsidence rates and increased evaporation in the warm, arid Aptian palaeoclimate (CarrollandBohacs, 1999). The coexistence of organic-matter-rich source rocks (FA4) and sandy reservoirs (FA2, FA6) in a balanced-fill to underfilled basin is precisely the configuration most favourable for the formation of an effective lacustrine petroleum system, as described by Bohacset al. (2000).

5.5.3. - Sequence stratigraphic analysis

The analysis of the five studied outcrops permits the reconstruction of a coherent sequence-stratigraphic framework within the geodynamic context of the Aptian post-rift stage of the Gabonese interior basin. At this stage of basin evolution, the Neocomian–Barremian rifting phase had ceased, and slow, regionally extensive thermal subsidence became the principal mechanism controlling accommodation generation. This interpretation is consistent with the lithospheric stretching and thermal relaxation model of McKenzie (1978), as subsequently developed for sedimentary basin analysis by AllenandAllen (2005). In the Gabonese interior basin, this post-rift regime has been documented by TeisserencandVillemin (1990), and Brink (1974). It exerted a fundamental control on the nature, magnitude, and frequency of the stratigraphic cycles recorded in the outcrops by imposing a low but regionally persistent rate of accommodation creation, in marked contrast to the differential tectonic subsidence that characterised the preceding syn-rift stage.

The recognition of key bounding surfaces provides the basis for the sequence-stratigraphic interpretation. The most prominent erosional surfaces correspond to the basal conglomeratic of level L1 at Bisséghé and MadukuMembo, the stacked channel complexes of Cocobeach Beach,L2, and the basal gravity-flow breccia of the Southern Lighthouse,L1. These surfaces are characterised by sharp erosive contacts between coarse-grained deposits and the underlying finer-grained layers. They record pronounced decreases in the accommodation-to-sediment supply ratio (A/S), as defined by Jervey (1988) and Cross (1988), and are therefore interpreted as sequence boundaries sensu Currie (1997). The clearly erosional base of level L5 at Maduku, marked by reworked pebbles, represents the most clearly expressed ravinement surface observed in outcrop. In the conceptual framework of Wheeler (1964), these surfaces correspond to major chronostratigraphic discontinuities, separating intervals of preserved sedimentary record from phases of no-deposition or erosion. In a post-rift setting, such surfaces are not interpreted as the direct product of active normal faulting, but rather as the result of lacustrine base-level falls controlled by climatic fluctuations and, in coastal sectors, by marine eustatic variations transmitted landwards, following the mechanisms described by PosamentierandVail (1988) and subsequently applied to continental successions by ShanleyandMcCabe (1994).

The analysis of stacking patterns, based on the fluvial facies classification of Miall (1978, 1996), reveals a cyclic vertical architecture controlled by the alternation of coarse-grained, fluvial-dominated systems tracts and finer-grained lacustrine or floodplain-dominated systems tracts. Two complete A/S cycles can be identified. The first oneis recorded mainly at Bisséghé and MadukuMembo, and itstarts with a degradational phase marked by the deposition of proximal alluvial-fan deposits containing angular granitic and gneissic basement clasts at Bisséghé,L1, together with massive to bedded braided-fluvial deposits at MadukuL1–L2. These deposits indicate an A/S ratio substantially below unity. The alluvial-fan facies, characterised by angular clasts up to 80 cm in diameter and fan-shaped depositional geometries, correspond to the high-energy depositional systems described by BlairandMcPherson (1994), typical of basin margins affected by residual relief and active denudation. In this Aptian post-rift context, the palaeocurrent directions measured at Maduku, ranging from N250° to N295°, are not interpreted as reflecting active syn-rift fault-scarp drainage. Instead, they are more probably recording the erosion of residual relief inherited from the rift phase, progressively denuded and peneplained during the post-rift landscape evolution, in agreement with models of passive-margin geomorphological development in West Africa proposed by DoustandOmatsola (1990). The basal gravity-flow breccia of Southern Lighthouse,L1, records instability along lacustrine basin margins inherited from the rift-related palaeotopography and remobilised downslope under residual-gradient conditions, without requiring active syn-rift seismicity.

This degradational stage passes upwards into a transitional systems tract characterised by conglomerates displaying fining-upward trends and cluster-imbricated clasts at Bisséghé,L2, together with isolated lenticular channels with erosive bases at MadukuL4-L5. These features indicate a progressive rise in base level and a corresponding increase in the accommodation, consistent with the sequence-stratigraphic concepts of Crosset al. (1993). The aggradational phase culminates in the establishment of an anoxic lacustrine environment, represented by papery, unbioturbated black shales at Maduku,L3, and by fine-grained clayey sandstones to varved dolomitic argillites at Bisséghé,L3. Within these deposits, small-scale, decimetre-thick coarsening-upward successions indicate the progradation of distal bars within a shallow lacustrine setting, consistent with lacustrine progradation models described by Gierlowski-KordeschandKelts (1994).

The second cycle, recorded principally at Southern Lighthouse and Cocobeach Beach, reproduces a comparable organisation. It starts with a degradational phase comprising massive polygenic conglomerates and stacked channel bodies at the Southern Lighthouse,L2-L3, and Cocobeach,L2. This is followed by a transitional phase represented by distal, bedded conglomerates and bioturbated sandstones displaying current ripples and load structures at the Southern Lighthouse,L5, and Cocobeach,L6. The cycle culminates in a lacustrine aggradational phase represented by varved, dolomitic, and bituminous black shales at Cocobeach,L3, L5, and L7. The CocobeachSouthern Landing Stage outcrop, composed entirely of anoxic bituminous, dolomitic varved argillites with high total organic carbon contents and a complete lack of bioturbation in levels L1 and L4, represents the lacustrine maximum flooding phase of this second cycle. It may be regarded as the continental equivalent of a maximum flooding surface sensu ShanleyandMcCabe (1994) and Van Wagoner et al. (1990).

These organic-rich intervals with high source-rock potential correspond to the category of persistently chemically stratified meromictic lakes defined by CarrollandBohacs(1999), in which bottom-water anoxia favours the preservation of organic matter. Their development as lacustrine source rocks is consistent with the Aptian post-rift evolution of the Gabonese interior basin, as discussed by BrownfieldandCharpentier (2006) forWest African petroleum systems. In this context, regional thermal subsidence generated slow but sustained accommodation, promoting the accumulation and preservation of organic matter within a stratified meromictic lake system, in accordance with the models of Katz (1990) and Bohacset al. (2000). Finally, the composite L8 sequence at Cocobeach Beach, organised as an inverse coarsening-upward succession from Sr to St, Sp, Sm and Gm facies, announces the degradational phase of a third cycle. This succession is interpreted as the progradation of a regressive wedge in response to base-level fall, consistent with the forced-regression model of Plintand Nummedal (2000).

With regard to external controls, post-rift thermal subsidence represents the dominant low-frequency forcing mechanism, sensu McKenzie (1978), imposing a low and regionally uniform rate of accommodation generation. Within this post-rift framework, most medium- and high-frequency variations in the A/S ratio were controlled by two complementary mechanisms. Climatic forcing appears to have played a major role. The widespread occurrence of varved argillites throughout the studied outcrops, notably the Bisséghé,L3, the Southern Lighthouse,L1 and L4, the Cocobeach,L5, and the Southern Landing Stage,L1-L3, records pronounced seasonality in detrital supply and organic productivity, comparable to the lacustrine rhythmites described by TalbotandAllen (1996). Episodes of basin-floor anoxia, recorded by bituminous black shales containing fish remains in the Cocobeach,L3, and by high-TOC, unbioturbated intervals in the Southern Landing Stage,L4, indicate warm and humid climatic phases associated with strong thermal stratification of the lake. These conditions correspond to positive hydrological-balance lake types as defined by CarrollandBohacs(1999), which are particularly favourable to organic-matter preservation, as also discussed by Katz (1990). Conversely, the coarse-grained conglomeratic intervals associated with flash-flood regimes may record comparatively more arid phases following models of fluvial-system response to climatic variability proposed by Olsenet al. (1995).

Marine eustatic forcing also appears to have influenced the coastal sectors of the Gabonese interior basin. The presence of algal oncoids in Southern Lighthouse,L7, indicates a photic, well-illuminated littoral lacustrine environment, sensu Gierlowski-KordeschandKelts (1994). In addition, the geometry of the transgressive succession in the Cocobeach,L8, suggests interaction between lacustrine base-level fluctuations and relative sea-level variations, consistent with the continental–coastal coupling described by ShanleyandMcCabe (1991, 1994). This coupling would have been particularly effective in a post-rift context because the progressive opening towards the Atlantic marine domain during the Aptian, as documented by Teisserencand Villemin (1990), and Briceet al. (1982), favoured the landward propagation of eustatic signals through regional base-level adjustment.

Overall, the five studied outcrops record the evolution of a fluvio-lacustrine depositional system undergoing post-rift maturation. The system was organised along a distal depositional ramp extending from residual-relief alluvial fans at Bisséghé to a meromictic lacustrine depocentre at Cocobeach Southern Landing Stage. This architecture is consistent with ramp-style lacustrine basin models developed for post-rift settings by Bohacset al. (2000). The succession is structured by two complete third-order sequence-stratigraphic cycles, sensu Currie (1997) and Olsenet al. (1995), superimposed on second-order regional thermal subsidence related to lithospheric relaxation, as described by McKenzie (1978) and AllenandAllen (2005). These cycles were further modulated by high-frequency climatic forcing, expressed by varved rhythmites and episodes of basin-floor anoxia, and by coastal eustatic forcing whose influence increased towards the distal, more marine-connected parts of the basin, in accordance with the sequence-stratigraphic model of ShanleyandMcCabe (1994).

5.6. Comparisons with Aptian post-rift deposits of the South and central Atlantic margins

5.6.1.Regional geodynamic context and stratigraphic positioning

The Como Formation is part of the transition from the late rift to the early post-rift phase of the African South Atlantic margin, evident across all conjugate margins of West Africa and South America through a distinctive succession of rock formations. The sequence of deposits under consideration can be categorised as follows, from bottom to top: coarse fluvio-lacustrine syn-rift deposits (Neocomian); deep organic-matter-rich post-rift lacustrine deposits (Barremian-Early Aptian); and pre-transgressive evaporitic confinement deposits (late Aptian); and finally, marine transgression and open carbonate to siliciclastic deposits (Albian-Cenomanian) (Teisserencand Villemin, 1990; Brice et al., 1982).

The Como Formation, which belongs to stages 2 and 3, is thus the stratigraphic and genetic counterpart of formations recognised across the entire circum-southern and northern Atlantic regions.

5.6.2.Congo and Angola basins

The Bucomazi Formation (lower-middle Aptian) of the Cabinda Basin (offshore Angola-Congo) has been identified as the most direct stratigraphic analogue of the Como Formation in Gabon. The lacustrine bituminous mudstones of the Bucomazi Formation, with TOC values reaching 8-12 wt.% and Type I-II kerogen, represent the principal source rock of the petroleum systems of the Angola and Congo basins (Brognonand Verrier, 1966; Brownfieldand Charpentier, 2006). The depositional conditions (stratified deep lake, bottom-water anoxia, early dolomitisation, varve facies) and geochemical characteristics (Type II kerogen, Tmax indicating early to moderate maturity) of the above sites are similar to those documented in the Como Formation. This is evidence of the palaeogeographic continuity of the Aptian intracontinental lake from Gabon to Angola, before the compartmentalisation of the large West African basin by transform faults (Teisserencand Villemin, 1990; Brownfield and Charpentier, 2006).

5.6.3. Cameroon basin

The Mundeck Formation (Aptian) of the Kribi-Campo sub-Basin (southern Cameroon) presents facies associations comparable to those of the Como Formation. Itconsistsof proximal fluvial basal conglomerates, fluvial sandstones with trough cross-bedding, lacustrine organic-matter-bearing mudstones, and intercalated carbonate layers (Ntamak-Nida et al., 2010). Analysis of the stratigraphic sequence of the Mundeck Formation reveals a lacustrine transgression-deltaic progradation-regression sequence-type evolution that is consistent with the documented sequence in the Como Formation. This observation serves to confirm the hypothesis that a common regional control exists, namely, post-rift subsidence and climate, on the depositional processes in both formations. Lithological differences (e.g., coarser and less carbonated facies) in the Mundeck Formation reflect a relatively more proximal position to the Cameroonian craton, source of great detrital materials (Ntamak-Nida et al., 2010).

5.6.4.Nigerian Benue Trough

The Benue Trough (Nigeria), whose Aptian opening is associated with the evolution of the Central West African transform margin, yields fluvio-lacustrine facies comparable to the Facies Association 1-3 of the Como Formation, albeit within a more narrowly compartmentalised failed-arm rift context (Benkhelil, 1989). The Aptian deposits of the Asu River Group Formation of the Benue Trough present fluvial sandstones with oblique cross-bedding, alluvial-plain mudstones, and carbonate levels, with palaeocurrent indicators directed towards the SW-WSW, indicating an antithetic drainage pattern relative to the Gabonese basin.

5.6.5. Western Moroccan Atlantic basins

The Aptian deposits of the Tarfaya and Essaouira-Agadir basins of the western Moroccan Atlantic margin show a comparable transition from lagoonal to evaporitic facies (lowermost Aptian) to open carbonate ramp facies (upper Aptian-Albian) (Frizon de Lamotte et al., 2009). This transition reflects the progressive marine transgression above a margin undergoing post-rift thermal subsidence. The basal Aptian evaporitic sequences of the western Atlantic Morocco basins (anhydrite, halite) constitute a lateral equivalent of FA7 of the Como Formation, testifying to the Pan-Atlantic character of the Aptian hydrological confinement episode.

5.6.6.Brazilian Campos and Santos basins

The Campos and Santos basins (offshore Brazil) are regarded as the most thoroughly documented conjugate analogues of the Gabonese margin (Guardadoet al., 1989). The Lagoa Feia Formation (Berriasian-Aptian) of the Campos Basin comprises lacustrine carbonates (micritic limestones, calcarenites, dolostones) and interbedded organic mudstones, deposited in a stratified deep lake equivalent to the FA4-FA5 of the Como Formation. The Itapema Formation (lower Aptian) of Santos Basin is characterised by the predominance of lacustrine microbialite carbonates (mudstone, packstone, stromatolite-bearing boundstone), which constitute the post-rift equivalent of the carbonate deposits of the FA5. These deposits were formed in a hypersaline lake with intense organo-sedimentary production (Wright and Barnett, 2015). The transition from the Lagoa Feia/Itapema lacustrine facies to the overlying evaporites (Aptian salt) of the Ariri Formation precisely replicates the FA5-FA7 sequence of the Como Formation, confirming the synchronicity of the Aptian evaporitic confinement phase on the basins of both conjugate margins.

6. Conclusions

A detailed analysis of the depositional environments of the Como Formation allows us to characterise fourteen lithofacies, grouped into seven Facies Associations (FA1–FA7) that reveal a continuous and coherent palaeoenvironmental succession, from coarse fluvial systems (alluvial fans, braided rivers) through a deep anoxic lake, vegetated floodplains, intralacustrine deltas, and ending with a confined evaporitic environment. This evolution, documented in both outcrop and borehole data, indicates a progressive decrease in accommodation space and an increasingly negative hydrological budget during the early Aptian. The geodynamic framework of the Como Formation records a phase of post-rift thermal subsidence (sag-type basin), following the Neocomian–Barremian rifting that structured the Gabonese interior basin. The absence of major intraformational unconformities, the lateral continuity of facies over large distances, and the regional coherence of palaeocurrent directions (NW–NNW) all argue for passive tectonics during deposition, with inherited rift structures playing an essentially passive role in guiding drainage and geometrical compartmentalisation. The angular unconformity between the Como Formation and the underlying Neocomian series marks the boundary between the syn-rift and post-rift phases. The identification of bounding surfaces and the analysis of stacking patterns reveal two complete third-order sequence stratigraphic cycles, structured by the alternation of degradational, transitional, and aggradational systems tracts. Sequence boundaries correspond to major erosional surfaces with sharp contacts between coarse-grained deposits and underlying fine-grained strata, recording pronounced falls in the accommodation-to-sedimentation (A/S) ratio. The lacustrine maximum flooding of the second cycle is represented by the anoxic, bituminous and dolomitic varved argillites of the Cocobeach S. Landing Stage, the continental equivalent of a maximum flooding surface. This cyclic organisation results from the superposition of a low-frequency (second-order) regional thermal subsidence and two higher-frequency forcings: a climatic forcing, recorded in varved rhythms and anoxia episodes, and a marine eustatic forcing, whose influence increases towards the distal parts of the basin in connection with the Aptian Atlantic opening. The fluvio-lacustrine system is thus organised along a distal ramp, from alluvial fans with residual relief to the meromictic lacustrine basin, in accordance with models of post-rift lacustrine basins. In terms of the petroleum system, the Como Formation comprises the constituent elements of a complete and functional lacustrine petroleum system. The bituminous mudstones of FA4 (deep anoxic lake) constitute source rocks of exceptional quality (TOC up to 25.5 wt.%, HI up to 764 mg HC/g TOC, Type II kerogen), attesting to optimal organic-matter preservation under stratified euxinic conditions. Potential reservoirs are represented by fluvial (FA2) and deltaic (FA6) sandstones, whilst evaporitic levels (FA7) and the overlying fine lacustrine facies provide an impermeable seal. The functional equivalent of this system is recognised in the major post-rift lacustrine petroleum provinces of the South Atlantic (Campos-Santos basins, Brazil; Angola-Congo Basin). The regional comparisons reveal that the Como Formation forms part of a palaeogeographic and stratigraphic continuum at the scale of the conjugate Atlantic margins. Its lacustrine and evaporitic facies associations have direct equivalents in the Aptian formations of Cameroon (Mundeck), Congo-Angola (Bucomazi), Brazil (Lagoa Feia, Itapema), and, at higher latitudes, in the Mesozoic evaporitic successions of the central Atlantic basins. This convergence highlights a shared geodynamic forcing (post-rift thermal subsidence) and climatic forcing (warm, semi-arid Aptian), the understanding of which is essential for evaluating the petroleum potential of the under-explored West African passive margins.

CRediT authorship contribution statement

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Data Availability

All data supporting the findings of thisstudy are available at the "Université des Sciences et Techniques de Masuku (USTM), Faculté des Sciences, Unité de Recherche en Sciences de la Terre et de l'Environnement (URESTE), Laboratoire de Paléobiodiversité, Paléoenvironnement et Pétrologie (L3P)"».

References

Allen, J.R.L., 1970. Physical Processes of Sedimentation. Allen & Unwin, London, 248 p.

Allen, J.R.L., 1982. Developments in Sedimentology, Sedimentary Structures. Their Character and Physical Basis Volume II. Volume 30, Part B, Elsevier, Amsterdam, 663 p.

Allen, P.A., Allen, J.R., 2005. Basin Analysis: Principles and Applications. Blackwell Scientific Publications, Oxford, 549 p.

Allen, P.A., Allen, J.R., 2013. Basin Analysis: Principles and Application to Petroleum Play Assessment. Third Edition, Wiley and Blackwell, Hoboken.

Benkhelil, J., 1989. Origin and Evolution of the Cretaceous Benue Trough of Nigeria. Journal of African Earth Science, 8, 251-282. http://dx.doi.org/10.1016/S0899-5362(89)80028-4.

Blair, T. C., McPherson, J.G., 1994. Alluvial fans and their natural distinction from rivers based on morphology, hydraulic processes, sedimentary processes, and facies assemblages. Journal of Sedimentary Research 64(3A), 450-489.

Bohacs, K.M, Carroll, A.R., Neal, J.E., Mankiewicz, P.J., 2000. Lake-basin type, source potential, and hydrocarbon character: An integrated sequence-stratigraphic-geochemical framework. In Gierlowski-Kordesch, E. H., Kelts, K. R. (Eds.), American Association of Petroleum Geologists studies in geology lake basins through space and time. McLean, VA: American Association of Petroleum Geologists, Studies in Geology 46, 3-34.

Brayshaw, A.C., 1984. Characteristics and origin of cluster bedforms in coarse-grained alluvial channels. In: Koster, E.H., Steel, R.J. (Eds.), Sedimentology of Gravels and Conglomerates. Canadian Society of Petroleum Geologists, Memoir 10, 77-85.

Brice, S.E., Cochran, M.D., Pardo, G.,& Edwards, A.D., 1982. Tectonics and sedimentation of the South Atlantic rift sequence: Cabinda, Angola. In: Watkins, J.S., Drake, C.L. (Eds.), Studies in Continental Margin Geology. American Association of Petroleum Geologist, Memoir 34, 5-18.

Brink, A. H., 1974. Petroleum geology of Gabon Basin. American Association of Petroleum Geologists Bulletin, 58(2), 216-235.

Brognon, G. P., Verrier, G. R., 1966. Oil and geology in Cuanza Basin of Angola. American Association of Petroleum Geologists Bulletin 50(1), 108-158.

Brownfield, M.E.,Charpentier, R.R., 2006. Geology and Total Petroleum Systems of the West-Central Coastal Province (7203), West Africa. U.S. Geological Survey Bulletin 2207-B, 1-52.

Calvert, S.E., 1990. Geochemistry and origin of the Holocene sapropel in the Black Sea. In: Ittekkot, V., Kempe, S., Michaelis, W.,Spitzy, A. (Eds.), Facets of Modern Biogeochemistry. Springer, Berlin, 326-352.

Cant, D., Walker, R., 1976. Development of a braided-fluvial facies model for the Devonian Battery Point Sandstone, Québec. Canadian Journal of Earth Sciences 13 (1),102-119.

Carroll, A.R.,Bohacs, K.M., 1999. Stratigraphic classification of ancient lakes: balancing tectonic and climatic controls. Geology 27(2), 99-102.

Chevalier, L, Makanga, J.F., and Thomas, R.J., 2002. Carte géologique de la République gabonaise au 1/1 000 000. Notice explicative. Council for Geosciences, Pretoria, 195 pp.

Cloetingh, S., Gradstein, F., Kooi, H., Grant, A.,Kaminski, M., 1990. Plate reorganization: a cause of rapid late Neogene subsidence and sedimentation around the North Atlantic?. Journal of the Geological Society147, 495-506.

Cohen, A.S., 2003. Paleolimnology: The History and Evolution of Lake Systems. Oxford University Press, Oxford, 500 pp.

Coleman, M.L., Raiswell, R., 1981. Carbon, oxygen and sulphur isotope variations in concretions from the Upper Lias of N.E. England. Geochimica et Cosmochimica Acta45(3), 329-340.

Cross, T.A., 1988. Controls on coal distribution in transgressive-regressive cycles, Upper Cretaceous, Western Interior, USA. In Wilgus, C.K.; Hastings, B. S., Posamentier, H., Wagoner, J. V., Ross, C. A., Kendall, C. G. St. C (Eds.), Sea-level Changes: An Integrated Approach, Society of Economic Paleontologists and Mineralogists Special Publication 42, 371-380.

Cross, T.A., Baker, M.R., Chapin, M.A., Clark, M.S., Gardner, M.H., Hanson, M.S., Zipperlin& D.A., 1993. Applications of high-resolution sequence stratigraphy to reservoir analysis. In Eschard, R., Doligez, B. (Eds.), Subsurface Reservoir Characterisation from Outcrop Observations (pp. 11-33). Éditions Technip.

Currie, B.S., 1997. Sequence stratigraphy of nonmarine Jurassic–Cretaceous rocks, central Cordilleran foreland-basin system. Geological Society of America Bulletin 109(9), 1206-1222.

Davison, I., 1999. Tectonics and hydrocarbon distribution along the Brazilian South Atlantic margin. In: Cameron, N.R., Bate, R.H., Clure, V.S. (Eds.), The Oil and Gas Habitats of the South Atlantic. Geological Society London Special Publication 153, 133-151.

Doust, H., Omatsola, E., 1990. Niger Delta. In Edwards, J. D. &Santogrossi, P. A. (Eds.), Divergent/Passive Margin Basins. American Association of Petroleum Geologists Memoir 48, 201-238.

Droser, M.L., Bottjer, D.J., 1986. A semiquantitative field classification of ichnofabric. Journal of Sedimentary Petrology 56(4), 558-559.

Eugster, H.P., Hardie, L.A., 1978. Saline lakes. In: Lerman, A. (ed.), Lakes: Chemistry, Geology, Physics. Springer, New York, 237-293.

Eugster, H.P., Kelts, K., 1983. Lacustrine chemical sediments. In: Goudie, A.S., Pye, K. (Eds.), Chemical Sediments and Geomorphology. Academic Press, London, 321-368.

Farrell, K.M., 1987. Sedimentology and facies architecture of overbank deposits of the Mississippi River, False River region, Louisiana. In: Ethridge, F.G., Flores, R.M., Harvey, M.D. (Eds.), Recent Developments in Fluvial Sedimentology. Society of Economic Paleontologists and Mineralogists Special Publication 39, 111-120.

Frizon de Lamotte, D., Leturmy, P., Missenard, Y., Khomsi, S., Ruiz, G., Saddiqi, O., Guillocheau, F., Michard, A., 2009. Mesozoic and Cenozoic vertical movements in the Atlas system (Algeria, Morocco, Tunisia): an overview. Tectonophysics475(1-2), 9-28.

Galloway, W.E., 1975. Process framework for describing the morphologic and stratigraphic evolution of deltaic depositional systems. In: Broussard, M.L. (ed.), Deltas: Models for Exploration. TX: Houston Geological Society, 87-98.

Gawthorpe, R.L., Leeder, M.R., 2000. Tectono-sedimentary evolution of active extensional basins. Basin Research 12, 195-218.

Genik, G.J., 1993. Petroleum geology of Cretaceous-Tertiary rift basins in Niger, Chad, and Central African Republic. American Association of Petroleum Geologists Bulletin 77(8), 1405-1434.

Gierlowski-Kordesch, E.H., Kelts, K.R. (Eds.), 1994. Global Geological Record of Lake Basins, vol. 1. Cambridge University Press, Cambridge, 427 p.

Gierlowski-Kordesch, E.H. & Kelts, K.R. (Eds.), 2000. Lake Basins through Space and Time. American Association of Petroleum Geologists Studies in Geology 46, 648 p.

Gloppen, T.G. & Steel, R.J., 1981. The deposits, internal structure and geometry in six alluvial fan–fan delta bodies (Devonian, Norway). In: Ethridge, F.G., Flores, R.M. (Eds.), Recent and Ancient Nonmarine Depositional Environments. Society of Economic Paleontologists and Mineralogists Special Publication 31, 49-69.

Guardado, L.R., Gamboa, L.A.P., Lucchesi, C.F., 1989.Petroleum geology of the Campos Basin, Brazil, a model for a producing Atlantic type basin. In: Edwards, J.D., Santogrossi, P.A. (Eds.), Divergent/Passive Margin Basins. American Association of Petroleum Geologists Memoir 48, 3-79.

Guiraud, R., Maurin, J.-C., 1992.Early Cretaceous rifts of Western and Central Africa: an overview. Tectonophysics 213(1-2), 153-168.

Hardie, L.A., Eugster, H.P., 1970. The evolution of closed-basin brines. Mineralogical Society of America Special Paper 3, 273-290.

Harms, J.C., Southard, J.B., Walker, R.G., 1982. Structures and Sequences in Clastic Rocks. Society of Economic Paleontologists and Mineralogists Short Course Notes 9, Society of Economic Paleontologists and Mineralogists, Tulsa, 249 p.

Hudeley, H.,Belmonte, Y., 1970. Carte géologique de la République Gabonaise au 1/1 000 000. Notice explicative. Bureau de Recherches Géologiques et Minières 72, 191 pp.

Jervey, M.T., 1988. Quantitative geological modelling of siliciclastic rock sequences and their seismic expression. In Wilgus, C.K.; Hastings, B. S., Posamentier, H., Wagoner, J. V., Ross, C. A., Kendall, C. G. St. C (Eds.), Sea-level Changes: An Integrated Approach. Society of Economic Paleontologists and Mineralogists Special Publication 42, pp. 47-69).

Katz, B.J., 1990. Controls on distribution of lacustrine source rocks through time and space. In Katz, B. J. (Ed.), Lacustrine Basin Exploration: Case Studies and Modern Analogs. American Association of Petroleum Geologists Memoir 50, pp. 61-76.

Keighley, D., Flint, S., Howell, J., Moscariello, A., 2003. Sequence stratigraphy in lacustrine basins: a model for part of the Green River Formation (Eocene), southwest Uinta Basin, Utah. Journal of Sedimentary Research 73(6), 987-1006.

Kelts, K.,Hsü, K.J., 1978. Freshwater carbonate sedimentation. In: Lerman, A. (ed.), Lakes: Chemistry, Geology, Physics. Springer, New York, 295-323.

Kelts, K., Talbot, M., 1990. Lacustrine carbonates as geochemical archives of environmental change and biotic/abiotic interactions. In: Tilzer, M.M.,Serruya, C. (Eds.), Large Lakes: Ecological Structure and Function. Springer, Berlin, 288-315.

Kendall, A.C., 1992. Evaporites. In: Walker, R.G., James, N.P. (Eds.), Facies Models: Response to Sea Level Change. Geological Association of Canada, St. John’s, 375-409.

Leeder, M.R., 1978. A quantitative stratigraphic model for alluvium, with special reference to channel deposit density and interconnectedness. In: Miall, A.D. (Ed.), Fluvial Sedimentology. Canadian Society of Petroleum Geologists Memoir 5, 587-596.

Leeder, M.R., 1999. Sedimentology and Sedimentary Basins: From Turbulence to Tectonics. Blackwell Science, Oxford, 592 p.

Leeder, M.R., Gawthorpe, R.L., 1987. Sedimentary models for extensional tilt-block/half-graben basins. In: Coward, M.P., Dewey, J.F., Hancock, P.L. (Eds.), Continental Extensional Tectonics. Geological Society London Special Publication 28, 139-152.

Lowe, D.R., 1975. Water escape structures in coarse-grained sediments. Sedimentology22(2), 157-204.

Massari, F., Colella, A., 1988. Evolution and types of fan-delta systems in some major tectonic settings. In: Nemec, W., Steel, R.J. (Eds.), Fan Deltas: Sedimentology and Tectonic Settings. Blackie, London, 103-122.

Mbina Mounguengui, M.,Guiraud, M., 2006. Marqueurs de tectonique synsédimentaire dans les séries syn- et post-rift du bassin intérieur du Gabon. Africa Geoscience Review 13(4), 375-383.

Mbina Mounguengui, M., Guiraud, M., 2009. Neocomian to Early Aptian syn-rift evolution of the normal to oblique-rifted North Gabon Margin (Interior and N’Komi Basins). Marine and Petroleum Geology 26(6), 1000-1017.

Mbina Mounguengui, M., Baudin, F., Lang, J.,Jocktane, O., 2003. Paléoenvironnements et caractérisations des roches mères pétrolières des séries pré-salifères du bassin intérieur du Gabon. Comptes Rendus Géoscience 335, 327-334.

Mbina Mounguengui, M., Lang, J., Guiraud, M.,Jocktane, O., 2002. Sedimentary dynamics and structural geology of pre-rift deposits of the interior basin of Gabon. Journal of African Earth Sciences 35, 315-329.

Mbina Mounguengui, M., Guiraud, M.,Lang, J., 2006. Dynamique sédimentaire des dépôts post-rift du bassin intérieur du Gabon. Africa Geoscience Review 13(4), 347-360.

Mbina Mounguengui, M., Lang, J., Guiraud, M., 2008. Sedimentary dynamics and extensional structuring related to Early Cretaceous rifting of Neocomian and Barremian deposits of the interior basin of Gabon. Journal of African Earth Sciences 51, 239-256.

McKenzie, D., 1978. Some remarks on the development of sedimentary basins. Earth and Planetary Science Letters 40(1), 25-32.

Miall, A.D., 1977. A review of the braided river depositional environment. Earth-Science Reviews 13(1), 1-62.

Miall, A. D., 1978. Lithofacies types and vertical profile models in braided river deposits. In Miall, A. D. (Ed.), Fluvial Sedimentology (Canadian Society of Petroleum Geologists Memoir 5, 597-604.

Miall, A.D., 1985. Architectural-element analysis: a new method of facies analysis applied to fluvial deposits. Earth-Science Reviews 22, 261-308.

Miall, A.D., 1996. The Geology of Fluvial Deposits: Sedimentary Facies, Basin Analysis and Petroleum Geology. Springer, Berlin, 582 p.

Miall, A.D., 2006. Reconstructing the architecture and sequence stratigraphy of the preserved fluvial record as a tool for reservoir characterization: a reality check. American Association of Petroleum Geologists Bulletin 90(7), 989-1002.

Mjøs, R., Walderhaug, O., Prestholm, E., 1993. Crevasse splay sandstone geometries in the Middle Jurassic Ravenscar Group of Yorkshire, UK. In: Marzo, M.,Puigdefabregas, C. (Eds.), Alluvial Sedimentation. International Association of Sedimentologists Special Publication 17, 167-184.

Moulin, M., Aslanian, D., Unternehr, P., 2010. A new starting point for the South and Equatorial Atlantic Ocean. Earth-Science Reviews 98(1-2), 1-37.

Nanson, G.C., Croke, J.C., 1992. A genetic classification of floodplains. Geomorphology 4(6), 459-486.

Nemec, W., Steel, R.J., 1984. Alluvial and coastal conglomerates: their significant features and some comments on gravelly mass-flow deposits. In: Koster, E.H., Steel, R.J. (Eds.), Sedimentology of Gravels and Conglomerates. Canadian Society of Petroleum Geologists Memoir 10, 1-31.

Ntamak-Nida, M.J., Bourquin, S., Makong, J.C., Baudin, F., Mpesse, J.E., Ngouem, C.I.,Abolo, G.M., 2010. Sedimentology and sequence stratigraphy from outcrops of the Kribi-Campo sub-basin: Lower Mundeck Formation (Lower Cretaceous, southern Cameroon). Journal of African Earth Sciences 58(1), 1-18.

Olsen, H., Due, P.H., Clemmensen, L.B., 1995. Palaeoclimatic significance of lacustrine shoreline periodicities, Kap Stewart Formation (Triassic-Jurassic), Jameson Land, East Greenland. In Plint, A. G. (Ed.), Sedimentary Facies Analysis.International Association of Sedimentologists Special Publication 22, 201-220.

Owen, G., 198.) Deformation processes in unconsolidated sands. In: Jones, M.E. & Preston, R.M.F. (Eds.), Deformation of Sediments and Sedimentary Rocks. Geological Society London Special Publication 29, 11-24.

Pemberton, S.G., Spila, M., Pulham, A.J., Saunders, T., MacEachern, J.A., Robbins, D., Sinclair, I.K., 2001. Ichnology and Sedimentology of Shallow to Marginal Marine Systems. Geological Association of Canada Short Course Notes 15, 343 p.

Peters, K.E., Cassa, M.R., 1994.Applied source rock geochemistry. In: Magoon, L.B., Dow, W.G. (Eds.), The Petroleum System - From Source to Trap. American Association of Petroleum Geologists Memoir 60, 93-120.

Platt, N.H., Wright, V.P., 1991. Lacustrine carbonates: facies models, facies distributions and hydrocarbon aspects. In: Anadón, P., Cabrera, L., Kelts, K. (Eds.), Lacustrine Facies Analysis. International Association of Sedimentologists Special Publication 13, 57-74.

Plint, A.G., Nummedal, D., 2000. The falling stage systems tract: recognition and importance in sequence stratigraphic analysis. In Hunt, D., Gawthorpe, R. L. (Eds.), Sedimentary Responses to Forced Regressions. Geological Society Special Publication 172, 1-17.

Posamentier, H.W., Vail, P.R., 1988. Eustatic controls on clastic deposition II - sequence and systems tract models. In Wilgus, C.K.; Hastings, B. S., Posamentier, H., Wagoner, J. V., Ross, C. A., Kendall, C. G. St. C (Eds.), Sea-level Changes: An Integrated Approach. Society of Economic Paleontologists and Mineralogists Special Publication 42, 125-154.

Postma, G., 1986. Classification for sediment gravity-flow deposits based on flow conditions during sedimentation. Geology 14(4), 291-294.

Postma, G., 1990. Depositional architecture and facies of river and fan deltas: a synthesis. In: Colella, A., Prior, D.B. (Eds.), Coarse-GrainedDeltas. International Association of Sedimentologists Special Publication 10, 13-27.
Retallack, G.J., 2001. Soils of the Past: An Introduction to Paleopedology, 2nd ed. Blackwell Science, Oxford, 404 p.
Rust, B.R., 1978. Depositional models for braided alluvium. In: Miall, A.D. (Ed.), Fluvial Sedimentology. Canadian Society of Petroleum Geologists Memoir 5, 605-625.
Savrda, C.E., Bottjer, D.J., 1989. Trace-fossil model for reconstructing oxygenation histories of ancient marine bottom waters: application to Upper Cretaceous Niobrara Formation, Colorado. Palaeogeography, Palaeoclimatology, Palaeoecology 74(1-2), 49-74.
Schlische, R.W.,Withjack, M.O., 2009. Origin of fault domains and fault-domain boundaries (transfer zones and accommodation zones) in extensional provinces: result of random nucleation and self-organized fault growth. Journal of Structural Geology 31(9), 910-925.
Schreiber, B.C., El Tabakh, M., 2000. Deposition and early alteration of evaporites. Sedimentology 47(Suppl. 1), 215-238.
Shanley, K.W., McCabe, P.J., 1991. Predicting facies architecture through sequence stratigraphy - an example from the Kaiparowits Plateau, Utah. Geology 19(7), 742-745.
Shanley, K.W., McCabe, P. J., 1994. Perspectives on the sequence stratigraphy of continental strata. American Association of Petroleum Geologists Bulletin 78(4), 544-568.
Smith, D.G., 1983. Anastomosed fluvial deposits: modern examples from Western Canada. In: Collinson, J.D., Lewin, J. (Eds.), Modern and Ancient Fluvial Systems. International Association of Sedimentologists Special Publication 6, 155-168.
Smith, N.D., Cross, T.A., Dufficy, J.P., Clough, S.R., 1989. Anatomy of an avulsion. Sedimentology 36(1), 1-23.
Talbot, M.R., Allen, P.A., 1996. Lakes. In Reading, H. G. (Ed.), Sedimentary Environments: Processes, Facies and Stratigraphy (3rd ed., pp. 83-124). Blackwell.
Talbot, M.R., Livingstone, D.A., 1989. Hydrogen index and carbon isotopes of lacustrine organic matter as lake level indicators. Palaeogeography, Palaeoclimatology, Palaeoecology 70(1-3), 121-137.
Teisserenc, P.,Villemin, J., 1990. Sedimentary basin of Gabon. Geology and oil systems. In: Edwards, J.D., Santogrossi, P.A. (Eds.), Divergent/Passive Margin Basins. American Association of Petroleum Geologists Memoir 48, 117-199.
Tissot, B.P., Welte, D.H., 1984. Petroleum Formation and Occurrence, 2nd ed. Springer, Berlin, 699 p.
Torsvik, T.H., Rousse, S., Labails, C., Smethurst, M.A., 2009. A new scheme for the opening of the South Atlantic Ocean and the dissection of an Aptian salt basin. Geophysical Journal International 177(3), 1315-1333.
Wagoner Van, J.C., Mitchum, R.M., Campion, K.M., Rahmanian, V.D., 1990. Siliciclastic Sequence Stratigraphy in Well Logs, Cores, and Outcrops. American Association of Petroleum Geologists Methods in Exploration Series 7, 55 p.
Warren, J.K., 2000. Evaporites, brines and base metals: low-temperature ore emplacement controlled by evaporite diagenesis. Earth-Science Reviews 52(1-3), 1-82.
Warren, J.K., 2006. Evaporites: Sediments, Resources and Hydrocarbons. Springer, Berlin, 1035 p.
Wheeler, H.E., 1964. Baselevel, lithosphere surface, and time-stratigraphy. Geological Society of America Bulletin 75(7), 599-610.
Wright, V.P., Barnett, A.J., 2015. An abiotic model for the development of textures in some South Atlantic Early Cretaceous lacustrine carbonates. In: Bosence, D.W.J., Gibbons, K.A., Le Heron, D.P., Morgan, W.A., Pritchard, T., Vining, B.A. (Eds.), Microbial Carbonates in Space and Time. Geological Society London Special Publications 418, 209-219.

Table caption

Data type	Name	Coordinates	Regions

		Longitude	Latitude	
Boreholes	NKG1	10.193279°	-0.150392°	Bifoun
	WE1	10.158512°	-0.083766°	Lambaréné
Outcrop sections	MadukuMembo River	9.569282°	0.934564°	Cocobeach
	South of the Cocobeach quay lighthouse	9.579650°	0.952495°	Cocobeach
	Cocobeach Beach	9.603427°	0.980812°	Cocobeach
	Cocobeach Landing Stage	9.589665°	0.967273°	Cocobeach
	Bisséghé River	10.232575°	-0.400938°	Lambaréné

Table Location and geographic coordinates of the investigated outcrop sections of the Como Formation and the boreholes in the Bifoun, Lambaréné, and Cocobeach regions.

Figure caption

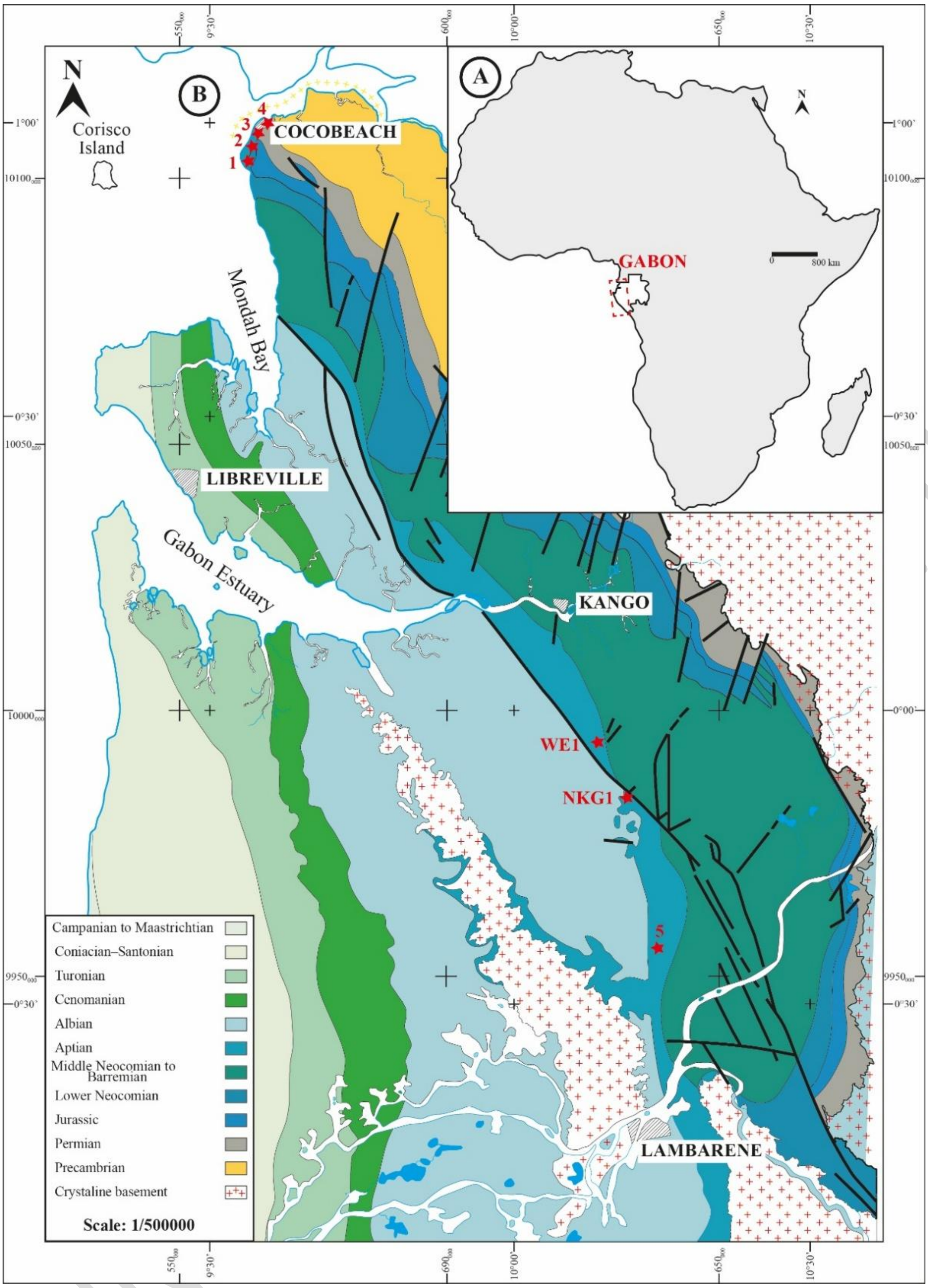

Fig. 1(**a**) Map of Africa and location of Gabon country and the Gabonese interior basin; (**b**) Geological map of western Gabon and location of the five studied outcrop sections: **1**. MadukuMembo river; **2**. South of the Cocobeach quay lighthouse; **3**. Cocobeach landing stage; **4**. Cocobeach beach and **5**. Bisséghé river, and the twoboreholes (**WE1** and **NKG1**) (modified after MbinaMounguengui&Guiraud, 2006).

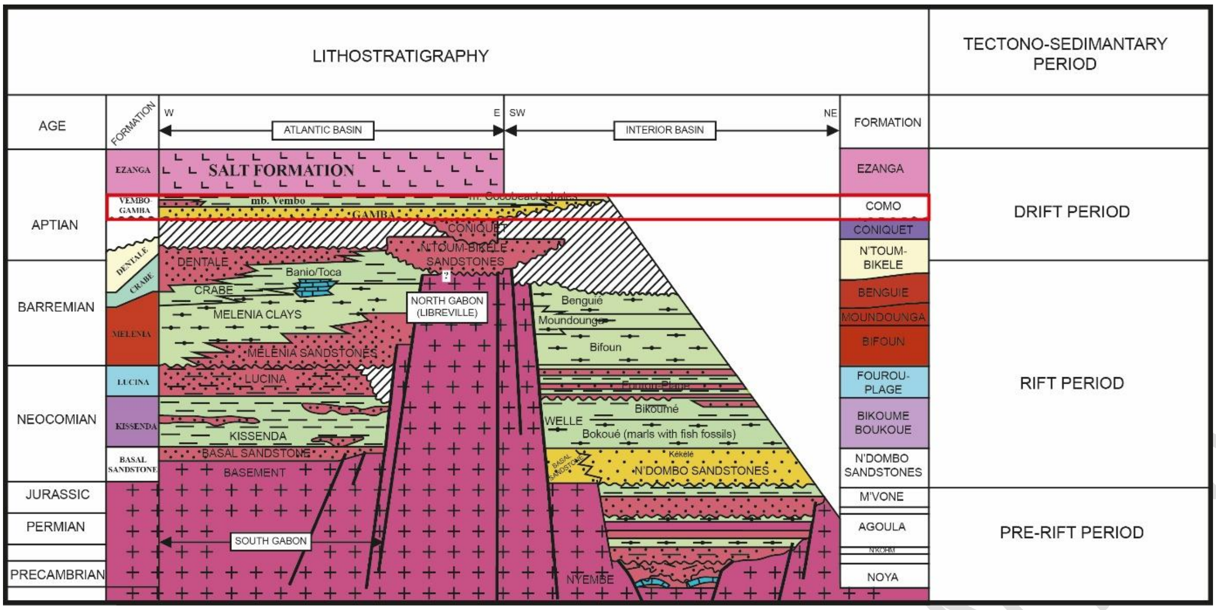

Fig.2. Palaeogeographic reconstruction and tectono-sedimentary evolution of the Atlantic and the Gabonese interior basins from the Precambrian to the Present and the stratigraphic position of the studied Como Formation.

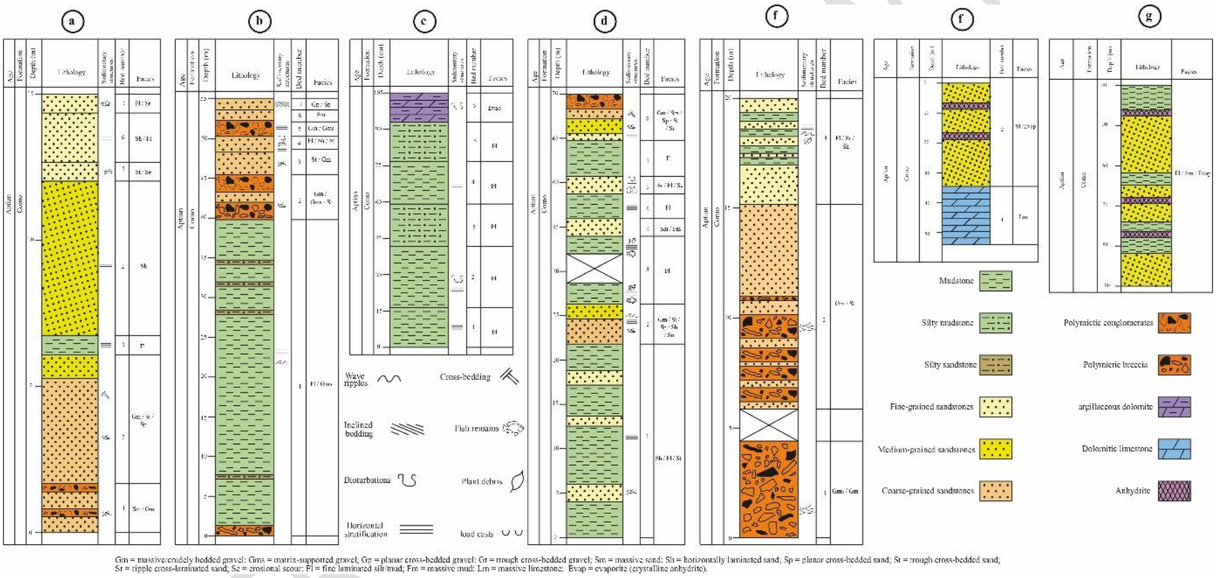

Fig. 3 Lithostratigraphic column of the investigated outcrop sections and boreholes of the Como Formation: **a**)MadukuMembo river,**b**) South of the Cocobeach quay lighthouse,**c**)Cocobeach landing stage,**d**)Cocobeach beach,**e**)Bisséghé river,**f**)Borehole NKG, and**g**)Borehole WE1.

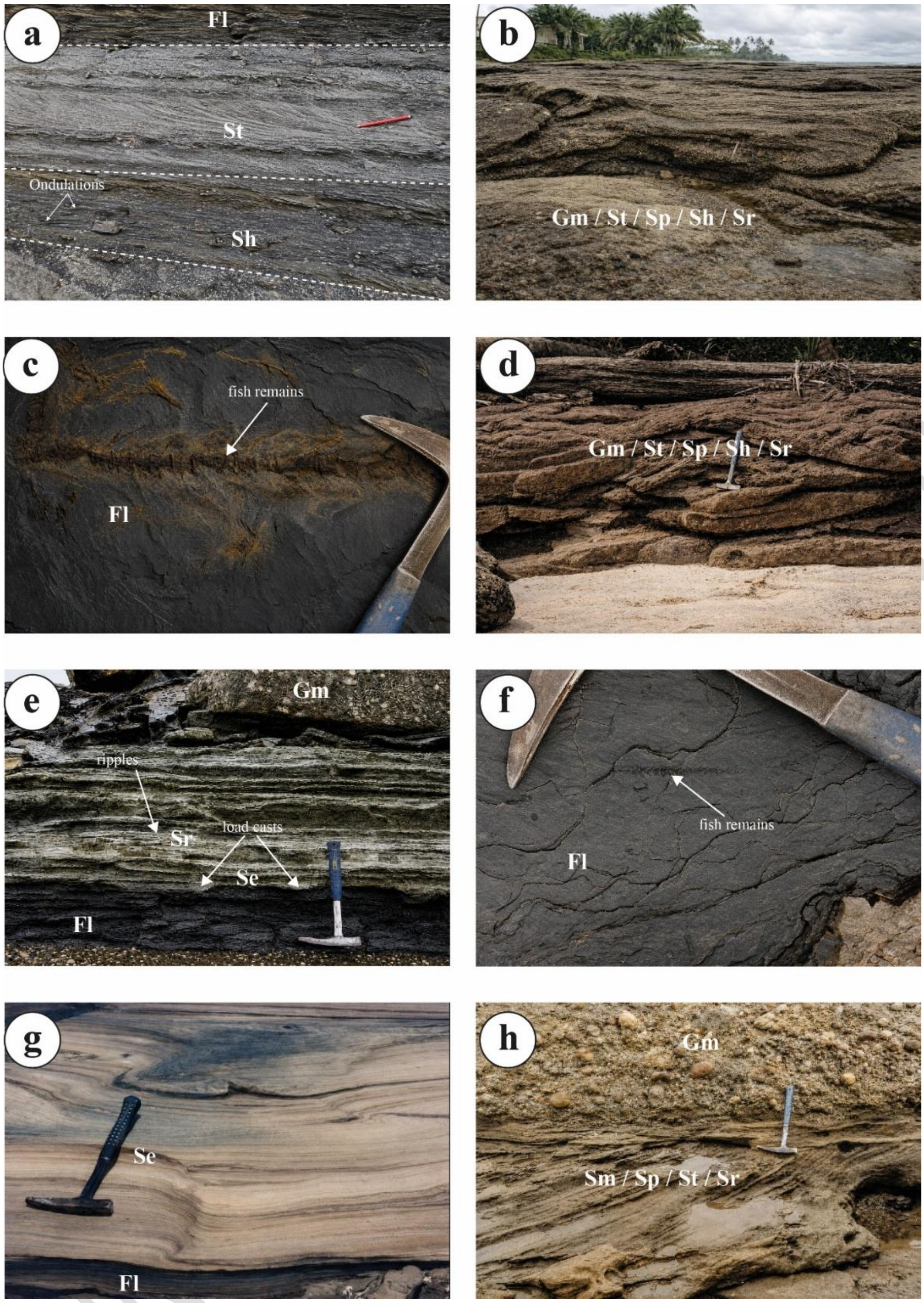

Fig. 4. Sedimentary lithofacies types from theCocobeachBeach section: **a**) Bed 1,**b**,**d**) Bed 2,**c**) Bed 3,**e-g**) Bed 6,**h**) Bed 8.

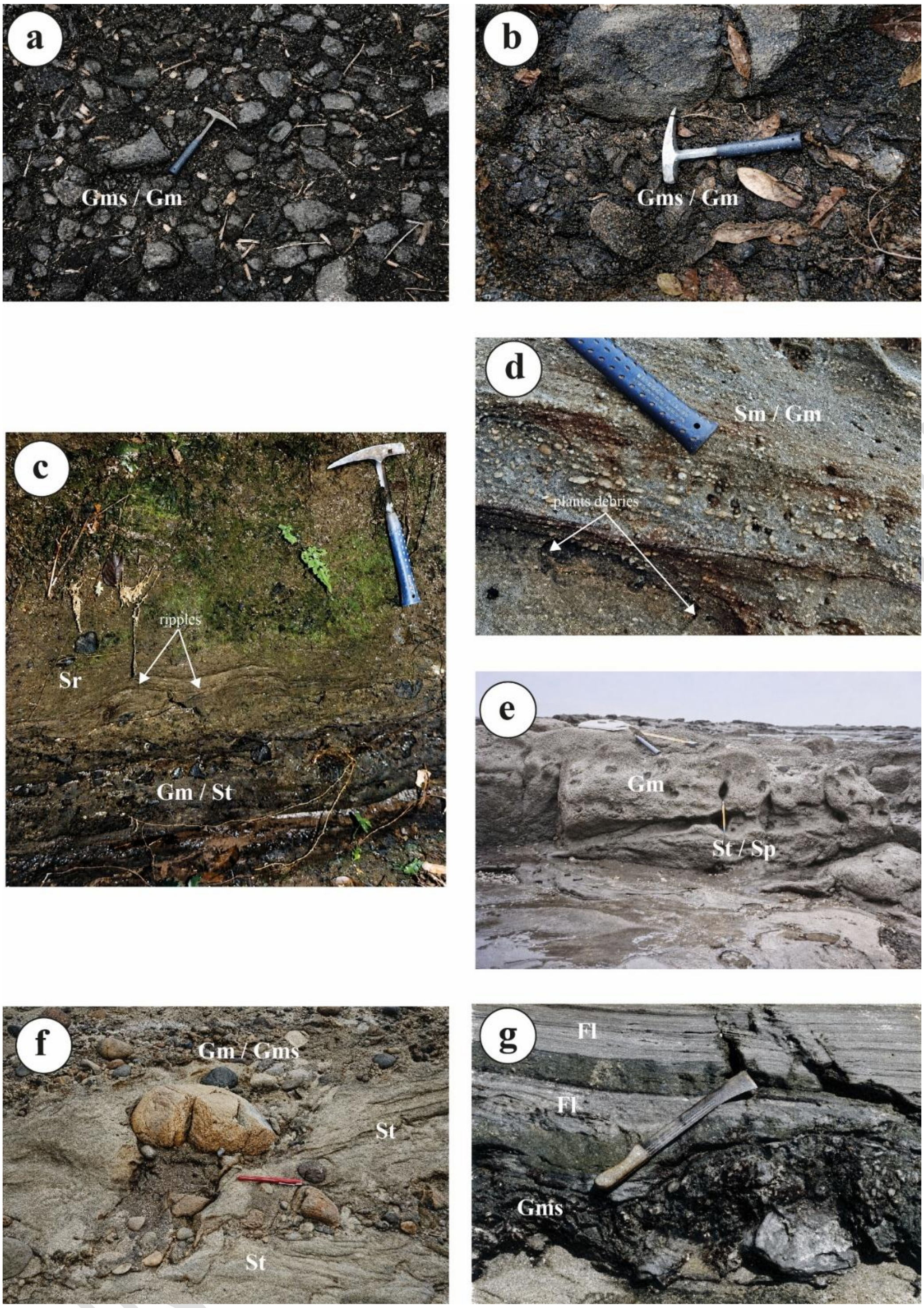

Fig. 5. Sedimentary lithofacies types from theBisséghé river section: **a-b**) Bed 1,**c**) Beds 2 and3);the MadukuMembo riversection: **d**) Bed 1,**e**) Bed 2;and the South of the CocobeachQuay Lighthouse section: **h**) Bed 2,**g**) Bed 1.

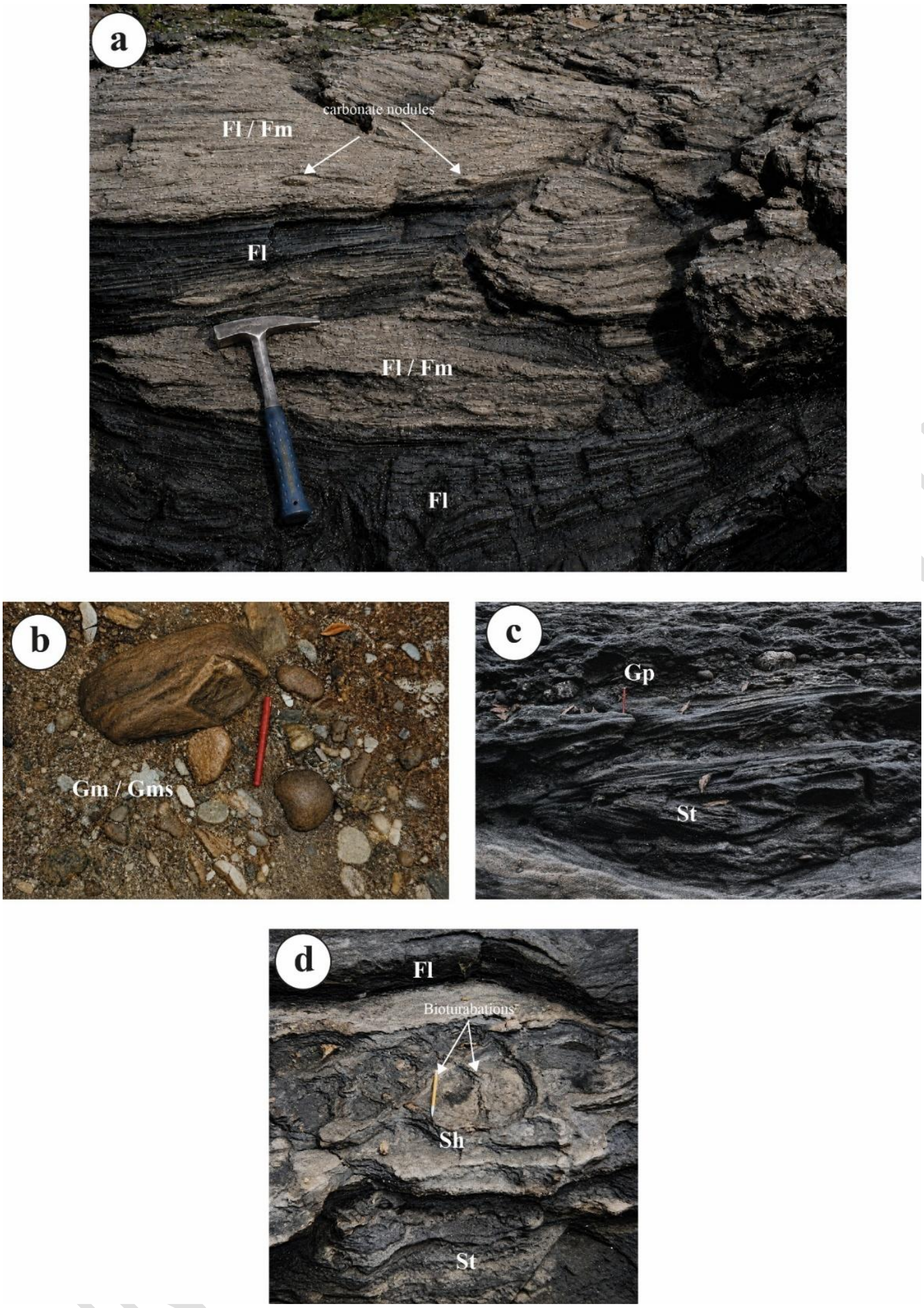

Fig. 6. Sedimentary lithofacies types: **a**) from theCocobeachSouthern Landing Stage section; **b**) Bed 5, **c**) Bed 7, **d**) Bed 4,.from the theSouth of the CocobeachQuay Lighthouse section.