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LITHOFACIES AND PALEOENVIRONMENTS OF CORED DEPOSITS OF THE ALBIAN RESERVOIRS IN THE ABIDJAN MARGIN (OFFSHORE OF CÔTE D'IVOIRE BASIN)

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ABSTRACT

Sedimentary reservoirs describe facies that characterise architectural segments of the basin. For example, channels and alluvial fans are the main silicoclastic depositional environments. Thus to some extent these sites have hydrocarbon potential. The analysis of the hydrodynamic mechanisms behind their emplacement and their potential was carried out using oil drill cores. They were exhumed between 6500 and 10000 feet, i.e. between 1981 and 3048 m deep in the Abidjan Margin, Gulf of Guinea province in Côte d'Ivoire. The facies is based on lithological, ichnological and mechanical criteria. Their interpretations reveal emplacement initiated by turbidites, hyperpycnites, and hemipelagites within channels and deltaic cones in majority.

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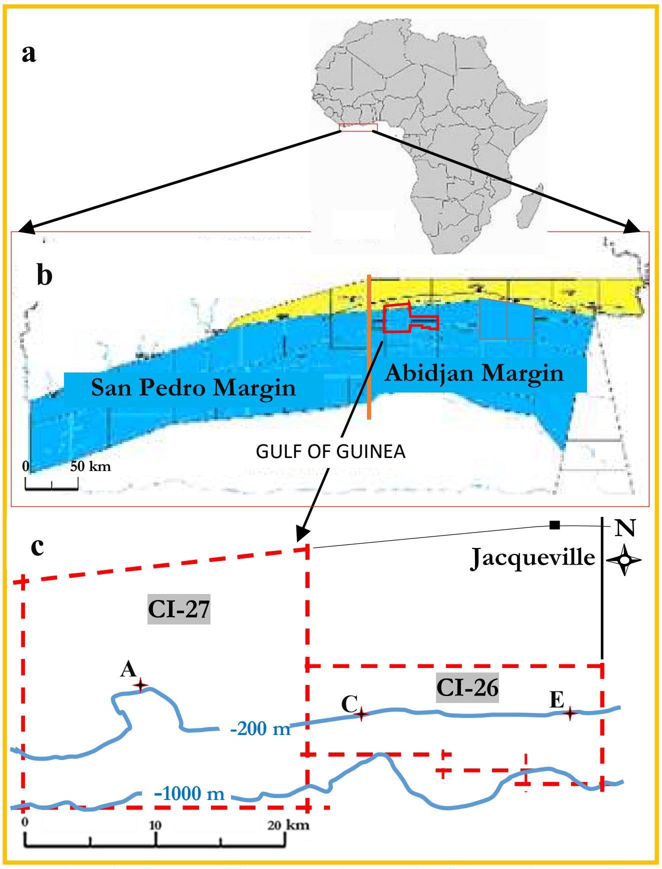
INTRODUCTION

Singulary a sedimentary facies integrates lithological, hydrodynamic and biogenic criteria in a basic and variable way (Homewood et al, 1999). In this case, the reservoirs of the Albian age petroleum systems in the Abidjan margin are organised in vertical sequences of sediments that form facies associations. These facies correspond to successions of particular depositional environments. A facies association induces a facies zone corresponding to a sedimentation domain following the architectural elements of the basin and corresponding to one or more depositional environments (Flügel, 1982). In addition, depositional sequences reflect hydrodynamic mechanisms (Mutti, 1992; Zavala & Acuri, 2016). The objective of this study is to specify, through the study of lithofacies, the geodynamic processes of preponderant deposits (turbidites, hyperpycnites, hemipelagites...) at the origin of the setting of the reservoirs of the petroleum systems of Albian age in the Abidjan Margin. It should be noted that in the context of the ivoirian sedimentairy basin, paleoenvironnemental reconstitutions studies of deposits, are mainly based on drill cutting dating from generally of the Lower Cretaceous. However, the techniques are based on lithological analyses, fossils contents, and geochemical procedures applied to cuttings samples (Digbehi, 1987; Chierici, 1996; Jardine et Magloire, 1965; Digbehi et *al.*, 1996, 1997; Ouattara et *al.*, 2016). In contrast to the cutting, more recent investigations have focused solely on searching forsedimentary structures and fossil traces in sedimentary cores of Cénomanian age (Féa et *al.*, 2019). This note is a contribution to the knowledge of lithofacies and the understanding of geodynamic depositional processes Albianreservoirs levels.

GEOLOGICAL SETTINGANDSTUDY AREA

The Gulf of Guinea Province is located along the West African coast of the Atlantic Ocean (Fig. 1a). In particular, it extends from the eastern Ivorian Basin to the northwestern Dahomey Mouth (Brownfield and Charpentier, 2006). The westernmost wing of this Gulf contains the Ivorian sedimentary basin, which is divided into an onshore and a deep offshore basin (Fig. 1b). The onshore part is crescent-shaped, concentrated around the town of Jacqueville, and extends from Fresco to the Ghanaian border for about 350 km. The offshore part extends from cast to west over a width of about 150 km, with water columns of up to 3,000 m between the coast and the continental shelf. This offshore arca is subdivided into two margins, the San Pedro margin to the west and the Abidjan margin to the east. The study area is located offshore of Jacqueville in the Abidjan margin and is formed by the grouping of oil blocks C1-26 and CI-27 where drill holes A, C and E are located (Fig. 1c). The tectono-stratigraphic architecture of the Abidjan margin is revealed by the geological section extending from the coast to the open sea through the Bélier and Espoir fields (Fig. 2). It exposes the filling terrain corresponding to very thick mud-sandstone deposits of Albian age. The sediments are made up of black muds rich in organic matter, giving the source rocks an oil and/or gas potential (Petroci & Beicip, 1990). Albian sandstones are thought to form reservoirs in the Lower Cretaceous of the Ivorian offshore basin from the continental shelf to the abyssal plain, at depths of over 5000 m (Chierici, 1996).



a- Location of Guinea Gulf. b- Structural areas of Ivoirian Basin. C-Position of boreholesA, C, andEin blocks CI-26 and CI-27.

Figure 1. Location of the study area

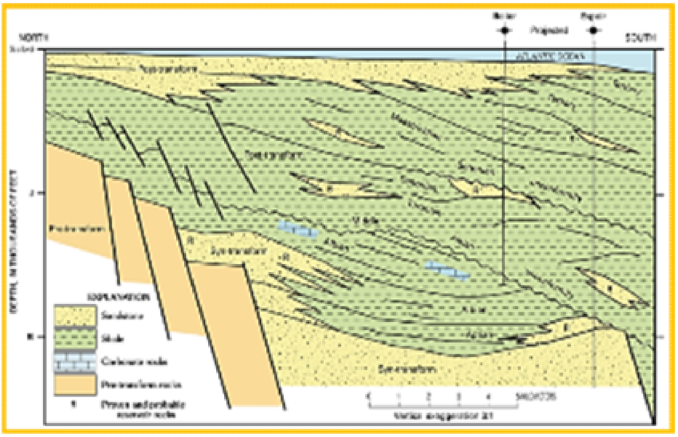


Figure 2. Geological section of the Bélier and Espoir in the Côte d'Ivoire Basin, Gulfof Guinea Province. Modified by Chierici (1996)

METHODOLOGY

In this study, the 14 sedimentary cores of Albian age made available to us by PETROCI's Centre Analyses et de Recherche (CAR) are located between 6500 and 10000 feet, i.e. between 1981 and 3048 m deep. Their cumulative thickness is around 446 feet (135.94 m) with respectively 193 feet (58.83 m) for borehole A, 193 feet (59 m) for borehole C and 60 feet (18.30 m) for borehole E. The facies study will consist of an analytical approach as defined by Anderton (1985). It about: (*i*) the description of lithological (mineralogy, grain size), biogenic and geodynamic (hydrodynamics, tectonics) characteristics restructured through lithostratigraphic logs; (*ii*) the classification of major facies families according to lithofacies coding rules (Ghibaudo, 1992; Reijers, 1995); and (*iii*) the interpretation of facies in terms of depositional processes (Bouma, 1962; Mutti, 1992: Zavala et al., 2018) and ichnological indices (Pemberton et al., 2009). The sequence analysis based on the search for sedimentary discontinuities and the reconstruction of depositional environments will be limited to the core samples from boreholeA, which will serve as a case study.

RESULTS AND INTERPRETATIONS

Observations from 14 drill cores in the Abidjan margin allow us to begin the facies study.

CHARACTERISATION OF FACIES

Facies characterisation highlights 14 sub-facies which are headed by four (04) main lithofacies (sandstone facies, mixed and heterolithic facies, mudstone facies, calciturbite facies) according to mineralogical, mechanical and biogenic affinities (Table 1).

SANDSTONE FACIES (lithofacies, tectofacies and biofacies)

Sandstone lithofacies

Pebbly sandstone (SP) : This facies shows muddy breccias, dismantled and flooded in a fine sandy-muddy matrix (Fig. 3a). Evidence of dismantling is observed with core sections from borehole A (A#4-b7: 8209'; A#4-b10: 8219'6") and evidence of reworking is displayed over a nearly 1 m long interval of unstable, brecciated mud-clasts that are accumulated in chaotic stages associated with probable gully surfaces (borehole C# 3-b10: 8219'6'-9645').

Origin 1: These chaotic deposits with breccias are considered to be mass transport deposits (MTD) whose competence and flow capacity would be able to dismantle and remobilise constituents under the effect of gravity and shear to form bedload facies (Evans et al, 1998; Zavala et al., 2006b, Zavala et al., 2018). They are found as base facies of turbidite flows **F3** (Mutti et *al*., 1991) and bottom load facies **B3s** of hyperpycnal flows (Zavala et al., 2006b).

Granular sandstone (GS): They are microconglomeratic (3 to 5 mm) with basal layers of 5 to 30 cm. The stony sandstone levels are poorly sorted with three (03) matrix types:

- fine matrix of clean sandstone (Facies 2a) (Fig. 3b);
- argilaceous matrix (Facies 2b) (Fig. 3c);
- calcareous matrix (Facies 2c).

Origin 2: they would be the result of flows of increased velocity combined with a rapid fall of the granules (Zavala et *al*., 2018). Furthermore, the intensity of the flow-related blasting effects is more pronounced the more prominent the erosion structures are. Apart from the grain size, the basal postures and erosive structures associted to these facies categorise them as bedload facies. Where the joints are diffuse, these layers are similar to ‘‘crude stratifications’’. They correspond to R3 of Lowe (1982), F5 of Mutti (1992) and B2 of Zavala et *al*. (2006b).

Table 1. Main lithofacies and common facies codes in the study area

MAINLITHOFACIES				LITHOFACIES CHARACTERISTICS	
Types of lithologies	Facies types (F*)			Dénominations	Code facies
Sandstone lithologies	Lithofacies	F1		Pebbly sandstone	SP
		F2		Granular sandstone	G S
		F3	F3a	Massive clean sandstone	S m
			F3b	Massive calcareous sandstone	SCalc m
			F3c	Massive argilaceous sandstone	S Arg m
		F4		Stratified sandstone	Sstr
		F5		Parallel bedded sandstone	Sl
		F6	F6a	Rippled sandstone	Sr
			F6b	Cross-bedded sandstone	Sx
			F6c	Hummocky Cross Stratified sanstone	Shcs
	Tectofacies	F7		Sandstone with brittle deformation	Sdef.br
		F8		Ductile deformed sandstone	Sdef.dc
	Biofacies	F.9		Bioturbated sandstone	Sb
Mixed andHeterolithicsLithologies	Mixedlithofacies	F10		Couplets sandstone-mudstone	SM
	Heterolithics	F11		Heterolithics muddy-sandy	HS -HM
MudstoneLithologies	Mudstone lithofacies	F12		Shally mudstone	Mf
		F13		Stratified mudstone	Mstr
Limestones Lithologies	Limestone lithofacies	F14		Calcitubidite	Calc.t

a-Brecciated sandstone showing muddy clasts (*Mc*). b, c- Granular sandstones subfacies. d- Clean sandstone with hydraulic jump marked by flame structures (*Fs*) stretched muddy chips (*Smc*).

Figure 3. Pebbly and granular sandstone lithofacies

Massive sandstones (Sm)

Three (03) sub-facies of massive sandstones Smare distinguish:

- facies 3a (Sm) is a clean sandstone set in micromicaceous, very fine- to fine-grained, sometimes fine-to medium-grained banks. They are generally poorly consolidated, olive-grey to olive-brown in colour and decimetric to metric thick (0.10 to 3 m), rich in clasts and siderite nodules. They are often associated with flame structures, or hydraulic jumps (Fig. 3d).
- facies 3b (SmCal) is calcite-cemented. Occasional shell clasts are known.
- facies 3c (SArg) is a massive fine to medium muddy, micaceous sandstone. Thicknesses vary between 0.3 and 1.20 m. It is poorly sorted, heterogranular, often associated with stretched mud-clasts

Origin 3: Massive facies Sm are attributed to flows with high sediment concentration (Mulder and Alexander, 2001a). Turbulent flows with deposition rates above 0.44 mm/s favour the massive character of sands (Sumner *et al.,* 2008), as do progressive bottom aggradations by turbulence with high suspended load (Kneller and Branney, 1995; Camacho et *al*., 2002; Zavala et *al*., 2018). The Sm facies described are similar to the turbidite facies Ta (Bouma, 1962), S3 (Lowe, 1982), F8 (Mutti, 1992) and S1 hyperpycnals (Zavala et *al*, 2006b).

Stratified sandstones (Sstr): They symbolise graded sandstones, consisting of a succession of several sandstone strata of varying nature, grain size and thickness. On observation, contrasts are seen from the base to the top of the same unit. In detail, one can appreciate the nuanced bands of clean, fine-grained sandstone at the base which contrast with increasingly muddy and/or carbonaceous sandstones towards the top. The refinements are flaser-bedding (Fig. 4a) and fining- up (Fig. 4b). They are abundant in the cored sediments of borehole C (#1, #2, #4). The joints between strata are often subtle.
The stratified facies (Sstr) reflect normal graded sands asTab turbidites (Bouma, 1962), F8/F9a,b (Mutti, 1992); and S1-S2to SLhyperpycnites (Zavala et *al*., 2006b).

Origin 4: The prince of sandstone stratification is thought to respond to a gradual decrease in flow competence due to a decrease in the load carried. In other words, as sediment-laden river water moves away from the coast, it loses its concentration by dilution, the thickness of the sediment column decreases due to rapid aggradation of the floor while lighter materials (muds, carbonaceous materials) float away (Kneller & Branney, 1995; Zavala et *al*., 2012; Cartigny et *al*., 2013).

Parallel bedded sandstones (Sl): They are fine to very fine sandstones with laminae on short spans of 5 to 30 cm. The laminae are parallel to subparallel, milli to centimetric, formed by muddy, carbonaceous and micaceous materials (Fig. 4c).

***Origin 5*:** This facies reveals indices of traction, deposition rate and flow velocity. Fallout rates below 0.44 mm/s result in laminations at the expense of massive structures (Arnott and Hand, 1989; Sumner et *al*., 2008). They are the consequence of diluted flows (Mulder and Alexander, 2001a). The parallel-bedded facies show correspondences with the turbidites Tb (Bouma, 1962), Tt (Lowe, 1982), F9 (Mutti, 1992) and the hyperpycnites S2 (Zavala, 2006b).

Wrinkle-bedding sandstones (Sr, Sx, Shcs): We note three (03) sub-facies with wrinkled bedding including current wrinkle bedding (facies 6a: Sr); inter-crossing bedding (facies 5b: Sx); HCS bedding (facies 6a: Shcs) (Fig. 4d). Individually, they show short spans (5 to 7 cm) and are associated with sandstone interbanks of the sandstone-mudstone alternations or towards the top of the sand-mud couplets.

Origin 6: Facies 6 (6a and 6b) respond to dilute flows (Mulder & Alexander, 2001a), in addition to low flow velocity (Sanders, 1965). On the other hand, HCS beds (facies 6c), which can be likened to ripples, occur as a result of combined flows (Mutti et *al*., 1994; Morsilli & Pomar, 2012), and may reflect not only a significant input of sand and rapid but episodic sedimentation (Khawar et *al*., 2006), but also sporadic alternations of erosion and sedimentation (Hamblin & Walker, 1979). The wrinkled sandstones are affiliated with the turbiditic facies Tc of Bouma (1962); Tt of Lowe (1982), F9b of Mutti (1992) and S3 hyperpycnal beds of Zavala et *al*. (2006a, 2006b).

Sandstone tectofacies

Brittle deformed sandstone (Sdef.br): The brittle deformations are frequently multiple microfaults (Fig. 4e), series of superimposed multiphase fractures (Fig. 4f) and dextral shearing cracks (Fig. 4g).

Origin 7: Brittle structures are induced by post-lithification stresses. The presence of normal and reverse microfaults (superimposed multiphase fractures) are comparable to transpression systems. In addition, dextral tension cracks represent crack enlargements by fluid injections with overpressure.

Ductile deformed sandstone (Sdef.dc) : Ductile deformations involve load features and water escape structures as shown respectively by figure 4h and 4i.

Origin 8: Load structures are syn-sedimentary deformations (Owen, 2003; Poyatos-Moré, 2014). As the sediments are liquefied, the interface between dense overlying and less dense underlying sediments will be more deformed the greater the difference in density. According to Owen (2003), the load patterns observed are pendulous and pseudonodular (attached; detached; ball and pillow) (Fig. 4i). In addition, the water escape structures reflect abrupt dehydration of the sediment.

Sandstone biofacies

At the scale of the sandstone layers, bioturbations can be partial or global. They are highlighted by the contrasts induced by the traces of burrowing organisms. This bioturbated sandstone facies (*Sb*) contains a diversity of ichnological sedimentary structures:

- **ichnofacies 9a:** *Teichichnus* indicate tortuous tunnel structures of 2 to 3 cm wide that cut through the sandy-muddy sediments (Fig. 4j).
- **ichnofacies 9b:** la *Fodichnia* has a mottled texture and are related to the scouring of mobile organisms ingesting sediments (Fig. 4k).
- **ichnofacies 9c:** Les *Zoophycos* are abundant. Feeding tracks in the sediments describe consecutive lobes (Fig. 4l).

Origin 9: In detail, the escape burrows or *Teichichnus* (ichnofacies 9a) are interpreted as products of vertical tunnel migration (Häntzschel, 1975). They indicate traces of locomotion related to the endangerment of burrowing organisms. These burrows therefore suggest stressful conditions associated with turbulent flows with a large input of sediment in a short time (Saunders et *al*., 1994; MacEachern et *al*., 2009). The feeding burrows are represented by abundant *Fodinichnia* (facies 9b) and Zoophycos (facies 9c). One of the obvious reasons for the abundance of traces of mobile and sessile feeding is the manifestation of periods of equilibrium favourable to the development of these organisms in the sediments (Pemberton et *al*., 1992). The mottled appearance of *Fodinichnia* trend to be similar with cryptobioturbations of *Macaronichnus* (Pemberton *et al.,* 2008).

MIXED AND HETEROLITHICS LITHOFACIES

Mixed lithofacies characterise synchronous depositional layers of composite lithologies from the same depositional event (Ghibaudo, 1992). Whereas heterolithic lithofacies are alternationof sandstone and mudstonelayers.

Mixedlithofacies

***Sandstone-mudstone couplets (SM)**:* These are mixed graded bpartite sandstone-mudstone facies. They reflect the tendency of the same bed to present basal sandstone fractions, then to progressively change to mud fractions towards the top (Fig. 5a). These are beds with a lower sandy division and an upper muddy division (Ghibaudo, 1992). With these SM-type structures, we observe that in parallel to lithological and granulometric variations, changes in sedimentary features can be recorded. Indeed, the proportion of coarse fractions decreases towards the top to the detriment of fine fractions that are increasingly muddy and abundant. Thus, they present associations with sometimes parallel bedding, ripples of currents. They show continuous lithological transitions from sandstones to muddy siltstones, from muddy siltstones to silty mudstone, then from silty mudstone to mudstone.

Origin 10: Two determining factors were identified as being at the origin of the design of the graded facies. Firstly, the combined effect of the density of the water in the receiving basin in relation to the kinematic effects of turbulent flows and Stockes law's. Secondly, variations in the apparent densities of the turbulent parent flows (water+sediment) can induce differentiation of superimposed flows during synchronous transport. Thus, graded sandstone-silt or sandstone-mud facies will be consequence of a process of stratification of sandstone-silt or sandstone-mud flows from the onset of the flow with rapid aggradation of massive sandy beds (Kneller & Branney, 1995; Zavala *et al*., 2012; Cartigny *et al.* 2013).

Heterolithic lithofacies

Heterolithicsandy/muddy (HS; HM) : The heterolithic structures are built on spans of 0.30 to 3 m, in which the individual thicknesses of the mud and sand layers vary between 2 and 8 cm. The contacts between the layers are subtle to sharp. The sands are often lenticular, very fine to fine, and moderately sorted. The sedimentary structures observed are often subparallel laminations, flame structures and current ripples, as well as frequent lenticular sands (Fig. 5b).

Locally we observe that these alternating lenticular sands are often sigmoidal, very fine to fine, moderately sorted, and sometimes provided with carbonaceous debris (Fig. 5c).

Origin 11: The interpretation of these heteroliths can be complex because of their heterogeneity. On the one hand, they could be affiliated with fluctuating tidal stream deposits with equivalent sandy terms of Tab facies (Bouma, 1962); F8/F9a, b (Mutti, 1992). Whereas the muddy terms mark the Tcde facies (Bouma, 1962). On the other hand, for some positions, where the muddy heterolithics tend to represent dominant stratified muds.They would be related to facies S4 of muddy hyperpycnal flows (Zavala, 2006b; Zavala & Arcuri, 2016).

MUDSTONE LITHOFACIES

Muddy facies are the second most abundant facies after sandstone facies. They have a variety of subfacies consisting of subfissile or compacted shales, rarely laminated or stratified. They are often silty and micromicaceous, locally carbonated, and oxidised. These muds often appear blackish to brownish-brown.

Shaly mudstone (Msh) : Facies Msh are characterised by schistose muds or shales cut into sheets parallel to the stratification plane (Fig. 6a). Frequent sub- millimetre to millimetre parallel silty streaks are observed. The latter may contain sporadic centimetric (<3cm) silty intercalations with convoluted bedding structures or lenticular sands.

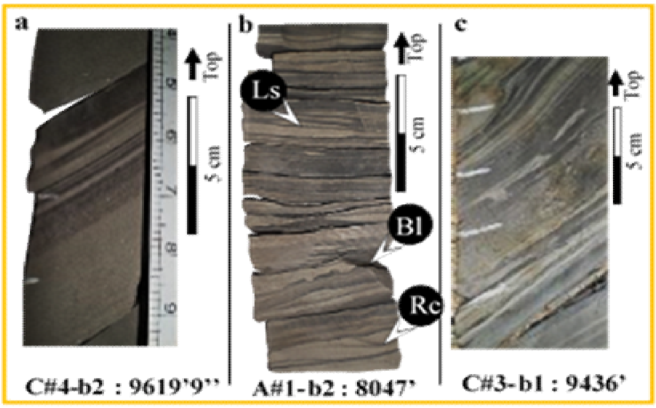
a- Flaser-bedding with alternating dark beds (*Db*) rich in muds and light beds (*Lb*) of fine lenticular sand (*Ls*) or bedload (*Bl*). b- Stratified sandstone showing fining-up structures. c-Longitudinal and cross-section of a parallel bedded sandstone debris. d- Hcs structure made of superimposed current ripples. e, f- Brittle deformations showing multiphase series of shearings. g- Calcareous sandstones associated to dextral shearing cracks (*Dsc*) with calcite-filled. h- Sandstones with water escape structures. i- Illustration of load-bearing structures of pendulous (*P*) and pseudonodular attached (*Pa*), detached (*Pd*) and ball and pillow (*Bo*) structures. j-*Teichichnus* (*Te*) formed with tortuous tunnel structures. k-Muddy sandstone with mottled texture characteristic of *Fodichnia* (*Fo*). l-Muddy sandstone with bioturbations marked by traces of *Zoophycos* (Zo).

Figure 4. Main characteristics of sandstone lithofacies

Origin 12**:** Fissile mud facies suggest settling of suspended particles in a deep and relatively calm to confined marine environment. However, the origin of silty streaks is more often interpreted as deposits of hemipelagic suspensions (O'Brien, 1989), than alternating slight silty inputs and calm. In addition, a common origin, where the silts are released from the muds by tipping and bouncing on the bottom, or a distinct origin with undulations followed by successive veneers of silts and muds is conceivable (Stow and Bowen 1980).

Stratifiedmudstone(Mstr) : The Mstr facies consist of graded subfissile silty muds up to 2 m thick. The presence of silts on the surface of the strata that form these muds can be illustrated by fine millimetre to centimetre- sized laminae, as well as splashes of silt balls (Fig. 6b).

Origin 13: Depending on the rheological character of each interface in relation to its apparent density (mud+silt+sand) during the the flow of the whole, stratifications of muddy flows occur. Moreover, the presence of fine lamellae, splashed balls and pillows highlights the superimposition of themud strata.In other word, the origine of the stratified muds is related tomarginal muddy flows competent to displace, and flat the ballsof silts. Thesefacies *Mstr* are describedas massive graded mudstones S4 of muddy hyperpycnal flows (Zavala et *al*., 2018).



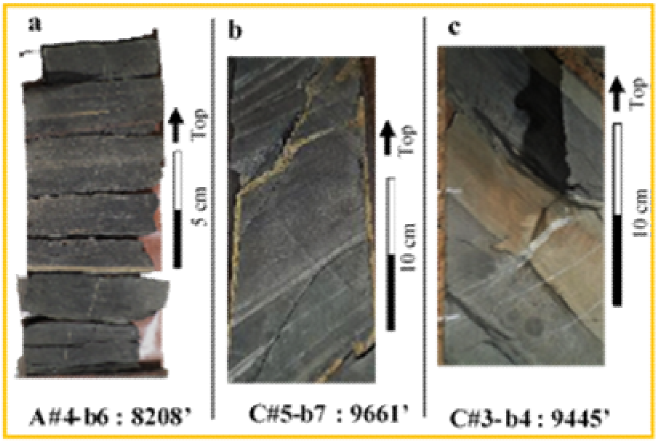
a-Sandstone-mudstone couplet. **b, c**- Heterolithic sandy-muddy exposing lenticular sands (*Ls*), bedload (*Bl*) and ripple currents (*Rc*).

Figure 5. Mixed lithofacies and lithofacies heterolithics

LIMESTONE LITHOFACIES

Calciturbidite (Calc.t) : They represent recurrent light and dark bands of limestone. These bands show a conchoidal break with thicknesses of5 to 8 cm.They are crossed by calcite veins and veinlets. Joints between the bands are determined by the colour contrast (Fig. 6c).They describe locally styloliths and interlocking hooks.

Origin 14: An interpretation should explain on the one hand, the source of the carbonate input and on the other hand, the existence of transport evidence (Kore, 2017). At the scale of the Ivorian sedimentary basin, the presence of limestones is known (Coulibaly et al., 2020b) and the sources are linked to the Albo- Cenomanian limestone banks (Spengler and Delteil, 1966). Indeed, the precipitation of limestone beds from calcium carbonate ($CaCO3$)by the dissolution of other limestones requires 'donor beds' and 'recipient beds' (Bathurst, 1975). In addition, colour variations within calciturbidite beds could be related to different carbonate sources on the margin (Reijmer et al., 2015b). Alterning of beds is a marker of turbiditic transport of limestone mud in a hydroplastic state. In addition, mechanical deformations driven by calcite vein expansions secant to the bands reflect post-lithification processes, as well as the hooks.



a-Shale mudstone. **b**-Stratified mudstones with fine silty lamellae. **c**-Calciturbidite limestones alterning yellowish-brown and greyish bands intersected by calcite-filled veins.

Figure 6. Mudstone lithfacies and limestone lithofacies

DISCUSSION

This discussion takes into account sedimentary discontinuities (Fig.7) to delineate sequences; and lithofacies assemblages to determine depositional environments in the offshore Albian horizons of the Abidjan margin. The identification of turbidic sequence patterns in this publication consists of an analysis of the lithological units from the cored samples of borehole A (Fig.8).

SEDIMENTARY DISCONTINUITIES

Following the typology of discontinuities defined by Delfaud (1974), we identify joints and diastemas, hardgrounds, and reworking surfaces. They often indicate depositional dynamics. In this case, at the core scale, joints and diastemas, and even reworking surfaces, are considered as minor discontinuities. They are located between or within units of an 'intrasequence'. Whereas only hardgrounds are of major order as they delimit two sequences 'intersequential'.

JOINTS ET DIASTEMAS

Joints were observed on all the sedimentary cores analysed, they are very frequent and reflect thin, often muddy levels separating two beds (Fig. 7a). On the other hand, diastemasare small interruptions in sedimentation marked by a clear surface separating two layers (Foucault & Raoul, 2019). They are of two (2) types:

1. AWith diastemas without an erosive base correspond either to (*1*) clear contacts consistent with stratification, which may or may not be supported by mud joints; or (*2*) irregular contacts interrupted by bioturbationslike *Zoophycos* (Fig. 7a).
2. *Diastemas with erosive bases corresponding to erosive surfaces* (Fig. 7b). These levels are seen as irregular contacts describing arrassing bases of coarser grain size than the underlying generally muddy and sometimes sandstone-silty roofs which are dishevelled. These contacts are often the site of muddy intraclasts and flame structures that are evidence of high energy deposition.

HARDGROUNDS

These surfaces embody synsedimentary, intraformational lithifications characteristic of seabeds and related to a cessation of sedimentation (Tucker & Wright, 1992). They consist of dense, rubefied, 3 to 5 cm thick, red ferruginous plates. In this case, we locate (03) three hardened surfaces delineating the sequences on core A (core 1: 8043'; core 3: 8138'; core 7: 8350'). They show calcite-filled fractured veins (Fig. 7c). The latter could suggest a major unconformity. In a marine context, the hardground surfaces are thought to have formed as a result of periods of emersion of the muds over a very long period (Riché, 1975). In addition, desiccation cracks and oxidised appearance would mark repeated sub-air exposures under significant oxidising conditions (Plint, 1984).

REWORKING SURFACES

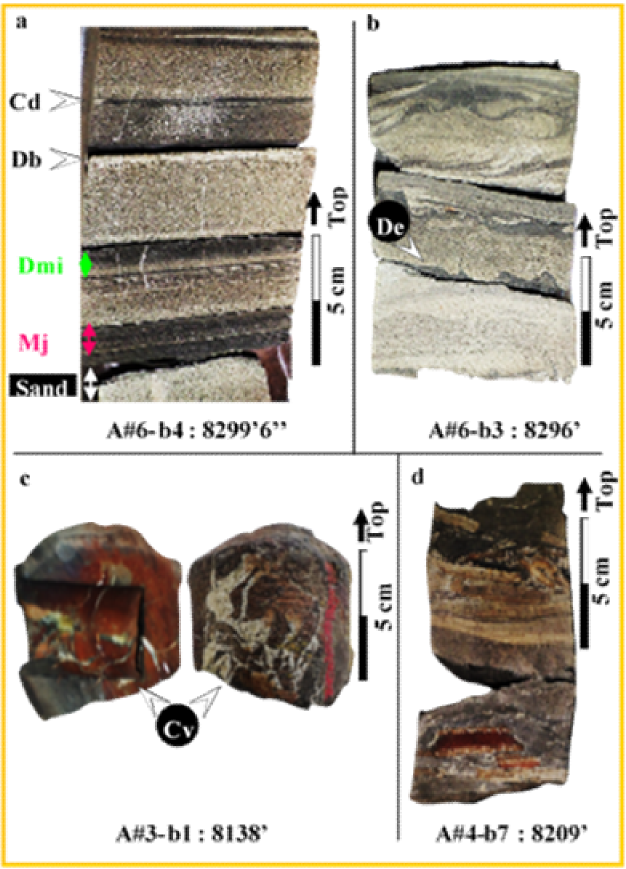
The reworking surfaces are generally located at the basal portion of the 0.3 to 1.0 m thick sandstone beds (A#4- b7: 8209'; Fig. 7d). They are associated with dismantling and resedimentation facies, suggesting high-energy flows capable of ripping and transporting mud pebbles and breccias.However, we note that some structures are embedded in massive fabrics while others are attached to HCS structures on top of muds, which is synonymous with an increase in the supply of sand and rapid but episodic sedimentation, Hamblin and Walker (1979) attributed to sporadic alternating erosion and sedimentation. The hematized structures indicate exposure to oxidizing conditions subsequent to their reworking, whereas the muddy matrices contemporary with their final deposition are exempt.

Turbiditesequences and depositional environmnents

At the core scale, the interpretation of lithological units in the depositional environment will be in the direction of sedimentationof the sequences.

Depth (ft)	Core	Lithology	Sedimentairy Features	Legend	
					Clean sandstone
					Muddy sandstone
					Calcareous sandstone
					Mudstone
					Heterolithic mud / sand
					Hardground
					Limestone
					Current ripples
					Bedload /flame structures
					Silt/sand lenses
					Scour surfaces
					Shell fragments
					Dish structures
					Convolute bedding
					Fracturing
					Muddy breccias
					Coal
					Siderite
					Calcite
					Pyrite
				Si	Silt
				F	Fine
				C	Coarse
				P	Pebbles

Figure 6. Lithostratigraphic logs of cored sediments from borehole A



a- Concordant diastema (*Cd*); Diastema with bioturbation (*Db*); Diastema with mud joint (*Dmj*); Muddy joint (*Mj*). b- Diastema with erosive base (*De*). c- Hardground affected by calcite-filled veins (*Cv*). d- Reworked surface associated with breccias and puddings.

Figure 7. Sedimentary Discontinuities

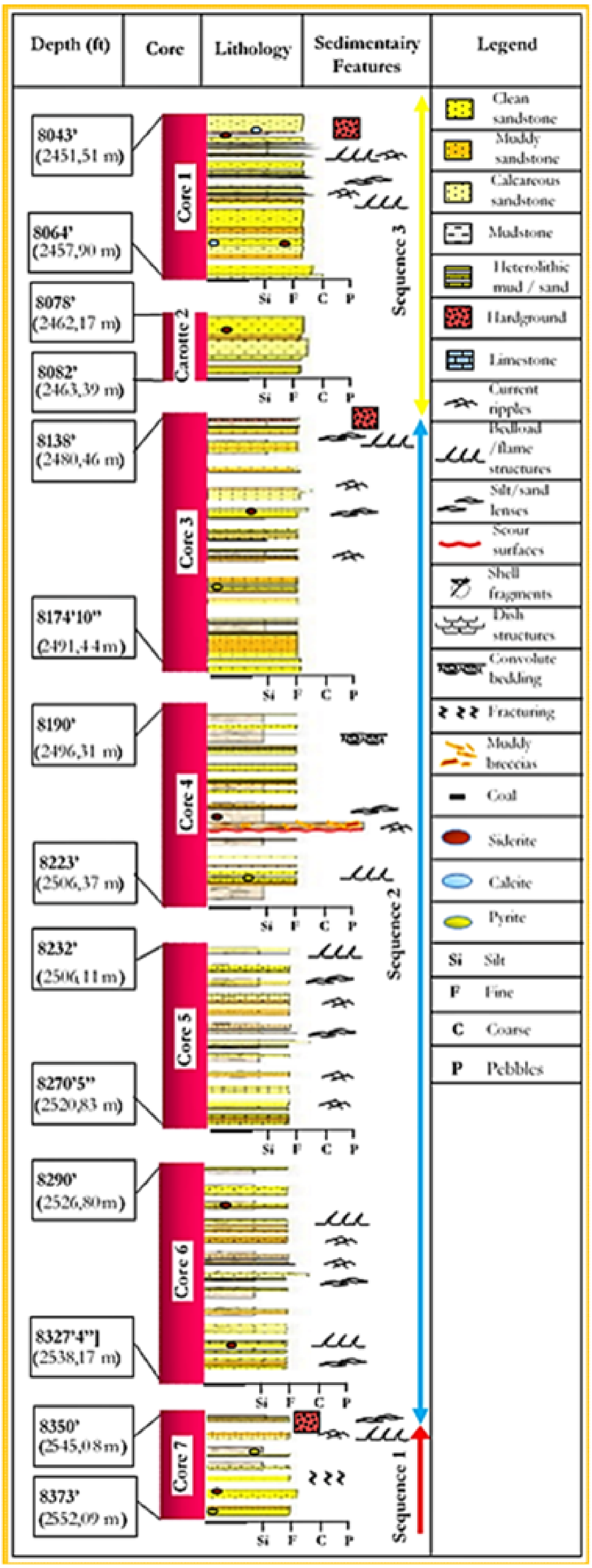


Figure 8. Lithostratigraphic logs of cored sequences from borehole A

TURBIDITE SEQUENCES AND PALEOENVIRONMNENTS

At the core scale (Fig. 8), the interpretation of lithological units in the depositional environment will be in the direction of sedimentation of the sequences.

FACIESASSOCIATIONS OF CORE SAMPLES FROM BOREHOLE A

Sequence 1

The Sequence 1 exposes only the Core 7 in three (03) units:

- ***Unit 1*** (8373'-8362'9'') shows decimetric (60 cm) banks of fine massive sandstone, locally fractured. The fractures observed are like brittle deformation structures showing series of multiphase shearings. This configuration reflects the return to equilibrium following the dehydration of liquefied sediments from the channel edges towards the centre of the channel. The massive character of the sandstone banks and the significant thicknesses indicate deposition by high density turbidites.
- ***Unit 2*** (8362'9''-8356'9'') is dominated by silty muds and is the result of suspension processes in offshore environment.
- ***Unit 3*** (8356'9''-8350') is alternation of bioturbated mudustones and laminated sandstone. Theyare subject to wave and tide actionin a shallow shelf environment.

Sequence 2

It includes cores 6, 5, 4, and 3 for eight (08) units.

Core 6 shows a basalsandstone-mudunit U1 and a summit sandstone unit U2:

- **Unit 1** (8327'4''-8307'9''), of a muddy-sandstone nature, exposes frequently laminated muds and muddy sandstones with muddy clasts. They are similar to *low density turbidite* processes. They suggest a deltaic distal alluvial fan environment.
- **Unit 2** (8290'-8307'9'') shows a clear enrichment in muddy sand with frequent muddy drapes and clasts as well as localised load features. Current ripples and fining up are also frequent compared to bioturbations which are rare and very localised. These are markers of *debris flows* within wave influenced tidal channels.

Core 5 constitutes **Unit 3** (8270'5''-8223') with fine muddy sands frequently bioturbated and intercalated with muddy levels. These bioturbations are feeding burrows represented by *Fodinichnia* and *Zoophycos* which are restricted to the muddy sands. Parallel to cross-bedding, mud drapes and fining-up extend to all sandstone types. It indicates *distal shallow marine turbidites*. This would be a wave and tide influenced continental shelf.

Core 4 (8223'-8190') forms ***Unit 4*** with a predominance of laminated silty muds interbedded with clean, muddy sandstones. Locally sideritic breccias are associated with the mud levels. The sandstone levels of 5 to 10 cm show laminations at the top expressing subparallel bedding and ripples. Locally there is a muddy sandstone with brecciated muddy clasts towards the base of the core. The silty muds and their associated sandstones are characteristic of distal turbidites. For regularly, they present both graded structurations and laminae in current ripples. However, the brecciated levels locally affected by muds and sandstones indicate *debris flows*. Furthermore, the complexity of its facies assemblages reflects proximal to medial alluvial fan deltaic environments.

Core 3 consists of four (04) units divided into sandstone units (U5 and U7) alternating with mud -sandstone units (U6 and U8):

- ***Unit 5*** (8174'10"-8169'3'') and ***Unit 7*** (8152'4'-8145') mark successions of massive banks of clean sandstone and well-developed carbonate sandstone (1 to 2 m). They reflect stable and rapid aggradations. These are deltaic deposits of the median alluvial fan which are the result of *high density turbidity flows*.
- ***Unit 6*** (8169'3''-8152'4'') and ***Unit 8*** (8145'-8138') are alternations of locally laminated black laminated muds, which alternate with interbanks sometimes graded with clean sandstone, muddy sandstone and rare carbonate sandstone (<10 cm). Muddy drapes, intraclasts and ripples are common, while *Zoophycos* and *Fodichnia* bioturbations are very localised. The organisation of sedimentary assemblages refers to depositional processes that are regulated by episodic *wave and tidal action* (Pemberton et *al*., 2009). This would be a transit environment ascontinental shelf.

Sequence 3

It consists of (03) three units and concerns only *Cores 2* and *1*.

- ***Unit 1*** (8082'-8078') forming *Core 2* shows affinities with *Unit 2* (8064'-8055') belonging to the lower portion of *Core 1*. These both units reflect *high density turbidites* suggesting median alluvial fan deltaic deposits.
- The heterolithic structures form ***Unit 3*** (8055'-8043'). They show a predominance of fine, clean lenticular sands (1-5 cm thick) associated with parallel, cross and HCS-bedded. Muddy clasts are present in the massive sandstone intercalations. They reflect major *low-density to distal turbidite* processes characteristic of a shallow shelf transitional domain subject to wave and tidal action.

MODELING OF TURBIDITE SEQUENCES

At the scale of the Ivorian offshore basin, data from lithological analyses of Cretaceous reservoirs based on excavation investigations are abundant in relation to the cores. This is no less true for the study of Albian reservoirs in the Abidjan margin. However, the results of the work on these two entities (cuttings and drill cores) show very little attraction to the application of complete sequence analyses. In particular, work integrating the determination of lithofacies, as well as the investigation of depositional processes and environments in order to establish models of turbidite sequences. Lithostratigraphic studies by Coulibaly et *al*. (2020b) based on drill cuttings highlight different facies to determine the depositional environments of each Cretaceous stage. Specifically, the Albian stages are subdivided into the Middle Albian with mud, sandstone, sand, limestone and kaolinite; and the Upper Albian with predominantly mud, marl, limestone, siltstone, sand, sandstone and sometimes kaolinite. Overall, the Albian sediments were deposited in a shallow, low- oxygen, continental-influenced proximal marine environment with variable hydrodynamics. However, if with the cuttings the definition of facies is limited only to the mineralogical nature of the sediments, while it is sometimes difficult to differentiate sands from sandstones. What can be said about accessory minerals and bioclasts, which would justify very imprecise paleoenvironmental conditions. Also the sedimentary structures are not visible with cuttings.

In addition, sedimentological and ichnological studies have been carried out on sediment cores from the Albo-Cenomanian Formations of the offshore Ivorian Basin (Féa et *al*., 2019). These studies show that with the observation of sedimentary structures (biogenic and mechanical), it is easier to define ranges of facies and sub-facies. Thus four groups of lithofacies have been established: conglomeratic to brecciated sandstones (CS, PS), clean sandstones (S) muddy sandstones (SM) and mudstones (HM, ML, MJ and M). We note that the lithofacies and/or subfacies of Féa et *al*. (2019) refer to the same lithofacies encountered in the Abidjan margin.

CONCLUSION

Examination of sedimentary core facies extracted from Albian reservoir horizons between 6500 and 10000 feet depth interval in the Abidjan Margin has highlighted the four main lithofacies types. The interpretation of facies families in relation to depositional processes reflects both particular tectonic contexts and varied hydrodynamic regimes. Sandstone facies are the most abundant. They are categorised into sandstone lithofacies, sandstone tectofacies and sandstone biofacies. They consist of generally fine to medium sandstones with clean, muddy and calcareous matrices. Their emplacement is induced by turbidites and hyperpycnal flows. Mixed lithofacies and heterolithic lithologies occur as stratified lithofacies and alternating sandstone-mudstone facies respectively. Mixed lithofacies are frequently associated with distal turbidites and low density turbidites. Whileheterolithicsreflect wave and tide reworked. The mud facies include shales correlated with hemipelagites and stratifiedmudstones related to muddy hyperpycnal flows. The banded calciturbidites are conchoidal in form and are traversed by calcite veins. These limestones are only found in core 3 of borehole C. They are very minor compared to the sandstone. The draft sequence analysis of the Albian formations from the core samples of borehole A proves that the cored deposits remain efficient materials for the palaeoenvironmental reconstruction relative to the cuttings.

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