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Cyclostratigraphy of the formations of the Ivorian terminal continental: Case of the "RO" drilling of Aboisso, South-East of Côte d'Ivoire

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Abstract

The RO drilling is located in the Ivorian Onshore Basin in the Aboisso area. To find a suitable area to meet the potable water needs of Abidjan city, litho-granulometric and log analyzes were carried out on forty-three (43) samples, to understand the sedimentary cyclicities in the establishment of hydraulic reservoirs (aquifers) along the borehole. The lithological results reveal six (6) lithologies which are among others sandy gravels, gravelly sands, kaolins, quartz sands, sandy-muddy gravel, and silty-clayey sand, which alternate all along drilling. These different alternations allowed the establishment of 42 lithological cycles, of which 35 were binary cycles, 6 ternary cycles, and a single quaternary cycle. The grain size results show that the sand fractions of these lithologies are coarse to very coarse, moderately graded to poorly graded, Platikurtic, with negative to positive asymmetries. Through these granulometric parameter arrangements, 23 cycles of grain size, 30 cycles of classification, 27 cycles of asymmetry, and 9 cycles of kurtosity were counted. The log signatures show 12 cylindrical shapes, 4 bell shapes, 3 jagged shapes, 3 egg shapes, and one funnel shape giving a total of 23 cycles. They indicate the existence of anastomosing and meandering fluvial systems.

Keywords: RO drilling; Ivorian Onshore Basin; Drinking water needs; Sedimentary cyclicities; Lithological cycles; Litho-granulometric; log signatures analyze

1. Introduction

According to the World Health Organization (WHO), each year around the world, around 50 million men, women and children are affected by waterborne diseases, of which one million have disabling sequels, and more than a billion working days are lost. In addition, every year around 4 million human beings, especially children, die from diseases related to water and the environment [1]. Water scarcity is the most serious socio-economic and human development issue in the broad sense. Côte d'Ivoire government, through its program of water for all, from the National Office of Drinking Water (ONEP)[1], could carried out several hydraulic drillings. Indeed, in order to respond to the major challenge of supplying drinking water to the populations of Abidjan city, which has experienced a demographic explosion since 2014 with an estimated population of 4,395,243 [2] and whose the usual supply source is not enough.

It was therefore initiated in the South of Côte d'Ivoire, more precisely in the onshore sedimentary basin, the campaign of 55 hydraulic drillings from 2016 to 2018 on the eastern part of the said basin from the region of the large bridges to the region of South Comoé in order to assess the water potential while identifying all the aquifers [3]. Studies were carried out on the Ivorian onshore sedimentary basin to show the sedimentary cyclicities [4-14]. There is, however, a deficit which allows to characterize the formations with a view to providing boreholes for the water supply of the populations.

[1] National Office for Drinking Water: https://onepci.net/en/

It is with this in mind that this study of the "cyclostratigraphy of the formations of the Ivorian terminal continental: case of the "RO"[2] drilling of Aboisso" was initiated to fill this gap. Cyclostratigraphy allows the identification, characterization, correlation and stratigraphic variation interpretations of the formations along the well. It is also the study of sedimentary cycles and their potential correlations to the astroclimatic cycles of Milankovitch[3]. The objective of this study is to determine the sedimentary cycles for the establishment of reservoirs (aquifer) in the Aboisso region in order to supply the city of Abidjan in drinking water. It will be achieved through the determination of lithological, grain size and log cycles contained in the Aboisso formations.

2. Study area

Aboisso department is located in the southeast of Côte d'Ivoire. It lies between longitudes 4°38' and 2°40'W and latitudes 5°05' and 5°48'N. It is bordered to the east by Ghana, to the south by Krindjabo and Adiaké, to the north by Bétié and to the west by Alépé (Figure 1).

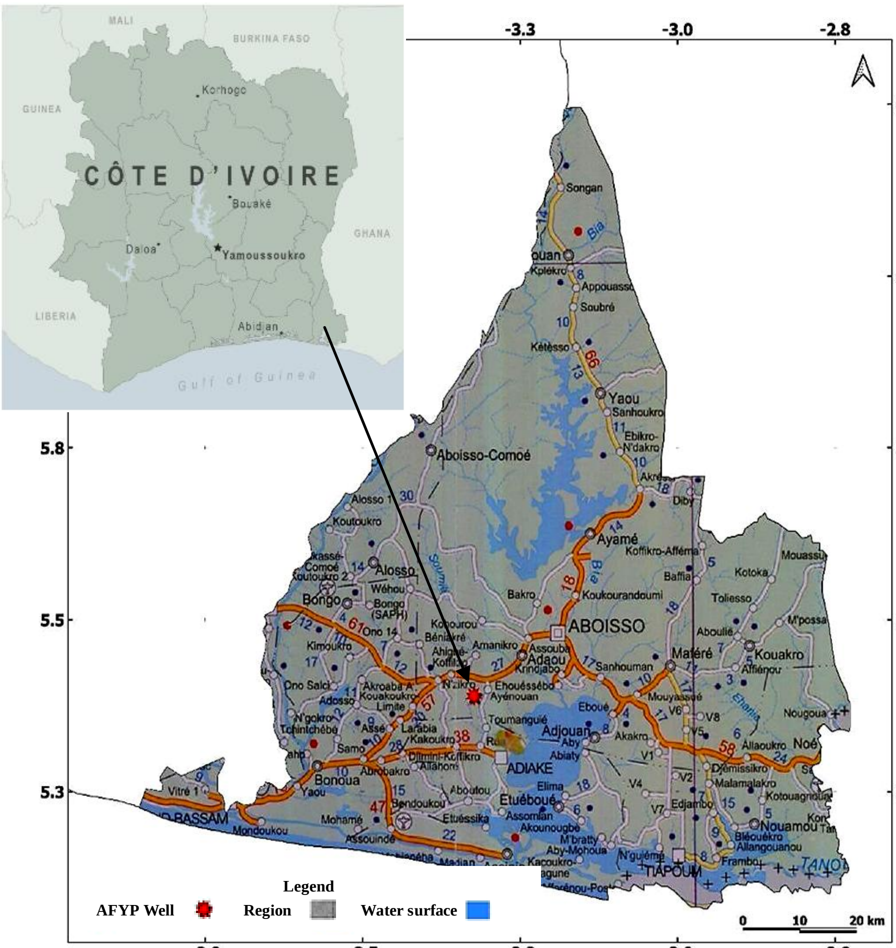

Figure 1 : Presentation of the location of the RO drilling in the department of Aboisso (excerpt from the geographical map of Côte d'Ivoire)

[2] RO is the drilling name

[3] https://earthhow.com/milankovitch-cycle/

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2. Material and Method

2.1. Sampling and Processing material

The equipment for the field surveys consists of a rotary mud drill for drilling (90° rotary drilling) for future core analyses. A PVC tube to raise the cuttings, surmounted by a drill rod to reach the desired depths. Besides, a shovel to take the samples was also used with a camera for photographs capture in order to find the sampling points. In addition, additional field data for the location of the wells was collected with a GPS.

In the laboratory, working equipment like allure paper to dry the collected sediments, a column of ten sieves to sieve sample in order to know the particle size of the particles which were then weighed using a balance (weighed) giving the mass of each of the fractions according to the diameters of the sieves. A 250 mL bowl was used to determine the porosity and a binocular magnifying glass is used to carry out the morphoscopy of the particles.

The STRATER 5 software was used to produce the stratigraphic logs and diagraphic signatures and EASYSIEVE to determine the granulometric parameters.

2.2. Method

A) Particle size cycle

A total of 92 samples were taken from the RO borehole. Sampling was done through the drilling machine which is connected to a tool called a rotary bit which, by abrasion and grinding, brings up the delays through the PVC tubes by means of a fluid called drilling mud. Once on the surface, drilling mud and amalgams undergone a physical treatment in order to separate them. Thereafter, they were bagged according to depth and taken to the laboratory. The sediments collected were first dried on allure paper, then a part of these sediments was taken and put in a 250 mL bowl in which water is added to determine the porosity. After which, the washing was carried out and the washed sediment was dried on tissue paper. In addition, 100 g of the dried sediments were used for particle size analysis. Using a vibrating sieve set at 50 for 10 minutes and a column of 7 sieves whose meshes are 04, 02, 01 mm, 500, 250, 125 and 63 microns, was used. After the 10 min, the residue from each sieve was then weighed to determine the proportion of each fraction in the sample. The data obtained was reported in Excel file. Also through Easysave software, the granulometric parameters such as the average which gives us precision on the average size of the grains of sand; the standard deviation which makes it possible to classify the sands by giving an idea of the sorting of the sediments, were determine.

B) Lithologic cycle

This will involve determining the nomenclature of the cuttings and the design of the lithological log. The nomenclature of cuttings was based on the different proportions of rudites, arenites and pelites. A name was assigned to each excavation from the GSB ternary diagram. Thus, it was easy to determine the clean sediments, mixed with 2 or 3 elements. In addition, the design of the lithological log was done using the Strater 5 software®[4] which is a software for measuring and interpreting well and borehole parameters. As concerning to the determination of the various cycles, it was a question of determining the lithological cycles which is to count the various lithologies.

C) Logging cycle

The determination of logging cycles consisted to count the different forms of gamma ray observed, in particular the cylinder, funnel, bell, egg and sawtooth shapes. Finally, the granulometric cycles consisted to determine the various granulometric parameters such as; grain size, asymmetry, grading, and kurtosis.

2.3. Results

A) Lithological cycles

The lithologic reconstruction was possible only from the log allowing to specify the limits of the layers, thus distinguishing the false from the true mixtures. Six (6) elementary lithologies constitute our lithological cycle. The mainly quartz sand, with a percentage of 26.42% in all the sediments while the GR signature is in

[4] https://www.goldensoftware.com

the form of peaks with values between 60 and 150 API. The gravelly sands with a mineralization only composed of quartz with a percentage of 24.53% of the sediments of the well with the GR value of these sediments lower than 20 API. Kaolins (or clay siltstones) with a proportion of 13.21% in all sediments with a GR signature values between 60 and 150 API. The silto-clayey sands which are quartzose have a proportion of 30.18% with the GR value of these sediments being at 60 API (Figure 2). The bouo-gravelly sands, made up of quartz grains, have a proportion of 3.77% with a GR signature value less than 30 API. The sandy-muddy gravels, also made up of quartz grains, possess a percentage of 1.897% with a GR value of 20 to 30 API.

B) Logging cycles

The six (6) elements in the lithologic cycle allowed lithologic reconstruction in the RO well. The lithologies associated with each letter are: a = gravelly sands, b = sandy-muddy gravels c = kaolins, d = sands, e = mud-gravelly sands, f = silty-clayey sands.

All binary and ternary cycles were developed in fluvial systems corresponding to periods of decline (a) and flood (b). The periods of decline (low water level) correspond to the activation of the fluvial channel which promotes the deposition of sands (a) where the deposition energy is high. As for the flood periods, they correspond to the deposits of kaolins (b) in the flood plain which is created during these periods by the fine elements. The (a)-(d) and (a)-(c)-(d) cycles thereby reflect a reduction in the deposition energy in the channel. The six elementary lithologies above constitute our lithological cycle, thus there are a total of 10 lithological cycles including four 4 binary cycles, 5 ternary cycles and a single quaternary cycle. All binary and ternary cycles were developed in a fluvial environment. In addition, for the logging cycles 13 cycles were counted including 5 cycles in cylindrical shapes, 2 cycles in egg shape, 2 cycles in sawtooth shape, 2 bell-shaped cycles and 2 funnel-shaped cycles. The RO well is therefore mainly characterized by braided fluvial deposits with a total percentage of 84.24% (Figure 2). From the logging it was possible to identify the limits between the layers and to distinguish six alternating lithologies. These are gravelly sands, sandy-muddy gravels, kaolins, sands, mud-gravelly sands and silty-clayey sands. In addition, the logging allowed the determination of the different lithological cycles which were highlighted by the lithological log and the logging cycles by the analysis of the different forms of GR. There are 10 lithologic cycles with a maximum of 6 elements (a-b-c-d-e-f) and 13 log cycles, mainly the Rey gamma forms observed are the cylinder, bell, egg, funnel and serrated (sawtooth) forms, (Figure 2).

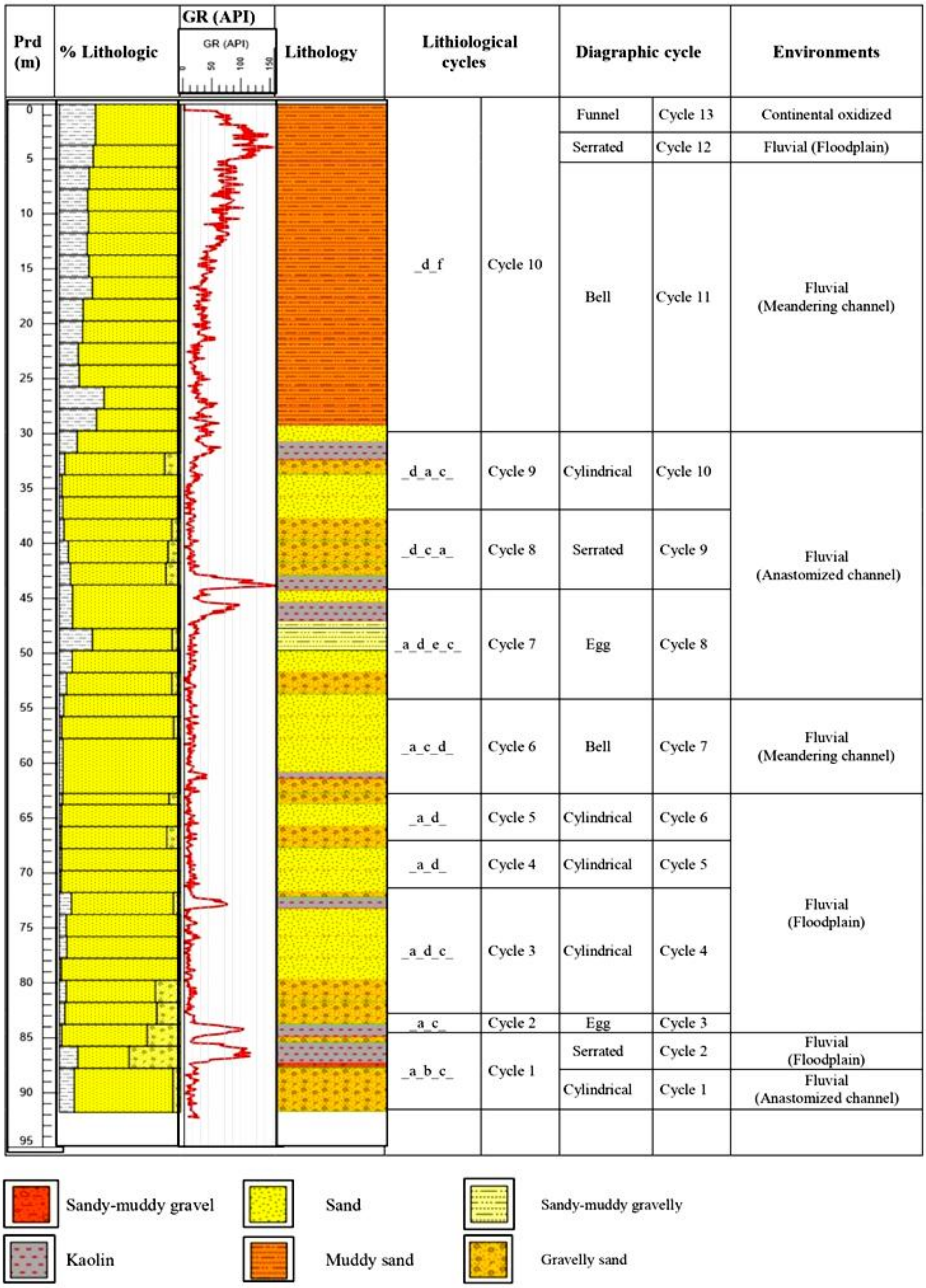

Figure 2: Log presenting the lithological and log cycles

C) Granulometric cycles

In the direction of the drilling sedimentation, there are 7 cycles including: 6 cycles of very coarse sands – coarse sands (TG_G) and 1 cycle of medium sands – coarse sands (M_G) through which the granulometric parameters cycles were identified *i.e.* the size of the grains, the classification, the asymmetry and the flattening of the grains indicated 8 cycles of grain sizes, 6 cycles of classification of the sands, 5 asymmetry cycles and 1 sand kurtosis cycle.

D) Average quartz grain sizes

The average particle size (m1) of the quartz grains vary from 0.451 nm; 0.571 nm and 1.269 nm, from which the classification such as the median size, the coarse size and the very coarse size involving medium sands, coarse sands and very coarse sands were deduced. The proportions of these sizes are respectively 2.4%, 69% and 28.6% (Figure 3). Coarse sands are the most dominant in this well. The median size cycle was composed of medium sand (M), coarse sands (G) and very coarse sands (TG). In the direction of sedimentation, there are 7 cycles including: 6 cycles of very coarse sands – coarse sands (TG_G) and 1 cycle of medium sands – coarse sands (M_G).

The TG_G and G_M cycles reflect a gradual decrease in the energy of deposits in the fluvial channels; each cycle startup begins with strong energy and ends with less strong energy. In the TG_G cycle, the decrease in energy was gradual between the very coarse sands (TG) and the coarse sands (G) while in the M_G cycle the decrease in energy is abrupt between the coarse sands (G) and medium sands (M) probably due to a decrease in slope (Figure 3).

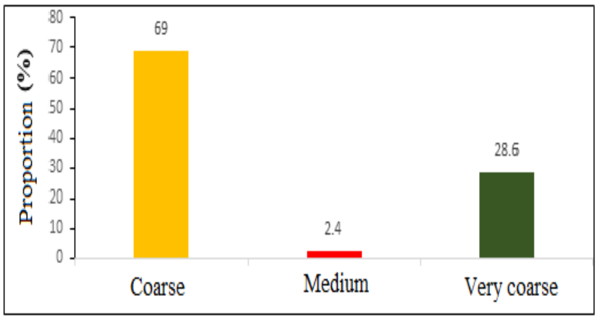

Figure 3: Average sizes proportion of quartz grains.

E) Classification of quartz grains

The classifications are identified in abundance order (Figure 4): moderately classified sands (66.67%), poorly classified sands (28.57%) and fairly well classified sands (4.76%).

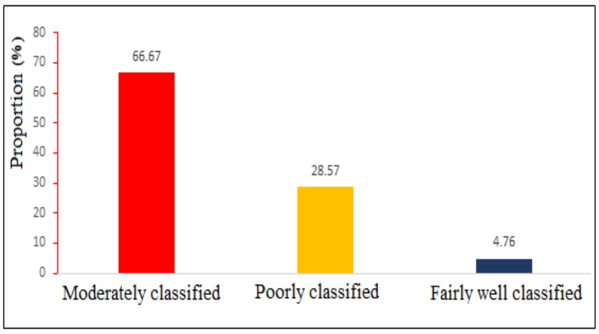

Figure 4: proportion of classification types

The quartz grain grading cycle consists of three elements (medium graded sands (MC), poorly graded sands (MeC) and moderately graded sands (AbC)). In the direction of sedimentation, there are 6 cycles including 2 cycles of moderately classified sands_fairly well classified sands (MC_AbC) and 4 cycles of moderately classified sand_poorly classified sand (MC_MeC) the depths which are summarized in the following table (Tableau I).

Tableau I
Type of classification of quartz grains

Depths (m)	Ranking
91.75m-85.44	MC_AbC
84.91m-75.75	MC_AbC
73.25m-53.75	MC_MeC
51.75m-49.75	MC_MeC
47.75m-21.55	MC_MeC
21.02m-1.83	MC_MeC

In the direction of sedimentation, we note that the very beginning of the cycle is marked by an average classification, namely the MC_ AbC cycles, this may be due to a mixture of several coarse and fine fractions from which the deposition energy is low. Beyond this cycle, the classification becomes good until the end, the MC_MeC cycles, hence a high transport energy which sorts the sediments better compared to a low energy in the opposite direction of sedimentation.

F) Skewness or asymmetry

Skewness values are ranged between -0.008 and 1.074. The asymmetries identified are in descending order: negative asymmetries (80.95%) and a symmetric one (19.05%). The most dominant are the sands whose asymmetry is negative (Figure 5). The cycles of asymmetry of quartz grains consist of two elements (negative asymmetry (N) and a symmetrical (S)). In the direction of sedimentation, 5 cycles are counted, distributed as follows: 4 Negative _Symmetric (N_S) cycles and one single Symmetric _ Negative (S_N) cycle. N_S cycles show a preponderance of coarse sizes compared to the average of the sample at the beginning of the cycle and evolve at the end of the cycle towards a balance between the fine sizes and the coarse sizes compared to the average. The S_N cycles are located at the top and suggest as many coarse sizes as fine sizes compared to the average of the sample at the end of the cycle where the deposition energy decreases. Therefore, it can be concluded that the ranking is good at the beginning of the cycle then at the end of the cycle it becomes less good.

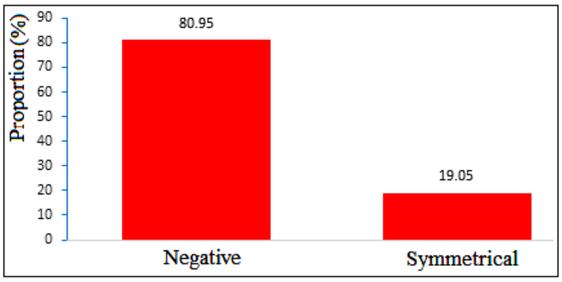

Figure 5: Proportion of asymmetry types

G) Kurtosis

In the analysis of the kurtosity (flattening) parameter, a single element in the cycle was highlighted, namely the platikurtic (P) which spreads over the entire length of the RO well (Figure 6).

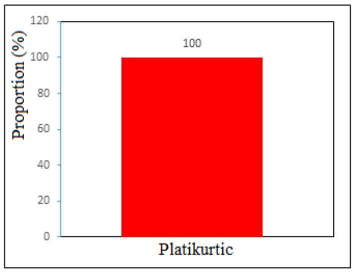

Figure 6: proportion of types of kurtosis

Since the proportion of kurtosis is 100% platikurtic, therefore it indicates that the curves of the sands are much extended in the direction of sedimentation, along the RO well.

These cycles are binary with the exception to the kurtosis cycle which is essentially platikurtic along the well. The quartz grains of Aboisso region are mostly coarse, moderately graded with negative asymmetries and very extensive curves (Figure 7).

Prd(m	Grain size cycles			Sand gradind cycles			Cycles asymmetry			Kurtosis cycles		
0	coarse			poorly classified			negative					
	coarse			poorly classified			negative					
5	coarse			poorly classified			negative					
	coarse			poorly classified	MC_McC	cycle 6	negative					
10	coarse	_TG_G_	cycle 8	poorly classified			negative	_S_N_	cycle 5			
	coarse			poorly classified			negative					
15	coarse			poorly classified			negative					
	coarse			poorly classified			negative					
	coarse			moderately classified			negative					
20	coarse			poorly classified			symmetrical					
	very coarse			poorly classified			symmetrical					
25	very coarse			poorly classified			symmetrical					
	coarse	_tg_g_	cycle 7	poorly classified			symmetrical					
30	very coarse			poorly classified			symmetrical					
	very coarse			moderately classified			symmetrical					
35	very coarse			moderately classified	MC_McC	cycle 5	symmetrical					
	coarse			moderately classified			negative					
	coarse	_G_TG_	cycle 6	moderately classified			negative	_N_S_	cycle 4			
40	coarse			moderately classified			negative					
	coarse			moderately classified			negative					
45	coarse			moderately classified			negative					
	Moyen	_G_M_	cycle 5	moderately classified			negative			platykurtic	_P_	cycle 1
50	coarse			poorly classified	MCMcC	cycle 4	negative					
	coarse	_TG_G_	cycle 4	moderately classified			negative					
55	very coarse			moderately classified			symmetrical					
	coarse	_TG_G.	cycle 3	moderately classified			negative					
	very coarse			moderately classified			negative					
60	coarse			moderately classified			negative					
	coarse	_TG_G_	cycle 2	moderately classified	MC_McC	cycle 3	negative					
65	coarse			moderately classified			negative					
	very coarse			moderately classified			negative	_N_S_	cycle 3			
70	coarse			moderately classified			negative					
	coarse			moderately classified			negative					
	coarse			moderately classified			negative					
75	coarse			fairly well classified			negative					
	coarse			moderately classified			negative					
80	very coarse	_TG_G.	cycle 1	moderately classified		cycle 2	negative					
	very coarse			moderately classified	MC_AbC		symmetrical					
85	very coarse			moderately classified			negative	_N_S_	cycle 2			
	very coarse			moderately classified			negative					
90	very coarse			fairly well classified			symmetrical					
	very coarse			moderately classified	MC_AbC	cycle 1	negative	_N_S_	cycle 1			
95												

Figure 7: Particle size cycles of the RO well

3. Discussion

3.1. Lithological and log cycle

The RO well are composed of 10 lithological cycles and 13 log cycles. The cycles are of degree of asymmetry; indicating a duration of passage different from the end of a cycle to the initial phase of another cycle. For example, the passage from (a) to (b) or from (c) to (d) is different from the passage from (b) to (a) or from (d) to (c). This variation is reinforced by the thickness of the layers which is therefore different overall. The deposition time of each layer of sediment is different from the other layers. The logging cycles are also asymmetrical, they are generally called autocycles; which reflects a development in continental (fluvial systems) and coastal (transitional) environments. The establishment of these cycles is due to internal factors which are here the different migrations of the river systems argues that autocycles are characteristic of continental, littoral and platform environments.

These cycles are climate controlled. At the level of fluvial systems, the alternation of wet period and arid period favors the deposition of fluvial sands and kaolins which also alternate. Kaolins are formed during periods of flooding (flood plain) and sands during periods of recession (active channel). During flood seasons, they can occur anytime and anywhere in any climate. But, according to [15], the frequency, intensity and pattern of floods recorded over several years in a stable area are essentially representative of a sustainable climatic environment. Also, states that in a fluvial series composed of an alternation of sandy and clayey facies, one is linked to the activity of the channel (sand) and the other to the flood (clay).

3.2. Granulometric cycles

In the granulometric cycles, the average size of the quartz grains decreases from the beginning to the end of each cycle; *i.e.* a progressive reduction in the energy of deposition in the fluvial channels which acts on the classification of the sands. The higher the energy, the better the grains are sorted, in other words the grains are better classified (medium to fairly good classification). In the RO well, the grains are deposited in this case preferentially and the risk of mixing different sizes is minimized. A slowdown in energy or a sudden loss of energy leads to poor sorting; there will be a high risk of mixing different sizes. The classification of the sands is therefore not a function of the size of the grains, but depends to the proportion of the granulometric fractions expressed in the sandy sediment [16, 17].

The asymmetry is also related to the deposition energy. A high deposition energy leads to a negative asymmetry which will correspond to a preferential deposition of coarse sizes and are the least sorted platikurtic compared to the average of the sample and vice versa.

As in the classification, the kurtosis is related to the number of granulometric fractions expressed in the sandy sediment. The smaller is this number, the sharper is the curve and vice versa.

According to the work of [18], the transport of sediment with variable grain size (mixture of different sizes) can oppose to a certain extent the preferential transport of fine grains compared to coarse ones. Coarser grains are more exposed to the flow than if they were represented alone in the bed, and vice versa for fine grains. In a sediment with varied grain size, if the transport energy is not sufficient to transport the coarse grains, then there will be sedimentation of sediment with variable grain size; which will favor a bad classification. This explains the poor classifications encountered in coarse gravelly sand and gravel with coarse sand. Additionally, can the particle size mixture result from a sudden loss of transport energy which will deposit all of its solid charge. This mixture can still be the result of the sampling which is done over a given interval. In this interval the energy may have varied during the different deposits.

In the RO well, the sediments encountered are coarse and have a negative asymmetry. The asymmetry is therefore linked to a high deposition energy relative to the average of the sample.

4. Conclusion

The aim of this study was to characterize the sedimentary cyclicities of the formations of the continental terminal of Aboisso locality. At the end of this study, three types of results were obtained: lithological cycles, logging cycles and grain size cycles. Along the RO well, 6 lithologies were identified, namely the gravelly sands (a), sandy-muddy gravels (b), kaolins (c), sands (d), mud-gravelly sands (e) and silty-clayey sands (f). Thirteen lithological cycles in total were found, distributed in order of abundance: three binary cycles (c-f), two binary cycles (a-d), one binary cycle (a-c), one ternary cycle (a-b-c), one ternary cycle (a-d-c), one ternary cycle (a-c-d), one ternary cycle (d-c-a), one ternary cycle (d-c-a), one ternary cycle (d-c-f) and finally one quaternary cycle (a-d-e-c). It is noticed that no cycle closes the 6 lithologies. The analysis of the gamma ray shapes suggested the identification of 13 logging cycles and 5 logging shapes which are: five cycle of cylindrical shapes, two cycles of egg shape, two sawtooth (serrated) cycles, two bell cycles and two funnel cycles. Cylindrical, egg-like shapes are characteristic of anastomotic fluvial systems. On the other hand, the bell shapes reflect the presence of meandering fluvial deposits, which testifies to a normal grano classification. The sawtooth deposits, on the other hand, show an aggradation of the fluvial floodplain deposits. The funnel shapes testify to an inverse grading whose placement of these deposits is an anatomosed fluvial system. The analysis of the cycles of the grain size parameters including eight cycles of the average grain size, six cycles of the grain classification, five cycles of grain asymmetry and one cycle of kurtosis were identified along the shaft. The quartz grains from Aboisso area were mainly coarse (69%), moderately classified (66.67%) with negative asymmetries (40.48%) and platikurtic flattening (100%).

The different cycles are asymmetrical and autocycles set up by the different migrations of the river systems. These systems created some reservoirs, whose the largest reservoir is located at heights of 47.83 m and 85.42 m, *i.e.* a total of 37.59 m in thickness, which is reservoir 1. Three good reservoirs (aquifers) were observed: reservoir 1 (85.42m_47.83m), reservoir 2 (45.62m_30.85m) and finally reservoir 3 (30.85m_4.80m). All of these reservoirs were developed in fluvial systems and their cap rocks are floodplain deposits and bar land. The floodplain deposits are beveled thus creating a communication between the three sub-reservoirs**.**

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