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Lithological Characterization of the ‘Baobab C5 8’ and ‘Phoenix 1-10’ Oil Wells in the Bongor Oil Basin in Chad

DOUMNANG MBAIGANE JeanClaude[1], MBAIGOLOUM DJERAKOUBOU Blaise[2], Léontine TEKOUM[3], MBAZOA Armelle Michele[4]
[1,2,3]Laboratoire de Géologie, Géomorphologie et Télédétection, Département de Géologie, Faculté des Sciences Exactes et Appliquées, Université de N’Djaména
[4]Université de Yaoundé 1 (Cameroun)
Email address: doumnang@gmail.com ; mbaigoloum@gmail.com ; leontinetekoum@yahoo.fr ; armelmbazoa19@gmail.com

Abstract— *The geological evolution of the African continent is marked by the formation of numerous intracontinental rifts. Following the opening of the South Atlantic, Chad suffered the creation of numerous oil basins (Erdis, largeau, Bongor, Salamat Doba) in the Cretaceous period. The Bongor Oil Basin, southern Chad, is an inverted rift basin located on a crystalline Cambrian basement that is regionally linked to the Mesozoic Cenozoic rift system and large shears in Central and West Africa. The objective of this work is to contribute to the knowledge of the lithology of the oil wells of the Bongor Basin by making a macroscopic and microscopic description of the lithological units of two main units of the basin : ‘Baobab C5-8’ and ‘Phoenix 1-10’. The work is based on measurements of the thicknesses of the different layers, on the passage of the grains to the meshes of the sieves and on the macroscopic and microscopic observation of the criteria for recognizing the rocks, namely the size of the grains, their shape, their color, their structure... The result of this work shows that for the well of ‘Baobab C5-8’, the order of succession of the layers from top to bottom is as follows: Sand - clay - sandstone - siltites - silty clay - sandstone and base. For the well ‘Phoenix 1-10’ the order is as follows: Sand - clay - sandstone - silty clay - siltite - shale clay - sandstone and granitoid. Lithological studies of the "Baobab C5-8" and "Phoenix 1-10" wells have shown the following: sands, sandstones, clays, shale clays and siltites. This work will greatly contribute to the knowledge of sediment stacks and open up prospects for research in other neighboring basins.*

Keywords— *Oil Basin, Baobab C5-8, Bongor, Phoenix 1-10, Wells, Southern Chad.*

I. INTRODUCTION

Chad is located in a vast area called the Pan-African Mobile Zone [1], formed mainly during an orogeny that took place towards the end of the Precambrian (700-520 Ma). It is a collection of relatively unstudied chains located between the West African Craton in the West, the Congo Craton in the South and the Nile Craton in the North East, which is rather poorly defined.

The pan-African tectono-thermal event represents the last active orogeny on Chadian territory and the rocks formed or influenced by this event constitute the bulk of the crystalline massifs (Tibesti Ouaddaï, massif central, Mayo kebbi and Yadé).

Now Chad is part of a stable block. Its geological history since the beginning of Paleozoic is marked by the deposition of sedimentary platform formations over most of the territory.

Paleozoic sediments accumulate in the north and east of the country following the latest pan-African tectonic shift. The posterior tectonics and the surrection of Tibesti and Ouaddaï limit sedimentation in the Erdis and Djado basin, which occupy northern Chad and adjacent regions [2][3][4][5].

Sediment accumulation in central and southern Chad began in late Jurassic-early Cretaceous, after the creation of a series of graben rifts, following the dismemberment of the supercontinent Gondwana and the separation of Africa from South America. The subsidence of this region and the sedimentation continues until quaternary and the deposits will form the basins of Lake Chad (Chadian basin), extending to the neighboring countries.

Structural elements affected Chad's tertiary and quaternary sediments. These structural elements were observed at the NE edge of Lake Chad by [4]. These authors have revealed a large cenozoic brittle tectonic between the Aïr massif and the shores of Lake Chad. The brittle tectonics are marked by a graben that extends from the NE edge of Lake Chad to Bilma and into Algeria [4][6][7][8]. The same ditches have been described within Chadian territory: Doba ditch, Bousso ditch, Baké-Birao ditch [9][10][11][12][13][14], Largeau ditch [12][9].

Research conducted by ORSTOM since 1960 in the 1970s by oil companies (aeromagnetry, gravity, seismic and drilling) has led to the discovery of oil and gas deposits in ditches whose existence had been demonstrated by geophysical work [15].

On the basis of geophysical and geological data then available, [16] shows that three basins could be of interest for oil research in Chad (Bassins des Erdis, Lac-Chad basin and Doba basin) [9][14][17].

The Erdis Paleozoic Basin.

The Erdis basin, which occupies the north-eastern part of Chad, also has a potential for hydrocarbons [18]. This basin shows successive halos passing towards the North-East from the Cambrian to the marine carboniferous (Mourdi series) [18]. The Mourdi series of marine sediments may constitute the mother rocks. Refractive seismic prospecting, carried out by

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CPGF (1962), revealed a powerful formation at 3500 m/s corresponding to the primary sandstones which can serve as reservoirs.

The Lake Chad Basin

The Lake Chad Basin lies north of Lake Chad and extends towards Niger. This basin is oriented North-North-West [5].

The secondary formations have been highlighted by deep drilling carried out in the framework of the development program (UNDP/FAO) of the Lake Chad Basin and by oil exploration carried out by [8] in the 1970s.

CONOCO has installed seven boreholes in a ditch located north of Lake Chad, west of Nokou (Kanem ditch or Termit Basin) ; the eighth was executed in 1990 by the Esso consortium (Sédigui2) in order to assess oil reserves.

In the southern zone, many basins have potential for hydrocarbons Doba and Baké Basin - Birao - Mangara or Doba - Déséo

The Doba basin

The Doba and Baké-Birao ditches were identified in 1954 by a team of ORSTOM geophysicists who carried out gravimetric routes, electric sounding and seismic prospecting in the Moundou Doba region [19]. The Bousso pit, oriented East-West, was identified during an aeromagnetic survey carried out in 1956 by SARM on behalf of the Office of Petroleum Research.

CONOCO drilled a total of seven boreholes in this ditch. The drilling campaign began in December 1973 with the Doba drilling [20][21], which was also the deepest (4261 meters).

The Salamat basin

The Salamat Basin lies to the east. In Salamat, the Kedeni borehole shows that the continental terminal probably constitutes the largest portion of the post-Cretaceous fill [22][23].

Sedimentation in this part of the Basin is relatively unknown. Drilling in the Am Timan region (water drilling, oil exploration) generally traversed approximately 20 meters of alluvial quaternary sedimentation before intersecting often lateritic sandy or clay formations attributed to the terminal continental shelf.

The Bousso basin (or Bongor)

The ditch of Bousso or Bongor is parallel with that of Doba and is located north of the latter. Two exploratory drillings were carried out in 1974 in the Bongor Basin (SSW of the city of Bousso), with depths of 2,589 m (Naramay 1) and 3,434 m (Sémégin 1), respectively, without touching the base [24].

The oil companies have also carried out some geological studies on the basin (in 2005 by Encana and 2007 by CNPCIC) but the results of this work have remained confidential.

However, the knowledge of sedimentary stacks from the mineralogical, structural, lithological point of view and also the vertical and lateral variations of the layers are very limited. The Bongor Basin is selected to lithologically characterize two oil wells "Baobab c5-8" and "Phoenix 1-10" and to conduct a comparative study.

This study will allow us to know the nature, thickness and order of succession of the different layers.

II. Geographical Overview of Chad

Chad is a country located in the center of Africa between 7° and 24° north latitude and 13° and 24° east longitude with an area of 1,284,000 km^2. The province of Bongor is located south of Chari Baguirmi (Fig. 2).

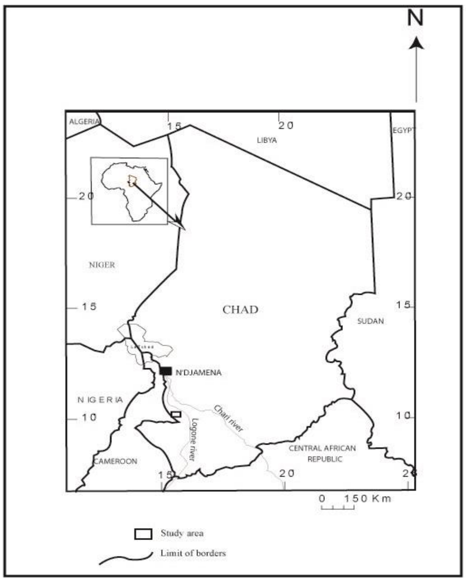
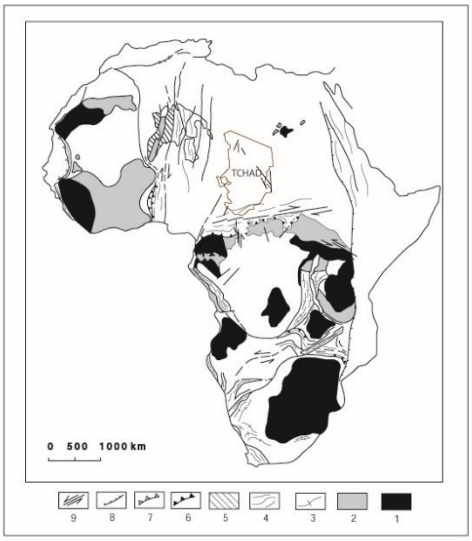


Fig. 1. Location map of the study area

III. Regional Geological Overview

Chad is located in a vast area called the Pan-African Mobile Zone by [1], formed mainly during an orogeny that took place towards the end of the Precambrian (700-520 Ma). It is a collection of relatively unstudied chains located between the West African Craton in the West, the Congo Craton in the South and the Nile Craton in the North East, which is rather poorly defined [23] (Fig. 2).



1. Archean formations ; 2. Paleoproterozoic formations ; 3. Kibarian formations ; 4. Panafrican formations ; 5. Pharusian formations ; 6. Panafrican overlaps ; 7. Hercynain overlaps ; 8. Mozambic belts boundaries ; 9. Shear zone.

Fig. 2. Map of African cratons, Chad in the Central African Mobile Zone

To the west, the pan-African zone includes the Tuareg and Nigerian shields (Transaharian belt [25][17] which are made up of a mixture of lands of various ages delimited by mega-shears and ophiolitic sutures [26][27][28].

To the east the area extends to Saudi Arabia. The Arabo-Nubian shield consists of bonding several volcanic arcs separated by ophiolites and the edges of reactivated continental plates [17][22][23].

Most of Chad, western Sudan, northern Cameroon and Central Africa would constitute the Central African Belt of the Pan-African Mobile Zone. The lineaments of Sanaga and Adamawa (Cameroon) represent the contact of this area with the Congo craton [29][30]. But its boundary with the Nile craton is very blurred.

Part of the zone (western Sudan and most of Chad, from eastern Tibesti to Mayo kebbi) should be included in a cratonic zone (Uweinat craton), the western boundary of this craton would coincide with the heavy zone located in central Chad east of Lake Fitri [23][31].

Now Chad is part of a stable block. Its geological history since the beginning of Paleozoic is marked by the deposition of sedimentary platform formations over most of the territory.

Paleozoic sediments accumulate in the north and east of the country following the last pan-African tectonic shift [32][33][34]. The posterior tectonics and the surrection of Tibesti and Ouaddaï limit the sedimentation in the basin of Erdis and Djado which occupy the north of Chad and the adjacent regions.

Sediment accumulation in central and southern Chad begins in late Jurassic-early Cretaceous, after the creation of a series of graben rifts, following the dismemberment of the supercontinent Gondwana and the separation of Africa from South America (Figure 3). Sedimentation takes place in the basins of central and southern Chad. The subsidence of this region and the sedimentation continues until quaternary and the deposits will form the basins of Lake Chad (Chadian basin), extending to neighboring countries [17][21][35].

Chadian subsoil lithostructural units are grouped into three groups:

1 - Precambrian basement consisting of crystallophyllian rocks and granitoids
2 - sediments of the post-primary platform cover;
3 - recent and sub-recent volcanoes.

IV. Geographical Overview of the Study Area

The study area is located southeast of the town of N'Djamena (the political capital of Chad) for a distance of approximately 300 km, in the sub-prefecture of Bousso, Province of Chari-Baguirmi, between latitudes 09°60 -10°40 North and longitudes 15°20 and 17°60 East (Fig.1).

The Bongor Basin or Bousso Basin is shared between the provinces of N'Djamena, Mayo Kébbi-Est, Tandjilé, Mandoul, Middle Chari and Chari Baguirmi [20][21].

V. Geological Context of the Study Area

A sedimentary basin is a geomorphological unit in the shape of a more or less regular basin, characterized by a combination of specific structural shapes (cuestas, buttonholes), flattening surface controls and accumulation forms. Sometimes the basin layout is expressed by a certain convergence of the hydrographic plots. Thus, the sedimentary basins bear the names of the major rivers that are the beneficiaries (Congo, Zambeze, Amazon, Mississippi). They are spread over all continents and latitudes. The best known sedimentary basins are located in the Hercynian region of the middle latitudes (Parisian, Aquitanian, Anglo-Flemish, Swabian-Franconian basins). However, the largest are spread over the Precambrian peaks of the lower latitudes (Chad, Congo, Zambezi, Amazon basins) or the high latitudes (Siberian basins, Mackenzie basin).

The Bongor Basin is a depression, 300 km long and 75 km wide. The deposit layer is mainly of the Lower Cretaceous and Cenozoic clastic rock. The thickness of the Early Cretaceous deposit is between 7000 and 3000 meters [20][21][24][17].

A. *Characteristics of geological layers*

The basin is a tearing basin resulting from the stalling and extension of the Central African shear zone during the Lower Cretaceous which created a mesh of fractures in the subsoil. Then the basin was strongly overturned and lifted during the Late Cretaceous, and united to form a basin unique to the Paleogene [35].

The Bongor Basin is formed in two layers: an upper layer and a lower layer. The upper layer is Tertiary-Quaternary and the lower Cretaceous. A large area of discordance is encountered between these two layers [36].

B. *Structural Characterization*

The work of ORSTOM and the oil companies has made it possible to identify, from the mid-sixties, rifts of lower Cretaceous age in the sedimentary basins of Central Africa and on the margin of the South Atlantic [17][6][37][15][38]. In the 1980s, several authors [39][41][42] contributed to the knowledge of these basins on a continental level. It is a network of ditches that extends through the African plaque [14][17][34] (Fig. 3).

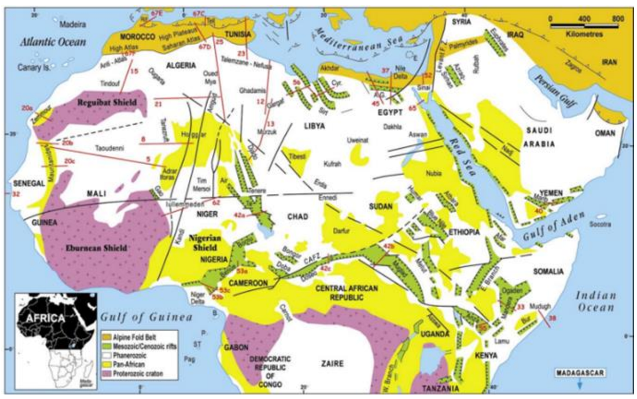


Fig. 3. Schematic geological map of Northern Africa, Central Africa and Arabia. Compiled from Wilson and Guiraud (1998). The major fault zones and Mesozoic–Cenozoic rifts are located. AG, Abu Gharadig; B, Bioko; CAFZ, Central African Fault Zone; Cyr, Cyrenaica; E, Eratosthenes Seamount; JP, Jos Plateau; P, Principe; Pag, Pagalu; S, Salamat; ST, Sao Tome; Te, Termit. (Source [35])

The structural evolution of the basin is dominated by the structural movement of the block since the Mesozoic era and by the influence of the ancient structure. Thus, the structural evolution of the Bongor Basin dates back to the Antecambrian era [36][42][43]. It is divided into five (5) stages: Antecambrian, Primary-Jurassic Platform, Cretaceous Fault Valley (First and Last Stage of Secondary), Maastricht-Paleocene Fault and Erosion Valley, and Pliocene-Modern Epoch Main Erosion (Main Stage).

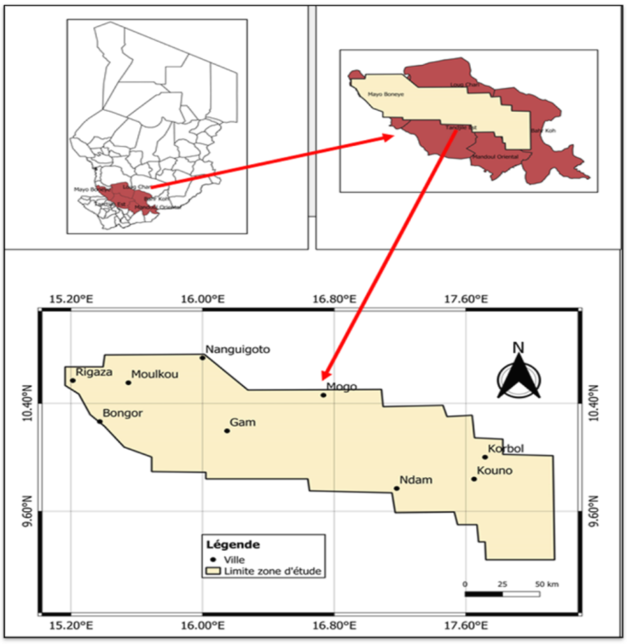


Fig. 4. Geomorphological map of the Bongor Basin (Source: [24])

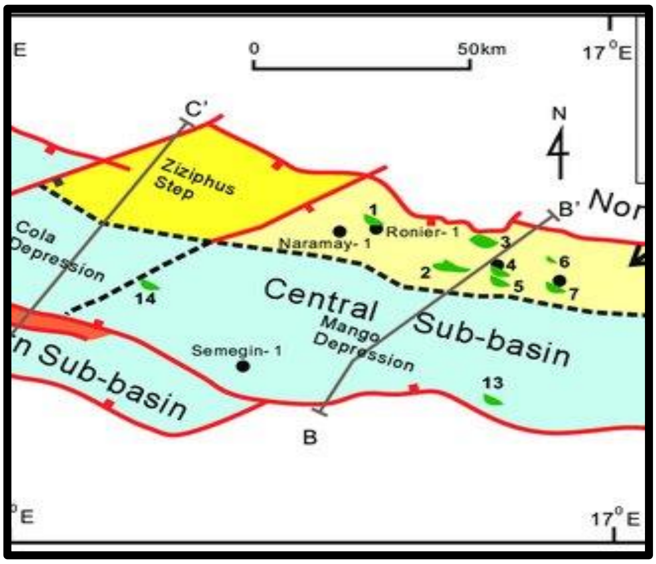


Fig. 5. Simplified units of the Bongor Basin, showing oil fields and wells. Oil/gas fields in Lower Cretaceous sandstones: 1. Ronier, 2. Mimosa, 3. Baobab, 4. Phoenix, 5. Phoenix S, 6. Raphia S-8, 7. Raphia S-6, 8. Daniela, 9. Lanea, 10. Lanea E, 11. Paveta, 11. Mold, 12. Mango, 14. Vitex, 15. Delo. (Source: [43]).

The main structural type of the Bongor Basin is a shovel-shaped depression with the South in a fault and the North projecting [42][43]. In this context, there is a change in the partial structure: from east to west, the structure of the basin has a complex change from North to fault and South to South to fault and North to protrude; on the surface there is the alternative change, on both sides of the south and north of the basin, of the areas of steep slopes and oblique slopes, giving the complex structural appearance of today. The typical structure of the Bongor Basin is the fault plateau turned at the first time of the Cretaceous Fault Valley stage, with the slanted back turned at the last time of the Cretaceous Fault Valley stage (Fig. 4 and 5).

The Bongor Basin is considered to be the representative basin of the faulted valley basins transformed by sliding and rotation [36][42][43]. The dominant structural styles are the large-scale inversion anticlinals in the Early Cretaceous succession, while the underlying basement sets of "buried hill" type may also be important.

C. Soils

The soils in the study area vary between two extreme elements: sand and clay with all intermediate states ranging from sandy clays to clay sands. Clays generally occur at the bottom of depressions and in the bed of natural streams (marigot), with large cracks typical of clay areas. These floors are generally swelling. Evaporation is also the source of dissipation of stagnant surface water, and soils in the exempted and flooded areas are observed. The soils in the study area are ferruginous soils, vertisols, hydromorphic and red ferralitic soils (Fig. 6).

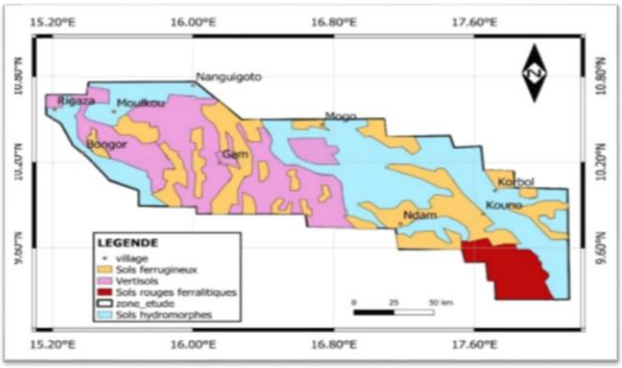


Fig. 6. Soil map of the study area

VI. Materials and Methods

The material used in the study consists of samples from the drilling cuttings from the "Baobab C5-8" and "Phoenix 1-10" wells (Table 1 and Table 2) and log descriptions of these wells. Six hundred and three (603) samples, including two hundred and sixty (260) from the "Baobab C5-8" well and three hundred and forty-three (343) from the "Phoenix 1-10" well, formed the bulk of the material.

The computer hardware used are Word, Excel and QGIS 3.6, Adobe Illustrator 2014.

The analyzes and observations were carried out in the laboratory (Photo 2-b, Photo 2-c). The material used is made up of: microscope, magnifying glass, sieves, filter papers, HCl hydrochloric acid reagents (Photo 1 - 1), Calcium chloride ($CaCl_2$), vibrating sieve devices on the “mud tank” (Photo 1 -

2), AFNOR sieve column or series of sieves (Photo 1 - 3), heating plate (Photo 1 - 4).

The cuttings collected from vibrating screens were placed on the mud tank (Photo 1 - 2).

Table 1. Features of the "Baobab" well

1	Operating company	CNPCIC
2	Bloc	Permis H
3	Pool Name	Bassin du Bongor
4	Field name	Baobab C5
5	Well name	Baobab C5-8
6	Geographical coordinates	Latitude: 10°13'28.97669"N Longitude: 17°00'28.83986"E
7	Type of well	Development
8	Well profile	Vertical
9	Planned depth	1560 m
10	Depth reached	1500 m
11	Elevation	GL : 338,204 m
12	Start of activities	30/10/2021
13	End of activities	14/11/2021
14	Phases of operations	2
15	Dimension (ϕ)	$14^{3/4''}$ et $9^{1/2''}$

Table 2. Characteristic of the "Phoenix1-10" well

1	Operating company	CNPCIC
2	Bloc	Permis H
3	Pool Name	Bassin du Bongor
4	Field name	Phoenix 1-10
5	Well name	Baobab C5-8
6	Geographical coordinates	Latitude : 10°08'51.23071"N Longitude : 17°03'31.74054"E
7	Type of well	Développement
8	Well profile	Vertical
9	Planned depth	1610 m
10	Depth reached	1610 m
11	Elevation	GL : 339.584m
12	Start of activities	14/03/2022
13	End of activities	02/04/2022
14	Phases of operations	2
15	Dimension (ϕ)	$14^{3/4''}$ et $9^{1/2''}$

The study method was carried out in the laboratory

A. Macroscopic observation

The macroscopic description was made by observing and recognizing the constituent elements of the rock with the naked eye.

The well samples collected from vibrating screens (Photo 1 - 2) were rinsed with water to remove clay particles from the grains. They were then wet sieved on a column of three (30) sieves (series of afnor sieves) calibrated with decreasing meshes of 500 µm, 250 µm and 125 µm (Photo 1 - 3), with a view to separating the different particle size fractions (coarse, medium and fine). The lithology of the wells (Baobab C5-8 and Phoenix 1-10) was derived from the description of the samples with the naked eye, monocular magnifier and microscope (Photo 2 - a).

B. Microscopic observation

Microscopic observation consists of the description of petrographic characteristics (mineralogical composition and classification) and the analysis of the sedimentological characteristics of the rock constituents. This observation allows us to know the origin, the sediment deposition environment, the mode and the duration of transport of the particles.

Photo. 1 (1) 10% HCl reagent; (2) vibrating sieve devices on the "mud tank"; (3) sieve column (AFNOR sieve series); (4) hot plate.

Photo 2 (a) samples for the study; (b) view of the thin-film workshop; (c) optical microscope used for descriptive analyzes of the samples; and (d) view of the GW-59 rig mobile laboratory.

C. Rock Recognition Criteria

The criteria for recognizing the rock to be studied are: appearance, color, shape, grain size, hardness, induration, roundness, grain sphericity, and hydrochloric acid (HCl) test. At the end of this study a name is assigned to the rock.

C 1. Appearance of the grains of the rock

The appearance of rock grains is the criterion frequently used to describe the rock in terms of particle size and induration of the rock fragments.

The three main classes of grain appearance used to describe rock types are:

· Rough: particle size perceptible to the naked eye.

· Arenaceous: particle size discernible by microscope.

· Clay: particle size indistinguishable from the field.

The two main induration classes used to describe rock types are:

· Unbound: in the form of individual grains.

· Consolidated: grains held together by cement or by dehydration.

C 2. Rock Color

Color is a useful indicator of the deposition environment, especially in clay rocks. Descriptive colors of rocks and typical deposition environments can be:

- Red and brown: ferric iron, an environmental oxidant (example: surface alteration)
- Green and Gray: ferrous iron, reducing medium (example: Glauconite and chlorite).
- Dark brown: organic matter, possible parent rock (example: Petroleum)
- Black: an anaerobic medium (example: phosphates or anthrax)
- Yellow: existence Metal Limonite

Each sample should be described by identifying the nature of the rock particles; their color or color; their matrix and cement.

C 3. Hardness and Induration

Hardness is a physical parameter based on the amount of force required to separate from the cut, using a sampling probe. Not to be confused with the Mohr hardness scale. While induration is the process by which a sediment is transformed into a sedimentary rock, usually called diagenesis (compaction and cementing). Since the particles will have a relatively uniform hardness, the induration will depend on the type and quantity of cement.

Rudaceous and arenaceous rocks, clayey have different characteristics. Rudaceous and arenaceous rocks can be: unconsolidated (cuttings disintegrate or are in the form of individual grains), friable (the rock crumbles with a slight pressure, the grains break off very easily with the sampling probe), slightly hard (the rock crumbles with a slight pressure, the grains break off easily with the sampling probe), moderately hard (the grains break off with the sampling probe, the cuttings can break with a certain pressure), hard (the grains are difficult to break off, extreme pressure causes the cuttings to break between grains) and extremely hard hard (grains cannot be detached). While clay rocks can be: soluble (easily dispersed or suspended) by running water, soft (no shape or resistance, the material tends to flow), plastic (easily molded and retains its shape, difficult to wash through a sieve), firm (the material has a defined shape and structure, easily penetrable and breakable by sampling probe), hard (sharp angular edges, not easily broken by probe).

Several other descriptive terms include: Breaking, in blocks, loose, amorphous and dense. Example: unconsolidated to friable, soft sometimes firm, hard to extremely hard, friable, soluble.

C 4. Size of a grain

Grain size is an accurate estimate that can be obtained using a grain size comparator. The determination of grain size from forage cuttings must follow a disciplined procedure to obtain an accurate estimate of: individual grain size, average grain size in an individual cut, and average grain size in all cuts of a single lithology.

C 5. Forme des grains

Practical descriptions of well sites, the shape of the grain is a function of roundness and sphericity. The shape is of importance It gives clues on two important geological parameters: the mode and distance of transport, porosity and permeability. For the morphological description of the grains, we used the modified 1934 Krumbein roundness and sphericity table (Figure 7).

The roundness of the grains (fig. 7) can be: angular (edges and parts are sharp, has little or no wear), sub-angular (faces are not modified, but edges and parts are rounded), sub-rounded (edges and parts are well rounded), rounded (original faces are completely destroyed, but some comparisons of the exposed faces can be presented, all original edges and parts are smoothed to the wide curve) and well rounded (no original face, edge or part).

Sphericity (Fig. 7) is the ratio of long to short axes. Thus, the grains may be: elongate, sub-elongate, sub-spherical, spherical.

Additionally, other descriptive terms may be used to supplement the above descriptive.

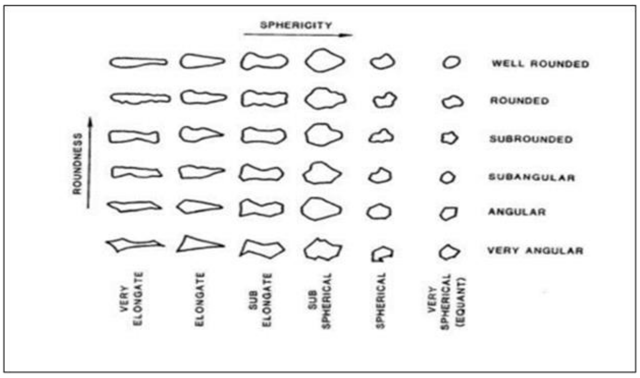


Fig 7. Sphericity and roundness of grains (Krumbein, 1934 modified).

VII. Results and Interpretations of Drill Cuttings

This section presents the results and interpretations of samples of cuttings taken during drilling. Macroscopic and microscopic observations of the sediments revealed the following sedimentary facies: sands, sandstones, clays, siltites and shale clays. The main lithological components observed from top to bottom in the two wells studied are sands, sandstones, shale clays, clays and siltites.

A. Description of "Baobab C5 - 8" well samples

The Baobab C5-8 well is a 1358 m thick, 1500 m deep well, divided into six (06) units (Fig. 9).

A 1. Unit 1 (12 m - 248 m)

Unit 1, about 236 m thick, is between 12 m and 248 m deep. It is made of sand and clay (Photo 3 - A).

- Sand

The bulk of the formation (about 90%) is coarse to medium and sometimes fine sand. The quartz sands encountered are mostly light gray, yellow-orange in color. The grains of these sands are mostly sub-angular to angular, subrounded and occasionally rounded. They are moderately striated, quartz, feldspathic, and occasionally clay-matrix.

- Argilite

The clays represent a thin layer (about 10%). They are brownish gray, slightly dark brown, sometimes dark gray, with an amorphous trace, sticky, partly washable.

A 2. Unit 2 (248 m - 462 m)

Unit 2, about 214 m thick, is between 248 and 462 m deep. It consists of sandstone and siltite (Photo 3 - B).

- Sandstone

Sandstones represent about 65% of unit 2. They are translucent to transparent, light gray to light brown, unconsolidated, coarse, medium and fine grained, subangular to angular, medium subrounded, sometimes rounded, well striated, quartz, and sometimes contains feldspar and a clay matrix (kaolinite).

- Siltite

Siltites represent about 35% of unit 2. They are greenish to dark gray, sometimes brownish gray, medium gray, firm, underlocked, sticky, partly sandy, and slightly limestone.

A 3. Unit 3 (462 m - 708 m)

Unit 3 is about 246 m thick and is between 462 and 708 m deep. It is characterized by the abundance of shale clays interspersed by sandstone sequences (Photo 3 - C) It is formed of three (03) sub-units:

- 462 to 490 meters

Between 462 m and 490 m, unit three consists of shale clay and sandstone, 28 m thick.

The shale clay is almost 65% brownish gray, more or less olive black, sometimes dark greenish gray, firm, slightly hard, sub-blocking, block, brittle, shattered, slightly limestone.

The sandstone representing approximately 35%, is translucent to transparent, gray to light gray, unconsolidated, poorly consolidated, medium fine grain, coarse grain, subrounded to sub-angular, moderately sorted, quartz, sometimes feldspathic, sometimes clay matrix.

- 490 to 611.5 meters

Between 490 m and 611.5 m deep, for a thickness of 121.5 m, unit 3 is made of sandstone and shale clay.

The sandstone, representing 65%, is brownish gray, minor olive black, greenish gray sometimes dark, firm, slightly hard trace, sub-block, block, squamous trace, brittle trace, burst trace, slightly limestone.

Shale clay, representing 35%, is translucent to transparent, light gray, unconsolidated, medium to coarse grain, rounded to rounded, sometimes sub-angular, moderately sorted, quartz, sometimes feldspathic, sometimes clay matrix.

- 611.5 to 708 meters

Between 611.5 and 708 m deep, unit 3 is made of sandstone and shale clay (Photo 3 - C) 96.5 m thick.

The sandstones (75%) are translucent to transparent, light gray, sometimes light brown, unconsolidated, poorly consolidated trace, coarse to medium grain, minor fine grain, very coarse trace, subrounded to sub-angular, moderately striated, quartz, sometimes feldspar, sometimes clay matrix, trace of kaolinite cement, trace of kaolinite.

The shale clay (25%) is slightly brownish gray, sometimes medium light gray, firm, slightly hard trace, block subblock, squamous trace, brittle trace, burst trace, slightly limestone.

Shale clay is 100% represented in the 611.8 to 679 m intervals. It is dark greenish gray, black olive minor, sometimes dark gray medium, greenish gray trace, firm, slightly hard trace, subblock, minor block, squamous trace, brittle trace, burst trace, slightly limestone.

A 4. Unit 4 (708 m - 1066 m)

Unit 4, which is about 358 m thick, lies in the depths of 708 and 1066 m, and consists mainly of shale clay (more than 90%) and interspersed with thin layers of siltite (Photo 3 - D):

- Shale clay

Shale clay (90%) is medium dark gray, slightly dark gray, minor dark greenish gray, gray at times brownish, slightly hard, sometimes firm, under-blocking, sometimes block, sometimes squamous, trace of shine, brittle, moderately limestone.

- Siltite

The siltite (10%) is light gray, sometimes brownish gray, sometimes graduated in very fine sandstone, firm, subblock, minor clay matrix, slightly limestone.

- Clay

Clay is represented at 100% between the intervals 896 to 927 and 950 to 1005 m. It is dark brownish gray, a little brownish black, sometimes medium dark gray, trace olive gray, firm, sometimes slightly hard, under-blocking block, sometimes squamous, trace of shine, brittle and carbonaceous, slightly limestone.

A 5. Unit 5 (1066 - 1359 m)

Unit 5, between 1066 m and 1359 m deep, is about 293 m thick. It consists of shale clay interspersed with thin layers of sandstone and occasionally siltites (Photo 3 - E). Unit 5 is subdivided into three depth intervals:

- 1066 to 1172.5 meters

Between this interval, the unit is formed of a succession of silty clay and sandstone, thickness 106,5 m.

Shale clay, approximately 75%, is brownish black, sometimes grayish black, dark gray; slightly and moderately hard; firm; subblock and block; sometimes squamous and brittle; slightly to moderately limestone.

The sandstone, representing about 25%, is light gray; translucent minor to transparent, light brown trace; unconsolidated, sometimes poorly consolidated; with grains varying from medium to fine; rounded to subrounded, sometimes sub-angular; well striated; with quartz and feldspar trace; with clay matrix and cement sometimes limestone.

- 1172.5 to 1307.5 meters

Unit 5, between the depth range 1172.5 m and 1307.5 m, is about 135 m thick. It consists of a succession of shale clay and siltite.

Shale clay (85%) is brownish black, minor dark gray, sometimes medium dark gray; slightly hard; firm, block and sub-block; sometimes squamous; sometimes shattered; with brittle trace; with carbon material in trace form.

Siltite (15%) is medium light gray, sometimes light gray, brownish gray; firm; subblocking; with minor clay matrix and moderately limestone.

- 1307.5 to 1359 meters

Unit 5 at this interval is about 51.5 m thick. It consists of a succession of shale clay and sandstone.

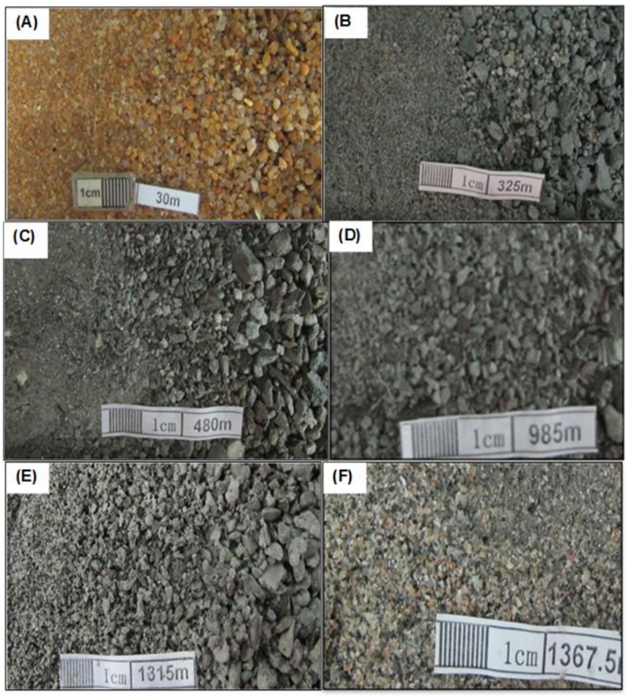


Photo 3. Samples of spoil taken from the Baobab well.
(A)- Taken at depth 30 m (U1), (B)- 335 m (U2), (C)- 480 m (U3), (D)- 985 m (U4), (E)- 1315 m (U5), (F)- 1367.5 m (U6). U=Unit

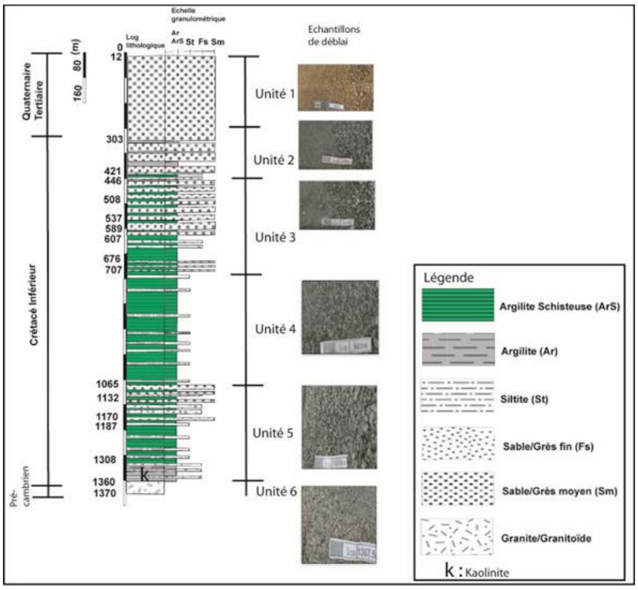


Fig. 8. Lithological section of the Baobab C5-8 well.

Shale clay (80%) is brownish black, common dark greenish gray, sometimes medium dark gray; moderately and sometimes slightly hard, block and subblock; minor squamous, sometimes exploded; rare carbonaceous material and slightly limestone. While sandstone (20%) is light gray, translucent minor to transparent, sometimes light pink ; moderately consolidated, sometimes poorly consolidated ; unconsolidated, fine-grained; subangular to subrounded, sometimes rounded; moderately sorted; quartz, feldspar; sometimes clay matrix, and trace limestone cement.

A 6. Unit 6: Precambrian base of (1359 m - 1500 m)

Unit 6, 141 m thick, between 1359 and 1500 m deep, consists of granitoids (Photo 3 - F).

These granitoids (100%) are varied in color, medium dark gray, translucent to transparent, sometimes brown, sometimes off-white; reddish, partially spotted; hard to very hard; macrocrystalline, sometimes microcrystalline; slightly altered; quartz, feldspar and ferromagnesian minerals (pyroxenes, micas).

B- Description of "Phoenix 1-10" well samples

The Phoenix 1-10 well is a thick well about 1598 m deep and 1610 m deep. It consists of six (06) units (Fig. 9):

B 1. Unit 1 (12 m - 176 m)

Unit 1 is about 164 m thick. It consists of a succession of sand and clay (Photo 4 - a).

- The sand

More than 90% of unit 1 is sand. It contains coarse to medium and sometimes fine grains. The sands are mostly red, light gray, yellow-orange, brown, pale yellow and ochre. The grains are mostly subangular to angular, subrounded, occasionally rounded; moderately sorted, quartz, feldspathic; occasionally clayey matrix with trace of kaolinitic cement.

- Argilite

Argilite constitutes approximately 5% of unit 1. It is brownish gray, slightly dark brown, sometimes dark gray, with an amorphous trace, sticky, partly washable.

B 2. Unit 2 (176 m - 313 m)

This layer consists mainly of sandstone interspersed with thin layers of clay (Photo 4. b), thickness 137 m.

- Sandstone (80%)

Sandstone is translucent to transparent; sometimes pale yellow, orange; unconsolidated; coarse, medium, fine; very coarse; subangular to subrounded; sometimes rounded; moderately striated; quartz, feldspar; occasionally clayey.

- Argilite (20%)

The clay is brownish gray, slightly dark yellowish brown, sometimes dark gray, with a trace of pale yellowish gray, soft, sometimes firm, amorphous; subblock; sticky; earthy; partly sandy, washable.

B 3. Unit 3 (313m - 840m)

Unit 3 consists of a predominance of clay-shale intercalated with siltites (Photo 4 - c).

- Clay-shale (85%) is the major part of this unit, it is medium gray, occasionally greenish gray, occasionally brownish black, slightly hard to hard, in blocks, slightly laminated, occasionally flaky, rare carbon material, slightly limestone.
- Siltite (15%) is gray-light colored, sometimes gray-brownish, slightly hard, sometimes firm, subblock, trace of block, sometimes clay matrix, sometimes limestone.

The presence of sandstone is found in the intervals 313; 340 meters and 628; 636 meters. These sandstones are characterized by their translucent to transparent appearance; multicolored (pale yellow, olive black, orange); unconsolidated; medium to fine, coarse grains; very coarse traces; subrounded to rounded,

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sometimes rounded, moderately sorted, quartz, little feldspar, occasionally clay matrix, trace of kaolinitic cement.

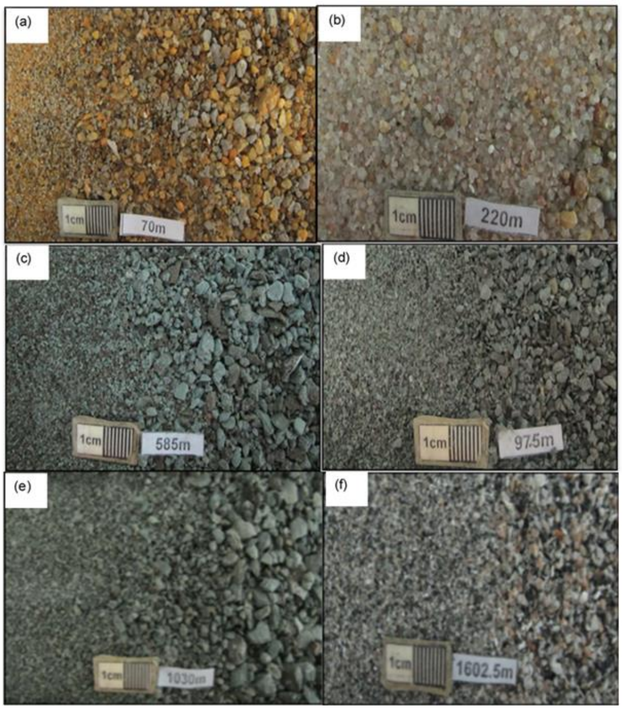

Photo 4. Phoenix well spoil samples. (a)- taken at a depth of 70 m (U1), (b)- 220 m (U2), (c) -585 m (U3), (d)- 975 m (U4), (e)- 1030 m (U5), (f)- 1602.5 m (U6). U=unit

B 4. Unit 4 (840 m - 1303 m)

Unit 04 is approximately 463 m thick at this depth interval. It is dominated by layers of shale clay intercalated by thin layers of siltites (Photo 4 - d and Photo 4 - e).

Shale clay (80%) is dark greenish-gray, sometimes yellowish-gray; firm; slightly soft; in sub-block and block; sometimes laminated; with trace of splinters; slightly limestone. While the siltites (20%) are light gray, sometimes brownish gray; slightly hard; sometimes firm; in sub-block and block trace; sometimes clay and limestone matrix.

B 5. Unit 5 (1 303 m - 1 386,5 m)

Unit 5, approximately 83.5 m thick, consists largely of shale-clay interbedded with fine siltstone couches.

- 1303 à 1373m

Unit 5, at this interval, is made up of a succession of shale clay and siltstone, 70 m thick.

Shale clay, representing 95% of unit 5 is dark greenish gray, sometimes yellowish gray; closed ; slightly soft; sub-block and block; sometimes laminated; with traces of splinters; slightly calcareous and sometimes carbonaceous. While the siltstones represent 50% of unit 5. They are light gray, sometimes brownish gray; slightly hard; sometimes firm; with sub-block and block trace; with a sometimes clayey matrix.

- 1373 à 1386,5 m

Unit 5 between this interval is formed by a succession of sandstone and shale clay. Sandstone (65%) is translucent to transparent; slightly light grey, sometimes light brown; unconsolidated, medium-grained, sometimes fine-grained; subrounded to rounded; moderately sorted; quartz, sometimes feldspar; with a rare clay matrix and traces of calcareous cement; medium porosity. While, Schistose clay (35%) is brownish black, sometimes greenish gray, sometimes medium gray; slightly hard to hard; in blocks, little laminated; sometimes burst; with rare carbonaceous matter; and slightly calcareous.

B 6. Unit 6 (1 386,5 m - 1 610 m)

Unit 6 is 100% granitoid (Photo 4 - f), 223.5 m thick. This granitoid is variegated in color (brown, slightly medium dark grey, sometimes whitish, sometimes orange, trace of red, partly marbled); hard to very hard; coarse to medium crystals, sometimes fine; sharp-edged; with developed fracture; slightly weathered; quartz, feldspar and ferromagnesian minerals (pyroxene, micas)

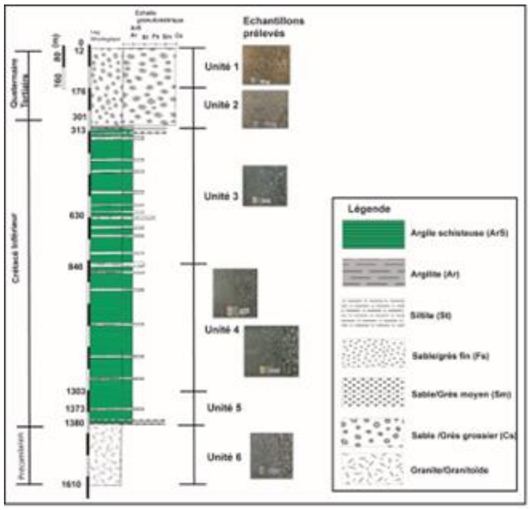

Fig. 9. Phoenix 1-10 Well Lithological Cut

VIII. Discussion

A. Petrography

Lithological studies of the "Baobab C5-8" and "Phoenix 1-10" wells have shown the following: sands, sandstones, clays, shale clays and siltites.

- Sandy stratum

It consists of more sand and highly oxidized clay in the two surveys studied. For the most superficial formations, the coloration becomes brownish red. They contain ferruginous braces, carbon debris, stem pieces and roots. Quartz grains are mostly light gray, with a low presence of quartz grains of other colors (red, yellow-orange and ochre), translucent, angular to sub-angular.

The mineral components of rock are mainly quartz; secondarily feldspars more or less altered and rarely ferromagnesians.

- Sandstone rich sequence

This unit is rich in sandstone interspersed with thin layers of siltites for the Baobab C5-8 well (280 - 480m deep) than those of Phoenix 1-10 (176 to 313 m deep) which are on the other hand rich in sandstone but between wedged clays.

The sandstones observed in the two wells at different depths constitute a consolidated gray-light colored bench with cement

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sometimes limestone. Quartz grains are smoky, very coarse to medium. Most forms are subangular to angular. Translucent to transparent, slightly light gray, sometimes light brown, unconsolidated, medium grain, sometimes fine grain, subrounded to rounded, moderately striated. Quartz, sometimes feldspathous, rare clay matrix, trace of limestone cement.

- Clay-shale

It constitutes the essential part of this formation, medium gray, occasionally greenish gray, occasionally brownish black, slightly hard to hard, in blocks, slightly laminated, occasionally flaky, rare carbonaceous material, slightly limestone.

B. Lithology

The samples of the 'Baobab C5-8' and 'Phoenix 1-10' wells are defined by the lithofacies of sand/sandstone (coarse, medium and fine), siltite, clay and shale clay.

These wells are respectively formed of six (06) units, the first of which are rich in sandstone and the other rich in clay, shale clay and siltite. The Phoenix well is formed from the base to the top of a progressive sequence whose particle size varies from Schisteuse clays to coarse sandstone. Baobab's is of a small retrogressive sequence and a large progressive sequence (Fig. 10).

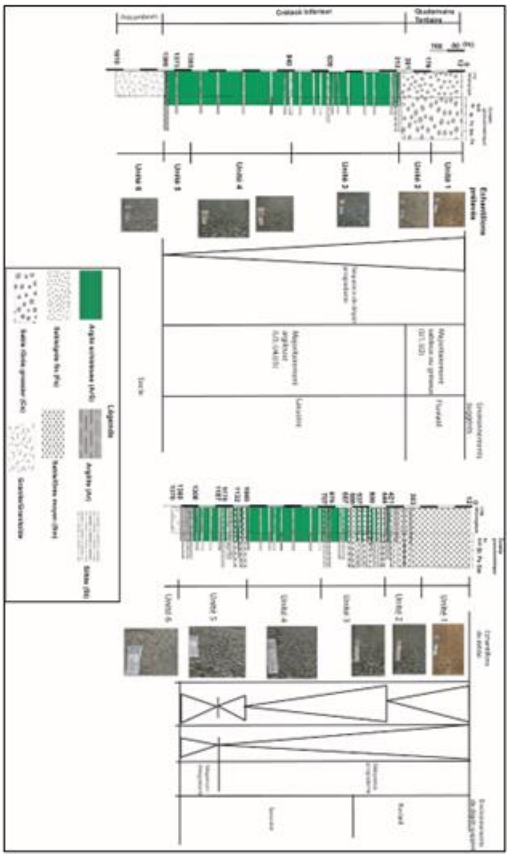

Fig. 10 Compared lithostratigraphic sections of the Baobab (b) and Phoenix (a) wells

Shale clays and clays are characteristic of anoxic conditions, lakes and floodplains [44][45]. Clay, silty facies are defined as deposits of floodplain or old channels [46]. Coarse grain sediments indicate high hydrodynamic energy. They are interpreted as residual deposits from the base of river channels [47][46], or from turbulent media [48]. The presence of sand, sandstone, clay, shale clay and siltite in both boreholes characterizes a variable deposition energy environment. According to [49] and [50], the deposition of coarse sands interspersed with clay is due to variations in deposition energy which increases (when a high turbulence current is present) leading to sandy sediments or decreases for clays. [51] states that when sand deposition is based on clay formation, it expresses a highly hydrodynamic medium.

The alternation of clay and sandy facies in the wells studied thus suggests a local hydrodynamism that is very contrasted with either a variation in flood intensity or lateral displacements of river beds in agreement with [52]. The thick clay layer in the boreholes is due to the settling process, indicating a low or no hydrodynamic deposition medium [48].

The Baobab well from the base to the top is formed at the base of shale clay with a high alternation of siltite and medium sandstone, and towards the surface of medium sandstone that can be flush. While the Phoenix well is formed at the base of a thick layer of shale clay with a low silty alternation, on which coarse sandstones are deposited (Fig.10). This suggested that the sediments of the Baobab well would have been deposited in a lake environment with a strong fluvial influence, and those of the Phoenix well in a lake environment with a weak fluvial influence.

IX. Conclusion

The Bongor basin consists of two layers: an upper layer and a lower layer. The lower layer is a Cretaceous layer and the upper layer is a Tertiary-Quaternary layer. Between the two layers a large discordance surface is developed.

The layers are arranged, from bottom to top and generally, in layers of the base, i.e. the base (Cambrian), the lower Cretaceous and the Tertiary-Quaternary.

The Precambrian is the base of the basin of this region, the Lower Cretaceous is the layer of the deposit of the interior of the basin, the part of the Lower Cretaceous is disintegrated. The deposition of the Tertiary layer is on the discordant surface of the Lower Cretaceous.

The lithological approach of the wells and of Baobab C5-8 and Phoenix 1-10 shows that this zone is dominated by the sandy and clayey shale facies and suggests a lacustrine deposition medium with a fluvial influence, with contrasting hydrodynamics.

Morpho-scopic observation shows dominance of glowing blunt grains indicating a more or less prolonged mode of aquatic transport.

The results show that the sediment studied originated from several continental sources under river influence and was deposited in shallow environments (lake or flood plain).

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