

Chemostratigraphic Characterization Tests on Sedimentary Formations in the Côte D'Ivoire Offshore Basin: Case of A-X and B-X Wells

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Abstract

The tests performed with two hundred and thirty-nine (239) samples from the A-X and B-X drillings help to know their sedimentological and chemostratigraphic characters. In sedimentological term formations are composed of sand, sandstone, limestone, siltstone and argillite that alternate along the drill. In chemostratigraphic term two megasequences (MS1 and MS2) have been identified. A correlation of chemostratigraphic data completed by the lithology results allowed a subdivision of oil wells that shows two main types of deposits environments. First, a proximal marine environment to continental and to Albian marked by a detrital flow deduced from the concentrations evolution of indicator elements of terrigenous material that are K, Mg, and Rb. On the other hand, a deep to shallow marine environment of Cenomanian to Paleocene marked by the presence of predominantly clay sediments and abundant glauconite in the lower Senonian. Nevertheless, there is a transition or intermediate environment that is characterized by the presence of glauconite and detrital flows.

Keywords

Chemostratigraphy, Characterization, Sediments, Offshore Basin, Albian-Paleocene, Ivory Coast

1. Introduction

Chemostratigraphy is stratigraphy based on variations in the content of chemical elements measured in sediments or in the remains of organisms [1]. It allows us

to characterize these heterogeneities using data from mineral geochemistry (major and trace elements, rare earths). It is a sediment characterization and correlation technique based on sensitivities due to variations in chemical composition, facies changes, weathering or diagenesis. In Côte d'Ivoire, the Cretaceous, a period of interest for oil companies, has been the subject of numerous studies including PETROCI and its partners [2] [3] [4]. Recent studies in the Ivorian offshore basin have also highlighted the impacts of the intermediate Cenomanian-Turonian biological crisis in the Ivorian basin [5]. In view of the energy development underway in Côte d'Ivoire, the application of this technique in the Ivorian sedimentary basin therefore becomes paramount. Its main objective is to establish a geochemical footprint for each of the sedimentary layers through the characterization and chemostratigraphy of sediments from boreholes A-X and B-X.

2. Presentation of the Study Area

The study area is located in the eastern part of the Abidjan margin. The two boreholes studied, A-X and B-X, are located in blocks CI 101 and CI 27 respectively (Figure 1).

These wells are LEO-2X; LEO-3X; LEO-4X and LEO-5X. Boreholes A-X and B-X each have the following specific features:

- Borehole A-X was drilled in 1982 and is located to the north-east of block CI 101. Its geographical coordinates are: Latitude: 4°53'05".04N; Longitude: 3°36'38".55W. The final depth is 3765 m. The study interval is between 790 m and 3765 m. With a water depth of 387 m, the borehole was drilled on the slope. This well contained gas, but remained at the exploratory drilling stage.
- Borehole B-X was drilled in 1982 and is located in the center of block CI 27. Its geographical coordinates are: Latitude: 5°00'34".37N; Longitude: 4°31'19".55W. It is a submerged borehole with a final depth of 3633 m. The study interval is between 2385 m and 3633 m. With a water depth of 106 m, the borehole was drilled on the continental shelf. It remained at the exploratory drilling stage, a dry hole.

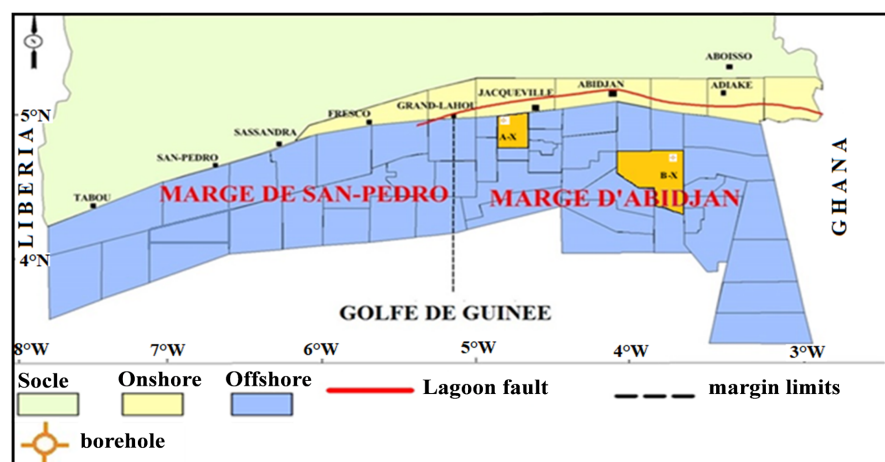


Figure 1. Location of the study zone.

3. Methodology

Chemostratigraphic studies are structured in several stages.

- Samples are collected at the core sample bank, where seven grams of drill cuttings are taken at intervals of thirty or sixty feet (ft) and placed in 500 ml beakers.
- Dichloromethane (approx. 20 ml) is added to each sample (7 g) in the beaker. After stirring, siphoning was performed. This operation, which removes soluble contaminants such as drilling mud (or oil) from the sample, is repeated until a clear liquid is obtained. This operation is performed under a fume hood. The sample is dried at room temperature under a fume hood, then stored in a labelled mini-grip bag.
- A sieving operation is then carried out on a column of sieves with different mesh sizes (2 mm, 1 mm, 500 μm and 250 μm). The sample fraction with a particle size between 2 mm and 1 mm is recovered for observation with a binocular magnifying glass.
- The lithological description, commonly referred to as “picking”, was carried out using a binocular magnifying glass; rounded grains were prioritized, as opposed to the compacted, flattened pieces in the form of chips that came from the fallout.
- The sample fraction from the picking process is ground using a vibro-grinder. The powder obtained is stored in a labeled mini-grip bag.
- To make the pellets, 4g of ground sample fraction and 1g of cereox (binder) were weighed on an electronic balance and homogenized using a vibratory mill. The mixture was then introduced into a press and compressed under a pressure of 10 tons.
- The experimental technique used to study the various pellets was X-ray fluorescence spectrometry (XRF). The principle involves subjecting a sample to intense X-rays, which ionize the atoms by ejecting the electrons in the layers close to the nucleus. The atom then returns to a stable state by reorganizing its electron cloud. In particular, the space left by the ejected electron is filled by an electron from a more external layer. At the end of the analysis, we have an on-screen record of all the chemical elements present in each sample.

4. Results

4.1. Lithological Characterization

After description with a binocular magnifying glass, the results obtained are presented according to stratigraphic stage. These stages were dated by the Biostratigraphy Department on the basis of palynological, micropalaeontological and nannopalaeontological studies using so-called diagnostic species from the fossiliferous contents of wells A-X and B-X. These are Eocene, Paleocene, Maastrichtian, Campanian, Lower Senonian, Turonian, Cenomanian and Albian for borehole A-X, and Lower Senonian, Turonian and Albian for borehole B-X.

The lithological description is given in the direction of sedimentation and by stratigraphic stage.

4.1.1. Lithological Characterization of the A-X Borehole Formations

The formations at the A-X well consist of sandstones, siltstones, mudstones, marls, sands and limestones (Figure 2).

- **Albian (3764.28 m) to (2633.472 m)**

The Albian consists of three intervals: Interval 1 (3764.28 m) to (3233.928 m); Interval 2, (3233.928 m) to (2898.648 m) and Interval 3, (2898.648 m) to (2633.472 m).

- Interval 1

This interval is characterized by a series of argillite, siltite, sandstone and limestone in proportions of 80% - 100%, 10% - 15%, 5% - 10%, 3% - 5%. The argillite is dark gray to moderate in color, firm and includes siltstones and micro-micas. Siltstone is light to moderate dark gray, firm, friable in places and slightly micro-mica.

Sandstone is light to moderate dark gray, firm, very fine-grained and translucent, well graded with siliceous cement. Limestone is light brown to light gray in color with a hard, microcrystalline and slightly clayey appearance with traces of carbonaceous debris.

- Interval 2

This interval is characterized by a series of argillites (90% to 100%), siltstones (5% to 10%) and sandstones (traces). The dark-gray to brownish-gray argillite is firm, slightly micro-micaceous and clayey in places. Traces of light-grey sandstone, slightly friable, very fine-grained and well graded.

- Interval 3

This interval is characterized by a 60% to 100% proportion of dark-gray, slightly friable clay, in the form of slightly micro-micaceous blocks, slightly silty

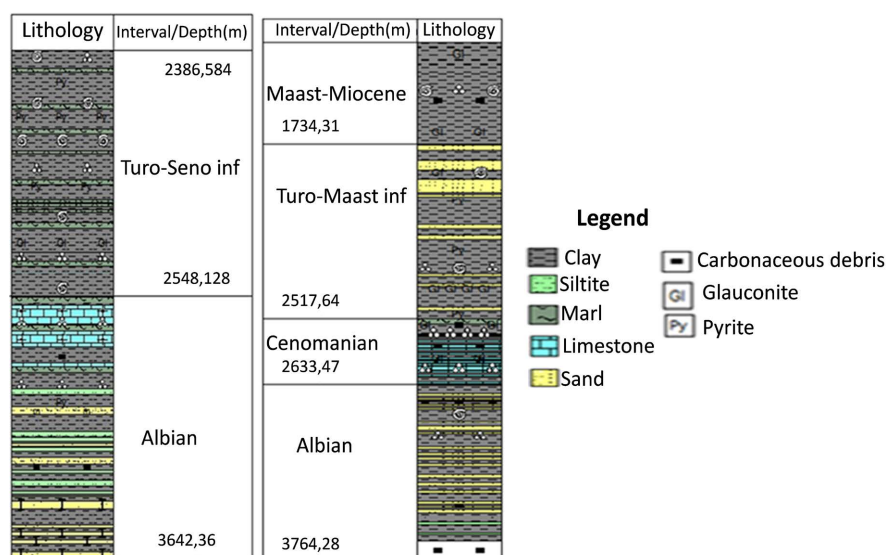


Figure 2. Lithostratigraphic column of boreholes A-X and B-X.

with traces of carbonaceous debris. The sand is translucent, rarely transparent, fine- to medium-grained, sub-rounded to sub-angular. They are well sorted. Light-gray, slightly crumbly, very fine-grained sandstone. Moderately dark-gray and rarely light-gray limestone, sometimes whitish, hard, slightly clayey with traces of carbonaceous debris. Moderately dark-gray silts, slightly micromicaceous, and locally clayey with traces of carbonaceous debris.

- **Cenomanian: (2633.472 m) to (2517.648 m)**

The Cenomanian has been divided into two intervals. The first runs from (2633.472 m) to (2554.224 m) and the second from (2554.224 m) to (2517.648 m).

- Interval 1

This interval is characterized by proportions of 20% to 65%, 35% to 80% and 10% to 15% respectively of moderate gray-brown to dark-gray limestone, often light gray, hard, slightly clayey with traces of carbonaceous debris. Dark gray argillite, in the form of firm, subfissile blocks, slightly micromicaceous, slightly silty with the presence of glauconite and carbonaceous debris and slightly calcareous. Dark-gray to light-gray, hard, very fine to fine, subangular, well-graded, slightly calcitic-cemented sandstone with glauconite and traces of carbonaceous debris. There are also traces of translucent, medium to coarse-grained, rounded to sub-rounded sand and traces of medium-dark gray, firm, slightly micromicaceous, locally clayey, slightly calcareous, glauconitic siltstone and traces of carbonaceous debris.

- Interval 2

This interval is characterized by proportions of 80% to 100% olive-gray, often gray-brown to moderate dark-gray marl, firm in blocky form, slightly micromicaceous, slightly silty with the presence of glauconite and traces of carbonaceous debris, and 10% to 20% fine- to medium-grained, slightly clayey, calcitic-cemented sandstone with traces of glauconite and sand.

- **Turo-Seno inf-Camp-maastrichtien inf: (2517.648 m) to (1734.312 m)**

This interval has been divided into two parts. The first runs from (2517.648 m) to (2279.904 m) and the second from 7480' (2279.904 m) to 5690' (1734.312 m).

- Interval 1

This interval is characterized by proportions of 50% - 70% translucent, rarely transparent, medium- to coarse-grained sand, 10% - 30% medium-dark gray, rarely olive-gray to light-gray, hard, transparent, translucent, fine- to very fine-grained sandstone and 30% - 100% moderate-dark gray argillite, in the form of firm, slightly silty blocks, with the presence of abundant glauconite towards the base and the presence of pyrite.

- Interval 2

This interval is characterized by proportions of 65% to 100% dark gray to brownish-gray, firm and blocky in places, slightly micaceous and non-calcareous argillite. 10% to 20% light-gray, slightly crumbly, translucent, fine- to very

fine-grained sandstone, well graded with siliceous cement. 5 to 15% translucent, rarely transparent sand with coarse to medium-grained, sub-angular to sub-rounded, well-graded grains. There are also traces of hard, microcrystalline, light-gray, slightly clayey limestone with traces of glauconite and carbonaceous debris.

- **Maast-Paleo-Eoc-Miocene: (1734.312 m) to (+1557.528 m).**

This interval is characterized by 80 to 100% mid-dark-gray argillite in the form of firm, very slightly silty, slightly micromicaceous blocks with traces of carbonaceous debris. Traces of sandstone, medium dark gray in color, sometimes light gray, slightly firm to crumbly, consisting of very small, well-classified grains and traces of limestone, medium white to brownish gray, hard and slightly clayey. Glauconite and traces of carbonaceous debris are also present.

4.1.2. Lithological Characterization of the B-X Borehole Formations

The formations at B-X include sands, sandstones, mudstones, siltstones, limestones and marls (Figure 2).

- **Albian (3642.36 m) to (2548.128 m)**

The Albian has also been divided into three intervals: Interval 1, from (3642.36 m) to (3002.28 m); Interval 2, from (3002.28 m) to (2596.896 m) and Interval 3, from (2596.896 m) to (2548.128 m).

- Interval 1

This interval consists of a series of argillites interspersed with very fine sand and sandstone. The respective proportions are 10% - 80% argillite, dark gray, firm, very micaceous, silty and non-calcareous. 10% translucent sand. They are fine to coarse-grained, angular to subangular in shape, and 30% - 90% light-gray sandstone, brownish-gray in places, slightly crumbly. They are medium-grained and rarely coarse-grained. They are angular to subangular in shape, with calcitic cement.

- Interval 2: (3002.28 m) - (2596.896 m)

This interval is composed of sands interbedded with sandstone mudstones and siltstones. The proportions of these rocks range from 10% to 70% translucent, sometimes transparent, sand. They are subangular to rounded in shape, with very fine to fine, sometimes coarse grains. 20% to 70% medium-dark gray clay. They are friable, micromicaceous, silty and non-calcareous. 10% - 50% light-gray to brownish-gray sandstone, firm to crumbly in places, composed of fine to very fine grains. They have a subangular form of calcitic cement and from 10 to 80% siltstone, firm to moderately hard, with the presence of limestone. Mica flakes, carbonaceous debris and glauconite grains are present in both intervals.

- Interval 3: (2596.896 m) - (2548.128 m)

The sediments encountered in this interval are composed of argillite and limestone. The argillite is 10 to 80% dark gray to medium, slightly silty, firm, slightly micromicaceous and slightly calcareous; the limestone is 20% to 90% pale yellowish-brown to yellowish-brown, firm to hard, clayey in places.

- **Lower Turo-Senonian: (2548.128 m) - (2386.584 m)**

This interval is composed mainly of argillite interbedded with marl. The argillite is 80% to 100% dark to medium gray, firm, slightly calcareous, slightly silty and slightly glauconitic, with a low proportion of pyrite.

However, the amount of marl seems to increase slightly with depth. The Turonian is deposited unconformably on the Albian.

4.2. Chemostratigraphic Characterization of Sedimentary formation in boreholes A-X and B-X

These studies provided information on the chemical composition of the samples. They also provide information on the origin of the sediments and highlight their paleoenvironment.

Chemical Analysis

The results of X-ray fluorescence spectrometry assays of major and minor (trace) elements are given respectively (in appendices). Concentrations are expressed for major elements in percentage by mass of oxide, and for trace elements in ppm.

1) Chemostratigraphic Characterization of A-X Wells

Shaft A-X extends from (3755.14 m) to (789.432 m). This interval dates from the Albian to the Miocene. Following the evolution of K/Al; Rb/Al; Mg/Al; Th/K; Nb/Zr, Ti/Th and Th/Al ratios. We have divided the A-X borehole into two mega-sequences (MS) (**Figure 3**). Mega-sequence 1 (MS1) runs from (3755.14 m) to (2651.76 m), and Mega-sequence 2 (MS2) runs from (2651.76 m) to (789.432 m).

MEGA-SEQUENCE1 (MS1)

Running from (3755.14 m) to (2651.76 m), the MS1 mega-sequence dates from the Albian. In this sequence, potassium contents are relatively higher than aluminum contents, ranging from 0.1 to 0.14, with an average of 0.12 and a maximum of 0.16; this is the K/AL ratio. Rubidium and magnesium ratios follow the potassium trend, with contents ranging from 7 to 9, with a maximum of 10 for Rb/Al and an average of 0.15 for Mg/Al.

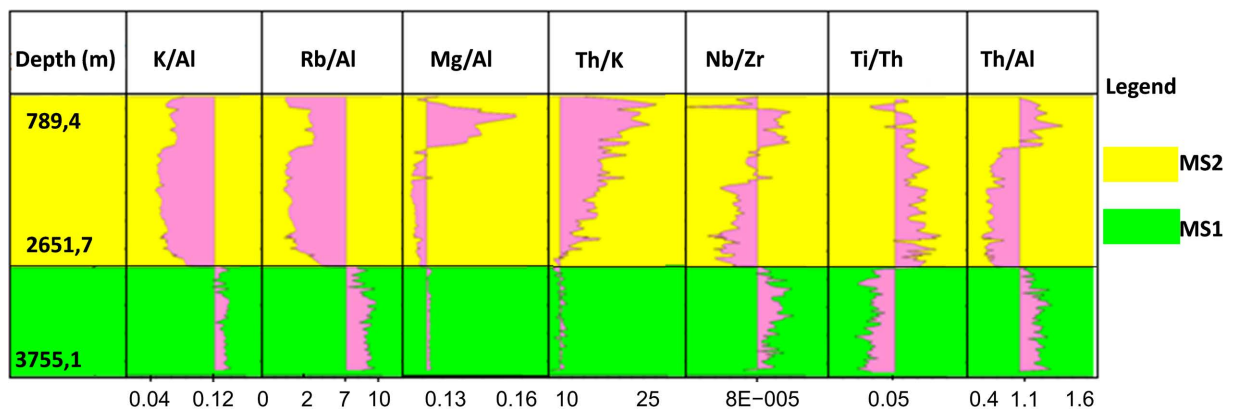


Figure 3. Chemostratigraphic profile of mega-sequences 1 and 2 from well A-X.

MEGA-SEQUENCE2 (MS2)

MS2 runs from (2651.76 m) to (789.432 m). This mega-sequence lies between the Albian and Miocene. Potassium contents are relatively much lower than aluminum contents, ranging from 0.04 to 0.08, with an average K/AL ratio of 0.06. Rubidium and magnesium ratios follow the potassium trend, with contents ranging from 2 to 5 for Rb/Al and an average of 0.1 for Mg/Al. The Th/K ratio also shows a gradual decrease in potassium content. With the Ti/Th and Th/Al ratios, thorium becomes less abundant than titanium and aluminum.

2) Chemostratigraphic Characterization of B-X Wells

Shaft B-X extends from 11900' (3627.12 m) to 7830' (2386.584 m). This interval lies between the Albian and Lower Senonian. Following the evolution of K/Al; Rb/Al; Mg/Al; Th/K; Ti/K and Nb/Zr ratios. We have divided the B-X well into two mega-sequences (MS). Mega-sequence1 (MS1) runs from 11900' (3627.12 m) to 8700' (2651.76 m), and Mega-sequence2 (MS2) runs from 8700' (2651.76 m) to 7830' (2386.584 m). The boundary between MS1 and MS2 is characterized by a sharp drop and evolution in potassium, niobium and magnesium content relative to aluminum (**Figure 4**).

MEGA-SEQUENCE1 (MS1)

The MS1 starts from (3627.12 m) to (2651.76 m), this mega-sequence dates from the Albian. In this sequence, potassium grades are relatively higher than aluminum grades, ranging from 0.1 to 0.16, with an average of 0.13 for the K/AL ratio. Rubidium and magnesium ratios follow the potassium trend, with contents ranging from 7 to 9 for Rb/Al and an average of 0.15 for Mg/Al. These grades are the same in both wells, and the behavior of the sediments in both wells is the same. This will enable us to make a correlation between these wells.

MEGA-SEQUENCE2 (MS2)

MS2 starts from (2651.76 m) to (2386.584 m). This mega-sequence lies between the Albian and Lower Senonian. Potassium contents are relatively lower than aluminum contents, ranging from 0.04 to 0.08, with an average K/AL ratio of 0.06. Rubidium ratios are also lower than aluminum ratios. Rubidium and magnesium ratios follow the potassium trend, with contents ranging from 2 to 5 for Rb/Al and an average of 0.1 for Mg/Al. The Th/K and Ti/K ratios also show a gradual decrease in potassium content.

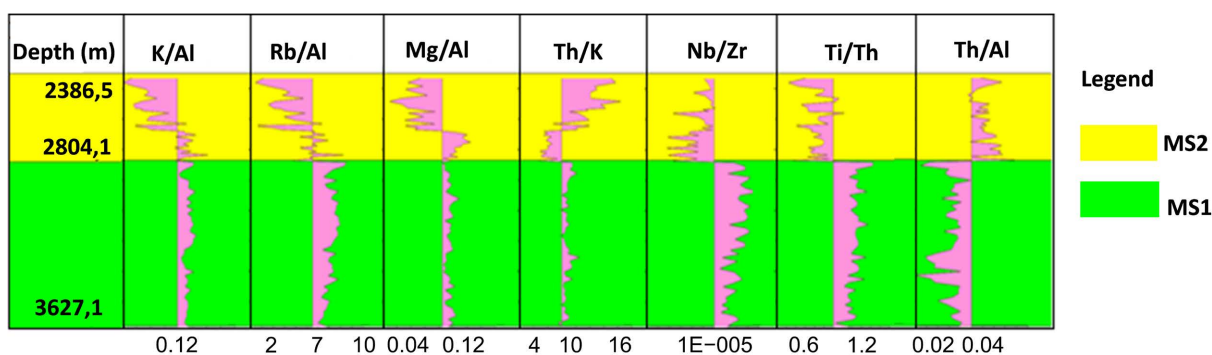


Figure 4. Chemostratigraphic profile of mega-sequences 1&2 from well B-X.

4.3. Principal Component Analysis (PCA)

PCA was used to deduce geochemical associations. The projection of the variables in the plane of the first two axes (axis 1 and axis 2) represents 33.92% and 18.29% respectively of the variance of the entire geochemical data set (Figure 5). The PCA plot shows the distribution of chemical elements in sediments and the associations between them. Six groups can be distinguished:

- Group 1: includes CaO and P₂O₅, characterized by values ranging from 0.4 to 0.6 on axis 2 and from -0.4 to -0.3 on axis 1. These two chemical elements are linked to carbonates.
- Group 2: includes Na₂O and Cl, characterized by values ranging from 0 to 0.17 on axis 1 and 0.5 on axis 2. These elements are strongly influenced by salt content (halite).
- Group 3: includes Sb₂O₅; U; As₂O₃; PbO; SrO; Ag; Cs; Te; CuO; Ba characterized by values ranging from 0.65 to 0.93 on axis 1 and from 0.1 to 0.45 on axis 2. On the one hand, we have U; PbO and CuO, which bind to organic matter in an anoxic environment, and on the other, elements bound to clay minerals.
- Group 4: includes Hf; CoO; Nb₂O₅; Y; Th; K₂O; Rb₂O characterized by values ranging from 0.55 to 0.79 on axis 1 and from -0.7 to -0.2 on axis 2. With K₂O; Rb₂O related to potassium feldspars, illite and mica and Hf; CoO; Nb₂O₅; Y; Th related to heavy minerals.
- Group 5: includes Ga and Al₂O₃ characterized by values ranging from -0.1 to 0 on axis 1 and -0.8 to -0.6 on axis 2. These elements are related to clay minerals.
- Group 6: with SiO₂ is characterized by values ranging from -0.5 on axis 1 and -0.27 on axis 2. This element characterizes the quartz pole of this analysis.

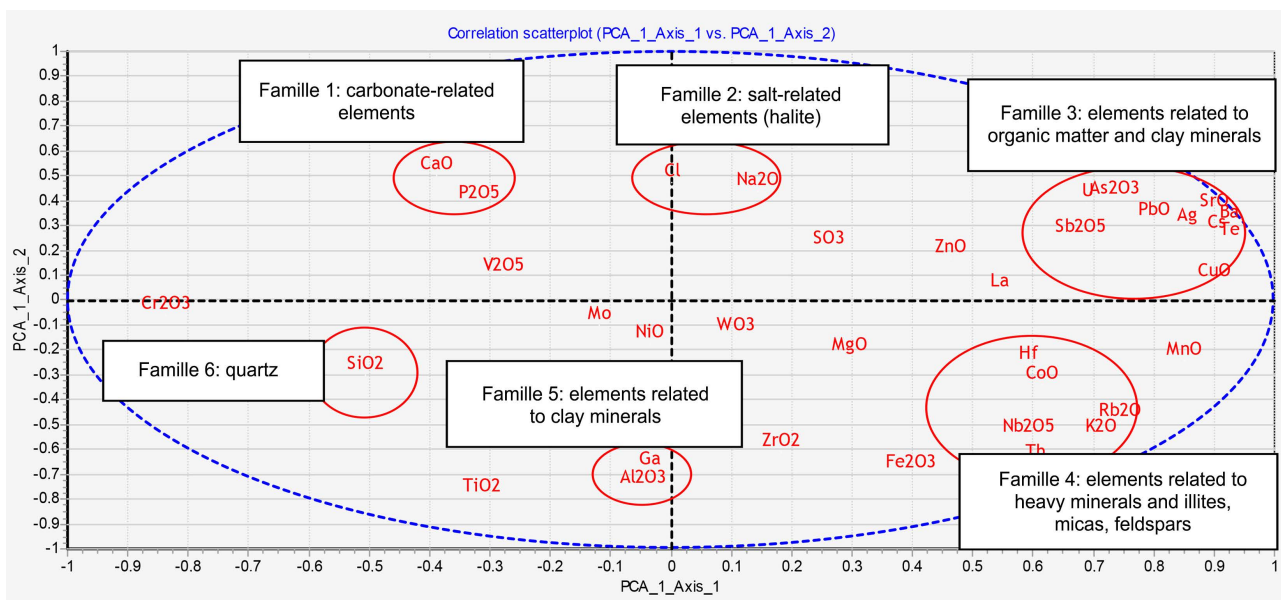


Figure 5. Principal component analysis (PCA).

The lithological and mineralogical affinities of Cr₂O₃, NiO, Co, Fe₂O₃, MgO cannot be determined from the PCA, as according to the first two axes, it explains 52.21% of the data variability. Generally speaking, Cr is incorporated in heavy minerals, particularly in chromium-bearing spinels, and is bound to clay minerals and feldspars. WO₃ is bound to drilling materials. Ni and Co bind to organic matter in anoxic environments.

5. Discussion

The evolution of geochemical profiles based on K/Al; Rb/Al; Mg/Al; Th/K; Ti/Th and Nb/Zr ratios has enabled us to make geochemical subdivisions of the formations in the two boreholes and to understand their paleoenvironment and the origin of the sediments. Both A-X and B-X were divided into two mega-sequences (MS). The boundary between mega-sequence 1 (MS1) and mega-sequence 2 (MS2) of the two boreholes is characterized by an abrupt drop and evolution in potassium (K), thorium (Th), rubidium (Rb), magnesium (Mg), niobium (Nb), titanium (Ti), aluminum (Al) and zirconium (Zr). This could reflect a geological anomaly such as an unconformity, sedimentation arrest or erosion. The sediments of the A-X MS1 behave in the same way as those of the B-X MS1, *i.e.* they are characterized by high levels of potassium relative to aluminum. Aluminum (Al) is a common chemical element in clays. Potassium (K), in the form of K₂O, and rubidium (Rb) are associated with clays. Concentrations of these elements are influenced mainly by the abundance and distribution of illite, smectite and mica, to a lesser degree, and potassium feldspars [6]. Potassium (K) is an element that passes quickly into solution in the aquatic environment. As potassium, rubidium and magnesium levels are high relative to aluminum in MS1 sediments, we have to take into account the fact that potassium and rubidium levels are high relative to aluminum in MS1 sediments.

These values lead us to suspect that this element is very present in the initial chemical composition and that the detrital source is therefore potassic. Furthermore, K/Al and Rb/Al ratios are used to model the proportion of kaolinite, potassium feldspars, illite and mica in [7]. This high potassium content is therefore linked to the presence of illite, mica and/or potassium feldspars, which are detrital elements. This high potassium (K) content in detrital elements therefore indicates a proximal marine to continental environment. K and Rb act in a similar way due to their strong chemical affinity in substitution phenomena. In fact, Rb does not occur naturally in its native state [8]; it is found in many soluble forms and can substitute for K in several common minerals such as micas (muscovite), potassium feldspars (microclines, orthoclases) and clay minerals (illites, montmorillonites). Interpretation of the Rb/Al geochemical profile would be analogous to that of K/Al. The distribution of Mg is governed by several factors, but its association with calcium indicates the presence of authigenic cement, biogenic material or precipitation. Principal component analysis (PCA) and correlation analysis show that there is no affinity between Fe and Mg. Chlo-

rite, biotite and smectite are therefore absent from this sequence, as Fe is a component of these minerals. The same is true between Ca and Mg, indicating that carbonate minerals are absent in MS1 clays. The proportion of Mg in this sequence is therefore linked to the presence of detritus from basic and ultrabasic igneous rocks [9]. Titanium is linked to the heavy minerals rutile and anatase [10] and Th to organic matter. Ti/K and Th/K ratios in MS1 show a richness in K relative to Ti and Th. This mega-sequence is therefore low in organic matter (OM). This lack of OM could be explained by the presence of oxygen in this level. This confirms the K/Al signature, which indicates that the MS1 sediments from both wells were deposited in a proximal marine environment. Nb/Zr content is higher in MS1 than in MS2 in both wells. The ratio of niobium (Nb) to zirconium (Zr) is high in the MS1 of both wells, meaning that this mega-sequence is richer in niobium-bearing minerals at the expense of zirconium. However, this ratio shows niobium depletion in the upper part of the MS1 of the second well (B-X). This abrupt change in niobium content allows us to subdivide the sequence at this level. Nb is an element found in heavy minerals such as rutile (refractory mineral), anatase, and even in opaque heavy minerals where they are associated with Ti such as magnetite, ilmenite, hematite... [10]. The geochemical profiles of the different MS2 ratios of A-X and B-X show a similar evolution. Indeed, K/Al, Rb/Al, Mg/Al and Nb/Zr ratios are low compared with those of MS1. Ti/K and Th/K ratios are high compared to MS1. This sudden drop in potassium content would indicate a depletion of illite, mica and potassium feldspar. This decrease could be explained by the alteration of sediments, which would favor potassium dissolution. This alteration is thought to be due to flooding of the sediments, which causes potassium to pass into solution. The sediments of mega-sequence2, unlike those of mega-sequence1, would have been deposited in a frank marine environment. The mega-sequences1 (MS1) of the two wells, following the ratios K/Al; Rb/Al; Mg/Al; Th/K; Ti/K and Nb/Zr, were divided into three sequences. Each of these sequences is separated by either a decrease, an increase or an alternation in the content of the various ratios indicated. The different MS1 sequences from both wells show a progressive decrease in potassium from the TD (total depth) upwards. This progressive decrease in potassium would indicate a gradual rise in water levels. This would mean a gradual transition from a proximal marine to continental environment to a frank marine environment far from terrigenous inputs. On the other hand, the MS2 of the A-X well has been divided into three sequences and that of the B-X well into two sequences. The S1 and S3 of MS2 from well A-X have the same behavior. They are depleted in potassium, rubidium and magnesium compared with aluminum, but enriched in potassium compared with titanium and thorium. This richness in potassium is due to the presence of glauconite (a rock composed essentially of glauconite, a clay mineral containing magnesium and potassium) in these sediments. The presence of this mineral in a sediment indicates a deep marine environment [11]. Note that the richness of K relative to Ti and Th decreases

es from base to top. The sediments in these sequences are thought to have their source in zirconium-bearing minerals, given their high Zr-to-Nb ratio. As for S2 of MS2 from the same borehole, it shows a sudden richness of K, Rb and Mg in relation to Al, Th and Ti in relation to K and Nb in relation to Zr. This potassium richness would indicate a change in the depositional environment. This could be explained by a regression from a deep to a shallow marine environment. The abrupt drop that separates the S1 from the S2 and then from the S3 could be due to a cessation of sedimentation, erosion or an unconformity. The S1 and S2 of the MS2 from the second drill hole show alternating decreases and increases in the content of K, Rb and Mg in relation to Al, Th and Ti in relation to K and Nb in relation to Zr. This alternation in content is due to the upwelling and downwelling of water in this zone, which mixes the input of continental elements with that of marine elements. The sediments in these sequences would therefore have been deposited in a transitional environment. In this study, chemostratigraphic ratios of K/Al, Rb/Al, Mg/Al, Ti/K and Th/k were used to determine depositional environments. K is a chemical element that is highly labile, *i.e.* it passes quickly into solution in an aquatic environment. This element is present in illite, potassium feldspar and micas. Its abundance in sediment is indicative of a proximal marine environment, as confirmed by KONE [12]. In general, the presence of smectite and illite in sediments, as well as kaolinite, suggests that these minerals are of detrital origin. The Albian interval of both wells is characterized by a very high potassium content, indicating that sediments in this interval were deposited in a proximal environment. These results corroborate those of BAMBA [2], who argue that the sediments in this interval were deposited in a platform-type environment with continental influence. The Ceno-Turo interval of both wells is characterized by a relative drop in potassium levels, indicating the weathering of K-rich sediments, and hence dissolution of the latter. The transition from a proximal to a clear marine environment is therefore in line with the work of [2], who argues that this interval is characterized by a decline in the planktonic population and the appearance of benthic forms with elongated tests, reflecting a decrease in oxygen levels. Moreover, according to [13] [14], the appearance of keeled forms reflects a relatively deep environment. All these data suggest a depositional environment of medium to external platform type. The Lower Senonian interval is characterized by a progressive increase in potassium content. There is thus a slow enrichment in detrital minerals, which would indicate an approaching coastline. These results corroborate those of [15] who argue that in this interval, the predominance of spores and pollen grains and the scarcity of peridinioid cysts reflect an environment relatively closer to the coastal domain. In the upper interval, there is an alternation of potassium richness and poverty, as well as a low proportion of glauconia and detrital minerals, which would be characterized by an intermediate depositional environment. These results are in agreement with those of [15] who would indicate that peridinioid cysts are abundant in the upper part (Campanian-Lower

Maastrichtian), which reflects open sea conditions due to the abundance of algal phytoplankton. It is therefore an environment where sea salinity is generally normal. We conclude that, in the various boreholes, depositional environments vary from the inner platform under predominant continental influence during the Albian to the middle to outer platform during the Turonian, then open sea conditions from the Upper Senonian to the Paleocene.

6. Conclusion

The lithological and geochemical characterization carried out on the A-X and B-X borehole formations has yielded two mega-sequences. The mega-sequences¹ of boreholes A-X and B-X and the mega-sequences² of these two boreholes. The mega-sequences¹ (MS1), which date from the Albian, were deposited in a proximal to continental marine environment, and are marked by a detrital flow deduced from the evolution of concentrations of terrigenous indicator elements (K, Mg, Rb). These sequences are also characterized by a clay lithology interspersed with sand banks. The mega-sequences² (MS2), which date from the Cenomanian to the Paleocene, are marked by the presence of predominantly clayey sediments and by the abundant presence of glauconite in the Lower Senonian, deposited in a shallow to deep marine environment. Nevertheless, a transitional or intermediate environment characterized by the presence of glauconite and detrital flows can be observed.

Conflicts of Interest

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