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# Correlations between Granulometric and Petrophysical Parameters of Sediments in the Continental Terminal of the South Comoé Region (Côte d'Ivoire)

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## Abstract

The evaluation of granulometric and petrophysical parameters conducted on drilling cuttings from South-Comoé (Adiaké and Aboisso) aims to characterize the Continental Terminal formations. This study also contributes to a better understanding of the geological formations in the studied localities. The granulometric and petrophysical parameters were determined using the statistical method of moments and laboratory tests. Furthermore, Python software was utilized to represent the various parameters and establish significant correlations between them. At the granulometric level, the sands are predominantly coarse and moderately to poorly sorted. Moreover, they exhibit positive skewness and are leptokurtic. Regarding the petrophysical parameters, total porosity values range from 33.33% to 55.14%, while bulk density values oscillate between 1.121 and 1.67 g/cm$^3$. The proportion of clay matrix varies between 0.53% and 44%. Correlation analysis reveals that total porosity increases while bulk density decreases. High total porosity is characteristic of a high clay proportion, fine grain size, poor sorting, and positive or negative skewness.

## Keywords

Granulometric, Petrophysical, Continental Terminal, South Comoé, Ivory Coast

## 1. Introduction

The Continental Terminal, a geological formation of major importance in West

Africa, is the subject of ongoing scientific investigations aimed at deepening our understanding of it. With this in mind, several studies have been conducted, notably those devoted to determining its lithostratigraphy [1] [2]. These studies have established that this formation is characterized by a large sandy bank with intercalated clays, overlain by silty-clayey sands. In addition to lithological analyses, emerging petrophysical studies have begun to provide additional information on the physical properties of the formations. In this regard, work has been carried out to determine the total porosity of the sediments in Banco Bay, which is an essential petrophysical parameter for understanding the reservoir properties of these formations [3]. However, it should be noted that very few studies have been devoted to the petrophysical aspect of the Continental Terminal, hence the need to integrate it into our work while reinforcing it with the analysis of complementary parameters (apparent density and clay matrix proportion). This study therefore aims to understand the architecture of the sedimentary formations of the Continental Terminal based on granulometric and petrophysical data. To do this, we will need to identify these different parameters and determine the relationship between them.

## 2. Materials and Methods

The material consists mainly of drill cuttings from boreholes drilled in the Sud-Comoé region (**Figure 1**):

- The Adiaké borehole, with a total depth of 323 m, an altitude of 74.38 m and

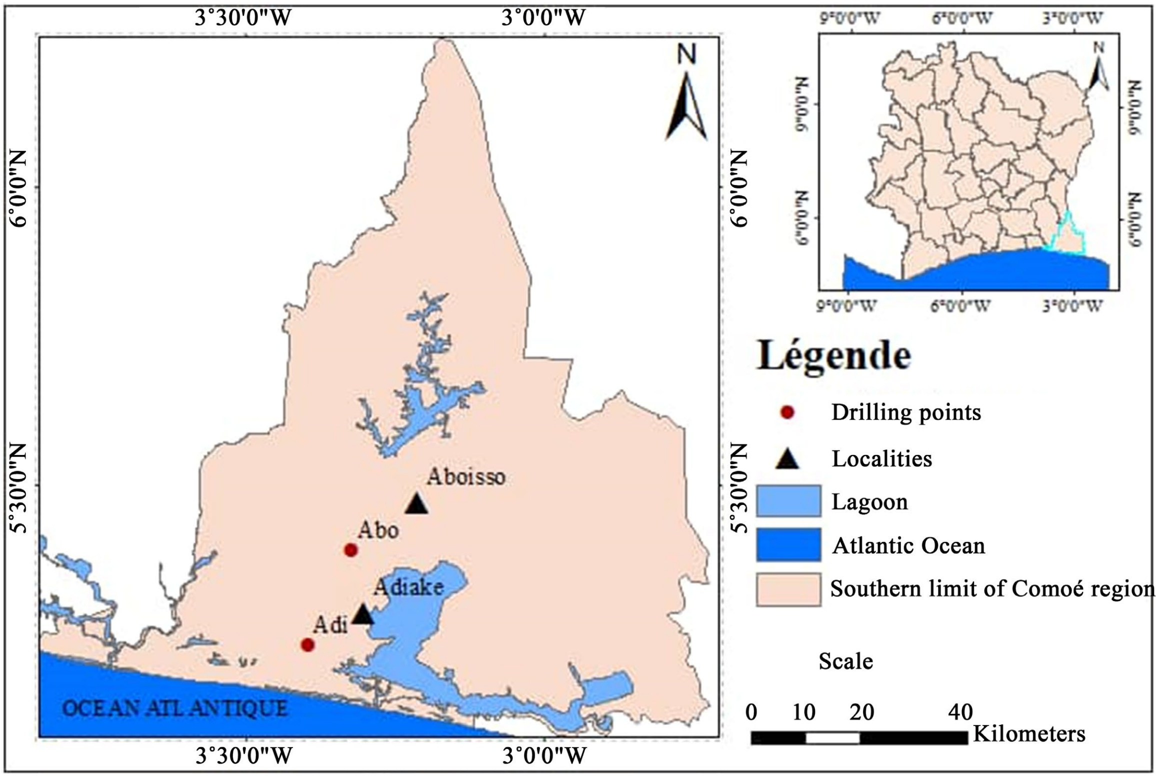


**Figure 1.** Location of the boreholes studied.

geographical coordinates X = 3˚23'47"W and Y = 5˚13'52"N;

- The Aboisso borehole, 95 m deep, with an altitude of 51.78 m and geographical coordinates X = 3˚19'23"W and Y = 5˚23'25"N.

The description and analysis of the sediments made it possible to determine the granulometric and petrophysical parameters of the sands. The application of the statistical method of moments helped to establish the granulometric parameters, in particular the arithmetic mean, standard deviation, asymmetry, and flattening. These parameters are interpreted according to the method of Folk and Ward (1957) [4]. The petrophysical parameters, bulk density, total porosity, and clay matrix proportion, were determined from laboratory tests. Bulk density is the ratio of the mass of dry sediment to its volume (volume of grains including voids). It is expressed in g/cm$^3$ and is determined by Equation (1):

$$d_a = \frac{M}{Vs} \tag{1}$$

$d_a$ = bulk density; $M$ = mass of dry sediment; $Vs$ = volume of sediment.

Porosity, expressed as a percentage (%), was used to determine the sediment's capacity to contain fluid. It is also the ratio of the volume of voids to the total volume of the sediment (Equation (2)).

$$n = \frac{Vp}{Vt} \times 100 = \frac{Vi - Vd}{Vs} \times 100 \tag{2}$$

$n$ = total porosity; $Vp$ = pore volume; $Vt$ = total volume; $Vi$ = initial volume; $Vd$ = displaced water volume; $Vs$ = sediment volume.

The proportion of the matrix was estimated after washing each sample through a 63 µm sieve. It corresponds to the ratio of the mass of the clay matrix to the total mass of the sample. It is expressed as a percentage (%) and is determined by Equation (3):

$$Pm = \frac{Mm}{Mt} \times 100 = \frac{Mt - Map}{Mt} \times 100 \tag{3}$$

$Pm$ = percentage of matrix; $Mm$ = mass of clay matrix (size < 63 µm); $Mt$ = total mass of dry sediment before washing; $Map$ = mass of dry sample after washing.

## 3. Results

### 3.1. Grain Size Parameters of the Sands from the South Comoé Boreholes

Grain size analysis of Adiaké sands reveals a strong predominance of coarse fractions, accounting for 84% of sediments. Very coarse sands represent 13.42% of the total, while medium sands are poorly represented (2.68%). The distribution of the classification shows a majority of poorly classified sands (57.72%), followed by moderately classified sands (38.25%) and a small amount of fairly well-classified sands (4.03%). The asymmetry values show that all sands are symmetrically positive. There is a preponderance of fine sizes compared to the average. The flattening indices reveal two categories of kurtosis. Leptokurtic values are in the majority (88.25%), with platykurtic values accounting for 12.75% of the total (**Figure 2**).

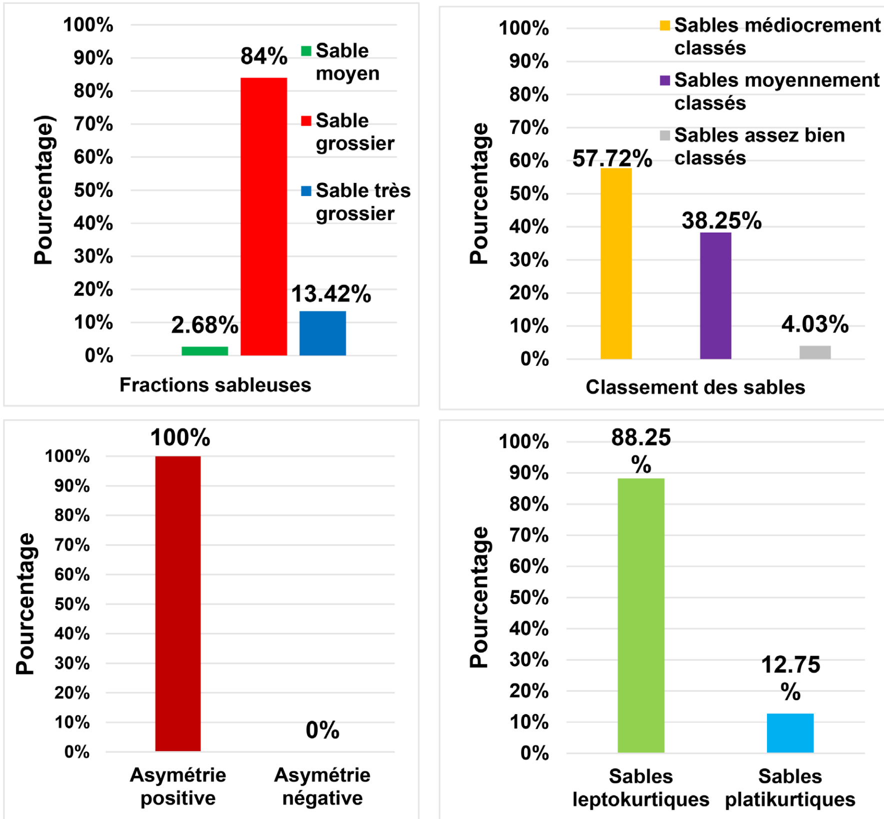


Figure 2. Histogram of the grain size parameters of Adiaké sands.

The granulometric analysis of the Aboisso sands shows a predominance of coarse sands, accounting for 83.33% of the total. These are followed by medium sands (10%) and very coarse sands (6.67%). The standard deviation values allow us to distinguish between medium-grade sand with a substantial fraction (70%) and poor-grade sand (26.67%), except for one sediment that is well graded (3.33%) and located at a depth of 75.75 m. Almost all of the sands show positive asymmetry (97.67%), except for one specimen characterized by negative asymmetry with a value of −0.15, located at a depth of 47.75 m. The flattening indices give two types of kurtosis. Leptokurtic values predominate with 73.33%, while platykurtic values are in the minority with 26.67% (Figure 3).

### 3.2. Petrophysical Parameters of the Sands from the South Comoé Boreholes

The apparent density values for the Adiaké borehole range from 1.36 to 1.67 g/cm$^3$, except for seven outliers between 1.19 and 1.34 g/cm$^3$. These outliers suggest highly porous areas. The arithmetic mean is 1.56 g/cm$^3$ and the median is 1.57 g/cm$^3$. Total porosity values range from 33.33% to 47.37%, except for seven outliers ranging from 48.28% to 52.46%. These outliers correspond to less cemented levels. The median is 38.7% and the mean is 38.52%. The proportion of clay matrix varies from 0.533% to 21.67% in the sediments, with five higher outliers ranging from 22.53% to 27%. The mean is 6.29% and the median is 4.8%. These outliers correspond to clay lenses (Figure 4).

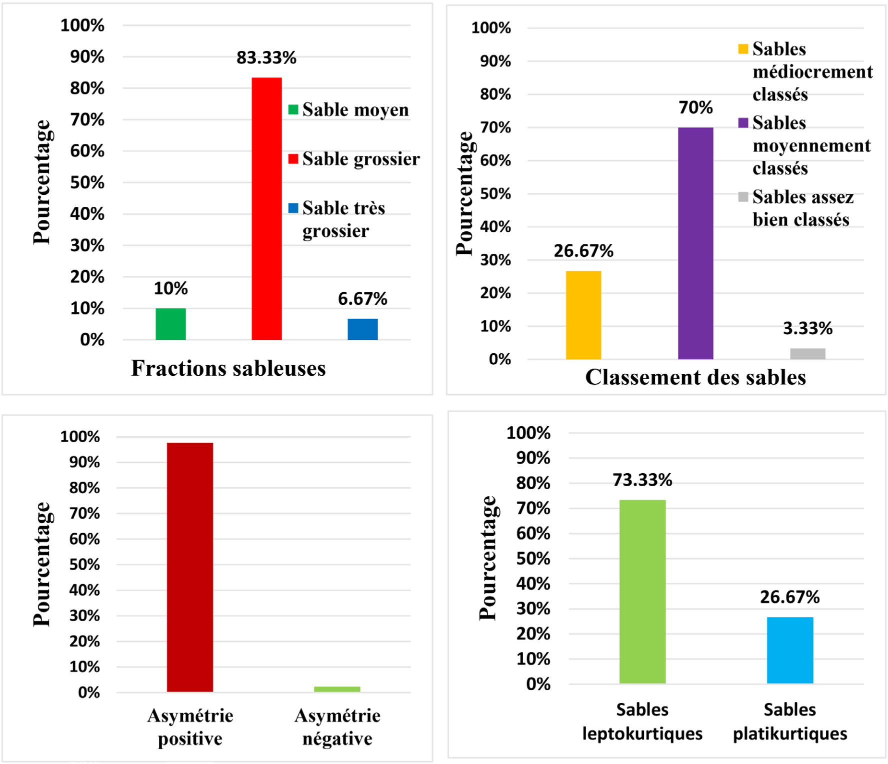


Figure 3. Histogram of the grain size parameters of Aboisso sands.

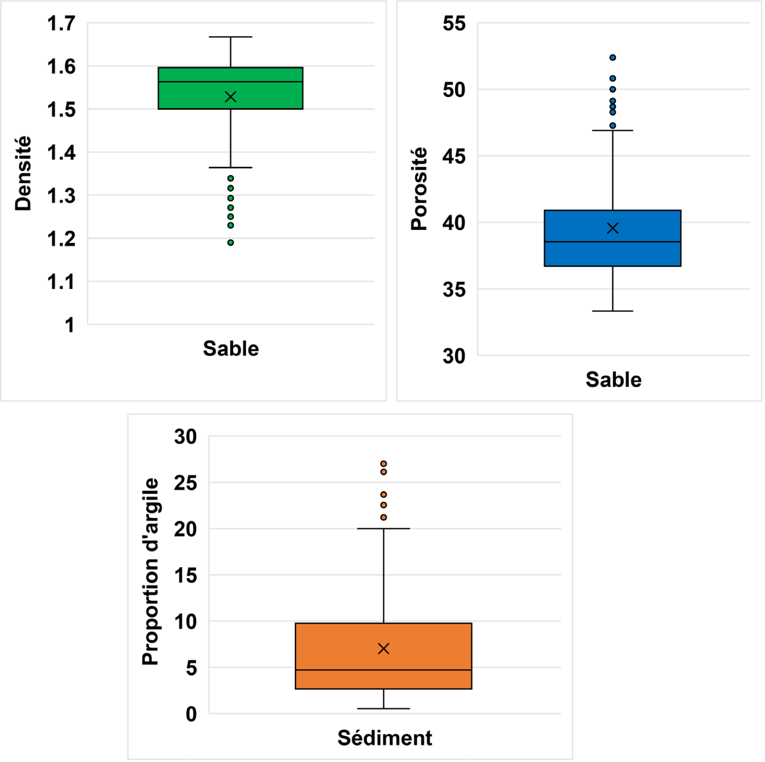


Figure 4. Boxplot of petrophysical parameters for Adiaké sands.

The bulk density of the sandy sediments from the Aboisso borehole ranges from 1.27 to 1.64 g/cm$^3$ with a median of 1.47 g/cm$^3$ and an average of 1.46 g/cm$^3$, which does not take into account the one lower outlier of 1.17 g/cm$^3$. These low densities could indicate highly porous areas. With regard to the total porosity of the sands, the values range between 34.25% and 50.46%, except for two outliers above 51.64% and 53.13% (**Figure 5**). These outliers would indicate sediment with little or no cementation. The mean is 41.88% and the median is 42%. As for the proportion of the matrix, it varies from 1.53% to 19.93%, with the exception of two outliers of 25% and 27%. These outliers could indicate the presence of clay lenses. The median is 6% and the average is 6.13%.

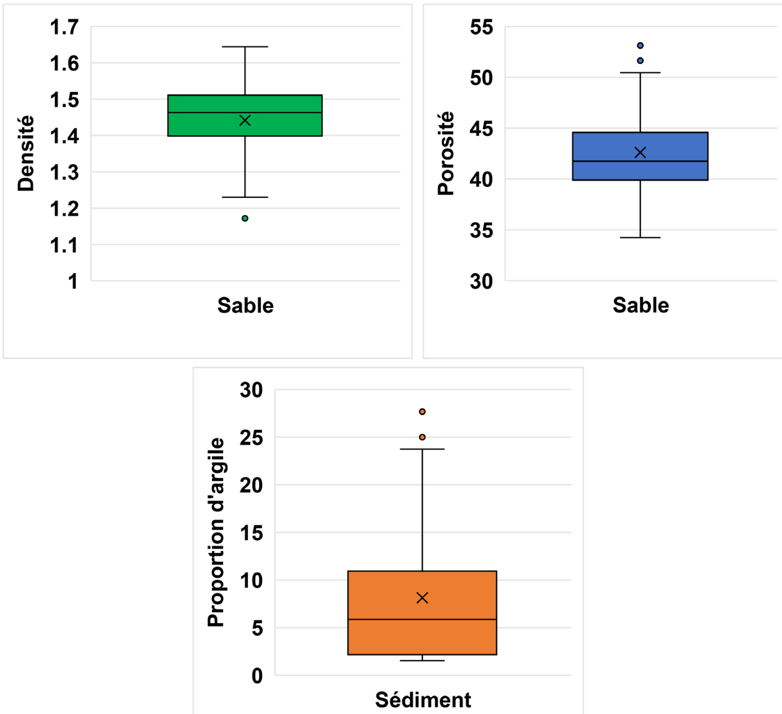


**Figure 5.** Boxplot of petrophysical parameters for Aboisso sands.

## 3.3. Correlation between Grain Size and Petrophysical Parameters

### 3.3.1. Relationship between Grain Size and Porosity

This graph shows the relationship between grain size and sand porosity. At Adiaké, porosity decreases significantly as sand grain size increases. Medium sands have the highest and most stable porosity, suggesting optimal particle arrangement (**Figure 6**).

In the town of Aboisso, porosity increases slightly with medium grains and then decreases with very coarse grains. This could be explained by the arrangement of the particles (**Figure 7**).

### 3.3.2. Relationship between Classification and Bulk Density

The parameters described are classification and bulk density. For the town of Adiaké, better classification significantly reduces density variability. Poorly classified sands show considerable heterogeneity (Figure 8).

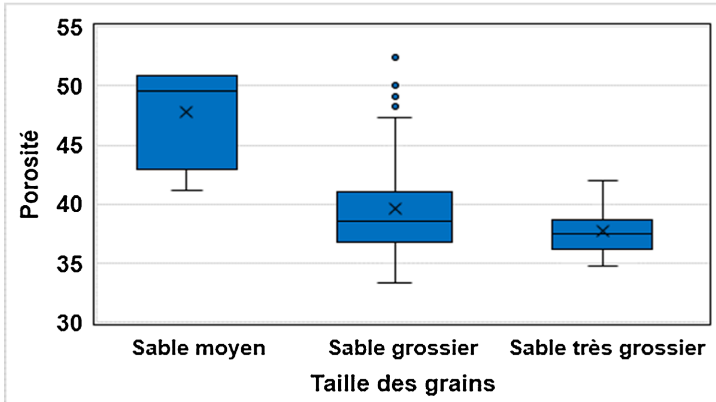


Figure 6. Porosity as a function of grain size in Adiaké.

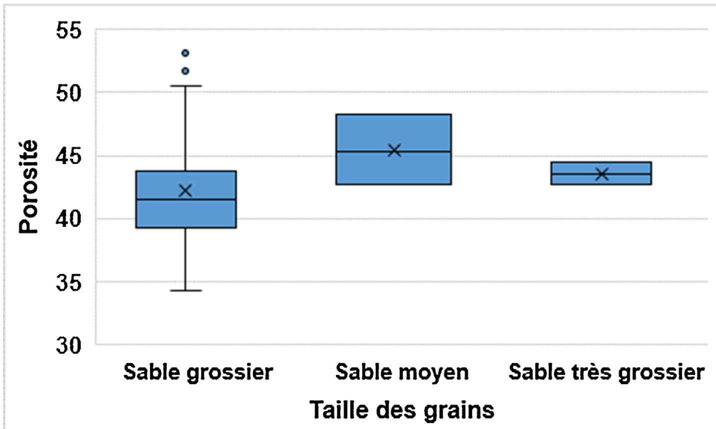


Figure 7. Porosity as a function of grain size in Aboisso.

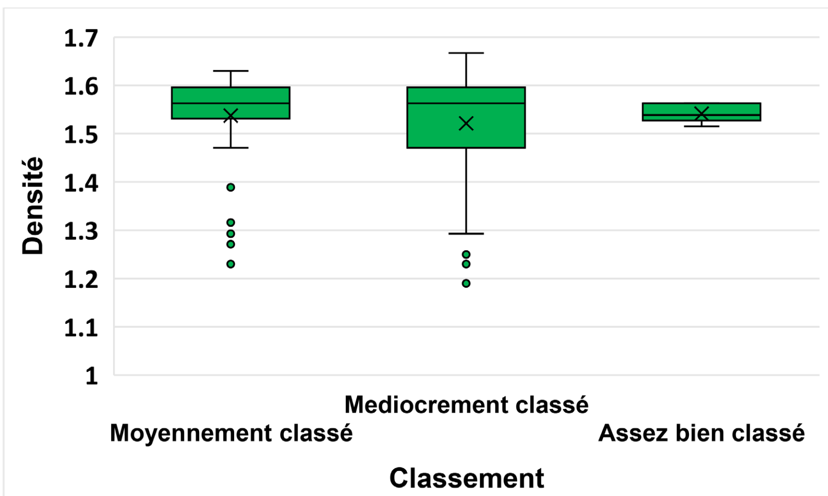


Figure 8. Apparent density according to classification at Adiaké.

In Aboisso, better grading also reduces density variability, making the material more homogeneous (Figure 9).

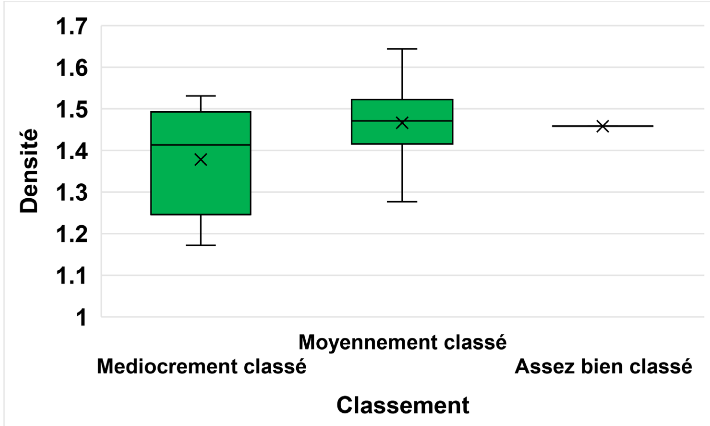


**Figure 9.** Apparent density according to classification at Aboisso.

#### 3.3.3. Relationship between Flattening and Clay Content

The parameters described are flattening and clay proportion. At Adiaké, platykurtic distribution is associated with a significantly higher and more variable clay content. Leptokurtic distribution corresponds to sediments with low clay content (Figure 10).

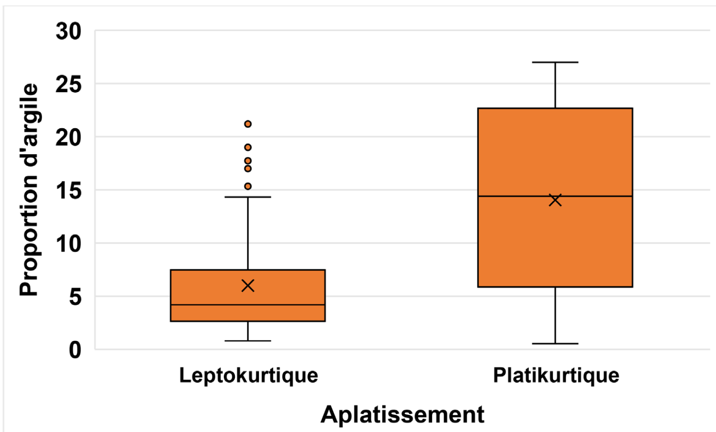


**Figure 10.** Proportion of clay according to flattening at Adiaké.

Similarly, in Aboisso, platykuritic sands contain more clay and show greater variability than leptokuritic sands (Figure 11).

#### 3.3.4. Multiple Correlations

- **Positive correlations**

These reflect a positive influence, *i.e.*, an increase in one variable leads to an increase in the other. They are subdivided into weak, medium, and strong correlations. For the city of Adiaké, the weak positive correlations are: density-skewness, density-kurtosis, porosity-sorting, and porosity-mean. These correlations show that the variance of one element influences the variance of the other by less than 25%. Their correlation coefficient is less than 0.5 ($r < 0.5$). The medium positive correlations ($0.5 < r < 0.75$) include clay percentage-mean, clay percentage-sorting, clay percentage-porosity, and sorting-mean. The variance of one element positively influences the variance of the other by between 25% and 50%.

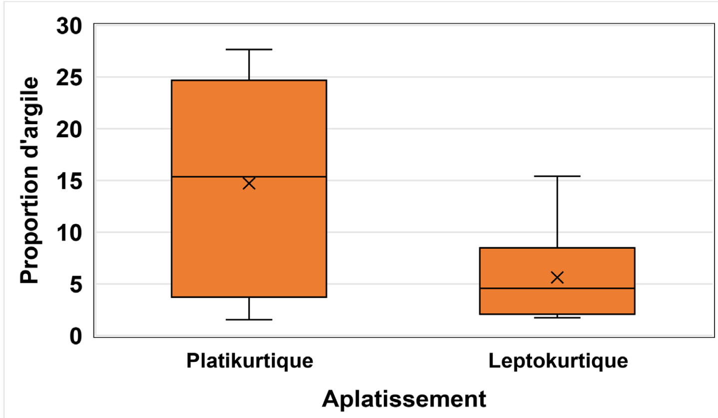


**Figure 11.** Proportion of clay based on flattening at Aboisso.

A strong positive correlation (kurtosis-skewness). The variance of one parameter influences the variance of the other by more than 50%. The values of the r coefficient are between 0.75 and 1.

- **Negative correlations**

These reflect a negative influence, *i.e.*, an increase in one variable leads to a decrease in the other. They are grouped into weak, moderate, and strong correlations.

In Adiaké, weak negative correlations (9) include clay percentage-skewness, clay percentage-kurtosis, average density, sorting density, porosity-skewness, porosity-kurtosis, average kurtosis, sorting kurtosis, and average skewness. These correlations show that the variance of one element negatively influences the variance of the other by less than 25%. The correlation coefficient is greater than −0.5 (r > −0.5). There are two average negative correlations: clay percentage-density and skewness-sorting. The variance of one parameter negatively influences the variance of the other by between 25% and 50%. The correlation coefficient is between −0.75 and −0.5 (−0.75 < r < −0.5). There is only one strong negative correlation: density-porosity. It is significant because the variance of one element negatively influences the variance of the other by more than 50%. The values of the coefficient r range between −1 and −0.75 (−1 < r < −0.75). Density is strongly negatively correlated with porosity; in other words, as density increases, porosity decreases (**Table 1**).

**Table 1.** Adiaké variable correlation matrix.

| VARIABLES | Pourcentage argile | Density | Porosity | Kurtosis | Skewness | Sorting |
|---|---|---|---|---|---|---|
| Mean | 0.62 | −0.46 | 0.45 | −0.29 | −0.48 | 0.61 |
| Sorting | 0.55 | −0.21 | 0.2 | −0.49 | −0.52 | |
| Skewness | −0.35 | 0.2 | −0.2 | 0.96 | | |
| Kurtosis | −0.29 | 0.13 | −0.14 | | | |
| Porosity | 0.71 | −0.98 | | | | |
| Density | −0.72 | | | | | |

- **Positive correlations**

An increase in one variable leads to an increase in another, so the influence is positive. There are weak, moderate, and strong correlations.

In Aboisso, there are four (4) weak correlations: density-skewness, porosity-mean, porosity-sorting, and sorting-mean. The correlation coefficient is less than 0.5 ($r < 0.5$). These correlations show that the variance of one element influences less than 25% of the variance of the other. There are two medium correlations: clay percentage-mean and clay percentage-sorting. The variance of one element positively influences between 25% and 50% of the variance of the other. The correlation coefficient is between 0.5 and 0.75 ($0.5 < r < 0.75$). Strong positive correlations include clay percentage-porosity and kurtosis-skewness. The variance of one parameter influences more than 50% of the variance of the other. The correlation coefficient is between 0.75 and 1 ($0.75 < r < 1$).

- **Negative correlations**

There is a negative influence, in other words, an increase in one parameter leads to a decrease in the other. Negative correlations are grouped into weak, medium, and strong correlations.

For the city of Aboisso, there are nine (9) weak correlations: clay percentage-skewness, clay percentage-kurtosis, average density, sorting density, kurtosis density, porosity-skewness, porosity-kurtosis, kurtosis-sorting, skewness-sorting. The correlation coefficient is greater than −0.5 ($r > -0.5$). These correlations suggest that the variance of one element negatively influences the variance of the other by less than 25%. The two average correlations are: average kurtosis and average skewness. The variance of one parameter negatively influences the variance of the other by between 25% and 50%. The correlation coefficient is between −0.75 and −0.5 ($-0.75 < r < -0.5$). Two strong correlations have been identified: clay percentage-density and density-porosity. These are significant because the variance of one element negatively influences the variance of the other by more than 50%. The correlation coefficient is between −0.75 and −1 ($-0.75 < r < -1$) (**Table 2**).

**Table 2.** Aboisso's variable correlation matrix.

| VARIABLES | Pourcentage argile | Density | Porosity | Kurtosis | Skewness | Sorting |
|---|---|---|---|---|---|---|
| Mean | 0.58 | −0.39 | 0.45 | −0.53 | −0.76 | 0.36 |
| Sorting | 0.57 | −0.34 | 0.4 | −0.22 | −0.22 | |
| Skewness | −0.18 | 0.038 | −0.12 | 0.93 | | |
| Kurtosis | −0.043 | −0.045 | −0.05 | | | |
| Porosity | 0.89 | −0.98 | | | | |
| Density | −0.89 | | | | | |

## 4. Discussion

The grain size analysis of the sands from the South Comoé boreholes reveals that the sands are coarse and moderately to poorly graded. These grain size characteristics are remarkably similar to those found in other formations in the Ivorian sedimentary basin, particularly the Tertiary formations in the onshore basin of the Abidjan region [5]. A predominance of coarse sands is observed in the Tertiary-Quaternary formations of the Anyama region in southern Côte d'Ivoire, corroborating our results [6]. This similarity suggests analogous paleoenvironmental conditions and comparable sedimentary processes on a regional scale. The observed grain size classification is a key indicator of sediment transport conditions. Medium-sized sands were transported by fairly regular currents, while poorly sorted sands were transported by irregular currents or variable hydrodynamic conditions. This variability in sorting reflects a mixture of grain sizes. Studies have shown that the higher the number of grain size fractions in a sediment, the poorer the sorting [7]. This observation suggests multiple sediment inputs or successive reworking. The positive asymmetry observed overall is of particular paleoenvironmental significance. When asymmetry is positive, the distribution peak is found in the smaller sediment sizes, *i.e.*, medium sands in our case [8]. This characteristic indicates a relative deficit in coarse particles and suggests selective sorting processes during transport or deposition. Furthermore, the predominance of leptokurtic sands is a significant marker of transport conditions. The flattening not only measures the shape of the grain size distribution curve but also reveals crucial information about the sedimentation process [9]. Leptokurtic distributions indicate constant-power transport and efficient sorting, while platykurtic curves indicate the presence of distribution tails, *i.e.*, an excess of coarse or fine sands. This duality, which is very common in sediments, may indicate multi-phase deposition [9]. Furthermore, studies emphasize that variations in kurtosis may also reflect changes in the intensity and regularity of transport agents over time [10].

Analysis of correlations between petrophysical and grain size parameters reveals fundamental relationships for understanding reservoir properties. The strong positive correlation between skewness and kurtosis confirms observations on the interdependence of grain size distribution shape parameters [11]. Fundamental work on 30 natural mudstones has established that permeability decreases logarithmically with porosity and that the relationship between permeability and porosity is strongly influenced by clay content, particularly at high porosities [12]. This observation is consistent with our results concerning the positive correlation between porosity and clay content. This demonstrates that clay matrices, while reducing permeability, can maintain high porosity. In addition, studies have shown that the mechanical and chemical compaction of clayey sands follows specific laws, where bulk density increases progressively with burial depth while porosity decreases exponentially [13] [14]. These relationships are consistent with the strong negative correlation between bulk density and porosity in this study. Classical studies have established the basis for understanding porosity-permeability relationships in sandstones [15] [16]. They show that early and late diagenesis significantly control these petrophysical properties. This work allows us to interpret the variations in apparent density observed in the Continental Terminal formations. Furthermore, recent criteria for evaluating geothermal reservoirs establish that a net sand or potential reservoir layer is defined as sandstone with a minimum porosity of 15% and a clay content of less than 30%. Although these thresholds are adapted to oil industry standards, they provide a reference framework for evaluating the reservoir quality of the Continental Terminal formations.

## 5. Conclusion

This study established significant correlations between the granulometric and petrophysical parameters of the Sud-Comoé sands (Adiaké and Aboisso). The arithmetic mean, standard deviation, and proportion of clay matrix are the dominant factors controlling the bulk density and total porosity of these formations. These correlations have enabled a better characterization of the sandy formations. Grain size parameters strongly influence petrophysical parameters. Sand with high total porosity therefore has low bulk density. It is more likely to contain more clay and have a fine grain size, poor grading, and positive or negative asymmetry. Aquifers were characterized and identified based on lithology, gamma ray logging, porosity, and matrix proportion. These aquifers are of good quality because they are separated by discontinuous clay beds and there is free circulation within them.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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