*IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)*
*e-ISSN: 2319-2402,p- ISSN: 2319-2399.Volume 18, Issue 1 Ser. 1 (January 2024), PP 45-53*
*www.iosrjournals.org*

# Correlative Study On The Distribution Of Major Chemical Elements And Traces Of The Minerals Of Petroleum Source Rocks Of Donga And Yogou Formations Of Termit Sedimentary Basin (Eastern Niger): The Implications Of The Depositional Environment

Alassane Ibrahim Maman Bachir[1,4*], Abdoulwahid Sani[2],
Dodo Nanatou Moutari[3], Baraou Idi Souley[2], Kouakou Alponse Yaou[4],
Maman Souley Abdoul Aziz[1]
*[1](Department Of Fossil Energy, University Of Agadez (Uaz), B.P. 199 Agadez, Niger)*
*[2](Department Of Geology, University Of Agadez Uaz), B.P. 199 Agadez, Niger)*
*[3](Department Of Mathematics, University Of Agadez Uaz), B.P. 199 Agadez, Niger)*
*[4](Civil Engineering, Geosciences And Geographic Sciences Laboratory, Institut National Polytechnique Félix Houphouët Boigny (Inp-Hb), Yamoussoukro Bp 1093, Côte D'ivoire)*

***Abstract:***
*Background: The coexistence of chemical éléments within a mineral or mineral assemblage is the result of certain affinities between these éléments. In the case of petroleum-bearing sedimentary rocks such as Donga and Yogou, these affinities often reflect the environmental conditions in which the rocks were deposited.*
***Materials and methods:*** *The statistical study of the chemical éléments present in the minerals of the Donga and Yogou drill cuttings is based on the integration of elemental mineral geochemistry data obtained with an RFX.*
***Results:*** *This study revealed the presence of 23 chemical éléments, of which Rb, Ba, Ni, V, Co, K, Fe, Al, Ti and Zr are derived from clay, detrital and heavy minerals, while the chemical éléments Cl, Mo, Pb, Zn, Cu, Cr, Si, S and Mn are linked to organic matter and are characteristic of an anoxic environment, with the exception of Si, which is derived from quartz in the Donga formation. The éléments Sr, Ca and Mg are largely derived from carbonates and P locally from phosphates. For the Yogou formation, the éléments Sr, Al, Fe, Ca, S and Mn come from clay minerals, pyrite and carbonates and are characteristic of suboxic to anoxic environments. The chemical éléments Ni, V, Ti, Zn, Cu and Ba are concentrated in detrital minerals of this formation, while the éléments Rb, Pb, Mg, K, Co and Cr are found preferentially in clay minerals, and the éléments Zr and Si in zircon and quartz respectively. The éléments P, Cl and Mo are linked to the salts present in these environments.*

***Key Word****: Major elements, trace elements, source rocks, Donga formation, Yogou formation, Termit basin and depositional environments.*

---

Date of Submission: 02-01-2024 Date of Acceptance: 17-01-2024

---

## I. Introduction

The concept of chemical elements (major, minor and trace elements) used in geochemistry results from quantitative considerations of elements within a mineral or an assemblage mineral (rocks). The study of the chemical element in minerals and rocks has shown that the ideal composition of these materials is often mostly theoretical, and that certain chemical elements can appear in small quantities as well as in large quantities within the minerals. Thus, independently of the study carried out on these elements, works have been carried out in order to consider them as a significant anomaly of the conditions of genesis of the mineral or the assemblage of minerals containing them [1]. While other works reveal that the coexistence of these chemical elements in the mineral or in the assemblage of minerals results from certain affinities between these elements [1], [2]. Therefore, they are often used for the interpretation of sediment deposit environments [3]–[6], the preservation process of the organic matter [7]–[12]; and the thermal degradation process of organic matter and hydrocarbon generation [13]–[18].

This study aims at characterizing the deposit environments of the Donga and Yogou formations from the elemental mineral geochemistry. The interest of this study is to contribute to the improvement of oil prospecting activities in the Termit sedimentary basin.

## II. Material And Methods

### Analyzed samples

Drill cuttings from the Donga and Yogou formations formed the samples set for this study. These samples were collected in collaboration with the Centre de Documentation et d'Archives Pétrolières du Niger (CDP). They include cuttings from the Koulélé-1D, Fana-1, Helit-1, Melek-1 and Ounissoui-E1 wells (Figure 1).

Sampling was carried out with a 10-meter sampling step.

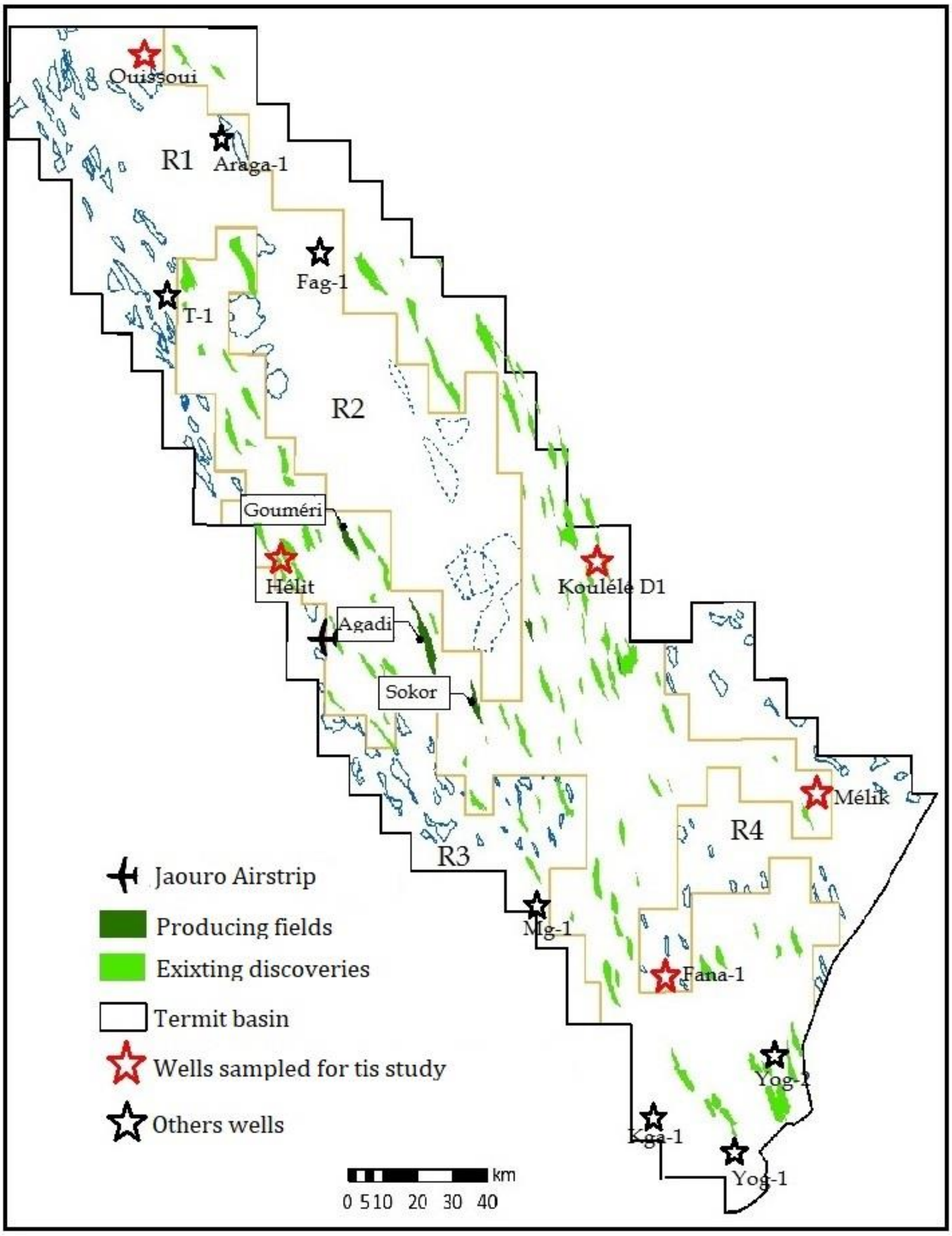

**Figure 1:** Termit sedimentary basin map with the locations of sampled wells (modified from [19])

### X-ray fluorescence (XRF) analysis

The sample size was estimated on the basis of a single proportion design. The target population from which we Rock cuttings samples were washed to remove drilling mud. X-ray fluorescence (XRF) analysis has been applied to determine the composition of chemical elements (major and trace) in these samples. FRX has been performed using a portable Niton XL3t® FRX spectrometer, coupled with a computer to ensure data transfer after the analysis using Niton Data Transfer (NDT) software. Measurements in All-Geo mode were carried out on an accessory fitted with a Radio Frequency Identification (RFID) chip, enabling the analyzer to detect it automatically and convert it into a benchtop analyzer. Thus, this enabled the major chemical element composition of total rock samples to be determined.

**Statistical analysis of trace chemical elements**

Statistical analyses of chemical elements have been carried out using R software. These analyses concern multiple correlations and Principal Component Analysis.

Multiple correlations enable us understand the various relationships between quantitative variables, in this case, the chemical elements (major and trace) present in the samples studied. To establish these relationships, Pearson's correlation has been applied. The measure is normalized and is defined between $-1 \leq r \leq +1$. The closer the correlation is to 1 or -1, the stronger is the link, and the closer it is to 0, the weaker or null it becomes. As the value of **r** has no intrinsic significance for the interpretation of the relationship, then its square, called the coefficient of determination, has been used. It is interpreted as the proportion of variance of a variable linearly explained by the other variable and vice versa. Proportions of at least 50% (equivalent to | **r** | > 0.7) have been retained.

Principal Component Analysis (PCA) makes variables return to a reduced-dimensional space distorting the reality in the least possible way. It is a multivariate data analysis method that enables the information contained in a table of quantitative variables to be summarized and visualized in order to establish the affinities between them.

## III. Results and discussions

### Chemical composition of the donga formation

The chemical elements present in the Donga formation are presented in Table no 1. They are composed of silicon, aluminum, iron, calcium, potassium, sulfur, titanium, magnesium, manganese and barium.

**Table no 1:** Elemental composition of chemical elements in the Donga formation

| Samples | PM.Dg | PH.Dg | PK.Dg_2 | PK.Dg_2 | PF.Dg_1 | PF.Dg_2 | PO.Dg |
|---|---|---|---|---|---|---|---|
| **Si** | 47.85 | 51.88 | 56.77 | 47.96 | 47.55 | 47.7 | 46.72 |
| **K** | 3.7 | 6.03 | 3.74 | 3.88 | 3.85 | 3.35 | 3.36 |
| **Ti** | 1.34 | 2.21 | 0.77 | 2.37 | 3.48 | 2.57 | 1.72 |
| **Mg** | 0 | 0.18 | 0.17 | 0.4 | 0.1 | 0.22 | 1.81 |
| **Mn** | 0,37 | 0,12 | 0,54 | 0,32 | 0,27 | 0,25 | 0,3 |
| **Ba** | 0,21 | 0,28 | 0,08 | 0,15 | 0,23 | 0,08 | 0,11 |
| **Fe** | 18,7 | 17,53 | 12,26 | 19,85 | 20,09 | 18,05 | 15,65 |
| **Ca** | 4,28 | 1,57 | 7,9 | 2,18 | 4,31 | 3,55 | 13,82 |
| **Zr** | 0,033 | 0,065 | 0,018 | 0,061 | 0,067 | 0,064 | 0,043 |
| **Sr** | 0,028 | 0,027 | 0,032 | 0,037 | 0,027 | 0,023 | 0,046 |
| **S** | 4,92 | 2 | 2,27 | 2,99 | 2,26 | 2,1 | 2 |
| **Rb** | 0,012 | 0,015 | 0,009 | 0,009 | 0,006 | 0,006 | 0,008 |
| **Pb** | 0,004 | 0,002 | 0,003 | 0,004 | 0,003 | 0 | 0,003 |
| **Zn** | 0,022 | 0,007 | 0,02 | 0,014 | 0,011 | 0,007 | 0,005 |
| **Cu** | 0.028 | 0.008 | 0.017 | 0.015 | 0.011 | 0.007 | 0.008 |
| **Ni** | 0.028 | 0.03 | 0.013 | 0.014 | 0.025 | 0.018 | 0.019 |
| **Cr** | 0.016 | 0.017 | 0.014 | 0.019 | 0.008 | 0.016 | 0.016 |
| **V** | 0.053 | 0.05 | 0.034 | 0.044 | 0.052 | 0.04 | 0.043 |
| **Co** | 0.0039 | 0.006 | 0.0022 | 0.0031 | 0.0047 | 0.0029 | 0.0025 |

Trace elements in this rock have concentrations below 5000 ppm. They include zirconium, chlorine, strontium, chromium, rubidium, nickel, phosphorus, copper, zinc, lead, vanadium, cobalt and molybdenum.

### Principal component analysis of chemical elements in donga rocks

The chemical elements present in the Donga samples have been represented on the first two axes (DIM 1 and DIM 2) of the principal component analysis (PCA) with a percentage of 57.2% (Figure 2). This is sufficient for the data interpretation. The results of the PCA and multiple correlations enabled us establish relationships between these elements by grouping them into four classes: class 1, class 2, class 3 and class 4 (Figure 2).

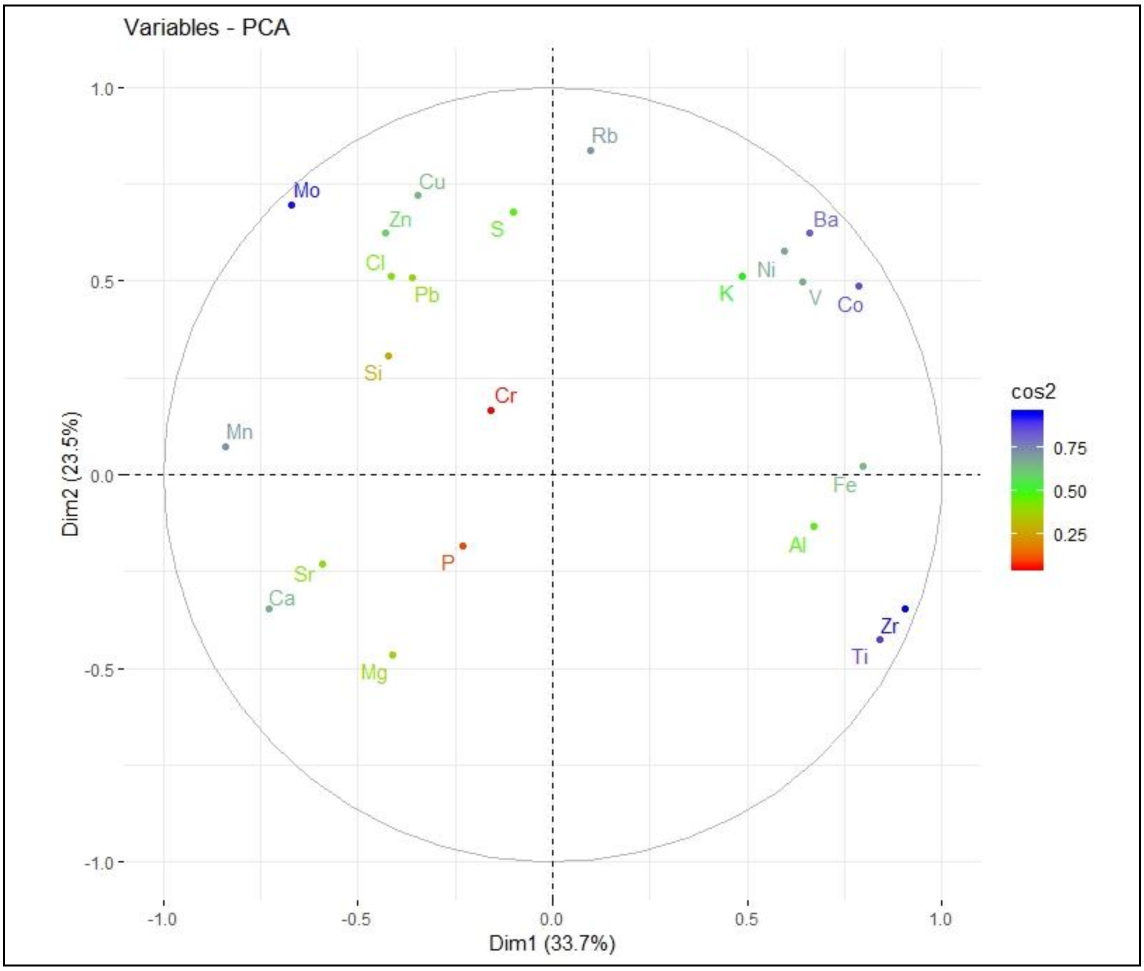

**Figure 2:** PCA of chemical elements in the Donga formation

**Multiple correlations of chemical elements in the donga formation**

Class 1 is made up of Rb, Ba, Ni, V, Co and K (Table no 2). This class is influenced by the positive zones of the Dim1 and Dim2 axes. The element Rb is rather explained only by the positive side of the Dim2 axis. These elements form weak (V_K and Rb_V), medium (Rb_Ni, Rb_Co, Ni_K and Rb_Ba) and strong (Rb_K, Ni_V, Ni_Co, Ni_Ba, V_Co, V_Ba, Co_K and K_Ba) or even very strong (Co_Ba) positive correlations. The weak and medium correlations have r values < 0.7. In these correlations, the variance of one element affects the other at 36%. These elements, therefore, come from several minerals. On the other hand, strong correlations (0.7 < r <0.9) and very strong correlations (0.9 < r < 1) show strong links between chemical elements. The variance of one element influences the variance of the other by more than 50%. It can be as high as 95 (Co_Ba); so, both elements come from the same mineral. Chemical elements with high correlations suggest that they are found in at least one and the same mineral with the presence of one which conditions the presence of the other in the samples studied. Class 1 includes chemical elements from clay minerals, detrital minerals and heavy minerals present in the Donga samples.

**Table no 2**: Positive correlation of Class 1 elements

| | **Rb** | **Ni** | **V** | **Co** | **K** | **Ba** |
|---|---|---|---|---|---|---|
| **Rb** | 1 | 0.563 | 0.367 | 0.575 | 0.794 | 0.615 |
| **Ni** | 0.563 | 1 | 0.867 | 0.862 | 0.581 | 0.868 |
| **V** | 0.367 | 0.867 | 1 | 0.776 | 0.369 | 0.878 |
| **Co** | 0.575 | 0.862 | 0.776 | 1 | 0.825 | 0.952 |
| **K** | 0.794 | 0.581 | 0.369 | 0.825 | 1 | 0.742 |
| **Ba** | 0.615 | 0.868 | 0.878 | 0.952 | 0.742 | 1 |

Class 2 contains more chemical elements (Table no 3**Erreur ! Source du renvoi introuvable.**): Cl, Mo, Pb, Zn, Cu, Cr, Si, S and Mn. These elements have positive or negative correlations that range from very weak to very strong. The most significant correlations in ascending order are Zn_S, Zn_Mn, Ci_Mo, Cu_S and Zn_Cu. These elements influence each other by more than 54%. The last two correlations reach over 86%. Some of these elements originate from the same mineral or deposit environment. According to [1], these elements come from an anoxic (oxygen-poor) environment. They are, therefore, linked to organic matter, hence the presence of sulfur in the environment. In this class, we note the presence of silicon, whose correlation with the other elements is very weak. This suggests an influence of quartz during FRX analysis, with some of the silicon in the other minerals being weakly expressed.

**Table no 3:** Correlation of Class 2 elements

| | **Cl** | **Mo** | **Pb** | **Zn** | **Cu** | **Cr** | **Si** | **S** | **Mn** |
|---|---|---|---|---|---|---|---|---|---|
| **Cl** | 1 | 0.806 | 0.317 | 0.021 | 0.199 | 0.376 | 0.171 | 0.177 | -0.006 |
| **Mo** | 0.806 | 1 | 0.488 | 0.566 | 0.602 | 0.317 | 0.53 | 0.424 | 0.492 |
| **Pb** | 0.317 | 0.488 | 1 | 0.589 | 0.662 | 0.01 | -0.006 | 0.56 | 0.416 |
| **Zn** | 0.021 | 0.566 | 0.589 | 1 | 0.928 | -0.038 | 0.394 | 0.738 | 0.746 |
| **Cu** | 0.199 | 0.602 | 0.662 | 0.928 | 1 | 0.074 | 0.111 | 0.925 | 0.574 |
| **Cr** | 0.376 | 0.317 | 0.01 | -0.038 | 0.074 | 1 | -0.016 | 0.192 | -0.112 |
| **Si** | 0.171 | 0.53 | -0.006 | 0.394 | 0.111 | -0.016 | 1 | -0.219 | 0.476 |
| **S** | 0.177 | 0.424 | 0.56 | 0.738 | 0.925 | 0.192 | -0.219 | 1 | 0.285 |
| **Mn** | -0.006 | 0.492 | 0.416 | 0.746 | 0.574 | -0.112 | 0.476 | 0.285 | 1 |

Class 3 includes the following minerals (Table no 4): P, Sr, Ca and Mg. They are explained by the negative sides of the Dim1 and Dim2 axes. The correlations between the elements Ca, Mg and Sr are strongly positive. They influence each other by 55% (Ca_Sr), 68% (Ca_Mg) and 75% (Mg_Sr). These elements largely derived from carbonates. Phosphorus correlates moderately with the other three elements (Sr, Ca and Mg), whose influence remains below 47%. It does not come from the same mineral like the other elements, but from the same deposit environment, which is here in situ. It could come from phosphates.

**Table no 4:** Positive correlations of class 3 elements

| | **P** | **Sr** | **Ca** | **Mg** |
|---|---|---|---|---|
| **P** | 1 | 0.684 | 0.67 | 0.676 |
| **Sr** | 0.684 | 1 | 0.742 | 0.87 |
| **Ca** | 0.67 | 0.742 | 1 | 0.828 |
| **Mg** | 0.676 | 0.87 | 0.828 | 1 |

Class 4 is composed of the elements Fe, Al, Ti and Zr (Table no **5**). The Correlations between these elements are positive. Only the positive side of the Dim1 axis better explains these elements. In the Table no 5, Ti_Zr (r = 0.915) are very strongly correlated; the variance of one explains by 84% the variance of the other. Considering the presence of anatase reported in the work of [20], we can assume that Ti comes almost exclusively from this mineral. In view of its strong correlation with Zr, these two elements originate from the same mineral (anatase). The other correlations, which are strong (Fe_Ti and Zr_Fe) and medium (Al_Fe, Al_Zr and Al_Ti), influence each other between 58% and 60%; and between 26% and 38% respectively. Iron is strongly correlated with Zr and Ti, and is thought to originate partly from anatase, but also from other detrital elements such as goethite. The weak influence of Al on the other elements shows that it largely derives from different minerals. It was, therefore, the aluminum in clay minerals that expressed itself the more.

**Table no 5:** Positive correlations of class 4 elements

| | **Zr** | **Al** | **Fe** | **Ti** |
|---|---|---|---|---|
| **Zr** | 1 | 0.62 | 0.76 | 0.915 |
| **Al** | 0.62 | 1 | 0.632 | 0.507 |
| **Fe** | 0.76 | 0.632 | 1 | 0.773 |
| **Ti** | 0.915 | 0.507 | 0.773 | 1 |

There is also a relationship between the different classes. Class 1 and class 4 are positively correlated, with Zr_Co, Fe_V and Fe_Co being the most notable. The influence between the variances of these elements remains below 32%, except the Fe_V relationship, where the influence is 50%. Classes 1 and 2 derive from the clay minerals, detrital minerals (anatase, muscovite, goethite and garnet) and heavy minerals present in the samples from the Donga formation. These elements are inherited from the weathering of continental rocks.

There is no significant correlation between classes 2 and 3. Nevertheless, the elements in these classes originate from the same anoxic environment except silicon, which comes from quartz.

Negative correlations exist between classes 1 and 3 on the one hand, and between classes 2 and 4 on the other (Table no 6). These correlations mean that there are substitutions between the elements in these different classes. In classes 2 and 4, they are medium (Cl_Al, Cl_Ti, Mo_Al, Mo_Fe, Zr_Zn, Zr_Cu, Zr_Si, Zn_Ti, Cu_Ti, Si_Fe, Si_Ti, Fe_Mn and Ti_Mn), strong (Mo_Zr and Zr_Mn) and very strong (Mo_Ti). In the medium correlations, the variances influence each other by less than 50%. Mo and Mn tend to replace Zr in minerals. The variance is even greater between Mo and Ti, approaching 84%. Mo gradually replaces Ti in anatase. In classes 1 and 3, negative correlations are averages whose variances influence each other only slightly (< 25%).

**Table no 6:** Negative correlations between classes 2 and 4

| | Cl | Mo | Zr | Zn | Cu | Si | Al | Fe | Ti | Mn |
|---|---|---|---|---|---|---|---|---|---|---|
| **Cl** | 1 | 0.806 | -0.475 | 0.021 | 0.199 | 0.171 | -0.664 | -0.436 | -0.641 | -0.006 |
| **Mo** | 0.806 | 1 | -0.833 | 0.566 | 0.602 | 0.53 | -0.614 | -0.615 | -0.913 | 0.492 |
| **Zr** | -0.475 | -0.833 | 1 | -0.675 | -0.607 | -0.542 | 0.62 | 0.76 | 0.915 | -0.857 |
| **Zn** | 0.021 | 0.566 | -0.675 | 1 | 0.928 | 0.394 | -0.097 | -0.161 | -0.543 | 0.746 |
| **Cu** | 0.199 | 0.602 | -0.607 | 0.928 | 1 | 0.111 | -0.091 | 0.021 | -0.513 | 0.574 |
| **Si** | 0.171 | 0.53 | -0.542 | 0.394 | 0.111 | 1 | -0.316 | -0.751 | -0.576 | 0.476 |
| **Al** | -0.664 | -0.614 | 0.62 | -0.097 | -0.091 | -0.316 | 1 | 0.632 | 0.507 | -0.404 |
| **Fe** | -0.436 | -0.615 | 0.76 | -0.161 | 0.021 | -0.751 | 0.632 | 1 | 0.773 | -0.588 |
| **Ti** | -0.641 | -0.913 | 0.915 | -0.543 | -0.513 | -0.576 | 0.507 | -0.773 | 1 | -0.663 |
| **Mn** | -0.006 | 0.492 | -0.857 | 0.746 | 0.574 | 0.476 | -0.404 | -0.588 | -0.663 | 1 |

**Composition of the chemical elements of the Yogou formation**

The major chemical elements present in the Yogou formation are listed in Table no 7. They include silicon, aluminum, iron, calcium, potassium, sulfur, titanium, magnesium, manganese and barium.

**Table no 7:** Elemental composition of chemical elements in the Yogou formations

| Samples | PK.Yg_1 | PH.Yg | PM.Yg_1 | PF.Yg_1 | PM.Yg_2 | PF.Yg_2 | PK.Yg_2 |
|---|---|---|---|---|---|---|---|
| **Si** | 53.66 | 61.61 | 55.77 | 62.49 | 54.81 | 63.29 | 52.73 |
| **P** | 0.09 | 0.2 | 0.14 | 0.1 | 0.16 | 0.18 | 0.12 |
| **Al** | 16.27 | 15.27 | 16.8 | 15.28 | 15.49 | 16.32 | 17.52 |
| **K** | 2.85 | 5.02 | 3.34 | 3.31 | 3.63 | 2.97 | 3.84 |
| **Ti** | 1.96 | 1.89 | 3.14 | 2.6 | 2.91 | 2.31 | 2.11 |
| **Mg** | 1.31 | 0.5 | 0.44 | 1.33 | 0.29 | 0.22 | 0.33 |
| **Mn** | 0.32 | 0.09 | 0.12 | 0.05 | 0.14 | 0.11 | 0.39 |
| **Ba** | 0.04 | 0.19 | 0.02 | 0.13 | 0.16 | 0.19 | 0.22 |
| **Cl** | 0.03 | 0.13 | 0.17 | 0.11 | 0.21 | 0.13 | 0.03 |
| **Mo** | 0 | 0.002 | 0.002 | 0 | 0.002 | 0.001 | 0.001 |
| **Fe** | 18.08 | 13.3 | 16.26 | 12.04 | 18.32 | 11.69 | 19.29 |
| **Ca** | 2.3 | 1.31 | 1.98 | 1.15 | 2.16 | 1.41 | 2.46 |
| **Zr** | 0.049 | 0.083 | 0.094 | 0.109 | 0.084 | 0.098 | 0.051 |
| **Sr** | 0.029 | 0.022 | 0.022 | 0.014 | 0.02 | 0.014 | 0.031 |
| **S** | 2.96 | 0.91 | 1.73 | 1.08 | 1.65 | 1.09 | 3.22 |
| **Rb** | 0.008 | 0.012 | 0.009 | 0.008 | 0.008 | 0.007 | 0.009 |
| **Pb** | 0.005 | 0.005 | 0.004 | 0.005 | 0.002 | 0 | 0.002 |
| **Zn** | 0.008 | 0.006 | 0.004 | 0.008 | 0.003 | 0.016 | 0.012 |
| **Cu** | 0.009 | 0.007 | 0.005 | 0.009 | 0.006 | 0.005 | 0.011 |
| **Ni** | 0.012 | 0.011 | 0.027 | 0.017 | 0.015 | 0.012 | 0.017 |
| **Cr** | 0.02 | 0.019 | 0.019 | 0.016 | 0.009 | 0.01 | 0.013 |
| **V** | 0.041 | 0.039 | 0.07 | 0.046 | 0.052 | 0.045 | 0.053 |
| **Co** | 0.0023 | 0.0054 | 0.0023 | 0.0033 | 0.002 | 0.0023 | 0.004 |

The trace elements in this rock also include zirconium, chlorine, strontium, chromium, rubidium, nickel, phosphorus, copper, zinc, lead, vanadium, cobalt and molybdenum. These are also elements with concentrations below 5000 ppm.

### Principal component analysis of chemical elements in Yogou rocks

The first two axes (Dim1 and Dim2) explain the chemical elements present in the Yogou samples. The percentage is 56.9% (**Figure 3**). The results of the PCA and multiple correlations also reveal four classes: class 1, class 2, class 3 and class 4.

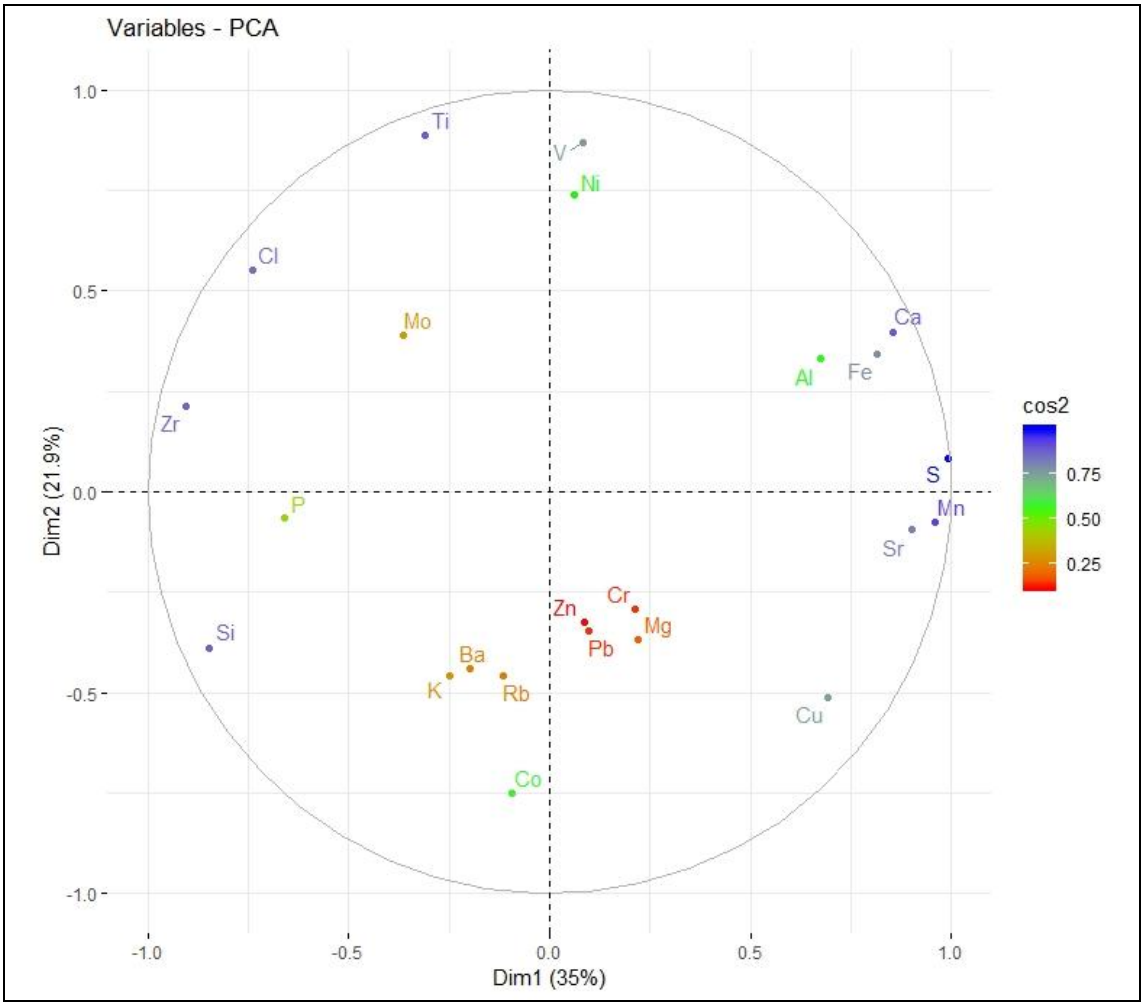

**Figure 4**: PCA of chemical elements in the Yogou Formation

### Multiple correlations of chemical elements in the Yogou formation

In class 1, most of the correlations are strong and positive, except the correlations between Fe_Ca and S_Mn where they are very strong (Table no 8). The variances range from 52% to 80% for strong correlations and 94% for very strong correlations. These correlations show that the chemical elements come from at least the same minerals (clays, pyrite and carbonates). Here, the proportion of iron comes largely from pyrite, given its affinity with sulfur contrarily to the Donga formation, where the presence of sulfur is largely due to detrital minerals (goethite, anatase, etc.). According to the works of [1], [21], Class 1 elements are characteristic from suboxic to anoxic environments. There are average correlations in this class, namely Sr_Al and Al_Fe; these elements do not originate from the same mineral. Class 1 is influenced by the Dim1 axis (positive side).

**Table no 8:** Positive correlations of Class 1 elements

| | **Sr** | **Al** | **Fe** | **Ca** | **S** | **Mn** |
|---|---|---|---|---|---|---|
| **Sr** | 1 | 0.598 | 0.831 | 0.821 | 0.885 | 0.894 |
| **Al** | 0.598 | 1 | 0.521 | 0.665 | 0.724 | 0.724 |
| **Fe** | 0.831 | 0.521 | 1 | 0.97 | 0.846 | 0.782 |
| **Ca** | 0.821 | 0.665 | 0.97 | 1 | 0.896 | 0.842 |
| **S** | 0.885 | 0.724 | 0.846 | 0.896 | 1 | 0.97 |
| **Mn** | 0.894 | 0.724 | 0.782 | 0.842 | 0.97 | 1 |

As for class 2 (Table no 9

**Table no**), only the Dim2 axis (positive side) explains the elements in this class. Correlations between elements are positive and strong (Ni_Ti and V_Ti) to very strong (Ni_V). Nickel's variance explains 60% of Titanium's variance and 95% of Vanadium's variance. These elements derive from the same minerals. Ti, here, does not come from anatase, but probably from heavy minerals. This class forms no significant correlation with class 1.

**Table no 9:** Positive correlations of class 2 elements

| | **Ni** | **V** | **Ti** |
|---|---|---|---|
| **Ni** | 1 | 0.952 | 0.771 |
| **V** | 0.952 | 1 | 0.804 |
| **Ti** | 0.771 | 0.804 | 1 |

Class 3 is explained by the negative sides of the Dim1 and Dim2 axes (Table no 10). Significant correlations are P_Mo, Cl_Mo, Zr_Si. P, Mo and Cl probably originate from salts present in the environment, which is also suboxic to anoxic, as in class 1. Zr and Si, which individually form weak positive correlations with the other elements derive from heavy minerals and quartz respectively. The strong correlation between Si and Zr might be due to zircon inclusions in the grains of quartz of the Yogou formation. There is no correlation between Class 3 elements and those of Classes 1 and 2. Class 3 elements are from the same environment as Class 1 elements.

**Table no 10:** Positive correlations of class 3 elements

| | **P** | **Cl** | **Mo** | **Zr** | **Si** |
|---|---|---|---|---|---|
| **P** | 1 | 0.579 | 0.762 | 0.342 | 0.458 |
| **Cl** | 0.579 | 1 | 0.703 | 0.693 | 0.277 |
| **Mo** | 0.762 | 0.703 | 1 | 0.176 | -0.071 |
| **Zr** | 0.342 | 0.693 | 0.176 | 1 | 0.771 |
| **Si** | 0.458 | 0.277 | -0.071 | 0.771 | 1 |

In the last class, only the Dim2 axis (negative side) explains the elements except for Cu, where the Dim1 axis (negative side) is also expressed (Table no 11). The chemical elements concerned are: Rb, Pb, Zn, Cu, Cr, Co, K, Mg and Ba. The correlations are mostly positive, except between certain elements where they are negative (Pb_Zn, Rb_Zn, Pb_Ba, Cr_Ba). Negative correlations show that these elements do not share the same source. However, substitutions occur between elements in the current deposit environment. The remarkable positive correlations ($0.7 < r < 1$) are: Rb_Co, Rb_K, Pb_Mg, Pb_Cr, Co_K. These elements originate, in part, from the same minerals, in occurrence clay minerals. Other positive correlations reflect the presence of detrital minerals. This class shows no remarkable correlation with the other classes.

**Table no 11**: Positive and negative correlations of class 4 elements

| | **Rb** | **Pb** | **Zn** | **Cu** | **Cr** | **Co** | **K** | **Mg** | **Ba** |
|---|---|---|---|---|---|---|---|---|---|
| **Rb** | 1 | 0.503 | -0.38 | 0.08 | 0.512 | 0.851 | 0.923 | -0.13 | 0.176 |
| **Pb** | 0.503 | 1 | -0.58 | 0.3 | 0.871 | 0.355 | 0.254 | 0.735 | -0.52 |
| **Zn** | -0.38 | -0.58 | 1 | 0.2 | -0.34 | 0.039 | -0.3 | -0.13 | 0.473 |
| **Cu** | 0.084 | 0.299 | 0.2 | 1 | 0.185 | 0.393 | 0.073 | 0.468 | 0.217 |
| **Cr** | 0.512 | 0.871 | -0.34 | 0.19 | 1 | 0.326 | 0.158 | 0.577 | -0.62 |
| **Co** | 0.851 | 0.355 | 0.039 | 0.39 | 0.326 | 1 | 0.866 | -0.03 | 0.516 |
| **K** | 0.923 | 0.254 | -0.3 | 0.07 | 0.158 | 0.866 | 1 | -0.32 | 0.494 |
| **Mg** | -0.13 | 0.735 | -0.13 | 0.47 | 0.577 | -0.03 | -0.32 | 1 | -0.49 |
| **Ba** | 0.176 | -0.52 | 0.473 | 0.22 | -0.62 | 0.516 | 0.494 | -0.49 | 1 |

## IV. Summary of correlations

Correlations between chemical elements are highly dependent on the minerals present in the studied sample. Two chemical elements may be strongly correlated in one sample and not in another. In this case, the two elements are not in the same mineral in the second sample. This is the case for iron, which is bound to sulfur in the Yogou samples, whereas it is bound to titanium and weakly bound to sulfur (correlation coefficient 0.26) in the Donga samples. In the first case, the iron comes from pyrite, and in the second case, a significant proportion of the iron comes from anatase and detrital minerals. Silicon is also strongly bound to zirconium in the Yogou samples, but it is not bound to any chemical element in the Donga samples. This is due to the inclusion of zircon in quartz in the Yogou samples, since almost all the silicon derives from quartz in both the Donga and Yogou formations.

## V. Conclusion

Based on the results of the PCR analysis of the chemical elements present in the Donga and Yogou formations, it can be stated that the correlations between the chemical elements are highly dependent on the minerals present in the sample under study. This is the case of iron and silicon. The former is linked to sulfur in the Yogou samples, whereas it is linked to titanium and weakly linked to sulfur in the Donga samples, although silicon is not linked to any chemical element. This study reveals that the chemism of the deposit environments of the Donga and Yogou formations is different. Thus, the Donga formation is deposited in anoxic environments, whereas the Yogou formation is deposited from suboxic to anoxic environments.

## Acknowledgements

The authors would like to express their sincere and honest gratitude to the Centre de Documentation et d'Archives Pétrolières du Niger (CDP).

## References

[1]. [N. Craigie, Principles Of Elemental Chemostratigraphy: A Practical User Guide. In Advances In Oil And Gas Exploration & Production. Springer International Publishing, 2018. Doi: 10.1007/978-3-319-71216-1.

[2]. G. Ataman, Géochimie Des Minéraux Argileux Dans Les Bassins Sédimentaires Marins Etudes Sur Le Bassin Triasique Du Jura, Vol. 25, N° 1. Persée - Portail Des Revues Scientifiques En Shs, 1966. Https://Www.Persee.Fr/Doc/Sgeol_0080-9020_1966_Mon_25_1

[3]. L. Drugat, « Geochemistry Of Speleothems From The South-East Of Europe (U-Th And 14c Chronology, Trace Elements, 87sr/86sr, 18o/16o, 13c/12c) For Climatic And Environmental Reconstructions During The Holocene », Theses, Université Paris-Saclay, 2018. Https://Tel.Archives-Ouvertes.Fr/Tel-02495354

[4]. K. Bjorlykke, Éd., Petroleum Geoscience: From Sedimentary Environments To Rock Physics, 2e Éd. Berlin Heidelberg: Springer-Verlag, 2015. Doi: 10.1007/978-3-642-34132-8.

[5]. P. A. Meyers, « Preservation Of Elemental And Isotopic Source Identification Of Sedimentary Organic Matter », Chem. Geol., Vol. 114, N° 3, P. 289-302, Juin 1994, Doi: 10.1016/0009-2541(94)90059-0.

[6]. J. M. Moldowan, W. K. Seifert, Et E. J. Gallegos, « Relationship Between Petroleum Composition And Depositional Environment Of Petroleum Source Rocks », Aapg Bull., Vol. 69, N° 8, P. 1255-1268, Août 1985, Doi: 10.1306/Ad462bc8-16f7-11d7-8645000102c1865d.

[7]. Z. Chen, D. Lavoie, C. Jiang, M. Duchesne, Et M. Malo, Caractéristiques Géologiques Et Evaluation Des Ressources Pétrolières De La Formation De Macasty, Ile D'anticosti, Québec, Canada. 2016. Doi: 10.4095/297893.

[8]. E. H. Nickel, « Mineral Chemistry Of Metal Sulfides. (Cambridge Earth Science Series), Cambridge (Cambridge University Press), 1978. Xvi+ 493pp., 167 Figs. Price £19.50. », Mineral. Mag., Vol. 43, N° 325, P. 186-187, Mars 1979, Doi: 10.1180/Minmag.1979.043.325.27.

[9]. P. Kenfack, « Mineralogic Characterization And Petroleum Potential Of Clays (Shales) Of The N'kappa Formation (Paléocene-Eocene) In The Douala Sedimentary Sub-Basin (South-West Cameroon) », Int. J. Geosci., Vol. 3, P. 696-709, Janv. 2012, Doi: 10.4236/Ijg.2012.34070.

[10]. T. A. Schwarzkopf, « Relationship Between Petroleum Generation, Migration And Sandstone Diagenesis, Middle Jurassic, Gifhorn Trough, N Germany », Mar. Pet. Geol., Vol. 7, N° 2, P. 153-170, Mai 1990, Doi: 10.1016/0264-8172(90)90038-I.

[11]. N. Timms Et Al., « Sedimentary Facies Analysis, Mineralogy And Diagenesis Of The Mesozoic Aquifers Of The Central Perth Basin, Western Australia », Mar. Pet. Geol., Vol. 60, Nov. 2014, Doi: 10.1016/J.Marpetgeo.2014.08.024.

[12]. J. I. Hedges Et R. G. Keil, « Sedimentary Organic Matter Preservation: An Assessment And Speculative Synthesis », Mar. Chem., Vol. 49, N° 2, P. 81-115, Avr. 1995, Doi: 10.1016/0304-4203(95)00008-F.

[13]. D. Mani, B. Ratnam, M. S. Kalpana, D. J. Patil, Et A. M. Dayal, « Elemental And Organic Geochemistry Of Gondwana Sediments From The Krishna–Godavari Basin, India », Geochemistry, Vol. 76, N° 1, P. 117-131, Mars 2016, Doi: 10.1016/J.Chemer.2016.01.002.

[14]. M. Smietana, « Pétrologie, Géochronologie (K-Ar) Et Géochimie Elémentaire Et Isotopique (Sr, Nd, Hf, Pb) De Laves Anciennes De La Réunion : Implications Sur La Construction De L'édifice Volcanique », Phdthesis, Université De La Réunion, 2011. Https://Tel.Archives-Ouvertes.Fr/Tel-00716829

[15]. C. Yu, N. Mu, W. Huang, W. Xu, Et X. Feng, « Major And Rare Earth Element Characteristics Of Late Paleozoic Coal In The Southeastern Qinshui Basin: Implications For Depositional Environments And Provenance », Acs Omega, Vol. 7, N° 35, P. 30856-30878, Sept. 2022, Doi: 10.1021/Acsomega.2c02596.

[16]. C. Duyck Et Al., « The Determination Of Trace Elements In Crude Oil And Its Heavy Fractions By Atomic Spectrometry », Spectrochim. Acta Part B At. Spectrosc., Vol. 62, N° 9, P. 939-951, Sept. 2007, Doi: 10.1016/J.Sab.2007.04.013.

[17]. J. C. Groen Et J. R. Craig, « The Inorganic Geochemistry Of Coal, Petroleum, And Their Gasification/Combustion Products », Fuel Process. Technol., Vol. 40, N° 1, P. 15-48, Oct. 1994, Doi: 10.1016/0378-3820(94)90033-7.

[18]. A. S. Ogunlaja, O. S. Alade, E. O. Odebunmi, A. Majavu, N. Torto, Et Z. R. Tshentu, « The Ratios Of Vanadium-To-Nickel And Phenanthrene-To-Dibenzothiophene As Means Of Identifying Petroleum Source And Classification Of Nigeria Crude Oils », Pet. Sci. Technol., Vol. 32, N° 19, P. 2283-2291, Oct. 2014, Doi: 10.1080/10916466.2013.795970.

[19]. W. Justin, « 5 Reasons To Put Savannah Petroleum #Savp On Your Watchlist », Févr. 2017. Https://Www.Voxmarkets.Co.Uk/Blogs/5-Reasons-To-Put-Savannah-Petroleum-Savp-On-Your-Watchlist/

[20]. M. A. Ibrahim, K. Yao, Et Z. Digbehi, « Mineralogical Characterization Of Upper Cretaceous Petroleum Source Rocks Of Termit Sedimentary Basin (Niger) ».