Romanian Journal of Petroleum & Gas Technology
VOL. V (LXXVI) • No. 2/2024

CONTRIBUTION TO THE GEOCHEMICAL STUDY OF KANZI AND MVUANGU PHOSPHATE ROCKS IN THE LEMBA OIL SUB-BASIN OF CENTRAL CONGO

Deko Oyema Bruno [1*]
Emmanuel Kazinguvu Atibu [2]
Dan Mandjumba Yenor [1]
Dominique Wetshondo Osomba [3]
Loma Wonga Mathias [4]
John Pote Wembonyama [5]

[1] University of Kinshasa, Faculty of Oil, Gas and Renewable Energy, Department of Exploration and Production Engineering, Democratic Republic of Congo
[2] University of Kinshasa, Department of Chemistry and Industry, Democratic Republic of Congo
[3] University of Kinshasa, Faculty of Science, Department of Geosciences, Democratic Republic of Congo
[4] Agence Congolaise de L'environnement (ACE), Democratic Republic of Congo
[5] University of Geneva, Faculty of Sciences, Department F.-A. Forel for Environmental and Aquatic Sciences and Institute for Environmental Sciences, 1211 Geneva 4, Switzerland
* e-mail: bruno.deko@unikin.ac.cd, brunosdeko@gmail.com

DOI: 10.51865/JPGT.2024.02.01

ABSTRACT

Located on the Congolese (DRC) side of the Lemba depression, our study area is the part that was returned by "ex-Zaïrep", just east of the concession currently operated by Perenco rep. Open to oil and mining exploration, we brought back phosphate rock samples from the field, which were analyzed by the Commissariat Général à l'Energie Atomique (CGEA) using the ED- XRF Xepos III spectrometer. These analyses were used to characterize the geochemistry of the Kanzi and Mvuangu phosphates.

The results of the Chemical Analyses (Oxides) and Chemical Elements are as follows: (1) *Major oxides* (%:) Al_2O_3 (21,21 – 17,24); SiO_2 (14,85 – 30,40); P_2O_5 (19,48 -13,34 %) finally Fe_2O_3 (8,544 – 10,74 %), and other oxides with concentrations in mg/kg (MnO, ZnO, Rb_2O, SrO, ZrO_2, Nb_2O_5, Sb_2O_5, Ta_2O_5); (2) *Major Chemical Elements* (%): Aluminum (11.22- 9.124); Silicon (6.939-14.21); Phosphate (8.5-5.823 %) and several trace metallic elements that will be exposed in another soil and sediment matrix to assess the state of the environment prior to mining and petroleum activities. The origin of these metallic elements, including heavy metals, rare earths and radionuclides, is phosphate. Phosphate rocks, such as apatite, may contain heavy metals, rare earths and radionuclides in their mineral structure.

The gravity anomaly map of the Lemba sub-basin, where the phosphate sites are located, clearly shows that the phosphates of Kanzi in the south and Mvuangu in the north are not

located in the central deposits, but in the upper parts of the sub-basin. These areas are potentially anticlines, which are geological structures capable of containing hydrocarbons. This study is a contribution to our knowledge of the phosphate resource in Kanzi and Mvuangu, and contribute to understanding the geological structures capable of containing hydrocarbons. It is also an important contribution in the field of geochemistry and gravimetry.

Keywords: phosphate rocks, geochemical analysis, oil exploration, gravity anomaly, soil fertilizers

INTRODUCTION

The phosphate rocks of Mvuangu and Kanzi are found in the depression of the coastal basin of the Democratic Republic of Congo, which was restored by "ex-Zairep", the coastal basin which has three main depressions: the Lemba depression our study area, and the other two which are the smaller Sintu and Malong-Tshikoko, located just east of the concession currently exploited by the Perenco representative. The Mayombian subsoil delimits it to the south by the Congo River and to the west by the northernmost point of the concession. This zone is at 5°00'S, 12°38'E, its easternmost points run along the meridian 13°11'E and its furthest point, the west is at 5°45'S, 12°15'E. Its approximate area is 4,916 square kilometers (1.2 million acres) [1] coastal and our study area of Lemba. [Figure 1].

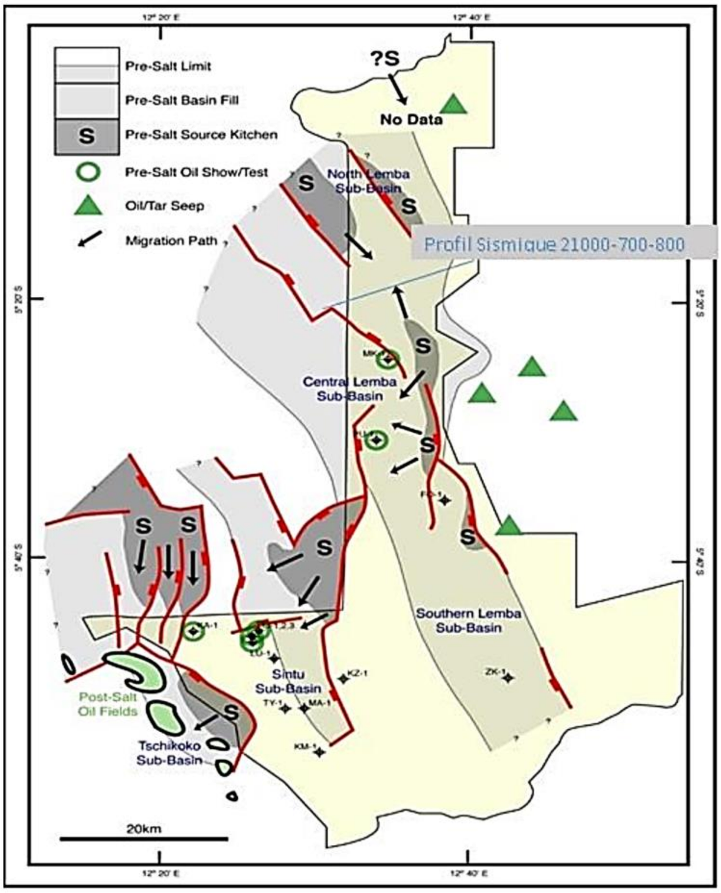

***Figure 1**. Structural map of the coastal basin* [1]

The Lemba sub-basin contains oil blocks and mining squares, all of which are open to exploration. The work carried out on the Kanzi and Mvuangu sites hosting phosphate deposits in the Lemba sub-basin did not include geochemical studies to assess the environment of the phosphate rocks. Instead, these studies focus on petrography and mineralogy [2], phosphate deposit evaluation [3], rocks as fertilizers with modifying properties [4], characterization of surface hydrocarbon showings [5], major element analysis [6] and other petroleum exploration studies. Following a study carried out in 1990 based on seismic data, six prospects were identified [7]. Evaluation of the technical data from Lemba Gap revealed that the organic matter in the pre-salt Bucomazi formation in Lemba Gap was more mature than that in Sintu Gap [8].

The gravity anomaly map of the Lemba sub-basin, where the phosphate sites are located, clearly shows that the phosphates of Kanzi in the south and Mvuangu in the north are not located in the central deposits, but in the upper parts of the sub-basin. These areas are potentially anticlines, which are geological structures capable of containing hydrocarbons. This study is a contribution to our knowledge of the phosphate resource in Kanzi and Mvuangu, and contribute to understanding the geological structures capable of containing hydrocarbons. It is also an important contribution in the field of geochemistry and gravimetry.

GEOGRAPHICAL LOCATION

Mvuangu deposit

Located around 25 km south-west of Lukula, more precisely in the Kakongo region, on the Lukula-Mavuma-Forbola-Muanda road axis, Surface area: 100 km^2, Certain reserves: Substantial but not yet evaluated, P_2O_5. The rock outcrops encountered in the Mvuangu locality (S 05°32'37.3"; E 012°42'0.8") are located behind the Saint-Joseph de Mvuangu Catholic elementary school, 100 m away, and near the N'buindi river on the right flank. The rock sample shows:

- low porosity;
- yellowish and/or whitish coloration;
- harder and more compact than Kanzi;
- predominantly quartz granules and pebbles, with a little calcite in places; medium-sized, subangular to subrounded.

Kanzi deposit

Located approximately 45 km west of Boma, on the Boma - Muanda road axis (Muanda Territory), Location: 5°49'0" South and 12°46'0" East, Outcrops of Kanzi phosphate rocks (S 05°33'01"; E 014°25'41.1") are visible 200 m behind the Tuwizana elementary school near the M'fuma river, Area: 12 km2, on the eastern flank. They occur in the form of cones, lenses and irregular layers. They have the same crystalline structure (very fine grain) and are compact. There are also variations in color (whitish below the flank and whitish-yellow above the flank). For total coverage, we note the effective absence of outcrops and other rock types in the vicinity. There is therefore no way of establishing several cross-sections on a site with the same formation and no variation in grain structure. Nor is there any way of taking structural measurements, since the layers are non-oriented, discontinuous (point deposits that have been deposited in all directions) and lack preferential planes. Traces of organic matter and brittleness are also present, as are medium-sized sub-angular to sub-rounded quartz grains. Certain reserves: 150 million tonnes. We sampled the phosphate-bearing rocks in the Kanzi and Mvuangu areas [Figure 2] Our samples are located in the southern part of the sub-basin (Kanzi and Mvuangu) and the northern part (Fundu-Nzobe and Ngudji).

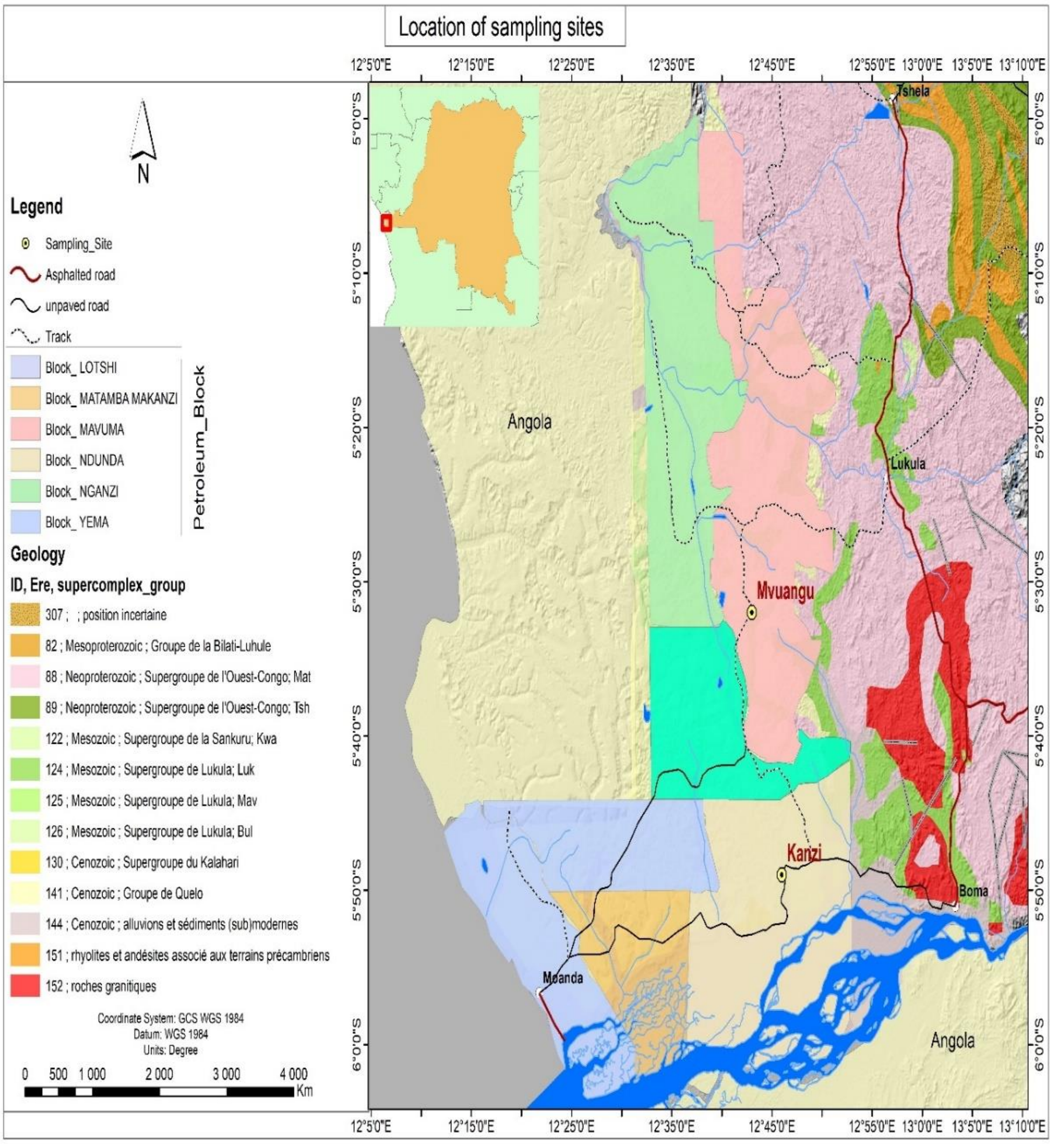

Figure 2*. Location of the Kanzi and Mvuangu sites in the Lemba sub-Basin*

Sampling site description

A field trip was organized to sample the phosphate rocks at the Kanzi and Mvuangu sites, i.e. the phosphate rock outcrops (Figure 3): the sampling period was from January 2 to 11, 2023 at the Kanzi and Mvuangu sites.

Mode of genesis

a) Mvuangu's phosphate rock, formed on a continental platform, is derived from the alteration of a "red" sandstone of Albian age (Vermelha, meaning "red" in French) or Lower Pinda, rich in iron oxide (hematite), silica and clay of continental origin. Particles of this sandstone are gradually deposited on a continental platform and mixed with a large deposit of fossil excrement rich in phosphate in solution as a result of marine erosion, on which they are mixed with terrigenous limestone debris resulting from the alteration of Oolitho-intraclastic limestone of Upper Pinda (marine) age and polygenic debris from Cenomanian and Turonian formations, where they are trapped, and consolidated to form the phosphate rock of Campanian-Maastrichtian age. The particles are bound together by a clay-ferruginous cement.

Figure 3*. Phosphate rock outcrops Kanzi and Mvuangu sites*

b) Kanzi phosphate rock, formed on a continental platform, is the result of the alteration of a green-colored silty sandstone (glauconite) of Santonian marine origin, rich in clay minerals (smectite, kaolinite, illite). This alteration resulted in the deposition of particles essentially consisting of silica without detrital grains (chalcedony or cryptocrystalline quartz), small organism debris (foraminifera and diatoms) in an oxidizing medium (iron oxides), which consolidated little by little, with greater deposition of fossil excrement (coprolites) of continental origin (bat and other excrement transported by the Congo River) and marine origin (coccolithophoraceans, diatoms, etc.) from the sea rich in phosphate in solution and laid down the phosphate-bearing rocks in the Maastrichtian period. Alteration of this silty sandstone gave this phosphate deposit a light yellow or brown color, due to the mixture of iron oxides and clays (limonite), reinforced by the transformation of silica (sardony). The transformation of these particles of these particles into rock as a result of early diagenesis took place "in situ", and the silica grains are bound together by a phosphate clay matrix. [9-10].

MATERIALS AND METHODS

To achieve the objectives assigned to this work, we used the following methodology (Figure 4):

- Data and information collection (Documentation (State structures);
- Analysis and processing (Ech_Roches)
- A laptop computer equipped with processing software: ArcGIS, Excel ;
- ED-XRF Xepos III spectrometer
- Hydraulic press (Specac 1000kg), + molds
- Precision balance (Metter Toledo)
- Retsch sieve shaker (63µm sieve)
- Interpretation (Results, Discussion, Recommendations).

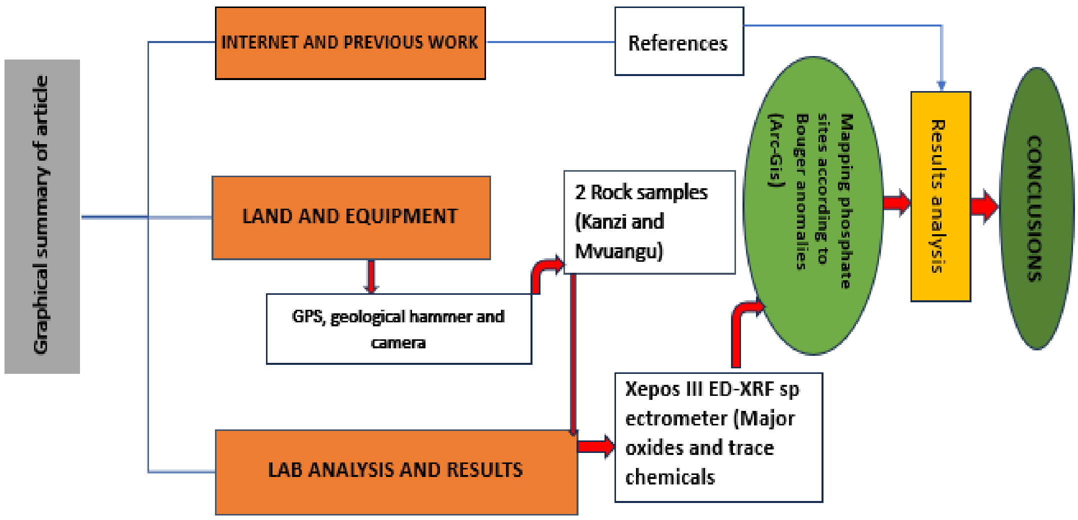

Figure 4. *Diagram describing the methodology used to produce the article*

Some measuring equipment were used (spectrometer ED-XRF XEPOS III, vibrating sieve shaker, hydraulic press, molds, scale). (Figure 5). Conditioning: (drying, grinding, sieving to 60µm, weighing and pressing or pelleting).

The sample was oven-dried for 24 hours and sieved using a Retsch sieve shaker. A 5 g test sample was mixed with 1 g Fluxana as a binder, homogenized in a bag and placed in a mold before being pelletized with a hydraulic press. [11]

X-ray fluorescence spectrometer - analytical protocol and calculation method

All elements (oxides and elements) were measured with the XEPOS III energy-dispersive X-ray fluorescence spectrometer (ED-XRF) (phot 1), using the "FP-Pellets CGEA" and "TQ-Pellets Fast" methods of the XEPOS III spectrometer. Standards ISM23103, ISE1144, ISE1213, ISE 890, ISE919, ISE961 and SOIL-7, containing certain elements of interest, were used.

Figure 5. *Some of the measuring equipment used*

The X-ray fluorescence spectrometer is a multi-element method, using four secondary targets, namely successively Molybdenum (39.76 KV voltage and 0.88 mA current), Aluminum Oxide (49.15KV voltage and 0.7mA current), Cobalt (35.79 KV current and 1 mA current) and finally HOPG Bragg Crystal (17.4 KV voltage and 1.99 mA current) of the palladium anode.

Detection limits, accuracy and sensitivity

Limits: elements with atomic numbers below carbon cannot be analyzed by X-ray fluorescence. The detection limit depends on the excitation source used and the experimental conditions under which the analysis is carried out. It is of the order of 10 ppm for elements such as (Zn, Cu, Pb) and can reach 100 ppm, or even 500 ppm for light elements.

Accuracy and sensitivity

Accuracy varies with the amount of material available for analysis. It also depends on the elements sought and the matrix in which the element is found.

Sensitivity depends on the sample preparation method and the material analyzed. It varies with the chemical elements. It approaches µg/g when a sample of the order of a gram is taken without dilution.

RESULTS AND DISCUSSIONS

Results and discussions are on Chemical Analysis (Oxides) table 1 and Chemical Analysis (Elements) table 2 by Analysis Method: X-ray Fluorescence.

Results of chemical analysis (Oxides)

Table 1 summarizes the results of chemical analysis (Oxides) by X-ray Fluorescence of phosphate rock samples from Mvuangu and Kanzi in the Lemba sub-basin.

***Table 1**: Results of chemical analysis of Kanzi and Mvuangu rock*

Chemical Analysis (Oxides)			
Labo Code	**FSGB0124**	**FSGB0224**	Units
Customer code	**KANZI**	**MUANGU**	
Na_2O	-	-	%
MgO	-	-	%
Al_2O_3	21.21	17.24	%
SiO_2	14.85	30.40	%
P_2O_5	19.48	13.34	%
SO_3	<0.0035	0.0649	%
K_2O	0.6594	0.6525	%
CaO	0.5978	3.265	%
TiO_2	0.5907	0.8973	%
V_2O_5	0.0714	0.0322	%
Cr_2O_3	1053	314.6	mg/kg
MnO	129.9	415.0	mg/kg
Fe_2O_3	8.544	10.74	%
ZnO	167.1	80.3	mg/kg
As_2O_3	15.6	-	mg/kg
Rb_2O	22.6	19.4	mg/kg
SrO	0.1419	0.07049	%
ZrO_2	0.0519	0.04350	%
Nb_2O_5	-	14.4	mg/kg
SnO_2	14.8	-	mg/kg
Sb_2O_5	705.3	80.5	mg/kg
Ta_2O_5	<1.2	<1.2	mg/kg
PbO	22.3	20.2	mg/kg

The presence of CaO proves that when organic matter accumulated, living organisms were also present. In addition, we note the significant presence of Al_2O_3 at 21.21% for Kanzi and 17.24% for Mvuangu, while SiO_2 at 14.84% for Kanzi and 30.4% for Mvuangu, and phosphate itself at 19.48% for Kanzi and 13.34% for Mvuangu. These are the dominant oxides in the phosphate rock samples from both sites.

The geochemical data for the phosphate rock found at Kanzi and Mvuangu are presented in the Figures 6 and 7 below.

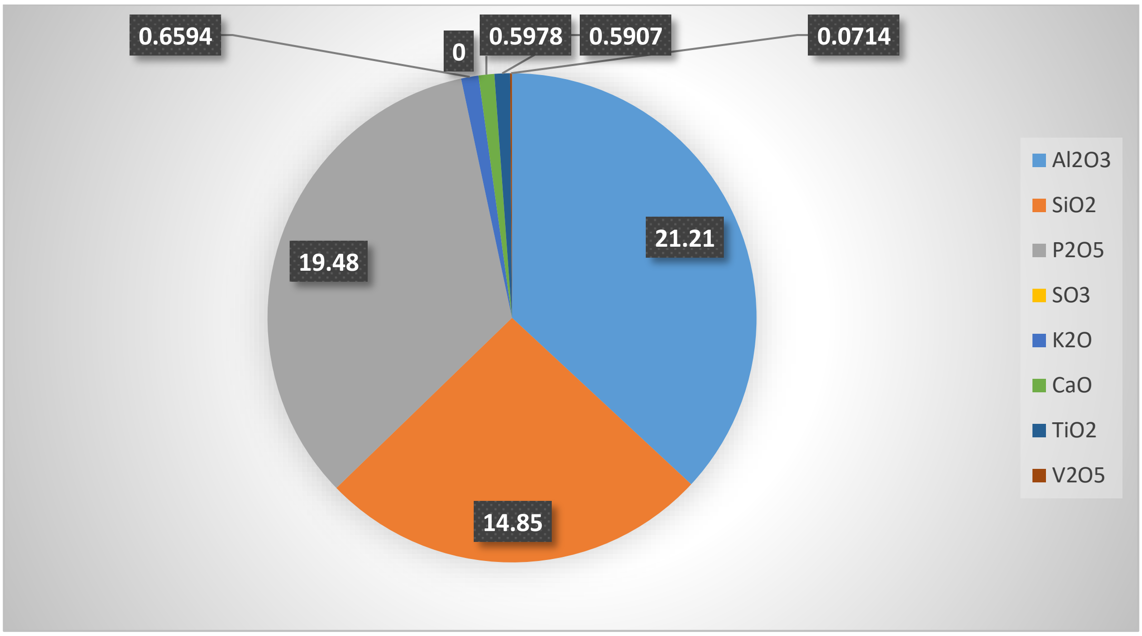

Figure 6. *Circular diagram of the distribution of elements in the Kanzi phosphate rock.*

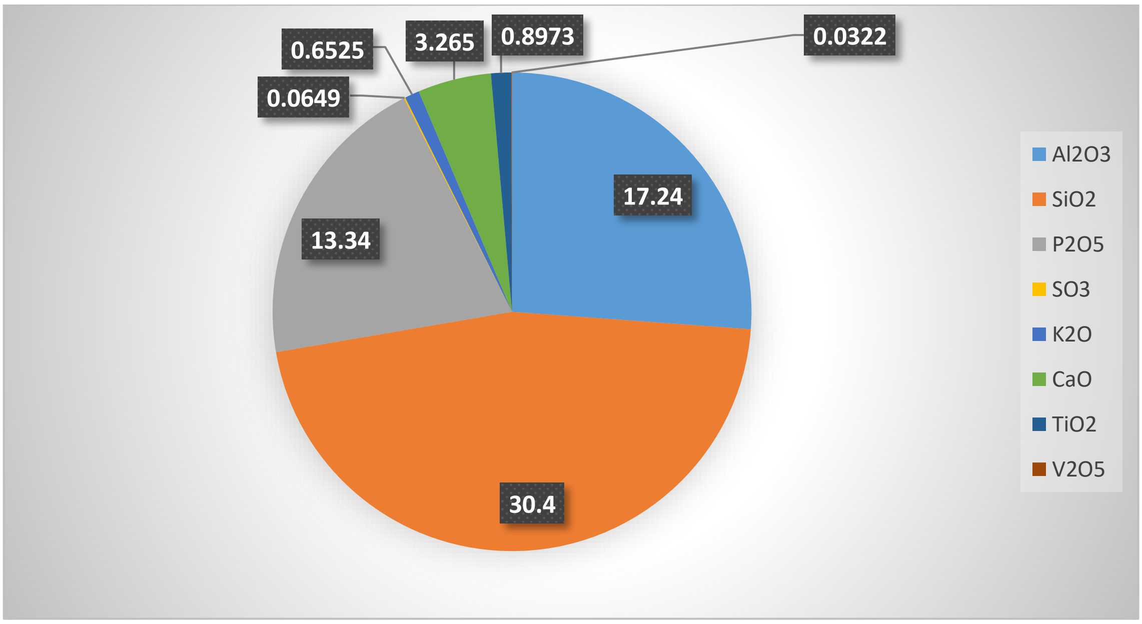

Figure 7. *Circular diagram of the distribution of elements in the Mvuangu phosphate rock.*

Mineralogical study of the powder (fine fractions smaller than 100 micrometers) of the Kanzi and Mvuangu phosphate rock by X-ray diffraction shows that the crystallized fraction consists mainly of fluorapatite and wavellite as potential sources of phosphorus. Quartz, feldspars and low levels of free carbonates and phyllosilicates (micas, smectites) are also present. The presence of wavellite indicates in situ transformation of the initial calcium phosphates [3]. These elements originate from the phosphate rocks at the sites studied. As previously mentioned, phosphate rocks, such as apatite, can contain ores, heavy metals, rare earth elements and radionuclides in their structure. [Figure 8 and 9].

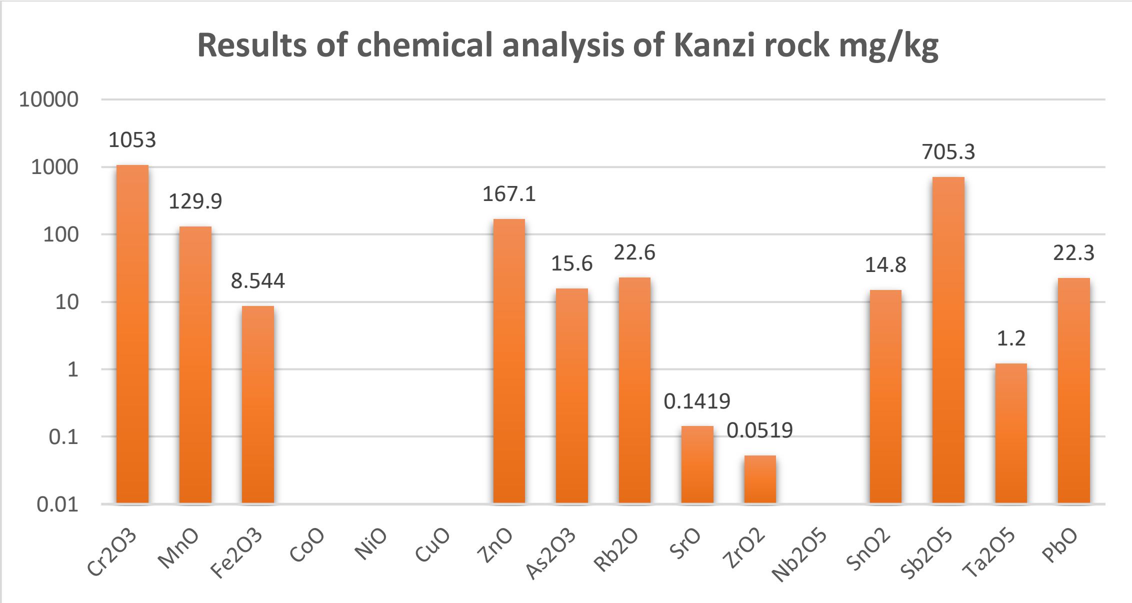

Figure 8. *Histogram of oxides in mg/kg in phosphate Kanzi rock*

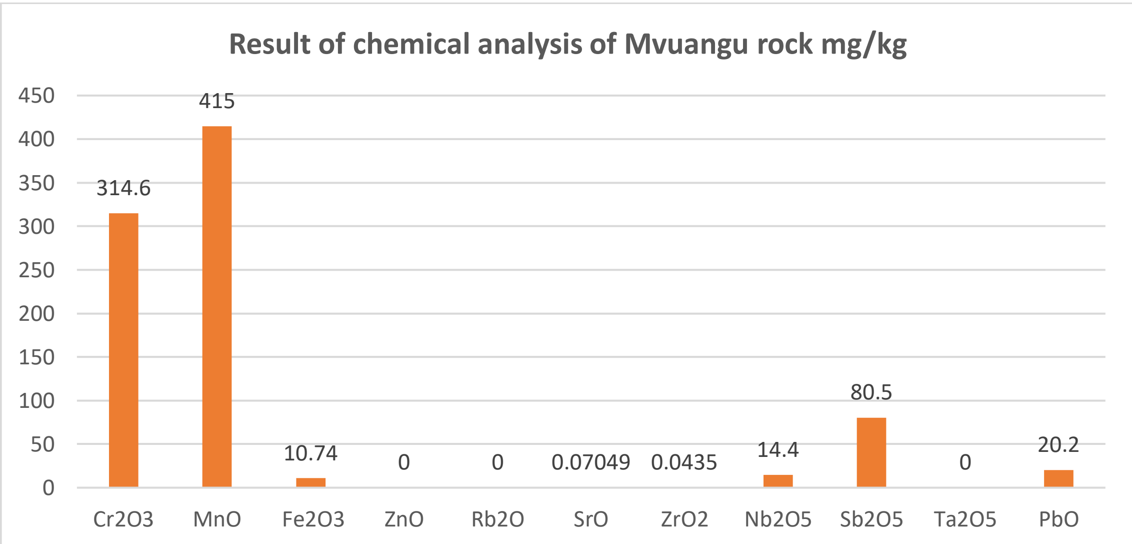

Figure 9. *Histogram of oxides in mg/kg in phosphate Mvuangu rock*

Results Chemical Analysis (Elements)

Table 2 summarizes the results of XRF chemical analysis of phosphate rock samples from Mvuangu and Kanzi in the Lemba sub-basin.

Table 2. Results of chemical analysis elements trace of Kanzi and Mvuangu rock (mg/kg)

Chemical Analysis (Elements)			
Labo Code	**FSGB0124**	**FSGB0224**	**Units**
Customer code	**KANZI**	**MUANGU**	
1. Sodium	-	-	%
2.Magnesium	-	-	%
3. Aluminum	11.22	9.124	%
4. Silicon	6.939	14.21	%
5. Phosphate	8.5	5.823	%
6. Sulfur	<0.0014	0.02597	%
7. Chloride	0.00217	0.00476	%
9. Potassium	0.5473	0.5419	%
10. Calcium	0.4272	2.334	%
11. Scandium	0.00001	-	%
12. Titanium	0.3541	0.5378	%
13.Vanadium	0.04	0.0180	%
14. Chrome	720.4	215.2	mg/kg
15. Manganese	100.6	321.5	mg/kg
16. Iron	5.976	7.509	%
17. Zinc	134.2	64.5	mg/kg
18. Gallium	15.8	12.8	mg/kg
19. Arsenic	11.8	-	mg/kg
20. Bromine	5.9	8.8	mg/kg
21. Rubidium	20.6	17.8	mg/kg
22. Strontium	0.12	0.05961	%
23. Yttrium	0.03136	0.00910	%
25. Zirconium	0.03842	0.03221	%
24. Niobium	-	10.0	mg/kg
25. Palladium	22.4	-	mg/kg
26. Silver	5.0	-	mg/kg
27. Cadmium	8.4	11.9	mg/kg
28. Indium	-	0.00001	%
29. Tin	11.6	-	mg/kg
30. Antimonium	530.9	60.6	mg/kg

31. Tellurium	<3	<3	mg/kg
32. Iodine	-	14.4	mg/kg
33. Cesium	-	80	mg/kg
34. Barium	1393	647	mg/kg
35. Lanthanum	-	211	mg/kg
36. Cerium	-	184	mg/kg
37. Praseodymium	<2	230	mg/kg
38. Neodymium	539	<2	mg/kg
39. Europium	-	0.00001	%
40. Tantalum	<1	<1	mg/kg
41. Gold	0.0	0.0	%
42. Thallium	-	1.1	mg/kg
43. Lead	20.6	18.8	mg/kg
44. Thorium	29.2	21.5	mg/kg
45. Uranium	146.2	156.4	mg/kg

According to [12-14], the mineralogical and chemical compositions of sedimentary rocks are indicative of their provenance as they are the end products of processes associated with chemical and mechanical weathering, transport, deposition, recycling and diagenesis. Figures 10 and 11 below show in a circular diagram the percentage distribution of chemical elements in the phosphate rock of Kanzi and Mvuangu.

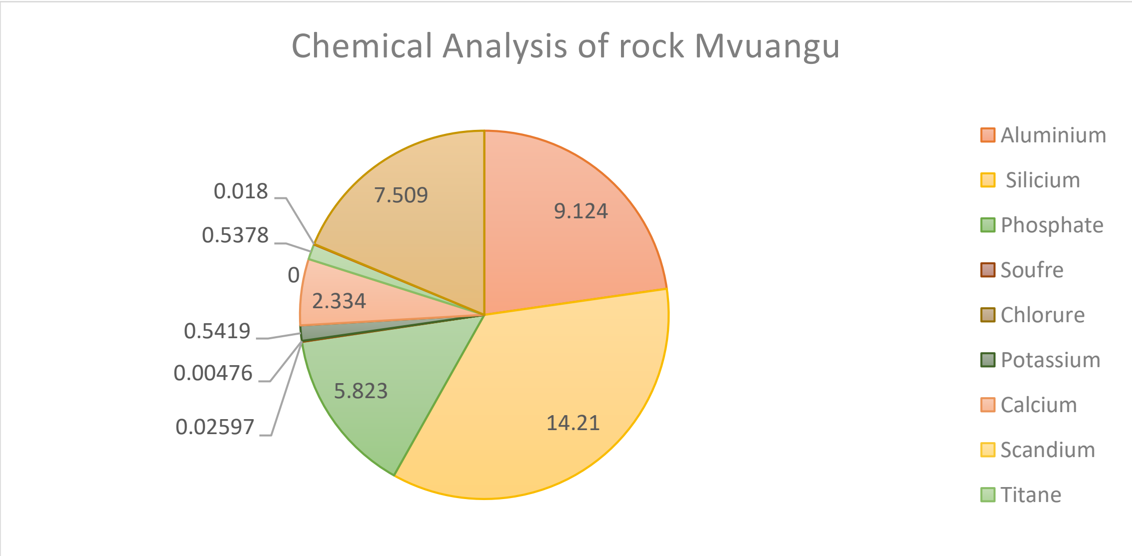

Figure 10. *Circular diagram of the percentage distribution of chemical elements in the Mvuangu phosphate rock*

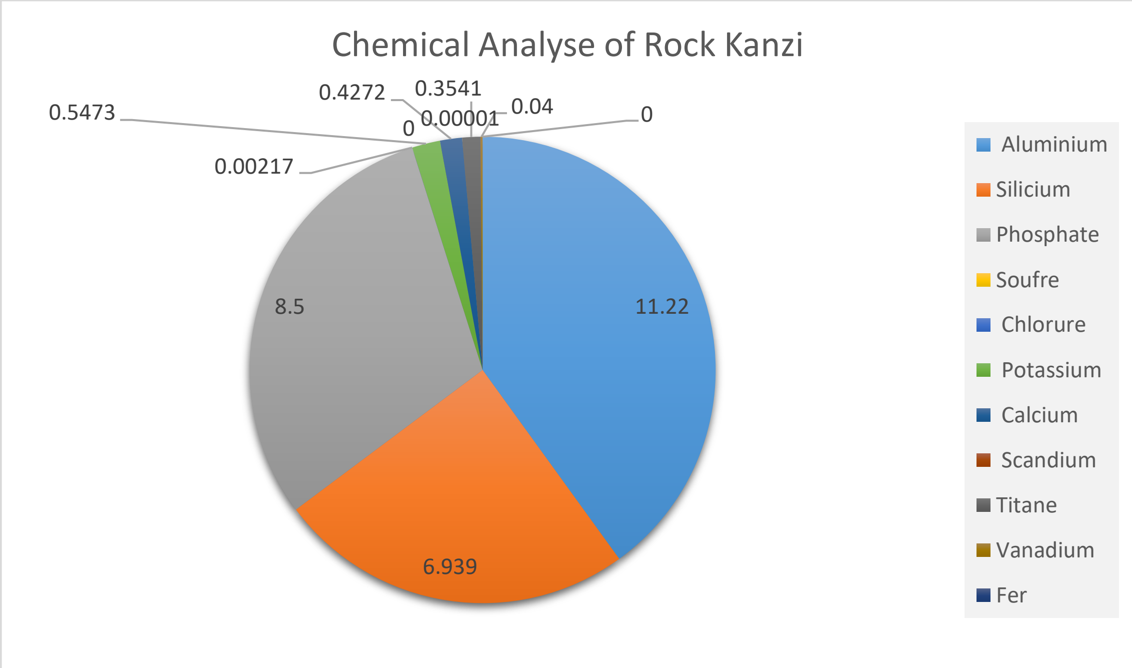

Figure 11*. Circular diagram of the percentage distribution of chemical elements in the Kanzi phosphate rock*

Figures 12 and 13 show the histograms of the distribution of metallic trace elements in the phosphate rocks of the Kanzi and Mvuangu sites, with a high uranium content of around 146.2 mg/kg and respectively 156.4 mg/kg. This demonstrates that the phosphate rock with its apatite structure contains several trace elements including radioelements. [12]

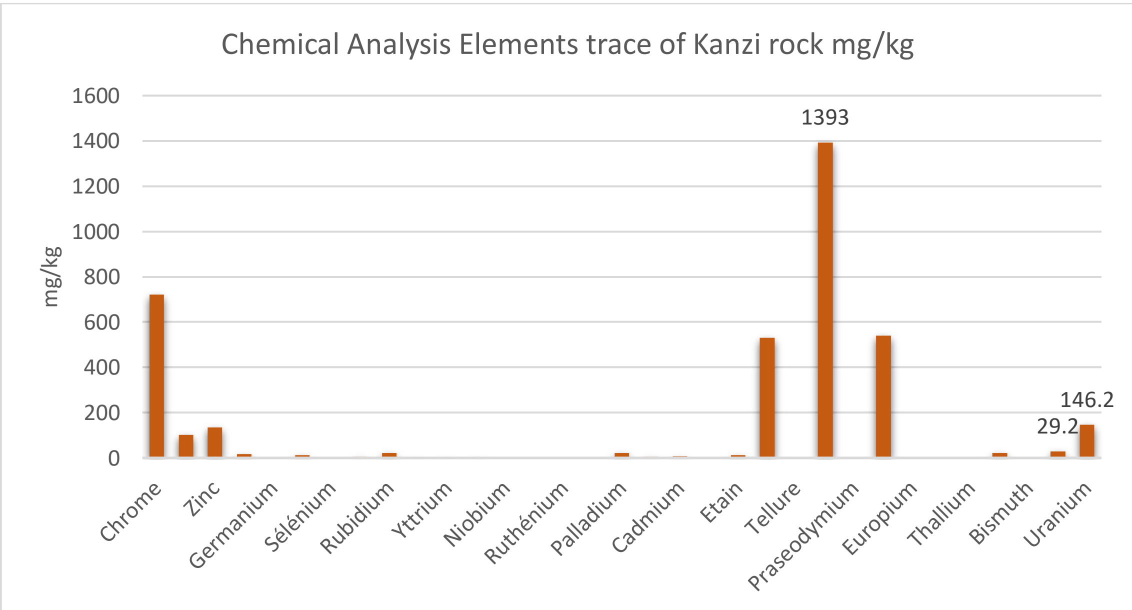

Figure 12*. Histogram of trace chemical elements in Kanzi phosphate rock in mg/kg*

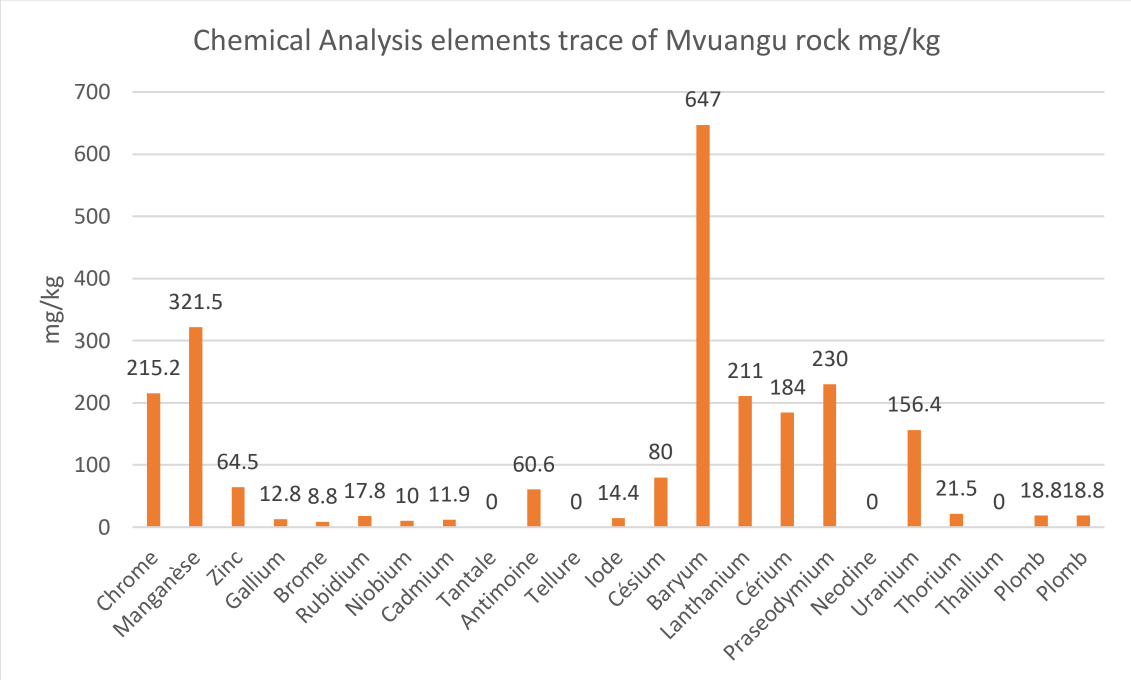

Figure 13. *Histogram of chemical trace elements in Mvuangu phosphate rock in mg/kg*

Bouguer anomaly in the Lemba depression

Once all these corrections have been made, the gravimetric values can be used to calculate the Bouguer anomaly, which is a function of various subsurface anomalies. Note that gravimetric values are measured from the Earth's surface and not from the geoid. Consequently, the theoretical value is calculated in terms of the ellipsoid, taking into account the density of the various materials between the Earth's surface and the geoid. Material density varies between the measurement surface and the reference surface.

To make the measurements to be comparable, all measurements must be brought back to the same reference plane. It is necessary to make a whole series of corrections. [15-16]. These various corrections lead to define a set of values that characterize the so-called motion anomaly.

The gravity anomaly map of the Lemba sub-basin, where the phosphate sites are located (Figure 14), clearly shows that the phosphates of Kanzi in the south and Mvuangu in the north are not located in the central deposits, but in the upper parts of the sub-basin. These areas are potentially anticlines, geological structures likely to contain hydrocarbons. [16-18]

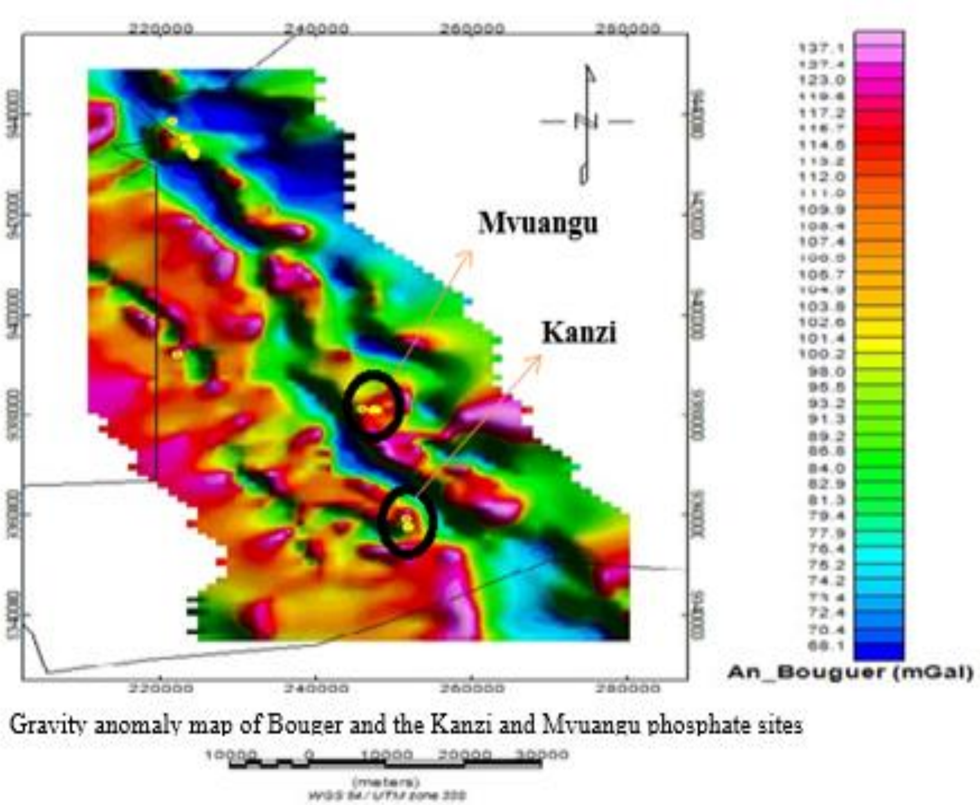

Figure 14*. The gravity anomaly map of the Lemba sub-basin, where the phosphate sites are located*

The use of local geological resources, also known as agro-minerals or fertilizing rocks, offers a solution for managing soil fertility in an integrated and adapted way, which can add efficiency to agricultural production [19-21]. For example, rock phosphates can provide phosphorus (P), secondary nutrients (Ca, Mg), and possibly some trace elements (Zn, Mo). Provide phosphorus (P), secondary nutrients (Ca, Mg), and possibly some trace elements (Zn, Mo). However, their agronomic effectiveness is somewhat dependent on the element phosphorus and its chemical reactivity [22-24]. Dependent on the element phosphorus and its chemical reactivity. For optimum recovery, these minerals need to be pre-treated to remove any metallic trace elements and produce concentrates that can be used in the phosphate industry. The obstacle to the exploitation of these deposits could be the radioactive uranium present (146.2-156.4 mg/kg), which could be an environmental problem the obstacle to exploiting these deposits could be the radioactive uranium present (146.2-156.4 mg/kg), which could be an environmental problem. The Congolese government is therefore advised to develop these two geographical phosphate zones not only to benefit from these phosphate deposits.

The very high levels of Fe [Figure 15], compared with other trace metals, in the phosphates of the Lemba sub-basin make it clear that, in the absence of appropriate environmental impact studies in this area, prior mining and oil exploitation will have very harmful impacts, as several trace elements will already be very sensitive without significant anthropogenic input. We will continue our research to verify the behaviour of trace elements in soils and sediments under the influence of phosphate rocks [25-26].

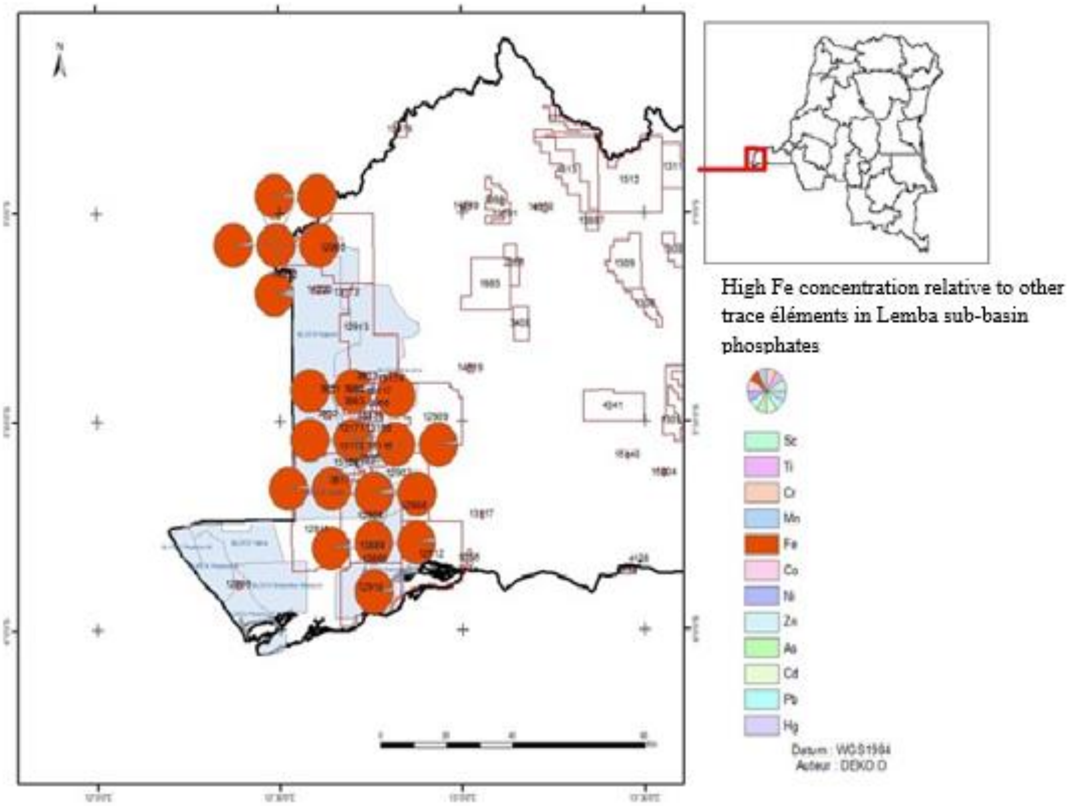

***Figure 15**. Map of elevated Fe content in the Lemba sub-basin*

CONCLUSIONS

The future of the phosphate rock sector at the Kanzi and Mvuangu sites is particularly promising, with Al_2O_3 at 21.21% for Kanzi and 17.24% for Mvuangu, SiO_2 at 14.84% for Kanzi and 30.4% for Mvuangu, and phosphate itself at 19.48% for Kanzi and 13.34% for Mvuangu. These are the dominant oxides in the phosphate rock samples from both sites.

The present study has enabled us to contribute to the geochemical study of the Kanzi and Mvuangu phosphate rocks in the Lemba Sub-basin of Central Congo, their stratigraphic context, their constituent minerals with several trace elements present in the rock. The superposition of the phosphate stations in our gravimetric motion anomaly map suggests structural studies to understand the oil traps in this sub-basin open to exploration.

Given the importance of these deposits for the development of agriculture in the Democratic Republic of Congo and the sub-region, it would be desirable to develop these phosphates by creating a local industry for the production of phosphate fertilizers, while at the same time contributing to job creation, given that mining is one of the main sources of formal employment in Africa.

REFERENCES

[1] Gaffney, Cline & Associates (Consultants) Pte. Ltd., Study on the reserves of the coastal basin of the Republic of Zaire, Study report, 16 p., 1988

[2] Ndumba D.R., Comparative petrographic and mineralogical studies of phosphate rocks from the Kanzi and Mvuangu deposits in Central Congo, DR Congo. 2023

[3] Barry G.S., Evaluation of phosphate deposits in Bas-Zaire, Republic of Zaire. Project, 1981

[4] Kasongo Koy R., Kanzi phosphate rock as a fertilizer with amending properties for sandy soils in the Kinshasa Hinterland (DR Congo). (2010)

[5] Deko Oyema B. et al., The study of surface showings in and around the Lotshi block in the coastal basin of the Democratic Republic of Congo, Open Journal of Yangtze Oil and Gas, 7, 84-100, 2022

[6] Wetshondo Osomba D., Characterization of Carbonate Rocks of the Nganzi Oil Exploration Block (Onshore DR Congo Coastal Basin). Open Journal of Yangtze Oil and Gas, 7, 149-165. 2022

[7] Surestream RDC, Exploration of the petroleum potential of the Yema and Matamba-Makanzi blocks; COPE 1 presentation. 2010

[8] Ashton P.R., Effective exploration of remote areas of Western DR Congo, Historical context on the Nganzi block; Presentation on behalf of SOCO International plc., 2010

[9] Boulvain F., Elements of Sedimentology and Sedimentary Petrology. Lab. Sedimentary Petrology, University of Liège, Belgium, 29p., 2017

[10] Van Staaten P., Agrogeology: The use of rocks for crops. Enviroquest Limited. Cambridge, Ontario, Canada. 2007

[11] Vualu Ibula Mambenga P., Approach to geochemical and geo-environmental characterization of a mining project in the context of a naturally high and/or anthropogenic geochemical background: Application to the Siscoe-Sullivan-Marban mining sectors, Val-d'Or, 2020

[12] Parr J., Yeats C., Binns R., Petrology, trace element geochemistry and isotope geochemistry of sulfides and oxides from the Pacmanus hydrothermal field, Eastern Manus Basin, Papua New Guinea. In CJ Yeats (Ed.), Seabed Hydrothermal Systems of the Western Pacific (pp. 53-57). Csiro exploration and mining report 1112F. 2003.

[13] Branoiu G., Dinu F., Stoica M.E., Suditu S., Ramadan I., About the Chemico-Mineralogical Characteristics of the Rocks from a Natural Gas Deposit in North-Western Romania, REV.CHIM. (Bucharest), 71 (9), 251-259, 2020.

[14] FAO, Use of Natural Phosphates for Sustainable Agriculture Joint FAO/IAEA Division, Rome. 2004

[15] Jacobsen B.H., A Case for Upward Continuation as a Standard Separation Filter for Potential-Field Maps. Geophysics. Vol.52, iss.8, 1033-1165, 1987

[16] Reyre D., Petroleum characteristics and geological evolution of a passive margin. The case of the Bas-Congo-Gabon basin. Build Ed. Research Centers. Explor. - Prod. Elf-aquitaine, Vol. 8, no.2, 332p. 1984

[17] Suresh G., Sutharsan P., Ramasamy V., Venkatachalapathy R., Assessment of Spatial Distribution and Potential Ecological Risk of the Heavy Metals in Relation to Granulometric Contents of Veeranam Lake Sediments, India. Ecotoxicol. Environ. Saf., 84, 117-124. 2012

[18] Congo Mines, Monograph on the possibilities for developing subsoil resources classified as "Mining Resources" in the Congo Central province. 2016.

[19] El Bamiki R., Geological study of phosphate occurrences in the Moroccan High Atlas: Understanding the geological controls on the accumulation of phosphate. Thesis, Université Montpellier, 2020

[20] Baize D., Trace elements in soils, geochemical backgrounds, natural pedogeochemical backgrounds and usual agricultural contents definitions and uses. INRA Environmental Courier, 57, pp. 63-73. 2009

[21] Zhang, J., Liu, C.L., Riverine Composition and Estuarine Geochemistry of Particulate Metals in China—Weathering Features, Anthropogenic Impact and Chemical Fluxes. Estuar. Coast. Shelf Sci., 54, 1051-1070. 2002.

[22] Verhaert, V., et al., Baseline levels and trophic transfer of persistent organic pollutants in sediments and biota from the Congo River basin (DR Congo), Environ. Int. 59, 290–302. 2013.

[23] Thevenon, F., Guédron, S., Chiaradia, M., Loizeau, J.-L., Poté, J., (Pre-) historic changes in natural and anthropogenic heavy metals deposition inferred from two contrasting Swiss Alpine lakes, Quaternary Science Reviews, 30(1-2), 224-233, 2011

[24] Thevenon, F., Poté, J., Water pollution history of Switzerland recorded by sediments of the large and deep Perialpine Lakes Lucerne and Geneva. Water Air Soil Pollut. 223, 6157–6169, 2012

[25] Teisserenc P., Villemin J., Sedimentary Basin of Gabon-Geology and Oil Systems. In: Edwards, J.D. and Santogrossi, P.A., Eds., Divergent/Passive Margin Basins, Volume 46, American Association of Petroleum Geologists Memoir, 117-199. 1989

[26] Adler, A., Devarajan, N., Wildi, W., Pote, J., Metal distribution and characterization of cultivable lead-resistant bacteria in shooting range soils. Soil Sediment Contam. An Int. J. 25, 378-394. 2016

Received: May 2024; Revised: July 2024; Accepted: July 2024; Published: July 2024