CHARACTERIZATION, POTENTIALITY AND RECOVERY OF HIGH VALUE-ADDED ORES LOST IN GOLD PANNING IN THE VAVATENINA DISTRICT

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ABSTRACT

Madagascar is one of the countries rich in natural resources, particularly mining resources. However, then as now, this mineral wealth has not brought the development required for the country and the well-being of the population, which is a flagrant paradox. The mining sector is one of the country's growth sectors through the large mines.

On the other hand, small-scale mines managed by small-scale miners are not part of it. Their means of production are archaic, manual and of low productivity, but they are of particular importance in their respective areas of intervention: they absorb unemployment, rural poverty and the reduction of rural exodus.

The Vavatenina district, which is a well-known gold mining area in the Analanjirofo region, attracts a large influx of people for artisanal gold mining. The urban commune of Vavatenina and the rural communes of Ambohibe and Miarinarivo are the most affected by this activity. It is also the study area for this research work.

Artisanal gold miners use the gold panning method. The pan is the appropriate tool for extracting gold from the other components (sand, earth, ore) associated with it. Handling the pan requires strength and perseverance and it is during gold extraction operations where many high value added minerals are lost. The minerals recovered will enable the operators to improve their living conditions, to develop the area affected by the activity and by ricochet to consider this sector (small mine) as one of the country's growth factors.

The research work carried out aims to characterize and quantify the minerals associated with gold during gold extraction by tapping. The methodology adopted for the realization of this research work is both qualitative and quantitative. Its concretization at term requires a priori by the passage through the chronological order of the following activities: the capitalization of the data relating to the artisanal gold industry, the descent in the study area to carry out surveys on the mining industry and collect samples (soil, sand, rock) in 13 primary and secondary deposits (alluvium, eluvium, ...) finally, the analysis of these samples to detect the various minerals associated with gold. X-ray fluorescence spectrometry (XRF) is the appropriate technology. The method of analysis by Turbo Quante-pellets Powder is one of the simplest, the most precise and the most economic analytical methods practiced for the determination of the chemical composition of ores detected there and which also made it possible to obtain the result of qualitative and quantitative Analyses relating to the AFC (Corresponding Factory Analysis) and the ACP (Analysis in Principal Components).

Forty-eight (48) ores of different concentrations were identified. Manganese, Vanadium and Yttrium are the most abundant minerals in all the samples with a respective concentration of 47.22%, 37.12% and 37.900%. Heavy metals are also present: Mercury, Cobalt and Nickel in interesting quantities in terms of beneficiation.
Research work aimed at recovering these ores using simple, mechanized equipment within the reach of small gold miners' stock exchanges is underway

Keyword: *gold deposit, Fluorescence X, artisanal mining, Vavatenina.*

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1. INTRODUCTION

Globalization is leading to changes in relations between States. The increase in the world demand for minerals is leading multinationals from the major industrial countries, but also from emerging countries, to look for new mining deposits to exploit. This is changing the landscape of mineral resource exploitation, without having a positive influence on development in general and on the fight against poverty in African mining-producing countries, including Madagascar in particular. This activity probably involves at least 15 million people in the world today, almost twice as many as ten years ago. For the African continent alone, between 4.5 and 6 million workers are concerned, 30% to 40% of whom are women and maintain nearly 40 million dependents, i.e. 1 African in 20 (Jaques & Zida, 2004).
The district of Vavatenina is among the gold regions of Madagascar with alluvial and eluvial plazas (Blanchot, 1978; Yarmoluk et al, 1980 and Bournat et al 1985). Small-scale or small-scale mining, often informal, plays an important role in gold mining. Gold panning is the main economic activity of the majority of the population, especially in rural areas where living conditions are often deplorable. The urban commune of Vavatenina and the rural communes of Ambohibe and Miarinarivo are the most affected by this activity. The most exploited deposits at present are: raised ancient alluvial deposits, bank alluvial deposits, swampy flats and river sands.
There are several reasons why the local population has decided to carry out this artisanal gold mining activity, among others : the demographic growth in the District of Vavatenina which increased from 221,625 to 305,399 inhabitants from 2008 to 2012, a growth rate of 0.2% per year (PCD CU Vavatenina, 2012), the intensification of the average poverty rate from 65% in 2008 to 76.5% in 2010, the low household income source forcing the population to find other alternatives a new source of income and finally the political crisis in the country in 2009.
Artisanal gold mining is a seasonal occupation where the products obtained are more or less profitable, random or even hazardous, and gold panners can be winners or losers. To deal with this situation of gold panners, i.e. to make their trade profitable, it is not enough to extract only the gold, but also to recover the minerals that accompany it during its extraction by panning. Questions arise, among others:
- Which minerals are associated with the gold during the panning operation?.
- How can these minerals be recovered from the gold?
- The majority of gold panners do not have a sufficient level of education or appropriate training in mining and how will they be able to detect and recover them?

The simultaneous recovery of gold and associated minerals has direct impacts not only on the socio-economic conditions of the miners but also on the local development of the mining area.
The purpose of this research work is to characterize and determine the quantity of minerals present in samples taken from primary and secondary deposits in the Vavatenina district using total reflection X-ray fluorescence technology.

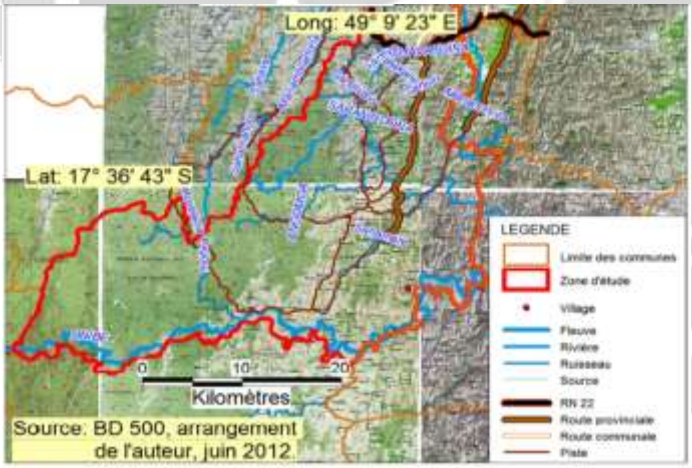
2. METHODOLOGIES

2.1. Study area: District of Vavatenina, Madagascar

The District of Vavatenina belongs administratively to the former Autonomous Province of Toamasina. It is located in the southern part of the Analanjirofo region and covers an area of 2,926km². It is the only district of the Analanjirofo region which does not have the seaside area. It is delimited in the North and in the East by the District of Fénérive-Est, in the South by the District of Toamasina II, in the West by the Districts of Amparafaravola and Ambatondrazaka. The chief town of the District of Vavatenina, is located 45 km south-east of Fénérive-Est. It is connected to the latter by the RN5 and then by the RN22.

Figure 1: Presentation of the map of the ex-province of Toamasina

The study area is located in the District of Vavatenina, in particular in the Rural Municipalities of Vavatenina, Ambohibe and Miarinarivo. These Communes, in the shape of a bell opening to the south, are separated from each other by a 25 km seasonal provincial road from the District capital: Vavatenina. The study area is located at latitude: 17°36 ′43″S and longitude: 49°9′23″E.



Source: BD 500, arrangement de l'auteur, juin 2012

Figure 2: Presentation of the Vavatenina District Study Area Map

2.2 General information on X-rays

X-rays are electromagnetic radiation of high frequency and short wavelengths.

2.2.1. Definition and production of X-rays

X-rays are electromagnetic radiation between 0.05 and 100Å. They are defined by their mode of production. They are emitted by the bombardment of the surface of a solid by cathode rays which are electron beams accelerated by voltages varying between 103 and 106V.

The range of X-rays is limited on the long wavelength side because the absorption of X-rays by the material is proportional to the wavelength. Thus, soft rays become very difficult to use and detect as the wavelength increases.

At shorter wavelengths, very high voltage sources are needed to produce X-rays called hard rays. X-rays overlap with gamma rays, which are electromagnetic radiation emitted by certain radioactive atoms. There is a big difference in the production of gamma rays and X-rays. Gamma rays are emitted from the nucleus of the atom while X-rays come from processes that occur in the orbits of electrons. Two sources of X-rays in X-ray fluorescence spectrometry are practically used.

X-ray tubes that use electron bombardment.

Radioactive elements that use gamma rays emitted from the nuclei of these elements.

There are other means of production, such as synchrotron radiation (particle accelerators) or proton-induced X-ray emission.

2.2.2. X-ray tubes

The usual source of x-rays is the Coolidge tube. It is a vacuum tube with two electrodes:

An emitting cathode, negatons are emitted by a tungsten filament heated by current, they are then accelerated by a high voltage and focused on a water-cooled metal target (anode).

An anode, or anticathode, which is a metallic mass raised to a positive potential.

The X-ray tube also has a window of such a nature that it does not absorb too much of the emitted X-rays.

Under the effect of electron bombardment, the atoms of the anticathode will be excited and then return to their ground state by re-emitting X-ray photon radiation. This radiation corresponds to the excess energy (called X-rays)

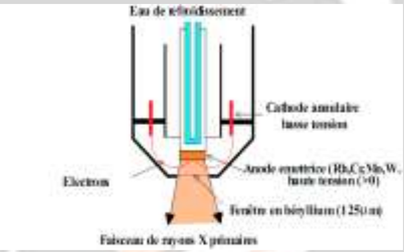


Figure 3: X-ray tube

Two quite distinct phenomena are at the origin of the nature of the X-rays produced:

- The emission of the continuous spectrum: the emission spectrum consists of a set of radiations whose intensity varies in a continuous way with the wavelength.
- The emission of characteristic lines: to the continuous spectrum is superimposed a spectrum of lines whose wavelengths are independent of the operating conditions of the tube and depend only on the nature of the anticathode.

2.2.3. Continuous spectrum

The continuous spectrum results from the energy loss of the colliding electrons colliding with the weakly bonded electrons of the target. The continuous background has the following characteristics :

- It appears regardless of the potential difference inside the tube.

- The continuous spectrum has a lower limit in wavelength. The spectrum starts abruptly at this wavelength, which does not depend on the anode material but follows the Duane-Hunt relationship :

$$h\,\nu_0 = \frac{hc}{\lambda_0} \qquad \textbf{(2.1)}$$

Avec

$h = 6{,}626.10^{-34}$ J.s^{-1} : Planck's universal constant

$c = 3.108$ m.s^{-1} : speed of light

λ_0 : frequency associated wavelength

$h\,\nu_0$: Photon energy expressed in [eV].

Relation (2.1) shows that the energy of the radiation in the emission spectra can never be greater than the kinetic energy of the electrons hitting the target. It can be written as

$$E = h\nu = \frac{12,398}{\lambda} \tag{2.1}$$

This relation is valid if the energy E is expressed in electron-volt [eV] and the wavelength λ in [Å].

2.2.3.1. Radioactive sources

When a monochromatic source is required, radioisotopes must be used because of their stability and small size. Some radioactive atoms are monochromatic radioactive sources. These are less intense than the characteristic emissions from an x-ray tube. The monochromatic nature of most radioactive sources makes them advantageous for the selective excitation of certain elements.

Often, the technique of secondary X-ray fluorescence is used with such sources. This technique involves causing the X-ray emission of a target subjected to gamma radiation from the radioactive source. The radiation characteristic of the atoms of the target causes the X-ray fluorescence of the sample. The choice of radioactive sources depends on the energy of the photons hν emitted and the half-period of the radioelement. The different sources most commonly used are shown in Table 1.

Table 1. Some radioactive sources with their period or half-life

Sources	Period	Disintegration mode
$^{241}_{95}\mathrm{Am}$	470 years	Emission α
$^{109}_{48}\mathrm{Cd}$	455 days	C.E.O
$^{55}_{26}\mathrm{Fe}$	2,7 years	C.E.O

2.2.3.2. X-ray properties

X-rays are electromagnetic waves. It embodies the duality of the wave and the corpuscle. Its wavelengths range from 10-5 to 100 Å.

Due to its corpuscular properties, there are phenomena of photoelectric absorption, incoherent scattering (wavelength modification), ionization of gases, scintillation production.

By its undulatory properties, there is a speed of propagation: c. Scattering, reflection, diffraction, polarization and coherent scattering are considerable.

2.2.3.3. Interactions of X-rays with matter

The interactions of X-rays with matter are complex. When an x-ray beam penetrates a materialized medium, a gradual decrease in its intensity (or energy) is observed. This decrease is due to the interaction of x-rays (photon) with matter (negaton). The lost energy is found in two forms:

- a part of the energy is absorbed by the matter (medium)
- the other side is scattered.

Figure 4 shows a simplified diagram of the interaction of x-rays with matter.

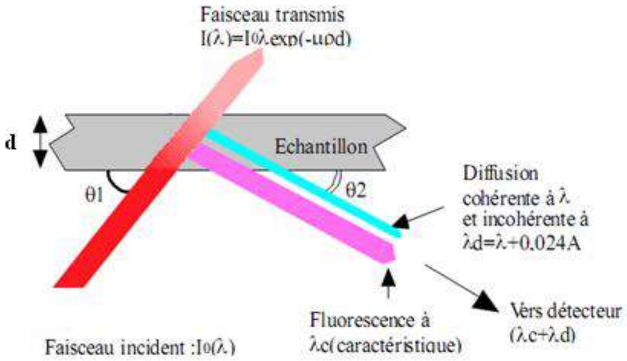


Figure 4: Interaction of X-rays with matter

In this figure, "d": represents the thickness of the sample.
When an X-ray beam passes through a material of thickness: x, specific mass: ρ, incident intensity : I_0 , is attenuated according to Beer-Lambert's law:

$$dI/I = -\mu\, dx$$

- -μ. dx represents the attenuation of the beam through a dx thickness;
- μ is the linear absorption coefficient ;
- the minus sign (-) indicates that the intensity is always decreasing as it passes through the material.

2.3 Theory of the energy dispersive X-ray fluorescence analytical method

X-ray fluorescence is a spectroscopy8 that involves internal transitions of negatons. Indeed, the negatons surrounding the nucleus successively fill the layers K, L, M, N according to the value of the main quantum number: n. Whatever the atom considered, the energy of the internal negatons is high and decreases from the nucleus to the peripheral layers. To expel an internal negaton from the orbit of the atom, an excitation energy higher than the binding energy of the negatons is required. In X-ray fluorescence spectroscopy, this expulsion is caused by an X-photon.

2.3.1. Principle of X-ray fluorescence

When a photon of sufficient energy tears an electron from the inner layers of an atom, this atom will thus find itself in an unstable state. The atom will regain its stability by internal rearrangement where the negatons coming from the outer layers will fill the hole. The difference in energy between the initial and final layers of the negaton is released by the atom in the form of high energy electromagnetic radiation (X-photon). The spectrum of electromagnetic radiation emitted during this process reveals a number of characteristic peaks. The peak energies allow us to identify the elements present in the sample (qualitative analysis) while the peak intensities provide the concentration of the elements (quantitative analysis).

2.3.2. Different types of X-ray fluorescence analysis

There are two types of X-ray fluorescence analysis.

- energy dispersive X-ray fluorescence analysis (EDXRF) ;
- wavelength dispersive X-ray fluorescence (WDXRF) analysis.

2.3.2.1. Energy dispersive X-ray fluorescence analysis

Energy dispersive X-ray fluorescence analysis is based on the direct determination of the energy of the lines collected by the detector. This type of analysis is suitable for direct excitation X-ray fluorescence analysis of solid samples where a secondary target (homogeneous plate) is inserted between the X-ray tube and the sample to be analysed. The X-rays coming from the tube excite the secondary target and the secondary target emits its characteristic lines which in turn excite the sample. Therefore, this method is used in the experimental part for the analysis of crayfish samples.

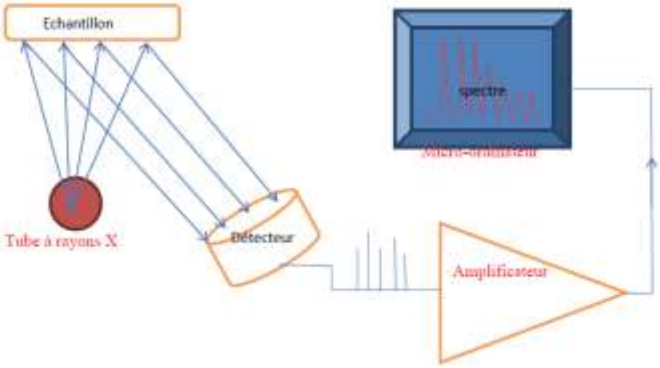


Figure 5 Energy dispersive X-ray fluorescence spectrometer

2.4. Laboratory work

2.4.1. Sampling procedure

Since the samples are solid ores processed into powder, their preparation procedures include the following six steps:

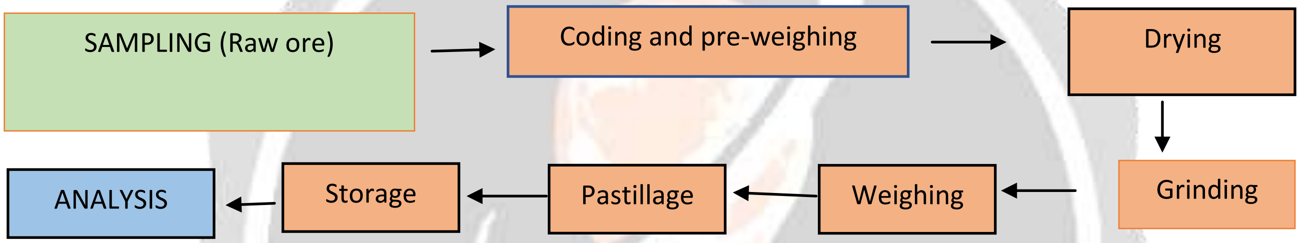


Figure 6. Sample preparation process

2.4.2. Sampling locations

Soil, sand and rock samples were taken at 13 different points (P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12 and P13), ten of which came from the secondary deposit (four alluvial and six eluvial deposits) and three from the primary deposit.

Figure 7: Satellite image of the location of the sampling sites

2.4.3. Sample coding

Prior to electric oven drying, the samples were coded at the sampling site before analysis at the INSTN laboratory to better distinguish and weigh for water loss. Soil, sands and ore blocks were coded as required. The table below contains all the information and measurements obtained from the sampling.

Table 2. Sampling and coding

Code	**Location**		**Date and time**	**Contact geographic**		**Depot type**	**Deposit**
	Village	**Commune**		**Latitude**	**Longitude**		
E01GSA	Ambodiovitra Nord	Ambohibe	14/10/16 à 9h	17°24′37,8″S	49°04′41,3″E	Secondaire	alluvionnaire
E02GSA	Ambodiovitra Sud	Ambohibe	15/10/16 à 15h	17°24′47,0″S	49°04′34,2 E	Secondaire	alluvionnaire
E03GSE	Ambodimanga Nord	Ambohibe	15/11/16 à 14h	17°25′49,2″ S	49°06′32,5″E	Secondaire	éluvionnaire
E04GSA	Mahanoro	Vavatenina	16/12/16 à 10h	17°27′25,2″S	49°09′24,5″E	Secondaire	alluvionnaire
E05GSE	Ambolofotsy	Vavatenina	28/1216 à 17h	17°26′50,8″S	49°09′24,5″E	Secondaire	éluvionnaire
E06GP1	Betsakotsako	Miarinarivo	04/01/17 à 9h	17°37′52,6″S	49°04′29,8″E	Primaire	Montagne
E07GP2	Betsakotsako	Miarinarivo	25/01/17à 14h	17°40′13,3″S	49°10′33,6″S	Primaire	Montagne
E08GP3	Betsakotsako	Miarinarivo	10/02/17 à 13h	17°46′10,6″S	49°18′34,9″E	Primaire	Montagne
E09GSA	Bongarano	Vavatenina	10/08/18 à 11h	17°28′13,6″S	49°09′43,6″E	Secondaire	alluvionnaire
E10GSE	Ambalahady	Vavatenina	18/08/18 à 17h	17°29′24,6″S	49°29′46,8″E	Secondaire	éluvionnaire
E11GSE	Tanambiavy	Vavatenina	30/08/18 à 9h	17°28′44,6″S	49°06′24,2″E	Secondaire	éluvionnaire
E12GSE	Ambalafary	Vavatenina	09/09/18 à 15h	17°28′64,3″S ,	49°08′692″E	Secondaire	éluvionnaire
E13GSE	Miandravato	Vavatenina	21/08/18 à 13h	17°24′13,6″S	49°05′46,4″E	Secondaire	éluvionnaire

2.4.4. Data processing

The following analyses were chosen to process the data: Analysis of Variance (ANOVA), Correspondence Factor Analysis (CFA) and Principal Component Analysis (PCA). They are applied to the results obtained from all the mineral elements detected by X-ray fluorescence spectrometry with a concentration of mg/kg, distribution of minerals in the sampling locations per sample.

2.4.4.1. Analysis of variance

Analyses of variance were performed on the mineral elements. The objective of this analysis method is to determine whether the "treatment" effect is "significant" at the risk of error or at the probability threshold (5%). The XLSTAT software has been used. It allows to perform analyses of variance on the most common types of experimental designs (total randomization, block factorial designs...). The notion of the significance of the difference at the 0.05 probability threshold is the following:

- The difference is non-significant (NS) when the observed probability of the Fisher test (F) is greater than 0.05 ;
- The difference is significant (S) when the observed probability of F is between 0.01 and 0.05 ;
- The difference is highly significant (HS) when the observed probability of F is less than 0.01.

The means of the values of the study parameters obtained after testing were plotted using a histogram. According to the Newman-keuls test that was applied, the means followed by the same letter constitute a statistically homogeneous group at the 5% threshold.

2.4.4.2. Correspondence Factor Analysis (C.F.A.)

Factor Correspondence Analysis is a method of data analysis used when the variables to be studied are qualitative or both qualitative and quantitative in nature. In this study, the variables are the different study sites and the individuals are the mineral elements. The purpose of this method is to graphically represent the relationships between the study sites and the mineral elements and to highlight the characteristic minerals of each sampling site. Factor Correspondence Analysis consists in drawing up a contingency table on Excel from the lists of minerals of the different sampling sites or exploitation sites. It is a double entry table where the rows correspond to the samples and the columns to the minerals. Species present in a sample have been coded as "1" and absent minerals have been coded as "0". The analysis was performed using XL-STAT 8.2 software and the results are in the form of a factorial design.

The interpretation of the factorial design takes into account the proximity of the points, the shape of the scatterplot and the significance of the axes. Only species with a high contribution to the axis are shown in the figure.

2.4.4.3. Principal Component Analysis (P.C.A.)

To determine the origin of sand, soil and rock variability from X-ray fluorescence spectrometry data, Principal Component Analysis or PCA is the appropriate statistical tool. PCAs are performed on XLSTAT PRO software.

The simultaneous study of a large number of quantitative variables from several individuals represented in a space larger than 2 is difficult. The objective of PCA is to represent globally and graphically all these complex data in a space of 2 dimensions with the least possible distortion of reality.

Indeed, the PCA will allow the projection of a data matrix with "n" dimensions on a 2-dimensional factorial plane with the first factorial axes called principal components that will retain a large part of the variability of the data set (Jolliffe, 2002).

Subsequently, the interpretation of these graphs will allow an understanding of the structure of the spectral data being analyzed. The PCA of the spectra was performed to investigate how the samples were grouped together. This was done on the basis of the spectral characteristics of the samples corresponding to the characteristics of the minerals.

3. RESULTS

X-Ray Fluorescence Analysis Results

The concentration displayed on the screen is noted X in mg.l-1 of solution to get the result in mg per 1000g we proceed to the calculation:

$$C \text{ en } {}^{mg}/100g = \frac{X.10^{-3} \times \text{dilution} \times V \times 100}{\text{Sample mass}}$$

Based on the analysis, forty-eight (48) mineral elements were detected in the thirteen (13) samples analyzed by the Turbo Quante-pellets powders method. These elements are listed in the tables below. The study range concerns the mineral elements with Z atomic numbers ranging from 11 to 92. A measurement on the samples gives the concentrations mentioned in the following table where the columns indicate the sample and the rows show the elements detected. The concentrations are expressed in milligrams per kilogram (mg/kg) or as a percentage. The results show that the soil, sand and rock samples taken from the different sites contain mostly Manganese, Vanadium and Yttrium. The trace elements present are Sodium, Magnesium, Aluminum, Silicon, Phosphorus, Sulfur, Chlorine, Potassium, Calcium, Titanium, Vanadium, Chromium, Manganese, Iron, Cobalt, Nickel, Copper, Zinc, Gallium, Germanium, Arsenic, Selenium, Bromine, Rubidium, Strontium, Yttrium, Zirconium, Niobium, Molybdenum, Silver, Cadmium, Tin, Antimony, Tellurium, Iodine, Cesium, Barium, Lanthanum, Cerium, Praseodymium, Neodymium, Erbium, Ytterbium, Hafnium, Tantalum, Tungsten, Mercury, Thallium, Lead, Bismuth, Thorium and Uranium. But there are also other elements which are Silver, Antimony, Cesium, Mercury below the limit of spectrum detection by Turbo Quante-pellets powder.

4. DISCUSSION

4.1. Discussions of Elements in Samples

The results of the Quante-pellets powders turbo analysis are presented in both spectrum and tabular form.

To facilitate the analysis of the results, we will classify our views on three (03) artisanal gold deposits and by class of samples:

- Alluvial secondary deposit (GSA): Samples in the alluvial deposits are found either on the river bed, the river bank and in the bottom of the rice field. The samples analyzed are the sands. The results obtained after the X-ray fluorescence analysis are classified by E01GSA, E02GSA, E04GSA and E09GSA (secondary alluvial deposit).
- Secondary Eluvial Deposit (SED): Samples on eluvial deposits in the gold layer are covered with lateritic material. The samples analyzed are soils. The results are classified into the following six (06) samples: E03GSE, E05GSE, E10GSE, E11GSE, E12GSE and E13GSE.
- Primary Deposit (PG): The samples in the primary deposits are found in mountainous rocks. The samples analyzed are magmatic rocks. They are composed of three samples: E06GP (1), E07GP (2) and E08GP (3).

4.1.1. Case of the sand sample

4.1.1.1. Spectrum

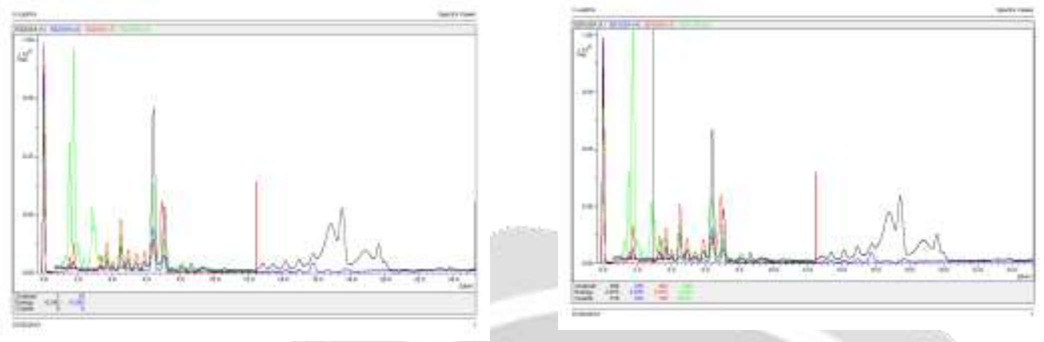


Figure 9. Spectrum of the sand sample, (Graph a) No. E01GSA, (Graph b) No. E02GSA

Thirty-three (33) elements are totally significant in all samples analyzed. It can be said that these elements constitute the Vavatenina gold sand. The quantities of these elements vary according to the sampling location and the category of deposits. The mineral with the highest concentration is Vanadium. The maximum concentration is 1526 ppm and is located in the alluvial secondary gold deposit of Ambodihovitra in the North of Ambohibe Commune. It is to be noted that the chance of 37.120% in the sample E01GSA. After Vanadium, Yttrium and Manganese still in sample E09GSA with 1002 dpi and 22.418% for Yttrium and 940.2 ppm with 21.035% for Manganese. They are located in Bongarano Commune of Vavatenina.

4.1.2. The case of the soil sample

4.1.2.1 Spectrum

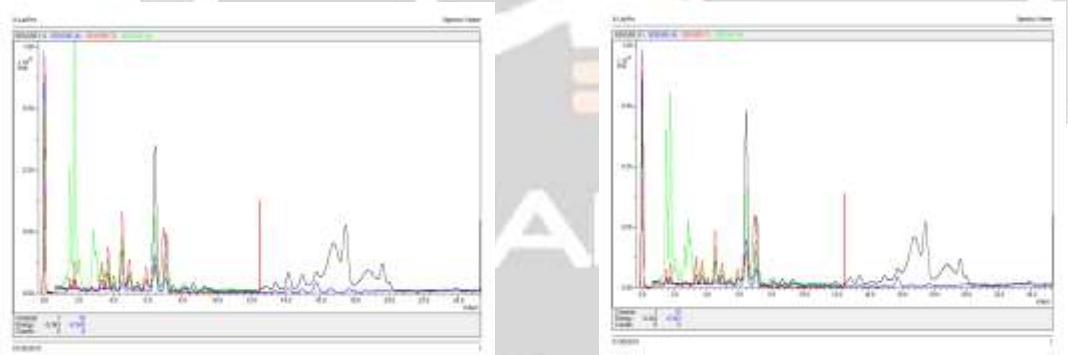


Figure 10. Spectrum of soil sample, (Graph a) No. E03GSE, (Graph b) No. E05GSE,

The eluvial secondary deposit of Vavatenina is composed of thirty-five (35) mineral elements in the 52 elements detected by X-ray fluorescence spectrometry with 100% significance. Manganese is the mineral always present in almost all samples analyzed with a higher quantity compared to other minerals. These high amounts vary from a maximum of 2463 ppm in sample No. E12GSE with 47.222% and a minimum of 421.7 ppm in sample No. E05GSE with 15.361%. The average Manganese concentration in all samples is 1258.36 ppm. These two samples are located in the Ambalafary and Ambolofotsy sites of the Municipality of Vavatenina. After Manganese, Zirconium is the mineral that carries a higher amount with the average concentration of 491.9 ppm in six (06) samples analyzed. The most remarkable quantity is 909.5 ppm in sample No. E12GSE with 17.437%. It is located in the Ambalafary site of the Municipality of Vavatenina.

Yttrium, Cerium and Chlorine have more or less high concentrations in the eluvial deposit of Vavatenina. For Yttrium, the most remarkable rate is 570.8 ppm with 14.259% of the sample No. E11GSE. For Chlorine and Cerium, the most important concentrations are respectively 552.7 ppm with 16.491% of sample No. E05GSE and 458 ppm with 8.781% of sample No. E12GSE.

4.1.3. Case of the rock sample

4.1.3.1 Spectrum

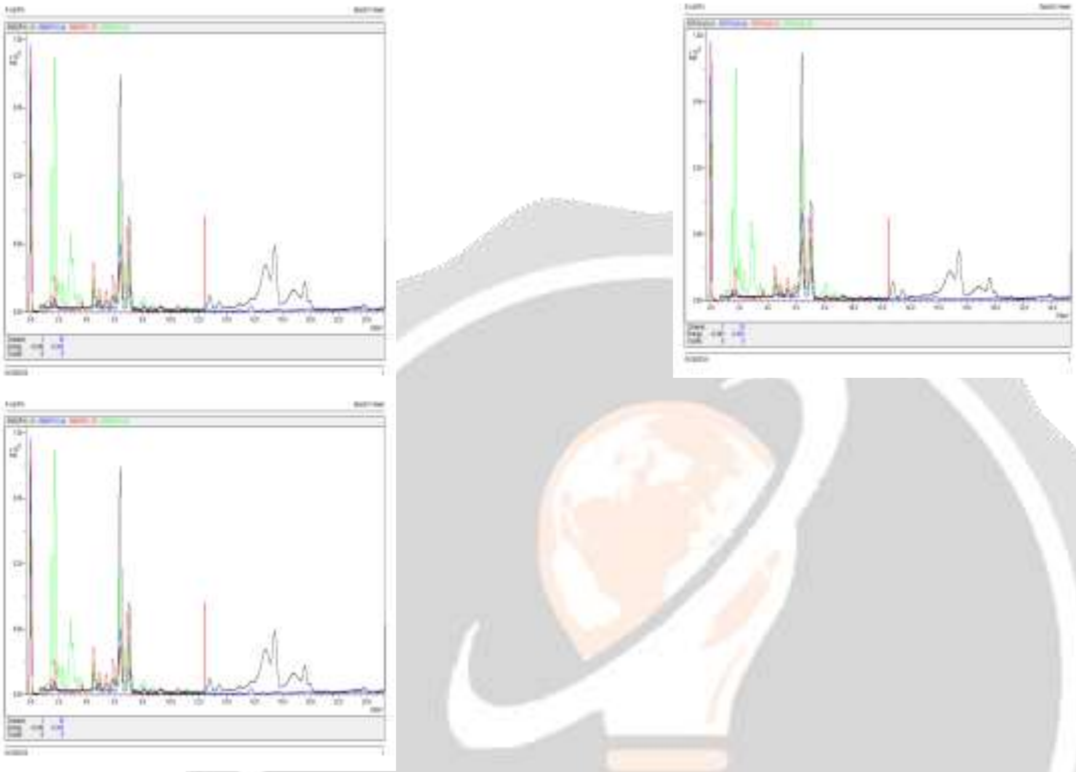


Figure 11. Spectrum of the rock sample, (Graph a) No. E06GP(1), (Graph b)

In the case of a primary deposit, almost the majority of the mineral elements detected by the X-ray fluorescence spectrometry analysis apparatus are present in this deposit with a significance of 84.61% of the detected elements present. Of the 44 elements detected, Manganese is the mineral with the highest concentration. The most remarkable concentration is located in the mining site of Andragazaha Betsakotsako of Miarinarivo Commune in sample No. E06GP(1). The Manganese concentration is 1280 ppm with 48.094% of the sample. Sulphide, Calcium and Vanadium are the minerals with the lowest concentrations after Manganese. These three (03) minerals have about the same value in ppm of which 335.8 ppm with 25.98% in the sample n° E07GP(2) for Calcium; 325.8 ppm with 22.991% in the sample n° E08GP(3) for Vanadium and finally 320.3 ppm with 12.039% in the sample n° E06GP(1) for Sulphide. Potassium has a lower concentration compared to the other minerals which weigh 0.001% in sample No. E08GP(3) and 0.001% in sample No. E08GP(3).

In short, it can be said that these thirty minerals represent the characteristic of the primary deposit of magmatic rock origin in Vavatenina. For the Vavatenina series, their spatial distribution is heterogeneous, especially in Vavatenina municipality itself and in the Angomoa region (Mahavita, 2014).

4.2. Distribution of mineral elements according to the alluvial gold deposit

The analysis of the results of the X-ray fluorescence spectrometry analysis of soil, sand and rock samples at the INSTN's Nuclear and Environmental Physics Analysis Laboratory is aimed at identifying the mineral elements constituting the gold deposit. It was done by applying the Correspondence Factor Analysis (CFA) on the assay results, mineral elements that are distributed in the alluvial secondary deposit, the eluvial secondary deposit and the primary deposit.

The first AFC was made on the global file of presence/absence of 33 mineral elements from the secondary alluvial deposit. The following figure represents the first factorial plan which explains the 78.73% of the total variability.

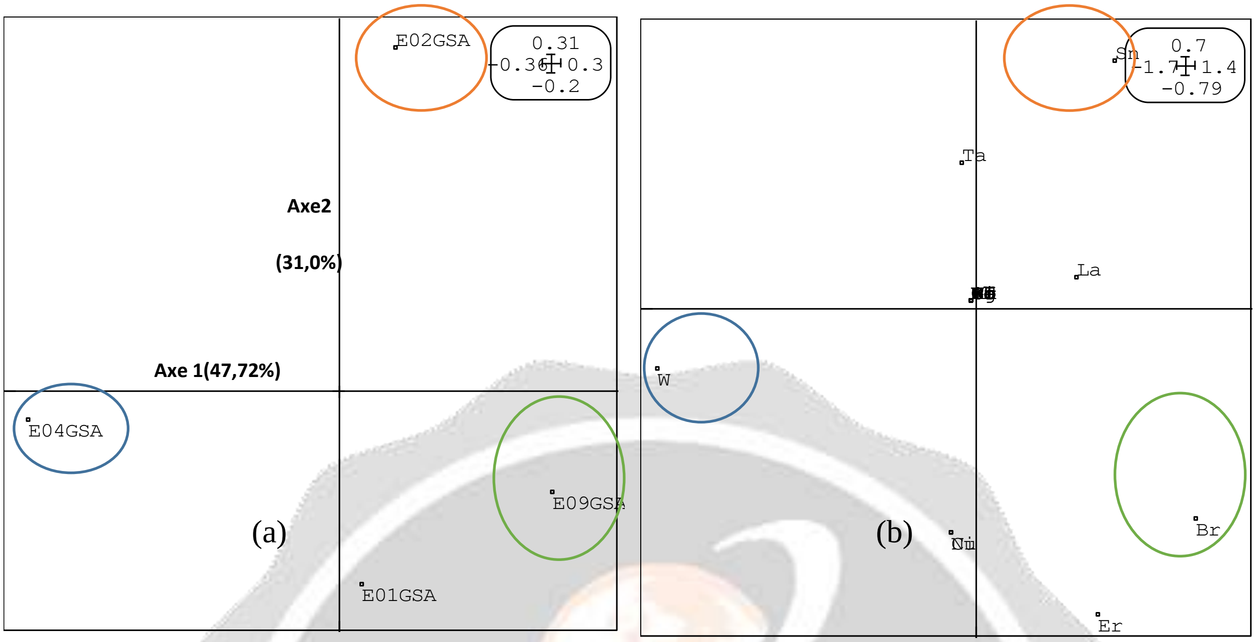


Figure 12. Factor maps in the secondary alluvial deposit, (a) 4 samples and (b) all 33 minerals.

Samples collected in the alluvial deposit type along axis 1 show E09GSA, E02GSA and E01GSA (positive x-axis) and the other samples in the E04GSA deposit (negative x-axis). This distribution leads to interpret this axis as representing the minerals that make up this deposit. The Mahanoro alluvial gold deposit (E04GSA) is characterized by Tungsten ore (w).

Along axis 2 are associated in positive ordinates the ores characteristic of the Ambodiovitra-2 alluvial deposit (E02GSA) such as Tin (Sn) and in negative ordinates the Bongarano alluvial deposit of (E09GSA) Bromine (Br).

The second analysis was performed on the matrix of 06 samples with 35 mineral elements in the secondary eluvial deposit. The results of this analysis are shown in the figure below. Axis 1 and 2 absorb 73.63% of the total variability.

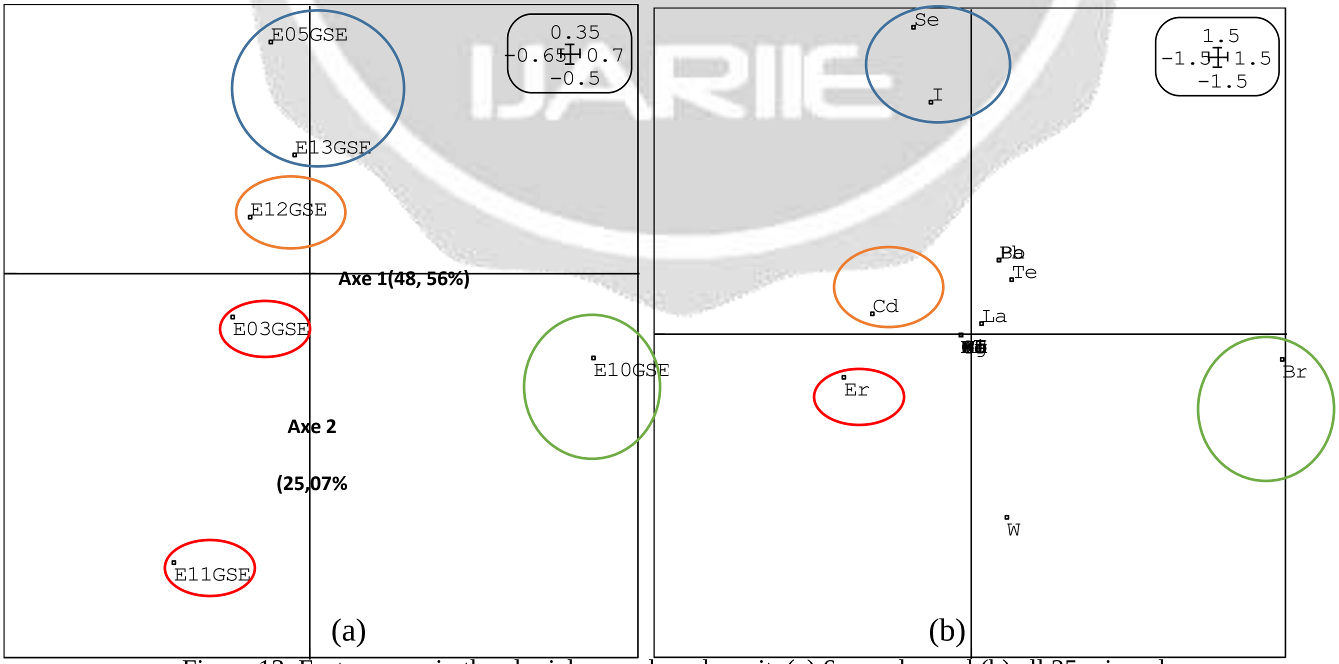


Figure 13. Factor maps in the eluvial secondary deposit, (a) 6 samples and (b) all 35 minerals.

The arrangement of the representative points of the samples : the factorial plans a and b show a very clear representativeness of the minerals in the eluvial deposit (E05GSE, E012GSE and E013GSE) on positive intercepts and the other samples (E03GSE, E10GSE and E11GSE) on negative intercepts.

The 05 samples analyzed are characterized by the following mineral elements: E05GSE and E13GSE (Selenium and Iodine), E12GSE (Cadmium), E03GSE (Erbium) and E10GSE Bromine. The presence of these minerals determines the distinguishing characteristic of the secondary eluvial deposit.

To determine the mineral elements in the primary deposit, the similarity matrix used for the factor analysis consists of 44 elements in rows and 03 samples in columns. The results of this analysis will be detailed in the following figure. Axis 1 and 2 absorb 100% of the total variability.

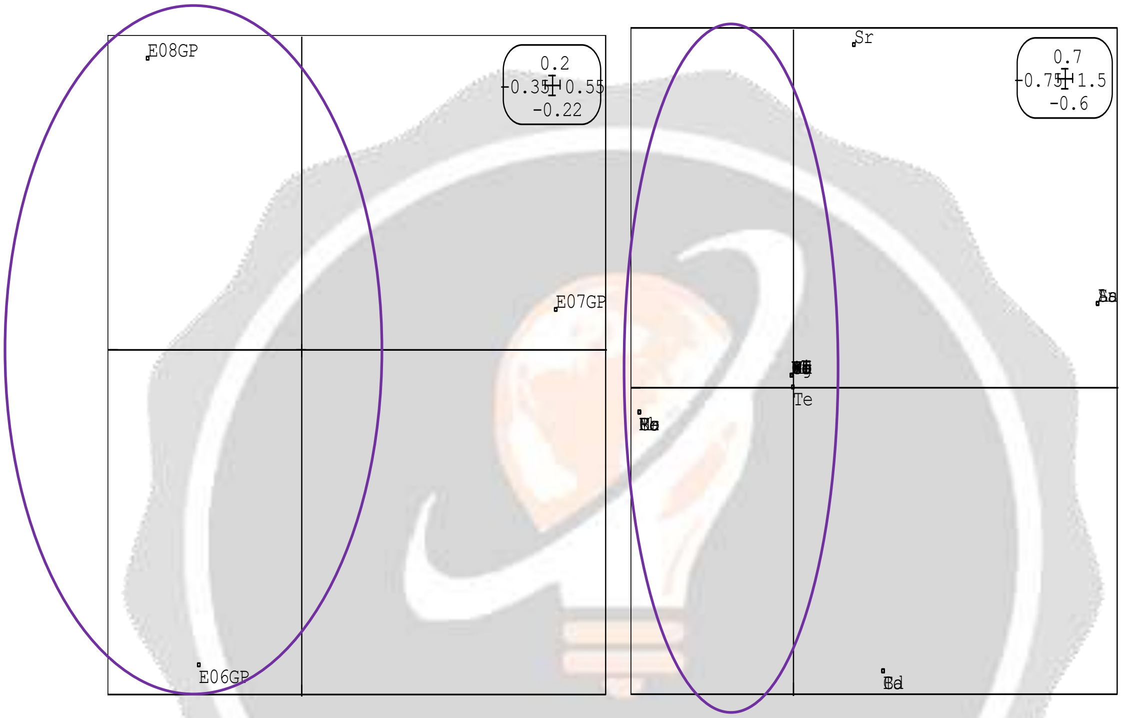


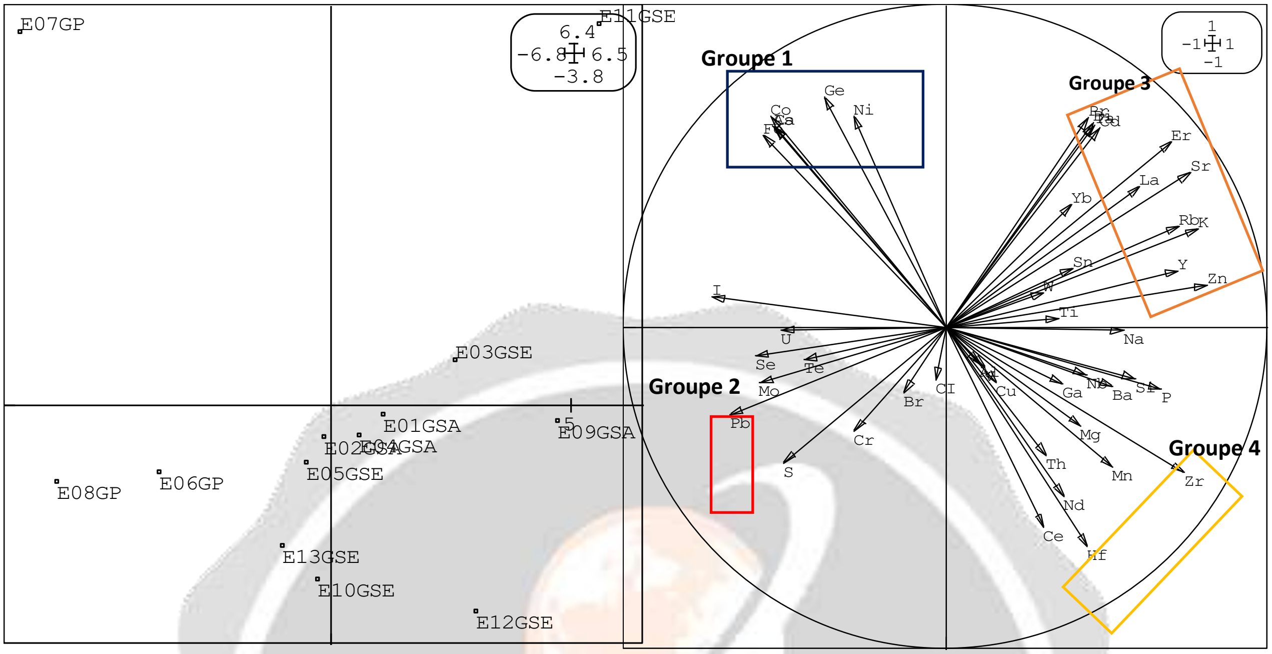
Figure 14. Factor maps in the primary deposit, (a) 6 samples and (b) all 44 minerals.

Axis 1 consists of sample E06GP1 and E08GP1 (negative x-axis) which is characterized by Bromine, Molybdenum, Cerium, and Tantalum as negative x-axis. Axis 1 distinguishes the deposit types in the mountain rock from those of the other samples (positive x-axis) such as Arsenic, Tin and Lanthanum.

4.3. Quantity of minerals in the gold deposit

Principal Component Analysis or PCA has been used to discern the quantities and qualities of minerals in deposits. The contingency table is made up in rows by the samples E01GSA, E02GSA, E03GSE, E04GSA, E05GSE, E06GP1, E07GP2, E08GP3, E09GSA, E10GSE, E11GSE, E12GSE, E13GSE) and in columns by the mineral element variables of soil, sand and rock: Na, Mg, Al, Si, P, S, CI, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Rb, Sr, Y, Zr, Nb, Mo, Ag, Cd, Sn, Te, I, Ba, La, Ce. Pr, Nd, Er, Yb, Hf, Ta, W, Pb, Bi, Th and U. The result of this analysis is detailed in the following figure

The factorial plan absorbs 41.86% of the total information, i.e. 25.57% for axis 1 and 16.29% for axis 2. Figure xx below represents the correlation circle of the different minerals present in the 13 samples. On the x-axis, Yb, Er, Sr, La, Rb, K, Y, Sn, W, Ti, Zn, Na, Nb, Sr, Ba, P, Ga, Cu, Mg, Mn and Zr are correlated on the positive x-axis. The elements correlated in negative abscissa are Y, U, Se, Te, Mo and Pb. On the ordinate axis, Fe, Co, As, Ca, Ge, Ni, Ta, Cd, Bi and Pr are correlated on the positive ordinate and oppose S, Cr, Br, CI, Ce, Hf, Nd, Th, Cu and Al on the negative ordinate. Pr, Bi, Cd, Ta, Re, La, Sr, Rb, K, Y and Zn contribute most to the formation of the x-axis which constitutes the higher amount in E11GSE, and the preponderant factor on this axis opposes the higher amount of Pb on E13GSE. On the other hand, in the positive order axis, E07GP2, which means a higher quantity of Fe, Co, As, Ca, Ge and Ni, on the same axis, Hf and Zr carry a remarkable quantity in E012GSE of the negative order.



(a) (b)

Figure 15. Factor map of samples from different gold deposits (a) and mineral element correlation circle (b)

In summary: Group 1 and 3 is in high quantity in the primary deposit and Group 3 and 4 in the eluvial secondary deposit. Thus the axis of the ordinate which separates the secondary and primary deposit.

In summary, Group 1 and 3 is in high quantity in the primary deposit and Group 3 and 4 in the eluvial secondary deposit. Thus the axis of the ordinate separating the secondary and primary deposits.

5. CONCLUSION

During the experimental work devoted to the determination of mineral elements in soil, sand and rock by the total reflection X-ray fluorescence spectrometry method of analysis, the mineral elements were identified using a high-resolution semiconductor detection chain and assayed by the Spectro X-LabPro software, after the various stages of sample preparation, transforming the sample into a very thin, flat and homogeneous film. The TXRF method requires only a small amount of sample. It has the advantage of being fast, less expensive and has a very high accuracy, but the probability of line emission varies in the same direction as the Z atomic number of the target element. Thus the analysis is restricted to elements between Sodium (Z=11) and Uranium (Z=92). This method is not recommended for the analysis of Gold and Silver.

In this study, 48 minor elements were identified and assayed. Manganese, Vanadium and Yttrium are the most abundant and represent concentrations of 47.222%, 37.120%, 37.900% in soil, sand and rock, respectively.

The total amount of mineral elements is low and varies from sample to sample. Manganese is the mineral with the highest concentration of 2463 mg/kg in E12GSE with 2.5019 g dry element and 1526 mg/kg (E01GSA) Vanadium with 2.5454 g samples. These three mineral elements have the highest concentration and are present in all samples analyzed. Their presence represents the characteristic of the Vavatenina gold deposit.

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