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RESEARCH ARTICLE

Preliminary exploration using pXRF in the Cassinga region

Exploración preliminar mediante FRXp en la región de Cassinga

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Key points:

The four areas studied, Cuíma-Samboto, Chipindo, Jamba and M'Popo-Tchamutete, show the same geochemical behaviour regarding Au pathfinders.

The NE-SW regional direction of structures and associated perpendicular ones were the preferential of hydrothermal fluids transport.

The study is ongoing and the samples collected in Neoarchean formations and adjacent granites are being studied.

ABSTRACT

A study was conducted in the Cassinga region with a portable XRF (pXRF) device to measure chemical elements in soils and rocks. Measurements were made in 318 outcrops and 1638 soils of the area. Four areas part of the Cassinga region were studied: Cuíma-Samboto, Chipindo, Jamba and M'Popo-Tchamutete where chemical elements were reported individually, and a multivariate study was conducted in each area. The main conclusions of this ongoing study are that the group pf elements/oxides such as MnO, Fe2O3,V, Cr, Co, Ni, Zn, Sb and As, corresponds to the pathfinders of Au mineralisations (As and Sb) and basic origin of elements, such as, Cr, Co, Ni and sulphides (Cu, Zn) and confirms enrichment in the four areas studied, Cuíma-Samboto, Chipindo, Jamba and M´Popo-Tchamutete. The geochemical behavior in terms of pathfinders for Au is associated with the major regional direction of NE-SW faults where hydrothermal fluids could have transported Au. Perpendicular structures associated with this major regional direction NE-SW also exhibit high concentrations of this group of elements especially associated with Neoarchean formations of the Jamba and Chipindo groups and in the adjacent limits of the old granites.

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Puntos clave:

Las cuatro zonas estudiadas, Cuíma-Samboto, Chipindo, Jamba y M'Popo-Tchamutete, muestran similar respuesta geoquímica en indicadores de Au.

La dirección regional de estructuras NE-SW y las perpendiculares asociadas fueron preferentes para el transporte de fluidos hidrotermales.

El estudio está en curso y se están estudiando las muestras recolectadas en formaciones Neoarcaicas y granitos adyacentes.

RESUMEN

Se realizó un estudio en la región de Cassinga con un dispositivo FRX portátil (FRXp) para medir elementos químicos en suelos y rocas. Se realizaron mediciones mediante FRXp en 318 afloramientos y 1638 suelos de la zona. Se estudiaron cuatro áreas que forman parte de la región de Cassinga: Cuíma-Samboto, Chipindo, Jamba y M'Popo-Tchamutete y donde los elementos químicos se seleccionaron individualmente y se realizó un estudio multivariado en cada área. Las principales conclusiones de este estudio en curso, basado en esta fase, en mediciones FRXp son que el grupo de elementos/óxidos como MnO, Fe2O3, V, Cr, Co, Ni, Cu, Zn, Sb y As, donde se encuentran los indicadores del Au como (As y Sb) junto con elementos de origen básico como Cr, Co, Ni y sulfuros (Cu, Zn) que confirman enriquecimientos en las cuatro zonas estudiadas, Cuíma-Samboto, Chipindo, Jamba y M´Popo-Tchamutete, donde el mismo comportamiento geoquímico en términos de indicadores de Au está asociado con la dirección regional principal de las fallas NE-SW, donde los fluidos hidrotermales podrían haber transportado Au, aunque las estructuras perpendiculares asociadas con él también exhiben altas concentraciones de este grupo de elementos especialmente asociados con formaciones Neoarcaicas. de los Grupos Jamba y Chipindo y en los límites adyacentes de los antiguos granitos.

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1. Introduction

The Cassinga mining region is located in the center of Angola in the municipality of Jamba, province of Huíla, Angola. The Archean Banded Iron Formation (BIF) associated with bimodal volcanism and the occurrence of polymetallic sulfides in the Cassinga region, probably configuring, in comparison with similar environments, a greenstone belt, as well as the granites intruded in this region, Neoarchean or more recent, were the target of prospecting for Au. In the Cassinga region, the best identified occurrences of Au that were and are the target of exploration are in the secondary environment, in the drainage network occupied by the tributary of the Cunene River, the Cului or Chitanda river and its main tributaries, Calonga, Candombala, Camene and Chinguinde, which had concentrations of Au in their alluvium considered interesting, at the end of the 19th century (Beetz, 1933). Since the beginning of the 20th century alluvial gold was exploited in an erratic way in the Cului and Cuandja rivers is small scale operations (Payne, 1967; Korpershoek, 1970).

This gold district, included in the iron de Cassinga mining region, is now considered an important gold region in Angola. In 1955, Companhia Mineira do Lobito (CML) and Sociedade Mineira do Lombige (SOMIL) abandoned prospecting for primary Au, which was resumed by the same companies in 1966 (McKee, 1975). The knowledge acquired about primary mineralizations and the location of alluvial explorations once again sparked interest in this metal. The increase in knowledge of primary deposits occurred through geochemical prospecting of soils, and through the detailed study of a set of anomalies identified in veins and shear zones (SOMIL, 1967), these being the sources of the Au found in river alluvium. The exploration method to delimite primary gold anomalies was high density soils and stream sediment geochemistry considering that the erosion and flat terrain made difficult to find proper outcrops (Payne, 1967). Primary gold exploration was carried out in quartz veins along the contacts of the greenstones and the granitic intrusions and also in gossans where evidences of copper were also found (Korpershoek, 1970). The gold-bearing veins, veins and shear zones are related to a granite intrusion in contact with green volcanic rocks and because of the installation and circulation of hydrothermal fluids where the presence of pyrite, chalcopyrite and secondary minerals such as covellite and malachite were reported (Korpershoek, 1970).

These veins are distributed randomly in the region but generally have a NE-SW orientation. The richest vein in the M'Popo region was recognized in an anomaly measuring around 600 m in length. Meyer and Saager (1985) consider that Au mineralizations in granite-greenstone belts are epigenetic and related with regional metamorphism that can mobilize and concentrate Au in suitable structures, as it seems to be the case in Cassinga region in comparison with Kaapvaal and Rodesian cratons.

Frimmel (2008) when studying Au production, reserves and resources associated with each genetic type of deposit, concludes that most of the Au concentrated in mineral deposits was added to the continental crust during a giant gold event occurred in the Mesoarchean era (3Ga) when the mantle temperature reached a maximum, and tectonic movements changed from vertical to sub horizontal (Astromineral, 1981).

Viljoen (1969) and Kirk et al. (2002) when studying the gold conglomerates of the basin from Kaapvaal with Re-Os isotopes determined an older age for Au and pyrite present in the conglomerates, than the same conglomerates, confirming that Au would not have been the result of transport by later hydrothermal fluids, but rather, result of the great crustal growth event in which most of the craton Kaapvaal would have been formed, and as evidence of an enrichment in noble metals from the mantle.

This theory favours the origin of the placer genesis, whereas the conglomerates would be originated from the erosion of the gold rich greenstone belt of Archean age and transported in an old river system (Kirk et al., 2003).

Viljoen (1982) refers in his study of several Au mineralizations in southern region of Africa that the primary origin of Au in greenstone belts, generally includes ultramafic rocks at the basis of greenstone belts, followed by mafic (tholeiitic) rocks and after more felsic rocks and on top of the stratigraphy the sediments. The same author states that the break in sedimentation in the stratigraphy of volcanism would have had relevance in the initial concentration of Au, in many cases, with high economic viability. Au occurrences in greenstone belts form in a wide variety of rocks, such as: volcanic rocks, BIF cherts, shales and graywackes and quartzites. They are dominantly epigenetically controlled mineralizations essentially by systems of folds and fractures, denoting behaviors, both ductile, as brittle with metamorphism from amphibolite facies to greenschist. To follow Au mineralization in quartz and carbonate veins is common to have hydrothermal alteration of carbonatization, sulphidization and potassium metasomatism. In BIF, sulfides replace the iron layers (Meyer and Saager, 1985; Anhaeusser, 2014).

A project called PLANAGEO, a 7-year project conducted in Angola between IGEO, Angolan Geological Survey and UTE, a consortium of the Geological Surveys of Spain and Portugal and a company IMPULSO in Angola, developed regional campaigns of geophysics and geology in an area of more than 470000 km^2 at the scale of 1:250000. In the last two years of the project regional scale mineral resources assessment was undertaken at the scale of 1:50000 but with a limited number of sites studied, was undertaken to increase the mineral potential of Au-Fe in the Jamba, M´Popo-Tchamutete, Samboto-Cuíma and Chipindo.

Mineral reconnaissance campaigns were undertaken in 16 sheets of 1:50000 scale for regional scale mineral resources assessment where field observations and pXRF measurements were made in rocks and soils and sample collection. Three 1:50000 scale sheets were studied in Chipindo and the same number in Cuíma-Samboto, 4 sheets were studied in Jamba and 6 in the M´Popo-Tchamutete region.

The objective of the study was to increase the knowledge in potential resources of Au in the Cassinga region by using the field measurements of pXRF, although it is just a preliminary study, where the authors continue studying the samples collected in the field.

2. Geological setting and mineral occurrences

The region is occupied by cratonic remains of a Neoarchean age terrain designated in the PLANAGEO as Cassinga Domain represented by the Jamba Group (2.71–2.60 Ga) consisting of a set of metasedimentary rocks with intercalations of bimodal volcanism (acidic and basic metavulcanites) and vulcanoclastic episodes. The region of study it is also characterized by the presence of Banded Iron Formations (BIF) that constitute important iron deposits. Presumably this is a greenstone belt whereas the gneiss-migmatite of the Jamba Group, and the complex above which the Jamba Group overlays, is in discordance and a meta arenitic rock dated (2.78-2.85-Ga) reinforcing the theory of a pre-Jamba remain crust assuring that we are in the presence of a greenstone belt. This sequence is intruded by the Jamba-Tchamutete Plutonic Suite also from age 2.568 ± 11 Ma e 2.607±7 Ma. Both, the greenstone belt metasedimentary rocks and the granitic rocks of Jamba-Tchamutete that intrude them are subject to a common tectono-thermic episode later that 2.7-2.6 Ga and a deformation that give them a general trend of NE-SW direction, the general direction of the Cassinga Domain. The Chipindo group and Chivanda Group considered contemporaneous, could be deposited in different places. Alternatively, may have been deposited in contiguous areas, but are currently displaced by strike-slip movement related to the large fault structure, with ENE-WSW direction, which occurs between the two groups of metasediments and appears to establish the northern limit of the Cassinga Geological Domain when, to the south, it delimits the occurrence of hypabyssal rocks of the Menongue Igneous Complex (CIM) and to the North appear Neoarchean protolith orthogneisses. CIM that intrudes the Jamba Group formations and the granitic rocks of Jamba-Tchamutete is overlayed by the Bale Group formations of detrital and pelitic material. The conclusions during PLANAGEO project geological mapping (Pereira and Ferreira, 2021) show that the transition belt between the Cassinga and Centro-Oeste Domains corresponds to a large strike-slip shear zone, at the scale of the SW Congo Shield. Also concludes that to the west of that shear zone, during the Eburnean event and the Namibe-Epupa event, which together, rework Neoarchean crust and Eburnean crust, a large area of crustal accretion progressively developed from the SW Congo Craton (De Witt and Linol, 2015) to SW Angola and Namibia. Furthermore, the transition belt contains exotic lithodemic units, possibly generated in different phases of one (or more than one) tectono-thermic event. An important conclusion is that the shear band accommodates an important zone of crustal weakness taken advantage of in the Mesoproterozoic to install the Complex Anorthosite Kunene (CAC) and associated acid magmatism.

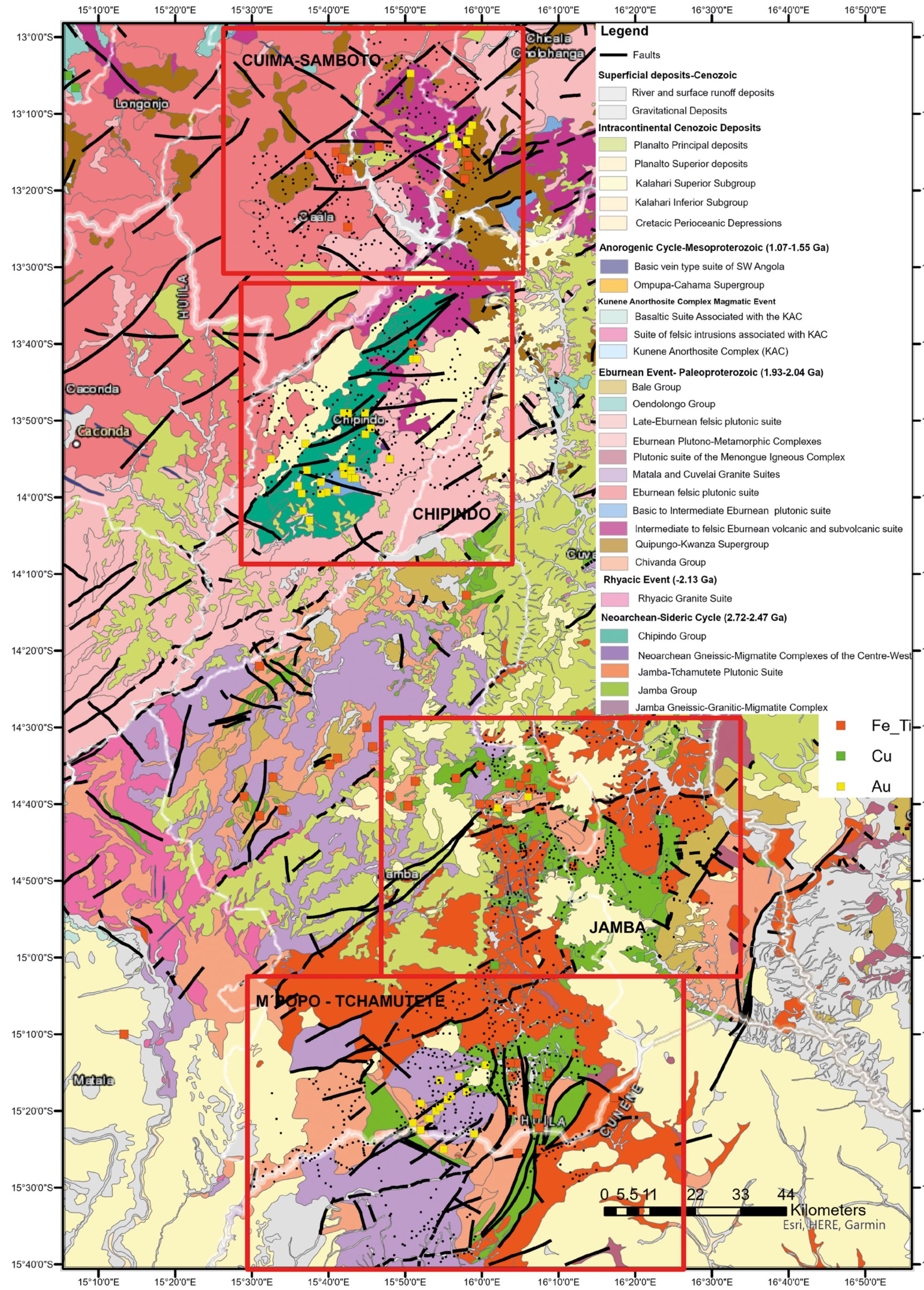

Figure 1. Geological map with the main mineral occurrences, rocks and soil pXRF measured sites in the region of Cassinga represented in black dots in red square areas (extracted from the Geological Map of Angola 1:1000000 scale- Geological Mapping coord. Merino-Martínez et al., 2022b; Mineral occurrences - Araújo et al., 2001).

Figura 1. Mapa geológico con las principales ocurrencias minerales y sitios medidos mediante pXRF de rocas y suelos en la región de Cassinga representado por puntos negros en cuadrados rojos (extraído del Mapa Geológico de Angola escala 1:1000000- coordinación de la Cartografía Geológica - Merino-Martínez et al., 2022b; Ocurrencias minerales - Araújo et al., 2001).

The Cassinga region, the most important Fe mining field in Angola, is divided between Cassinga Norte (Jamba and Osse region) and Cassinga Sul (M´Popo-Tchamutete region), separated by granitic rocks in a range of 40 km^2 (Machado e Silva et al., 1966). These two important sectors are N-S oriented. Generally, the Cassinga Fe deposits correspond to an important supergene enrichment related to “Banded Iron Formations” (BIFs). These rocks consist of bands of quartzite rocks and ferruginous levels associated with phyllites, black schists, and basic and acidic metavolcanic rocks that give shape to the lithostratigraphic unit undifferentiated Jamba Group of Archean age (McKee, 1975; Astromineral, 1981). Cassiga Sul (M´Popo- Tchamutete) where mineral occurrences are of Au in M´Popo shear zone in quartz veins with sulfides and Au, and the Fe in Tchamutete deposits (Fig. 1) and also in veins called Pungo-Anbongue and Candanbala probable the origin of the gold found in the alluvium of the Colui river and affluents (Machado e Silva et al., 1966). To the north the Chipindo alluvial Au deposits in bimodal metavolcanic rocks and metasedimentary rocks of Neoarchean-Siderian age composed of detritic formations such as metaconglomerates and alluvial planes containing high grades of Au (Oliveira, 1980). The northern area of this Fe-Au potential region is Cuíma-Samboto where Cuíma was exploited for Fe in the past, whereas secondary Au mineralizations are known to occur in Samboto alluvial system, and primary source is attributed to the quartz veins.

3. Methods

The area was divided into four areas Cuíma-Samboto, Chipindo, Jamba and M´Popo-Tchamutete, which was based on the knowledge of the location of the known mineralizations of Au and Fe, the geological knowledge of the host formations, the acquired with the geophysical airborne survey, and the study of publications of similar mineralizations in other countries of Africa related with the Congo Craton. The selection of regional potential areas for metallic mineral exploration was backed by the study of old exploration reports, the Mineral Catalogue of Angola, unpublished thesis and other publications that were compiled to build a comprehensive mineral database. The most important publications related with the Cassinga district were referred in the introduction section. The field work was made using the usual tools in exploration, base maps of geology, location of mineral resources, remote sensing maps and magnetics and radiometric maps in a tablet, hammer, compass, lent, bags and shovel and a portable XRF (Hitachi/X-MET800 model, with a 45kV X-ray tube, 25 mm^2 detection area was used). Measurements with pXRF were made in the 318 outcrops and 1638 soils of the area. The study was made in the last phase of the project therefore number of samples measured is low due to the deadlines of the project, but samples were collected and are being studied that will give ideas for the continuation of the study. Portable XRF measurements of 60 seconds using the MINING-LE-FP method. The XRF analysis is based on specific energy, to each element, that is necessary to induce electron transitions between layers of the atom, once a sample is irradiated with X-rays. As those transitions are accompanied by photons emissions, with characteristic energies, it allows the identification of the atomic species and the chemical element, as well as its concentration, from the intensity of the detected radiation. It is important to consider that the penetration of X-rays into the material being analyzed is very low, normally in the tens of microns. Therefore, and to have a greater representation of the object being analyzed, the analysis was repeated and at least three analyses were made in the same location.

This method presents limitations such as high detection limits, beam dispersion, especially when analyzing irregular samples, or the effect of grain size (Ravansari et al., 2020). To control the quality of these analysis certified reference materials (CRM) were used daily before the field work and SiO2 as a blank sample to control the contamination. The CRM used were: NIST 2711, soil of Montana, USA, OREAS 904 of Cu ore from Lady Annie Mine, Mount Isa, Queensland, Australia and, GBM 911-15 Ni ore from Eastern Goldfields, Western Australia and the results were consistent and not significant deviated from the reported values. Measurements were taken directly on the sample site in the field and soils were measured after homogenization of the sample in the field. It was possible to measure K_2O(%), CaO(%), TiO_2(%), MnO(%), Fe_2O_3(%), V(mg/kg), Cr(mg/kg), Co(mg/kg), Ni(mg/kg), Cu(mg/kg), Zn(mg/kg), As(mg/kg), Rb(mg/kg), Sr(mg/kg), Zr(mg/kg), Nb(mg/kg), Sb(mg/kg), Ba(mg/kg), Pb(mg/kg), Th(mg/kg), although in many situations, some of the elements were rejected in the final dataset. The output of the equipment was also subject to file cleaning of non-valid data. Data below detection limit do not show in the results, therefore half of the minimum was used in absent values if a percentage of missing values is no bigger than 30% of the total population. Geological materials are generally quite heterogeneous causing great geochemical variability due to texture, mineralogy, alteration, color, hardness, rock structure or presence of mineralization. Therefore, the greatest possible number of analyzes were acquired on a given outcrop (especially in the case of areas where there were signs of mineralization) of any of the geological units present in the work area, to have the most complete geochemical characterization possible of the object to be studied.

The present study has in mind that portable XRF chemical analysis interpretations are more useful to observe distribution of target chemical elements than to observe precise concentrations of these elements. Nevertheless, with the small number of samples from each area, analyzed in ALS Laboratory of South Africa, the results were compared using the pXRF readings of the same soils. The straight line adjusted in the biplot diagrams and the R2 determined the results were good for Fe, Zn, Th, Pb, Cr, V, and Mn (R2 >0.5), Ni and Co (R2 >0.3) and Ba, Zr, Nb, Sr, Rb, As and K (R2 <0.3). Usually, the reason for the lower results of R2 is explained with the difference of the analysis itself. The conclusion from that comparison is that we should give importance to the correlation between elements within each sub-cluster (Samboto, Cuíma, Chipindo, Jamba and M´Popo-Tchamutete) and the distribution of the elements in the field in each sub-cluster and compare between sub-clusters, considering that we made at least three pXRF measurements in each site and each day the CRM materials showed that the equipments were working in good conditions. Therefore, we decided to proceed and calculate basic statistics to confirm if distribution of chemical elements was similar in the different sub-clusters Cuíma, Samboto, Chipindo, Jamba and M'Popo-Tchamutete. Distributions in maps were represented as mean ± standard deviation to avoid real values. Furthermore, Multivariate analysis was conducted in the form of a variation of PCA called Nonlinear Iterative Partial Least Square (NIPALS) in the 1636 soil measurements using STATISTICA 12.0 software, but the procedure was done separately between the referred areas and presented in a single map (Fig. 7). An iterative procedure algorithm with maximum number of 50 iterations and convergence criteria of 0.0001. The iterative method NIPALS used to build the principal components model (find the eigenvectors) for the representation of multivariate variables (Risvic, 2007). The number of components was fitted by cross-validation. An important difference between the classical PCA and the NIPALS-PCA is the significance and limit of the principal components. Classical PCA significance of principal components determines the number of principal components until all the data are explained. The limit and the significance of the principal components is based on the method of cross-validation. The cross-validation method was V-fold validation. In V-fold cross-validation, the data are divided into v segments, v−1 of which is used to build up the model and the rest is used for testing. This process is repeated for all possible permutations of the training and testing segments and the overall Q2 and Q2V are calculated for the newly added principal component using the test samples. Given the estimated values of Q2 and Q2V, it is possible to determine whether a principal component is significant.

NIPALS PCA was used to extract more information from the data and, at the same time, perform a quality control of the data. This method is usually obtained in the industry to control the quality of data produced.

4. Results

The results of the exploratory work in the field are here presented in different zones from north to south as: Cuíma-Samboto, Chipindo, Jamba and M´Popo-Tchamutete. Although the great events of regional NE-SW structures cross all area and can be responsible for regional fluid mobilization, different field campaigns and analysis justify the presentation of results in separate sub-areas.

4.1. Cuíma-Samboto

Samboto sector is the east side of the area where Au mineralizations are of alluvial origin (Godinho, 1960) and correspond to the 280B 1:50.000 scale sheet. The main origin of these mineralizations is the important structures NE-SW especially in the intersection with structures of NW-SE direction and

E-W. Pathfinders such as As have maximum concentrations of 531 (mg/kg), compared to median of 3 (mg/kg) of 118 measurements in soils, in the northern area of Samboto, near a Au occurrence (Sacova) in the intersection between NE-SW to NW-SE direction faults, in schists and quartzites of N´Gola and Vila Branca Group and surrounded by quartz- felspathic porphyry, microgranites and dacites of the plutonic and subvolcanic eburnean suites reflected in the magnetic . A pathfinder such as Sb occurs with higher-than-average values in a N-S direction coincident with an alignment observed in the magnetic map which can correspond with a structure not mapped (Table 1). To the SE the Au alluvial occurrences are related with the drainage system of the Cuando river mostly related with N´Gola group schists and quartzites and the NE-SW intersected with NW-SE direction faults.

	Samboto					
	Valid N	**Mean**	**Median**	**Minimum**	**Maximum**	**Std.Dev.**
K_2O(%)	118	0.790	0.567	0.119	3.251	0.542
CaO(%)	118	0.054	0.004	0.004	3.185	0.319
TiO_2(%)	118	0.725	0.707	0.203	1.613	0.261
MnO(%)	118	0.029	0.024	0.001	0.133	0.022
Fe_2O_3(%)	118	4.780	4.059	0.785	13.489	2.872
V(mg/kg)	***118***	***85.182***	***86.500***	***5.000***	***268.000***	***53.401***
Co(mg/kg)	118	8.199	3.000	3.000	46.000	9.201
Ni(mg/kg)	118	17.004	4.000	4.000	99.000	20.643
Zn(mg/kg)	118	29.034	24.500	2.000	125.000	23.689
Sb(mg/kg)	118	5.992	2.500	2.500	42.000	6.545
Pb(mg/kg)	118	17.203	14.000	1.000	63.000	13.193
Cu(mg/kg)	118	16.271	16.000	16.000	32.000	2.074
As(mg/kg)	***118***	***11.873***	***3.000***	***0.5000***	***531.000***	***49.888***
	Cuima					
	Valid N	**Mean**	**Median**	**Minimum**	**Maximum**	**Std.Dev.**
K_2O(%)	160	0.696	0.4743	0.01000	4.55	0.633
CaO(%)	160	0.148	0.0040	0.00400	5.60	0.583
TiO_2(%)	160	0.634	0.6151	0.07610	1.88	0.284
MnO(%)	160	0.110	0.0275	0.00500	3.82	0.437
Fe_2O_3(%)	160	6.539	3.6167	0.41100	81.27	10.373
V(mg/kg)	160	68.494	60.0000	5.00000	355.00	59.886
Co(mg/kg)	160	8.7625	3.0000	3.00000	122.00	13.641
Ni(mg/kg)	160	19.3063	4.0000	4.00000	129.00	29.270
Zn(mg/kg)	***160***	***296.3625***	***24.5000***	***2.00000***	***22849.00***	***2006.750***
Sb(mg/kg)	160	2.5000	2.5000	2.50000	2.50	0.000
Pb(mg/kg)	159	12.8742	13.0000	1.00000	52.00	8.207
Cu(mg/kg)	***160***	***451.2563***	***16.0000***	***16.00000***	***27106.00***	***2793.737***
As(mg/kg)	160	6.6688	0.5000	0.50000	394.00	32.868

Table 1. Statistical results of soil pXRF measurements in Samboto and Cuíma regions.

Tabla 1. Resultados estadísticos de las mediciones de FRXp del suelo en las regiones de Samboto y Cuíma.

Cuíma sector is to the W of Samboto area, the Cuíma mineralizations still have remains of older exploitation of Fe. The pXRF analysis indicated very high concentrations of Cu and Zn compared with the mean values, in 160 soil measurements, especially near the open pit of Cuíma-A. Although these anomalous sites (>mean+2SD), most of the data were obtained in a considered background level (mean+0.25SD to mean+0.75SD; Fig. 2; Martín-Méndez et al., 2022b).

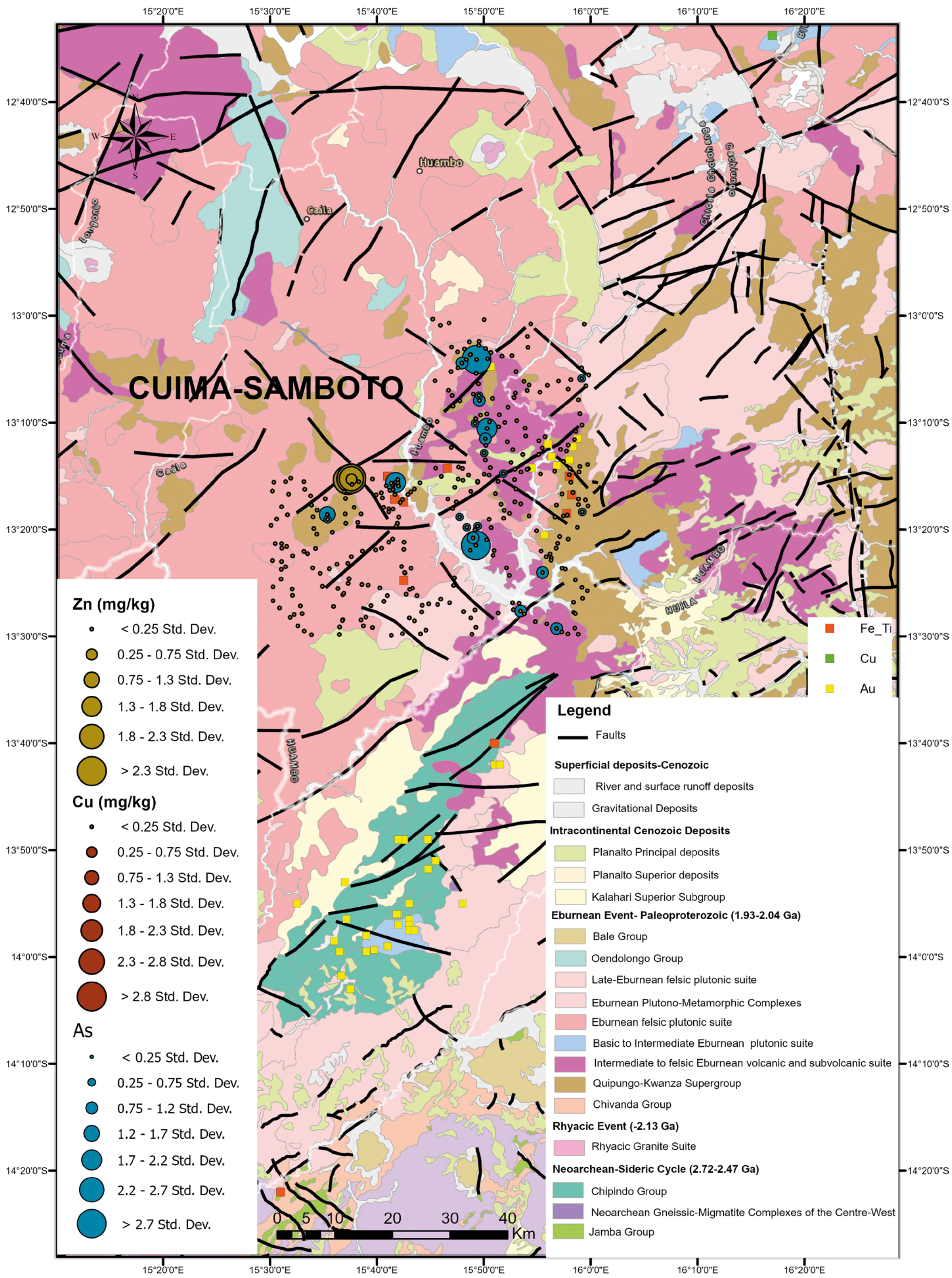

Figure 2. Zinc, Cu and As distribution (Mean±Standard Deviation) in soils in the geological and mineral occurrences map of Cuíma-Samboto area (adapted from the Geological Map of Angola 1:1000000 scale- Geological Mapping coord. Merino-Martínez et al., 2022b; Mineral occurrences - Araújo et al. 2001).

Figura 2. Distribución de Zinc, Cu y As (Media±Desviación Estándar) en suelos en el mapa de ocurrencias geológicas y minerales del área Cuíma-Samboto (adaptado del Mapa Geológico de Angola escala 1:1000000- coordinación de la Cartografía Geológica - Merino-Martínez et al., 2022b; Ocurrencias minerales - Araújo et al., 2001).

The mining district is composed of Cuíma A-E and occurs in the of very altered argillitic rocks showing metasomatic alteration and fluid circulation with visible altered sulfides in volcano sedimentary rocks included in the Eburnean Acid Plutonic Suite. The main mineralization is Fe from hematite and magnetite and the area is covered by laterite, the soils surrounding the open pits are red.

4.2. Chipindo

Chipindo sector, located to the north of Jamba region, is known to have Au mineralizations associated to the formation of Neoarchean Chipindo Group (Fig. 3). Arsenic distribution in soils, the most important pathfinder of Au, is clearly related with fragile structures within Chipindo Group formations and in the northern extent of the NE-SW dominant direction faults, the perpendicular direction also contains important concentrations of As, and the intermediate to felsic volcanic and subvolcanic suite of Paleoproterozoic formations the same (Torquato and Oliveira, 1977; Oliveira, 1980; Merino-Martínez et al., 2022).

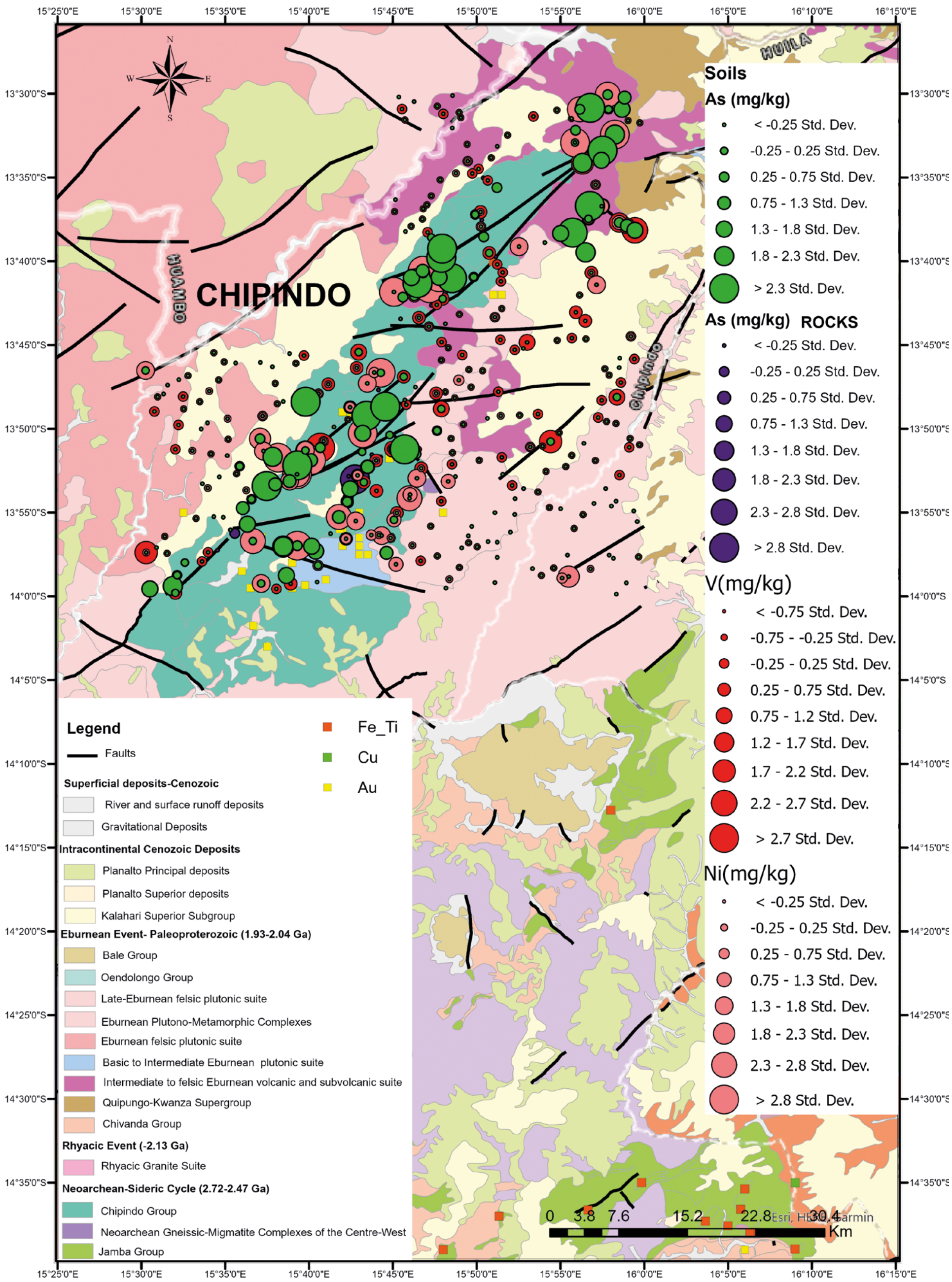

Figure 3. Arsenic and Ni, V in soils and As in rocks (Mean±Standard Deviation) in the geological and mineral occurrences map of Chipindo area (adapted from the Geological Map of Angola 1:1000000 scale- Geological Mapping coord. Merino-Martínez et al., 2022b; Mineral occurrences - Araújo et al., 2001).

Figura 3. Arsénico y Ni, V en suelos y As en rocas (Media±Desviación Estándar) en el mapa de ocurrencias geológicas y minerales del área de Chipindo (adaptado del Mapa Geológico de Angola escala 1:1000000- coordinación da Cartografía Geológica - Merino-Martínez et al., 2022b; Ocurrencias minerales - Araújo et al., 2001).

The Au occurrences appear mostly in the Chipindo Group formations of Neoarchean-Sideric age such as quartzites, conglomerates and bimodal metavolcanic rocks, coincident with the same NE-SW faults and in some perpendicular structures to those with WNW-ESE direction in the Transition Zone in Centro-Oeste Subdomain (Fig. 3).

Soils were measured in 333 sites using pXRF, but only a few number of elements are reliable for interpretation. The high V concentrations, ranging from 7 mg/kg and 502 mg/kg, in the Chipindo group developed soils, well correlated (0.82) with Fe which ranges from 0.24% to 18.7%. Concentrations of Sb are also localized near the Au occurrences, near the fault structures NE-SW. Rocks were determined and interesting values in V and As were determined (Table 2).

	Chipindo Soils					
	Valid N	**Mean**	**Median**	**Minimum**	**Maximum**	**Std.Dev.**
K_2O(%)	333	1.005	0.714	0.079	4.173	0.745
TiO_2(%)	333	0.642	0.613	0.210	1.893	0.251
MnO(%)	333	0.0252	0.020	0.001	0.138	0.020
Fe_2O_3(%)	333	2.913	2.206	0.248	18.731	2.536
V(mg/kg)	***333***	***54.8963***	***40.000***	***7.000***	***502.000***	***56.182***
Ni(mg/kg)	***333***	***14.703***	***5.000***	***5.000***	***100.000***	***18.926***
Zn(mg/kg)	333	27.0663	26.000	3.500	95.000	17.586
As(mg/kg)	333	3.012	0.500	0.500	60.000	6.117
Pb(mg/kg)	333	19.273	18.000	1.500	58.000	10.110
	Chipindo Rocks					
	Valid N	**Mean**	**Median**	**Minimum**	**Maximum**	**Std.Dev.**
K_2O(%)	20	2.500	1.940	0.144	6.608	1.937
TiO_2(%)	20	0.498	0.395	0.026	2.426	0.543
MnO(%)	20	0.025	0.009	0.001	0.093	0.030
Fe_2O_3(%)	20	4.739	2.826	0.085	36.767	8.017
V(mg/kg)	***20***	***105.375***	***63.500***	***4.000***	***469.000***	***131.370***
Ni(mg/kg)	20	25.500	12.500	12.500	98.000	24.942
Zn(mg/kg)	20	20.000	3.000	2.000	69.000	25.037
As (mg/kg)	***20***	***20.825***	***2.000***	***0.500***	***253.000***	***58.875***
Pb(mg/kg)	20	14.300	16.000	1.000	26.000	7.463

Table 2. Statistical results of soils and rocks pXRF measurements in Chipindo region.

Tabla 2. Resultados estadísticos de mediciones FRXp de suelos y rocas en la región de Chipindo.

4.3. Jamba

Jamba, also known as Cassinga Norte region, Fe mineralizations were heavily exploited in the past (Batista et al., 2021). Only the eastern part, where Jamba Group outcrops, was subject to the field campaign in the present study due to various constraints of the project. Therefore, the region of Cambibia and Osse were not subject to field reconnaissance and pXRF measurements (Pereira et al., 2022).

The outcrops of Archean formations of Jamba and Chivanda Groups and the contemporaneous granitic rocks of Jamba-Tchamutete from Cassongue and Indungo region were object of the field campaign (Pereira and Osório, 2021).

Copper, Fe and Au mineralizations were observed, Cu and Au associated with sulfides such as chalcopyrite, bornite and pyrite and one Au occurrence was associated with magnetite. The anomalous concentrations of As, Cu and Ni (above mean+2.2 standard deviations) were observed in the limits of these two Neoarchean groups (Jamba and Chivanda) in metarenite and metaconglomerate rocks and quartzites with a general orientation WNW-ESE that can reach in As, 1210 mg/kg measured with pXRF in soils and 427 mg/kg in rocks, and also in the limits of Jamba Group and Jamba-Tchamutete granitic intrusions showing that Au (represented by its pathfinder As) is associated with sulphides. The area was heavily subject to tectonics and the anomalous concentrations measured in rocks and soils are also associated with faults of ENE-WSW, and NE-SW (Fig. 4; Table 3).

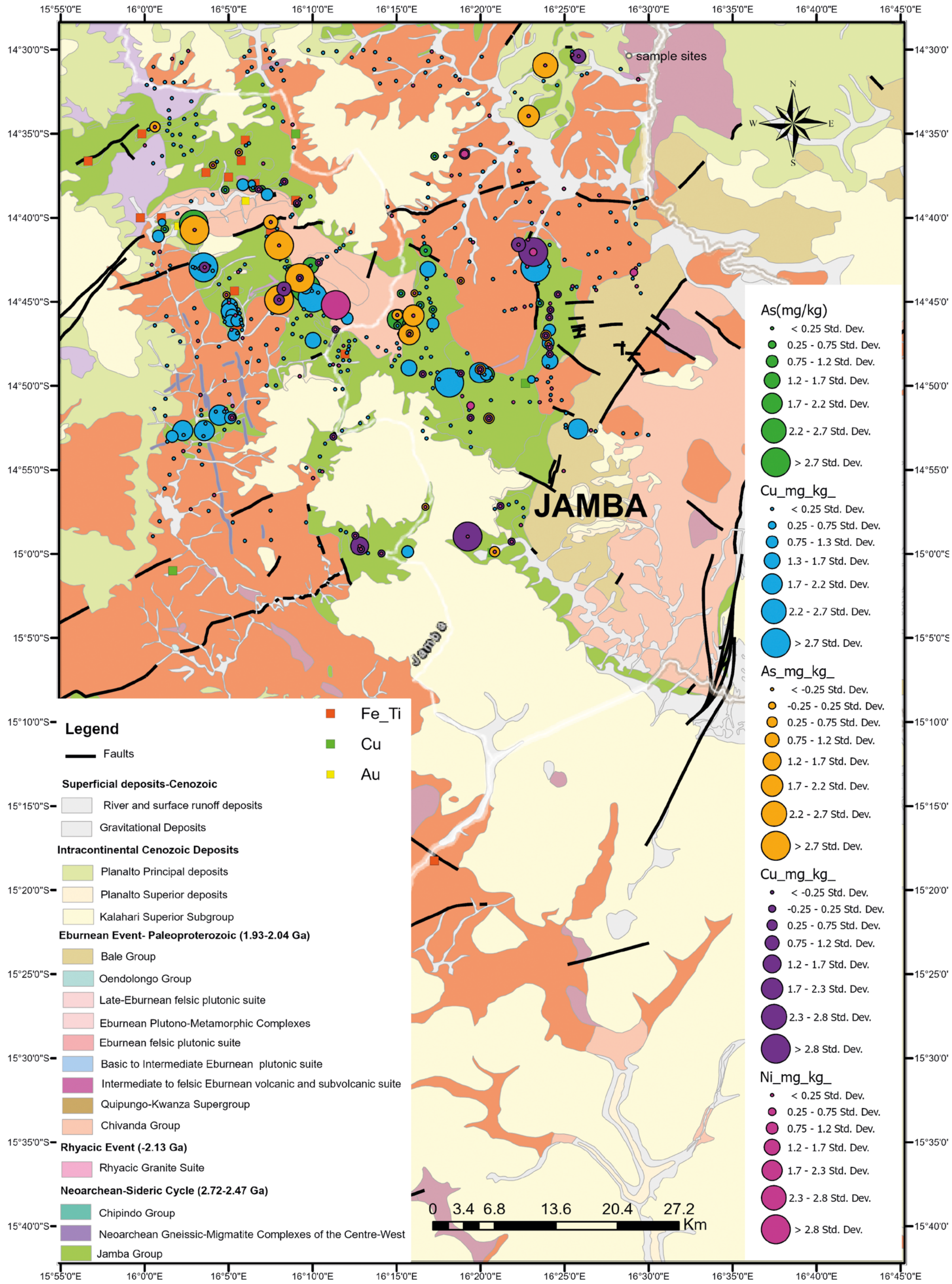

Figure 4. Arsenic and Cu in soils and rocks and Ni in rocks (Mean±Standard Deviation) in the geological and mineral occurrences map of Jamba area (adapted from the Geological Map of Angola 1:1000000 scale- Geological Mapping coord. Merino-Martínez et al., 2022b; Mineral occurrences - Araújo et al., 2001).

Figura 4. Arsénico y Cu en suelos y rocas y Ni en rocas (Media±Desviación Estándar) en el mapa de ocurrencias geológicas y minerales del área de Jamba (adaptado del Mapa Geológico de Angola escala 1:1000000- coordinación da Cartografía Geológica - Merino-Martínez et al., 2022b; Ocurrencias minerales - Araújo et al., 2001).

	Jamba soils					
	Valid N	Mean	Median	Minimum	Maximum	Std.Dev.
K_2O(%)	384	0.755	0.519	0.032	4.275	0.697
CaO(%)	384	0.248	0.121	0.014	5.834	0.569
TiO_2(%)	384	0.956	0.836	0.157	2.719	0.480
MnO(%)	384	0.073	0.043	0.003	2.499	0.145
Fe_2O_3(%)	384	6.745	4.450	0.306	33.973	6.160
V(mg/kg)	***384***	***135.355***	***101.125***	***18.429***	***550.250***	***103.274***
Co(mg/kg)	***384***	***45.687***	***36.000***	***15.000***	***657.000***	***54.835***
Ni(mg/kg)	***384***	***39.368***	***34.750***	***10.500***	***294.250***	***34.906***
Zn(mg/kg)	384	30.108	27.750	4.167	113.750	17.498
Sb(mg/kg)	384	15.557	5.000	5.000	86.000	13.725
Pb(mg/kg)	384	14.073	12.000	2.000	192.000	17.941
Cu(mg/kg)	***384***	***26.488***	***8.000***	***8.000***	***1052.500***	***85.742***
As(mg/kg)	***384***	***12.342***	***0.500***	***0.500***	***1210.500***	***66.395***
	Jamba rocks					
	Valid N	**Mean**	**Median**	**Minimum**	**Maximum**	**Std.Dev.**
TiO_2(%)	117	0.446	0.333	0.017	4.690	0.560
MnO(%)	117	0.239	0.079	0.005	2.037	0.384
Fe_2O_3(%)	117	12.386	8.505	0.225	73.190	13.115
V(mg/kg)	***117***	***219.926***	***116.667***	***21.000***	***3532.750***	***382.199***
Cr(mg/kg)	***117***	***173.730***	***16.300***	***16.300***	***1566.500***	***254.934***
Co(mg/kg)	***117***	***104.077***	***45.000***	***15.500***	***2312.000***	***262.240***
Ni(mg/kg)	***117***	***95.403***	***30.000***	***8.500***	***5726.500***	***528.954***
Zn(mg/kg)	117	39.119	30.000	2.667	396.167	44.338
Sb(mg/kg)	117	22.429	27.000	6.000	57.667	14.619
Pb(mg/kg)	117	38.914	13.500	4.500	1782.333	166.305
Cu(mg/kg)	***117***	***262.770***	***5.750***	***5.750***	***7030.333***	***984.681***
As(mg/kg)	117	39.085	0.500	0.500	427.200	92.100

Table 3. Statistical results of soil and rock pXRF measurements in Jamba region.

Tabla 3. Resultados estadísticos de mediciones FRXp de suelos y rocas en la región de Jamba.

4.4. M'Popo-Tchamutete

These two areas are in the west side, M'Popo granite covered by a relatively thin layer of detrital material, resulting from the weathering of the massif itself and possibly with some contribution from adjacent detrital materials, appears to be intruding both the Cuvelai granite and the lithologies of the Jamba Group. This granitic rock is medium to coarse grained, non-porphyritic, presenting abundant quartz, apparently with two feldspars, some biotite and in some places it presents rare limonitized boxworks. It is a globally altered granite, presenting widespread chloritic and sericitic alteration in the observed outcrops, with some kaolinization, hematitization and eventually epidotization occurring locally. The intensity of the alteration is slight along the eastern limits of the massif, increasing in intensity towards the west, towards M'Popo, where there are veins of quartz, mineralized in gold (Carvalho and Simões, 1969). In this area numerous quartz veins occur cutting the basic metavolcanic units and the granites of the Cuvelai granitic suite. They have large dimensions, decametric widths and hectometric extensions, generally aligned along N45E to N60E, N30W and more rarely N80E to E-W. In the group of veins with the direction N45E to N60E, gold mineralization was reported, with gold occurring, either free or associated with pyrite, with sphalerite, galena, chalcocite and bornite (Carvalho, 1993).

From the field reconnaissance the referred quartz veins with NE-SW direction have concentrations measured with pXRF 1.8 and 2.3 standard deviations above the mean values of Cu and Cr, also As was recorded 2.7 SD above mean in one site in that big structure, showing that Au (represented by its pathfinder As) is associated with sulphides (Fig. 5).

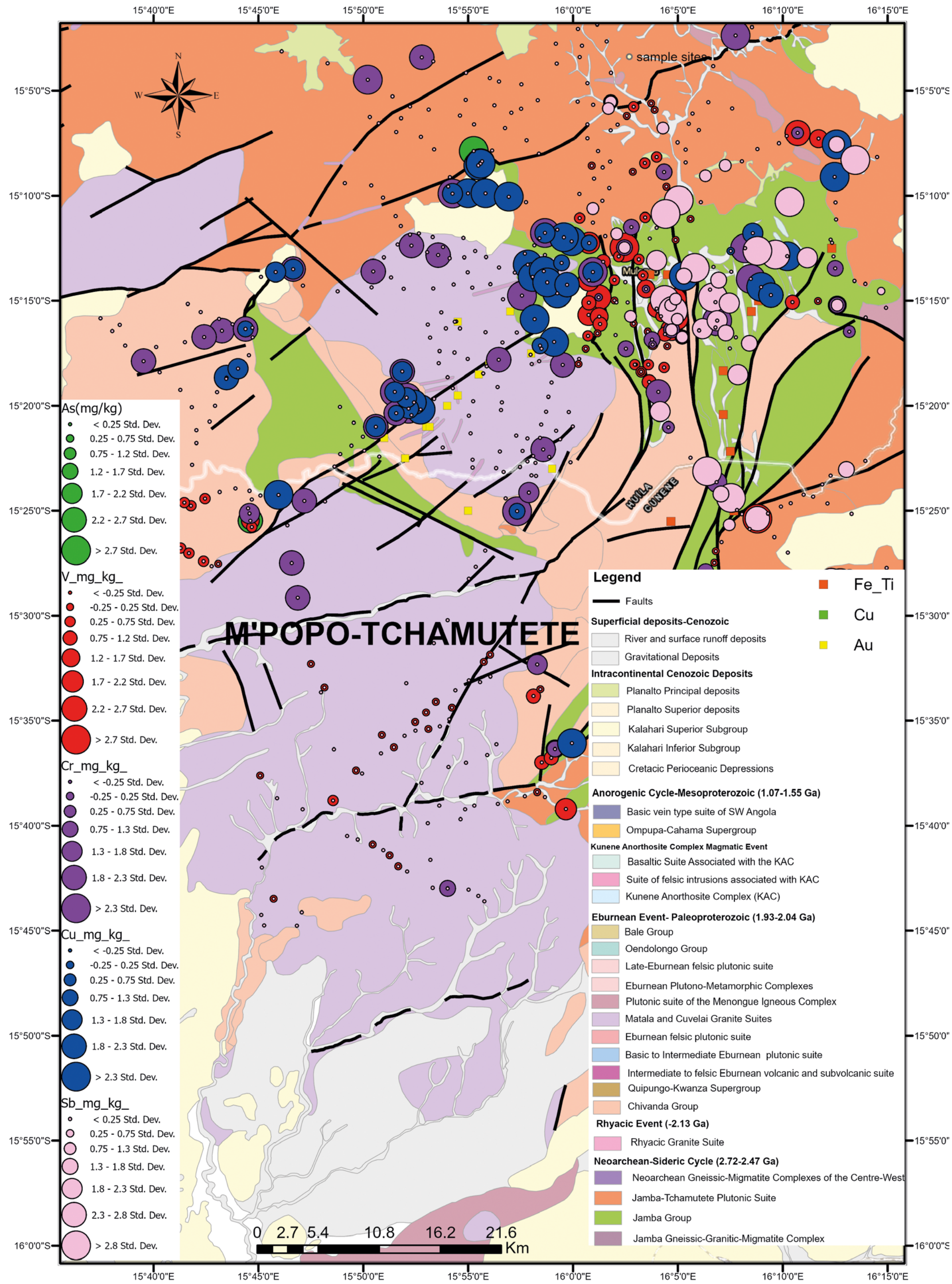

Figure 5. Distribution (Mean±Standard Deviation) of V, Cr, Cu, Sb in soils in the geological and mineral occurrences map of M'Popo-Tchamutete area (adapted from the Geological Map of Angola 1:1000000 scale- Geological Mapping coord. Merino-Martínez et al., 2022b; Mineral occurrences - Araújo et al., 2001).

Figura 5. Distribución (Media ± Desviación Estándar) de V, Cr, Cu, Sb en suelos en el mapa de ocurrencias geológicas y minerales del área de M'Popo-Tchamutete (adaptado del Mapa Geológico de Angola escala 1:1000000- coordinación de la Cartografía Geológica - Merino-Martínez et al., 2022b; Ocurrencias minerales - Araújo et al., 2001).

Variable	Soils					
	Valid N	Mean	Median	Minimum	Maximum	Std.Dev.
K_2O(%)	556	1.15651	0.96506	0.01084	4.794	0.8885
TiO_2(%)	556	0.53186	0.46090	0.03186	2.660	0.3733
MnO(%)	556	0.10390	0.03825	0.00090	0.884	0.1461
Fe_2O_3(%)	556	4.21197	1.77354	0.18743	33.901	5.5000
V(mg/kg)	***556***	***36.10492***	***7.50000***	***7.50000***	***1235.000***	***100.2340***
Cr(mg/kg)	***556***	***69.02488***	***16.00000***	***16.00000***	***1037.000***	***128.8908***
Co(mg/kg)	556	16.44379	1.50000	1.50000	99.000	21.0929
Ni(mg/kg)	556	23.41906	5.00000	5.00000	278.000	40.9484
Cu(mg/kg)	556	16.01094	8.50000	8.50000	195.500	25.6593
Zn(mg/kg)	556	18.24266	3.50000	3.50000	182.000	28.9096
As(mg/kg)	***556***	***13.17071***	***0.50000***	***0.50000***	***3644.000***	***158.9630***
Pb(mg/kg)	556	11.95686	12.41667	0.50000	69.667	9.7171
Sb(mg/kg)	556	1.89473	0.00045	0.00045	85.000	7.8982
Variable	**Rocks**					
	Valid N	**Mean**	**Median**	**Minimum**	**Maximum**	**Std.Dev.**
K_2O(%)	133	2.48025	2.50997	0.01072	5.615	1.7035
TiO_2(%)	133	0.34717	0.23392	0.01084	1.826	0.3900
MnO(%)	133	0.12398	0.04116	0.00323	0.835	0.1747
Fe_2O_3(%)	133	6.22356	1.79775	0.34105	65.373	10.1563
V(mg/kg)	***133***	***66.01617***	***14.00000***	***14.00000***	***2003.000***	***191.5299***
Cr(mg/kg)	133	63.61654	18.50000	18.50000	706.000	131.5768
Co(mg/kg)	133	22.11905	1.50000	1.50000	529.000	50.3172
Ni(mg/kg)	133	22.81341	3.00000	3.00000	256.750	43.6988
Cu(mg/kg)	***133***	***68.69737***	***5.00000***	***5.00000***	***7179.000***	***622.0949***
Zn(mg/kg)	133	32.23997	26.00000	3.00000	157.500	32.7686
As(mg/kg)	133	4.95238	0.50000	0.50000	77.833	10.6948
Pb(mg/kg)	133	18.45712	16.33333	1.00000	127.000	17.9787

Table 4. Statistical results of soil and rock pXRF measurements in M’Popo-Tchamutete region.

Tabla 4. Resultados estadísticos de mediciones FRXp de suelos y rocas en la región de M’Popo-Tchamutete.

In the Tchamutete area, the Jamba Group materials are limited by a system of faults that may have developed in association with a shear zone called the “Cuvelai shear zone” oriented NNE-SSW. In this structure, deformation appears with the development of very steep anticlinal and synclinal folds, with subvertical axial planes and axes with a pending to the south. These structures are bordered by subvertical faults, which jointly define large structures with preferred N-S orientations, which then turn south to the west, acquiring a NNE-SSW trend (Fig. 5; Sousa et al., 2021; Martín-Méndez et al., 2022a).

In this trend lateral alternation of the Jamba group with Chivanda group is observed, where the intense tectonism resulting from Paleoproterozoic deformation were responsible for the fluid circulation, the old and newer intrusions of Jamba-Tchamutete and Cuvelai respectively, surround this shear zone and influence circulation and composition of the fluids. In these structures N-S, NNE-SSW we observed (Fig. 5) anomalous (> 1.8 SD above the mean values) of Cr, Cu and V.

4.5. Multivariate analysis

The PCA assumes that the studied variables tend to multivariate normality. The Probability–Probability chart (P-P) showed that the sets of variables tend to the theoretical curve (normal) as a whole. However, when those are separated, the same tendency does not occur. The best tendency to normality was observed in the P-P diagrams of the soils from Chipindo. Even so, certain elements (As and Ni) seem to deviate more than others from that tendency (Fig.6).

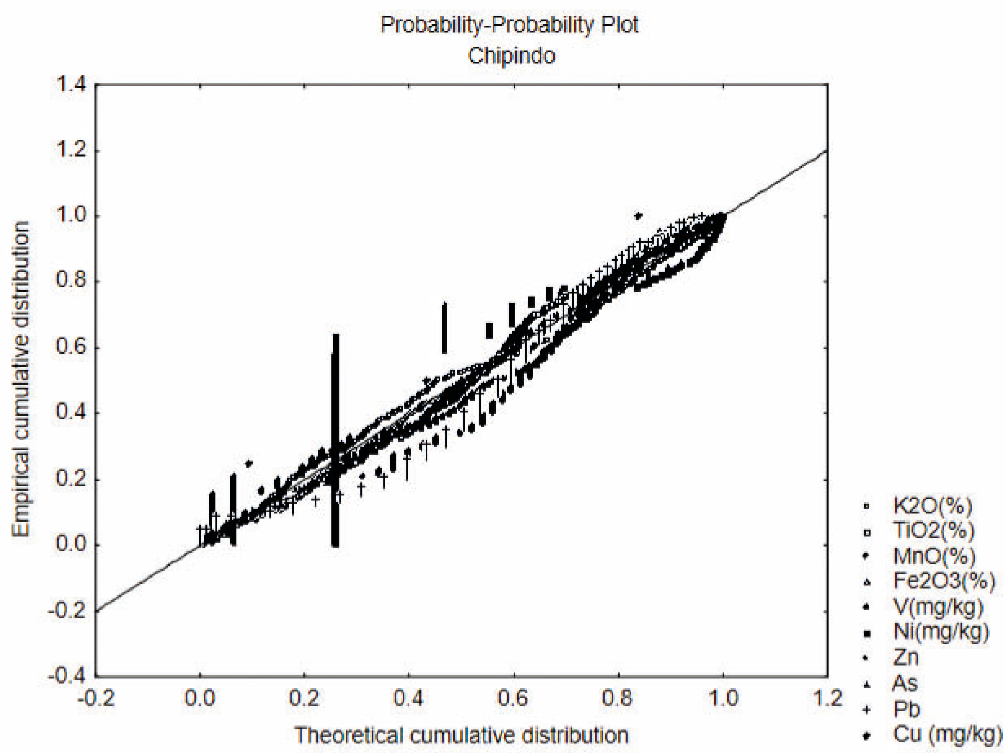

Figure 6. Probability–Probability plot (P-P) representing empirical cumulative distribution versus theoretical cumulative distribution of the chemical elements/oxides concentrations testing possible multivariate normality in Chipindo area.

Figura 6. Gráfico de probabilidad-probabilidad (P-P) que representa la distribución acumulativa empírica versus la distribución acumulativa teórica de las concentraciones de elementos químicos/óxidos que prueban una posible normalidad multivariada en el área de Chipindo.

The other diagrams tend to confirm the same tendency in major elements, whereas minor elements tend not to follow the same tendency. Although, overall multivariate normality is in general acceptable.

Table 5 represents the summary of the calculation of the three principal components determined by the prediction model (Q2cumul) with the respective cumulative variance explanation R2X of the soils measured in all mineralized areas. The elements concentrations in the soils of the different mineralized areas have an explained variance of 59, 43, 53.6 and 71.8 %, respectively.

The results show that the NIPALS principal components selected, have more or less the same associations of elements/oxides between Chipindo and Jamba bimodal metavolcanic Neoarchean rocks especially related with structures of NE-SW general direction and are MnO, Fe_2O_3, V, Cr, Co, Ni, Cu, Zn, Sb, As reflecting both basic and acid volcanics and the presence of sulphides (Cu, Zn) with possibility to have Au (pathfinders As and Sb). Also, the Paleoproterozoic granitic intrusion of Matala-Cuvelai (M´Popo Granite) is reflecting a mobilization of fluids into the main direction structures NE-SW with the same group of elements/oxides and the same in the northern part of Chipindo where faults in the Paleoproterozoic volcanic and sub-volcanic suites of rhyolites and andesite acid to intermediate volcanic rocks also present the same group of elements/oxides. In Cuíma-Samboto the group is more influenced by old exploitation of Cuíma, therefore it is more difficult to relate with the other areas. Nevertheless, the group of elements/oxides is still not changing much and is related with the acid and intermediate volcanic rocks of Paleoproterozoic volcanic and sub-volcanic suites and also with the Paleoproterozoic Supergroup of Quipungo-Kwanza composed of schists, quartzites and metaconglomerates of N´Gola and Vila Branca groups.

Area	PC	R^2X	R^2X(Cumul.)	Eigenv	Q^2	Limit	Q^2(Cumul.)	Signif	Iterat
M'Popo	1	0.375683	0.375683	4.883873	0.307913	0.078586	0.307913	S	5
Tchamutete	2	0.119092	0.494775	1.548201	-0.060935	0.084988	0.265740	S	20
	3	0.096210	***0.590985***	1.250729	-0.092091	0.092553	0.198122	UNKN	20
Jamba	1	0.236375	0.236375	6.618487	0.177801	0.038232	0.177801	S	5
	2	0.121017	0.357392	3.388489	0.083374	0.039558	0.246351	S	9
	3	0.075082	***0.432474***	2.102286	0.031143	0.040985	0.269822	UNKN	29
Cuima	1	0.245058	0.245058	5.635645	0.029753	0.046088	0.029753	S	7
Samboto	2	0.181998	0.427057	4.188663	0.147346	0.048067	0.172714	S	13
	3	0.109050	***0.536106***	2.507566	0.037323	0.050234	0.203591	UNKN	7
Chipindo	1	0.458654	0.458654	4.127884	0.345434	0.113788	0.345434	S	8
	2	0.159833	0.618487	1.438500	0.071014	0.127644	0.391917	S	10
	3	0.099770	***0.718257***	0.897928	-0.076070	0.145455	0.345660	UNKN	41

Area-Mineralized area, PC principal component, R2X explained variance, R^2X(Cumul.) cumulative explained variance, Eigenv-eigenvalue, Q^2 -predictive variation, Limit - ratio of PC degree of freedom and the total degree of freedom, Q^2 (Cumul.) -cumulative predictive variation, Signif -significance of a PC in the predicted model, Iterat -number of iteration needed in each component, UNKN -unknown significance of the respective PC, S- significant PC

Table 5. Summary of principal components analysis with three components and 59, 43, 53.6 and 71.8 % of explained variance of M'Popo-Tchamutete, Jamba, Cuíma-Samboto and Chipindo, respectively.

Tabla 5. Resumen del análisis de componentes principales con tres componentes y 59, 43, 53.6 y 71.8 % de varianza explicada de M'Popo-Tchamutete, Jamba, Cuíma-Samboto y Chipindo, respectivamente.

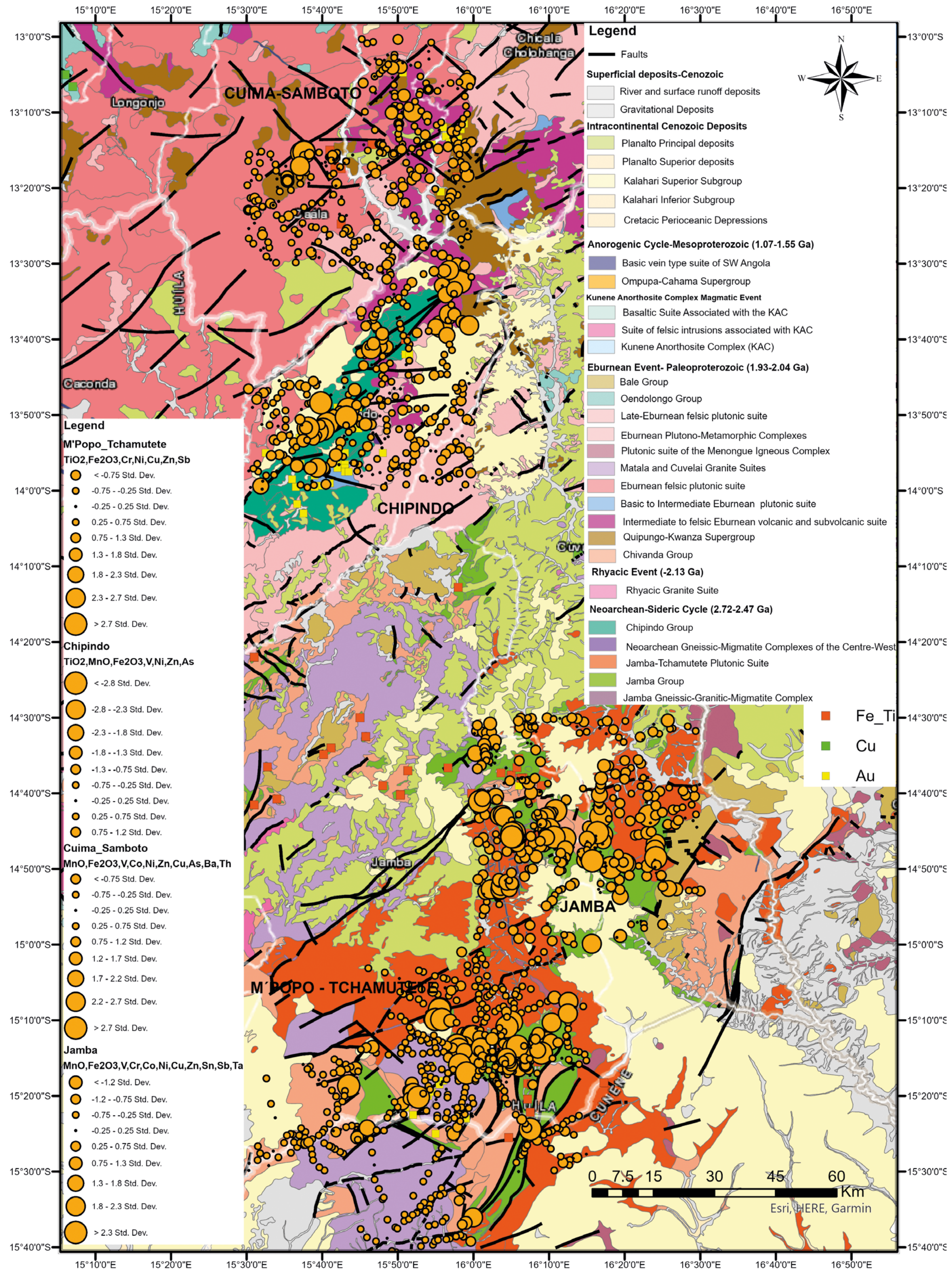

Figure 7. Distribution of the NIPALS components with the respective chemical elements grouped from the measurements of soils of the four areas M´Popo-Tchamutete, Chipindo, Cuíma-Samboto and Jamba.

Figura 7. Distribución de los componentes NIPALS con los respectivos elementos químicos agrupados a partir de las mediciones de suelos de las cuatro áreas M´Popo-Tchamutete, Chipindo, Cuíma-Samboto y Jamba.

5. Discussion

De Witt and Thiart (2005) show that the metal distributions in the Archean cratons compared to Post-Archean rocks of the former continent of Gondwana reveal that Archean cratons are richer in metals than younger rocks (i.e. mineral diversity has apparently decreased with time). These metal signatures appear to have been inherited close to the time that the craton separated from the mantle and reflect mantle heterogeneity as well as the tectonic and magmatic processes involved in craton formation. Frimmel (2008), studying Au production, reserves and resources associated with each genetic type of deposit, concludes that most of the Au concentrated in mineral deposits was added to the continental crust during a giant gold event that occurred in the Mesoarchean era (3Ga) when the mantle temperature reached a maximum and tectonic movements changed from vertical to sub-horizontal. The main Au mineralizations in known Archean Terrains in Africa occur in the Zimbabwe and Kaapvaal cratons. Therefore, Au in the less studied Congo craton (this case in its southern sector, the Angolan Shield) was a target of the present study, although yet in an early stage. Viljoen (1969) and Kirk et al. (2002), when studying the gold conglomerates of the Kaapvaal basin with Re-Os isotopes, determined an older age for the Au and pyrite present in the conglomerates, than the same conglomerates originated from the erosion of the greenstone belt, with evidence that the Au was older than the host rock, this could favor the theory of the placer as well as the theory of the hydrothermal gold where it would be transported by hot fluids from great deeps and install in fractures (Kirk et al.,2003). This theory favours the origin of the placer genesis, whereas the conglomerates would be originated from the erosion of the gold rich greenstone belt of Archean age and transported in an old river system (Kirk et al., 2003).

The origin of gold in Cassinga region could also be explained by a placer origin as a secondary gold where field observations of the present mining in old river systems in Chipindo may confirm this statement and also hydrothermal which is valid when observing the distribution of Cu, As, Cr, Co, and Ni in Chipindo, Jamba and M'Popo - Tchamutete, where anomalous concentrations are mostly related with the Neoarchean bimodal volcanic and sedimentary rocks and Neoarchean Jamba-Tchamutete granites. Although, the pos Eburnean tectonics also remobilize the fluids to more recent intrusions such as the Cuvelai granite (M'Popo granite), those are especially to the hydrothermally altered zone related with the Cuvelai Shear Zone, and to Paleoproterozoic Acid and Intermediate riolites and andesite volcanic rock suite to the NE of Chipindo and to the Bale detrital formations. Viljoen (1982) states in his study of several Au mineralizations in the southern region of Africa that the primary origin of Au in greenstone belts occurs in mafic and ultramafic rocks which is still confirmed in the study areas by the associations of elements generated by NIPALS-PCA components that include Ni, Cr and Co typically from a more basic source. The same author states that the break in sedimentation in the volcanism stratigraphy would have been relevant in the initial concentration of Au, in many cases, with high economic viability. Gold occurrences in greenstone belts form in a wide variety of rocks, including volcanic rocks, BIF cherts, schists, greywackes and quartzites. They are predominantly epigenetic mineralizations essentially controlled by systems of folds and fractures, denoting behaviors, both ductile and brittle, with metamorphism from the amphibolite facies to green schist, these conclusions with the present study, are still confirmed to the Cassinga region, although the study is still preliminary, and the samples collected need to be studied. Accompanying Au mineralization in quartz and carbonate veins is common hydrothermal alteration of carbonatization, sulfidation, potassium metasomatism and in the BIF the sulfides are frequently replacing the Fe layers (Meyer and Saager, 1985) which still can be confirmed with the field observations in the Cassinga region. The present study was made only with pXRF measurements were made, therefore is still in a preliminary stage, but samples were collected and are being studied to confirm the field measurements and the ideas expressed that corroborate these preliminary results and what is said by other authors in relation to greenstone belts in Africa.

6. Conclusions

Pathfinders of Au occur in different lithologies were confirmed by pXRF measures of elements in soils and in rocks. Multivariate analysis using Nonlinear Iterative Partial Least Square (NIPALS) – PCA statistics defined a group including pathfinders of Au associated to greenstone belt rocks. The elements/oxides such as MnO, Fe2O3, V, Cr, Co, Ni, Cu, Zn, Sb and As were grouped as a factor analysis in the 1636 soils in all four potential Au areas of Cuíma-Samboto, Chipindo, Jamba and M´Popo-Tchamutete. Pathfinders of Au (As and Sb) are included along with elements of basic rock origin such as Cr, Co, Ni and sulphides (Cu, Zn) confirming enrichments in:

- The bimodal volcanic and BIF formations of the Jamba and Chivanda groups of Neoarchean age, and also associated with fragile and ductile structures to where the fluids may have been remobilized;
- The granitoids of the Jamba-Tchamutete Suite, also of Neoarchean age, adjacent to the Jamba Group, where they occur in major faults and in the limits of the intrusions with Jamba formations, Eburnean Plutono-metamorphic complex and Chipindo formations;
- Eburnean granite of Cuvelai, which displays extensive areas of strong hydrothermal alteration, one of them, notable for its extension and intensity of effects, located in the M’Popo area, where vein systems associated with this granite emerge and pathfinders of Au are located, remobilized by tectonics with the intervention of hydrothermal fluids, confirmed by Au exploitation in the past;
- In Chipindo Group with an approximate age (< 2.55 Ga), where small gold nuggets have traditionally been extracted, representing paleo-placers and where Au pathfinders occur in the preferential direction of NE-SW and perpendicular;
- In Paleoproterozoic conglomerates and microconglomerates of the Chivanda and Bale Groups where confirmed by the exploitation of Au of lithified conglomerates in the past.

The four areas studied, Cuíma-Samboto, Chipindo, Jamba and M´Popo-Tchamutete seem to have the same geochemical behavior in terms of pathfinders of Au, where a major NE-SW regional direction is the preferential, used by hydrothermal fluids that could transport Au, although perpendicular structures associated with the primer also exhibit high concentrations of this group of elements that include Au pathfinders and sulphides, within Neoarchean formations of Jamba and Chipindo groups and in the adjacent limits of the Neoarchean granites. This study is ongoing and the samples collected are being studied and the authors hope to increase the number of pXRF measurements in the future work in each area.

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