International Scholars Journals

African Journal of Geography and Regional Planning ISSN 3627-8945 Vol. 7 (5), pp. 001-009, May, 2020. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Review

Numerical modeling of the polymetallic bodies of Tighza deposit (Central Morocco) by using the GIS tool and geostatistics

Amina Kassou[1]*, Mohamed Aissa[1], Hajib EL Kasmi[2] and Ali Essahlaoui[3]

[1]Laboratory of the Mineral and Energetic Resources studies, Department of Geology, Faculty of Sciences, PO Box 11201, Zitoune, Meknes, Morocco.
[2]National School of Agriculture, Meknes, PO Box S/40, km. 10, Haj Kaddour road, Meknes, Morocco.
[3]Laboratory of Geo-Engineering and Environment, Department of Geology, Faculty of Sciences, PO Box 11201, Zitoune, Meknes, Morocco.

Accepted 04 April, 2020

The various departments of the Touissit Mining Company are facing a problem of organization and storage of the generated information. Consciently at this situation, and taking into account the volume of product data, which continues to grow on one hand and their possible loss on the other hand, and due to the enormous potential of the Geographic Information Systems (GIS) in terms of data collection, analysis and dissemination, the Touissit Mining Company decided to establish a geographic information system by means of a computerized database, in order to guide the exploration and exploitation work and to assist the mining managers to make suitable decisions. This work is complemented by a statistical and geostatistical treatment of the geochemical data, and the realization of thematic maps which can lead to the development of a geochemical model providing information about the polymetallic mineralizations distribution in this district.

Keywords: GIS, mining geology, statistics, geostatistics, Tighza, Central Morocco.

INTRODUCTION

The Tighza deposit is the first producer site of the lead concentration and the 2nd supplier of the silver in Morocco. His lifetime spans over 15 years. Indeed, the Touissit Mining Company (TMC) conducted in 2008 a turnover of 291.4 milliards dirhams against 247.3 in 2007, with an increase of over 17%. This increase is due, among other things, to the positive evolution of the sold tonnages (+14.3% lead, +48.9% zinc).

For the mining operators, the viability of the site is capital. The current research aimed to extend the exploitation life of the Tighza deposit. This research raises, within the Touissit Mining Company (TMC), a problem of information organization and storage which generated by its various departments, especially that of geology at its 3 exploitation sites (Signal, Ighrem Aousser and Sidi Ahmed). Faced with this situation, and taking into account the volume of product data, which continues to grow on one hand and their possible loss on the other hand, the Touissit Mining Company decided to establish a geographic information system by means of a computerized database which allows the storage, processing, interpretation and access to information on the geological context, geochemical distribution, geophysical anomalies distribution and metal concentrations, in order to guide the exploration and exploitation work and to assist the mining managers to make suitable decisions.

This work is complemented by a statistical and geostatistical treatment. So, a multivariate analysis, by using principal component analysis (PCA) has identified the principal factorial axes. The geostatistical treatment of geochemical data has firstly consisted to a variograms modelling of different chemical elements. Then, it has consisted to the production of variographic maps. Finally, it has been to an establishment of the spatial distribution maps by kriging for each element. The obtained thematic

*Corresponding Author E-mail: kassou.amina@gmail.com

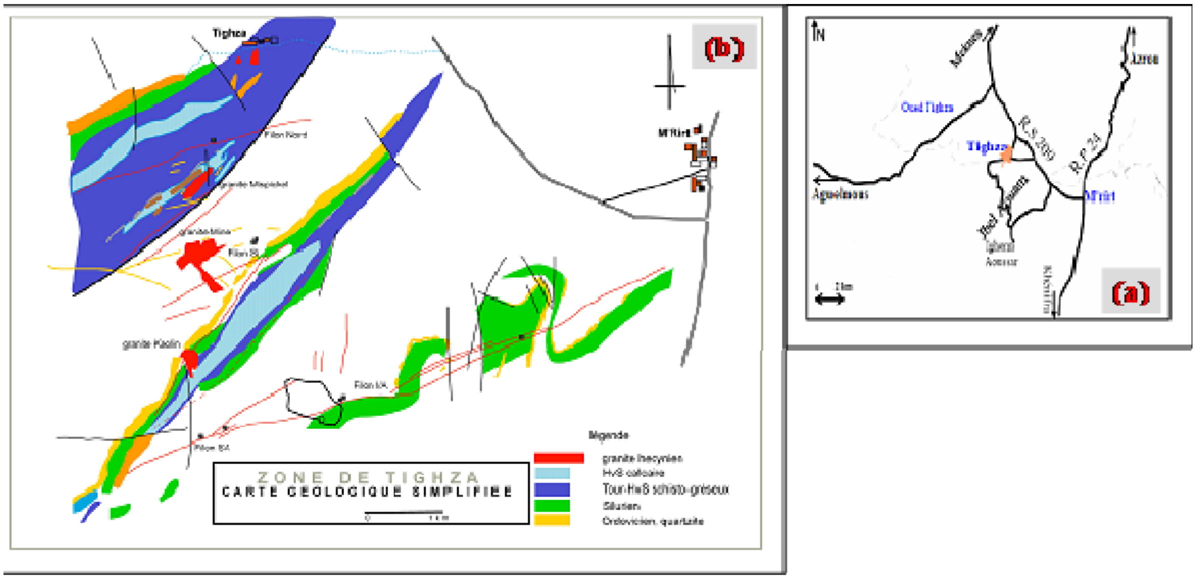

Figure 1. Geographic location (a) and geological context of Tighza mining district (b)

maps could lead to the development of a geochemical model, which is informing about the distribution of metals in this district.

Monography of the tighza mining district

Geographic location

The Tighza mining district is located in the north east of Central Morocco, near the western edge of the Middle-Atlas Causse, about thirty kilometres in the northwest of the Khenifra city and 7 km from the M'rirt city. It is accessible via the main road N 24 joining Azrou to Khénifra, thus via the Secondary Highway 209 which connects M'rirt to Meknes (*Figure 1a*).

Geological context

Geologically, the Tighza mining district, part of the Kasbat-Tadla-Azrou anticlinorium, rightly illustrates the Hercynian geology of the greater unity of the Moroccan western Meseta. It consists of the Paleozoic sedimentary rocks of Ordovician to Carboniferous (*Figure 1b*). These lands are affected by a low regional metamorphism (anchi to epizonal) which have been distorted by the different phases of the Hercynian orogeny wich structured the entire region of Central Morocco into an ensemble of the anticlinoria and synclinoria and the transcurrent shearing zones with a repeated games allowed the establishment of a polymetallic mineralization economically important of economic importance ((Cheilletz (1984); Faïk (1988); Bouabdelli (1989); N'Tarmouchent (1991); Ballouki (1995); Bennasser (1996); Bensahal (2001) and Nerci (2007)). The vein-type mineralizations, which hosted in the Paleozoic formations, are represented by the Pb, Zn, Ag, W and Au. They are currently being exploited by the Touissit Mining Company (TMC). It provides 52% of the Pb national production, 26% Ag and 3.2% Zn. The annual production is 350 000 ttv, 30 000 t Pb and 4 000 t Zn. The reserves are estimated at over 5 millions ttv (Wadjinny (1998)).

Contribution of GIS to the numerical modeling of mineralized bodies

This work was based primarily on the topographic map of the Tighza mining district (1/5000), the M'rirt topographic map (1/50 000), the Tighza geological map (1/5000) and the different geochemical profiles data of the district.

The data numerical modeling on the topography, geology and geochemistry as well as the available cores drilling data in the Tighza polymetallic district has been achieved through the establishment of a GIS database. The approach consists of transcripts of the available various maps (planimetric representation developed in this paper), in a digital format. In this work, the ArcGIS software was used to develop a spatial database by scanning, georeferencing and development of a number of information layers from different maps: (1) Topographic maps (district boundaries, contours, spot heights, drainage pattern, roads, tracks, localities, wall). (2) Geological maps (geological, overlapping, faults, mineralized veins and metamorphic aureole). (3) Geochemical data (geochemical profiles: 4178 geochemical samples were digitized, which 2105

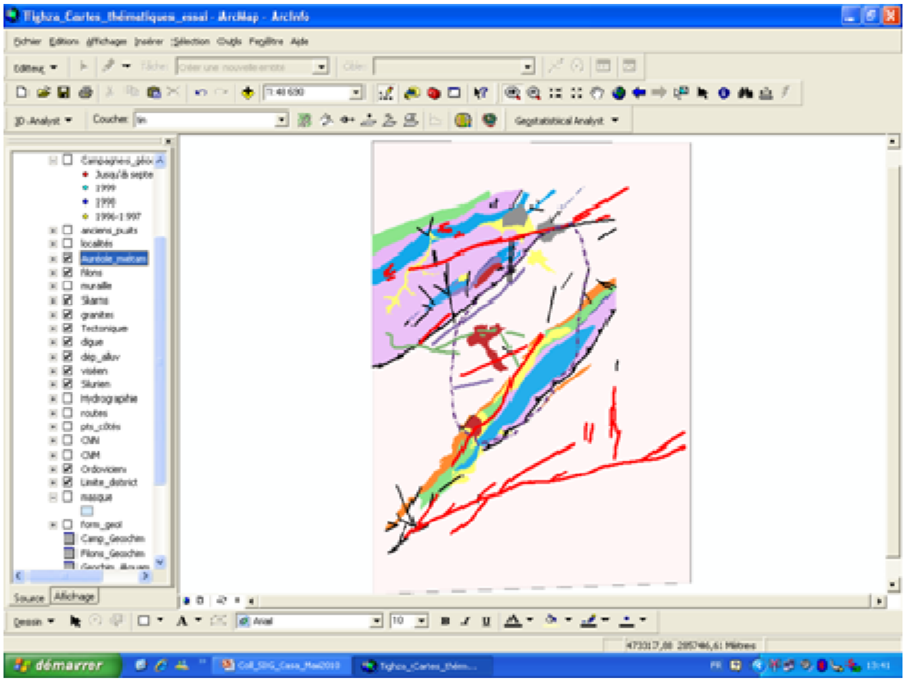

Figure 2. Geological and metallogenic maps developed by using the GIS tool

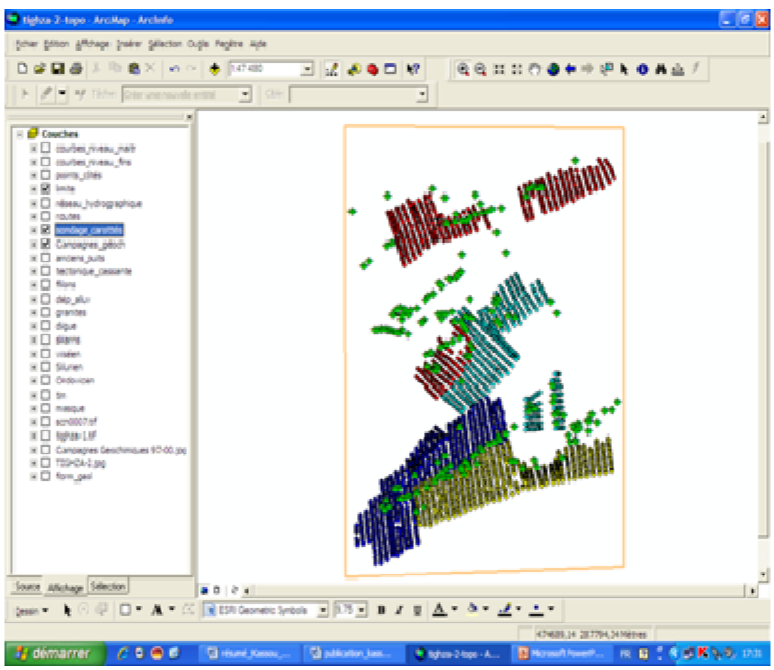

Figure 3. Geochemical profiles and Cores drilling maps

analyzed samples). (4) Cores drilling data (329 cores drilling, which 377 analyzed samples). Subsequently, we proceeded to the alphanumeric data integration, consisting of a description of each graphic object contained on each information layer (*Figure 2 and Figure 3*).

A Digital Elevation Model (DEM) of Tighza sector has been developed by basing on digitazed contours and spot heights from the topographic map 1/5000. The digitazed contour interval is at 5 m and the altitude is between 1060 and 1490 m (*Figure 4*).

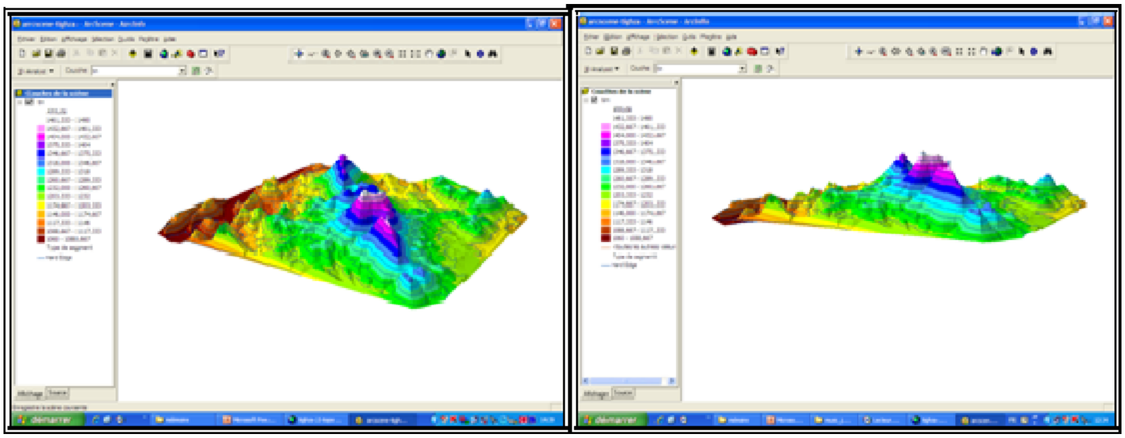

Figure 4. Digital Elevation Model (DEM) of the Tighza mining district

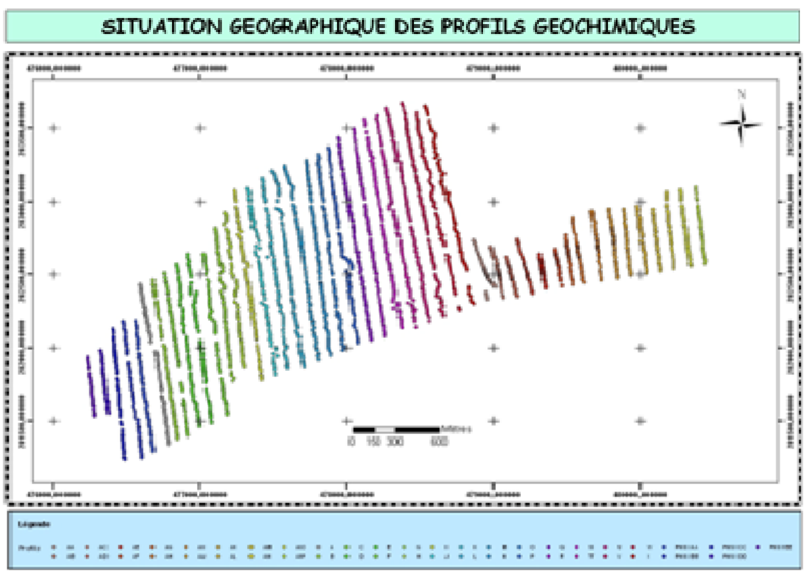

Figure 5. Location map of the geochemical profiles

Statistical analysis of the geochemical profiles

The data statistical analysis is essentially to describe the relationship between the variables and observations in our data matrix. This matrix consists of p variables and N individuals. Thus, our statistical series consists of 33 quantitative variables measured in 2105 individuals sampled in different sites (*Figure 5*). The quantitative variables taken into account in this treatment are the levels of heavy metals (Li, Be, B, V, Cr, Co, Ni, Cu, Zn, As, Sr, Y, Nb, Mo, Ag, Cd, Sn, Sb, Ba, W, Pb, Bi, Ge and Se) and the contents of major elements (SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, K_2O, MnO, TiO_2 and P_2O_5).

The main objective of this study is to strip these geochemical data by statistical and geostatistical approach whose the aim is to firstly give an overview on the geochemical behavior and on the other hand, recognize the dispersion of the polymetallic mineralization constituting the Tighza mining district. The profiles were made and organized so as to align in a NS direction. In total, 2105 samples have been made following 45 lines with the same variables. The samples are approximately distributed as follows a regular grid of about 10 m.

Principal Component Analysis (PCA)

In a first step, we work by taking into account all of the geochemical profiles without elimination and with a uniform weighting. The study was performed by using the centred reduced data. The first analysis after calculating the distance profiles in the gravity center G of the points cloud showed the existence of individuals (a total of 41samples representing only 1.9% of all profiles) which have a very large distance to the origin. So they

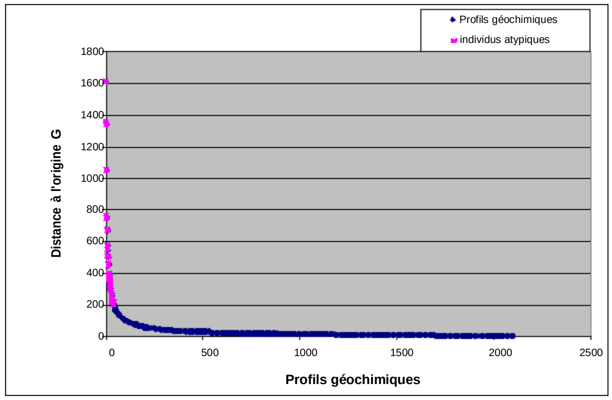

Figure 6. Distance from the origin G of the geochemical profiles

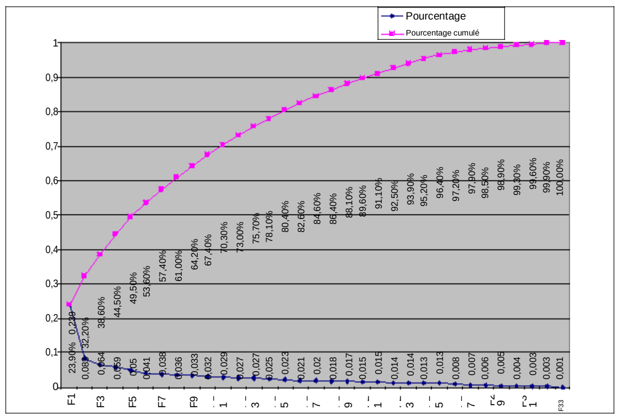

Figure 7. Graphic of the percentages and cumulative percentages of the absorbed variance by its eigenvalues

contribute significantly to the total variance. Therefore, these individuals are called atypical. On account of their strong contribution, they are removed before entering the principal component analysis (*Figure 6*).

So, the data matrix to be processed is an array of 2064 individuals and 33 variables. We conducted a multivariate technique of principal component analysis (PCA).

It consists of a hierarchy of contained information in a data table by calculating the maximum elongation axis of a points cloud as follows a several axes. This method allows us to highlight the interrelationships among variables and possible similarities between individuals or individuals groups which present the similar characteristics on a particular axis.

The principle of the geochemical data treatment in principal component analysis technique is to combine the chemical elements which have the similar chemical characteristics by creating for each grouping a synthetic variable: the "principal component". This technique synthesizes the inter-elementary relationships by extracting the eigenvectors of the correlation matrix. It develops the linear combinations of the original variables which produce the factors expressing the inter-elementary relationships. A set of the new uncorrelated variables, for which we have the numerical values at each sample point is generated. The models of principal component analysis are calculated by using adequate statistical software. The interpretation of the principal component analysis factors is an important basis of our study, which are based our work of the sampling mediums characterization. Thus, the geochemical campaigns samples are ordered along a factorial axis, so that those who most resemble vis-à-vis the principal component are grouped along this axis. Each principal component contains a part of the total described information by its "eigenvalue". We interpret jointly a several factorial axes, we cumulate the expressed information on each principal component.

The distribution of the total variance in terms of the factors noted a dominant first principal component explaining about 23.87% of the total variance. So, for the better data representation, we take the first principal components; with the first ten selected factorial axes (F1, F2,. ..., F10), we have nearly 67.38% of the inertia (or dispersion) of all point cloud (*Figure 7*).

The correlation circles (*Figure 8*) distinguish two poles,

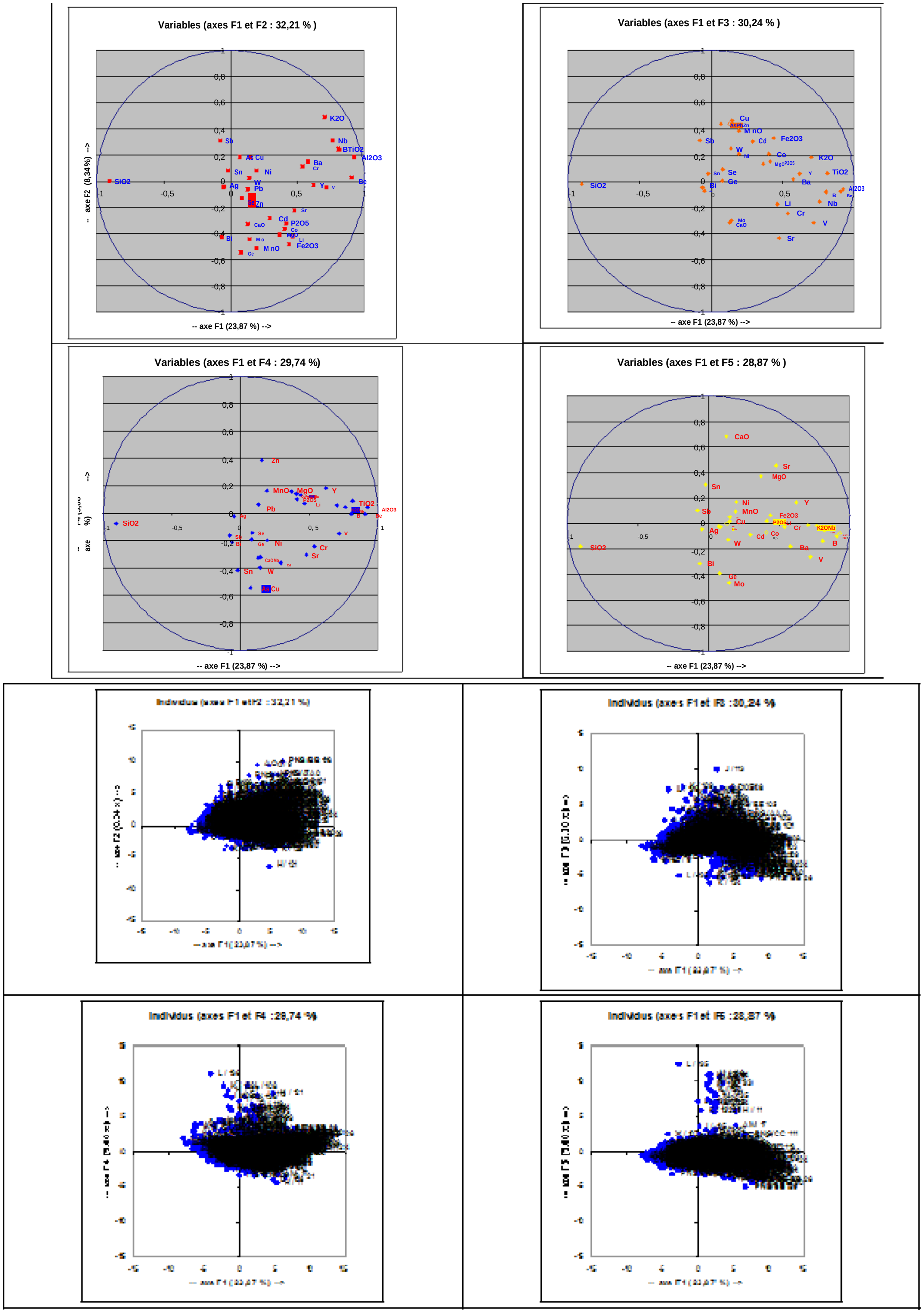

Figure 8. Projection of the variables and individuals ccording to the first four factorial designs absorbing the maximum total variance

one negative and the other positive manifested by the anomalies of metal concentrations following (we present here only the results of the five principal axes):

- The factorial axis 1 (23.87% of the variance) is positively determined by Cr, Ba, Y, K_2O, V, Nb, B, TiO_2, Be and Al_2O_3; and negatively by SiO_2.

- The factorial axis 2 (8.34% of the variance) is positively determined by Sb Nb and K_2O; and negatively by G, MnO, Fe_2O_3, Mo, Bi, Li, MgO, Co, CaO and P_2O_5.

- The factorial axis 3 (6.38% of the variance) is positively determined by Cd, Sb, Fe_2O_3, MnO, Pb, As, Zn andCu; and negatively by Sr, CaO, V and Mo.

- The factorial axis 4 (5.88% of the variance) is positively determined by Zn; and negatively by Cu, As, Sn, W, Cd, CaO, Mo and Sr.

- The factorial axis 5 (5% of the variance) is positively determined by Sn, MgO, Sr and CaO; and negatively by Mo, Ge, Bi and V.

The figure 8 also shows that in the principal planes which are projected on individuals, the axes represent the individuals with a high metal content similar to those projected on the correlation circle of variables mentioned earlier. The calculation of the effect of individuals on the factorial axis was made to identify the individuals which have a negative or positive effect on the axes; by calculating the root of each factorial axes eigenvalue and selecting all the individuals which are an absolute value greater than the square root of the eigenvalue. The individuals who define the five principal axes are many and varied, making the graphic too busy and unreadable. We quote for example, some individuals which determine their effect on the principal axes:

- The factorial axis 1 (23.87% of the variance) is positively determined by the individuals D/109, Q/133, PNS/CC2, P/121, X/126, L/119, V/107 and E/5; and negatively by the individuals AK1, AL3, AI101, PNS/DD103, AI100, AO8, A/25 and Q/21.

- The factor axis 2 (8.34% of the variance) is positively determined by the individuals V/119, L/116, W/123, U/106, T/125, Q/123, S/120 and F/117; and negatively by the individuals PNS/CC111, H/11, D/8, B/0, PNS/BB17, AO17 and F/13.

- The factor axis 3 (6.38% of the variance) is positively determined by the individuals P/137, G/102, AF11, N/103, AM6, J/14 and H/8; and negatively by the individuals K/134, PNS/BB26, AN11, AJ15, L/135, AN10 and AO25.

- The axis factor 4 (5.88% of the variance) is positively determined by the individual I/3, X/28, AL10, B/2, R/115, O/11, C/119, W/4 and P/29; and negatively by the individuals L/136, K/109, H/121, R/138, M/136, X/108 and I/108.

- The axis factor 5 (5% of the variance) is positively determined by the individuals B/110, R/24, AN19, AC7, A/119, S/4, PNS/AA14, AB18, AA7 and G/3; and negatively by the individuals PNS/BB29, F/32, C/121, AO26, PNS/EE11, PNS/CC30, E/5 and D/114.

The principal component analysis results provide the degree of the chemical elements association with the factors. These results help to determine how much of the variability of a particular chemical element is attributable to the variations of the mineralized bodies and the associated factors with a specific mineralization.

Ascending Hierarchical Classification (AHC)

The Ascending Hierarchical Classification is an automatic method of the complementary classification of the principal component analysis. It can classify the individuals or individuals groups previously identified by the PCA method. The AHC technique proceeds by successive aggregation of the individuals and individuals groups in terms of their similarities in comparison to an ensemble of criteria. So, this procedure involves a choice of two criteria for the grouping of the individuals and individual classes. Many grouping criteria are related to the objectives of our study and the variables type that we use. The first criterion is the choice of the distance between the individuals (*index which measures how two individuals are different*). The second criterion concerns the distance between the individuals groups.

In this study, we performed an Ascending Hierarchical Classification method to all 2064 individuals by using the Ward criterion (*minimizing the intra-class variances and maximization of the inter-class variances*). This classification provides a set of partitions represented as a tree called dendrogram or classification tree that allows us to establish the individuals groups based on their geochemical similarity, based on the euclidean distance between the individual and the center of gravity (average). At the initial stage, each geochemical profiles sample form a class. It has 2064 classes. In the first step, we group the first and nearest two samples. The typology is then formed in 2064 classes. The sum of squares of the cloud points distances (geochemical profiles) in the center of gravity is equal to (N-1)*p (or (2064-1)*33=68079 in our cases). The quality of this type is 1-(0/68079) =1, where 0 is the distance from Ward. The 2064 class typology explains 100% of the total sum of squares total. The figure above shows a hierarchical classification tree for the geochemical profiles. Five classes are distinguished (*Figure 9*):

Geostatistical study of the geochemical profiles

In this subsection, we propose to establish the geochemical profiles cartography for each chemical element by using the geostatistical modeling (kriging). It suffices to make the estimate calculating experimentally the spatial structure and modelling it. It is the aim of the variography, which is the heart of geostatistical analysis.

This study was was performed by using the Surfer 8 software. It consists of three steps:

* Establishment of the experimental variogram and fitting a model,

* Production of the variographic maps

* Kriging for mapping.

The search for the anisotropies is then refined by calculating the experimental variogram in several directions, and we study the direction difference. We will simply present in this article for example only three calculated variographic maps of 33 (*Figure 10 (on the left)*). These maps are made with a pitch h between 31m and 1566m. The geostatistical studies based on the calculated variograms from the variables show the anisotropy in the mineralization distribution contained in the Tighza deposit. The anisotropy is marked at the NE-SW major axis and NW-SE minor axis. The color scale corresponds to the taken values by the variogram for each direction and every measuring step.

When the model is properly adjusted, the interpolation can be performed anywhere. The Kriging is often made on a regular grid to obtain the studied variable map. The figure 10 (*on the right*) shows the estimated concentrations result of each chemical element by kriging. This map reveals the important concentrations trends throughout the studied district.

CONCLUSION

The inconvenient, cumbersome and slow to access to the transcribed geographic information onto paper are so many reasons which encourages the responsible mining managers to model through a GIS, the spatial available data. The graphic modeling of the bottoms and the important spatial database quantity can be accessed at almost to the geographic information for its use and update, and therefore improving the efficiency and profitability of the considered process.

The computerized work, performed on geochemical profiles data of the Tighza mining district, is complemented by a statistical and geostatistical treatment of the geochemical profiles, also the establishment of the thematic maps which used to develop a geochemical model informing about the polymetallic concentrations distribution in this district. The statistical and geostatistical methods are the reliable, rapid and quantitative means for the study and interpretation of such geochemical profiles, which are many. They bring clear undeniable added value for the cartography, evolution analysis and mineral contents variation. This added value lies in:

* The use of the intrinsic spatial structure of the phenomenon to its estimate,

* The rigorous integration of auxiliary variables which associated to the interest phenomenon by thereby improving the estimation,

* The quantifying the associated error with each estimate.

This statistical work will be complemented by a statistical and geostatistical treatment of the mineralized veins and those of core drilling data, in order to synthesize a comprehensive summary of the polymetallic body distribution in the Tighza mining district.

ACKNOWLEDGEMENTS

This work was performed under the Protars III D15/31 Project and with the support of the fellowship N° b11/006 granted by the National Center for Scientific and Technical Research, and the Touissit Mining Company. We thank all who contributed, in one way or another, to make this work. A particular thanks to the TMC geologists and Directorate, which we like to express our gratitude.

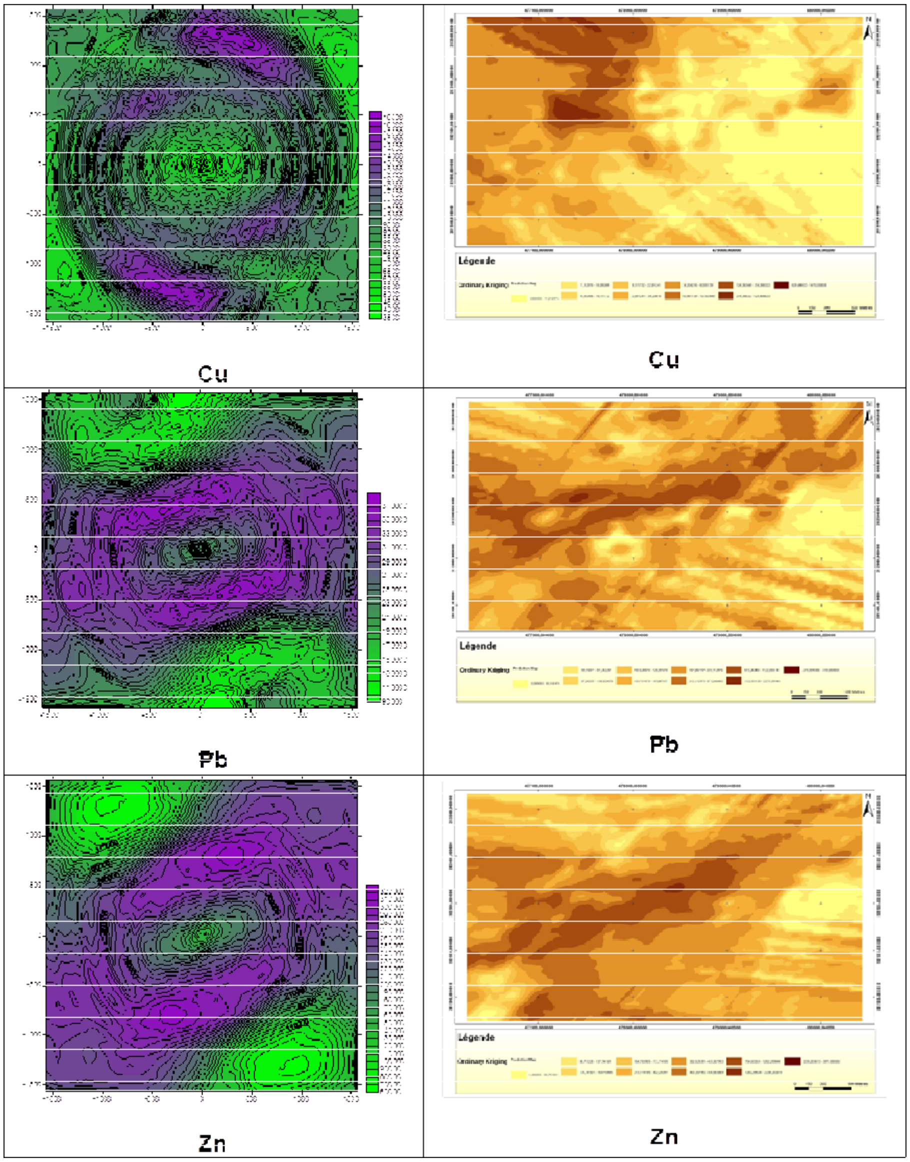

Figure 9. Variographic maps (on the left) and Ordinary kriging maps of some chemical (on the right)

REFERENCES

Balouki S (1995). «Study of the hydrothermal gold mineralization and associated fluids in the Tighza shear zone. (Jbel Aouam, Central Morocco)». *3rd cycle thesis, Cadi Ayyad Univ. Marrakech. p. 193*

Bennasser M (1996). «Lithostratigraphy, Hercynian tectonic, paleofield of the late-Hercynian forces and fracturing-mineralization relationship of the Aouam region (eastern central Morocco) ». *3rd cycle thesis, 5th Mohamed Univ, Fac. Sc. Rabat. p. 300*

Bensahal A (2001). «Hercynian structure of Khouribga -Oulmès anticlinorium between Ez Zehiliga and Tiddas (Hercynian Central Morocco). Ordovician - Devonian basement structure; formation and deformation of its Carboniferous coverage: Sidi Kassem Basin». *PhD thesis, 5th Mohammed Univ. - Agdal, Rabat. p. 248.*

Bouabdelli M (1989). «Tectonics and sedimentation in an orogenic basin: the Visean furrow of Azrou-Khenifra (Eastern Hercynian Central Morocco)». *State thesis, Fac. Sc, Louis Pasteur Univ, Strasbourg. pp.262*

Cheilletz A (1984). «Contribution to the metallogeny of the polymetallic district (W-Mo-Cu-Pb-Zn-Ag) of Jbel Aouam (Central Morocco)». *State thesis, I.N.P.L., C.R.P.G., E.N.S.G. Nancy. pp. 250*

Faik F (1988). «Paleozoic of the Mrirt region (Eastern Central Morocco): stratigraphic and structural evolution». *3rd cycle thesis. Fac. Sci. Paul Sabatier Univ., Toulouse. pp. 233*

Nerci K (2007). «The gold mineralization of the Tighza polymetallic district (Central Morocco): an example of the late-Hercynian perigranitique establishment». *3rd cycle thesis, 2nd Orléans, Univ., France. p. 304*

N'Tarmouchent A (1991). «Hercynian magmatism of M'rirt region (Eastern Central Moroccan Massif). Cartography, geochemic petrology and geodynamic context». *3rd cycle thesis, Fac. Sci. Fez. p. 169*

Wadjinny A (1998). «Lead in Morocco: case of the Touissit and Jbel Aouam districts*». Mining Research Chronicle 531-532, pp. 9-28.*