Fernández, E. 2006. Integration of geological data by weights of evidence and logistic regression in the Iberian Pyrite Belt, Spain. *Boletín Geológico y Minero,* 117 (Núm. Monográfico Especial): 563-566
ISSN: 0366-0176

Integration of geological data by weights of evidence and logistic regression in the Iberian Pyrite Belt, Spain

E. Fernández

IGME. c/ Ríos Rosas 23. 28003 Madrid
E-mail: evamarff@gmail.com

ABSTRACT

A preliminary investigation has been carried out by the Geological Survey of Spain, to evaluate mineral potentiality in the NW domain of the Iberian Pyrite Belt. Research focused on volcanogenic massive sulphide deposits of the so-called "Vocano Sedimentary Complex" from Lower Carboniferous. Four evidential maps (lithologic, gravity, magnetic and structural) were incorporated into a geographical information system and integrated in a mineral potential map, using weights of evidence and logistic regression methods. The goal is the application of a new methodology in this area that may facilitate mineral resources decision-making processes. Promising results were achieved concerning the use of such mathematical methods to applied geology.

Key words: Favorability map, geographical information systems, logistic regression, massive sulphides, weights of evidence

Integración de datos geológicos mediante pesos de evidencia y regresión logística en la Faja Pirítica Ibérica, España

RESUMEN

El Instituto Geológico y Minero de España ha llevado a cabo una investigación preliminar para evaluar el potencial minero del Dominio NO de la Faja Pirítica Ibérica. El énfasis de la investigación recayó en el estudio del llamado "Complejo Vulcano Sedimentario" de edad Carbonífero inferior. Cuatro mapas de evidencia se incorporaron a un sistema de información geográfica (litológico, gravimétrico, magnético y estructural), lo que permitió su integración en un mapa de potencial de mineralización, mediante la aplicación de métodos de pesos de evidencia y regresión logística. El objetivo final es ayudar a la toma de decisiones en futuros trabajos de exploración minera. Los resultados obtenidos son prometedores en cuanto a uso de estos métodos matemáticos con fines de geología aplicada.

Palabras clave: mapa de favorabilidad, pesos de evidencia, regresión logística, sistemas de información geográfica, sulfuros masivos

Introduction

The Iberian Pyrite Belt (IPB) is one of the most important metallogenic provinces in the world with more than 1700 Mt of sulphide ore deposits. There are several reasons supporting the application of potential mapping techniques to the IPB. Mining has been indeed active in the belt since the Chalcolithic era; consequently new approaches and tools are currently required to help identify mineral deposits. On the other hand, there is a complete array of data available concerning the area. Implementation of such methods is also relevant since they may also enable new research lines in relation with mineral resources of the belt.

Since the 80´s, mineral potential mapping has been developed as a research tool for well explored areas with many data or new exploration zones at a very low cost. Advances in spatial modelling techniques have been possible due to the availability of more powerful computer systems and the development of geographical information systems (GIS).

Geological setting

The study area is located in the NW domain of the IPB in the province of Huelva, Spain. The zone is approximately 30x20 km^2 and corresponds with the geological map MAGNA 937 (scale 1:50.000).

The mineralization model is of volcanogenic massive sulphides (VMS) and is genetically related to submarine volcanic activity. Most common mineral associations are pyrite with complex sulphides of Cu-Pb-Zn and Au-Ag as accessories.

It is important to stress that the mineral deposits discovered have a very strong stratigraphic control. They are hosted in the volcanic rocks of the Volcano Sedimentary Complex. Bearing in mind this idea, a synthesis of the geological map has been carried out according to whether mineral deposits are present or not. Thus, two main lithologic groups have been distinguished. The first group -hosting mineral deposits- is the Volcano Sedimentary Complex (Lower Carboniferous) composed by acid, intermediate and basic volcanic rocks stratified with slates and jaspers. The second group -metasedimentary rocks- is barren and it is based on slates, greywackes and quartzites outcropping in the P-Q Group (Late Devonian) and the Culm Group (Upper Carboniferous). Within the study area, 13 mines and occurrences have been documented, including exclusively those of pyrite.

Methodology

The present project deals with mathematical geology. Therefore, it aims at applying an array of statistical methods that integrate geological information for mapping mineral potential. In brief, potential modelling is a multi-stage activity that can be summarized as follows: Multiple geological evidential maps are selected from a dataset as massive sulphide predictors. Thereafter, statistical methods are employed to evaluate spatial associations between data and combining together evidential maps to finally obtain the favorability map.

The computer environment used for both manipulation and combination of spatial data was the GIS ArcView 3.2 as well as the Spatial Data Modeller extension develop by the Geological Survey of Canada (Kemp *et al.* 2001) for spatial data modelling using weights of evidence, logistic regression, fuzzy logic and neural network analysis.

Weights of evidence and logistic regression

In this case, two data driven methods were selected for combining together multiple binary maps for potential mapping. Weights of evidence (Bonham-Carter *et al.* 1988; Wright and Bonham-Carter, 1996; Agterberg 1992; Wilkinson *et al.* 1999) and logistic regression (Chung and Agterberg, 1980; Reddy and Bonham-Carter, 1991) are loglinear methods that yield posterior probability values, although having different mathematical backgrounds i.e. Baye´s rule and regression analysis, respectively. One limitation with weights of evidence respect to logistic regression is that it assumes conditional independence between input maps with respect to mineral deposits; this assumption was tested by the χ^2 pairwise test. Explanations concerning the mathematics behind such methods are beyond the scope of this communication and can be further elucidated reviewing the literature mentioned above.

Application to the dataset: Practical case in the IPB

The prior probability value (0,062) is initially calculated as the number of cells containing deposits divided by the total number of cells in the study area. This value represents the probability of occurrence of a mineral deposit if any cell is randomly selected, such value being unique for the whole area. The advantage of applying this methodology is that the final probability map shows values that are higher or lower than the prior probability and as a result, the target area is strongly reduced.

Four evidential maps were selected as inputs for the weights of evidence and logistic regression methods: lithology, shear bands, vertical derivative of total magnetic field and vertical derivative of Bouguer anomaly. Maps were reclassified into binary maps to feed the models, choosing the cutoff threshold that maximizes the contrast.

Table 1 shows contrast and regression coefficients for the evidential maps arranged decreasingly. The contrast is expressed as $C = W^{+} - W^{-}$, W being the weights positive and negative calculated as log ratios of conditional probabilities These parameters estimate the strength of the spatial association between mineral deposits and binary evidential maps (the higher the value, the stronger the correlation) and are used to weight each evidence map (Table 1). From the table it can be observed that the shear bands binary map is the theme that better correlates with mineral deposits and as expected, both parameters coincided in the qualitative order of themes.

Evidence theme	**Weights of Evidence** *Contrast*	**Logistic Regression** *Coefficient*
Shear bands	1,5644	1,2855
Magnetic	1,5561	0,8807
Gravity	1,2383	0,8763
Lithology	1,1122	0,5990

Table 1. Binary evidential maps contrast and regression coefficients
Tabla 1. Coeficientes binarios de contraste y regresión para cada tipo de mapa de evidencia

Following the mentioned estimations, the next step was the overlapping of the input binary maps in a unique conditions map with 2^n classes, n being the number of input maps. A posterior probability value was calculated for the 16 classes, subsequently obtaining the massive sulphides potential map that was reclassified into three classes (low, moderate and high favorability) to generate the map of Figure 1. The posterior probability intervals considered are summarized in Table 2.

WofE	Logistic regression	Favorability
0,0121-0,0941	0,0193-0,0663	Low
0,0941-0,2166	0,0663-0,1145	Moderate
0,2166-0,7436	0,1145-0,4283	High

Table 2. Posterior Probability values of the final classes
Tabla 2. Valores de Probabilidad Posterior de las clases finales

Results

Patterns obtained by the two methods are equal due to the unique conditions map is a common feature, what changes is the posterior probability values. In the weights of evidence method they range 0,012-0,744 and in the logistic regression method 0,019-0,428. In fact, if the Spearman´s rank correlation coefficient (r_s) is calculated, $r_s = 1$ is reported, which means that there is a perfect correlation between the posterior probability maps.

The potential map shown above can be used to define and locate interest areas which can be the objective of more detailed studies. As it was expected the higher favorability values are confined to the Sedimentary Volcanic Complex lithologies, hence verifying the hypothesis of the strong stratigraphycal control of massive sulphides. In addition, it has been calculated that the 85% of mineral deposits are located over moderate and high favorability areas of the potential map.

Conclusions

It is the first attempt to apply mineral potential mapping in the Iberian Pyrite Belt and the present work proves that it can be a worthy tool to facilitate mineral resources research in this area. Principal conclusions and remarks are the following:

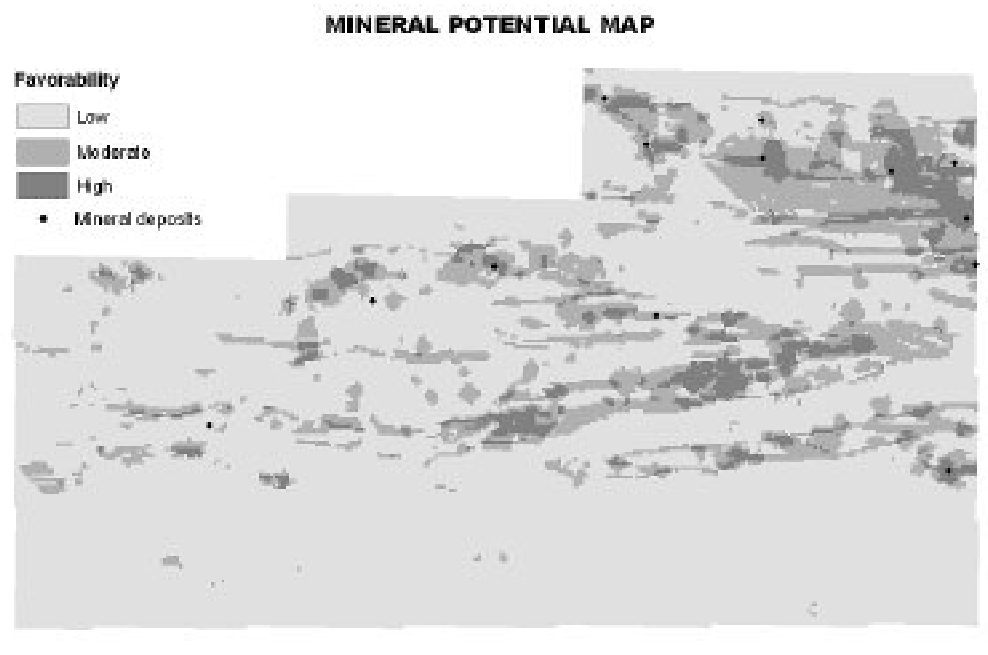

Fig. 1. Weights of evidence and logistic regression final map
Fig. 1. Mapa final de pesos de evidencia y regresión logística

1. Contrast and regression coefficient are parameters that can be used to measure spatial associations between data. The shear bands evidential theme has the stronger spatial association with mineral deposits, followed by the magnetic, gravity and lithologic evidential maps.
2. Weights of evidence and logistic regression methods generate similar map patterns owing to the fact that they are based on the same unique conditions map. Nevertheless, the logistic regression posterior probability values are lower than the ones resulting from the weights of evidence method. It can be concluded that although both methods yield similar patterns (r_s = 1), logistic regression is more conservative.
3. The last purpose of mineral potential mapping is to help in the decision making process. After applying these methods the initial study area is reduced to the zones of high favorability in the potential map, which should be further investigated on the field.

Other methods like fuzzy logic and artificial neural networks (Radial Basis Functional Link Net) will also be performed in the study area, to compare if high favorability zones coincide with the ones obtained by weights of evidence and logistic regression.

References

Bonham-Carter, G.F., Agterberg, F.P. and Wright, D.F. 1989. Weights of evidence modelling: a new approach to mapping mineral potential. Statistical Applications in the Earth Sciences. *Geological Survey of Canada Paper* 89-9, 171-183.

Chung, C.F. and Agterberg, F.P. 1980. Regression models for estimating mineral resources from geological map data. *Mathematical Geology* 12 (5), 473-488.

Kemp, L.D., Bonham-Carter, G.F., Raines, G.L. and Looney, C.G. 2001. Arc-SDM: Arcview extension for spatial data modelling using weights of evidence, logistic regression, fuzzy logic and neural network analysis

Leistel, J.M., Marcoux, E., Thiéblemont, D., Quesada, C., Sánchez, A., Almodóvar, G.R., Pascual, E. and Sáez, R. 1998. The volcanic-hosted massive sulphide deposits of the Iberian Pyrite Belt. *Mineralium Deposita,* 33, 2-30.

Recibido: diciembre 2005
Aceptado: julio 2006