Chapter 81
Application of GIS-Based Weights of Evidence Method for Metallogenic Prediction to Copper Resources in Western Region of Zhejiang, China

Wei Shen and Haiyan Du

Abstract In western region of Zhejiang province, structure and magma activity occur frequently; Proterozoic eon and Paleozoic era of copper mineralization favorable layers are distributed in those regions; the NE orientation deep fractures develop and move; the Shengong period and early Yanshanian of magma activity closely relate to mineralization. There are well metallogenic conditions of Au, Ag and Cu minerals in the regions according to the long-term and complex geological evolution, tectonism and magmatic activity. Based on analysis of tectonism, stratum, rock, fractures and minerogenetic map in the region, the geological variables are obtained by the multi-source information of geological abnormity, minerogenetic abnormity using MAPGIS and MORPAS software. The study regions are divided into 1755 grid cells with 5km×5km. The five minerogenetic prospect regions of Cu deposits are obtained by weightsof evidence modeling, which show that weight of evidence method is a good tool for minerogenic prediction.

Keywords Weights of evidence • Minerogenic prediction • Mineral deposits • Metallogenetic belts

81.1 INTRODUCTION

The weights of evidence (WofE) is one of the most popular methods for mapping mineral prospectivity, which use the Bayesian theory of conditional probability to quantify spatial associations between evidence layers (or geological factors) and known mineral occurrences. It combines the prior probability of mineral occurrence with the conditional probability of mineral occurrence for each evidential layer using Bayes' rule to derive posterior probabilities of mineral occurrence [1, 2].

W. Shen (✉)
China University of Geosciences, Xueyuan Road 29, Beijing, P.R. China
e-mail: shenweihome@sina.com

H. Du
China Geological Library, Xueyuan Road 29, Beijing, P.R. China

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In WofE modeling, a map pattern consisting of points (e.g., mineral deposits on 1:200,000 map) is related to one or more map patterns that are continuous in that they assume values at all points in the study area. Suppose that a study area is digitized as a number (n) of pixels and that X_i ($i = 1, 2, \ldots, p$) are a number of binary explanatory variables used to predict a dichotomous random variable Y representing the presence (Y_k=1) or the absence (Y_k= 0) of mineralization at the k-th pixel. Provided that n is very large, we can redefine the situation in terms of binary sets B_i corresponding to the X_i, and a set D corresponding to Y. In most WofE applications, the B_i are binary with or without missing data, but the method also can be used with multi-state explanatory variables [3].

WofE is based on the idea of prior and posterior probability; the former is the probability that a terrain unit contains an event before considering any existing predictor variables (the favorable conditioning factors); the latter is an "adjustment" or response of the prior probability, taking into account the evidence from one or more spatial patterns. Positive and negative weights (W^+ and W^-) are initially calculated; the magnitude of these weights depends on the measured association between the response variable and each class of each predictor variable. The difference between W^+ and W^- defines the contrast (C=W^+- W^-), an overall measure of the degree of the spatial association between each class of the predictor variables and the response variable. The MORPAS (Metal Ore Resource Prediction and Assessment System) that provides tools for weights of evidence, logistic regression, fuzzy logic, and neural networks based on MAPGIS, has been used in this study as a useful tool for automatically calculating the mentioned parameters [4].

81.2 OVERVIEW OF WEIGHTS OF EVIDENCE

When there is a single pattern B, the odds $O(D|B)$ (i.e., $O = p/(1 - p)$) for occurrence of mineralization if B is present is given by the ratio of the following two expressions of Bayes's rule:

$$P(D|B) = \frac{P(B|D)P(D)}{P(B)}, P(\overline{D}|B) = \frac{P(B|\overline{D})P(\overline{D})}{P(B)} \tag{81.1}$$

where the set $\overline{D}$ represents the complement of D. Consequently,

$$\text{In} \quad O(D|B) = In \;\; O(D) + W^+ \tag{81.2}$$

where the positive weight for the presence of B is

$$W^+ = \text{In}\frac{P(B|D)}{P(B|\overline{D})} \tag{81.3}$$

The negative weight for the absence of B is

$$W^{-} = \text{In}\frac{P\left(\overline{B}\middle|D\right)}{P\left(\overline{B}\middle|\overline{D}\right)} \tag{81.4}$$

When $p = n$, there are two relations:

$$P\left(D\middle|\bigcap_{i=1}^{n} B_i\right) = \frac{P\left(\bigcap_{i=1}^{n} B_i\middle|D\right)P(D)}{P\left(\bigcap_{i=1}^{n} B_i\right)} P\left(\overline{D}\middle|\bigcap_{i=1}^{n} B_i\right) = \frac{P\left(\bigcap_{i=1}^{n} B_i\middle|D\right)P\left(\overline{D}\right)}{P\left(\bigcap_{i=1}^{n} B_i\right)} \tag{81.5}$$

Conditional independence of D with respect to $B_1, B_2, \ldots, B_n$ implies that

$$P\left(\bigcap_{i=1}^{n} B_i\middle|D\right) = \prod_{i=1}^{n} P\left(B_i\middle|D\right) P\left(\bigcap_{i=1}^{n} B_i\middle|\overline{D}\right) = \prod_{i=1}^{n} P\left(B_i\middle|\overline{D}\right) \tag{81.6}$$

$$\text{Consequently,} \quad P\left(D\middle|\bigcap_{i=1}^{n} B_i\right) = P(D)\frac{\prod_{i=1}^{n} P\left(B_i\middle|D\right)}{P\left(\bigcap_{i=1}^{n} B_i\right)} P\left(\overline{D}\middle|\bigcap_{i=1}^{n} B_i\right)$$

$$= P\left(\overline{D}\right)\frac{\prod_{i=1}^{n} P\left(B_i\middle|\overline{D}\right)}{P\left(\bigcap_{i=1}^{n} B_i\right)} \tag{81.7}$$

From these two equations it follows that

$$\frac{P\left(\overline{D}\middle|\bigcap_{i=1}^{n} B_i\right)}{P\left(\overline{D}\middle|\bigcap_{i=1}^{n} B_i\right)} = \frac{P(D)\prod_{i=1}^{n} P\left(B_i\middle|\overline{D}\right)}{P\left(\overline{D}\right)\prod_{i=1}^{n} P\left(B_i\middle|\overline{D}\right)} \tag{81.8}$$

This expression is equivalent to

$$\text{In } O\left(D\middle|\bigcap_{i=1}^{n} B_i\right) = \text{In } O(D) + \sum_{i=1}^{n} W_i^{+} \tag{81.9}$$

The log-odds on the left side of this expression is also known as the posterior logit. It is simply the sum of the prior logit and the weights of n map layers. The posterior probability follows from the posterior logit. Similar expressions apply when either one or both patterns are absent [5].

81.3 EXAMPLE OF APPLICATION

WofE modeling of mineral potential involves a three-stage process: (a) estimation of prior probability (P_{prior}) of prospect occurrence, (b) estimation of weights to be assigned to presence and absence of spatial evidence with respect to the prospects, and (c) updating of P_{prior} by using these weights to estimate the posterior probabilities ($P_{posterior}$).

Based on regional geological background analysis relationship and between minerals and geological background, the study regions are divided into 1755 grid cells with 5km×5km and the eleven geological variables (or evidential layers) are obtained by 1:200 000 geological maps and related minerals distribution maps (or layers). The weights for each geological variable (or evidential layer) are implemented in a GIS environment using MORPAS and MAPGIS (see Table 81.1). Based on proximity analysis, the posterior probability map and the five metallogenic prospective regions of Cu deposits are worked out by tectonism, stratum, rock, fractures, geological abnormity, minerogenetic abnormity, the values of posterior probability and the measures of the association of training sites (Fig. 81.1).

Table 81.1 Weights for each geological variable (or evidential layer)

Variable (or layer)	Criteria	W^+	W^-	Contrast
Percentage of favorable stratum areas	1 for >15%	0.738	-0.354	1.092
	0 for <=15%			
Entropy of stratigraphic combination	1 for >20%	0.026	-0.686	0.712
	0 for <=20%			
Values of factor abnormality for metallogenic element cluster	1 for presence	1.052	-0.122	1.175
	0 for absence			
Syntectic type granite	1 for presence	0.357	-0.086	0.443
	0 for absence			
Yanshanian rock mass	1 for presence	0.449	-0.384	0.833
	0 for absence			
Fracture equidensity	Calculated values	0.212	-0.243	0.455
Number of fracture intersection points	Calculated values	0.113	-0.006	0.118
Number of Ag deposits occurrences	Calculated values	1.534	-0.109	1.644
Number of Au deposits occurrences	Calculated values	1.712	-0.126	1.838
Number of Pb-Zn deposits occurrences	Calculated values	0.129	-0.003	0.132
Number of Fe deposits occurrences	Calculated values	0.385	-0.031	0.416

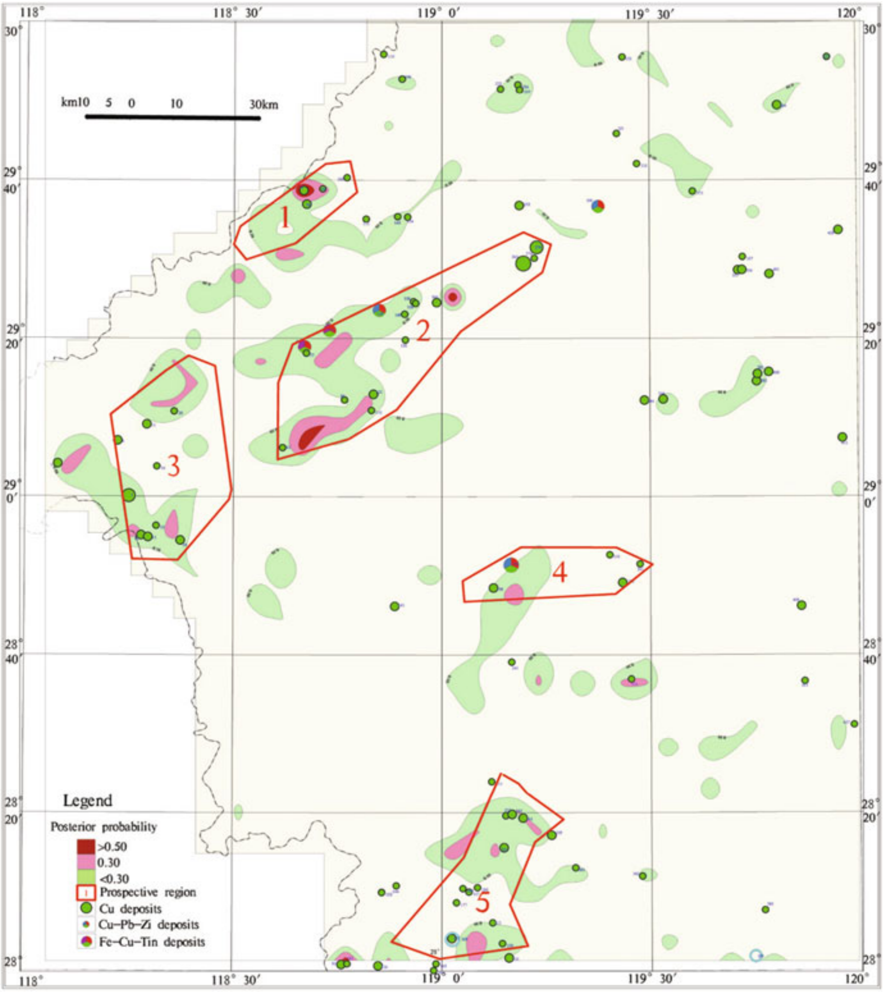

Fig. 81.1 Posterior probability map and five metallogenic prospective regions of Cu deposits

81.4 CONCLUSIONS

The study regions are divided into 1755 grid cells with 5km×5km and the eleven geological variables (or evidential layers) are obtained by 1:200 000 geological maps and related minerals distribution maps and based on regional geological background analysis relationship and between minerals and geological background. The weights for each geological variable (or evidential layer) are implemented in a GIS environment using MORPAS and MAPGIS. The weights of evidence model is considered as reasonable and delineates permissive regions for Cu deposits. The weights of evidence model has the additional characteristics that it is well defined, reproducible, objective, and provides a quantitative measure of confidence.

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