Journal of Mining and Earth Sciences

Website: http://tapchi.humg.edu.vn

# Mineral potential mapping for tin ore using weights of evidence at Maty - Du Long Area, Ninh Thuan Province, Viet Nam

Dung Tien Nguyen [1,*], Tinh Thanh Bui [1]

[1] *Faculty of Geosciences and Geoengineering, Hanoi University of Mining and Geology, Vietnam*

ARTICLE INFO

*Article history:*
Received 10 Oct. 2016
Accepted 05 Mar. 2017
Available online 30 June 2017

*Keywords:*
Maty-Du Long
Ninh Thuan province
Original tin ore
Weights of evidence method (WOE)
Geographic information systems (GIS)

ABSTRACT

*According to the results of the previous research, a potential of original tin ore was preliminarily estimated for Maty - Du Long area, Ninh Thuan province. This research is to introduce the application of the weights of evidence method (WOE) combining with geographic information systems (GIS) to establish a tin potential map in Maty- Du Long area, Ninh Thuan province based on factors of geology, faults, geochemical anomaly and known mineral occurences. The weights of factors were calculated by using WOE method and performed by ArsGIS software. The final tin potential map was classified into three levels: high, medium and low potential of tin mineralization. The high tin potential covers 1.62% of the study area. It is initial results and useful for prospecting tin mineralization in next stage.*



## 1. Introduction

In recent years, geographical information systems (GIS) combing with geomathematical methods on earth sciences, and especially, on potential mineral mapping have been applied widely (Asadi and Hale, 2001; Bishop et al., 1975; Carranza et al., 1999; Hariri, 2003; Partington, 2010; Porwal et al., 2010). This application was generally used at an early stage for a small scale, and then, based on the initial results, more detailed investigations are being carried out on mineral potential areas at larger scales. Many methods and tecniques on generating favorable maps for mineral deposits were proposed such as the papers of Carranza et al., 1999; Hariri, 2003; Porwal et al, 2010 and Partington, 2010. Literature review shows that, weight for input factors can be carried out using data-driven and knowledge-driven methods. In the first method, evidential weights are estimated subjectively based on expert opinion about spatial association of target deposits with certain geologic features, whereas in the second one, the evidential weights are determined objectively with respect to locations of known target deposits. The most data-driven used methods are logistic regression, weights of evidence, and artificial neural networks. Weights of evidence (WOE) belongs to

*Corresponding author
*E-mail:* buithanhtinh@humg.edu.vn

the data-driven method that has been widely applied for generating mineral potential maps with high accuracy (Asadi and Hale, 2001; Bishop et al., 1975; Carranza et al., 1999; Hariri, 2003; Partington, 2010; Porwal et al., 2010).

Previous studies have indicated that Maty- Du Long area has a potential of tin ore with typical deoposits at Suoi Giang, Tap La, Dong Thong, Khe Den and Ta Nang. Beside studying results from those deposits, there is no systematically research about tin potential mapping for this area. Therefore, mapping tin potential areas for the study area is important for prospecting, explorating, and exploting in the near future.

Aim of this research is to introduce an application of the GIS-based WOE modeling for tin mineral potential mapping in Maty- Du Long area, Ninh Thuan province of Vietnam based on petrographical, geochemical, structural and mineral occurrences.

## 2. Weights of evidence

Weight of Evidence (WOE) was first proposed Bonham-Carter et al. (1989) for establishing relationships between input maps (called evidential maps) and deposits based on Bayesian theory. Accordingly, a set of evidential maps is created. Locations of known mineral occurrences are considered as points. These evidential maps are used as input maps and the output map will show the probability of occurrence and the associated uncertainty of the estimated probability.

According to Bayes rule, a binary hypothesis is tested when a certain domain (binary predictor pattern) is present (equation 1) or absent (equation 2).

$$P\{B|D\} = \frac{P\{B \cap D\}}{P\{D\}} = \frac{N\{B \cap D\}}{N\{D\}} \quad (1)$$

$$P\{B|\overline{D}\} = \frac{P\{B \cap \overline{D}\}}{P\{\overline{D}\}} = \frac{N\{B \cap \overline{D}\}}{N\{\overline{D}\}} \quad (2)$$

where P{B|D}is the conditional or posterior probability of a mineral occurrence given the presence of the predictor pattern; $N\{B \cap D\}$ is the conditional probability of being in the predictor pattern D, given the presence of a mineral occurrence B; N{D} is the prior probability of being in the predictor pattern; $P\{B|\overline{D}\}$ is the conditional probability of a mineral occurrence given the absence of a predictor pattern; $N\{B \cap \overline{D}\}$is the conditional probability of the absence of a predictor D given the presence of a mineral occurrence; $N\{\overline{D}\}$is the probability of being in the absence of a predictor pattern.

where W+ and W− are the weights of evidence when a binary is present and absent respectively. The weights for binary patterns are:

$$W^{+} = \ln LS = \ln \frac{P\{B\backslash D\}}{P\{B\backslash \overline{D}\}} \quad (3)$$

$$W^{-} = \ln LN = \ln \frac{P\{\overline{B}|D\}}{P\{\overline{B}|\overline{D}\}} \quad (4)$$

The variances of the weights can be calculated by the following expressions,

$$s^2(W^{+}) = \frac{1}{N\{B|D\}} + \frac{1}{N\{B|\overline{D}\}} \text{ và}$$

$$s^2(W^{-}) = \frac{1}{N\{\overline{B}|D\}} + \frac{1}{N\{\overline{B}|\overline{D}\}}$$

The contrast C = W+ - W- quantifies the spatial correlation between each binary map and the known events, providing a useful measure of the spatial association between a binary predictor pattern and the mineral occurrence points.

Positive spatial association, if C > 0; Negative spatial association, if C < 0; No spatial association, if C = 0.

For large areas with large numbers of mineral occurrences, for each test domain, the maximum contrast often gives the best measure of spatial correlation with the mineral occurrence points (Bonham-Carter, 1994; Turner, 1977). For small areas with small number of mineral occurrences, the uncertainty of the weights could be large and C can be meaningless and the Studentized value of C, calculated as the ratio of C to its standard deviation, C/s(C), serves as a test that the spatial correlation between the mineral occurrence points and a test domain is statistically significant (Bonham-Carter, 1994). The standard deviation of C is the square root of the sum of the variances of the weights. The Studentized value of C is used to define the optimum cut off.

$$s(C) = \sqrt{s^2(W^{+}) + s^2(W^{-})}$$

There procedures are implemented in a GIS. Binary maps (test domains), representing the four deposit recognition criteria, are generated and for each map the weights are calculated (i.e., a value of W+ for presence and of W- for absence) at every location (pixel). Then the weighted binary maps are combined to create a final predictive map.

In this method, the assumption of conditional independence of factors was checked. Depend factors need to rejected from mapping the tin potential areas. The $\chi^2$ values between all pairs of factors were calculaterd at the 99% significant level. A detailed description of this modeling is available in Bonham-Carter (1994).

## 3. Study area and data used

### *3.1. Description of the study area*

The study area belongs to Ninh Hai and Bac Ai districts, Ninh Thuan province (Vietnam), covering an area of 375.8 km$^2$. The area is between latitudes 14°20'08"N-14°29'55"N, and longitudes 107°33'04" E-107°44'47"E.

Geologically, the structure of the study area includes La Nga formation ($J_2$*ln*), Deo Bao Loc formation ($J_3$*đbl*), Don Duong ($K_2$*đd*) and loose Quaternary sediments. In this area, magma complexs include Dinh Quan complex (Di-GDi/$J_3$-*đq*), Deo Ca complex (GDi-G-Gs/K*đc*), Ca Na complex (G/$K_2$*cn*) and dikes (Fig. 1). Tectonic activities were strong with faults of northeast-southwest and northwest-southeast strikes. These faults play an important role in tin ore-forming process in the study area.

Inductively coupled plasma analysis indicated that Sn is common, followed by W, Mo, Cu, Pb, Zn. Minerals are mainly casiterite, wolframite (Mn,Fe)$WO_4$, chalcopyrite ($CuFeS_2$), sphalerite (ZnS), galena (PbS), molipdenite ($MoS_2$). Table 1 shows that contents of elements are high in the area. Some typical minerals were identified clearly using microscopy in Fig. 2 (Đỗ Hữu Trợ và nnk, 2005).

### *3.2. Data used*

The input data for the analysis in this study include mineral occurences, lithology, faults and geochemical anomalies which are information using for original tin prospecting .

The geologic map at 1:25.000 scale in Maty-Dulong area is used for defined geological formations and complexes.

*Table 1. ICP result of 45 samples at ore bodies in the study area (Đỗ Hữu Trợ và nnk, 2005).*

| Value | Content (g/t) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mo | As | Zn | Bi | Pb | Cu | W | Sn | Ta | Nb |
| Min | 11 | | 35 | 10 | 10 | 23 | 11 | 218 | 3 | 16 |
| Max | 610 | | 774 | 761 | 1399 | 260 | 560 | 53346 | 18 | 115 |
| Average | 89.88 | | 131.64 | 134.56 | 99.82 | 64.09 | 97.86 | 6,452.64 | 7.77 | 43.03 |

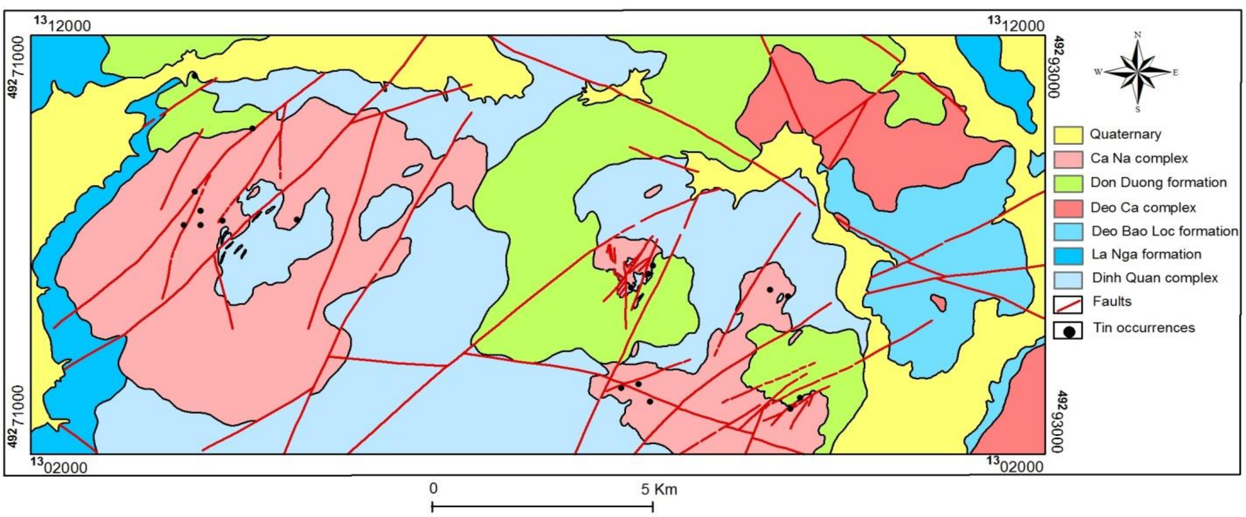


*Fig 1. Simplified geological map of Ma Ty - Du Long area.*

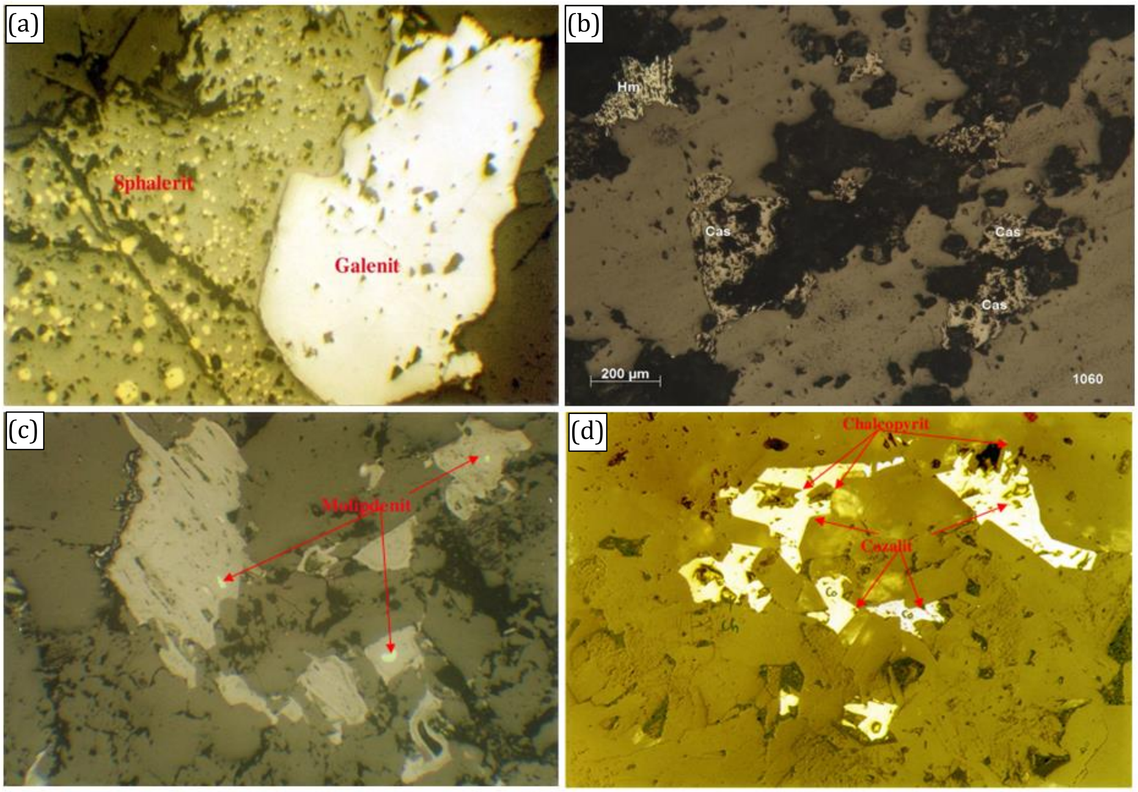


*Fig 2. Minerals under microscopy in the studies area (Cas: Calsiterite, Hm: Hematite).*

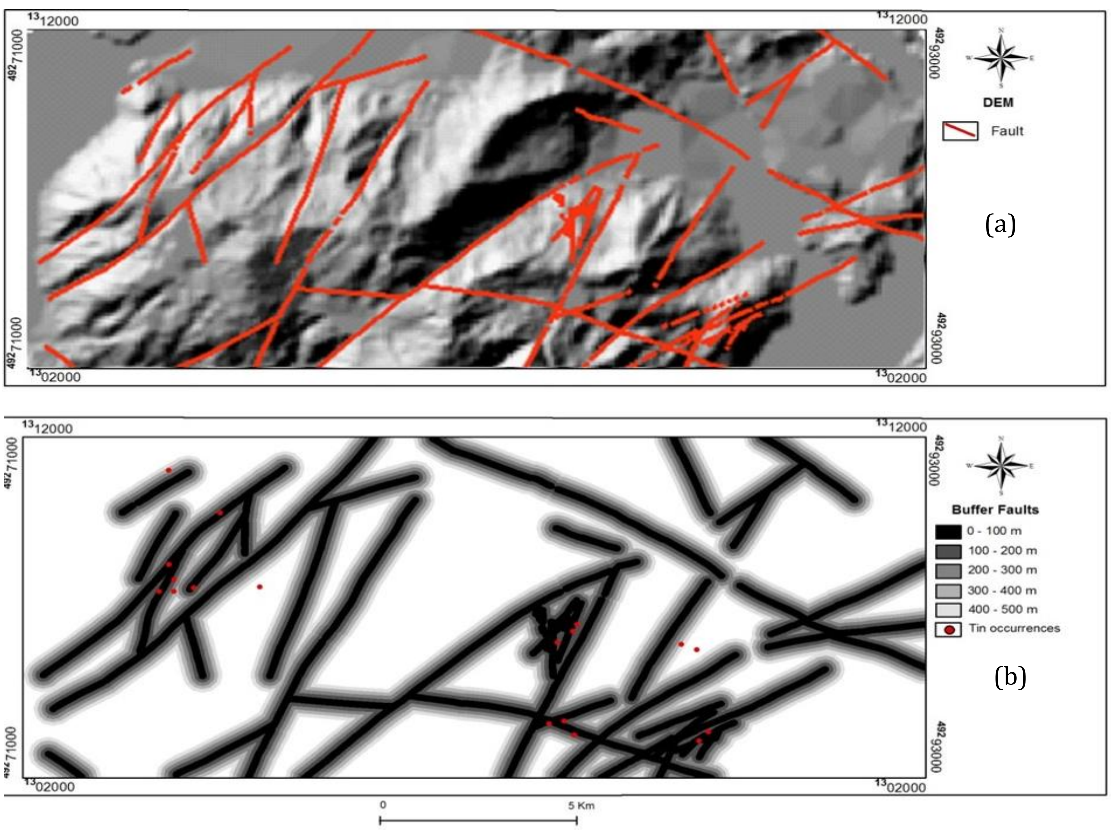


*Fig 3. DEM and buffered fault map in Maty-Dulong area.*

Tin mineral occurrences in the study area are defined based on analyzed results of geologic and mineral mapping at 1: 50.000 scale, map of Phan Rang - Cam Ranh (Đỗ Hữu Trợ và nnk, 2005; Đoàn địa chất Việt Tiệp, 1986). In addition, the position of chemical sample that has high content of tin mineral is considered as a mineral occurrence for tin exploration in the study area (Đỗ Mạnh An và nnk, 2012). The caculation results selected eighteen mineral occurrences responding the conditions in searching areas. (Fig.1)

Lineaments are derived from a Digital Elevation Model (DEM) that was generated from topographic maps at the scale of 1:10.000. The lineaments are combined with faults to create a lineaments layer. Two striking lineaments/faults systems are divided separately into southeast-northwest and northeast-southwest striking systems. Then, they are buffered to 100 m in different classes of <100; 100-200; 200-300; 300-400; 400-500m (Fig.3).

Based on geochemical anomaly of elements maps at the scale of 1:50,000 the group map Phan Rang - Cam Ranh, nineteen geochemical anomaly hoops of the elements are denfined (elements: Mo, W, Sn, Cu, Pb, Zn) (Đỗ Hữu Trợ và nnk, 2005; Đoàn địa chất Việt Tiệp, 1986).

## 4. Results and discusion

### *4.1. Estimation of weights of evidential maps*

Results of weights-of-evidence modeling are shown in Table 2. The results showed that Ca Na complex has the highest value of weight in comparison with other complexes, with fourteen in eighteen mineral occurrences. The contrary values (C) of Ca Na complex is 2.52 units. The 100 m buffer zone from faults is considered as the most meaningful with ten out of eighteen mineral occurrences and the contrary value (C) is 2.13 (Table 2). The results in Table 2 show that the number of mineral occurrences laying on grochemical anomoly hoops W, Sn, Mo, Cu, Pb and Zn is quite high when the contrast is larger than 3.

*Table 2. Scores and weights of input layers and classes.*

| Information layer | Area ($m^2$) | Occurrences | $W^+$ | $W^-$ | C | $S^2(W^+)$ | $S^2(W^-)$ | S(C) | C/S(C) |
|---|---|---|---|---|---|---|---|---|---|
| Buffer 100m - ĐG | 29,850,000 | 10 | 1.46 | -0.67 | 2.13 | 0.10 | 0.13 | 0.47 | 4.49 |
| Ca Na complex | 50,720,000 | 14 | 1.26 | -1.26 | 2.52 | 0.07 | 0.25 | 0.57 | 4.44 |
| Geochemical anomaly W | 853,500 | 5 | 4.32 | -0.32 | 4.64 | 0.20 | 0.08 | 0.53 | 8.82 |
| Geochemical anomaly Sn | 4,182,000 | 12 | 3.61 | -1.08 | 4.69 | 0.08 | 0.17 | 0.50 | 9.37 |
| Geochemical anomaly Mo | 1,862,000 | 5 | 3.54 | -0.32 | 3.86 | 0.20 | 0.08 | 0.53 | 7.33 |
| Geochemical anomaly Cu | 871,000 | 3 | 3.79 | -0.18 | 3.97 | 0.33 | 0.07 | 0.63 | 6.27 |
| Geochemical anomaly Pb | 950,000 | 3 | 3.70 | -0.18 | 3.88 | 0.33 | 0.07 | 0.63 | 6.13 |
| Geochemical anomaly Zn | 852,000 | 3 | 3.81 | -0.18 | 3.99 | 0.33 | 0.07 | 0.63 | 6.31 |

*Table 3. The calculated results of the value $\chi^2$.*

| Layers | Ca Na complex | W | Sn | Mo | Cu | Pb | Zn |
|---|---|---|---|---|---|---|---|
| Buffer 100m - faults | 0.1 | 0,087 | 0,003 | 0,09 | 0,05 | 0,045 | 0,045 |
| Ca Na complex | | 0,242 | 1,004 | 0,6 | 0,06 | 0,064 | 0,06 |
| W | | | 1,7 | 0,03 | 0,45 | 0,22 | 0,89 |
| Sn | | | | 1,09 | 0,22 | 0,5 | 0,5 |
| Mo | | | | | 0,22 | 0,89 | 0,22 |
| Cu | | | | | | 2,88 | 2,9 |
| Pb | | | | | | | 2,88 |

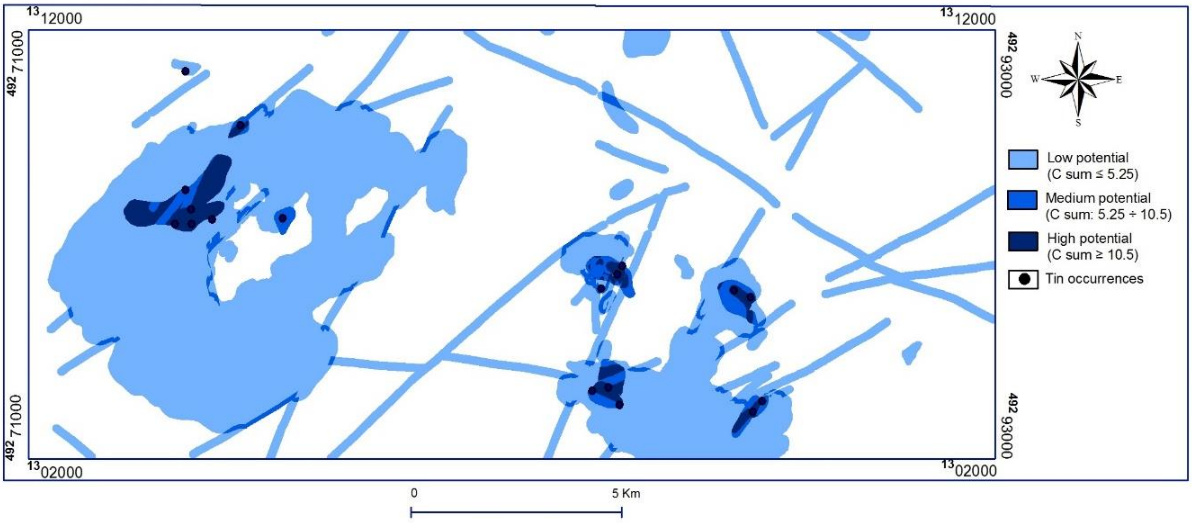


*Fig 4. Tin potential map in Ma Ty - Du Long area, Ninh thuan province, Vietnam.*

An independent condition was used for testing for each pair of datas and the $\chi 2$ value of pairs was calculated under Bonham-Carter suggestions (Bonham-Carter, 1994). Results show that all calculated $\chi 2$ values are satisfied with 99% sinificant level (Table 3). This means that all pairs of factors are coditional independence and they can be combined together to produce the tin potential map.

### *4.2. Generation of the Tin potential map*

The tin potential map in Maty Dulong area is obtained by combining the contrasts (C) of eight factors : the buffer 100 m of the fault systems, Ca Na complex and the geochemical anomalies of Sn, W, Mo, Cu, Pb, Zn using of ArcGIS software. Depending on the sum values of weights, the map is classified by different levels: low, medium and high tin potential. The distance value for classifying potential map zoning is calculated as (Nguyễn Thám và nnk., 2012).

$$\frac{C\_sum_{max} - C\_sum_{min}}{3} = \frac{17.88 - 2.13}{3} = 5.25$$

Therefore, the high tin potential area will have the sum value over 10.5 (*C_sum* ≥ 10.5), the medium potential: *C_sum*: 5.25 ÷ 10.50 and the low potential: *C_sum* ≤ 5.25 (Fig. 4). The high tin potential area has 9 in 18 known mineral occurences (50%). This area covers 1.62% of study area. Five typical tin mineral occurences (Suoi Giang, Tap La, Đong Thong, Khe Đen and Ta Nang) are perfectly situated in the high tin potential area. It means that the results are reliable and meaningful for prospecting tin mineralization in next stage.

## 4. Conclusions

In this study, the WOE method was applied to produce a tin potential map in Maty-Dulong area, Ninh Thuan province based on geological, structural, geochemical data and mineral occurences. As a result, the final map is classified into three levels: low, medium and high tin potential The high potential areas accounting for 1,62% of the total area in searching areas with 9 in 18 known mineral occurences. The result from comparing with 5 mine occurences (Suối Giàng, Tạp La, Động Thông, Khe Đen and Tà Năng) in the report appraising the original tin ores in Maty-Dulong in 2005 is completely the same, it is also the evidence for exact points of the method and the results are useful for prospecting tin mineralization in next stage.

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