Establishing a Tungsten Deposit Group and a Pattern Grid Exploration in the Nui Phao Area, Northeastern Vietnam

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Abstract. Nui Phao area (northeastern Vietnam) has a high potential for tungsten resources. The tungsten ore bodies mainly appear in lens-shaped within granitic rocks of the Da Lien complex in the studied area. Minerals accompanying tungsten deposits are composed of fluorite, native gold, native bismuth, chalcopyrite, a lesser amount of allanite, cassiterite, and rare molybdenite. Based on collecting, synthesizing, geological processing data, and the mathematical method, studied objects of the exploration process are quantitatively described. Tungsten oxide (WO_3) contents of the major ore body vary from 0.20 to 1.11% with a coefficient of variation (V_c) of 91.2% (unevenly). Generally, the tungsten oxide contents compliance with rules of the standard lognormal distribution. Major tungsten orebody average 56.7 m in thickness and its coefficient of variation (V_m) of 61.2% (unstable). Quantitative calculations reveal the Nui Phao tungsten deposit belongs to the III-type of mining exploration group. To explore this type of minerals, a linear grid pattern should be applied. Results show that the appropriate pattern grid exploration for reserve level 122 is $50 \div 60 \times 30 \div 35$ m; these values can be applied to other deposits occurring in similar geological settings.

Keywords: Mining deposit group · Pattern grid exploration · Tungsten ore · Nui Phao area · Vietnam

1 Introduction

The beginning of any mineral explorations is often applied with the orientation exploration grid, following the principle of geological similarity [2, 4, 5, 8, 9, 17]. However, applications of this principle have some certain issues due to ore bodies are frequently not the same in size, thickness, and internal orebody structure, so on. Therefore, the application of geological math modes in the research-exploration data processing is evaluated as the most efficient method for selecting suitable exploration grid of each specific mineral object and mining deposit groups [8, 14, 15, 18]. Many projects have

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achieved many successes in geological research by applying for statistical methods in setting up an exploration grid [2, 12, 15, 19, 20]. This indicates that this step plays an essential role in evaluating the effectiveness and reliability of mineral exploration.

Based on the complexity, size, and shape of mineral deposits, the Circular of Vietnam Ministry of Natural Resources and Environment (VMNRE) [17] classified deposits into four groups as follows: (1) Group I comprising large deposits that are simple in geological structure, with the least variation in thickness and grades, thus, the highest level of resources are 121 by applying normal grid of drill holes; (2) Group II is composed of relatively large deposits having more complicated structure, more variable thickness, and significant grade variability. By applying a normal grid of exploration, only up to reserves of level 121 might be defined; (3) Group III consists of highly complicated structure deposits. The ore thickness varies significantly, with very uneven grade distribution. Deposits that belong to this group are often smaller in size and minerals distribute unevenly. Category of reserve 122 can be established by a normal grid exploration; and (4) Group IV deposits are extreme complexity in geological structure, grade distribution, and thickness. They are usually small deposits or ore-pocket with very complicated shapes. To establish category reserve 122, dilling in combination with underground works must be applied.

It is documented that Northeastern Vietnam is abundant in mineral resources for developing mining and metallurgical industry. Although some tungsten ore deposits have been investigated during geological mapping in northeastern Vietnam, most of them are evaluated as small to medium deposits. However, the tungsten ore in the Nui Phao area is an exception [4, 6, 9]. Up to date, there have been no adequate and systematic studies on the geological aspects in combination with tungsten mineralization, especially the mining exploration group and exploration grid in the area. Thus, the results of this work will be important in mineral exploration and mining for the future.

The purposes of this study are to establish a tungsten mining group in the Nui Phao area based on applying statistical models to determine a pattern grid exploration of estimated tungsten orebody parameters. However, these methods can be used or solving problems from other areas having the same geological conditions.

2 Geological Features of the Nui Phao Area

Northeastern Vietnam belonged to the South China plate, and it is separated from northwestern Vietnam by the Song Hong (or Red River) shear zone, which is one of the main tectonic structures of Vietnam [7, 11, 16]. In which geological strata and igneous rocks have been found dating from the early Paleozoic to the Quaternary. The Nui Phao area is located near the town of Dai Tu in northeastern Vietnam, approximately 80 km north of Hanoi (Fig. 1a). The Nui Phao area coincides with a strong, WNW-trending, positive magnetic anomaly, which extends for over 2 km in length and 400 m to 500 m width. Drilling has confirmed polymetallic mineralization along 1.3 km of this strike length, but the zone is open along strike in both directions.

The lithology of the Nui Phao area is composed mainly of clay shale muscovite-bearing quartzitic sandstone, chert; sandstone interbeds of coaly shale rocks that were suggested as Ordovician-Silurian age and named Phu Ngu formation [9]. In the northern study area, intrusive rocks of granite are exposed in mass-shaped, termed as Da Lien block (Fig. 1b). Quaternary sediment mainly exposes along valleys and/or lowlands.

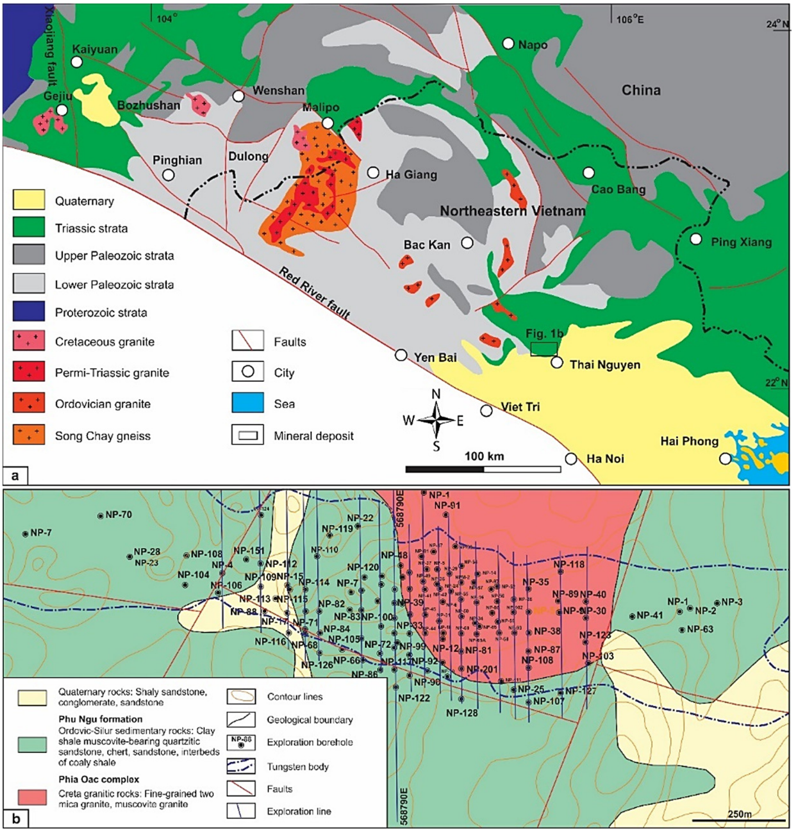

Fig. 1. General geological diagram of the southwestern South China plate and Northeastern Vietnam (adapted from [3, 13, 21]) (a); A general geological map of the Nui Phao area, Thai Nguyen province (adapted from [4, 6]) (b)

There are three fault systems recorded in this study which were well documented in the previous researches [4, 6]. They are composed of northeast-southwest (NE-SW), northwest-southeast (NW-SE), and near west-east (W-E) trending systems, of which the NW-SE one is the major system, controlling the structure of the Nui Phao area. Most of the orebodies are associated with the fault system in the Da Lien and Nui Phao granitic massives [1, 6].

3 Features of the Tungsten Orebody at the Nui Phao Area

3.1 The Major Characteristics of the Tungsten Orebody

The Nui Phao deposit contains several tungsten orebodies, in which the major orebody is a prospective one, and is being explored and exploited by Tiberon Minerals Company. Mineralization in the studied area has the following characteristics.

The major tungsten orebody occurs as greisens formed both internally and externally contact between the Da Lien granite and Phu Ngu sedimentary rocks (Fig. 2). This orebody is extended about 2 km along with strike line (from east to west), and ranging from 200 m to 400 m in width. The thickness of this orebody can be up to 159 m in the east and 43 m in the west. The high point of the Da Lien granite massive named "granite blade" that plays as a key point of the major orebody. To the east of the granite blade, the major tungsten orebody plugs to the east and is related to a metamorphic zone of granite rocks of up to 50 m thickness (mainly internal greisenized granitoids). To the north and south, the major tungsten orebody is controlled by the granite boundary. To the west of the granite blade, the orebody is inclined to the west and thinned, but its scale may be larger (up to 450 m of width).

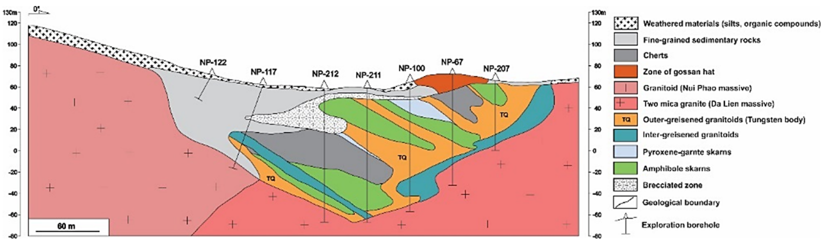

Fig. 2. Geological cross-section along line No. 568790E of the Nui Phao area (adapted from [4, 6])

The upper part of the major tungsten body is strongly oxidized, forming a gossan zone, which is rich in quartz and iron. The part of the orebody is developed to northwest-northwest direction; it is showing the surface of polymetallic skarn/greisen major tungsten zone. The orebody is exposed to the area with dimensions of 850 m × 200 m × 10 m (length × width × depth).

The lithological units of the major mineralized zone are composed of the interchanged combination of the products of thermal metamorphic processes, scarification, albitization, and greisenization of dike and granite. They are surrounded by the Nui Phao and Da Lien granite massifs and are covered by the clay and weather materials of 20 to 40 m in thickness. The major tungsten orebody is spilled from the skarn and greisen orebodies by the ridge of the Da Lien granite massive. Sometimes, metasomatic rocks compose mainly of pyroxene-(garnet) skarn, amphibole-biotite-(danalite) skarn, calc-silicate hornfels, marble, and magnetite-(danalite) skarn. Dike rocks of granitoids intrude sedimentary rocks of the Phu Ngu formation and are also metasomatized. The skarn alteration surrounding the Da Lien granite contact is overprinted by albite fluorite greisenization accompanied by biotite and pyrrhotite, and quartz veins have appeared too. The polymetallic (Sn-W-Mo) mineralization is consists of fluorite, scheelite, native gold, native bismuth, chalcopyrite, and they are mainly developed in the greisenized rocks. Other minor minerals are allanite, cassiterite, and rare molybdenite and Pb-Zn sulphides.

3.2 Quality of Tungsten Orebody

Tungsten orebodies mainly present at contact zones between two mica granitoid and the pyroxene-garnet skarns. They are mainly located in Proterozoic Phu Ngu formation and greisenized granite and are classified as outer and inter contact zones, respectively. Most of the ores belong to veinlet-disseminated type, making an account for around 90% of all ore types which are recorded in the studied area. This type of ore is similar to quartz-scheelite ore, which is commonly distributed in feldspar metamorphic skarn rocks and overlapping greisen metamorphic rocks, partly less than the distribution in the greisenized granite. Ore minerals are mainly scheelite, wolframite, chalcopyrite, molybdenite, pyrite, magnetite, ranging from 10 - 40% in the composition. Whereas, the gangue minerals are often taken a larger proportion, comprising quartz, feldspar, biotite, and clay minerals group (Fig. 3).

The magnetite is anhedral to sub-euhedral in shape, with the size ranges from 0.20–0.80 mm, rarely up to around 2 mm. Magnetite appears in ore bunch, band-shaped, disseminated and scattered in skarn rocks (Fig. 4a, b), and are often associated with pyrite I and chalcopyrite I (Fig. 4c, d).

The scheelite in the veinlet-disseminated tungsten ore type is 0.05–0.50 mm in size, sometimes ≈1 mm, and majority produce in anhedral and/or granular crystals. Based on characteristics of distribution, morphology, size, ore minerals relation, and mineral association, they can be distinguished two scheelite genesis. The scheelite I have a paragenetic relationship with pyrite I and chalcopyrite I that forming a mineral association (Fig. 5a, b).

Scheelite II exists in the form of semi- idiomorphic and allotriomorphic granular with sizes ranging from 0.2 to 1.5 mm, sometimes > 2 mm. Scheelite II is distributed closely with quartz I and fluorite to form fissures, veins, disseminate in greisenised (outer-greisen) skarn rocks, and even in greisenised granite (internal greisen) of Da Lien massive. Scheelite II with quartz I and fluorite that was forming a mineral association (Fig. 5c, d).

Wolframite is generally anhedral granular, sometimes hypidiomorphic tabular or columnar crystals in the veinlet-disseminated tungsten ore type between 0.01–.074 mm in size. They are frequently scattered between quartz and mica or other silicate minerals; however, some wolframite grains associated with pyrites and chalcopyrites are also observed (Fig. 6).

Copper minerals appear mainly in sulphides including chalcopyrite, bornite, tetrahedrite. In which, chalcopyrites are often anhedral granular textures between 0.2–0.5 mm in size.

Molybdenites are subhedral to anhedral in a quartz vein with foliated or scaly aggregation texture and are associated with magnetite, pyrrhotite (Fig. 7). The grain size of the mineral varies 0.05–0.20 mm.

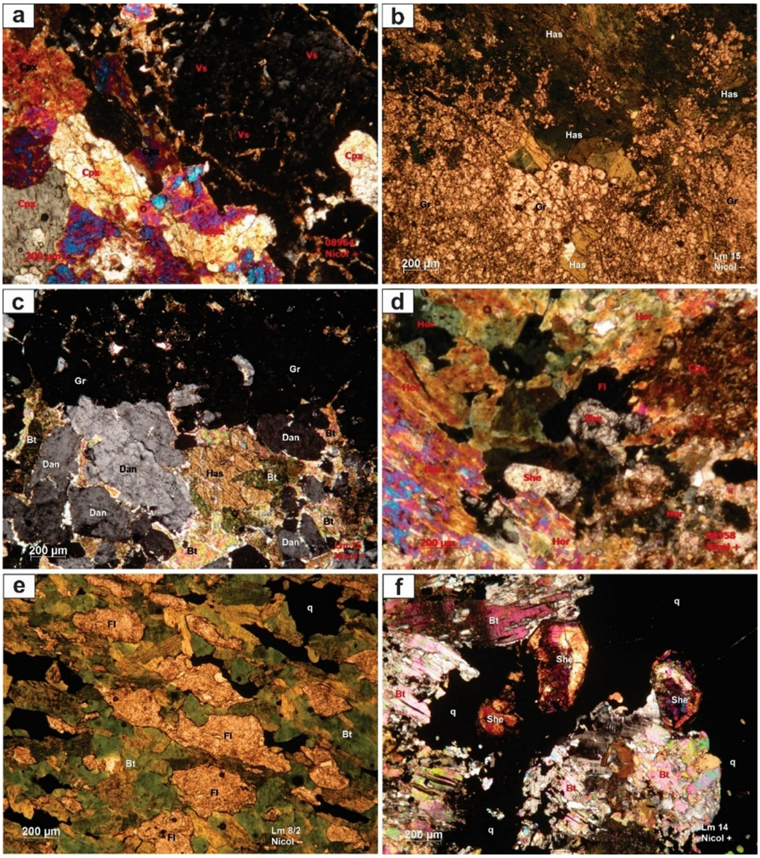

Fig. 3. The gangue minerals of Nui Phao tungsten deposit; Pyroxene (hedenbergite) - vesuvian mineral association (a). Garnet minerals are replacement by hastingsite (b); Hastingsite is replacement by biotite, danburite (c) and is corroded by the scheelite, fluorite, and ore minerals (d); Biotite mineral occurs with minerals of the greisenized process (e), and ore minerals (f).

4 Background of the Methods Used

4.1 One-Dimensional Statistical Models

Based on exploration data, the method is applied to highlight descriptive parameters of the orebodies, including chemical compositions, thickness, technical and physical properties.

Probability theory and its models: The sampling distribution of analytical results is considered as a random variable when derived from a random sample of size n; they are displayed as frequency nomogram or cumulative frequency. If we increase the number of measurement points and decrease the size of the range, then its nomogram will become a continuous curve represented by the distribution of the probability of the occurrence of random variables. This curve form is distributed as a reflection of the geological processes, properties or phenomena to be studied.

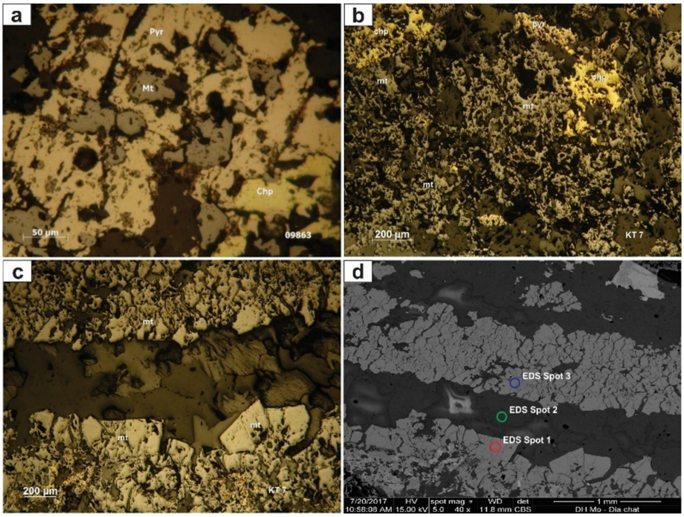

Fig. 4. Magnetite (Mt) occurred closely with pyrrhotine I (Pyr) and chalcopyrite I (Chp), they form a mineral association (a, b); Magnetite of xenomorphic texture, band-shaped in the skarn rocks (c- is captured under reflection contrast microscopy, d- is captured under scanning electron microscope-SEM).

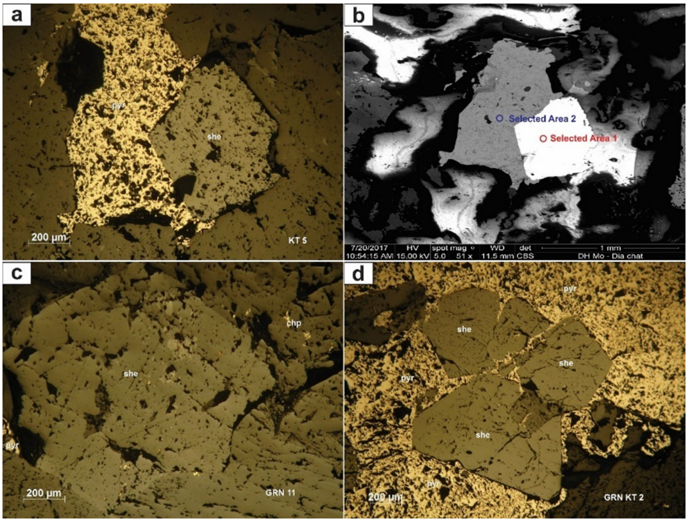

Fig. 5. Scheelite I is captured under reflection contrast microscopy (a) and SEM with checking points of mineral components (b). Scheelite II is distributed in the outer and inter greisenized zone (c, d).

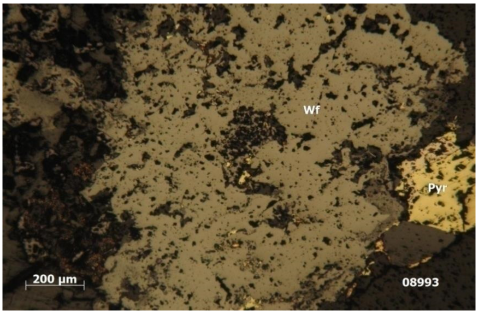

Fig. 6. Wolframite (W) is disseminated in granite rocks, which is corroded by pyrrhotine (Pyr).

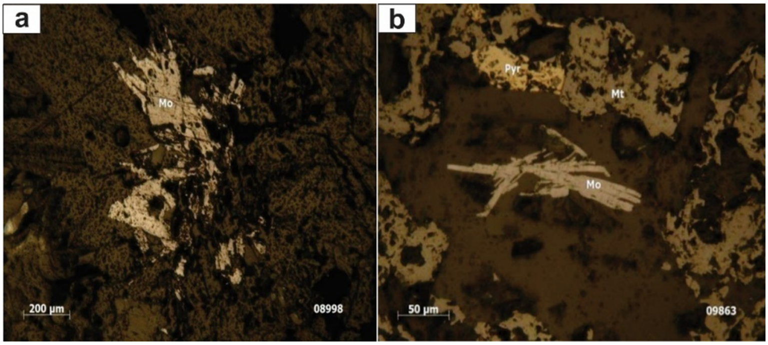

Fig. 7. Molybdenite (Mo) are lamella, foliated in greisenized rocks (a), and quartz vein cutting skarn rocks (b).

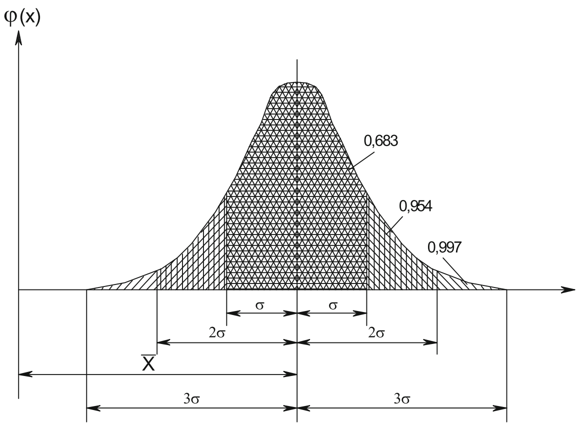

Fig. 8. Diagram of the normal standard distribution function.

The purpose of distributional function testing is to select mathematical equations to determine the mean and appropriate variance. Based on the distribution function, it is possible to determine the probability of random values occurring in any specified interval.

The law of statistical distribution is divided into two groups, namely the group of discrete distribution rules: uniform distribution, binomial, polynomial, Poisson, and the group of continuous distribution rules, including Fiser, Student, normal distribution, lognormal, gamma, power standard distributions, and so on.

The authors introduce some distribution models commonly used in exploratory geological research.

* *Normal standard distribution:* If the research parameters belong to the standard statistical distribution model, the statistical characteristic quantities are determined by the following formulas.

The average is a value representing the middle of a set of data values.

$$\overline{y} = \frac{1}{n}\sum_{i=1}^{n} y_i \text{ or } \overline{y} = \frac{1}{n}\sum_{j=1}^{n} n_j\overline{y_j} = \sum_{j=1}^{n} f_j\overline{y_j} \quad (f_j = \frac{n_j}{n}) \tag{1}$$

In case of a large number of samples, we are divided data within class intervals (Z = 1 + 3.322lgN), the average content is determined by the formula: $\overline{y} = \sum_{i=1}^{n} f_i\overline{y_i}$.

where $\overline{y_i}$- the mean of data within i class intervals, f_i – the frequency of the respective i class interval: $f_i = \frac{n_i}{n}$, n_i – total numbers of samples within i class; n - total numbers of studied samples.

The formula determines sample variance.

$$\sigma^2 = \frac{1}{n-1}\sum_{i=1}^{n} (y_i - \overline{y})^2 \text{ or } \sigma^2 = \frac{1}{n-1}\sum_{j=1}^{n} (y_j - \overline{y})^2 = \sum_{j=1}^{k} f_j(y_j - \overline{y})^2 \tag{2}$$

where σ^2- variance; y_i – the value of the studied parameter at i sample (i work); $\overline{y_j}$ - the mean of data within j class intervals; n - total numbers of studied samples; n_j- total numbers of samples within j class.

The coefficient of variation is calculated by the formulas.

$$V = \frac{\sigma}{\overline{y}}100\% \tag{3}$$

The formula determines standard deviation.

$$\sigma = \sqrt{\sigma^2} \tag{4}$$

where σ- standard deviation.

The equation exactly defines normal distribution.

$$f_{(y)} = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{(y-\overline{y})^2}{2\sigma^2}} \tag{5}$$

The equation defines the normal distribution function.

$$F_{(y)} = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{y} e^{\frac{(y-\overline{y})^2}{2\sigma^2}} dy \tag{6}$$

* Lognormal Standard Distribution

In case of data are not belong to normal standard distribution, values are corrected logarithmically to apply the lognormal distribution. The formulas determine the statistical values of the lognormal distribution:

The mean of data sets is determined by the formula.

$$m = e^{\overline{\ln y}+\frac{1}{2}\sigma^2 \ln} \tag{7}$$

The formula determines sample variance.

$$D = e^{2m+\sigma_{\ln}^2} \tag{8}$$

The formula determines the coefficient of variation.

$$V = \sqrt{e^{\sigma_{\ln}^2} - 1} \times 100\% \tag{9}$$

The equation precisely defines the lognormal distribution.

$$f_{(y)} = \frac{1}{\sigma_{\ln y}\sqrt{2\pi}} e^{\frac{(\ln y-\overline{\ln y})^2}{2.\sigma^2 \ln y}} \tag{10}$$

The equation defines the lognormal distribution function.

$$F_{(y)} = \frac{1}{\sigma_{\ln y}\sqrt{2\pi}} \int_{-\infty}^{y} \frac{1}{y} e^{\frac{(\ln y-\overline{\ln y})^2}{2.\sigma^2 \ln y}} dy \tag{11}$$

where $\overline{\ln y}$ - the mean values of ln y_i; $\sigma_{\ln y}$- standard deviation of ln y_i.

* *Statistical distribution test:* To test the statistical distribution, we are using the method of kurtosis and skewness improver theory. The method follows these steps.

The skewness (A) is determined by the formulas.

$$A = \frac{\sum_{i=1}^{n} (y - \overline{y})^3}{n.\sigma^3} - 3 \tag{12}$$

The kurtosis (E) is determined by the formulas.

$$E = \frac{\sum_{i=1}^{n} (y - \overline{y})^4}{n.\sigma^4} \tag{13}$$

The formulas calculate standard deviations (σ_A, σ_E).

$$\sigma_A = \sqrt{\frac{6}{n}} \text{ And } \sigma_E = \sqrt{\frac{24}{n}} \tag{14}$$

The standard for skewness is determined by $t_A = \frac{A}{\sigma_A}$, and standard for kurtosis is determined by

$$t_E = \frac{A}{\sigma_E} (\text{with A} - \text{ skewness, E} - \text{kurtosis}) \tag{15}$$

If $|t_A| \geq 3$ or $|t_E| \geq 3$, the distribution does not conform to the normal standard distribution being studied, then testing the lognormal distribution is using to the problem. Still, the values in equations of $12 \div 15$ as y_i replace with ln y_i, σ replace with σ_{lny}, respectively.

4.2 Morphological and Internal Structural Orebodies

The coefficient of ore-bearing (OB_p) is determined based on thickness, distribution, and length of the orebody as follows.

– Based on thickness.

$$OB_p^m = \frac{\sum_{i=1}^{N} t_i}{\sum_{i=1}^{N} T_i} \tag{16}$$

where t_i - thickness of the portions of ore value in the i-th work, m; T_i - thickness of rock layer containing tungsten ore, m; N - number of explored works.

– Based on the distribution of the ore.

$$DO_p^S = \frac{\sum_{i=1}^{N} TA_p}{AR} \tag{17}$$

where $\sum_{i=1}^{N} TA_p$- total area of the orebodies in the explorated region, m^2; N - number of orebodies; AR - the area of the explored region, m^2.

– Based on the length of the ore.

$$LO_P^L = \frac{\sum_{i=1}^{N} TL_P}{\sum_{i=1}^{N} TL_c} \tag{18}$$

where $\sum_{i=1}^{N} TL_P$- total length of orebodies, m; $\sum_{i=1}^{N} TL_c$- total length of exploration lines, m.

Coefficients of Discontinuity of the Orebodies (DO_{np})

$$DO_{np} = \frac{i}{OB_p^m} \tag{19}$$

where i - the number of discontinuity determined on exploration lines cross-section; OB_p^m- coefficient of ore bearing.

Cofficient of Anisotropy in Morphological Orebody (η)

$$\eta = \frac{X}{Y} \tag{20}$$

where X, Y-thickness and width of the ore body determined based on the geological map, m;

The ore dressing coefficient (ξ) is calculated as follows.

$$\xi = \frac{MC_{tb}}{NC_{CN}} \tag{21}$$

where MC_{tb} - mean contents of payable tungsten bodies, (WO_3, %); NC_{CN} – cut-off grade of the ore, %.

Boundary modules (BM_K). Based on comparing the real circumference and perimeter of the orebody, the complexity of the orebody boundary is calculated as follows.

$$BM_K = \frac{e\varphi}{4.7a + 1.5\frac{L\varphi}{a} - 1.77\sqrt{L\varphi}} \tag{22}$$

where a - half of the maximum boundary value, m; $L\varphi$ - circumference of the orebody converted to ellipse shape; $e\varphi$ - the real perimeter of the orebody, m.

Orebody Shaped Index (θ)

$$\theta = \frac{V.BM_K}{OS_{cc}} \tag{23}$$

where V - coefficient of payable orebody thickness, %; OS_{cc} - coefficient of orebody structure complexity, %.

$$OS_{cc} = 1 - \frac{mt_k n_k}{mt_q n_q} \tag{24}$$

where mt_k - average thickness of dirt rock layers in the orebody, m; n_k - number of dirt rock layers; mt_q - average thickness of the ore beds, m; n_q - number of ore beds.

5 Proposed Methodology

In a studied area, statistical estimation, descriptive patterns, and characteristic orebodies (i.e., shape, morphology, and structure) are used to create a mining deposit group and an exploration grid. The estimated results can provide useful statistical information on the characterization of morphology and geological structural orebodies. The mineral parameters of ore deposit can be estimated to be extensively utilized for quantitating mineral resource and determining geological exploration works in a studied area by applying statistical and random function methods [18]. However, these methods have not been widely utilized to identify a mining deposit group and a pattern grid exploration [15].

Based on previous materials, the geo-mathematic methods were applied to estimate the effective characterization of tungsten mineralization in the Nui Phao area. After that, a statistical model and random function theory were applied to estimate the exploration data of the major tungsten orebody. This methodology has been proposed and shown in Fig. 9.

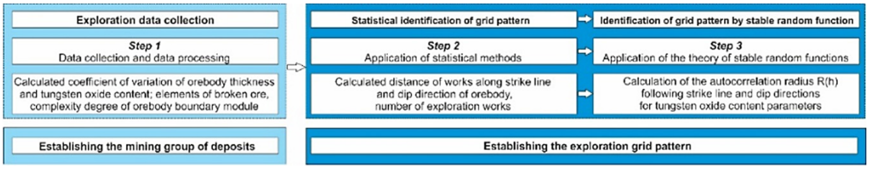

Fig. 9. Three steps for estimating the characterization of tungsten mineralization in the studied area.

Step 1- Exploration data collection: the obtained data on the major tungsten orebody was collected and analyzed, then the data was processed. Each calculated parameter was associated with the tungsten orebody. The goal of this step was to establish the mining deposit groups.

Step 2- Statistical identification of grid pattern: As an initial step, the processing requirements were performed using statistical methods. Next, the selected orebody features were applied to the given dataset to identify the pattern grid exploration. Lastly, a distance of geological exploration works was calculated to evaluate the grid distances following the strike line (line to line), and dip direction (point to point).

Step 3- Identification of grid pattern by stable random functions: the grid pattern obtained from Step 2 was combined the results of this step by application of the theory of stable random functions. At this step, the auto-correlation radius (R(h)) based on the strike and dip formats of the orebody were estimated and plotted. The goal was to establish the pattern grid exploration.

The proposed methods could be used by any scientists for improving methodology and extended applying domain. The methodology is introduced below.

5.1 Establishing a Mining Deposit Group

In this study, variations in geological parameters (i.e., average values, variance, and coefficient) are determined to guarantee the truthfulness, efficiency, and non-error in data processing for ensuring reliability. According to the probability distribution function, the probability of random numbers prevailing in the arbitrary selection range is identified following Wellmer (1998) [18].

5.2 Establishing the Pattern Grid Exploration

The methods are consist of the statistical and theory of random function methods. The statistical methods allow measuring the errors of estimated reserves and the density estimation of the grid exploration. The methods of random functions are determined the correlation function of the norm based on the construction of correlation plots and an anisotropy coefficient. They are presented in more detail in Khang et al. (2020) [10].

6 Results and Discussion

The distribution, structural, and morphological features, as well as their relationships, are clarified based on previous synthetic [4, 5, 6, 9], and additional research materials. In this studied area, they exist at a depth of the tungsten bodies.

6.1 Elements for Making a Mining Deposit Group

According to Pogrebiski (1973) [14], he argues that elements for making a mining deposit group and a pattern grid exploration are the following factors, they are the first factor of geological structure and orebody morphology; the second one is mineral deposit scale or orebody size and structural orebody, and the third factor is the stable degree of orebody thickness and evenly of orebody contents.

To determine the factors, they have distinguished based on the coefficient of variation as following Tables 1 and 2.

Table 1. Establishing a stable degree of orebody thickness and evenly of orebody contents

Coefficient of variation (V, %)	Thickness (m)	Content (%)
<40	Stable	Evenly
40 ÷ 60	Quite stable	Quite evenly
60 ÷ 100	Unstable	Unevenly
100 ÷ 150	Very unstable	Very unevenly
150	Especially unstable	Especially unevenly

Table 2. The standard elements for making the mining deposit groups

Elements	Mining deposit groups			
	I	II	III	IV
Coefficients of discontinuos are	Continous ($K_p = 1$)	Weak discontinuity ($K_p = 0.75 \div 1$)	Discontinuity ($K_p = 0.25 \div 0.75$)	Strong discontinuity ($K_p < 0,25$)
Stable degree of thickness	Stable ($V_m < 40\%$)	Unstable ($V_m = 40 \div 100\%$)	Very unstable ($V_m = 100 \div 150\%$)	Especially unstable ($V_m > 150\%$)
Complexity degree of orebody boundary module	Very simple ($M_k = 1 \div 1.2$)	Simple ($M_k = 1.2 \div 1.4$)	Average ($M_k = 1.4 \div 1.6$)	Complicated to very complicated ($M_k > 1.6$)
Evently degree of content	Evenly ($V_c < 40\%$)	Unevenly ($V_c = 40 \div 100\%$)	Very unevenly ($V_c = 100 \div 150\%$)	Especially unevenly ($V_c > 150\%$)

6.2 Determination of Exploration Tungsten Deposit Group

6.2.1 Statistical Features of the Major Tungsten Orebody

The results on the statistical analysis of content and thickness of the major tungsten orebody are presented in Table 3.

Table 3. Statistical features of the tungsten oxide content of the major orebody

	Tungsten oxide (WO_3) contents					Distribution pattern
	Mean content (%)	Variance (σ^2)	Coefficient of variation (V_c, %)	t_A	t_E	
Major tungsten body	0.41	0.14	91.3	1.82	1.63	Lognormal standard

Table 4. Statistical features of tungsten thickness of the major orebody

Parameters of true thickness					Distribution pattern
Average (m)	Variance (σ^2)	Coefficient of variation (V_m, %)	t_A	t_E	
56.7	124.1	61.2	2.23	2.61	Normal standard

Table 3 shows that in the major orebody, the mean tungsten oxide content is 0.41%, its coefficient of variation (V_c) is 91.3% (unevenly to very unevenly). On the whole, the tungsten oxide contents of the major orebody have complied with the standard normal distribution.

The major tungsten body shows an average thickness of 56.7, its coefficient of variation (V_m) of 61.2%, and stable to very unstable distributions, indicating that the major orebody thickness has complied with the standard normal distribution.

6.2.2 Characterization of Continuous Mineralization

The degree of ease of available exploration geology is mainly influenced by characteristics of continuous mineralization. This suggests that a systematic investigation of the continuity of the tungsten mineralization can follow as the applying Eqs. (16), (17), and (18) which are showed below.

Table 5. Measured results of coefficients of tungsten ore bearing in the Nui Phao area

	OB_p^m	DO_p^S	LO_p^L
Major orebody	0.35	0.041	0.39

Applying Eqs. (19), (20), and (21), the degree of discontinuous ore, morphological anisotropy, and coefficients of extractive metallurgy, mineral processing of the major tungsten orebody can be evaluated.

Table 6. Calculated results of discontinuous tungsten in orebodies

	Coefficients of discontinuous ore	Coefficients of morphological anisotropy	Coefficients of ore dressing
Major orebody	11.43	0.2	2.05

The results presented in Tables 5 and 6 points out that the major tungsten body can be an interruption and uninterrupted types; its coefficient of interruption ore is complex ($DO_{np} = 11.43$). Major tungsten body is commonly anisotropy shape. Tungsten contents belong to the medium type with the coefficient of ore dressing is 2.05.

6.2.3 Complexity Degree in the Tungsten Body Boundary Module and Its Shaped Index

The morphological characterizations (i.e., shapes, strike and dip formats), and the complexity degree of the internal structure of major tungsten orebody are measured by applying Eqs. (22), (23), and (24). The results in the tungsten body boundary module and its shaped index are displayed below (Table 7).

The results of the complexity of the major tungsten orebody are simple to complex and its shaped index is medium (Table 7).

Table 7. Complexity degree in the tungsten body boundary module and its shaped index

	Area (m^2)	Boundary module	Complexity degree	Shaped index
Major orebody	809,100	5,927	1.42	0.32

Generally, the systematic investigation of the tungsten body indicates that the thickness varies from medium to small sizes, and its shape is quite medium. Variations in coefficients of thickness are invariable to variable types and interruption ones. The tungsten oxide contents are even to uneven distribution, implying that it has belonged to the average contents, buried by the burden, and light dips. The characteristics of the Nui Phao tungsten orebody and the materials from the VMNRE [17], the Nui Phao tungsten deposit can be categorized into deposit group III.

6.2.4 Determination of Pattern Grid Exploration of the Nui Phao Tungsten Deposit

Based on the exploration of geological parameters, the determination of a triangle grid exploration or optimization of the grid exploration can be identified. They are dependent on mining geological structure characteristics and consider mainly explorer objects. The key of tungsten body parameters can mostly be as point reserves. If variation in thickness or tungsten oxide contents of the orebody is the greatest, the characteristics of the largest orebody can be utilized for selecting the exploration grid.

a. Exploration System of the Effectiveness

Relative errors of the major tungsten orebody are calculated by using the method proposed by Khang (2020) [10], and their results are shown in Table 8.

The tungsten reserve of the major orebody shows an error of less than 50%, and it is estimated following category reserves 122 (Table 6). This suggests that the pattern grid exploration has been used for the tungsten body of the Nui Phao deposit which must be suitable for calculating category reserves 122 and it has to be normalized by the VMNRE [17].

Table 8. Relative errors of the tungsten reserves of the major orebody

	Relative errors of the tungsten reserves (%), $t = 2$			
	Area	Thickness	Content	Tungsten reserve
Major orebody	1.28	12.6	26.5	28.5

b. Density Estimation for Grid Exploration

Based on the method proposed by Khang (2020) [10], the density of the grid exploration can be identified, and its results are shown below (Table 9).

The results display that a linear should be used for the grid exploration of the tungsten deposit. The spacing of the explored line is utilized to be 60 m with 35 m spacing from the explored point to the nearest one. The number of exploration work is 476 works/km^2.

Table 9. The density of the grid exploration is calculated by using the statistical method

	The distance along orebody (m)		Density (m^2)	Number of explored works/km^2
	sf – strike format	*df* - dip format		
Major orebody	60	35	2100	476

Table 10. The grid exploration density is calculated by using a stable random function

	Anisotropy index	The distance along orebody (m)		Density (m^2)	Number of explored works/km^2
		sf – strike format	*df* - dip format		
Major orebody	0.54	50–60	30–35	1500–2100	476–667

There is a certain relationship between the geological parameter of the orebody and the distance between explored works. This implies that the spacing density of explored works can play a significant issue for a particular grid exploration. It is caused by the exploration conditions which are not uneven distribution over the geometric grid. As a result, the proposed method of Khang (2020) [10] should be used to transform the collected value to the explored point of the base grid cells for the study area. The spacing of the explored line is used to be 50–60 m with 30–35 m spacing from the explored point to the nearest one.

To guarantee the accuracy of the method, the biggest ones are chosen to perform measuring the autocorrelation radius along with strike and dip formats for content parameters of the major tungsten body.

As soon as the authors establish an experimental auto-correlation radius $R(h)$ deals with major tungsten body, the method proposed by Khang (2020) [10] is applied to conduct modelling. And then, we convert experimental induction line ($R(h)$) to theoretical line ($R^*(h)$), which led to plot the figures, and calculation size of the impact zone (H) that is estimated following strike and dip formats (Fig. 10).

The study shows that the line spacing 60 m, and 35 m spacing from the explored point to the nearest one is used to display better results than the line spacing 70 m and 30 m spacing from the explored point to the nearest one. The number of explored works is calculated to be between 476–667 works/km^2.

The methods of statistical analysis and stable random function are combined to help to identify the grid exploration of reserve 122. The line spacing is used to be from 50 to 60 m, and spacing from the explored point to the nearest one is between 30 $\div$ 35 m (Table 11).

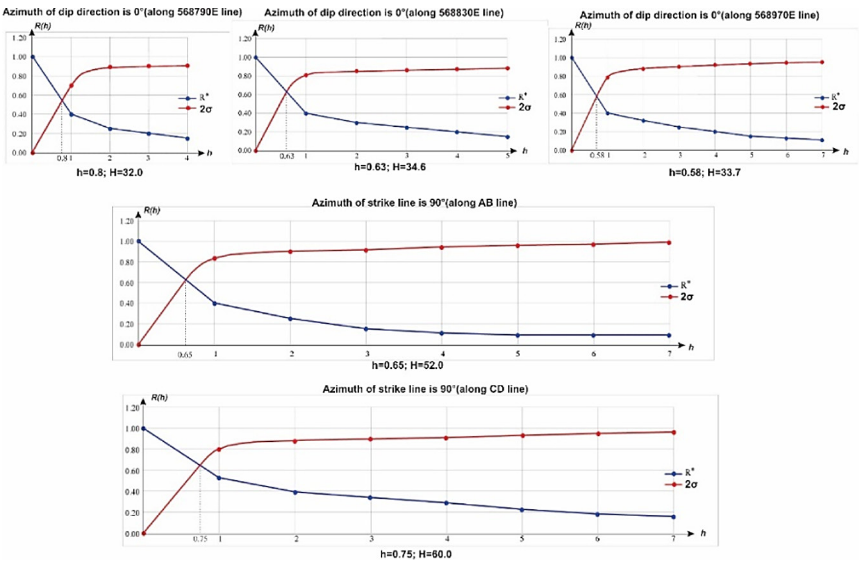

Fig. 10. Auto-correlation plots of the major tungsten body: R* - the theoretical tungsten line of correlation plots; 2σ – the experimental lines.

Table 11. Grid exploration calculated for tungsten reserves code 122

	The distance along orebody (m)		Number of explored works/km^2
	sf – strike format	*df* - dip format	
Major orebody	50 ÷ 60	30 ÷ 35	430 ÷ 606

7 Concluding Remarks

Quantification of exploration data and collection data obtained tungsten orebody are using for assessment in the mining deposit group and pattern grid explorations. The study introduced a method by combining statistical analysis and quantitative data of the orebody to determine in the distance of grid along strike and dip of orebody for tungsten metallic exploration object in the Nui Phao area, Northeaster Vietnam. The statistical method and random function overcome and obtain the tungsten mining groups and a pattern grid exploration.

The results show that the major tungsten orebody in the Nui Phao area is mainly lens-shaped, fully distributed in granitoid rocks of the Phia Oac complex. The tungsten oxide contents are between 0.20% ÷ 1.11% and variations in the coefficient of (V_c) are 91.2%, implying that they can be arranged in the standard lognormal rule. The tungsten bodies are characterized by 56.7 m thickness and 61.2% of variations in coefficient (V_m).

Based on the Circular of the VMNRE and the quantitative calculation results, this study can categorize Nui Phao tungsten deposit into deposit group III. The linear grid pattern should be used for exploration. In this area, the pattern grid exploration for mineral reserve code 122 is chosen to be (50 ÷ 60) m × (30 ÷ 35) m. The results of this study are significant materials for recommending a mining deposit group and a pattern grid exploration not only for tungsten ore in the Nui Phao area but also for other tungsten ores which display similarly geological conditions.

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