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Identification of geochemical anomalies associated with Sn-W mineralization in the Dong Van region, North-Eastern Vietnam, using statistical methods

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Abstract
Sn-W multimetal mineralization in the Dong Van region, North-Eastern Vietnam was studied using statistical and multivariate approaches based on 890 samples of stream bottom sediments collected for assaying for 27 elements. The findings of frequency analysis demonstrated that Pb, As, Bi, Li, Sn, W, Ta, Ce, Ag, Sb, and Be have close ties with multimetal ores, implying that these elements can be used as prospecting indicators for multimetal mineralization. In addition, correlation matrix and dendrogram studies were also applied to subdivide the elements in the stream bottom sediment samples assays into two groups: associated with multimetal mineralization (Be-Sn-W-Bi, and, to a lesser extent, Li-Pb sub-groups) and not associated with the mineralization: (As-Cd-Sc-Cr-Ce-La, Co-Ni-V, and Ga-Ge-Ba sub-groups). Sn and W were found to be the best indicator elements for the mineralization, according to the findings of geochemical modeling and location of their anomalies in the region. Furthermore, extensive Sn and W anomalies were identified in the Dong Van region (using threshold values (mean ± 3 STD), providing the most important indications for multimetal mineralization prospecting in the region. The studies also suggest genetic ties between the region's multimetal mineralization and the northwest-southeast fault system and concealed granitoid blocks. Finally, the performed statistical analyses (with the use of threshold values) of stream bottom sediments assays allowed revealing indicator elements and their geochemical anomalies and using them as an effective tool in further prospecting and exploration for multimetal mineralization in the region.

Keywords
geochemical anomalies, Sn-W mineralization, statistical methods, Dong Van region, North-Eastern Vietnam

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ГЕОЛОГИЯ МЕСТОРОЖДЕНИЙ ПОЛЕЗНЫХ ИСКОПАЕМЫХ

Научная статья

Выявление геохимических аномалий, связанных с Sn-W минерализацией в провинции Донг Ван, северо-восточный Вьетнам, с использованием статистических методов

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Аннотация
Изучение Sn-W комплексной (поликомпонентной) минерализации в провинции Донг Ван, северо-восточный Вьетнам, проводилось с использованием статистических и мультивариантных подходов на основе 890 проб донных отложений водных потоков, отобранных для анализа на 27 элементов. Результаты частотного анализа показали, что Sn, W, Pb, As, Bi, Li, Ta, Ce, Ag, Sb и Be имеют тесные связи с комплексными рудами, что означает, что эти элементы могут быть использованы в качестве поисковых индикаторов комплексной (поликомпонентной) минерализации. Кроме того, были проведены исследования с использованием корреляционных матриц и дендрограмм для разделения элементов в анализах проб донных отложений на две группы: связанные с комплексной минерализацией (подгруппы Be-Sn-W-Bi и, в меньшей степени, Li-Pb) и не связанные с минерализацией (подгруппы As-Cd-Sc-Cr-Ce-La, Co-Ni-V и Ga-Ge-Ba). Sn и W были признаны лучшими элементами-индикаторами минерализации, согласно результатам геохимического моделирования и расположению их аномалий в провинции. Более того, в провинции Донг Ван были выявлены обширные геохимические

аномалии Sn и W (с использованием пороговых значений содержаний (среднее ± 3 STD)), что дает наиболее важные указания для поисков комплексной минерализации в провинции. Исследования также указывают на генетические связи между комплексной минерализацией провинции и системой разломов направления северо-запад – юго-восток и скрытыми гранитоидными блоками. В итоге проведенный статистический анализ содержаний (с использованием пороговых значений) в пробах донных отложений позволил выявить индикаторные элементы и их геохимические аномалии и использовать их в качестве эффективных инструментов при дальнейших поисках и разведке комплексной минерализации в провинции.

Ключевые слова

геохимические аномалии, Sn-W минерализация, статистические методы, Geostatistic, провинция Донг Ван, северо-восточный Вьетнам

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Introduction

Mineral resource research relies heavily on stream sediment surveys. In fact numerous types of deposits have been identified by this way in North-Eastern Vietnam [1, 2]. However, the processing of such data to find multivariate geochemical patterns and signals linked to mineralization is a complicated problem [3]. Principal component analysis is a useful data analysis technique for reducing the number of variables in a dataset or identifying components to reveal hidden patterns in multivariate data [4, 5]. In addition to basic principal component analysis, there are several other types of principal component analysis [6, 7]. These methods may be used with raw data, log-transformed data, selected data, and other types of data [8].

Traditional statistical analysis tools such as probability graphs, univariate and multivariate analysis methods [8–10], and fractal and multifractal models have all been proposed to differentiate geochemical anomalies from background [11–14]. Reimann et al. [15] compared various statistical methods for determining element concentration threshold values. They found that the box plots, median ± 2 median absolute deviations, and empirical cumulative distribution functions work better than mean ± 2 standard deviations for estimating anomaly threshold values. Fractal and multifractal algorithms have frequently been used to identify geochemical anomalies due to spatial autocorrelation nature of data [16–18].

The Dong Van region in northeastern Vietnam is regarded as a significant prospective area for multimetal ores (i.e., Fe, Mn, Sn, W, and Au) [1]. Furthermore, since tin, tungsten, and gold commonly occur in association with arsenic mineralization, such as As-Sn-W-Au Nam Khi, Lang Xum, Lang Me, and Lang Lup deposits, mineralization plays an important role as a source of precious metals for industry[1] [19]. From 1965 until the present, this region was surveyed at a scale of 1:500,000–1:50,000 for geological mapping and mineral exploration [20–23]. However, geological sample collecting and geochemical data processing are insufficient to identify prospective Sn-W mineralization areas. As a result, more research needs to be undertaken in the Dong Van region of northeastern Vietnam, in order to identify new multimetal ore areas.

Statistic and multivariate analysis were used to process 890 geochemical samples, in order to identify multimetal mineralization/ore occurrences in the Dong Van region.

1. Geological setting

The Song Hien zone is located within the northeast block of the Vietnam's segment. It is a 200 kilometer-long NW-SE trending tectonic zone, which hosts the Song Hien Permian-Triassic and Triassic volcanic-sedimentary strata with subordinate middle-late Paleozoic terrigenous-carbonate rocks (Fig. 1). The Song Hien zone is thought to be a pre-late Paleozoic-early Mesozoic intracontinental rift basin related to the Emeishan plume [24–27], or a pre-late Paleozoic-early Mesozoic back-arc basin formed by rifting within the merged Indochina-South China plate [28].

The study area belongs to the Song Hien zone of Northeast Vietnam (Fig. 1, A). The lithology of the Dong Van region comprises mostly Triassic sedimentary rocks (marlaceous shale, oolithic limestone, siltstone, tuffaceous sandstone, shale, sandstone), Devonian, Carboniferous, and Permian sedimentary rocks (i.e., conglomerate, clay shale, carbonate rocks, and marly sandstone). Cambrian, and Ordovician sedimentary rocks are also present in the Song Hien margin. Triassic gabbro and unknown age granitoid rocks occur in the central and western part of the zone [21–23, Fig. 1, B]. Quaternary sediments are mostly found along valleys (i.e., sandstone and gravelstone). The Dong Van region is located in the northern part of the Song Hien zone extending from northwest to

[1] USGS. Minerals Yearbook. United States Geological Survey: Reston, VA, USA; 2014. https://doi.org/10.3133/mybvI

southeast (Fig. 1, B). The Cao Bang-Lang Son-Tien Yen strike-slip fault zone in the northern part and the Duong Thuong-Du Gia reverse fault in the southern part play an important role in controlling the Song Hien structural zone [20]. The intrusive magmatic rocks in this area were considerably controlled by these faults and other minor fault systems, contributing to the area's more intricate structure [22].

There is a primary multimetal mineralization zone in the studied area, namely Dong Van, extending from northwest to southeast and covers 1,190 square kilometers. The zone I mainly encompassed by Triassic sedimentary rocks [21–23, Fig. 1, B]. According to Truyen et al. [22], uneven concentrations of Sn, W, and As were found in this mineralized zone, as illustrated by Thang et al. [29].

2. Materials and methodologies

2.1. Collection and preparation of bottom sediment samples

Geochemical exploration techniques for exploring mineral deposits usually use bottom sediment samples. For this study, eight hundred ninety geochemical samples of recent bottom sediments were collected along river and streams at 25–50 m intervals. Surface sediments (0–3 cm deep) were collected by means of hand shovel from all points (on both river sides) with low current velocities, in order to take fine and recent material. Each sample contained around 25–130 g of recent bottom sediment, depending on a sediment sample particle size (Fig. 2).

The sample sets were processed based on distinct characterizations of the zone's bottom sediments.

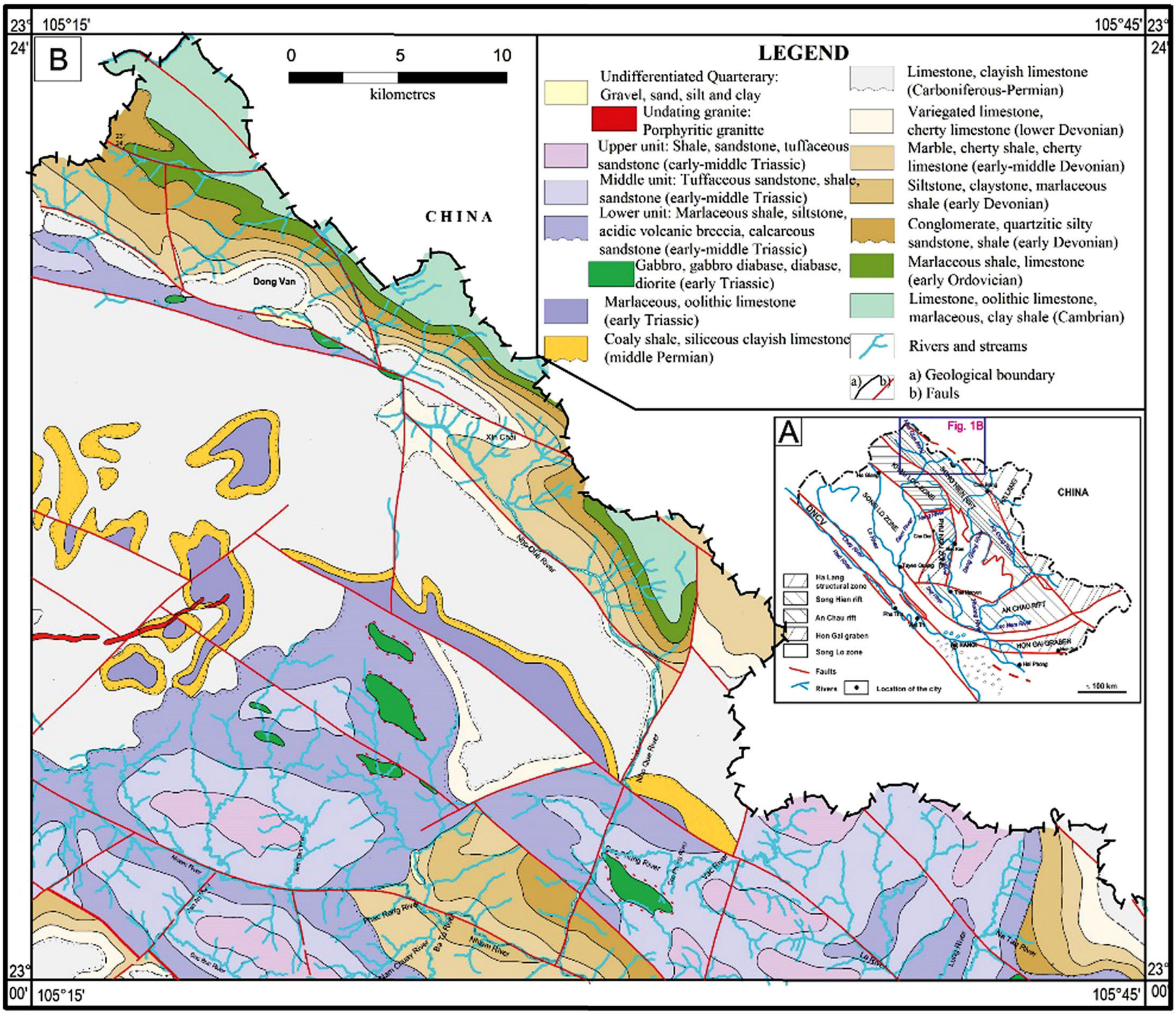

Fig. 1. Tectonic sketch map of northeastern Vietnam, showing the study area (*A*) [20]; Simplified geological map of the Dong Van region (*B*) (modified from [22])

In addition, the contents of 27 chemical components (elements) were measured using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) (i.e., Ag, As, Be, Ba, Bi, Cd, Ce, Co, Cr, Cu, Ga, Ge, La, Li, Mo, Nb, Ni, Pb, Sb, Sc, Sn, Sr, Ta, V, W, Y, and Zn).

2.2. Data transformation

In this study, a total of 27 elements (variables) (i.e., Ag, As, Be, Ba, Bi, Cd, Ce, Co, Cr, Cu, Ga, Ge, La, Li, Mo, Nb, Ni, Pb, Sb, Sc, Sn, Sr, Ta, V, W, Y, and Zn) in the bottom sediment samples were processed. If the variables did not demonstrate asymmetric distribution, skewness (statistical distribution test) and transformed variables were used to assess the normal distribution of each variable [30]. Furthermore, ten distribution models (geometric, special discrete, uniform, triangular, Pareto, binomial, exponential, lognormal, normal, and transformed gamma) were developed to achieve normality and transition for skewed variables [8, 31–33].

2.3. Multivariate analysis

Multivariate analysis methods are used to clarify and explain correlations between multiple factors linked with statistical data throughout the assessment and collecting of this data.

Geostatistic 9.0 is used to examine the findings of correlation coefficients and cluster studies, which assist in analyzing links between elements and element grouping.

The purpose of cluster analysis is to reduce the number of significant subgroups of people or things in an extensive data collection. Data subdivision (grouping) is performed on the basis of the items' similarity, based on predetermined characteristics.

Ward (1963) describes Ward's mathematical technique as a criterion for studying hierarchical clusters. Ward [34] introduced a universal agglomerative hierarchical clustering technique, in which the criteria for picking the pair of clusters to be joined at each level are based on the optimal value of an objective function.

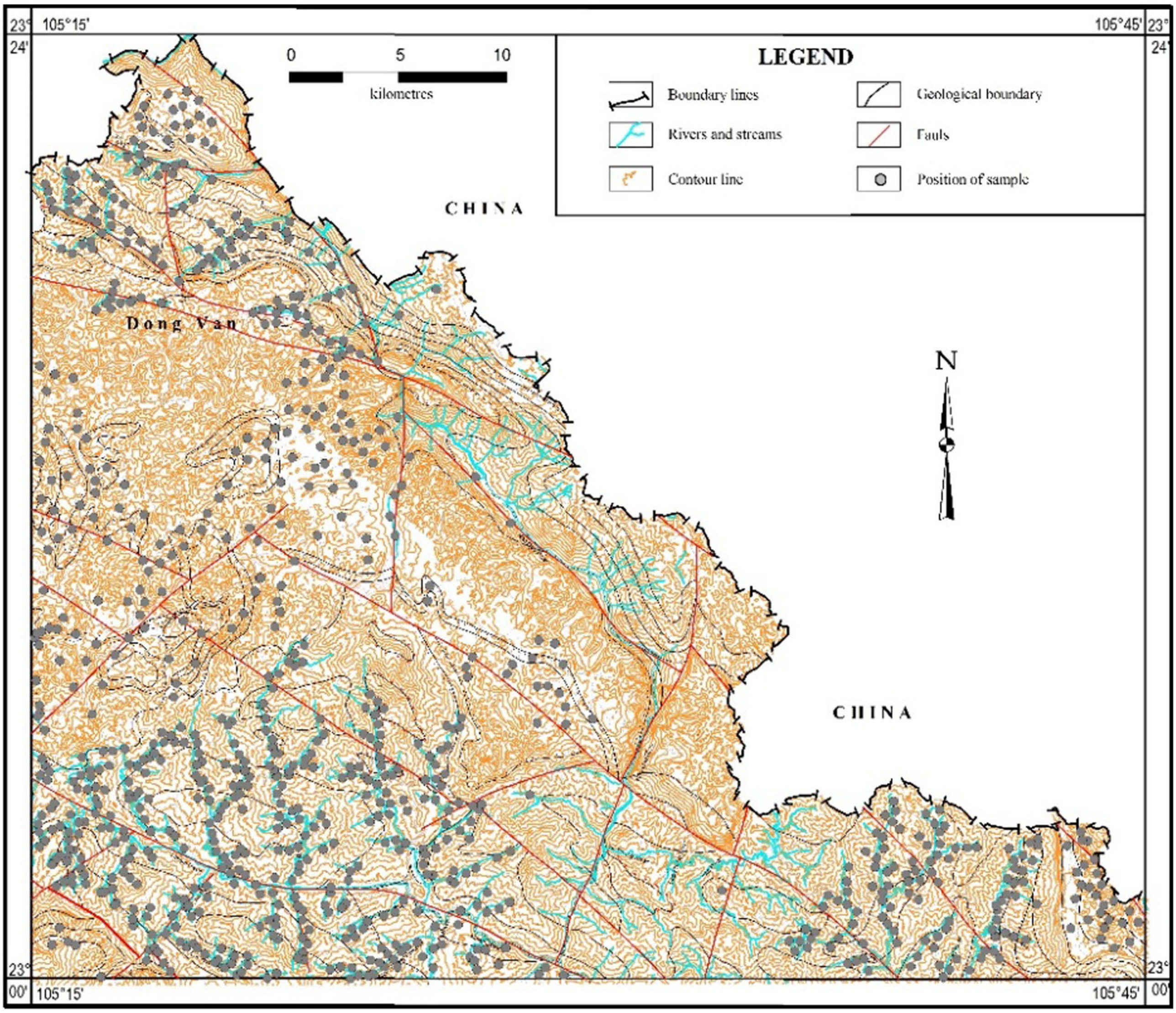

Fig. 2. General map of the Dong Van region, northeastern Vietnam showing bottom sediment sample points (shown as black dots)

Eigenvalues and eigenvectors are used to generally express covariance and correlation coefficient matrices.

In the meanwhile Varimax rotation was performed to enhance the factor loads. Ward's approach was used to carry out Pearson's correlation coefficients cluster analysis (or hierarchical cluster analysis), and the results were shown in a dendrogram.

3. Results and discussion

3.1. The characteristics of statistical element distribution

Statistical distribution models for elements of multimetal ores and associated elements can be used to identify the laws of their statistical distribution. Results of geochemical data statistical analysis for the whole region were displayed separately. The resulting element contents hierarchy in the whole region was as follows: Pb > As > Bi > Li > Sn > W > Ta > Ce > Ag > Sb > Be > Mo > La > Nb > Cr > Ni > Cd > Y > Cu > Ba > Co >Sc> Zn > Sr > V (Table 1). Moreover, Pb, As, Bi, Li, Sn, W, Ta, Ce, Ag, Sb, and Be constituted more than 90 % of the total, indicating obvious association with multimetal ores. Finally, these elements can be used as indicators when prospecting for multimetal mineralization.

Using the three-sigma limit method, the geochemical samples were statistically processed in this study (Table 2). We used mean value, variance, and coefficient of variation as the basic statistical metrics. In addition, skewness and kurtosis techniques were used to test the element distribution models and the majority of the element contents on the basis of geometric distribution criteria (Table 3). Geostatistic 9.0 software program evaluated the distribution models and statistical analysis [35].

The distribution rules of the indicator elements did not adhere to the normal standard distribution and were modified to geometric distribution, pursuant to the characterization of the statistical distribution of Sn and W in secondary geochemical dispersion haloes (Table 3). The overall contents of Sn and W are higher than crustal abundance (Sn* = 2.5 ppm, W* = 1.3 ppm [36]), while the distributions of the Sn

Table 1

Frequency analysis of the elements contents [ppm] in the sediment samples

Element	Amount of Information (AI)	Information Combination (IC)	Probability (%)	Element	Amount of Information (AI)	Information Combination (IC)	Probability (%)
Pb	0.573	0.573	**30.02**	Nb	0.337	1.842	96.49
As	0.572	0.810	**42.41**	Cr	0.313	1.868	97.87
Bi	0.564	0.987	**51.69**	Ni	0.235	1.883	98.64
Li	0.561	1.135	**59.46**	Cd	0.197	1.893	99.18
Sn	0.546	1.260	**65.98**	Y	0.190	1.903	99.68
W	0.527	1.365	**71.52**	Cu	0.095	1.905	99.80
Ta	0.512	1.458	**76.39**	Ba	0.082	1.907	99.89
Ce	0.492	1.539	**80.62**	Co	0.069	1.908	99.96
Ag	0.471	1.609	**84.31**	Sc	0.046	1.909	99.99
Sb	0.439	1.668	**87.39**	Zn	0.029	1.909	100
Be	0.435	1.724	**90.31**	Sr	0.000	1.909	100
Mo	0.413	1.773	92.87	V	0.000	1.909	100
La	0.369	1.811	94.86				

Note: AI and IC are described by Hung et al. (2020) [2].

Table 2

Statistical characteristics of the indicator elements (ppm) in the Dong Van region

Parameters	Ag	As	Be	Pb	Bi	Sb	Ce	Sn	Ta	W	Ge	Li
Mean	1.27	49.39	5.67	27.9858	0.98	19.2444	87.55	14.6279	23.0603	19.7104	5.5618	46.403
Median	0.33	27.63	1.90	23.31	0.47	3.2	78.15	8.805	5.255	5.87	5	33.715
Mode	18.54	49.00	31.60	10.77	4.03	37.24	64.05	49.07	20.63	48.02	0	40.19
Standard deviation	13.10	75.83	29.49	21.7042	3.62	60.9511	40.018	45.4845	46.9017	61.1201	1.579	47.3386
Variance	171.60	5750.53	869.61	471.0731	13.09	3715.039	1601.45	2068.839	2199.772	3735.672	2.4934	2240.944
Coefficient of variation (%)	1029.03	153.55	520.29	77.55	371.94	316.72	45.71	310.94	203.39	310.09	28.39	102.02
Skewness	25.87	6.32	14.85	2.252	18.13	6.19	2.35	14.913	4.109	9.053	2.463	7.51
Kurtosis	717.33	52.41	270.95	9.444	384.99	47.879	7.91	273.92	22.217	106.11	4.073	83.746
Minimum	0.04	2.00	0.10	0.77	0.03	0.24	16.05	0.07	0.13	0.02	5	5.69
Maximum	370.70	945.65	636.31	209.29	85.61	743.58	337.75	986.44	415.76	967.95	10	703.89
Summary	1132.97	43954	5044.38	24907.39	865.90	17127.49	77916.67	13018.85	20523.7	17542.25	4950	41298.7

and W contents vary from uneven to extremely uneven. On this basis, the different geochemical anomalies can be identified at a local scale. This indicates that Sn and W can form small primary geochemical anomalies. This data can allow primary geochemical dispersion haloes to be detected. This in turn can be used to identify prospective targets for Sn-W mineralization in the Dong Van region.

3.2. Correlation and cluster analyses application

The correlation analysis findings allow a pair correlation matrix of the best indicator elements to be created for the geochemical landscape (pattern) of the entire region. Table 4 shows the elements pair correlation matrix. Among the indicator elements, Be, Sn, W, and Bi demonstrate obvious correlation. Sn and W especially establish the element association as an indication for multimetal ore prospecting. Li also demonstrated marked correlation with Be and Bi, indicating Li participation in ore-forming processes.

Thus, the calculations showed close correlation ties between Be, Sn, W, and Bi, thus indicating that they formed stable association.

A dendrogram was created, in order to determine the correlation ties between the studied elements in the secondary geochemical haloes in the Dong Van region based on the pair-correlation analysis findings (Fig. 3). Pearson's correlation coefficients were used to statistically measure the ties.

The dendrogram depicts associations between the elements studied and allows for their grouping/subgrouping. Multimetal mineralization-associated elements are represented by two sub-groups, Be-Sn-W-Bi, and, to a lesser extent, Li-Pb. At the same time, three other sub-groups, i.e., As-Cd-Sc-Cr-Ce-La, Co-Ni-V, and Ga-Ge-Ba, not associated with the mineralization, can be distinguished. For instance, the dendrogram also defines a local Co-Ni-V branch, which indicates that Co, Ni, and V are not syngenetic components of the multimetal ores in the region.

Table 3

Testing of Sn, W statistical distribution models

Distribution model	Sn (ppm)							W (ppm)						
	Deviation	Actual deviation	Chi square (18.307)	Conforming to Chi square test	λ (1.358)	Conforming to Kolmogorov-Smirnov test	Synthesizer	Deviation	Actual deviation	Chi square (18.307)	Conforming to Chi square test	λ (1.358)	Conforming to Kolmogorov-Smirnov test	Synthesizer
Geometric	2.486	1	3.267	1-Yes	0.160	**1-Yes**	0.300	5.045	1	31.429	1-No	0.345	**1-Yes**	1.973
Gamma	24.441	2	61.592	2-No	1.562	2-No	4.515	22.369	2	51.685	2-No	1.470	2-No	3.906
Lognormal	61.402	3	164.788	3-No	3.412	3-No	11.514	32.496	3	88.052	3-No	1.889	3-No	6.201
Special discrete	104.029	5	459.352	4-No	7.294	5-No	30.463	58.635	4	147.230	4-No	3.282	4-No	10.459
Pareto	115.827	6	487.814	5-No	7.537	6-No	32.196	98.299	5	412.558	5-No	6.929	5-No	27.638
Exponential	94.306	4	606.050	6-No	6.356	4-No	37.7853	111.040	6	449.417	6-No	7.227	6-No	29.871
Binomial	287.065	10	926.397	7-No	20.737	10-No	65.874	281.168	10	1223.811	7-No	20.239	10-No	81.753
Normal	266.722	9	2150.286	8-No	14.912	7-No	128.438	260.992	9	2059.889	8-No	14.689	7-No	123.336
Triangular	234.503	7	4426.587	9-No	17.320	8-No	254.552	231.131	7	4598.079	9-No	17.081	8-No	263.743
Uniform	251.125	8	8564.185	10-No	18.822	9-No	481.669	244.535	8	8120.654	10-No	18.324	9-No	457.075

Note: The Kolmogorov-Smirnov test was implemented in Chakravarti et al. [31].

Table 4

The correlation coefficient for indicator elements (ppm) in the sediment samples

	Ag	As	Be	Bi	Ce	Li	Pb	Sb	Sn	Ta	W
Ag	1										
As	0.032	1									
Be	0.062	0.445	1								
Bi	0.051	0.205	**0.711**	1							
Ce	0.026	0.262	0.082	0.142	1						
Li	0.044	0.425	**0.569**	**0.542**	0.386	1					
Pb	−0.009	0.310	0.173	0.057	0.331	0.333	1				
Sb	0.071	0.407	0.392	0.499	0.437	0.465	−0.027	1			
Sn	0.006	**0.623**	**0.645**	0.213	−0.027	0.377	0.325	0.106	1		
Ta	−0.021	−0.019	−0.045	−0.036	−0.000	−0.078	0.110	−0.073	0.041	1	
W	0.018	0.438	**0.588**	0.412	−0.048	0.400	0.264	0.176	**0.666**	0.138	1

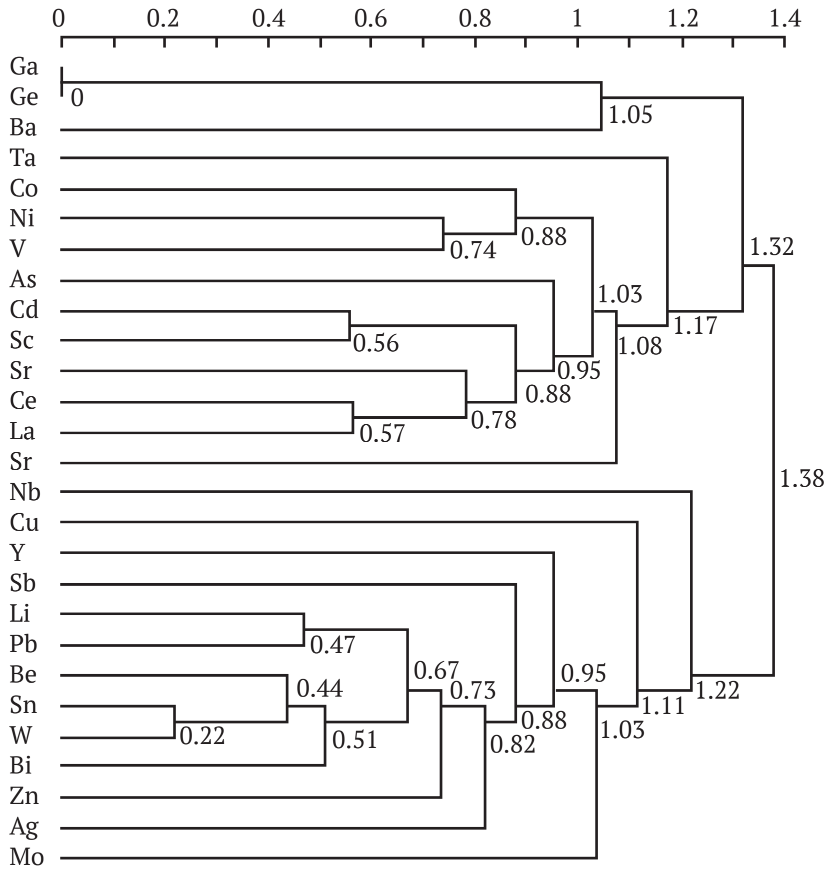

Fig. 3. Dendrogram of elements contents in the Dong Van region's geochemical landscape (ppm). Numbers indicate cluster analysis linkage distances based on Ward's agglomerative clustering algorithm

A combination of multivariate correlation and dendrogram analysis was used, in order to determine the relevance of syngenetic element association for prospecting multimetal ores in the study region. As a result, Be, Sn, W, and Bi were recognized as a members of the syngenetic association. Despite the high contents of some other elements in the samples, they cannot be considered as indicators of multimetal mineralization (or some other mineralization) in this region.

3.3. Geochemical anomaly modeling

Secondary geochemical dispersion is the movement of elements at or just below the Earth's surface, which results from weathering, erosion, and deposition. External circumstances can damage and modify ore bodies, mineralization zones, and change geochemical landscape of a region. Some minerals can be dissolved, washed-out, some elements can migrate, while others can be accumulated with an increase of their contents. The material elements of the secondary geochemical haloes are redistributed in the weathering conditions. The haloes can be considerably larger than primary ore bodies. The secondary geochemical haloes and geochemical anomalies are of crucial importance in prospecting concealed mineral deposits in the region. Geochemical anomaly diagrams were used to represent the spatial variation of the element contents in the region and predict prospective areas for multimetal mineralization.

Secondary geochemical anomalies of Sn and W were constructed, in order to represent the spatial distribution of these good indicator elements for multimetal ore prospecting in the Dong Van region. Creating such geochemical anomaly diagrams is aimed at establishing the distribution and accumulation of indicator elements in certain locations (Figs. 4, 5). This allows for the interpretation and selection of anomalies connected with mineralization, while eliminating anomalies that provide no information about any mineralization.

In order to reveal prospective anomalies, isolines for Sn and W (the indicator elements) contents based on three preset anomaly thresholds were constructed and mapped taking into account geochemical background values. The anomaly thresholds of the first order (mean ± 1 STD), second order (mean ± 2 STD), and third order (mean ± 3 STD) were selected using the statistical processing findings to estimate geochemical background values based on the local average values (Table 5, Figs. 4, 5). For this purpose, mean and STD

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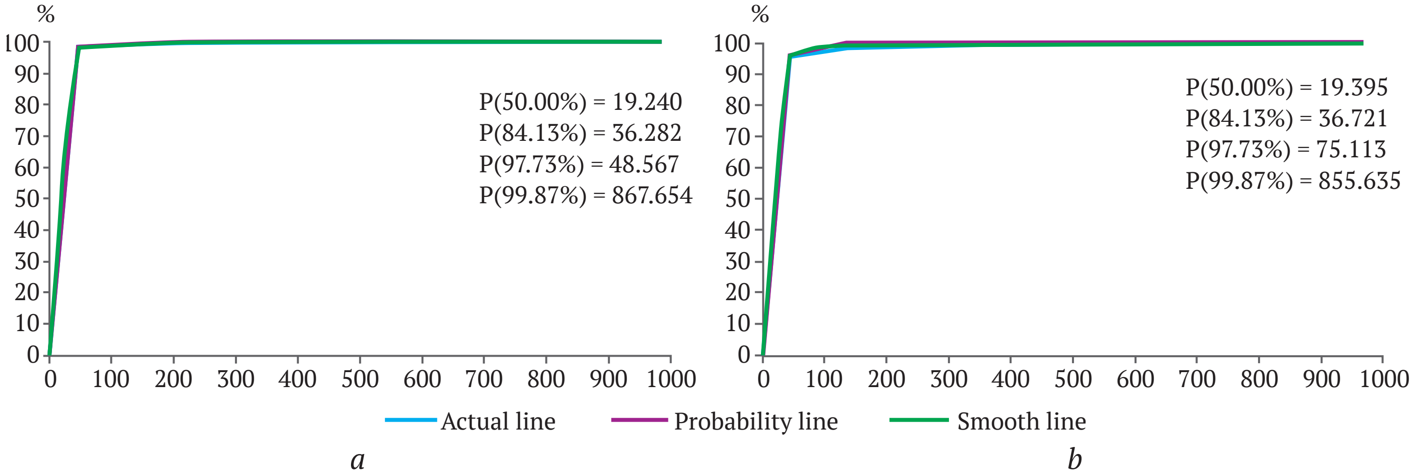

Fig. 4. Sn (*a*) and W (*b*) occurrence graphs based on their distribution in the Dong Van region, showing probability at three anomaly thresholds and background

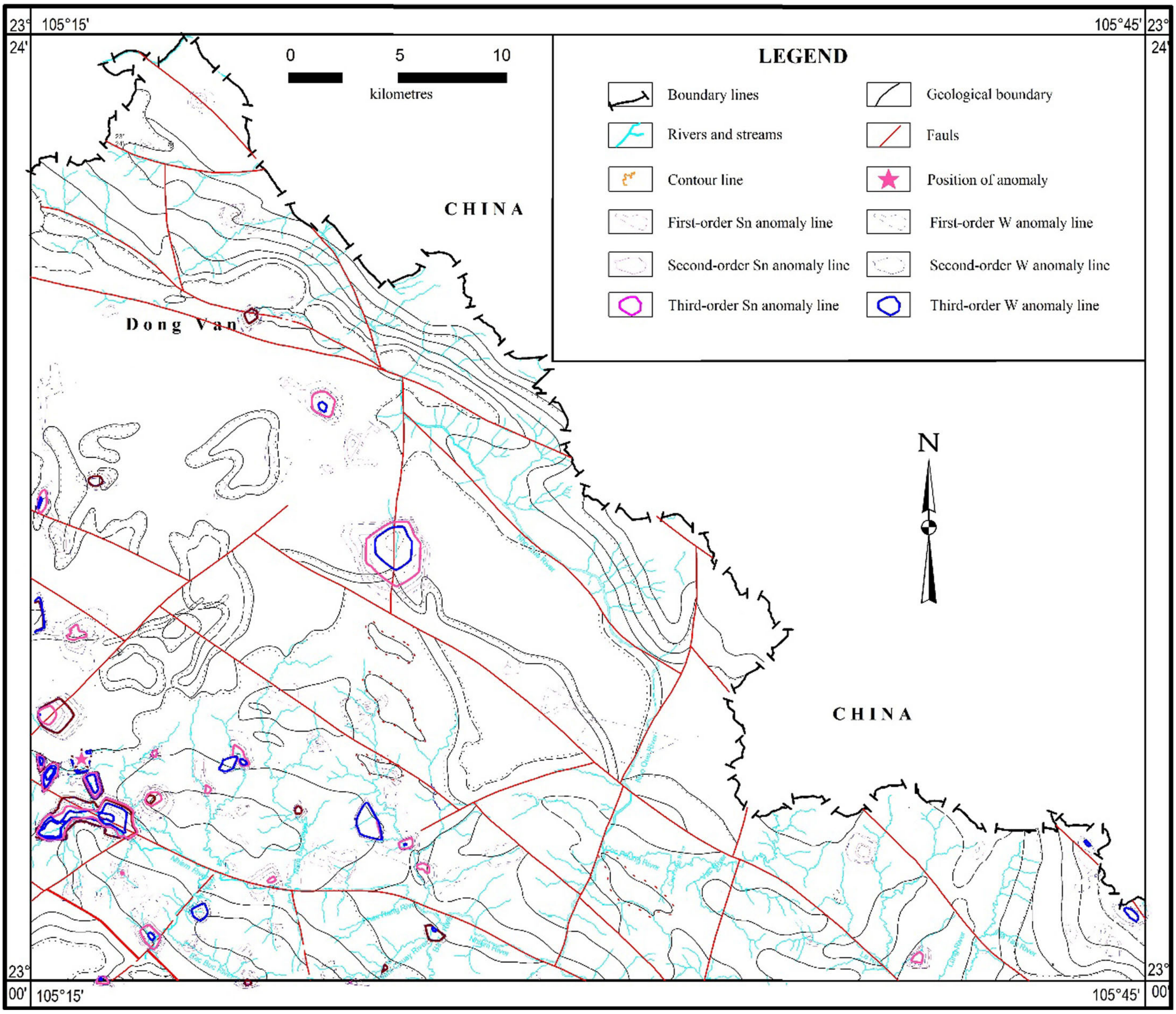

Fig. 5. General map of the Dong Van region showing Sn-W anomaly indicating prospective area

Table 5

Anomaly contents of Sn, W in the Dong Van region based on anomaly thresholds using calculated, theoretical, and probability standard deviation

Element (ppm)	Method	Crustal abundance	Back-ground	First-order anomaly	Second-order anomaly	Third-order anomaly	Anomaly
Sn	Calculated standard deviation (CSD)	2.5	19	65	110	156	156
	Theoretical standard deviation (TSD)	2.5	19	19	20	20	20
	Probability standard deviation (PSD)	2.5	19	38	57	76	76
	Probability distribution (PPD)	2.5	19	36	49	868	868
W	Calculated standard deviation (CSD)	1.3	19	81	142	203	203
	Theoretical standard deviation (TSD)	1.3	19	20	20	20	20
	Probability standard deviation (PSD)	1.3	19	38	56	75	75
	Probability distribution (PPD)	1.3	19	37	75	856	856

Note: Crustal abundance values for the indicator elements (Sn* = 2.5 ppm, W* = 1.3 ppm) were taken from Fortescue [32].

values were calculated on the basis of geometric distribution. Geochemical anomalies associated with multimetal mineralization can be selected, while geochemical anomalies not connected with the mineralization can be rejected based on the geochemical anomaly diagrams for the indicator elements, in combination with prospecting data to ascertain the geochemical anomalies.

Tin occurrence locations in the mineralized zone are expressed in the geochemical anomalies of Sn and W. The geochemical anomalies of the indicator elements were identified in three separate areas, as shown in Fig. 5. The anomalies are often elliptical, extending northwest-southeast in accordance with the established mineralization zone orientation. Most of the geochemical anomalies are confined to the Song Hien formation area. The geochemical anomalies identified, particularly those of tin and tungsten adjacent to the mineralized zone, are relatively large and have a complex shape. This indicates the potential presence of concealed ore bodies associated with the granitoid massive. Geochemical anomalies with no ties to mineralization are often presented by limited secondary accumulations located on local slopes and similar land forms.

Conclusions

Multimetal mineralization in the Dong Van region, northeastern Vietnam was studied using statistical and multivariate analytic approaches based on 890 geochemical sediment samples. The findings of frequency analysis demonstrated that Pb, As, Bi, Li, Sn, W, Ta, Ce, Ag, Sb, and Be have close ties with multimetal ores. This implies that these elements can be used as prospecting indicators for multimetal mineralization. Furthermore, extensive Sn and W anomalies were identified in the Dong Van region, providing the most important indications for multimetal mineralization prospecting in the region. In the region under examination, correlation matrix and dendrogram studies were also used to subdivide elements in the stream sediment samples assays into two groups: those associated with multimetal mineralization (Be-Sn-W-Bi, and, to a lesser extent, Li-Pb sub-groups); and those not associated with the mineralization: (As-Cd-Sc-Cr-Ce-La, Co-Ni-V, and Ga-Ge-Ba sub-groups).

Threshold value (mean ± 3 STD) was then applied to identify the indicator elements anomaly locations (and background levels) associated with known multimetal mineralization in the region. Thus, such anomalies can be a promising tool for further multimetal mineralization prospecting and exploration.

According to the findings of geochemical modeling and location of the anomalies in the region, Sn and W are the best indicator elements for the mineralization. The studies also suggest genetic ties between the region's multimetal mineralization and the northwest-southeast fault system and concealed granitoid blocks.

Finally, the statistical analysis (with the use of threshold values) of stream bottom sediments assays enabled indicator elements and their geochemical anomalies to be established, and for them to be used as an effective tool in further prospecting and exploration for multimetal mineralization in the region.

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