Caspian Journal of Environmental Sciences
Online ISSN: 1735-3866
Print ISSN: 1735-3033

Soil geochemistry study of the listvenite area of Ayvacik (Çanakkale, Turkey)

Alaaddin Vural[1*], Doğan Aydal[2]

1. Department of Geological Engineering, Faculty of Engineering and Natural Sciences, Gümüşhane University, Gümüşhane, Türkiye
2. Department of Geological Engineering, Faculty of Engineering, Ankara University, Ankara, Türkiye

** Corresponding author's E-mail: alaaddinvural@hotmail.com*

ABSTRACT
Objective of this study is to use soil geochemistry surveys using statistical methods for the exploration of possibly gold mineralization related to Alakeçi listvenite area (Bayramiç, Çanakkale, Turkey). In the scope of soil geochemistry, about 350 soil samples were analyzed and evaluated for nine elements including gold. Element concentrations for Cu, Pb, Zn, As, Sb, Mo, Ni, Co and Au (all element except Au in ppm, Au in ppb) were 10-265, 10-90, 15-545, 5-800, 2-60, 4-8, 10-6300, 15-1255 and 40-300 respectively. The gold concentrations were comparatively detected in low value than important ore deposit and exhibited no correlation with other elements (except Mo). However, positive correlation was observed between Cu and Zn; Sb and As; Mo with As and Sb; Au and Mo; Ni and Co. In literature, Cu, Zn, As, Sb and Mo were widely used as pathfinder elements for exploration of gold mineralization. So, these elements were accepted as pathfinders in this study and their distribution maps were prepared. The element distribution maps for pathfinder elements and gold displayed remarkable zoning in the central to southeast site of the area connected with tectonic lines and lithological borders. So, in conclusion, this part in the area needs to be investigated in detailed with geophysics and drilling methods for blind gold mineralization.

Key words: Listvenite/listvenitization, Gold anomalies, Pathfinder elements, Soil geochemistry, Çanakkale, Türkiye.

INTRODUCTION
Although the concept of listvenite long ago entered the geological literature, listvenite mineralization models proposed are still controversial (Murchission *et al.* 1845, Bates & Jackson 1982). The listvenitization/listvenite mineralization was firstly used for Ural goldfields of Russia which is situated in Listvenya. Over time, the concept of listvenite was accepted by many authors and it was used in many studies (Aydal 1990; Koç & Kadioglu 1996; Vural, 2006; Zoheir & Lehmann 2011, Frost *et al.* 2013; Vural & Aydal 2016a; Hinsken *et al.* 2017; Yusuf *et al.* 2019). With a generic definition, listvenite is defined as carbonatization, silicification, pyritization and serpentinization of ultramafic rocks by hydrothermal and / or metasomatic processes. So, listvenites are an alteration type occurred by hydrothermal fluids moving in shear zones of ophiolitic suites (Uçurum 2000; Vural 2006, Zoheir & Lehmann, 2011, Kiliç & İnceöz, 2015; Vural & Aydal 2016 a, b; Belogub *et al.* 2017; Yang *et al.* 2019). The listvenite, which is the subject of this study, fits this definition. Because listvenite/listvenitization has a close relation to the precious and base metals, it continues to attract attention of many researchers. Although the listvenite is observed in a small location, due to its importance for gold mineralization, soil geochemistry study was conducted the area. So the aim of the study is to be tested the soil geochemistry in investigation of possibly gold mineralization depending on the listvenitization in the area.

Caspian J. Environ. Sci. Vol. 18 No. 3 pp. 205~215
DOI
Received: Dec. 25. 2019 Accepted: May 18. 2020
Article type: Research

MATERIALS AND METHODS

Geological setting

Alakeçi mylonitic zone (AMZ) (Okay *et al*. 1990, Vural 2006, Vural & Aydal, 2016b, 2016a), including listvenites is situated in Biga peninsula, NW Anatolia, Turkey. Basement rocks of the region, according to Okay *et al.* 1990, southeast to northwest, include Sakarya, Ayvacık-Karabiga and Ezine zones. In the study area, we observe metamorphic rocks of Kazdağ group (consists of gneisses, amphibolite and marble) belonging to Sakarya Zone, ophiolitic mélange belonging to Ayvacık-Karabiga Zone and mylonitic gneiss in mylonitic zone (AMZ) which developed between these two zones, and metaserpentinites. All these units were cut Tertiary magmatics and/or covered sedimentary and volcanics (Fig. 1).

Mylonitic gneiss between ophiolitic mélange and Kazdağ Group formed the hilly Alakeçi Mylonitic Zone in an east-northeast trend consistent with the main foliation of Kazdağ Group. Along these zones, listvenite extends in the northwest-southeast direction with a length of 1.5-2 km and a width of 400-500 meters, and cutting northeast-southwest trending dextral. Listvenite is mainly consisted of Fe-Mg carbonate (probably derived from olivine), quartz and fuchsite (Cr-bearing mica). These minerals are accompanied by disseminated chromite and to a lesser extent pyrite. As a result of the conversion of iron carbonates to iron oxides, the listvenites are yellowish green, reddish brown.

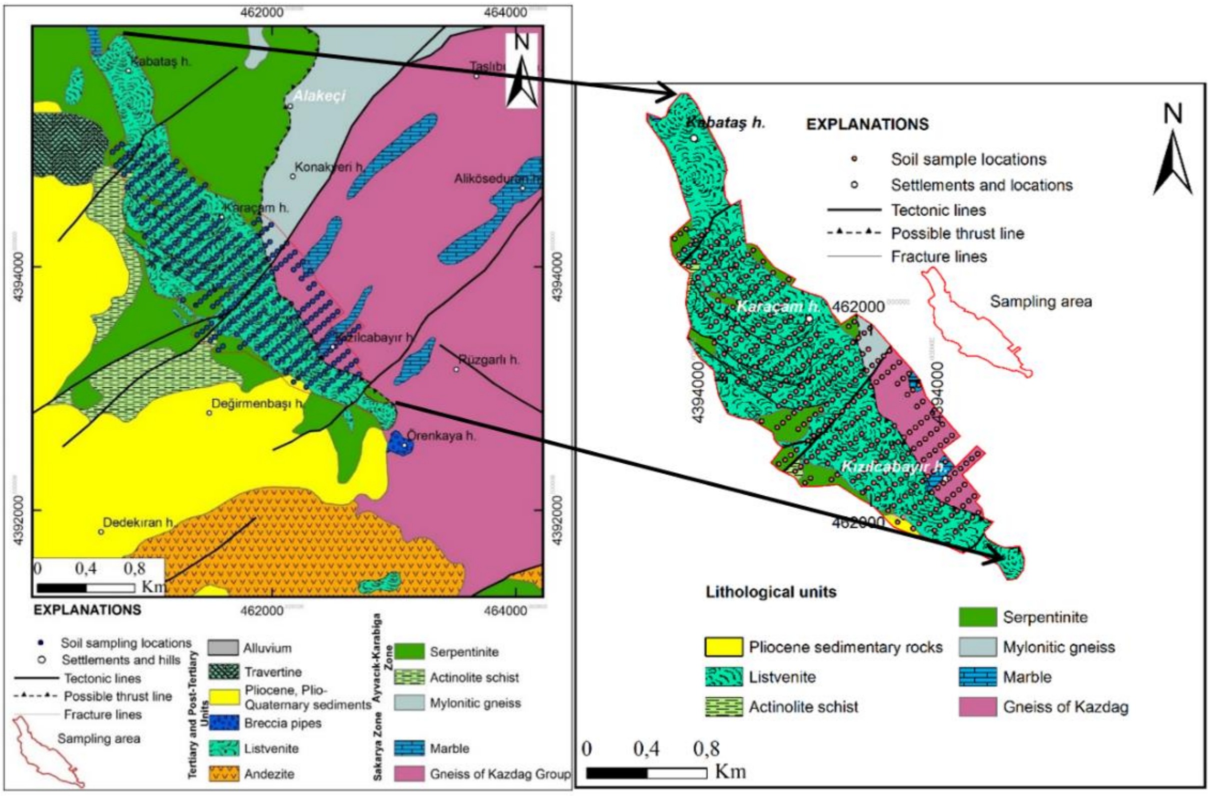

Fig. 1. Geology and sampling map of the study area (After Vural 2006).

Methology

Sampling and analytical procedure

From Alakeçi listvenite area, for geochemical purposes, 350 soil samples were collected from 15-30 cm in depth of soil profile B, in a rectilinear grid at equal distance along evenly spaced lines. The lines are oriented perpendicularly to NW-SE trending listvenite zone. (Fig. 1). During the sampling, sampling procedures recommended by Rose *et al.* 1991, were followed and the necessary sensitivity was taken to prevent contamination. The samples were sent to the Laboratory of Mineral Research and Exploration of Turkey (MTA in Turkish, Government organization of Turkey). Samples were dried at a temperature of 60 ºC for 24 h, <80 mesh fraction obtained by dry sieving was retained in order to be used in chemical analysis (Rose *et al.* 1991). Sample preparation and analysis processes were also carried out according to the procedures of the MTA laboratory. So, samples were

Caspian J. Environ. Sci. Vol. 18 No. 3 pp. 205~215 Received: Dec. 25. 2019 Accepted: May 18. 2020
DOI Article type: Research

analyzed in this laboratory by applying its procedures for Ag, As, Mo, Sb, Cu, Pb, Zn, Co, Ni and Bi by a flame atomic absorption spectrometer, Shimadzu AA-680 FAAS with single element hollow cathode lamb, and for gold by a graphite-furnace atomic-absorption. MTA's standards were used during the analytical process. First, a series of mixed standard solutions containing each metal ion were prepared from stock metal solutions, and then these solutions were introduced to the instrument to generate calibration charts. Finally, the soil samples were taken into solution form after being digested with aqua regia reagent (3:1 ratio conc. HCl and HNO_3) were measured in the device, and concentrations of the solutions containing each metal ion were determined via relevant calibration charts. The concentrations measured in mg L^{-1} (or µg L^{-1}) in solution were then converted to ppm (or ppb) by the following Formula 1:

$$\text{Concentration (ppm or ppb)} = \frac{C \times V \times D}{m} \qquad (\mathbf{1})$$

C: The concentration value of mg/L or µg/L measured in aqueous solution by AAS
V: Final volume (mL) after being digested the soil samples with aqua regia
m: Weighed soil mass (g)
D: Dilution coefficient
Accuracy and sensitivity tests of sample analysis were performed according to following routine procedures: Accuracy of the method was verified by a certified reference material, CRM Sandy Soil. The method, aqua regia wet digestion – AAS determination, was applied to CRM and the results are depicted in Table 1. As shown in the table, the recoveries are quite satisfactory. The results of the *t*-test on whether the certified value and the obtained value are the same, are also quite satisfactory (Skoog *et al.* 2004).

Table 1. Analysis of a certified reference material, CRM sandy soil, for accuracy of the method (N = 3).

	X_{CRM}	s_{CRM}	X_F	s_F	R (%)	E (%)	RSD (%)	$X_F - X_{CRM}$	$s_F/\sqrt{N}$	t_c	$t_{critical}$*	Comparison
Cu	63,6	4,0	61,2	3,2	96,2	-3,8	5,2	-2,400	1,848	-1,30	4,30	Same
Pb	120,0	8,0	114,2	3,4	95,2	-4,8	3,0	-5,780	1,986	-2,91	4,30	Same
Zn	607	30	575	34	94,7	-5,3	6,0	-32,400	19,780	-1,64	4,00	Same
As	67,7	4,2	60,7	4,2	89,6	-10,4	6,9	-7,040	2,425	-2,90	4,30	Same
Ag	24,6	1,6	22,3	1,4	90,8	-9,2	6,1	-2,270	0,785	-2,89	4,30	Same
Mo	53,6	4,0	47,8	3,6	89,1	-10,9	7,5	-5,830	2,078	-2,80	4,30	Same
Au	(25)**		21	2	84,9	-15,1	10,7	-3,780	1,305	-2,90	4,30	Same
Ni	48,4	3,0	44,4	2,9	91,8	-8,2	6,6	-3,960	1,686	-2,35	4,30	Same
Co	12,4	0,6	11,7	0,8	94,0	-6,0	6,6	-0,750	0,445	-1,69	4,30	Same

Note: If $t_c \geq t_{critical}$ or $t_c \leq -t_{critical}$, Ho (null hypothesis) is rejected. So, there is a statistically significant difference between the 2 results compared. t_c is calculated by the following formula:

$$t_C = \frac{X_F - X_{CRM}}{s_F/\sqrt{N}}$$

* $t_{critical}$ value for p = 0.05
**The value given is for informational purposes, not certified.
X_{CRM} : Mean of the certified value
s_{CRM} : Standard deviation of the certified value
X_F : Mean of the found value
s_F : Standard deviation of the found value
R : Recovery
E : Error
RSD : Relative standard deviation
t_c : Calculated *t* value
$t_{critical}$: Critical *t* value

Precision of the method was evaluated with relative standard deviation (RSD). The solution containing the corresponding metals at a concentration of 0.1 mg L^{-1} was analyzed 20 times by the same method. The standard deviation of the results obtained was calculated and RSD% values were found for each metal with the following

Caspian J. Environ. Sci. Vol. 18 No. 3 pp. 205~215 Received: Dec. 25. 2019 Accepted: May 18. 2020
DOI Article type: Research

Formula 2:

$$\text{RSD (\%)} = \frac{s}{\overline{X}} \times 100 \qquad (2)$$

RSD : Relative standard deviation
s : Standard deviation
$\overline{X}$: Mean value

LOD (limit of detection), which is the lowest concentration detected by the method, was calculated by taking three times the standard deviation of the results obtained after the analyses of 20 blank solutions. LOQ (limit of quantification), which is the lowest concentration detected quantitatively by the method, was calculated by taking 10 times the standard deviation of the results obtained after the analyses of 20 blank solutions. RSD, LOD and LOQ values of each metal are given in Table 2.

Table 2. Analytical figure of merit of the method.

	LOD		**LOQ**		**RSD**
	μg L^{-1}	**ppm***	**μg L^{-1}**	**ppm***	**%**
Cu	10	1,0	33	3,3	2,1
Pb	25	2,5	83	8,3	3,2
Zn	10	1,0	33	3,3	2,6
As	20	2,0	66	6,6	1,7
Ag	010	1,0	33	3,3	2,1
Mo	15	1,5	50	5,0	1,2
Au**	0,13	0,013	0,4	0,04	2,2
Ni	15	1,5	50	5,0	1,3
Co	15	1,5	50	5,0	1,4

*ppm LOD and ppm LOQ values were calculated by Formula 1. The ppm concentration can also be expressed in mg kg^{-1}.
**measured by graphite furnace AAS.

Evaluation of data

All data were analyzed with IBM SPSS 21 statistical software and also evaluated spatially with ArcMap 10.7. The descriptive statistics of data (minimum, maximum, geometric mean, standard deviation, median etc.) and also correlation coefficients were determined for 9 elements. The statistical analysis results were given in Tables 3-5. Kolmogorov-Smirnov (K-S) nonparametric test was used to check whether the data showed normal distribution. Histogram and Q-Q diagrams were also plotted to determine the probability properties of raw data (Fig. 2).

Table 3. Descriptive statistics for geochemical data in soils of Alakeçi listvenite.

	N*	**Upper Crust Value****	**Mean**	**Median**	**Geometric Mean**	**Minimum**	**Maximum**	**Std. Deviation**
Cu	342	28	38.30	33,00	32,90	10	265	29,120
Pb	340	17	24.38	20,00	22,33	10	90	10,386
Zn	342	67	64.18	55,00	58,31	15	545	38,812
As	325	4,8	93.32	50,00	61,43	5	800	86,083
Sb	220	0,4	4,75	4,00	3,54	2	60	6,151
Ag	1	0,053	2.00	2,00	2,00	2	2	
Mo	16	1,1	4.50	4,00	4,36	4	8	1,366
Au	38	1,5	64,21	40,00	53,96	40	300	52,589
Ni	340	47	1517,29	1250,00	916,47	10	6300	1271,054
Co	338	17,3	104,20	80,00	78,38	15	1255	98,088

*N represents the number of samples to which the metal of interest is quantitatively detected.
**Upper crust element concentration of Rudnick and Gao (2010).

Element distribution mapping

Element mapping for gold and its pathfinder elements to explore the potential gold enrichment/mineralization were prepared using ArcMap 10.7 software with kriging, prediction technique. In this technique, optimal weights are calculated by determining the spatial dependence between sample points. The most commonly used method for determining the spatial dependence is variogram or covariance function. There is no priority of preferring one

Caspian J. Environ. Sci. Vol. 18 No. 3 pp. 205~215
DOI
Received: Dec. 25. 2019 Accepted: May 18. 2020
Article type: Research

function over another, and one can be easily preferred. According to the regional variable theory, semi-variance parameter is used to determine the degree of relationship between points on the surface (some details on the technique were given in the relevant section below).

Because of the extremely high values of the elements in soil data, it was preferred to use the background concentrations of the upper continental upper crust proposed by Rudnick and Gao, 2010, rather than calculating the threshold values in this study.

Table 4. Significance levels of the Kolmogorov–Smirnov test (K–S p) and skewness and kurtosis values for the raw and log-transformed data from soil samples.

	Raw data			Log-transformed Data		
	Skewness	**Kurtosis**	**K-S[a]**	**Skewness**	**Kurtosis**	**K-S[a] p**
Cu	4,583	28,604	,000	,791	2,154	,000
Pb	1,524	6,561	,000	-,362	,109	,000
Zn	6,927	75,537	,000	,581	3,158	,000
As	2,927	17,269	,000	-,599	,026	,000
Sb	6,036	44,620	,000	1,292	2,288	,000
Mo	2,509	4,898	,000	2,509	4,898	,000
Au	3,150	11,287	,000	1,802	2,700	,000
Ni	1,127	,814	,000	-1,171	1,326	,000
Co	5,408	55,838	,000	,145	-,345	,002

a. Lilliefors Significance Correction

b. Ag is constant. It has been omitted.

RESULTS AND DISCUSSION

Statistical evaluation of the data

Table 3 reports a summary of the descriptive statistics for 9 elements of the soil samples data, including mean, median, geometric mean, minimum, maximum and standard deviation. Element concentration of soil were ranged for Cu, Pb, Zn, As, Sb, Ag, Mo, Ni, Co and Au (all element except Au in ppm, Au in ppb), from 10 to 265; 10 to 90; 15 to 545; 5 to 800; 2 to 60; 2; 4 to 8; 10 to 6300; 15 to 1255 and 40 to 300 respectively. These concentrations are generally higher than the expected normal soil values. Except Ni and Co, all elements exhibited high values in more than one sampling location, Ni and Co displayed one and two high values respectively. These extremely high concentrations in sampling set are thought to be due to improved listvenitization of the ultramafic rocks due to hydrothermal alteration/metasomatism processes. In order to find out the probability properties of the elements in soil samples, histograms, Q-Q diagrams of both raw data, logarithmic transformed data and Box-Cox transformed data were prepared (and K-S test was applied (Fig. 2, Table 4). In Table 4, the kurtosis, skewness and K-S results are given in detail for raw and log-transformed data. Due to skewness of raw data, for all elements, concave shapes and both high and low values were obtained (Jena 1996; Anderson 2008; Carranza 2009; Carranza *et al.* 2009; Zuo *et al.* 2009; Carranza & Sadeghi 2010; Almasi *et al*. 2015; Vural 2019). The raw data of all examined elements showed skewness, and concave geometry. High and low values were also observed. Therefore, it was found that the examined elements exhibit deviations from the normal distribution. Log normal data were found to be relatively close to the normal (Gaussian) distribution (Box-Cox conversions data were not used in this study because they did not yield satisfactory results). So, for element distribution mapping, log-transformed data were used. Factor analysis, clustering analysis and also correlation coefficients are used in the determination of pathfinder elements that guide the exploration for indicator elements [the element(s) subject to mineral exploration] (Miranda *et al.* 1996; Diaz *et al.* 2002). In this study, only correlation analysis was used to detect pathfinder elements for gold ($p \leq 0.05$ and $p \leq 0.01$) and the multi element correlation coefficients of soil samples are shown in Table 5. Considering the correlation coefficients calculated for the elements, gold has no correlation with other elements (except Mo). However, positive correlations were observed between Cu and Zn (0.75), Sb and As (0.65), Mo with As (0.51) and Sb (0.57), Au and Mo (0.73) as well as Ni and Co (0.73). Since gold values in the soil exceeded detection limits and reached remarkable values at only a few sampling points in the study area, correlation analysis results were not very satisfactory for gold. In many studies, some elements for gold have been proposed as pathfinder elements. For example, Anand *et al.* 2019, stated that the development of deep weathering and ferruginous horizon leads to enrichment of gold and pathfinder elements (soil formation process in one aspect) and in this process, As, Sb and W accompany the gold as pathfinders.

Caspian J. Environ. Sci. Vol. 18 No. 3 pp. 205~215 Received: Dec. 25. 2019 Accepted: May 18. 2020
DOI Article type: Research

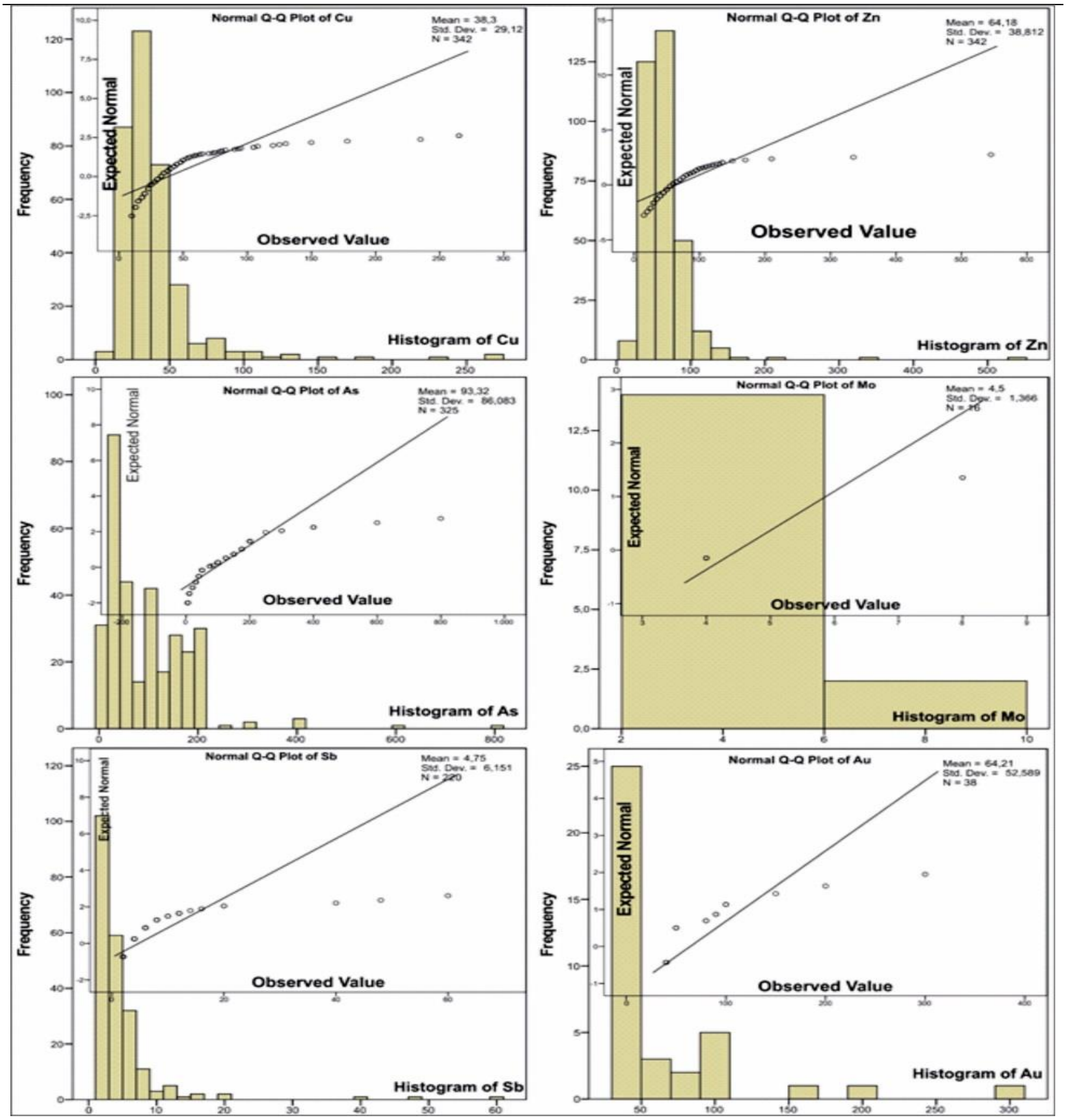

Fig. 2 . Histogram and normal Q-Q plots of the raw data.

Table 5. Correlation coefficient of the elements.

	Cu	Pb	Zn	As	Sb	Mo	Au	Ni	Co
Cu	1								
Pb	0.42	1							
Zn	0.75	0.44	1						
As	-0.03	0.05	0.08	1					
Sb	0.08	0.06	0.12	0.65	1				
Mo	-0.13	-0.24	-0.24	0.51	0.57	1			
Au	-0.02	-0.13	-0.07	0.05	0.10	0.73	1		
Ni	-0.26	-0.10	-0.01	0.36	0.18	0.05	-0.09	1	
Co	-0.19	-0.03	0.02	0.37	0.20	0.03	-0.10	0.73	1

In the study conducted by Nude *et al*. 2012, factor analysis and hierarchical cluster analyzes were performed to determine the possible pathfinder elements for gold. As a result, they stated that As and Cu can be used as pathfinder

Caspian J. Environ. Sci. Vol. 18 No. 3 pp. 205~215
Received: Dec. 25. 2019 Accepted: May 18. 2020
DOI
Article type: Research

in secondary environments such as lateritization. Ellsmore *et al.* 2010, reported that Ag, As, Bi, Pb, Hg, W, Zn and Sn are good pathfinders for gold in soils derived from basic rocks, especially basaltic rocks. Given the literature mentioned above and also performing correlation analysis, Cu, Zn, As, Sb and Mo were accepted as pathfinder elements for gold in the study. The reason for the presence of Mo in these elements considered as pathfinder is thought to be a porphyry system which is thought to exist deeply in the region. Mo, which is probably a part of the deep porphyry system, reaches the surface due to its mobility and acts together with these elements under the effect of similar physicochemical conditions (Vural 2006, Vural & Aydal 2018).

Evaluation of element distribution maps

Element distribution maps for gold and its pathfinders Cu, Zn, As, Sb and Mo were prepared using ordinary kriging prediction technique by ArcMap 10.7 (Fig. 3). This technique has been used synonymously with geostatistical interpolation for many years. It was recommended by Krige, 1951, for the first time and its use has become widespread with Matheron's, 1963, formulation (Cressie 1993). Kriging technique is a method that can be easily adapted to many situations. Kriging uses semi-variograms to determine values at non-sampled points. Since the semi-variogram is a function of distance, the weighting of the sampling points varies according to the geographical location of the sample locations. Therefore, there is low weighting for distal points and high weighting for proximal ones (Distribution maps and detailed comparison of the techniques used are given by Vural 2019). As mentioned above, the conversion of data to normal distribution has been used in different conversion methods. In this study, the log conversion technique among these methods yielded satisfactory results compared to the others in converting the given data.

When elements distribution maps which prepared using kriging evaluated, it was determined that (Fig. 3) Cu and Zn anomalies (> 28 ppm for Cu and > 67 ppm for Zn) are concentrated in the central region and southeast of the study area. A second enrichment zone for Cu and Zn is located in the northwest of the study area. It is also found that Cu and Zn anomalies are closely related to tectonic lines in the area. In addition, Cu and Zn anomalies are observed in a small area at Karaçam near the center of the study area.

According to distribution map, As anomaly values (> 5 ppm) are mostly located in the center of the study area and are related to the main tectonic line.

Sb anomalies (> 2 ppm) (according to the data determined at limited points) are concentrated in the southeast of the study area and in the central part of the site. Sb anomalies are also closely related to tectonic lines in the area.

It is observed that Mo anomalies (> 2 ppm) developed on the main tectonic line in the central part of the study area and along the probable thrust line extending to the southeast of the site.

When the distribution map in terms of gold is evaluated, it is seen that high gold concentrations (> 40 ppb) are developed on the main tectonic line in the central part of the study area and on the possible thrust line in the southeast of the study area.

According to element distribution maps, gold and its pathfinder elements have similar distribution patterns. So, it was concluded that element enrichment in listvenites are related to tectonic lines and also boundary between listvenites and wall rock (Fig. 3). It was also concluded that the element distribution maps have compatibility with the elements exhibiting a positive correlation.

CONCLUSION

The findings obtained in this study can be listed as follows:

In this study, prospective gold mineralization in Alakeçi listvenite area (Bayramiç, Çanakkale) was investigated by statistical and spatial statistical evaluations of the results obtained from soil geochemistry study. So that, 350 soil samples were evaluated for Au, Cu, Pb, Zn, As, Sb, Mo, Ni and Co.

Result of the geochemical analysis was determined that the concentrations of Cu, Pb, Zn, As, Sb, Mo, Ni, Co and Au (all element except Au in ppm, Au in ppb) were 10-265, 10-90, 15-545, 5-800, 2-60, 4-8, 10-6300, 15-1255 and 40-300 respectively. These concentrations are generally higher than the expected normal soil values for the elements. These (extremely) high concentrations in sampling set are thought to be due to improved listvenitization of the ultramafic rocks due to hydrothermal alteration processes.

Caspian J. Environ. Sci. Vol. 18 No. 3 pp. 205~215 Received: Dec. 25. 2019 Accepted: May 18. 2020
DOI Article type: Research

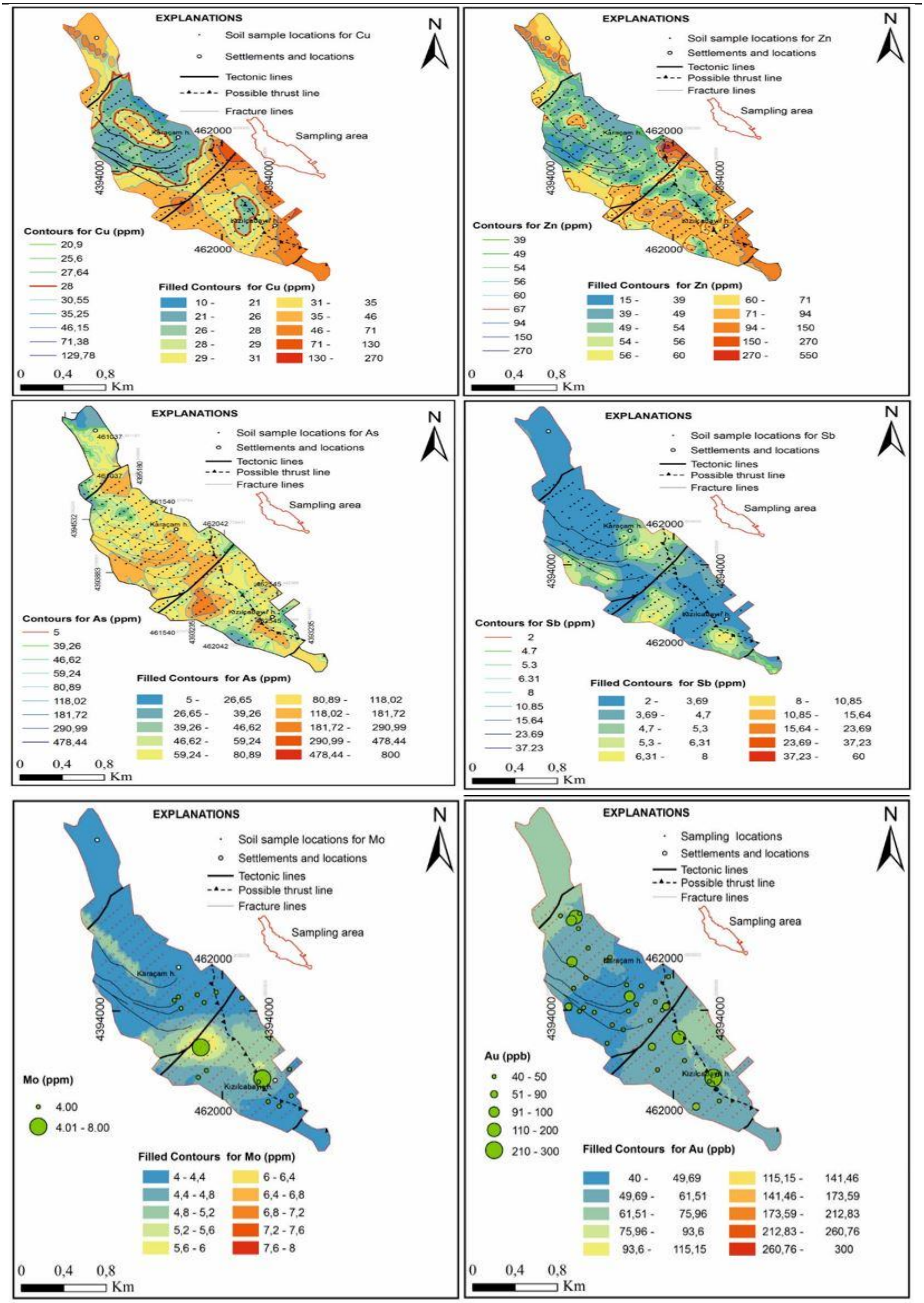

Fig. 3. Element distribution of gold and its pathfinders.

Caspian J. Environ. Sci. Vol. 18 No. 3 pp. 205~215
DOI

Received: Dec. 25. 2019 Accepted: May 18. 2020
Article type: Research

Although there was no significant correlation between gold and other elements (except Mo) in the correlation analysis, a positive correlation was found between Cu and Zn, between Sb and As and also between Mo and As along with Sb. Given the correlation analysis results and also literature data, Cu, Zn, As, Sb and Mo were accepted as pathfinder elements for Au. Element distribution maps for gold and its pathfinders were prepared. It was concluded that gold and its pathfinder elements offer similar distribution patterns. This shows that the elements accepted as pathfinder for gold are accurate. In addition, according to the distribution map patterns, it was also concluded that the element enrichments developed in the listvenite site are associated with the tectonic lines and occurred along the boundaries of the listvenite and the wall rock.

As a result, when geostatistical data, geological map of the area and element distribution map data were evaluated together, it was concluded that possibly gold mineralization can be expected and explored in the central and southeast part of the target area which is closely related to NE–SW and NW-SE trending fault system and also thrusting fault zone between rocks of Kazdağ groups as well as mélange and listvenite; the reason for necessity of conducting geophysical and drilling researches for detailed studies.

ACKNOWLEDGEMENT

This study was produced from the first author's doctoral dissertation and it was supported by MTA (Mineral Research and Exploration of Turkey). At first the authors thanks to all MTA’s officials. A special thanks to Ali Gündoğdu for his contributions to the analytical processes. The authors also thanks to the editor and the anonymous reviewers for their improvement of the manuscript.

Declarations

It is confirmed that this work has not been published, not under consideration for publication elsewhere, approved by all authors and, if accepted, it will not be published elsewhere in the same form, in English or in any other language.

REFERENCES

Almasi, A, Jararirad, A, Afzal, P & Rahimi, M 2015, Orogenic gold prospectivity mapping using geospatial data integration, region of Saqez, NW Of Iran (Jeospatial Veri Entegrasyonu ile Orojenik Altın Prospeksiyon Haritasının Oluşturulması, Saqez Bölgesi, Kb İran), *Bulletin of the Mineral Research and Exploration*, 150, 67-78.

Anand, RR, Hough, RM, Salama, W, Aspandiar, MF, Butt, CRM, González-Álvarez, I & Metelka, V 2019, Gold and pathfinder elements in ferricrete gold deposits of the Yilgarn Craton of Western Australia: A review with new concepts, *Ore Geology Review*, 104: 294-355.

Anderson, DAJS 2008, Quantitative Analysis of Tin and Tungsten-Bearing Sheeted Vein Systems, *Economic Geology*, 103: 1043-1056.

Aydal, D 1990, Gold-bearing listwaenites in the Arac Massif, Kastamonu, Turkey, *Terra Nova*, 2: 43-52.

Bates, R, Jackson J (1982) Glossary of geology, Second edition. American Geological Institute, Virginia, 749 p.

Belogub, EV, Melekestseva, IY, Novoselov, KA, Zabotina, M V, Tret’yakov, GA, Zaykov, VV & Yuminov, AM 2017, Listvenite-related gold deposits of the South Urals (Russia): A review, *Ore Geology Review*, 85: 247-270.

Carranza, EJM 2009, Controls on mineral deposit occurrence inferred from analysis of their spatial pattern and spatial association with geological features, *Ore Geology Review*, 35: 383-400.

Carranza, EJM, Owusu, EA & Hale, M 2009, Mapping of prospectivity and estimation of number of undiscovered prospects for lode gold, southwestern Ashanti Belt, Ghana. *Mineral Deposite*, 44: 915-938.

Carranza, EJM & Sadeghi, M 2010, Predictive mapping of prospectivity and quantitative estimation of undiscovered VMS deposits in Skellefte district (Sweden), *Ore Geology Review*, 38: 219-241.

Cressie, NAC 1993, Statistics for spatial data. Revised ed, John Wiley & Sons, New York, 928 p.

Diaz, R, Aldape, J, & Flores, M 2002, Identification of airborne particulate sources, of samples collected in Ticoma’n, Mexico, using PIXE and multivariate analysis, *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, 189: 249-253.

Ellsmore, R, Buckman, S & Simpson, C 2010, Soil geochemistry and pathfinder element distribution associated

Caspian J. Environ. Sci. Vol. 18 No. 3 pp. 205~215 Received: Dec. 25. 2019 Accepted: May 18. 2020
DOI Article type: Research

with the Hillgrove Antimony-Gold-Tungsten deposit, New England Orogen, NSW. New England Orogen Armidale, NSW: University of New England, pp. 141-144.

Frost, BR, Evans, KA, Swapp, SM, Beard, JS & Mothersole, FE 2013. The process of serpentinization in dunite from new Caledonia, *Lithos*, 178: 24-39.

Hinsken, T, Bröcker, M, Strauss, H & Bulle, F 2017, Geochemical, isotopic and geochronological characterization of listvenite from the Upper Unit on Tinos, Cyclades, Greece, *Lithos*, 282-283: 281-297.

Kiliç, AD, İnceöz, M, 2015, Mineralogical, geochemical and isotopic effect of silica in ultramaphic systems, eastern Anatolian Turkey. *Geochemistry International,* 53: 369-382.

Koç, S & Kadioglu Y 1996, Mineralogy, geochemistry and precious metal content of Karacakaya listwaenites, Turkey, *Ofioliti,* 21: 125-130.

Mathéron G 1963, Principles of geostatistics. *Economic Geology*, 58: 1246-1266.

Miranda, J, Andrade, E, Lopez-Suarez, A, Ledesma, R, Cahill, T, & Wakabayashi, P 1996, A receptor model for atmospheric aerosols from a southwestern site in Mexico City, *Atmospheric Environment*, 30: 3471-3479.

Murchission R, de Verneuil E & Von Seyserling A 1845, The geology of Russia in Europe and the Ural Mountains. Geology, 1. London, John Murray, 700 p.

Nude, PM, Asigri, JM, Yidana, SM, Arhin, E, Foli, G & Kutu, JM 2012, Identifying Pathfinder Elements for Gold in Multi-Element Soil Geochemical Data from the Wa-Lawra Belt, Northwest Ghana: A Multivariate Statistical Approach, *International Journal of Geosciences,* 3: 62-70.

Okay, A, Siyako M & Bürkan K 1990, Biga yarımadasının jeolojisi ve tektonik evrimi. *Türkiye Petrol Jeologları Derneği Bülteni*, 2: 83-121. [In Turkish].

Rose, AW, Hawkes, H & Webs, J 1991, Geochemistry in mineral exploration, 2nd ed. Academic Press, Londan, England, 657 p.

Rudnick R, Gao S 2010, Composition of the Continental Crust. In H, Holland , K, Turekian, eds., Readings from the treatise on geochemistry. Elsevier, London, 681 p.

Skoog, DA, West, DM, Holler, FJ & Crouch, SR 2004, Fundamentals of analytical chemistry, 8th Ed., Brooks/Cole-Thomson Learning, 10 Davis Drive, Belmont, CA 94002, USA, 1179 p.

Uçurum A 2000, Listwaenites in Turkey: perspectives on formation and precious metal concentration with reference to occurrences in east central Anatoilia, *Ofioliti,* 25: 15-29.

Vural, A 2006, Investigation of gold enrichments in Bayramiç (Çanakkale, Turkey) and its near vicinity. PhD Dissertation, Ankara University, Ankara, Türkiye.

Vural, A & Aydal D 2016a, Soil geochemical prospecting at lisvenite area, Bayramiç, (Çanakkale Turkey). 34th National and the 2nd International Geosciences Congress, February 22, 2016, Tehran, Iran.

Vural, A & Aydal D 2016b, Using soil geochemistry for gold exploration:Ayvacık (Çanakkale-Northwest Turkey). 34th National and the 2nd International Geosciences Congress proceedings book. 22-24 Feb. 2016 Tehran, Iran.

Vural, A & Aydal D 2018, Kısacık-Ayvacık (Çanakkale) Altın Cevherleşmesinin Jeolojik, Mineralojik, Jeokimyasal Açıdan İncelenmesi. 8. Jeokimya Sempozyumu, May 02-06, 2018, Antalya/Türkiye, 121-122. [In Turkish].

Vural, A 2019, Evaluation of soil geochemistry data of Canca area (Gümüşhane, Turkey) by means of inverse distance weighting (idw) and kriging methods- preliminary findings, *Bulletin of the Mineral Research and Exploration,* 158: 195-216.

Yang, Y, Zhao, L, Zheng, R & Xu, Q 2019, Evolution of the early Paleozoic Hongguleleng–Balkybey Ocean: Evidence from the Hebukesaier ophiolitic mélange in the northern West Junggar, NW China, *Lithos*, 324–325: 519-536.

Yusuf, M, Kumar, M, Khan, MA, Sillanpa, M & Arafat, H 2019, Hydrothermal listvenitization and associated mineralizations in Zagros Ophiolites: Implications for mineral exploration in Iraqi Kurdistan, *Journal of Geochemical Exploration,* 102036.

Zoheir B & Lehmann B 2011, Listvenite–lode association at the Barramiya gold mine Eastern Desert, Egypt, *Ore Geology Reviews*, 39: 101-115.

Caspian J. Environ. Sci. Vol. 18 No. 3 pp. 205~215
DOI
Received: Dec. 25. 2019 Accepted: May 18. 2020
Article type: Research

بررسی ژئوشیمی ناحیه لیسونتیل آیواچیک (کاناکاله، ترکیه)

علاالدین وورال[*1] ، دوگان آیدال[2]

۱-گروه مهندسی زمین شناسی، دانشکده مهندسی و منابع طبیعی، دانشگاه گمیشان، گمیشان، ترکیه

۲- گروه مهندسی زمین شناسی، دانشکده مهندسی، دانشگاه آنکارا، آنکارا، ترکیه

(تاریخ دریافت: ۹۸/۱۰/۰۴ تاریخ پذیرش: ۹۹/۰۲/۲۹)

چکیده

هدف از این مطالعه، استفاده از مطالعات ژئوشیمی خاک به کمک روش‌های آماری برای اکتشاف احتمالی معادن طلا مرتبط با ناحیه آلاکچی لیستونتیل (بایرامیک، کاناکاله، ترکیه) است. برای بررسی ژئوشیمی خاک، در حدود ۳۵۰ نمونه آزمایش، و برای ارزیابی ۹ عنصر از جمله طلا ارزیابی شد. غلظت عناصری مانند مس، سرب، روی، آرسنیک، آنتی موآن، مولیبدن، نیکل، کوبالت و طلا (همه عناصر بجز طلا بر حسب قسمت در میلیون و طلا بر حسب قسمت در میلیارد) به ترتیب، ۲۶۵-۱۰، ۹۰-۱۰، ۵۴۵-۱۵، ۸۰۰-۵، ۶۰-۲، ۸-۴، ۶۳۰۰-۱۰، ۱۲۵۵-۱۵ و ۳۰۰-۴۰ بود. غلظت های طلا در مقایسه بسیار پایین تر از ذخایر مهم معدن بود و هیچ ارتباطی با عناصر دیگر (به استثنای مولیبدن) نداشت. با وجود این ارتباط مثبتی بین مس و روی؛ آنتی‌موآن و آرسنیک، مولیبدن با آرسنیک و آنتی موآن؛ طلا و مولیبدن؛ نیکل و کبالت مشاهده شد. در منابع، مس، روی، آرسنیک، آنتی موآن و مولیبدن به طور گسترده‌ای به عنوان عناصر راهگشا برای اکتشاف معادن طلا استفاده شده‌اند. بنابراین، در مطالعه حاضر نیز این عناصر به عنوان راهگشا پذیرفته شده و نقشه‌های انتشار آنها آماده شد. نقشه‌های انتشار عناصر برای عناصر راهگشا و طلا منطقه‌بندی قابل ملاحظه‌ای را در سایت‌های مرکزی و جنوب شرقی ناحیه متصل به خطوط تکتونیک و مرزهای لیتولوژیک به نمایش گذاشتند. بنابراین، در نتیجه‌گیری، این بخش در این ناحیه نیاز به مطالعه با جزئیات بیشتربه همراه روش‌های ژئوفیزیک و دریل زدن دارد تا معدن طلا یافت شود.

*مولف مسئول

Bibliographic information of this paper for citing:

Vural, A, Aydal, D 2020, Soil geochemistry study of the listvenite area of Ayvacik (Çanakkale, Turkey). Caspian Journal of Environmental Sciences, 18: 205-215

Caspian J. Environ. Sci. Vol. 18 No. 3 pp. 205~215
DOI
Received: Dec. 25. 2019 Accepted: May 18. 2020
Article type: Research