



University of Miskolc
Faculty of Earth Science and Engineering

**Gold and silver—one pair or two singles? —geochemical analysis of
precious metals in the Rudabánya mineralization**

Student:

Mohamed Abdelnaby Oraby

2nd year MSc. Student, Earth Science Engineering Program

Institute of Mineralogy and Geology

Supervisor:

Prof. Dr. Földessy János

Institute of Mineralogy and Geology, University of Miskolc

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Abstract

In the mineral exploration routine gold and silver are regarded as sister elements, with close correlation and formation of Au-Ag solid solutions. In Rudabánya this was an initial assumption of the recent exploration strategy by exploring gold using the information from known silver enrichments. The strategy failed after the first sampling run. Thus, this study is aimed at discovering the reasons and offering the first steps for a new vision for the exploration of gold. Rudabánya is regarded as one of the significant complex ore occurrences in Hungary. Originally known as an iron ore mine, base metal explorations began many years ago with the exploration of Cu and Pb enrichments. The presence of silver was known to occur jointly with lead ores. All the previous studies since 1930 up until now have been about iron ore and base metals, with only a few reports about the presence of gold. But neither study has yet offered meaningful genetic considerations. During the last 40 years, several different sampling campaigns produced data that differ in sampling, assaying method, detection limit, accuracy, and precision. In our study, we aim to clarify the genetic linkage of gold and silver in Rudabánya using a geochemical approach. It is now timely to clarify if the gold can be considered as a by-product for the planned barite extraction in Rudabánya and the silver as a possible valuable by-product of any future polymetallic ore extraction. Moreover, the present study will be the first directive analysis of a larger work aimed at analyzing the Au and Ag behavior in-depth with reference to different lithologies and geological settings.

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This work is dedicated to the soul of my father, may God have mercy on him, and to my family; my mother, my siblings, and my future wife (Aicha) for their psychological support and encouragement constantly.

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1. Introduction

1.1. Motivation and objective

The main purpose of this research is to clarify the genetic linkage of gold and silver in Rudabánya with geochemical and GIS methods. The results set the path for further gold and silver studies in the region. In this study the first steps are presented, with a detailed analysis of available geochemical data, the conclusions of which are planned to be the base of detailed instrumental mineralogy and host rock petrology works in the next stage.

1.2. General statement

According to **Nemeth et al. (2013)**, **Less et al. (2006)**, and **Kovács et al. (1989)**, the Rudabánya's Ore-Bearing Complex rocks are part of the Silicikum stratigraphic superunit (spreading over from Hungary to Slovakia) which is placed broadly in the Silica Nappe to the north of Rudabánya. The Silicikum sequence begins with the Permian evaporite (anhydrite and black shale, Perkupa Evaporite Formation). Lower Triassic rocks include littoral sandstone and aleurolite (Bódvaszilas Sandstone Formation), shallow water marl (Szin Marl Formation), and laminar or nodular limestone (Szinpetri Limestone Formation). Anisian rocks are euxin facies, thick-bedded or massive limestone and dolomite (Gutenstein Formation), followed by platform facies limestone and dolomite (Steinalm Formation). In the later Middle and Upper Triassic sections of the sequence, carbonate platforms and reefs alternated with rocks of basin facies. Near the Rudabánya basin, formations from the Middle Jurassic are also present.

Structurally, the Rudabánya deposit complex is now placed in the Darnó Zone, a significant strike-slip fault zone that was active from the Late Oligocene to the Late Miocene (**Foldessy et al., 2010; Nemeth et al., 2013; Szentpétery, 1997; Zelenka et al., 1983**). Darnó Zone is the Silica Nappe's southeast boundary. This nappe unit comprises around NNE-SSW oriented ridge of Paleozoic and Mesozoic rocks, surrounded by basins filled with approximately 100 m thick late Tertiary sediments. On the crest of the ridge, remnants of Pliocene Pannonian sediments that have been uplifted illustrate the fault zone's ongoing activity. Silica nappe has a complex structure that has been additionally complicated by the displacements of the Darnó Zone, which have juxtaposed fault blocks with varying strata. Along with this tectonized nature, the stratigraphic sequence is clearly recognizable in the mining region.

1.3. Mineralization

Rudabanya has complex mineralization. The earliest ore formation process was the siderite precipitation in the Bodvaszilas Homokkő Formation (**Bodor et al., 2013**), followed by **stratiform Zn-Pb sulfide mineralization** hosted by the Szin Marl Formation (**Nemeth et al., 2013**). The minerals pyrite, baryte, sphalerite, and galena are present in this ore. Despite its tiny grain size, the most common ore mineral is sphalerite, which is banded with alternating and undulating laminae composed of numerous ore mineral compositions. This mineralization was accumulated during the sedimentation process and is unaffected by metasomatic and weathering processes. Based on its facies and texture, it conforms to the **sedimentary-exhalative (SEDEX)** deposit type, which is accumulated near hydrothermal vents on the ocean floor (**Nemeth et al., 2013**). **Iron metasomatism**, which mostly affects Szinpetri limestone, Guttenstein dolomite carbonate rocks, is the best-known ore type. Metasomatism refers to the transformation of a rock's texture by hydrothermal solutions through the replacement and recrystallization of the rock-forming minerals. The produced mineral is siderite, and the resulting rock is called locally spar iron ore.

Another form of Rudabanya mineralization is epigenetic **breccia forming baryte and Zn-Pb sulfide mineralization**. This kind is comparable to the SEDEX ore deposition described above, but it substitutes metasomatic characteristics with a replacement texture that is restricted to the rim of carbonate blocks and fault zones. **Németh et al. (2017)** described the abundant **primary copper sulfide mineralization** as associated with brecciated carbonate rocks impacted by iron metasomatism. This mineralization occurs as a dissemination or as a component of the breccia matrix. Tetrahedrite, bornite and chalcopyrite are the predominant minerals in this mineralization. For the subsequent mineralization phase, upon the uplift of the ore containing lithological units, limonitization in the oxidation zone took place, with the removal of elements and redistribution of the residual ones predominated during decomposition in a near-surface position (weathering) under oxidative conditions, where limonite ore formed as a result of **supergene enrichment** in carbonate, marl, and sandstone rocks. In this area, all rocks older than Pannonian, including limonite bodies, have a low-temperature imprint; **Szakall et al. (2001)** classified this as **late hydrothermal mineralization**.

The exact ages of the majority of mineralization stages remain controversial. Due to its stratigraphic position, the stratiform ore are Early Triassic. The metasomatic and early hydrothermal events imprinted a layered structure of distinct carbonate formations; therefore, these must precede the emplacement of the Silica Nappe. In addition, the first period from

which the Darno Zone started being evolved is unclear possibly in the Early Paleogene. The late hydrothermal overprint, on the other side, was governed by structures from a later phase of the Darno Zone and was likely also created during the Neogene. **Supergene oxidation and cementation activities** may have been active throughout the whole Cenozoic or perhaps earlier (Szakall et al., 2022).

1.4. Samples and analytical methods

The geochemical sampling was performed in 2008-2010 by the Rotaqua KFT geologists' team during the Pb-Zn-Cu and barite explorations. In accordance with the dominant trend of the Darnó Zone, geochemical surface soil samples were collected along transversal lines NE–SW (**Fig. 1**). The open pit area and the waste dumps were excluded from this sampling since they cannot be considered to have undisturbed soil cover. Between 2008 and 2019, there were two soil sampling campaigns. It yielded two sets of soil geochemical datasets with varying samples and assays. The average distance between geochemical soil samples was 200 x 50 m. but the assay run was performed on every second sample, i.e., 200 x 100 m.

Three independent datasets were analyzed with statistical tools:

The first geochemical dataset (Nr1) includes 448 soil samples. The assay was carried out for 36 elements by Au-ICP21 (Fire Assay for gold) analysis for gold and ME-ICP41 (Aqua Regia with ICP-AES Finish) analysis for other elements. All these analyses have been operated using the Inductively Coupled Plasma Atomic Emission Spectroscopy instrument (ICP-AES) by the ALS Global laboratory. The second geochemical dataset (Nr2) includes 70 soil samples. The assay was carried out for 52 elements by ME-MS41L (Aqua Regia Super Trace Analysis, with higher resolution than the assays of the Nr1 area) Analysis using the Inductively coupled plasma mass spectrometry instrument (ICP-MS) by the ALS Global laboratory.

Owing to the substantial difference in the analytical technique as well as the detection levels of the assays, we treat the datasets separately and attempt to compare their main parameters after separating statistical analysis.

The two datasets differ in general bedrock geology:

The Nr1 dataset has been collected from an area where Lower to Middle Triassic carbonate rocks outcropped at the surface or under the weathering crust, with exposed metasomatic Fe, primary Cu, primary (SEDEX and epigenetic) Pb-Zn-Ag ores and their weathered varieties in the oxidation zone. From the sampling, the areas with young cover

(Pannonian and younger) were excluded, but the Miocene conglomerate zone (on the SE) and a small block with Paleozoic shales were included.

The Nr2 dataset refers to the thicker Pliocene-Pleistocene sedimentary sequence under the soil cover, overlying rocks from deeper stratigraphic levels of the Triassic, i.e., in this area Lower Triassic sandstone, siltstone, shale is dominant potential ore host (which is spatially the footwall zone of the metasomatic iron ore). The dataset also includes a small number of samples taken from the thin soil cover directly lying over the bedrock, near the SE border of the sampled area.

The sampled areas overlying the geological map of the area are shown in **Figure 2**. For confidentiality, the coordinates are not included.

The third dataset involves a number of core samples from drillholes intersected complex ore mineralization during the recent exploration. I used this third geochemical dataset to compare surface and underground geochemical data. It includes 23 drillholes with 1098 samples, the assays were generally at 1 m length half-core samples. For assaying these samples, both the above-mentioned analytical techniques were used.

This study is structured into three major parts in accordance with the three geochemical datasets.

1.5. Quality assurance and control

Quality assurance (QA) is an effective method used to ensure the accuracy of chemical analysis of rock and soil samples. Before sending a batch of samples to the lab for analysis, QA procedures were carried out. to Check the quality of the assays, blanks, standards, and duplicates samples were inserted between the samples as part of the QA process before being submitted to the ALS Global laboratory.

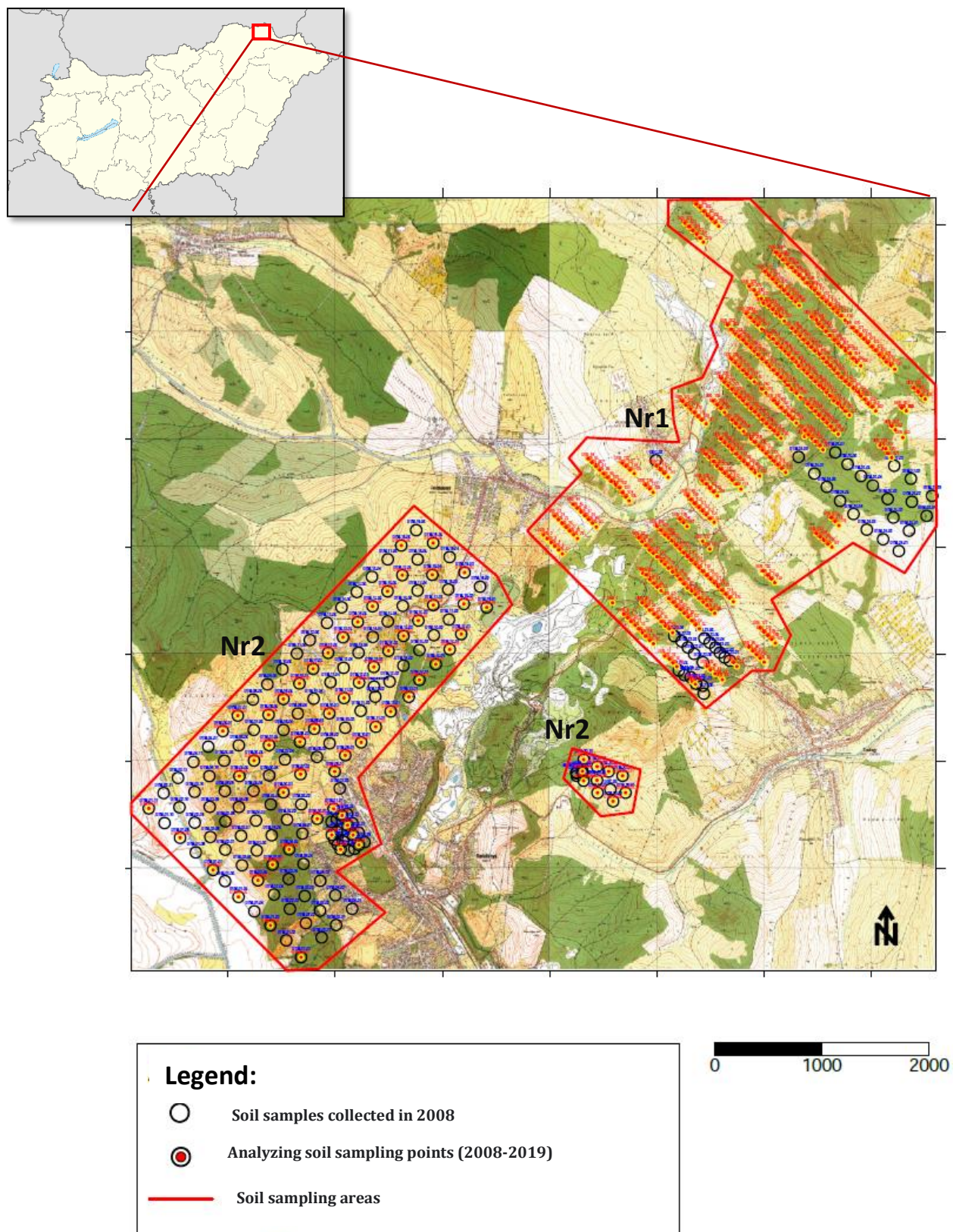


Figure 1: location map of the study area shows the sampling areas of Nr1 and Nr2 soil samples.

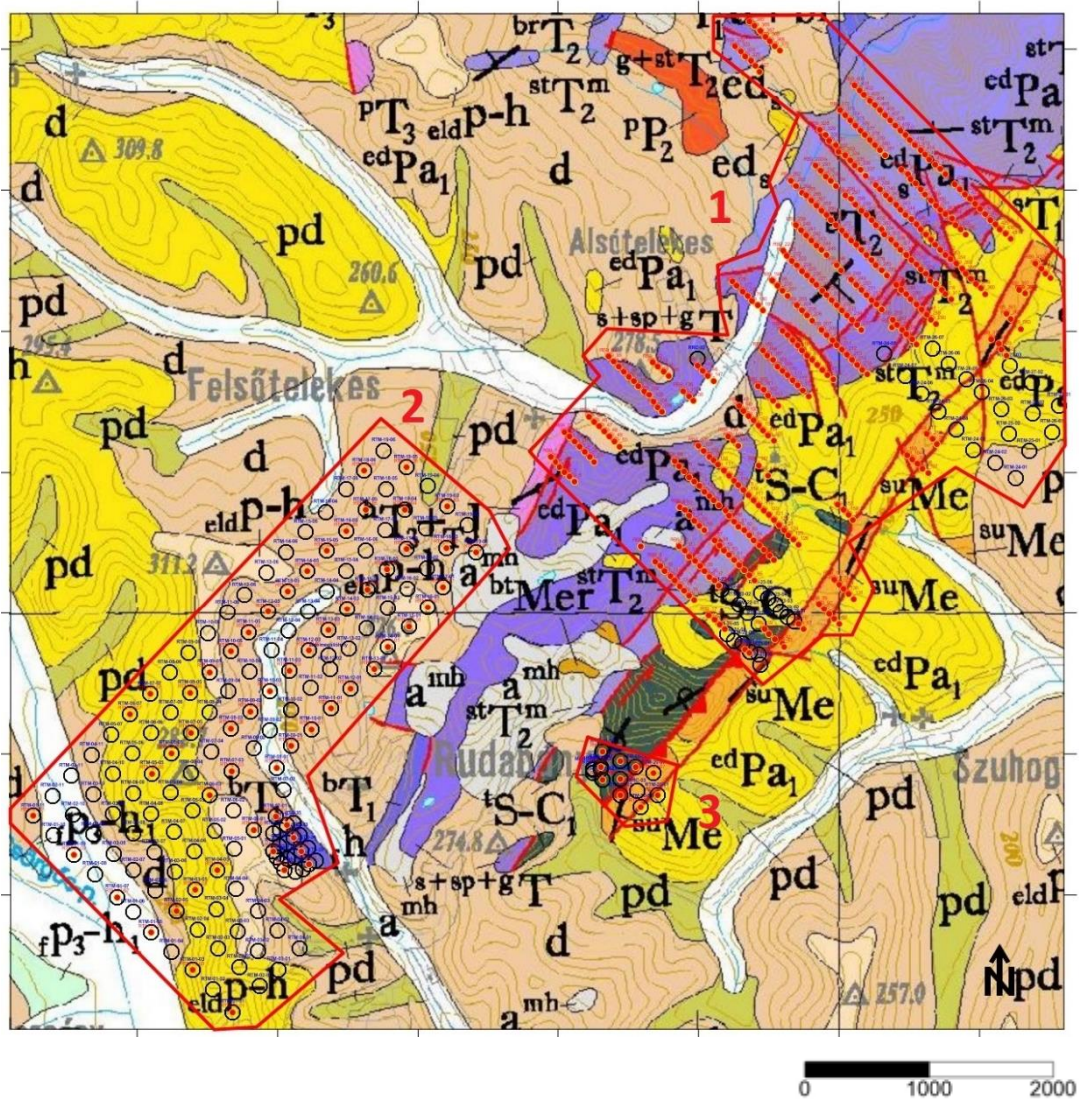


Figure 2: The sampled areas overlying the geological map of the area. 1) Triassic carbonates, 2) Pannonian-Pleistocene sediments, 3) Devonian shale/Miocene conglomerate.

2. Nr1 geochemical dataset

2.1. Introduction

There are a total of 448 soil samples in the first geochemical database. For the gold element, an Au-ICP21 (Fire Assay for gold) analysis was performed, whereas for the remaining elements (35 elements), a ME-ICP41 (Aqua Regia with ICP-AES Finish) analysis was used. The ALS Global lab has performed all these tests utilizing an Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) instrument. The gold assay is performed at a lower detection limit of 0.001 ppm whereas the silver assay is performed at a lower detection limit of 0.2 ppm. In all cases where samples values were lower than the detection limits, I used a compromise to make them suitable for the statistical analysis. I replaced the $< 0,1 \dots$ etc. values with the half of the lower detection limit in all samples and elements in our datasets.

2.2. Basic statistics

The statistical parameters for 36 variables (Au, Ag, Al, As, B, Ba, Be, Bi, Ca, Cd, Co, Cr, Cu, Fe, Ga, Hg, K, La, Mg, Mn, Mo, Na, Ni, P, Pb, S, Sb, Sc, Sr, Th, Ti, Tl, U, V, W, and Zn) of ICP-AES results have been developed to understand the comparative framework for the geochemical dataset. Basic statistical parameters were estimated such as Mean and Median, as well as measures of dispersion such as Standard Deviation (**Table 1**). The dataset comprises the Au with a detection limit of < 0.001 ppm, a maximum concentration of 0.021 ppm, and an average is 0.0023 ppm. For the Ag element, the maximum concentration is 69.5 ppm, the minimum concentration is < 0.2 ppm, and the average is 0.9 ppm. The statistical parameters for the other elements are listed in Table 1. The low standard deviation of some elements like gold indicates that the obtained values are close to the value of the mean (i.e., no outliers, no near-surface intense enrichment anomalies). The high standard deviation of silver indicates that the obtained maximum values are indicative for an intense near surface.

Table 1: The basic statistical parameters of the first geochemical dataset assay, pct = %.

Variable	Minimum or lower detection limit	Maximum	Mean	Median	SD
Au_ppm	0.001	0.0210	0.0023	0.0020	0.0020
Ag_ppm	<0.2	69.5	0.9	0.1	4.8
Al_pct	0.3	3.6	1.9	2.0	0.6
As_ppm	2.0	224.0	20.5	15.0	18.9
B_ppm	<10	30.0	5.8	5.0	2.9
Ba_ppm	50.0	3050.0	369.4	210.0	430.6
Be_ppm	<0.5	2.2	1.2	1.2	0.3
Bi_ppm	<2	5.0	1.5	1.0	0.8
Ca_pct	0.0	20.4	2.4	0.5	3.7
Cd_ppm	<0.5	15.8	0.5	0.3	1.0
Co_ppm	2.0	31.0	11.4	12.0	3.7
Cr_ppm	4.0	48.0	26.7	27.0	8.3
Cu_ppm	4.0	457.0	25.2	22.0	27.5
Fe_pct	0.7	9.4	2.8	2.8	1.1
Ga_ppm	<10	10.0	7.4	5.0	2.5
Hg_ppm	<1	34.0	1.0	1.0	1.8
K_pct	0.1	0.5	0.2	0.2	0.1
La_ppm	<10	40.0	19.6	20.0	6.3
Mg_pct	0.1	10.1	1.0	0.4	1.4
Mn_ppm	137.0	8400.0	1183.4	919.0	916.1
Mo_ppm	<1	3.0	0.5	0.5	0.2
Na_pct	<0.01	0.1	0.0	0.0	0.0
Ni_ppm	4.0	64.0	23.8	24.0	8.2
P_ppm	100.0	2080.0	539.8	410.0	371.0
Pb_ppm	6.0	9200.0	143.2	47.5	652.2
S_pct	<0.01	0.2	0.0	0.0	0.0
Sb_ppm	<2	349.0	6.3	2.0	23.2
Sc_ppm	1.0	8.0	4.4	4.0	1.3
Sr_ppm	4.0	268.0	25.4	19.0	20.3
Th_ppm	<20	10.0	10.0	10.0	0.0
Ti_pct	<0.01	0.0	0.0	0.0	0.0
Tl_ppm	<10	10.0	5.0	5.0	0.5
U_ppm	<10	10.0	5.1	5.0	0.6
V_ppm	8.0	77.0	40.0	41.0	12.1
W_ppm	<10	10.0	5.0	5.0	0.2
Zn_ppm	16.0	2970.0	158.5	96.5	247.1

2.3. Correlation Analysis

Correlation analysis is a statistical technique for calculating the degree to which two variables are linearly related to one another. correlation analysis determines how much one variable shifted because of a shift in another one. To demonstrate the geochemical affinity, the Pearson correlation type is used to calculate the correlation between different elements (**Table 2**). Pearson correlation is the most frequent approach for numerical variables; it assigns a number between -1 and 1, where 0 is no correlation, 1 is total positive correlation, and -1 is total negative correlation. 0.7 correlation between two variables indicates a significant and positive association. Positive correlation means that if variable A increases, so does variable B. Negative correlation mean that if A increases, B decreases (**Boslaugh and Watters, 2008**). The correlation between variables can be classified into "weak," "moderate," or "strong" relationships depending on the value of the correlation coefficient for example, 0.9-1 very strong, 0.7-0.89 strong, 0.4-0.69 moderate, and 0.1-0.39 weak (**Schober et al., 2018**). Concerning the target elements, Au shows very weak correlation or relationship with other elements whereas Ag shows strong correlation with Sb (0.94), Pb (0.9), Hg (0.86), Cd (0.78), As (0.77), Zn (0.69), W (0.68), Na (0.65), and Cu (0.61) while shows moderate correlation with Ba (0.51), Fe (0.49), Mn (0.47), and Mo (0.42).

2.4. SPLOM

The scatterplot matrix, abbreviated SPLOM, is a graphical tool that combines several scatterplots to establish a relationship (if any) between a set of variables. **Hartigan (1975)** developed SPLOMs so that data users might easily identify interesting correlations between variables. Using Minitab software and ioGAS software, the scatterplot matrix and correlation coefficient are produced respectively. The results match the results of correlation analysis (**Fig. 3**). Au shows a weak positive linear relationship with all elements mentioned above (Correlation coefficient ranges from 0.093 to 0.24; Weak association) whereas Ag shows very strong positive linear relationships with Sb, Pb, and Hg, and moderately strong positive linear relationships with Cd, As, Zn, Na, and Cu. While Ag shows a weak association with Ba, Fe, W, Mn, and Mo.

2.5. Principal Component Analysis (PCA)

Pearson (1901) developed the PCA as a mechanical version of the main axis theorem but the formal definition of principal component analysis is a statistical method for decreasing the number of dimensions in a dataset. To achieve this goal, a linear transformation is performed on the data to produce a new coordinate system in which the variance in the data may be expressed with fewer dimensions than the original data. PCA creates a principal component coefficient known as eigenvectors that illustrate the relative significance of each component. It refers to the chemical elements and their variation or loaded concentration in the processed geochemical dataset (Principal components) i.e., it represents the loading of each chemical element in each component. Consequently, they are utilized to compute point totals for each PC in the massive dataset. Not only that but also calculating the loading value of each component compared to other components which is indicated by eigenvalue which represents the concentration or loading of all elements in each component and by which we select the best component to show it graphically then correlate the different elements using this component. The grouping of the elements is reflected by the sampling point scores. The number of displayable components must have an eigenvalue higher than 1 based on the Kaiser criterion (**Cloutiera et al., 2008**).

The PCA was made by utilizing ioGAS software to categorize the elements in the relevant component (PC). **Table 3** shows the result of PCA where the loading values (eigenvalues) of the dataset in each component and the eigenvectors show the loading value of each element in each component. PC1 and PC2 cover around 69.01% of the total variance of the selected elements, therefore the information on correlation can be taken from PC1 and PC2. PC1 has a 56.05% of the total variance, an eigenvalue of 8.408, and is distinguished by positive loading of all selected elements. For PC2, it has a 12.96% of the total variance, an eigenvalue of 1.944, and is distinguished by positive loading of Au, Sb, As, Cu, Ba, Fe, Mn, Mo. Au shows remarkable positive loading values in $PC4 > PC3 > PC2$ while Ag shows positive loading in $PC1 > PC4$. The eigenvalue of PC4 is less than 1 but it's included because it has positive loading of Au and Ag which are the target elements.

Table 2: Correlation matrix of the first geochemical dataset assay showing the different relationships among elements.

	Au	Ag	Al	As	B	Ba	Be	Bi	Ca	Cd	Co	Cr	Cu	Fe	Ga	Hg	K	La	Mg	Mn	Mo	Na	Ni	P	Pb	S	Sb	Sc	Sr	Ti	Tl	U	V	W	Zn	
Au	1																																			
Ag	0.14	1																																		
Al	0.03	-0.17	1																																	
As	0.16	0.77	-0.14	1																																
B	-0.067	0.21	0.013	0.28	1																															
Ba	0.096	0.51	-0.081	0.63	0.12	1																														
Be	0.052	-0.0043	0.84	0.062	0.12	0.08	1																													
Bi	-0.056	0.15	-3.90E-04	0.071	0.096	-0.0018	0.014	1																												
Ca	0.057	0.12	-0.26	0.25	0.2	0.04	-0.3	-0.13	1																											
Cd	0.13	0.78	-0.12	0.59	0.12	0.36	0.033	0.081	0.18	1																										
Co	0.053	-0.14	0.38	-0.1	-0.23	-0.059	0.42	0.077	-0.56	-0.22	1																									
Cr	0.034	-0.22	0.94	-0.23	-0.13	-0.16	0.79	0.062	-0.46	-0.18	0.53	1																								
Cu	0.18	0.61	-0.019	0.73	0.27	0.47	0.084	0.062	0.08	0.31	0.024	-0.071	1																							
Fe	0.24	0.49	0.39	0.61	0.21	0.54	0.57	0.099	-0.19	0.32	0.36	0.36	0.62	1																						
Ga	0.066	-0.11	0.66	-0.11	-0.11	-0.12	0.57	0.27	-0.33	-0.087	0.44	0.71	-0.031	0.28	1																					
Hg	0.093	0.86	-0.17	0.64	0.14	0.41	0.013	0.15	0.12	0.88	-0.14	-0.2	0.41	0.37	-0.078	1																				
K	0.079	-0.034	0.71	0.096	0.33	0.035	0.69	-0.049	0.13	0.042	0.064	0.55	0.13	0.41	0.35	-0.017	1																			
La	-0.086	-0.22	0.25	-0.3	-0.27	-0.18	0.32	0.11	-0.68	-0.26	0.53	0.46	-0.17	0.048	0.35	-0.21	-0.11	1																		
Mg	0.021	0.043	-0.06	0.13	0.23	-0.038	-0.19	-0.11	0.78	0.16	-0.52	-0.25	-0.01	-0.24	-0.2	0.075	0.22	-0.57	1																	
Mn	0.23	0.47	-0.008	0.56	0.16	0.49	0.23	0.061	0.074	0.3	0.18	-0.068	0.48	0.7	-0.007	0.37	0.2	-0.14	-0.13	1																
Mo	0.2	0.42	-0.13	0.52	0.13	0.27	0.055	0.032	0.029	0.5	0.056	-0.13	0.43	0.41	-0.039	0.47	0.046	-0.11	0.0088	0.49	1															
Na	0.076	0.65	-0.091	0.61	0.3	0.47	-0.067	-0.016	0.42	0.47	-0.27	-0.22	0.54	0.27	-0.19	0.58	0.12	-0.34	0.41	0.24	0.24	1														
Ni	0.22	-0.076	0.65	0.046	-0.061	0.016	0.67	0.018	-0.31	-0.098	0.61	0.7	0.17	0.59	0.52	-0.068	0.56	0.29	-0.29	0.33	0.18	-0.1	1													
P	0.11	0.054	0.083	0.081	0.28	0.034	0.0076	-0.12	0.48	0.22	-0.37	-0.078	0.13	-0.021	-0.19	0.049	0.42	-0.46	0.58	0.097	0.11	0.22	-0.0024	1												
Pb	0.15	0.9	-0.16	0.74	0.22	0.45	0.029	0.13	0.13	0.89	-0.16	-0.2	0.58	0.47	-0.097	0.89	-0.0071	-0.22	0.074	0.39	0.52	0.6	-0.083	0.076	1											
S	0.082	0.15	0.13	0.19	0.3	0.25	0.057	-0.07	0.38	0.3	-0.35	-0.03	0.18	0.056	-0.14	0.14	0.39	-0.44	0.54	0.083	0.12	0.3	-0.037	0.84	0.17	1										
Sb	0.15	0.94	-0.2	0.78	0.18	0.51	-0.01	0.12	0.15	0.85	-0.15	-0.24	0.63	0.48	-0.12	0.91	-0.023	-0.25	0.051	0.45	0.49	0.64	-0.063	0.074	0.93	0.16	1									
Sc	0.024	-0.073	0.76	0.0013	-0.1	0.072	0.82	0.054	-0.46	-0.1	0.57	0.79	0.035	0.53	0.62	-0.06	0.41	0.47	-0.41	0.18	-0.021	-0.14	0.63	-0.33	-0.049	-0.27	-0.075	1								
Sr	0.12	0.17	-0.25	0.29	0.11	0.24	-0.17	-0.16	0.6	0.2	-0.31	-0.37	0.12	0.007	-0.26	0.16	0.023	-0.43	0.5	0.083	0.23	0.39	-0.11	0.35	0.17	0.3	0.2	-0.29	1							
Ti	-0.051	-0.095	0.34	-0.17	-0.084	-0.12	0.31	0.022	-0.28	-0.096	0.26	0.42	-0.042	0.076	0.27	-0.081	0.18	0.34	-0.16	-0.018	-0.034	-0.12	0.21	-0.089	-0.078	-0.085	-0.11	0.33	-0.28	1						
Tl	0.04	0.24	0.014	0.3	0.096	0.12	-0.023	0.0048	0.13	0.01	-0.043	-0.042	0.4	0.15	-0.044	0.1	0.078	-0.11	0.054	0.098	0.032	0.3	0.029	0.061	0.19	0.037	0.2	-0.029	0.074	-0.026	1					
U	0.037	0.37	-0.15	0.46	0.37	0.17	-0.11	0.22	0.23	0.12	-0.15	-0.2	0.42	0.22	-0.11	0.19	-0.043	-0.21	0.16	0.23	0.14	0.36	-0.12	0.012	0.34	-0.0068	0.28	-0.13	0.15	-0.06	0.2	1				
V	-0.017	-0.2	0.91	-0.18	0.0056	-0.16	0.82	0.042	-0.31	-0.13	0.4	0.91	-0.078	0.32	0.62	-0.16	0.64	0.35	-0.063	-0.061	-0.08	-0.18	0.57	0.049	-0.17	0.11	-0.22	0.7	-0.29	0.4	-0.045	-0.16	1			
W	0.017	0.68	-0.11	0.37	-0.014	0.25	-0.011	0.09	0.057	0.77	-0.095	-0.12	0.057	0.14	-0.046	0.85	-0.041	-0.11	0.07	0.14	0.29	0.46	-0.062	0.017	0.66	0.09	0.7	-0.051	0.15	-0.082	-0.0045	-0.0056	-0.099	1		
Zn	0.12	0.69	-0.064	0.67	0.31	0.39	0.2	-0.0097	0.27	0.81	-0.21	-0.17	0.41	0.48	-0.095	0.75	0.25	-0.31	0.19	0.42	0.52	0.44	0.0079	0.22	0.8	0.27	0.76	-0.023	0.23	-0.067	0.063	0.14	-0.081	0.54	1	

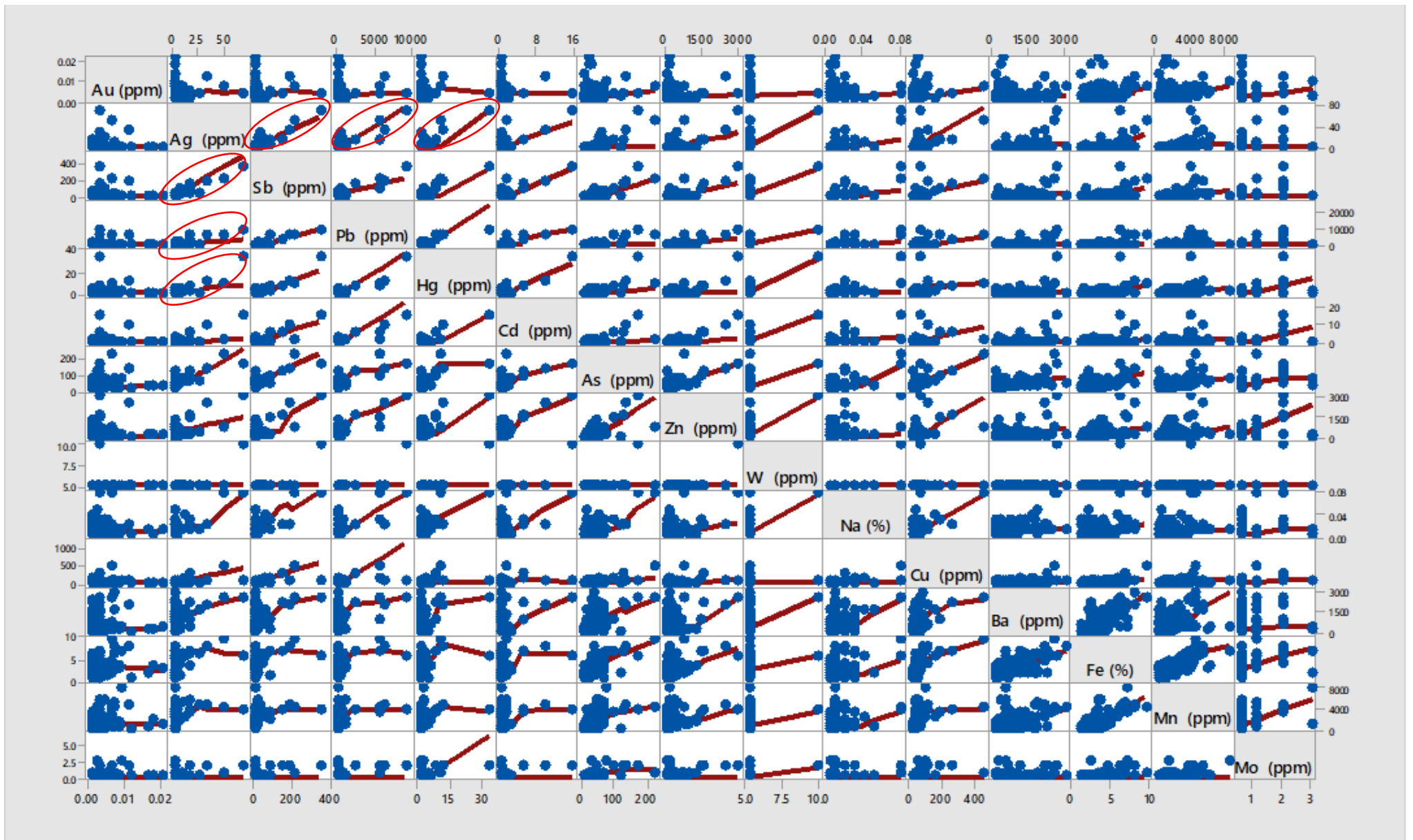


Figure 3: Scatterplot matrix of Au, Ag, Sb, Pb, Hg, Cd, As, Zn, W, Na, Cu, Ba, Fe, Mn, and Mo elements shows the degree of association among them.

Table 3: Loading values of each element in each component (Eigenvectors) and eigenvalues of each component. Au has high loading in PC2, PC3, and PC4 but Ag has high loading in PC1 and PC4.

Eigenvectors	PC1	PC2	PC3	PC4
Au (ppm)	0.06966	0.2238	0.5765	0.7616
Ag (ppm)	0.3195	-0.08536	-0.1002	0.0958
Sb (ppm)	0.3294	-0.106	-0.04462	0.06773
Pb (ppm)	0.3222	-0.1306	0.02516	0.03302
Hg (ppm)	0.3091	-0.2556	0.05124	-0.01607
Cd (ppm)	0.2925	-0.2788	0.1868	-0.06588
As (ppm)	0.2951	0.1836	-0.1606	-4.11E-04
Zn (ppm)	0.2831	-0.09155	0.1737	-0.203
W (ppm)	0.23	-0.4333	0.07691	0.005712
Na (%)	0.2325	-0.04367	-0.4316	0.3738
Cu (ppm)	0.2302	0.3508	-0.2437	0.1453
Ba (ppm)	0.2095	0.2459	-0.3255	-0.00936
Fe (%)	0.2145	0.4213	0.06268	-0.1686
Mn (ppm)	0.1997	0.4	0.1719	-0.2701
Mo (ppm)	0.2068	0.1365	0.4129	-0.3115
Eigenvalues	8.408	1.944	1.065	0.8464
Percentage (%)	56.05	12.96	7.101	5.642

PCA is a highly effective approach to be considered in preliminary evaluations than previous methods mentioned above, where with fewer variables acquired, less information loss, and visualization becomes significantly more meaningful. After making the PCA loading plots by plotting each pair of components, the significant variables can be more visibly differentiated and correlated to each other where the elements or vectors with high positive correlation move together to the periphery of the circle forming small angles (close vectors) while those with less positive correlation have the same position but one of them is close to the center, for non-correlated vectors they form 90° angle between them, and for negatively correlated vectors they diverge by 180° angle. This approach of correlating the elements to each other through PCA is effective and has been used by several studies before (Cloutiera et al., 2008).

In **figure 4**, the Au show uncorrelation in all loading plots of highly loaded PC pairs, while Ag shows a high or strong correlation with Sb, Pb, Hg, As, Zn and Cd. Other elements like Fe and Mn show a high correlation, Also Zn and Mo show a high correlation. This result was confirmed by checking the 3D plot of PCA through ioGAS software.



Figure 4: Loading plots of PC1-PC2, PC1-PC3, PC1-PC4, and PC3-PC4. Green circles represent the highly correlated elements and orange circles represent unique uncorrelated gold.

2.6. Statistical and spatial geochemical distribution of Au and Ag in the soil samples

The graphical approaches of estimating statistical parameters from histogram and probability plots assume that the distribution of Au and Ag is positive skew where most of the samples show a low concentration of Au and Ag while very small portions are distinguished by relatively high concentrations which are considered as anomalies or outliers (**Fig. 5**). Furthermore, the possible anomaly threshold values for Au and Ag are indicated in figure 5. Generally, the maximum concentration recorded for Au is 0.021 ppm and the minimum concentration is < 0.001 ppm, and for Ag, the maximum concentration is 69.5 ppm, and the minimum concentration is < 0.2 ppm.

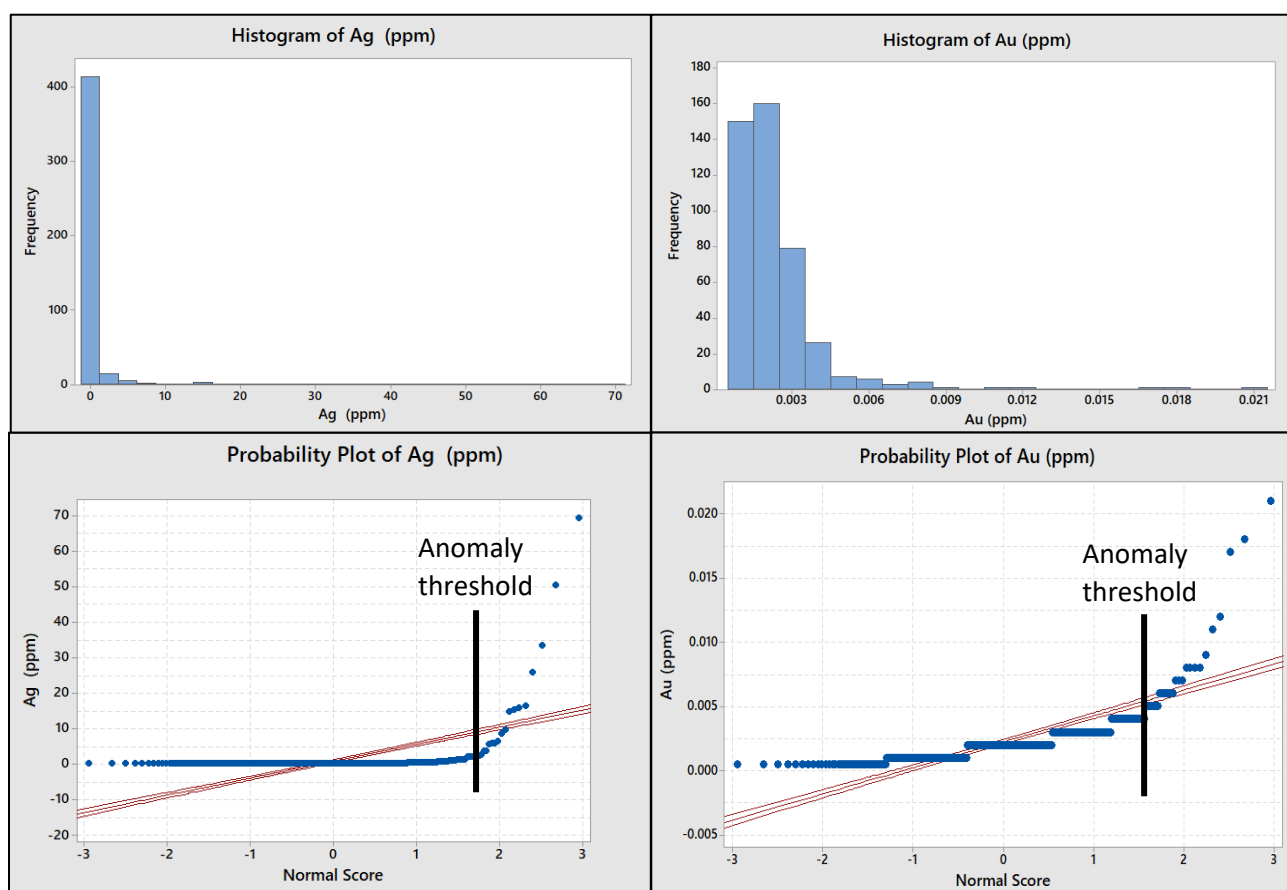


Figure 5: Histograms and probability plots of Au and Ag showing that the distribution of their concentration is not a normal distribution. Also, the possible anomaly threshold values are indicated.

Variable Maps offer a different map view for each of the specified variables. Each different element can be compared for high or low concentrations using variable maps. The data in these maps are spatially represented. Using ioGAS software, variable maps have been made for Au, Ag, and some of the pathfinder elements of Ag (**Fig. 6**). Coordinates are not included on the maps for confidentiality.

The Au and Ag spatial distribution of concentrations is visibly different. The gold concentrations show a linear NNW-SSE direction. Ag, Pb, Zn, and Sb multi-point enrichment which can be surrounded by a closed near-circular polygon for As, Sb, Ag, and an elongated near-elliptical one for Pb and Zn. So, the spatial distribution of gold concentrations is slightly different than those of silver and its pathfinder elements. Furthermore, the gold in figure 6 shows both a structurally controlled enrichment, which may be linked with linear elements and weaker but more extended areal anomalies. A pronounced concentration of high values appears in the southern end of the dataset area, where two mutually crossing linear enrichments are surrounded by a broader, practically NNW-SSE running enrichment halo. The anomaly areas are open to the South, NW, and NE continuations.

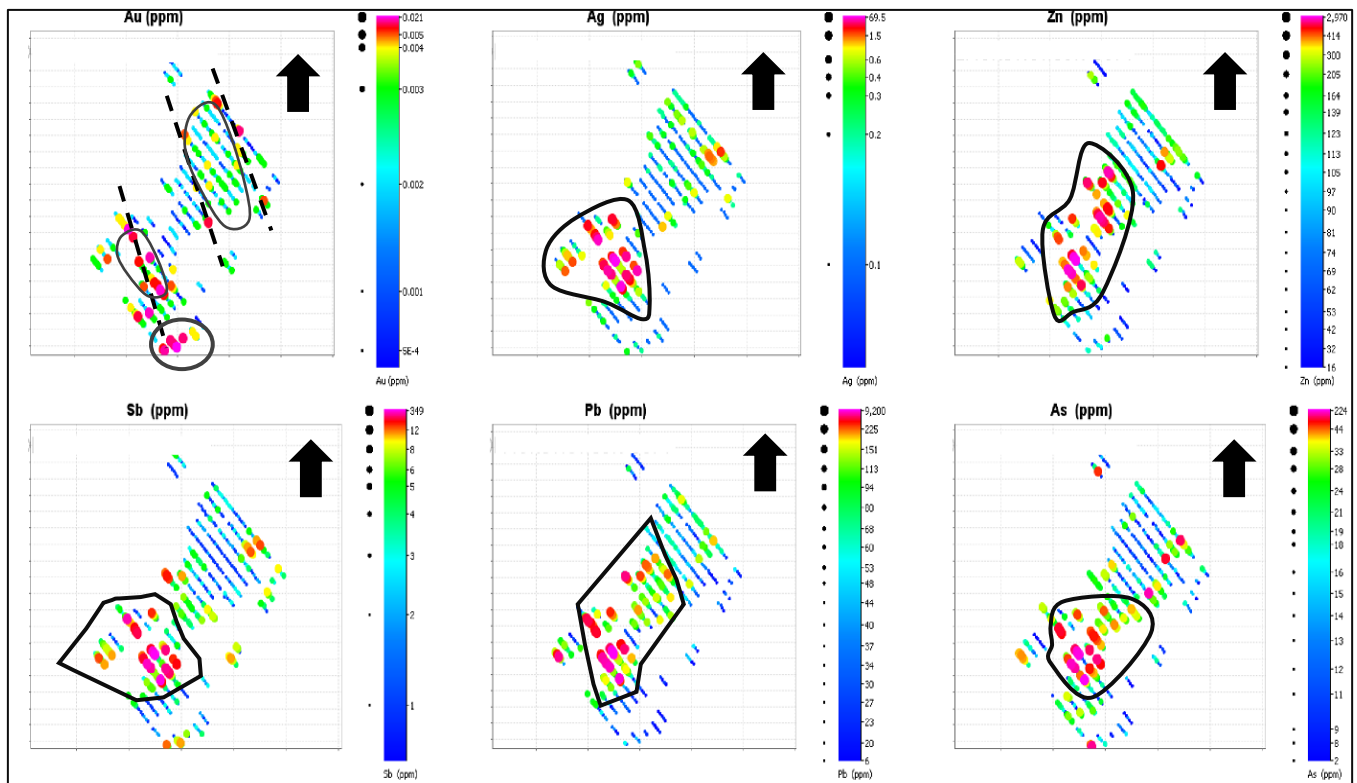


Figure 6: Variable maps of Au, Ag, Zn, Sb, Pb, and As showing the spatial distribution of those elements through the sampling area.

A grid is generated by interpolating located data into a uniform or regular grid, which is subsequently presented as a continuous colored. ioGAS software contains a gridding function that generates interpolated grid cell values by using a modified Inverse Distance Weighting (IDW) algorithm. So, some anomaly maps have been made to detect the anomalies of high concentrations of those elements (**Fig. 7**). Coordinates are not included on the maps for confidentiality. These anomaly maps highlight the anomalous values in isoline maps. This illustration enhances the NNW-SSE fault control of the gold and highlights that the largest maximum of Ag, Pb, and Sb also fall onto this fault zone. As shows a more dispersed character.

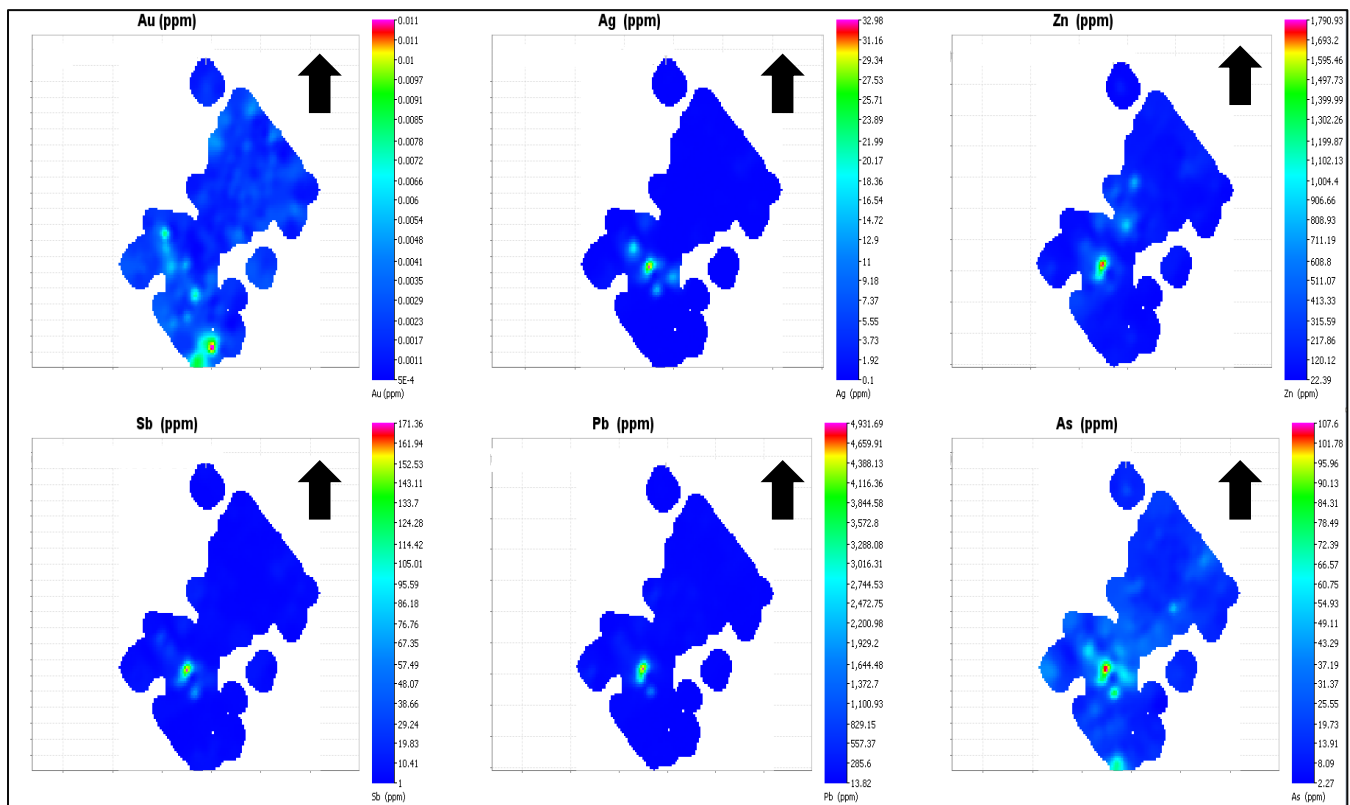


Figure 7: Anomaly maps of Au, Ag, Zn, Sb, Pb, and As showing the spatial distribution of the anomalies of those elements through the sampling area.

3. Nr2 geochemical dataset

3.1. Introduction

There are a total of 70 soil samples in the second geochemical dataset. For 52 elements, a ME-MS41L (Aqua Regia Super Trace Analysis) analysis was performed. The ALS Global lab has performed this analysis utilizing an Inductively coupled plasma mass spectrometry instrument (ICP-MS). The gold assay is performed at a lower detection limit of 0.0002 ppm whereas the silver assay is performed at a lower detection limit of 0.001 ppm. In all cases where samples values were lower than the detection limits I used a compromise to make them suitable for the analysis. I replaced the < 0,1 ... etc. values with the half of the lower detection limit in all samples and elements in our datasets.

3.2. Basic statistics

The statistical parameters for 52 variables (Au, Ag, Al, As, B, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cu, Fe, Ga, Ge, Hf, Hg, In, K, La, Li, Mg, Mn, Mo, Na, Nb, Ni, P, Pb, Pd, Pt, Rb, Re, S, Sb, Sc, Se, Sn, Sr, Ta, Te, Th, Ti, Tl, U, V, W, Y, Zn, and Zr) of ICP-MS results have been created to understand the general framework for the geochemical dataset. The dataset includes the Au element with a minimum concentration of <0.0002 ppm, a maximum concentration of 0.0093 ppm, the average is 0.0012 ppm. For the Ag element, the maximum concentration is 0.6 ppm, the minimum concentration is 0.042 ppm, and the average is 0.14 ppm. The statistical parameters for the other elements are listed in **Table 4**. The low standard deviation of some elements like gold and silver indicates that the obtained values are close to the value of the mean. The high standard deviation of the other elements like Arsenic and Barium indicates that the obtained values are dispersed through a wide range.

Table 4: The basic statistical parameters of the second geochemical dataset assay.

Variable	Minimum or lower detection limit	Maximum	Mean	Median	SD
Au (ppm)	<0.0002	0.0093	0.0012	0.001	0.0012
Ag (ppm)	0.042	0.6	0.14	0.1	0.1
Al (%)	0.7	2.3	1.4	1.3	0.3
As (ppm)	6.3	75.1	13.8	11.0	10.5
B (ppm)	<10	10.0	5.1	5.0	0.6
Ba (ppm)	133.5	1840.0	380.4	332.0	228.4

Be (ppm)	0.4	1.5	0.8	0.8	0.2
Bi (ppm)	0.2	0.7	0.4	0.4	0.1
Ca (%)	0.0	13.1	0.4	0.2	1.6
Cd (ppm)	0.0	0.3	0.1	0.1	0.1
Ce (ppm)	33.8	68.4	50.7	50.2	5.5
Co (ppm)	2.9	21.3	10.3	10.5	3.0
Cr (ppm)	10.1	31.4	19.8	18.8	4.7
Cu (ppm)	9.2	89.6	25.6	22.8	13.0
Fe (%)	1.1	3.4	2.2	2.2	0.6
Ga (ppm)	2.6	7.3	4.3	4.1	1.1
Ge (ppm)	0.0	0.1	0.0	0.0	0.0
Hf (ppm)	0.0	0.1	0.0	0.0	0.0
Hg (ppm)	0.0	0.4	0.2	0.2	0.1
In (ppm)	0.0	0.1	0.0	0.0	0.0
K (%)	0.1	0.2	0.1	0.1	0.0
La (ppm)	15.1	29.7	22.3	22.1	2.8
Li (ppm)	5.9	24.5	13.3	12.7	4.4
Mg (%)	0.1	0.9	0.3	0.3	0.1
Mn (ppm)	84.9	2300.0	702.3	637.5	376.3
Mo (ppm)	0.2	1.1	0.4	0.3	0.2
Na (%)	0.0	0.0	0.0	0.0	0.0
Nb (ppm)	0.3	1.0	0.5	0.5	0.1
Ni (ppm)	8.7	36.5	17.9	16.9	6.2
P (ppm)	0.0	0.1	0.0	0.0	0.0
Pb (ppm)	14.2	85.2	33.6	27.3	15.3
Pd (ppm)	<0.001	0.0	0.0	0.0	0.0
Pt (ppm)	<0.002	0.0	0.0	0.0	0.0
Rb (ppm)	7.5	21.1	13.0	12.6	3.0
Re (ppm)	<0.001	0.0	0.0	0.0	0.0
S (%)	0.01	0.1	0.0	0.0	0.0
Sb (ppm)	0.7	5.4	2.1	2.0	0.8
Sc (ppm)	1.1	6.2	3.6	3.4	1.1
Se (ppm)	0.1	0.8	0.4	0.4	0.2
Sn (ppm)	0.4	1.1	0.7	0.7	0.2
Sr (ppm)	8.9	150.5	29.5	24.2	22.0
Ta (ppm)	<0.005	0.0	0.0	0.0	0.0
Te (ppm)	0.01	0.5	0.1	0.0	0.2
Th (ppm)	2.4	8.8	5.0	4.9	1.1
Ti (%)	0.005	0.0	0.0	0.0	0.0
Tl (ppm)	0.1	0.2	0.1	0.1	0.0
U (ppm)	0.4	1.8	0.9	0.9	0.3
V (ppm)	15.5	64.2	30.6	28.6	7.6
W (ppm)	0.03	0.2	0.1	0.1	0.0
Y (ppm)	1.8	18.0	10.1	10.1	2.7
Zn (ppm)	23.4	118.0	50.7	49.9	15.5
Zr (ppm)	0.4	3.9	1.7	1.5	0.9

3.3. Correlation Analysis

To illustrate the geochemical affinity, the correlation between different elements was calculated by using the Pearson correlation type (**Table 5**). Concerning the target elements, Au shows a very weak correlation or relationship with all elements except Ag, Na, Nb, Pd, Re, Ti, and W, it shows a negative correlation. Whereas Ag shows strong correlation with Ba (0.84), Pb (0.79), In (0.71), Sb (0.68), S (0.68), Hg (0.62), and Cd (0.62) while shows moderate correlation with Cu (0.58), Zn (0.55), and W (0.47).

3.4. Principal Component Analysis (PCA)

The PCA was made by using ioGAS software to classify the elements in the relevant component (PC). **Table 6** shows the result of PCA where the loading values (eigenvalues) of the dataset in each component and the eigenvectors show the loading value of each element in each component. PC1 and PC2 cover around 69.85% of the total variance of the selected elements, therefore the information on correlation can be taken from PC1 and PC2. PC1 has a 59.25% of the total variance, an eigenvalue of 7.109, and is distinguished by the positive loading of all selected elements. For PC2, it has a 10.6% of the total variance, the eigenvalue of 1.272, and is distinguished by positive loading of Ag, Ba, Pb, S, and W. Au shows remarkable positive loading values in PC3 > PC1 and negative loading in PC2 while Ag shows positive loading in PC1 > PC2 and negative loading in PC3. The eigenvalue of PC3 is less than 1 but it's included because it has positive loading of Au which is one of the target elements.

Table 5: Correlation matrix of the second geochemical dataset assay showing the different relationships among elements.

	Au	Ag	Al	As	B	Ba	Be	Bi	Cs	Cd	Ce	Co	Cr	Cu	Fe	Ga	Ge	Hf	Hg	In	K	La	Li	Mg	Mn	Mo	Nb	Ni	P	Pb	Pd	Pt	Rb	Re	S	Sb	Sc	Se	Sn	Sr	Ta	Te	Th	Ti	Tl	U	V	W	Y	Zn	Zr
Au	1																																																		
Ag	-0.018	1																																																	
Al	0.14	-0.17	1																																																
As	0.21	0.078	0.18	1																																															
B	0.054	-0.044	-0.042	0.25	1																																														
Ba	0.018	0.84	0.043	0.14	-0.11	1																																													
Be	0.22	-0.062	0.74	0.23	-0.12	0.14	1																																												
Bi	0.21	0.18	0.55	0.42	0.31	0.23	0.31	1																																											
Cd	0.13	-0.019	0.043	0.75	0.046	0.12	0.043	-0.042	1																																										
Ce	0.18	0.62	-0.029	0.43	0.076	0.63	0.23	0.33	0.24	1																																									
Co	0.11	-0.22	0.26	-0.023	0.11	-0.2	0.5	0.23	-0.37	-0.082	1																																								
Cr	0.18	0.11	0.43	0.29	-0.0022	0.25	0.65	0.37	0.025	0.48	0.33	1																																							
Cu	0.19	-0.12	0.33	0.31	0.0038	0.063	0.85	0.52	0.03	0.13	0.36	0.53	1																																						
Cv	0.22	0.58	0.21	0.41	0.072	0.58	0.45	0.48	0.094	0.11	0.11	0.55	0.37	1																																					
Fe	0.23	0.041	0.85	0.33	-0.043	0.22	0.74	0.72	0.12	0.32	0.25	0.7	0.87	0.5	1																																				
Ga	0.18	-0.14	0.98	0.23	-0.041	0.055	0.79	0.56	0.055	0.065	0.28	0.53	0.97	0.32	0.89	1																																			
Ge	0.2	-0.1	0.33	0.44	0.1	-0.034	0.66	0.31	0.14	0.26	0.59	0.41	0.43	0.48	0.42	0.42	1																																		
Hf	0.22	0.25	0.34	0.51	0.12	0.2	0.45	0.33	0.23	0.59	0.0055	0.46	0.45	0.58	0.46	0.42	0.44	1																																	
Hg	0.11	0.62	0.059	0.23	0.25	0.48	-0.036	0.63	-0.11	0.53	-0.026	0.21	0.06	0.56	0.31	0.083	0.067	0.23	1																																
In	0.11	0.71	0.33	0.31	0.058	0.82	0.28	0.58	0.092	0.66	-0.027	0.41	0.36	0.71	0.53	0.36	0.14	0.41	0.66	1																															
K	0.16	0.0052	0.8	0.26	-0.035	0.18	0.58	0.68	0.007	0.27	0.23	0.48	0.75	0.33	0.81	0.79	0.36	0.45	0.23	0.47	1																														
La	0.064	-0.22	0.25	0.041	0.06	-0.2	0.53	0.17	-0.29	-0.11	0.3	0.25	0.4	0.11	0.22	0.28	0.6	0.015	-0.15	-0.059	0.16	1																													
Li	0.16	-0.17	0.74	0.43	0.28	-0.019	0.37	0.79	0.28	0.11	0.14	0.31	0.66	0.16	0.78	0.71	0.27	0.3	0.25	0.32	0.72	0.11	1																												
Mg	0.079	0.27	0.62	0.33	0.26	0.44	0.28	0.76	0.2	0.27	-0.050	0.23	0.53	0.36	0.69	0.58	0.12	0.27	0.43	0.64	0.59	-0.063	0.77	1																											
Mn	0.074	0.26	-0.13	0.13	-0.11	0.3	0.44	-0.06	-0.053	0.51	0.37	0.62	0.097	0.43	0.17	-0.017	0.47	0.23	0.011	0.18	0.03	0.39	-0.23	-0.17	1																										
Mo	0.21	0.29	-0.091	0.42	0.11	0.19	0.14	0.22	0.084	0.5	0.18	0.25	0.075	0.62	0.038	0.022	0.4	0.43	0.35	0.37	0.12	0.14	-0.1	-0.078	0.35	1																									
Nb	-0.11	0.087	0.4	0.16	-0.0074	0.24	0.29	0.35	0.1	-5.80E-04	0.15	0.11	0.29	0.041	0.38	0.33	0.089	-0.0011	0.043	0.31	0.24	0.24	0.4	0.35	-0.011	-0.19	1																								
Ni	-0.064	0.033	0.3	-0.23	-0.28	0.15	0.5	-0.2	-0.21	0.027	0.21	0.25	0.4	0.15	0.16	0.32	0.21	0.1	-0.29	0.1	0.22	0.25	-0.17	-0.11	0.27	0.047	0.012	1																							
P	0.26	0.0031	0.56	0.65	0.13	0.14	0.68	0.63	0.23	0.52	0.33	0.73	0.73	0.61	0.81	0.66	0.67	0.6	0.26	0.41	0.67	0.37	0.64	0.47	0.44	0.36	0.14	0.079	1																						
Pb	0.22	0.16	0.33	0.26	-0.14	0.22	0.45	0.5	-2.60E-05	0.52	0.22	0.33	0.33	0.57	0.38	0.4	0.35	0.22	0.4	0.6	0.21	0.31	0.17	0.33	0.47	0.16	0.19	0.55	1																						
Pd	0.04	0.79	-0.26	0.035	-0.1	0.67	0.066	-0.038	-0.074	0.65	-0.064	0.28	-0.13	0.55	-0.054	-0.19	0.077	0.37	0.46	0.52	-0.045	-0.11	-0.35	-0.085	0.51	0.4	-0.17	0.2	0.067	0.18	1																				
Pt	-0.15	0.0073	-0.24	0.094	-0.066	0.21	-0.083	-0.34	0.25	-0.023	-0.14	-0.14	-0.17	0.079	-0.26	-0.21	0.057	-0.0058	-0.18	-0.048	-0.27	-0.0039	-0.28	-0.21	0.077	0.13	-0.18	0.03	-0.11	-0.091	-0.021	1																			
Rb	0.018	0.13	0.024	0.11	-0.059	0.079	0.09	-0.0043	0.17	0.18	-0.054	0.18	0.038	0.11	0.13	0.031	-0.013	0.28	0.03	-0.01	0.023	-0.081	0.11	0.015	0.16	-0.039	0.0018	-0.036	0.16	0.031	0.093	-0.044	1																		
Re	0.13	-0.069	0.81	0.12	0.0039	0.056	0.71	0.64	-0.17	0.15	0.45	0.43	0.85	0.32	0.82	0.87	0.47	0.4	0.15	0.36	0.83	0.43	0.7	0.55	0.096	-0.0043	0.34	0.3	0.67	0.51	-0.11	-0.31	0.04	1																	
Sc	-0.22	0.15	-0.071	-0.14	-0.095	0.13	-0.054	-0.17	-0.073	-0.024	-0.21	-0.02	-0.086	-0.019	-0.039	-0.063	-0.26	-0.03	-0.094	0.083	-0.25	0.037	-0.2	0.0039	0.017	-0.097	0.25	0.033	-0.25	-0.13	0.027	0.24	0.016	-0.14	1																
S	0.035	0.68	0.068	0.29	-0.11	0.18	0.18	0.33	0.13	0.19	-0.14	0.12	0.08	0.54	0.23	0.062	0.11	0.3	0.43	0.72	0.26	-0.14	0.061	0.36	0.24	0.33	0.29	0.14	0.23	0.48	0.52	0.005	0.027	0.15	0.016	1															
Sb	0.12	0.68	0.076	0.29	0.23	0.65	0.11	0.81	-0.054	0.71	-0.052	0.53	0.17	0.11	0.32	0.73	0.77	0.32	0.11	0.25	0.51	0.37	0.085	-0.11	0.44	0.36	0.57	-0.17	0.11	0.23	0.033	0.03	0.5	1																	
Se	0.19	-0.15	0.3	0.22	0.025	0.0093	0.75	0.64	-0.059	0.055	0.41	0.54	0.9	0.29	0.89	0.92	0.47	0.39	0.21	0.33	0.73	0.37	0.72	0.62	0.02	-0.063	0.33	0.18	0.68	0.28	-0.2	-0.3	0.04	0.85	-0.13	-0.022	0.22	1													
Sn	0.26	-0.043	0.19	0.2	-0.084	-0.0021	0.29	0.17	0.06	0.2	0.14	0.22	0.26	0.34	0.23	0.25	0.3	0.27	0.017	0.11	0.25	0.071	0.13	-0.02	0.22	0.45	-0.023	0.19	0.35	0.42	0.13	0.023	0.072	0.22	-0.16	0.13	0.041	0.14	1												
Sr	0.12	0.16	0.63	0.2	-0.15	0.26	0.64	0.43	-0.17	0.31	0.26	0.5	0.7	0.48	0.6	0.67	0.38	0.43	0.2	0.48	0.56	0.33	0.31	0.32	0.19	0.31	0.22	0.49	0.47	0.																					

Table 6: Loading values of each element in each component (Eigenvectors) and eigenvalues of each component. Au has high loading in PC3, but Ag has high loading in PC1 and PC2.

<i>Eigenvectors</i>	<i>PC1</i>	<i>PC2</i>	<i>PC3</i>
<i>Au (ppm)</i>	0.04772	-0.5724	0.7205
<i>Ag (ppm)</i>	0.3222	0.2196	-0.07761
<i>Ba (ppm)</i>	0.328	0.2061	-0.02369
<i>Pb (ppm)</i>	0.2801	0.3111	0.2248
<i>In (ppm)</i>	0.3381	-0.1072	-0.1499
<i>Sb (ppm)</i>	0.3193	-0.2162	-0.1915
<i>S (%)</i>	0.2967	0.1619	0.0228
<i>Hg (ppm)</i>	0.2702	-0.2837	-0.3246
<i>Cd (ppm)</i>	0.315	-0.03073	0.1851
<i>Cu (ppm)</i>	0.3038	-0.1914	0.1193
<i>Zn (ppm)</i>	0.3079	-0.2918	-0.1791
<i>W (ppm)</i>	0.2103	0.4442	0.4221
<i>Eigenvalues</i>	7.109	1.272	0.9376
<i>Percentage (%)</i>	59.25	10.6	7.813

In figure 8, the Au show uncorrelation in all loading plots of highly loaded PC pairs, while Ag shows a high or strong correlation with Ba and S. For other elements like Cu and Cd show a high correlation, Also Zn, Sb, Hg, and In show high correlation. The 3D plot of the PCA is checked through ioGAS software to validate these results of PC pairs plots.

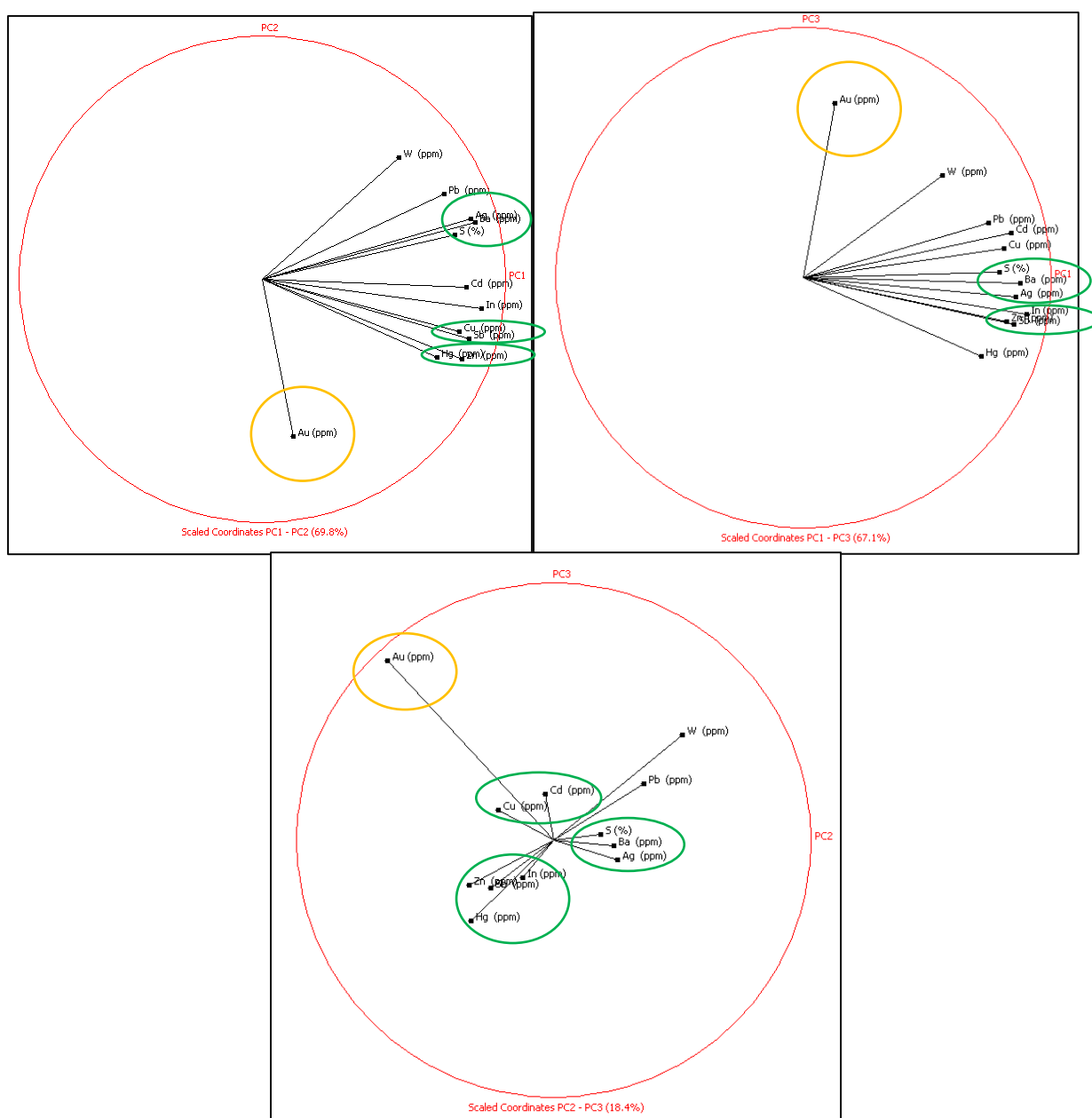


Figure 8: Loading plots of PC1-PC2, PC1-PC3, and PC2-PC3. Green circles represent the highly correlated elements and orange circles represent unique uncorrelated gold.

3.5. Statistical and spatial geochemical distribution of Au and Ag in the soil samples

The histogram and probability plots assume that the distribution of Au and Ag is positive skew where most of the samples show a low concentration of Au and Ag while very small portions are distinguished by relatively high concentrations which are considered as anomalies or outliers (**Fig. 9**). Furthermore, the possible anomaly threshold values for Au and Ag are indicated in figure 9. Generally, the maximum concentration recorded for Au is 0.0093 ppm and the minimum concentration is <0.0002 ppm, and for Ag, the maximum concentration is 0.6 ppm, and the minimum concentration is 0.042 ppm.

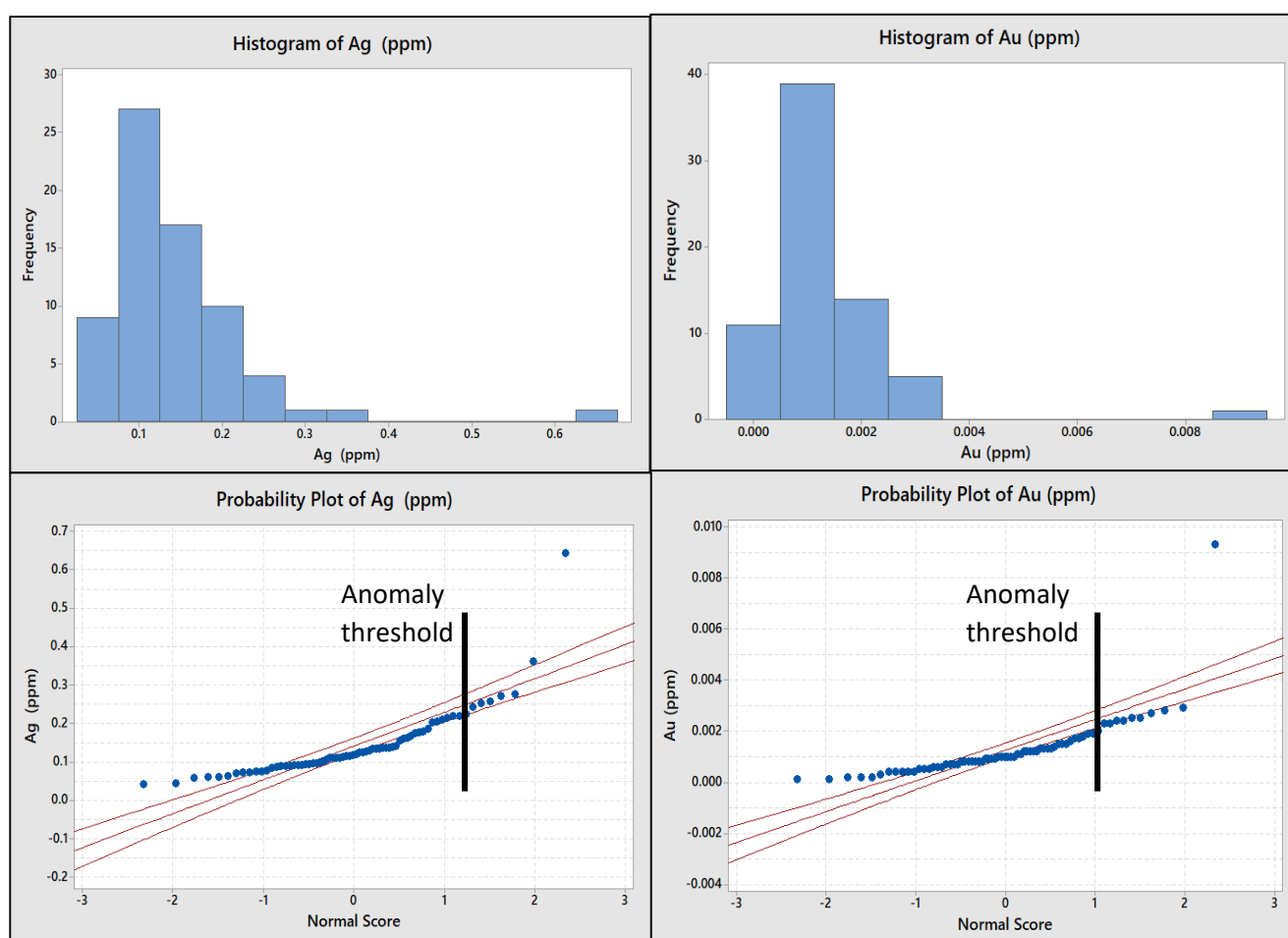


Figure 9: Histograms and probability plots of Au and Ag showing that the distribution of their concentration is not a normal distribution.

Variable maps have been made for Au, Ag, and some of the pathfinder elements of Ag by using ioGAS software (**Fig. 10**). For confidentiality, coordinates are not included on the maps. The spatial distributions of Ag concentrations and the pathfinder elements (e.g., Ba, Pb, Sb, S, Cu, and Zn) are consistent or similar while the spatial distribution of Au is slightly different than Ag and its pathfinder elements. Furthermore, the gold shows a definite regional stratigraphic enrichment on the SW half of the sampled area, it is prolonged well over the known and explored zone of the Rudabanya mineralization and overlaps the area, where the Mesozoic mineralized sequence of Rudabanya is covered by the Miocene basin sediments of the Borsod coal basin. There is no sign of linear structural control of the anomalies. The Red circle indicates the strong Au anomaly on the outcrop areas of the Paleozoic sediments and Miocene conglomerate. Prolongation of the sampling towards SW direction is perspective and can be recommended.

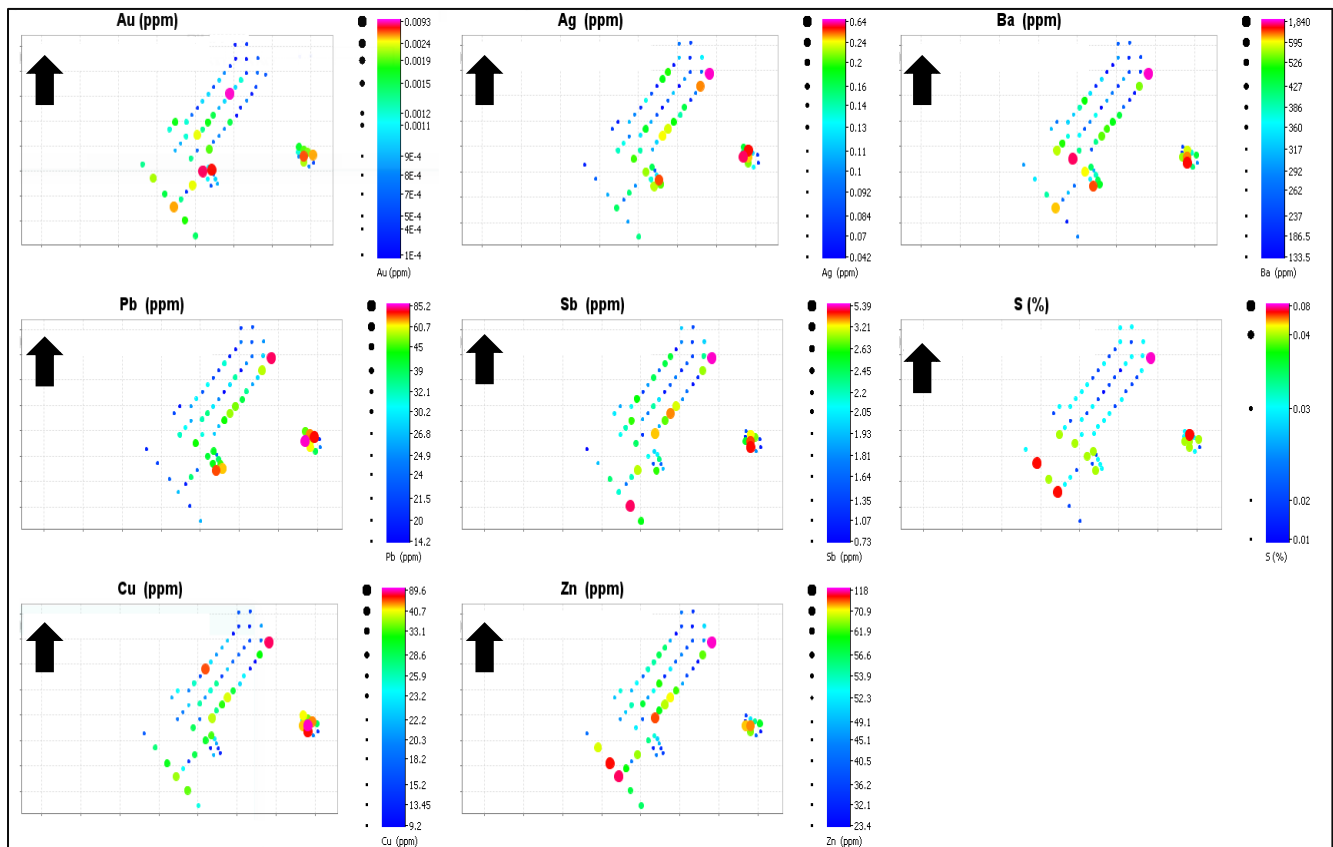


Figure 10: Variable maps of Au, Ag, Ba, Pb, Sb, S, Cu, and Zn showing the spatial distribution of those elements through the sampling area.

Some anomaly maps have been made using ioGAS software to detect the anomalies of high concentrations of those elements (**Fig. 11**). Coordinates are not included on the maps for confidentiality. The spatial distribution of anomalous areas of Ag, Ba, Pb, Sb, S, Cu, and Zn are similar and located close to the far NE of the sampling area while the spatial distribution of anomalous areas of Au is different and near to the center of the sampling area. Furthermore, Anomaly maps of Nr2 datasets clearly show (1) connection to the Nr1 dataset on the North, (2) enrichment of values in the Nr2/A dataset (in which they are few samples separated slightly from the main Nr2) lying over the Plaeozoic sediments, and (3) clear continuation of the anomalies towards the SE end, in the Neogene covered unexplored area.

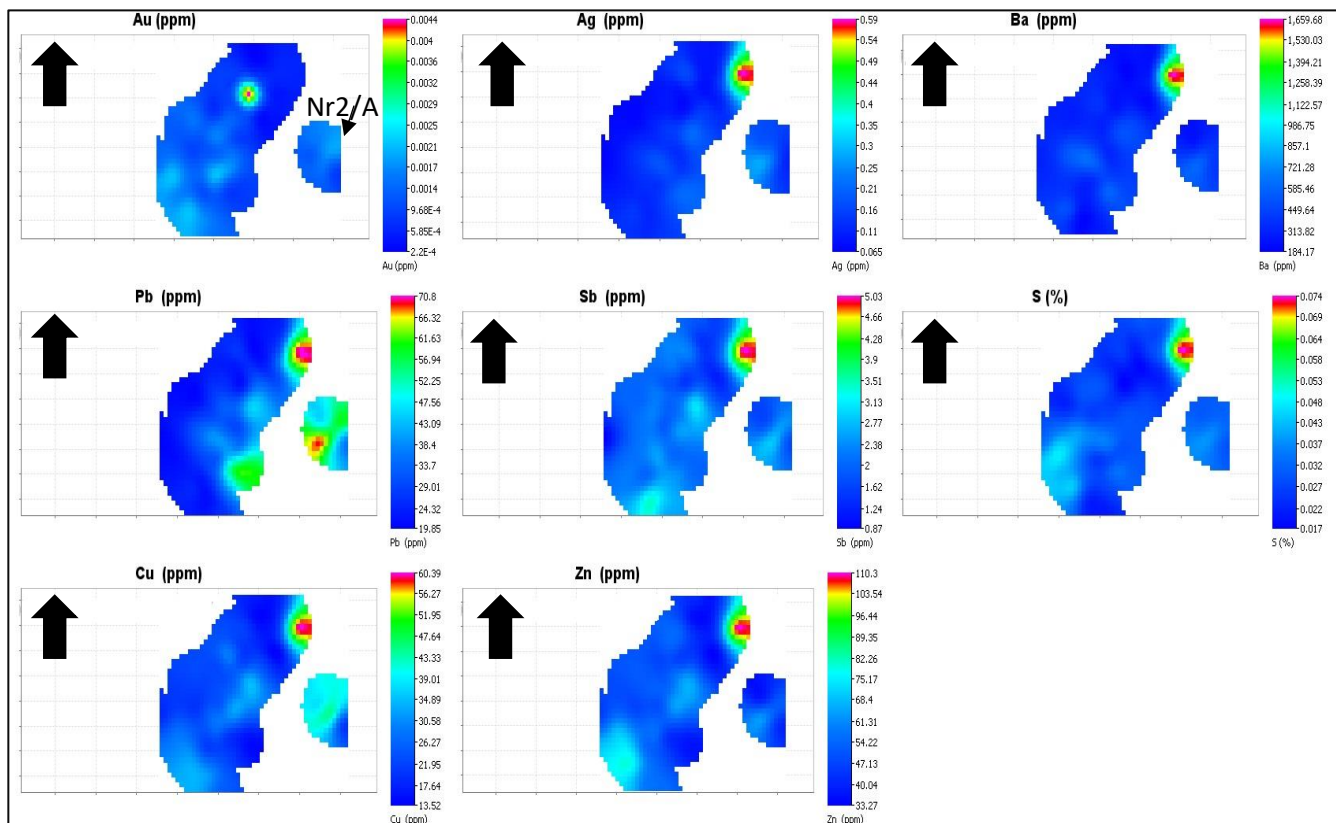


Figure 11: anomaly maps of Au, Ag, Ba, Pb, Sb, S, Cu, and Zn showing the spatial distribution of the anomalies of those elements through the sampling area.

4. Nr3 geochemical dataset

4.1. Introduction

Several drillholes of the recent exploration campaign (with various lengths to max. 300 m and various dips and azimuths) intersected complex ore mineralization (**Fig. 12**). It resulted in a geochemical dataset that allows comparing geochemical data of the oxidation zone and the primary mineralization. It includes 23 boreholes with 1098 samples, the assays were at 1 m length half-core samples. For the assays of 53 elements, the assay for gold was performed using Au-AA23 analysis utilizing fire assay and AAS (Atomic Absorption Spectrometry), and for other elements, the ME-MS41 (Aqua Regia with ICP-MS finish) analysis was used utilizing Inductively coupled plasma mass spectrometry instrument (ICP-MS). The gold assay is performed at a lower detection limit of 0.001 ppm whereas the silver assay is performed at a lower detection limit of 0.2 ppm.

4.2. Basic statistics

The basic statistical parameters of the Au and Ag concentrations in each borehole are listed in **Table 7**. For Au, the boreholes T-12/A, T-17, and T-6 show relatively high concentrations with max. concentrations in their samples were 1.28 ppm, 0.5 ppm, and 0.46 ppm respectively. For Ag, the boreholes T-11/A, T-12, T-12/A, T-14, T-14/A, T-15, T-15/A, T-17, T-5, T-6, U.1, and T-30 show very high concentrations with max. concentration goes up to 904 ppm.

4.3. Downhole geochemical distribution

From the basic statistics that were made for the whole dataset, we recognized that boreholes T-12/A, T-17, and T-6 show relatively high concentrations of Au. Through ioGAS software, some downhole plots of logs were made to those boreholes to highlight the distribution of Au and its correlation with other common elements in the area like Ag, Cu, Pb, Ba, Sb, Mn, and Fe.

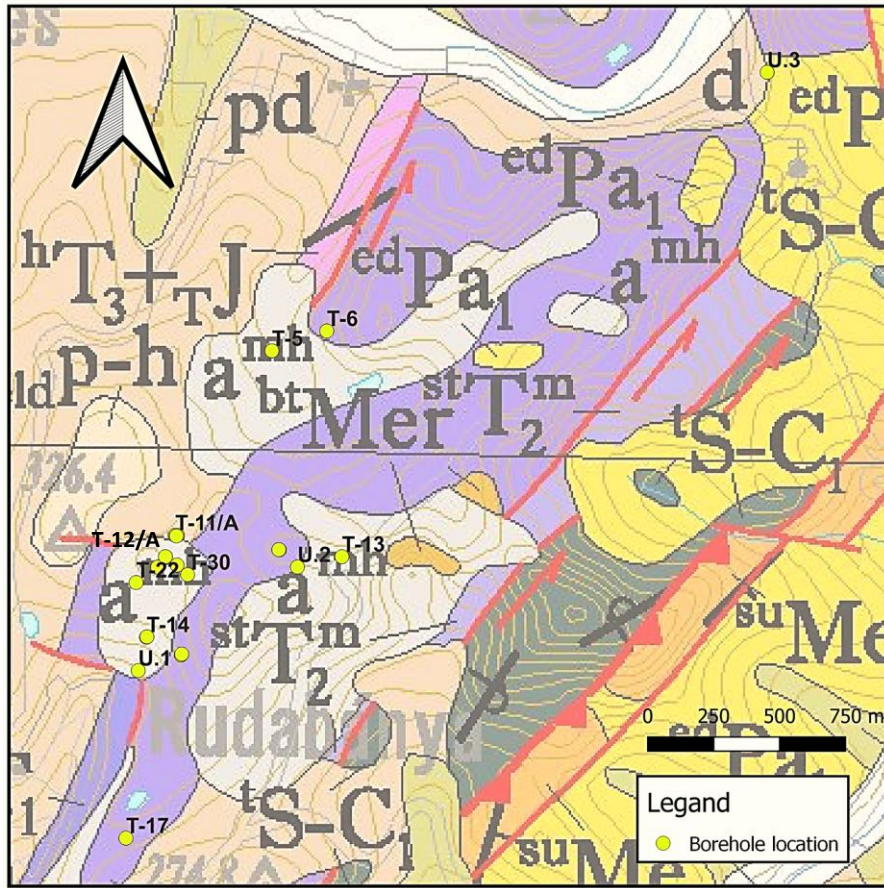


Figure 12: Location map shows the location of boreholes.

Figure 13 demonstrates the downhole plot (geochemical log) of the T-12/A borehole (Length = 86.6 m, dip = 55°, and azimuth = N220) in which we can highlight two positive anomalies for Au concentrations; the first one is situated at depth from 68 m to 69 m with 0.77 ppm showing high correlation with Ba, Mn, and Fe (related to spade breccia), while the second anomaly is located at depth from 85.40 m to 86.60 m with 1.28 ppm showing high correlation only with Mn and Fe (related to spade breccia). For Ag, it has two positive anomalies as well showing a high correlation with Pb at two depths from 22.7 m to 25.3 m and from 31.6 m to 32.4 m (related to clayey marly breccia).

Table 7: The basic statistical parameters for Au and Ag of borehole geochemical dataset assay.

Borehole	Au (ppm)					Ag (ppm)				
	Min.	Max.	Mean	Median	SD	Min.	Max.	Mean	Median	SD
T-11	0	0.01	0.0005	0	0.001864	0.1	8.8	1.856	0.2	2.49
T-11/A	0.001	0.062	0.008	0.004	0.01	0.1	48.7	5.3	1	9.73
T-11/B	0.0005	0.008	0.002	0.002	0.001	0.1	23.9	2.874	1.1	4.73
T-12	0.001	0.03	0.005	0.003	0.005	0.1	60.7	4.544	2.1	7.57
T-12/A	0.001	1.28	0.07	0.005	0.2	0.1	107	10.19	2.45	24.31
T-13	0	0.018	0.001	0.001	0.003	0.1	7.4	0.794	0.3	1.365
T-14	0.001	0.007	0.002	0.001	0.002	0.5	45.4	7.67	2.85	13.76
T-14/A	0.0005	0.011	0.001	0.001	0.001	0.25	97.4	8.57	1.5	20.73
T-15	0	0.092	0.008	0.002	0.01	0.1	84.2	6.43	0.5	16.09
T-15/A	0.0005	0.014	0.003	0.002	0.003	0.1	50.6	6.94	1.9	11.2
T-17	0.0005	0.5	0.01	0.001	0.054	0.1	904	13.3	0.1	98.5
T-20	0.0005	0.004	0.001	0.001	0.0009	0.1	0.1	0.1	0.1	0
T-5	0.0005	0.05	0.005	0.001	0.008	0.1	304	7.06	1.2	31.22
T-6	0.0005	0.46	0.008	0.001	0.04	0.1	729	13.34	0.8	73.86
U.1	0.005	0.02	0.006	0.005	0.0034	0	257	16.7	0.8	56.8
U.2	0.005	0.03	0.01	0.01	0.005	0.005	25	2.826	1	4.833
U.3	0.005	0.07	0.008	0.005	0.015	0.005	13	1.836	0.502	3.328
U.3A	0.005	0.005	0.005	0.005	0	3	10	6.143	6	2.34
T-30	0.002	0.01	0.004	0.0025	0.002	0.01	55.9	3.74	1.14	9.38
T-22	0.002	0.018	0.004	0.0025	0.003	0.01	19.15	2.402	0.04	4.967
T-23	0.002	0.013	0.0054	0.005	0.002	0.01	6.7	1.16	0.205	1.686
T-24	0.0025	0.016	0.0057	0.005	0.0035	0.01	9.89	1.264	0.06	2.363
T-27	0.0025	0.019	0.0071	0.006	0.005	0.02	11.2	2.682	1.83	2.651

Figure 14 illustrates the downhole plot of the T-17 borehole (Length = 300.3 m, dip = 60°, and azimuth = N315) in which we can highlight one positive anomaly for Au concentration which is situated at a depth from 172 m to 173 m with 0.5 ppm showing low correlation with Fe and Mn (related to silty and sandy breccia). For Ag, it has one positive anomaly as well showing a high correlation with Pb at a very shallow depth from 6 m to 7 m (related to clayey marly soil).

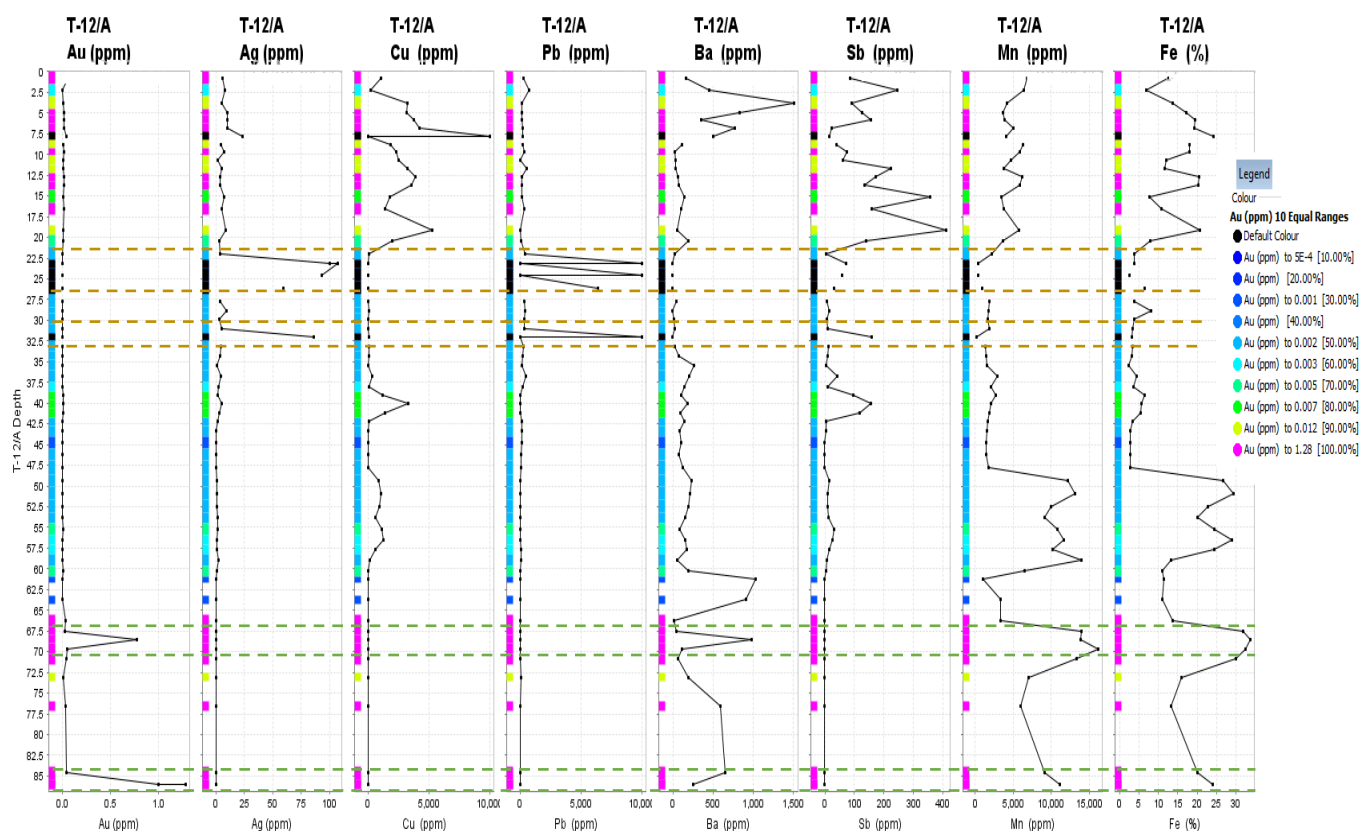


Figure 13: Geochemical downhole log of T-12/A borehole showing the vertical distribution of Au, Ag, Cu, Pb, Ba, Sb, Mn, and Fe.

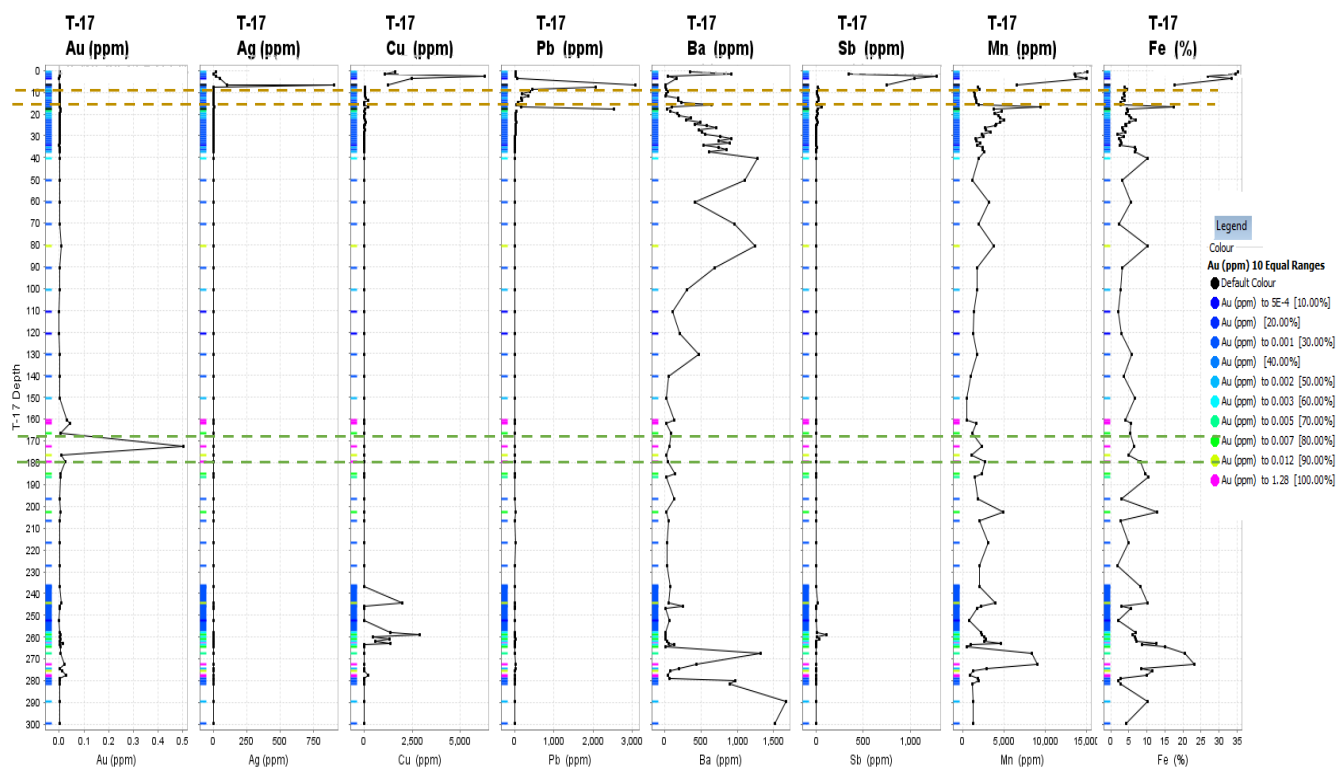


Figure 14: Geochemical downhole log of T-17 borehole showing the vertical distribution of Au, Ag, Cu, Pb, Ba, Sb, Mn, and Fe.

Figure 15 presents the downhole plot of the T-6 borehole (Length = 300 m, dip = 45°, and azimuth = N135) in which we can highlight one positive anomaly for Au concentration which is situated at a depth from 211 m to 212 m with 0.46 ppm showing moderately high correlation with Fe and Mn (related to siltstone and sandstone). For Ag, it shows a high correlation with Pb, Sb, Mn, and Fe and a low correlation with Cu at a very shallow depth from 152 m to 153.9 m (related to clayey marl).

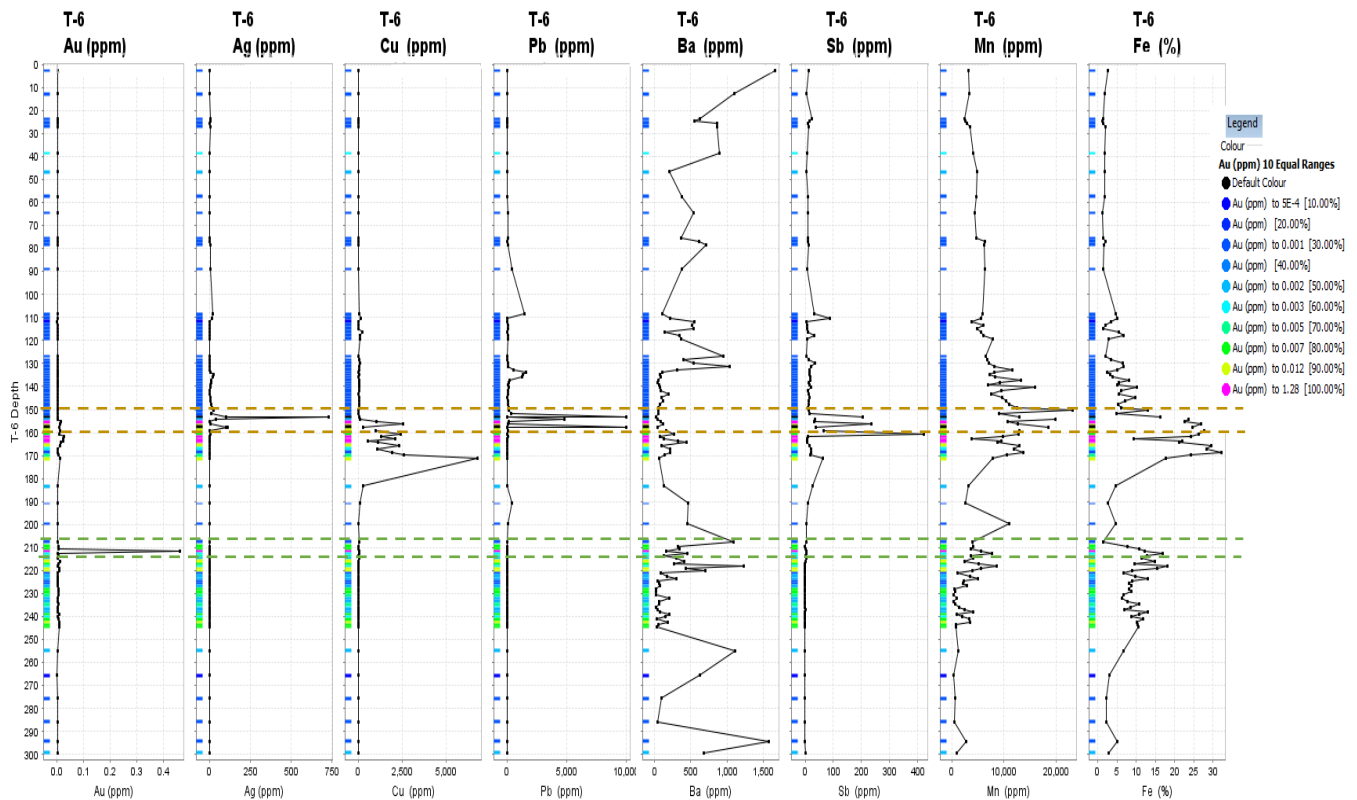


Figure 15: Geochemical downhole log of T-6 borehole showing the vertical distribution of Au, Ag, Cu, Pb, Ba, Sb, Mn, and Fe.

In figures 16, 17, and 18 and for better comparison between drillhole and surface soil samples assay, we made other geochemical downhole logs for the same boreholes (T-12/A, T-17, and T-6) including Au, Ag, and other pathfinder elements that give good correlation with Ag in the Nr1 and Nr2 geochemical datasets. The results show that Au shows a low correlation with S in T-17 and a good correlation with Mo and Hg in T-6. While Ag gives a high correlation with Hg, Cd, Zn, S, Mo, and As almost in the three boreholes (T-12/A, T-17, and T-6).

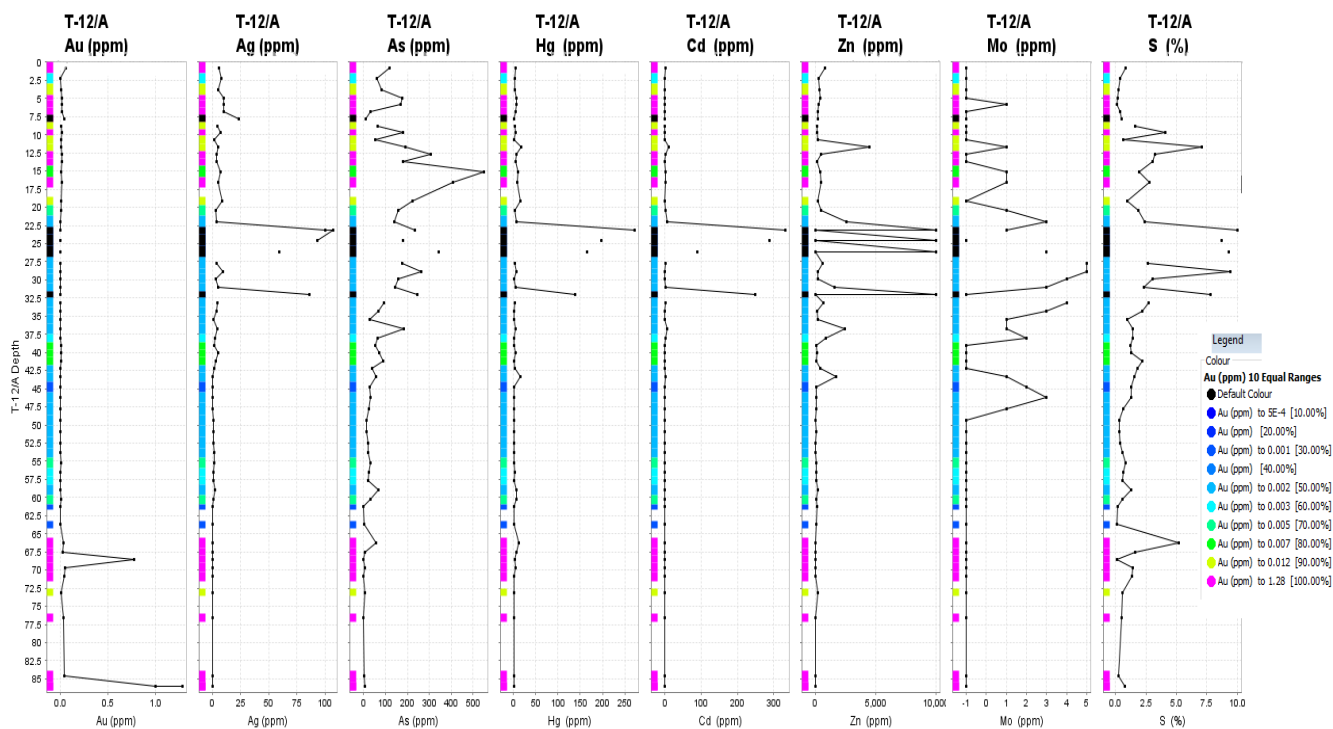


Figure 16: Geochemical downhole log of T-12/A borehole showing the vertical distribution of Au, Ag, As, Hg, Cd, Zn, Mo, and S.

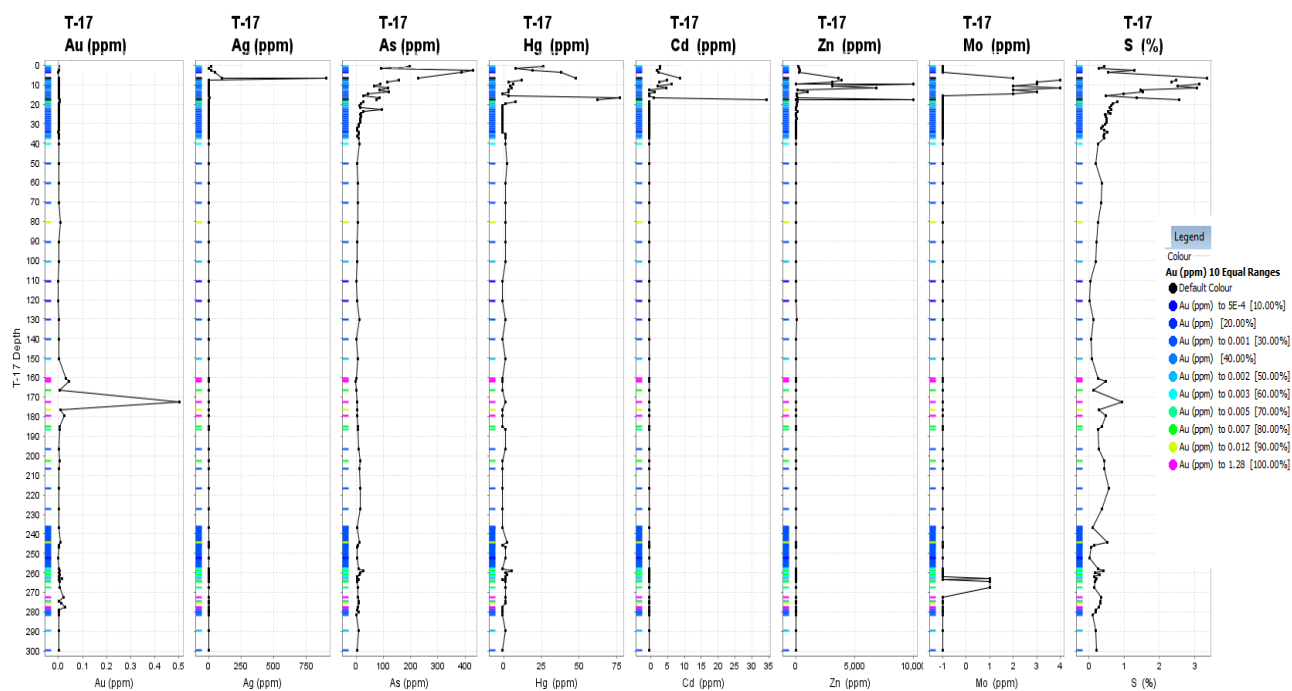


Figure 17: Geochemical downhole log of T-17 borehole showing the vertical distribution of Au, Ag, As, Hg, Cd, Zn, Mo, and S.

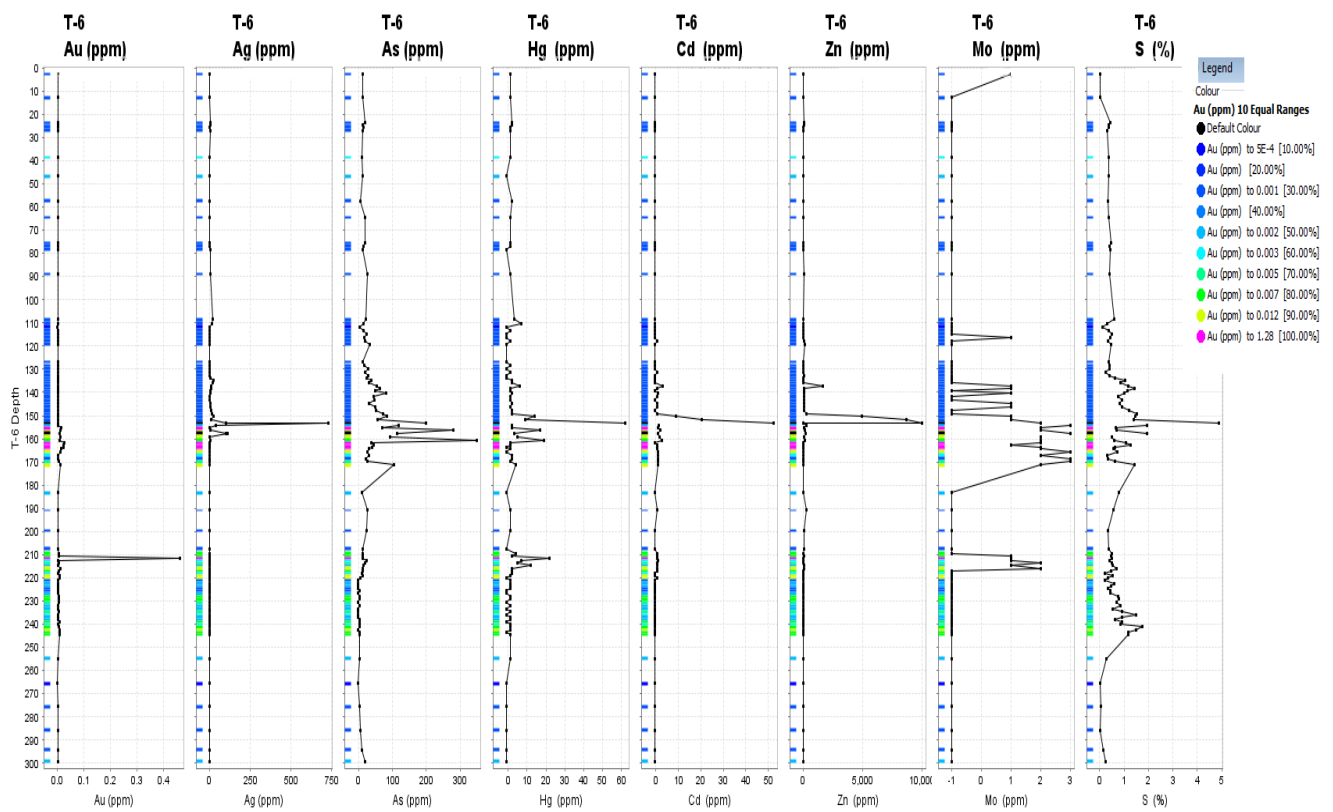


Figure 18: Geochemical downhole log of T-6 borehole showing the vertical distribution of Au, Ag, As, Hg, Cd, Zn, Mo, and S.

5. Conclusion

This study employs a geochemical strategy to clarify the linkage between gold and silver in Rudabánya. We studied three datasets acquired from the Rudabánya area during explorations of base metals and barite in the period from 2006 to 2022. Nr1 dataset which basically covers B-level soil geochemistry data of the upper levels of Lower Triassic and Middle Triassic sediments, and it also includes the thin structural slab of the Miocene Szuhogy Conglomerate Formation on the eastern border. Nr 2 dataset which covers B-level soil geochemistry data of Pannonian, Pliocene sediments and to a small the earliest Lower Triassic sedimentary rocks, i.e., Bódvaszilasi Homokkő Formation and Szini Márga Formation. Nr 3 dataset contains all the drill core assay data from the boreholes drilled in the study area. Nr1 and Nr2 datasets were analyzed in detail, and the Nr3 dataset was utilized only to compare and support the interpretation.

The findings of the present study support the following:

1. The Nr1 and Nr 2 datasets were sampled with the same methodology but produced different mean values of the assayed elements. This is due to several factors, which might be different assaying methods for both, or the different geological backgrounds. Despite the differences in the mean values, the multi-element correlations for Au and Ag give similar patterns in each dataset.
2. Gold has no meaningful correlation with any of the elements in either dataset (in our model, $> 0,6$ was considered as the threshold or the lowest level of a meaningful element correlation). Interestingly, it gives a non-constant varying correlation with Ba, Mn, Fe, Mo, and Hg in the borehole dataset.
3. On the contrary, silver has a strong correlation with a number of elements in both datasets. Pb, Sb, Hg, and Cd are commonly enriched in both Nr1 and Nr2 areas, while additionally As, Zn, Cu, Na, and W are characteristic for the Nr1 area, and Ba, In, S in the Nr2 Area. We interpret these differences as a similarity with the sedimentary hosted stratiform Pb-Zn-Ag deposit style in the Nr1 area, and epigenetic, hydrothermal sulfide mineralization in the Nr 2 area.
4. It should be mentioned that late Neogene Zn, As, Sb, and Hg mineralization may occur in both areas, which cannot be separated chemically from the above deposit styles.
5. The results demonstrate that the gold is poorly concentrated in the surface samples but has drill intersections in some boreholes (with concentration going up to 1.28 ppm). From that point, it could be studied mineralogically. Moreover, gold enrichment is not linked to silver enrichment either in the surface or underground exploration and it is not a typical carlin gold type.
6. These findings pave the way for future comprehensive research of gold and silver in the area.

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