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Research Article

STATISTICAL EVALUATION OF GEOCHEMICAL DATA AND PATHFINDER ELEMENTS OF GOLD MINERALIZATION IN THE AYTIM PROSPECT, CENTRAL KYZYLKUM, UZBEKISTAN

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ABSTRACT
This study evaluates element enrichment, lithological controls on gold distribution, and potential pathfinder elements in the central sector of the Aytim prospect. Published summary statistics for 20 elements in 3,498 samples collected from exploration trenches and drill holes were examined, including crustal abundance-normalized enrichment factors, coefficients of variation, lithology-specific mean values, and a pairwise correlation matrix. The threshold $|r| \geq 0.195$ was used only as an empirical screening criterion for comparatively strong associations. An exploratory principal component analysis was also considered using a correlation matrix rounded to two decimal places. The enrichment sequence is Sb (100.3) > Au (32.5) > As (29.8) > Cd (14.72) > Mo (11.0) > W (8.33) > Ag (7.71). High coefficients of variation for Au, Ag, and Mn indicate strongly heterogeneous distributions. The highest Ab enrichment factors were reported for siltstone (216), sandstone (157.5), silty sandstone (152), schist (150), and carbonaceous schist (139). At the scale of the complete dataset, Au–As, Au–Co, Au–Ni, and Au–Mn correlations are weak, although several local associations were reported within individual lithological groups. The first two principal components explain only 21.46% of the total variance, so the multivariate interpretation is exploratory rather than confirmatory. The results indicate a dominant Sb–Au–As geochemical enrichment pattern. Arsenic, antimony, and silver should therefore be treated as context-dependent pathfinders and evaluated together with favorable lithology, tectonic disruption, and quartz–sulfide alteration. Robust validation requires a complete 3,498 × 20 analytical dataset, detection limits, and spatially referenced sample coordinates.

Keywords: *Aytim Prospect; Gold; Geochemistry; Enrichment Factor; Coefficient Of Variation; Correlation; Principal Component Analysis; Lithological Control; Arsenic; Antimony*

INTRODUCTION
Reliable statistical interpretation of large geochemical datasets is essential for evaluating gold mineralization. Geochemical concentrations commonly show right-skewed distributions, may be censored by analytical detection limits, and often combine several geological populations. Consequently, mean and maximum values alone do not adequately characterize element distributions. Descriptive statistics, normalization to reference crustal abundances, robust statistical methods, multivariate analysis, and spatial integration in a geographic information system (GIS) provide complementary approaches for identifying meaningful geochemical patterns [Aitchison, 1986; Reimann *et al.,* 1986; Carranza, 2009; Filzmoser *et al.,* 2009].

Available source materials for the central sector of the Aytim prospect report include statistical parameters for 20 elements in 3,498 samples, lithology-specific mean concentrations, crustal abundance-normalized enrichment factors, a correlation matrix, and selected element associations [Anonymous]. These aggregated data make it possible to compare study area-wide trends with local relationships reported for individual lithological groups. However, because the raw analytical results and sample coordinates were not available, the findings must be interpreted as descriptive and exploratory.

The objective of this study is to evaluate the principal geochemical enrichment patterns of the Aytim prospect, assess the lithological dependence of gold accumulation, identify potential pathfinder elements, and critically examine the statistical reliability and limitations of the available summary data.

MATERIALS AND METHODS

The source dataset comprises 3,498 geochemical samples collected from exploration trenches and drill holes [Anonymous]. The source report states that gold was determined by fire assay and fire-assay–spectrometric methods, whereas the remaining elements were measured by spectral analysis. The dataset includes Au, Ag, Cu, Pb, Zn, As, Sn, Cd, Sb, Ga, Ge, Mo, W, Be, Ni, Co, Cr, V, Mn, and P.

The source report provides the following sample counts for lithological groups: carbonaceous schist, 946; silty sandstone, 926; schist, 579; argillaceous schist, 304; siltstone, 72; silty schist, 44; brecciation zones, 49; quartz and quartz veins, 43; and sandstone, 20. These categories total 2,983 samples, leaving 515 samples without a clearly specified lithological classification in the available text. This discrepancy was explicitly considered when interpreting lithology-related results.

A crustal abundance-normalized enrichment factor was defined as $EF = C\_mean/C\_crust$, where C_mean is the mean concentration in the sample population and C_crust is the selected reference crustal abundance. EF

> 1 indicates enrichment relative to the reference value, whereas $EF < 1$ indicates depletion. The coefficient of variation was calculated as $CV = (\sigma/C\_mean) \times 100\%$, where σ is the standard deviation. A high CV indicates a strongly dispersed distribution but does not, by itself, demonstrate the presence of a spatially localized ore body.

The source correlation matrix used $|r| \geq 0.195$ as a selection threshold. In this study, this value was retained only as an empirical screening criterion for comparatively strong associations and was not interpreted as a 5% significance threshold. If every pair were based on $n = 3,498$ observations, the approximate two-sided critical value of Pearson's r at $\alpha = 0.05$ would be about 0.033. Statistical significance and effect size must therefore be evaluated separately, particularly because multiple testing and unequal pairwise sample sizes may affect inference.

An exploratory principal component analysis (PCA) was reported from a 20 × 20 correlation matrix rounded to two decimal places. Because the PCA was not calculated directly from raw concentrations, the results were used only to visualize broad associations. Mean gold concentrations across arsenic and silver concentration classes were also compared descriptively. No inferential tests were applied because class-specific sample sizes, dispersion estimates, and confidence intervals were unavailable.

RESULTS

The summary statistics indicate that most elements have mean concentrations close to or below the selected crustal reference values, whereas a smaller group is distinctly enriched. The enrichment sequence is Sb (100.3) > Au (32.5) > As (29.8) > Cd (14.72) > Mo (11.0) > W (8.33) > Ag (7.71) > Sn (1.59) > Zn (1.13). The high enrichment factors of Sb, Au, and As define the dominant geochemical signature of the sampled area. The Mo–W–Sn enrichment is subordinate and should not be assigned a genetic interpretation without mineralogical and spatial evidence.

Gold (346.52%), silver (217.81%), and manganese (196.04%) have the highest coefficients of variation, indicating strongly heterogeneous concentration distributions. Arsenic (103.71%), lead (103.22%), molybdenum (92.70%), vanadium (87.31%), and germanium (82.34%) are also highly dispersed. In contrast, beryllium (6.37%), phosphorus (15.70%), antimony (16.90%), and chromium (28.91%) show comparatively low variability. The combination of a high EF and low CV for Sb may indicate relatively

widespread enrichment within the sampled population; a spatial map is required before it can be interpreted as either a regional background feature or an exploration anomaly.
The highest gold enrichment factors were reported for siltstone (216), sandstone (157.5), silty sandstone (152), schist (150), and carbonaceous schist (139). Lower values occur in argillaceous schist (88) and silty schist (16). These values demonstrate substantial lithological variation, but the group sizes range from 20 to 946 samples. Consequently, the stability and representativeness of the lithology-specific means are not uniform.

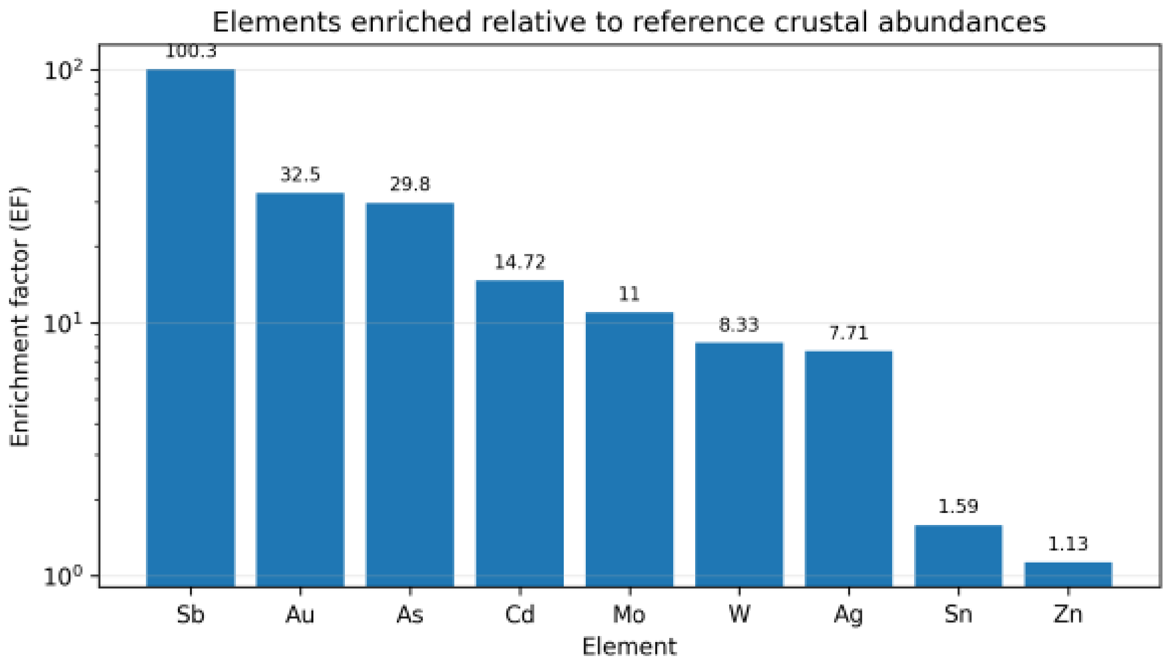

Figure 1. Elements enriched relative to the selected reference crustal abundances (EF > 1).

Table 1: Principally enriched elements in the Aytim dataset.

Element	Mean concentration (y/e)	(Coefficient of variation (%)	EF
Au	0.13	346.52	32.5
Ag	0.54	217.81	7.71
As	50.64	103.71	29.8
Sb	20.05	16.90	100.3
Cd	2.94	33.17	14.72
Mo	11	92.70	11.0
W	10	0.85	8.33
Sn	3.98	36.80	1.59
Zn	86.16	47.65	1.13

Using the screening threshold $|r| \geq 0.195$, the strongest reported correlations are Mo–V ($r = 0.510$), Co–Mn (0.470), Ni–Co (0.420), Zn–Ni (0.400), Cu–V (0.320), Zn–Co (0.290), Zn–Cd (0.280), and Cd–Ni (0.280). A weak negative relationship occurs for Ga–V ($r = -0.220$). These associations indicate co-variation among several petrogenic and polymetallic elements, but their geological causes cannot be established without spatial and mineralogical information.

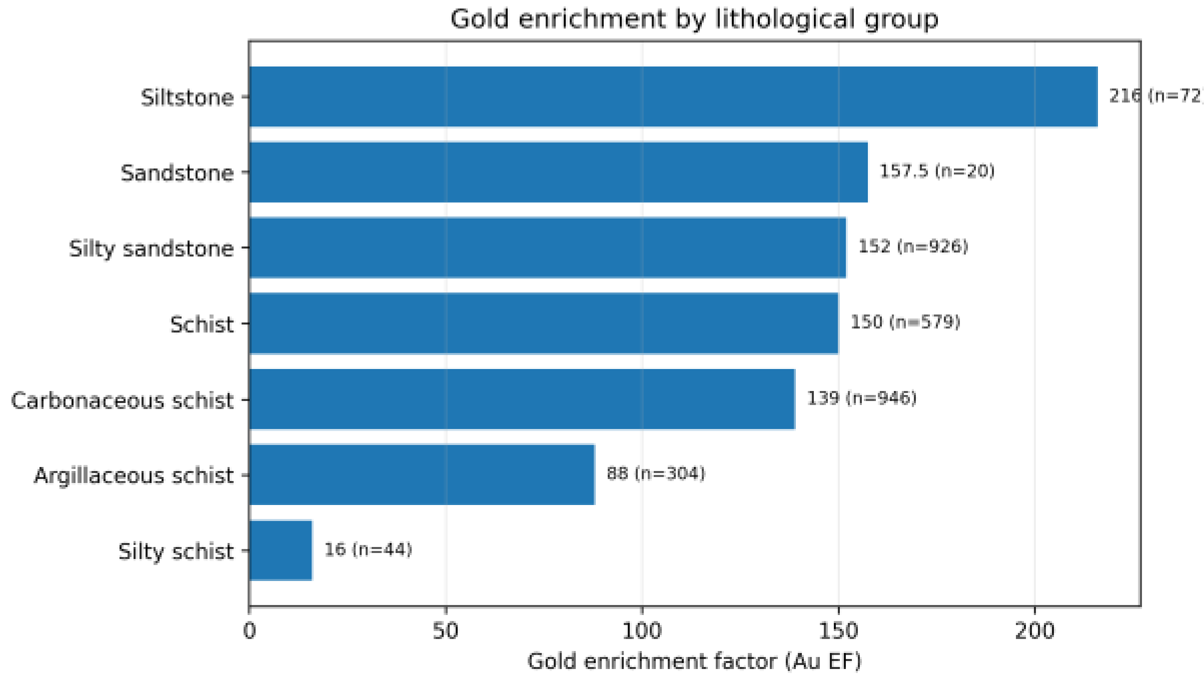

Figure 2. Gold enrichment factors by lithological group; sample sizes are shown in parentheses

Table 2. Lithological groups, sample sizes, and reported gold enrichment factors.

Lithological group	**n**	**Au EF**	**Interpretive note**
Siltstone	72	216	Highest value; relatively small sample group
Sandstone	20	157.5	High value; negligible sample group
Silty sandstone	926	152	High value; local Au–As association reported in the source
Schist	579	150	High value; local Au–As association reported in the source
Carbonaceous schist	946	139	High enrichment in the largest lithological group
Argillaceous schist	304	88	Local Au associations with Be, V, Pb, and Cd
Silty schist	44	16	Lowest reported Au EF; small sample group
Brecciation zones	49	Not reported	Au EF not provided in the available text
Quartz and quartz veins	43	Not reported	Au EF not provided in the available text
Other/unclassified	515	Not reported	Lithological category not specified

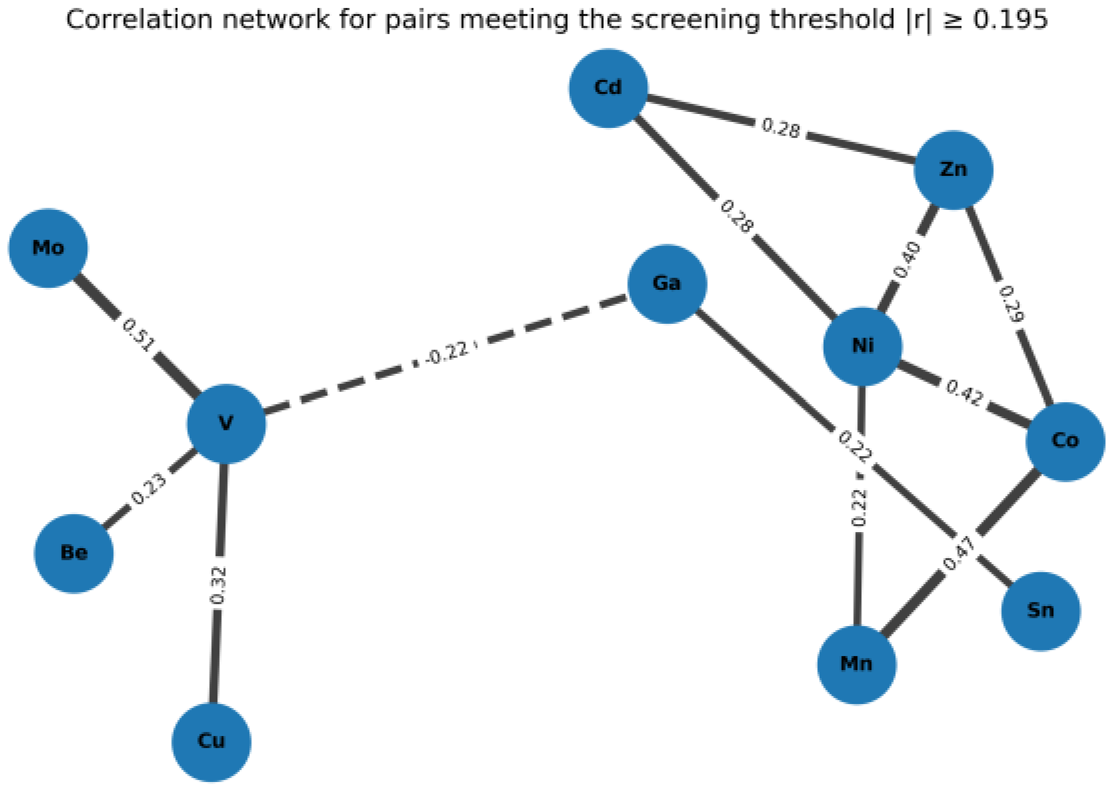

Figure 3. Correlation network for element pairs meeting the empirical screening threshold |r| ≥ 0.195. Dashed lines indicate negative correlations.

Table 3. Highest reported pairwise correlations.

Element pair	**r**	**Direction**
Mo–V	0.51	Positive
Co-Mn	0.47	Positive
Ni–Co	0.42	Positive
Zn–Ni	0.40	Positive
Cu–V	0.32	Positive
Zn–Co	0.29	Positive
Zn–Cd	0.28	Positive
Cd–Ni	0.28	Positive
Be–V	0.23	Positive
Sn–Ga	0.22	Positive
Ga–V	−0.22	Negative
Ni–Mn	0.22	Positive

Gold shows weak correlations with As ($r = 0.121$), Co (0.082), Ni (0.065), and Mn (0.062) in the complete matrix. Therefore, it is more accurate to state that Au is absent from the set of strongest pairwise relationships than to describe it as statistically autonomous. The source report also records local Au–Mn and Au–Co associations in carbonaceous schist, Au–As in silty sandstone and schist, Au–Be, Au–V, Au–Pb, and Au–Cd in argillaceous schist, and Au–Ag in sandstone. The reliability of these subgroup relationships cannot be evaluated without group-specific sample sizes for each pair, p-values, and confidence intervals.

In the exploratory PCA derived from the rounded correlation matrix, the first component explains 13.47% of the total variance and the second explains 7.99%, for a combined total of 21.46%. This low proportion indicates that the first two components capture only a limited part of the multielement variability. Ni, Co, Mo, Zn, V, Cd, and Mn have comparatively high loadings on PC1. PC2 primarily contrasts V, Cu, Mo, Be, and Cr with Ga, Co, Zn, and Ni.

Au, As, Ag, Sb, and W occur close to the center of the first two-component solution, indicating low loadings specifically on PC1 and PC2. This pattern should not be interpreted as complete statistical independence. Reanalysis of raw concentrations should account for values below detection limits, data closure, skewness, and outliers through appropriate log-ratio transformations and robust PCA [Aitchison, 1986; Filzmoser *et al.,* 2009].

Across the reported Ar concentration classes, mean Au increased from 0.03 y/e in the <10 y/e As class to 0.60 y/e in the 500–999 y/e As class and then decreased to 0.40 y/e in the ≥1,000 y/e As class. This descriptive pattern is compatible with a possible positive Au–As relationship over part of the concentration range. However, the class-specific sample counts, dispersion statistics, and confidence intervals are unavailable, so the trend cannot be considered statistically confirmed.

Gold does not show a stable monotonic increase across the reported silver classes. Mean Au varies between approximately 0.10 and 0.30 y/e and is 0.15 y/e in the ≥10 y/e Ag class. Therefore, silver cannot be treated as a universal pathfinder across the complete sample population, although it may remain useful as a local indicator in specific lithological settings, particularly in sandstone.

DISCUSSION

The high enrichment factors of Sb, Au, and As define an antimony-gold-arsenic geochemical signature in the Aytim dataset. However, pathfinder selection should not be based on enrichment factors alone. Variability, lithological setting, spatial distribution, mineral hosts, and hydrothermal alteration must also be considered. The high EF and low CV of Sb suggest that antimony enrichment is relatively widespread, whereas local gold targets are more likely to be distinguished by coincident As, Ag, and other geochemical or structural indicators.

The dataset-wide Au–As correlation of $r = 0.121$ represents a small effect size. With a large sample size, it may still be statistically distinguishable from zero, but statistical significance would not necessarily imply exploration utility. The high variability of Au, possible multimodality, and mixing of lithological populations may suppress study area-wide correlations. These hypotheses should be tested using log-transformed and rank-based correlations, lithological stratification, and robust statistics [Reimann *et al.,* 1986; Carranza, 2009]

High Au enrichment factors in siltstone, sandstone, silty sandstone, schist, and carbonaceous schist indicate that gold accumulation is not restricted to a single rock type. Fracturing in fine-grained and layered rocks, relatively high brittleness and permeability in sandstone, and reducing conditions associated with carbonaceous material and sulfides are plausible mechanisms for gold deposition. Nevertheless, these mechanisms are not demonstrated by the summary statistics and require direct structural, petrographic, and mineralogical verification.

Previous work on the Aytim area noted the possible role of carbonaceous rocks in concentrating Re, U, Mo, V, and Au [Sayitov *et al,* 2017]. Studies of the Adzhibugut and Kokpatas objects described gold–pyrite–arsenopyrite and gold-sulfide-quartz assemblages and emphasized the importance of lithology, silicification, and sulfidation [Pirnazarov & Koloskova, 2003; Turamuratov *et al.,* 2005]. These studies provide useful regional analogs but do not constitute direct genetic evidence for the Aytim dataset.

The heuristic distinction among chalcophile elements (Au, As, Ag, Cu, Pb, and Zn), lithophile elements (Mo, Sn, W, and Be), and predominantly rock-forming or petrogenic elements (Co, Mn, Ni, V, Ga, Cr, and

Ge) suggests that several geochemical controls may be superimposed. A definitive conclusion regarding separate sources or mineralizing processes would require the identification of mineral hosts, alteration assemblages, and spatial zoning.

The results support an integrated exploration approach that considers: (1) lithological units with high reported Au enrichment factors, including siltstone, sandstone, silty sandstone, schist, and carbonaceous schist; (2) carbonaceous and sulfide-bearing rocks; (3) As and Sb enrichment; (4) local Ag, Cu, Pb, and Zn associations; and (5) tectonic brecciation and quartz–sulfide veining. Prospective positions should be defined by the spatial coincidence of several independent criteria rather than by a single high geochemical value.

When the complete georeferenced analytical database becomes available, the workflow should be expanded to include the treatment of values below detection limits, robust background–anomaly thresholds based on medians and median absolute deviation, appropriate compositional or log-ratio transformations, lithology-stratified Spearman correlations, robust PCA and cluster analysis, variography, local Moran's I, GIS integration, and cross-validation [Aitchison, 1986; Reimann *et al.,* 1986; Carranza, 2009; Filzmoser *et al.,* 2009].

REFERENCES

Aitchison, J. (1986). The Statistical Analysis of Compositional Data. London: Chapman & Hall. 416 p.

Anonymous (No Year). Aytim Prospect, Central Sector. Geochemical database for exploration trenches and drill holes: 3,498 samples and 20 elements. *Unpublished geological survey materials*.

Carranza, E.J.M. (2009). Geochemical Anomaly and Mineral Prospectivity Mapping in GIS. Amsterdam: Elsevier. 368 p.

Filzmoser, P., Hron, K., & Reimann, C. (2009). Principal component analysis for compositional data with outliers. Environmetrics, 20, 621–632. *https://doi.org/10.1002/env.966*

Pirnazarov, M.M., & Koloskova, S.M. (2003). Natural types of primary ores at the Adzhibugut gold deposit (Central Kyzylkum). *Mining Bulletin of Uzbekistan*, 2, 13–17. *[In Russian].*

Reimann, C., Filzmoser, P., Garrett, R.G., & Dutter, R. (2008). Statistical data analysis explained: *Applied environmental statistics with R. Chichester: John Wiley & Sons*. 362 p. *https://doi.org/10.1002/9780470987605*

Sayitov, S.S., Tsoy, V.D., & Alimov, Sh.P. (2017). Rhenium-bearing carbonaceous rocks of the Aytim deposit (Central Kyzylkum). *Geology and Mineral Resources*, 3, 13–18. *[In Russian].*

Turamuratov, I.B., Tsoy, V.D., Pirnazarov, M.M., & Koroleva, I.V. (2005). Natural ore types of gold deposits in the Kokpatas ore district. *Mining Bulletin of Uzbekistan*, 2, 17–22. *[In Russian].*

Vinogradov, A.P. (1962). Average contents of chemical elements in the principal types of igneous rocks of the Earth's crust. Geochemistry, 7, 555–571. *[In Russian*].