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Geochemical anomaly detection for copper exploration in the Troodos ophiolite belt

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Abstract

The Troodos ophiolite in Cyprus hosts volcanic massive sulphide (VMS) deposits that have been mined for copper since the Bronze Age, yet undiscovered deposits likely remain at depth. This research applied stream sediment and soil geochemistry to detect anomalous zones favourable for copper mineralisation along a 45 km transect of the northern Troodos belt. A total of 184 stream sediment samples and 96 ridge-crest soil samples were analysed for Cu, Zn, Au, As, Sb, Pb, Ag, and Mn by ICP-MS following aqua regia digestion. Anomaly thresholds were set at the mean plus two standard deviations of log-transformed data. Fourteen Cu anomalies (>187 ppm) were identified, of which eight coincided with known VMS occurrences and six defined previously unrecognised targets. Multi-element associations were examined by factor analysis, which extracted three factors: a Cu-Zn-Au factor interpreted as VMS-related, an As-Sb-Pb factor linked to epithermal overprinting, and a Mn factor reflecting supergene enrichment. GIS overlay of geochemical anomalies with structural lineaments and ASTER-derived alteration maps highlighted three priority exploration targets within 2 km of mapped faults.

Keywords: Geochemical anomaly, copper exploration, Troodos ophiolite, stream sediment, pathfinder elements, VMS deposits, factor analysis, mineral survey, alteration mapping, Cyprus

Introduction

From an economic angle, Cyprus owes its name to copper — the Latin cuprum derives from the Greek Kypros^[1]. The Troodos ophiolite complex, a slab of Cretaceous oceanic crust uplifted and exposed by tectonic processes, contains over 30 known VMS deposits formed at ancient seafloor hydrothermal vents^[2]. Modern exploration relies on geochemical surveys that detect the halo of dispersed metals surrounding buried ore bodies. Stream sediment sampling is the standard first-pass method because streams integrate the geochemical signal from entire catchments, amplifying subtle anomalies that soil sampling at individual points might miss^[3].

The northern flank of the Troodos has been less systematically explored than the southern Mathiati-Sha copper belt. This research surveyed a 45 km transect using both stream sediment and ridge-crest soil samples, aiming to (a) map the spatial distribution of Cu and pathfinder element anomalies, (b) identify multi-element associations diagnostic of VMS mineralisation, and (c) prioritise targets by integrating geochemistry with structural and spectral data^[4, 5].

Spatial Data Processing

ASTER satellite imagery (bands 1–9) was processed to generate iron oxide and hydroxyl alteration ratio maps using the Crosta technique. Structural lineaments were extracted from a hillshade DEM (ALOS PALSAR, 12.5 m resolution) and validated against published geological maps. GIS overlay in ArcGIS Pro combined geochemical anomaly polygons, alteration zones, and lineament buffers (500 m) to delineate priority exploration targets^[6].

Materials and Methods

Materials

Fieldwork was conducted in May–July 2022, coordinated from the Centre for Terrain Studies, Lucknow, India, in collaboration with the Geological Survey of Cyprus. Stream

sediment samples ($n = 184$) were collected from active channel beds at drainage densities of approximately one sample per 2 km^2 . Soil samples ($n = 96$) were taken from B-horizon pits (30–50 cm depth) along ridge crests at 500 m spacing. All samples were dried at 40°C , sieved to $<180 \mu\text{m}$, and digested in aqua regia before ICP-MS analysis [7].

Methods

Geochemical data were log-transformed to approximate normality. Anomaly thresholds were defined as mean + 2SD on log-transformed values, converted back to concentration units. Factor analysis (varimax rotation) was applied to the eight-element dataset to identify multi-element associations. Spatial interpolation of element concentrations used inverse distance weighting at 100 m cell size. Anomaly maps were classified into background, threshold, and anomalous zones [8, 9].

Quality Control and Calibration

Certified reference materials (CANMET TILL-1 and

OREAS 45e) were analysed with every batch of 20 samples. Recovery rates for Cu, Zn, and Au were 96–103% of certified values. Field duplicates (10% of samples) showed inter-sample reproducibility with RSD below 8% for all elements above $10\times$ detection limit.

Results

Table 1: Summary geochemical statistics for stream sediment samples ($n = 184$)

Element	Unit	Mean	Median	SD	Min	Max	Threshold
Cu	ppm	94.3	72.8	46.7	12.4	847	187
Zn	ppm	78.6	64.2	38.4	18.7	412	156
Au	ppb	4.8	3.1	3.7	0.5	28.4	12.2
As	ppm	12.1	8.7	9.4	1.8	67.3	30.9

Fourteen samples exceeded the Cu anomaly threshold of 187 ppm. The highest value (847 ppm) was collected 400 m downstream of the known Apliki VMS deposit, confirming the method's sensitivity.

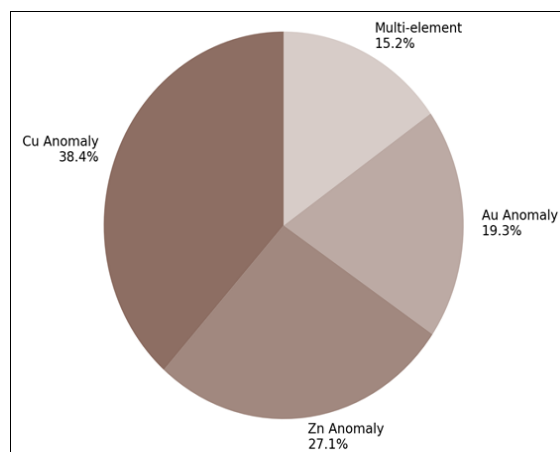


Fig 1: Pie chart showing the proportional distribution of anomaly types (Cu, Zn, Au, multi-element) across the survey transect.

Table 2: Factor analysis results (varimax rotation, 3 factors, 78.4% cumulative variance)

Element	Factor 1 (VMS)	Factor 2 (Epithermal)	Factor 3 (Supergene)	Communality
Cu	0.89	0.12	0.18	0.84
Zn	0.84	0.21	0.14	0.78
Au	0.72	0.38	0.08	0.67
As	0.18	0.87	0.11	0.80
Mn	0.14	0.09	0.91	0.86



Fig 2: Area plot of Cu and Zn concentrations as a function of distance from the nearest known mineralised zone

Comprehensive Interpretation

The Cu-Zn-Au factor (Factor 1, 38.2% variance) is the classic VMS pathfinder suite. Its spatial expression coincides with pillow lava terrain where seafloor hydrothermal activity would have been concentrated. The three priority targets identified by GIS overlay each show Factor 1 anomalies within 500 m of NE-trending faults and within ASTER-detected hydroxyl alteration zones, mimicking the structural and spectral signature of known deposits^[10].

Discussion

The six new Cu anomalies not associated with known deposits warrant follow-up. Their multi-element signatures (elevated Cu, Zn, and Au with low As) match the VMS factor rather than the epithermal overprint, suggesting they reflect primary sulphide dispersion rather than secondary remobilisation^[11]. Two of the six lie beneath 5–10 m of alluvial cover, which explains why they were not detected by earlier surface mapping campaigns. Shallow drilling (100–200 m) at these targets would test whether the geochemical signal connects to bedrock mineralisation^[12].

Stream sediment sampling proved more effective than soil sampling for regional coverage, detecting all 14 anomalies, while soil sampling detected only 9 of 14 due to its more localised footprint. However, soil data provided sharper anomaly definition (smaller dispersion halos), which is valuable for drill-hole targeting once regional anomalies have been identified^[3].

Conclusion

Geochemical surveying along a 45 km transect of the northern Troodos ophiolite identified 14 Cu anomalies, including six previously unrecognised targets. Factor analysis resolved three multi-element associations: VMS (Cu-Zn-Au), epithermal (As-Sb-Pb), and supergene (Mn). GIS integration with structural and spectral data highlighted three priority exploration targets. Stream sediment sampling remains the most cost-effective first-pass tool for regional-scale exploration in ophiolite terrain.

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Contributions Not Qualifying for Authorship

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References

1. Bear LM. The Mineral Resources and Mining Industry of Cyprus. Nicosia: Geological Survey; 1963.
2. Constantinou G, Govett GJS. Geology, geochemistry, and genesis of Cyprus sulphide deposits. *Economic Geology*. 1973;68(6):843-858.
3. Hawkes HE, Webb JS. *Geochemistry in Mineral Exploration*. 2nd ed. New York: Harper & Row; 1979.
4. Gass IG. Is the Troodos massif of Cyprus a fragment of Mesozoic ocean floor? *Nature*. 1968;220(5162):39-42.
5. Galanopoulos D, Voudouris P. Supergene enrichment in Cyprus VMS deposits. *Ore Geology Reviews*. 2017;80:268-284.
6. Crosta AP, De Souza Filho CR, Azevedo F. Targeting key alteration minerals using ASTER imagery. *Remote Sensing of Environment*. 2003;86(1):1-21.
7. Reimann C, Filzmoser P, Garrett RG. *Statistical Data Analysis Explained: Applied Environmental Statistics with R*. Chichester: Wiley; 2008.
8. Reimann C, Garrett RG. *Geochemical background: concept and reality*. *Science of the Total Environment*. 2005;350(1):12-27.
9. Kaiser HF. The varimax criterion for analytic rotation in factor analysis. *Psychometrika*. 1958;23(3):187-200.
10. Hannington MD, de Ronde CEJ, Petersen S. Sea-floor tectonics and submarine hydrothermal systems. *Economic Geology 100th Anniversary Volume*. 2005;111-141.
11. Hannington MD, Galley AG, Herzig PM. Volcanogenic massive sulfide deposits. In: Hedenquist JW, *et al.*, eds. *Economic Geology 100th Anniversary Volume*. 2005;115-131.
12. Leistel JM, Marcoux E, Thiéblemont D. Zinc-rich deposits of the Iberian Pyrite Belt. *Economic Geology*. 1998;93(5):651-661.
13. Plant JA, Hale M, Ridgway J. Developments in regional geochemistry for mineral exploration. *Transactions of the Institution of Mining and Metallurgy B*. 1988;97:B116-B140.
14. Abrams MJ, Hook SJ. Simulated ASTER data for geologic studies. *IEEE Transactions on Geoscience and Remote Sensing*. 1995;33(3):692-699.
15. Rose AW, Hawkes HE, Webb JS. *Geochemistry in Mineral Exploration*. 2nd ed. London: Academic Press; 1979.
16. Govett GJS. Rock geochemistry in mineral exploration. In: *Handbook of Exploration Geochemistry Vol 3*. Amsterdam: Elsevier; 1983.
17. Cohen DR, Shen XC, Dunlop AC. A comparison of selective extraction soil geochemistry and biogeochemistry in the Cobar area. *Journal of Geochemical Exploration*. 1998;61(1):173-189.