DATA-DRIVEN DELINEATION OF GEOMETALLURGICAL DOMAINS IN PORPHYRY COPPER SYSTEMS

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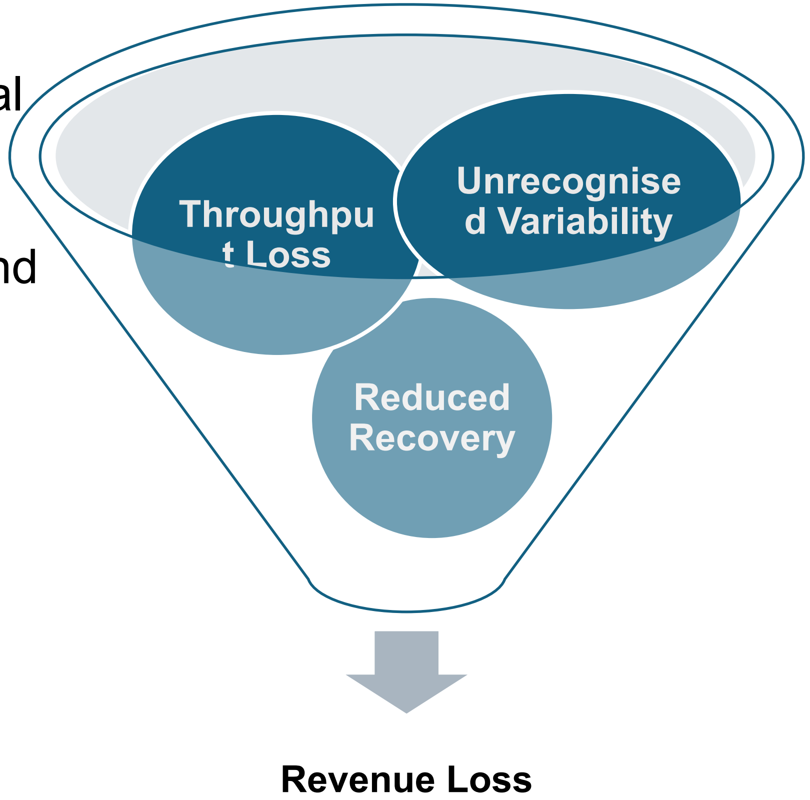
Introduction

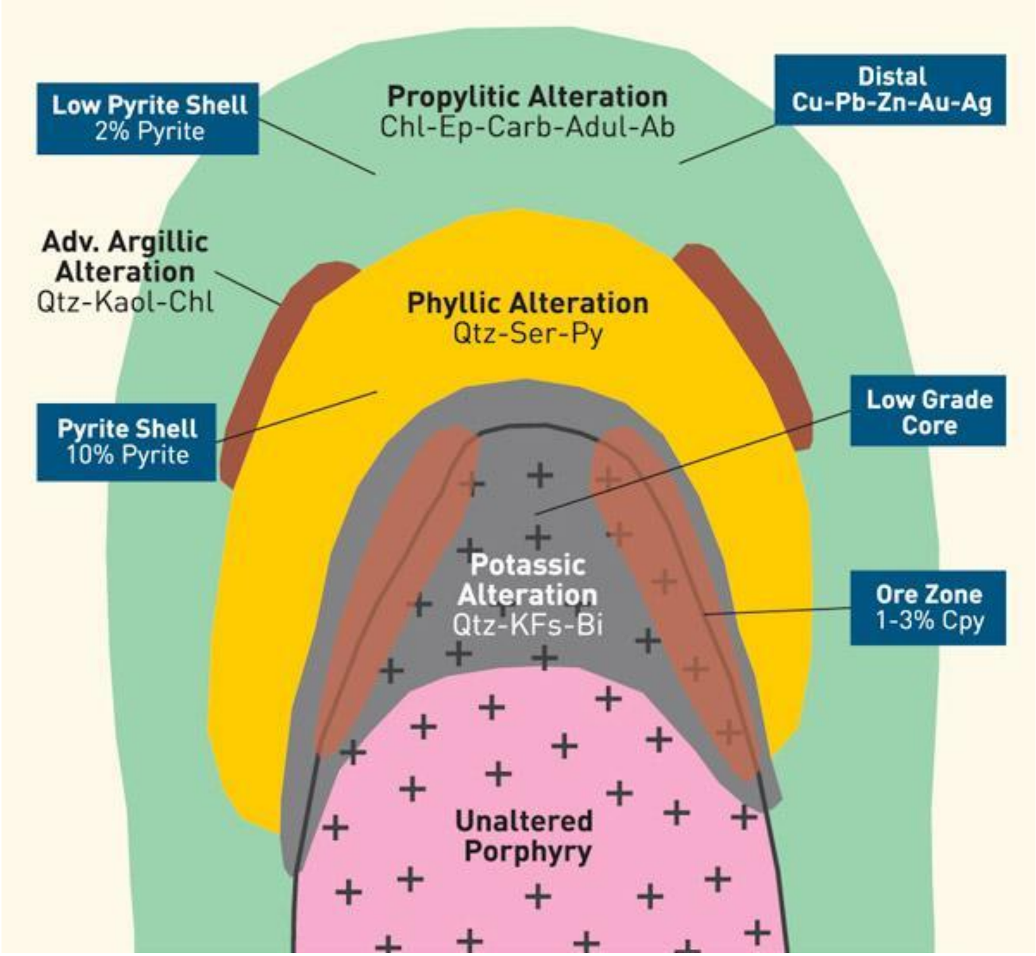
- Partitioning the orebody into geospatially coherent domains is important to ensure processing stays predictable from blast-hole to final concentrate.
- Domains are often assigned based on lithology or alteration, with the assumption they'll behave uniformly in the plant.
- However, geology-only domains don't always align with metallurgical performance.
- Blending rocks with different grindability can raise mill energy demand and lower recovery.
- Unsupervised machine learning techniques are increasingly used to expose these hidden patterns in assay and metallurgical test data.



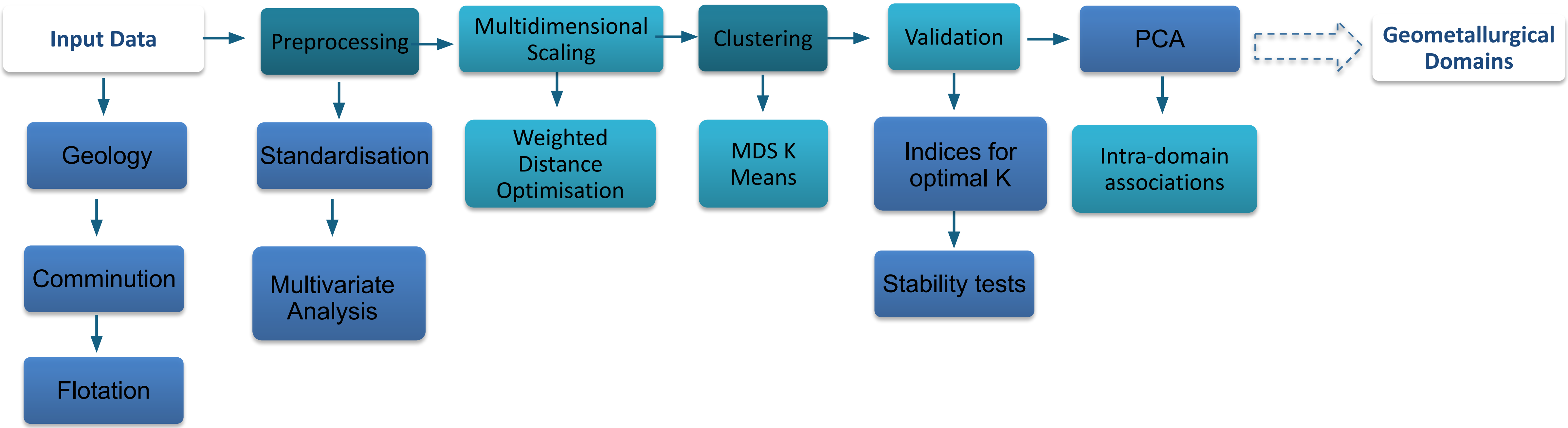
Introduction

This study applies an adaptive weighting and clustering approach to a porphyry copper dataset

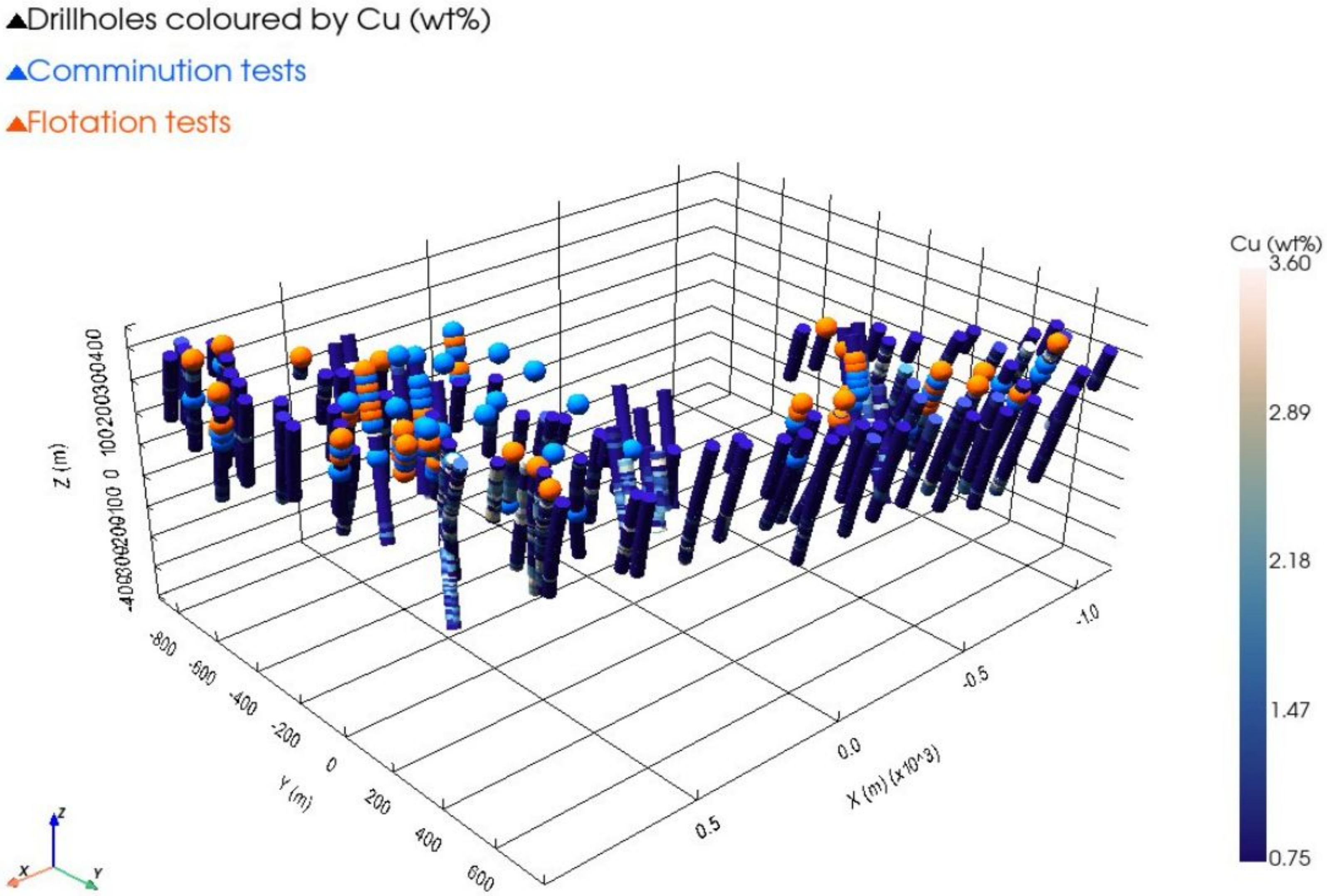
- Standard Porphyry Cu systems show concentric alteration and grade shells formed by hydrothermal fluids.
- Characterised by potassic core, surrounded by a phyllic shell, argillic caps and a broad propylitic halo.
- Grade shells are typical low in the potassic, with a subsequent high grade ore zone, and progressively lower grades outwards.



Workflow Overview



Database Overview



Subset	Samples	Added variables
Full	2000	18 element assays
Comminution	60	BWI, DWT, M, A, F80, P80, Graphitic C
Flotation	53	Fr, Xr, LCT

- BWI – Bond Work Index
- DWT - Drop Weight Test
- M – mobility index
- A – size of the screen used
- F80 and P80 – apertures for which 80% of the material in the feed and product passes through

- Fr –fraction of the initial sample mass recovered
- Xr – metal grade after 1st recovery
- LCT – Locked Cycle Test

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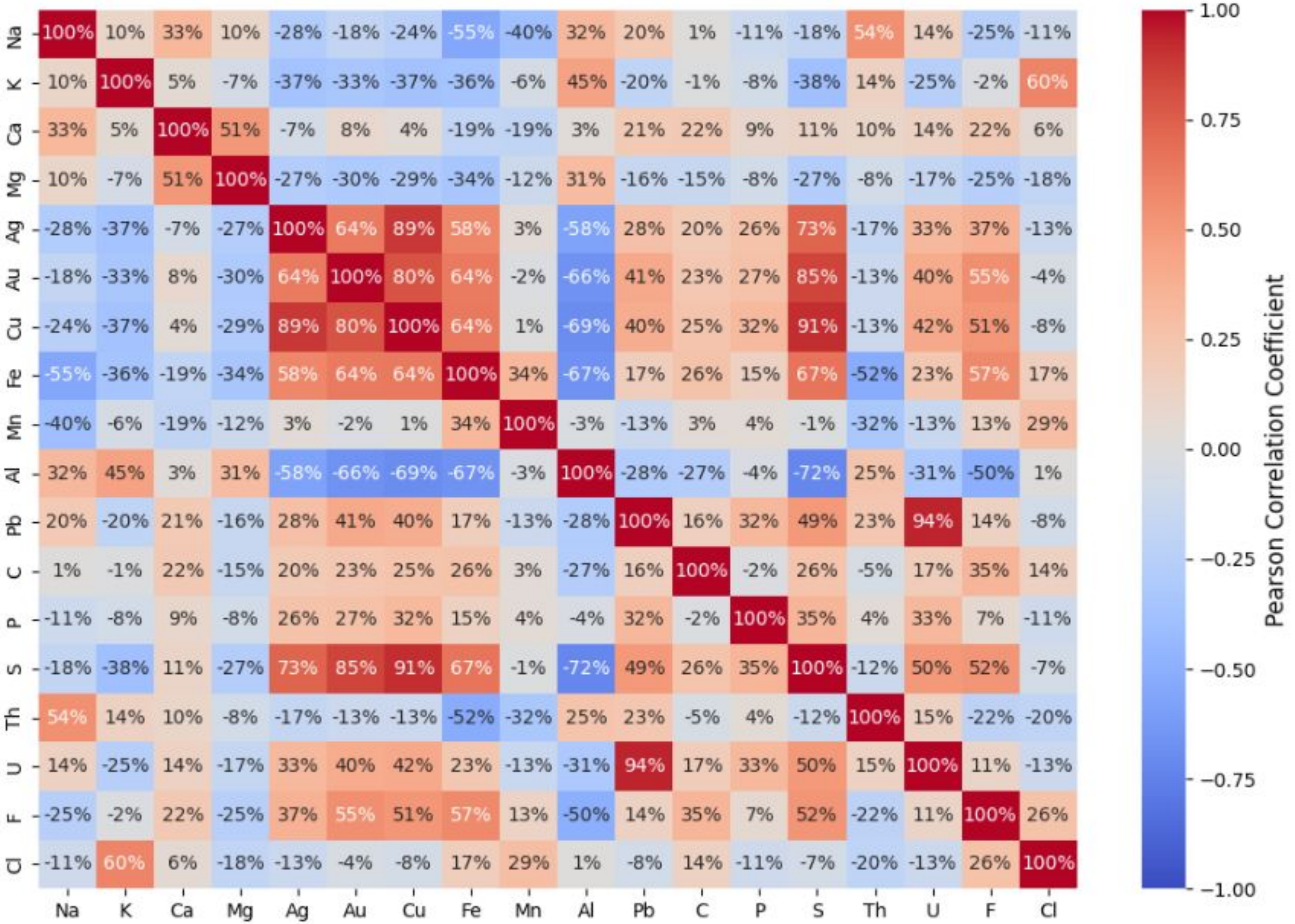
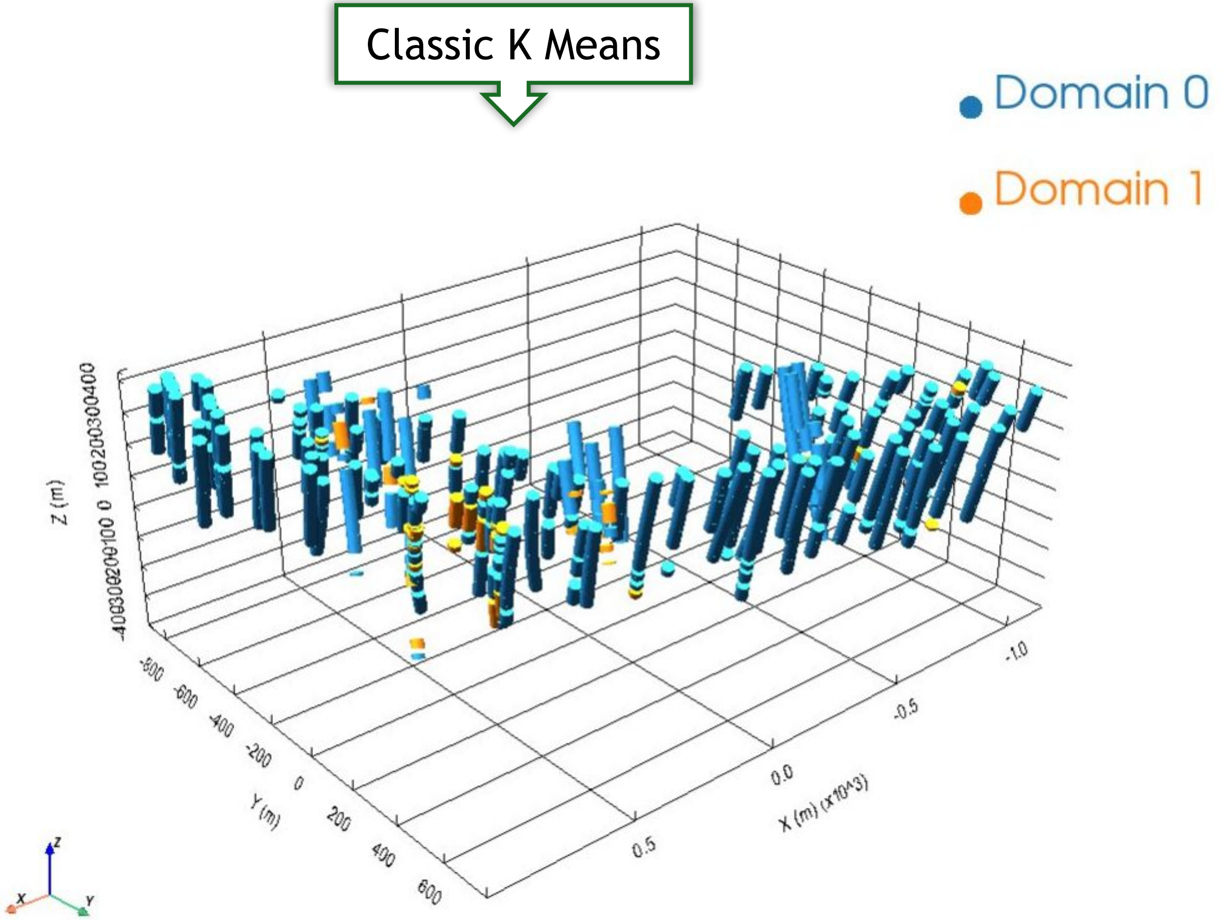
Multivariate Analysis

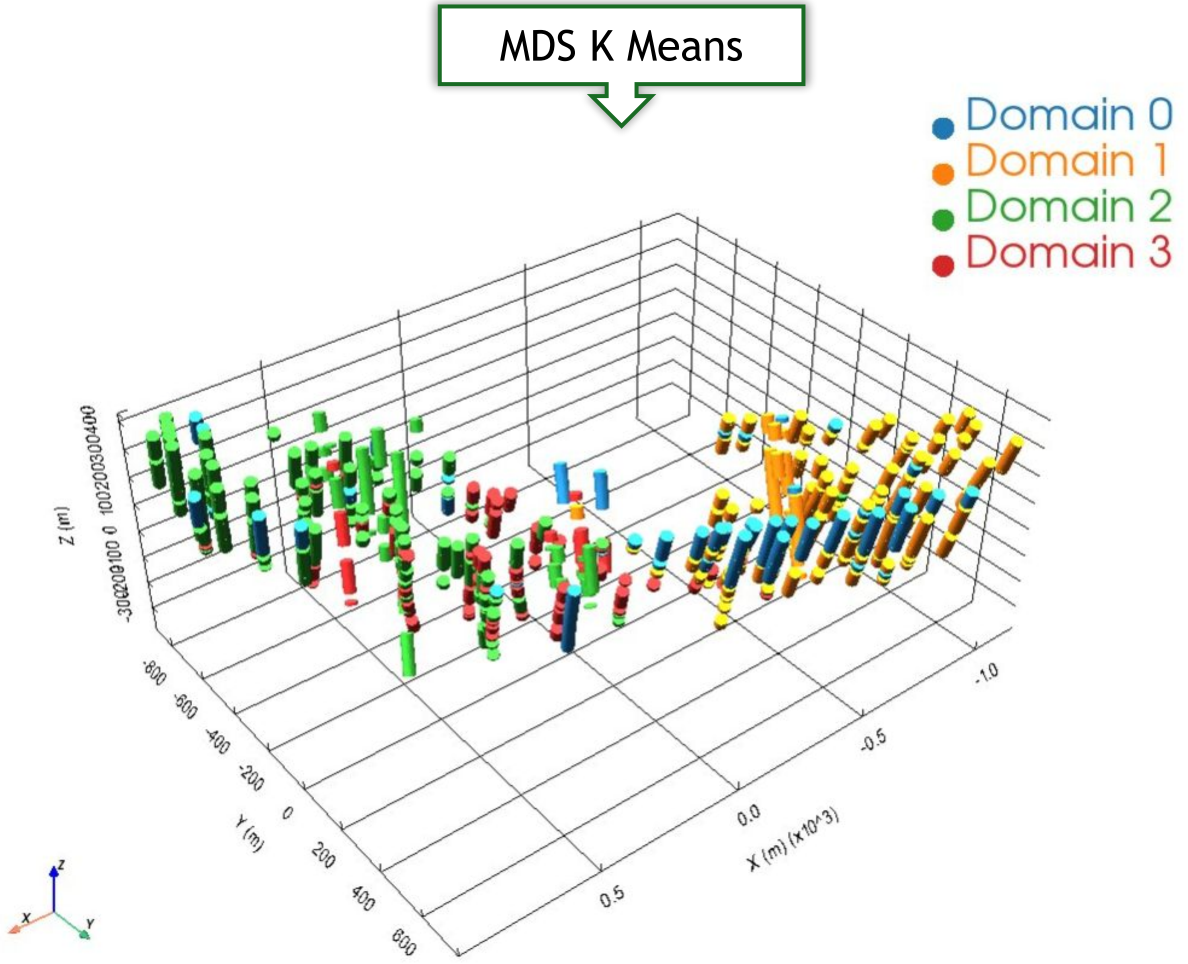
Geology is foundational for all downstream processes.

- Clear sulfide/ore suite with Cu-Fe-S positively correlated, along with Au-Ag
- Na-Ca-Mg positively correlated
- Potassic K effects trend negatively with Na
- C shows mixed correlations



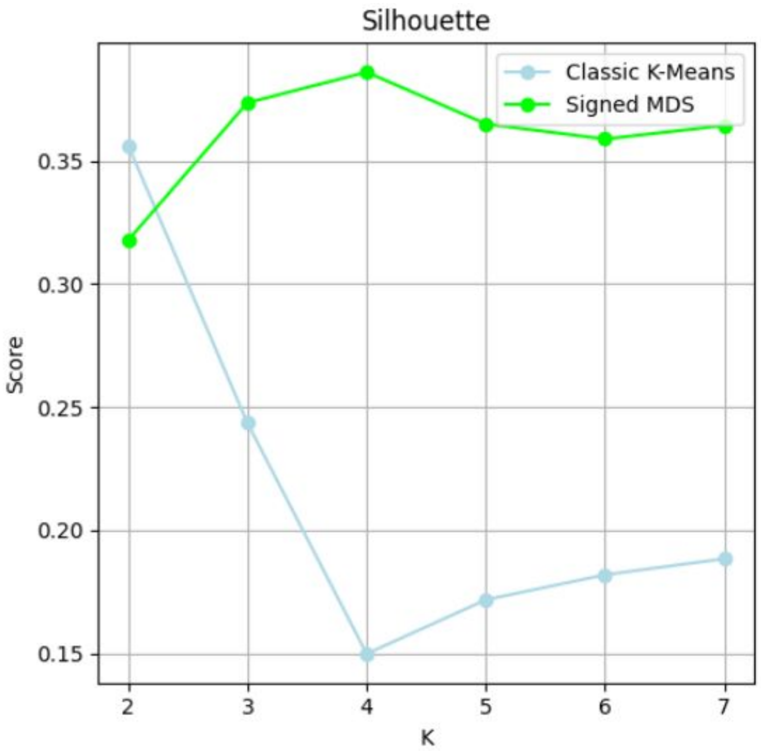
Geological Domains

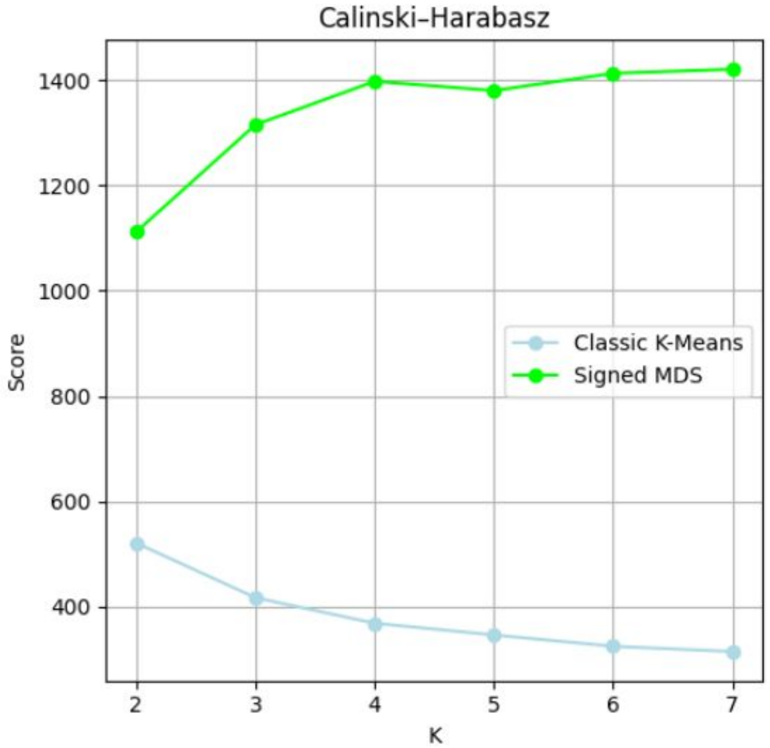


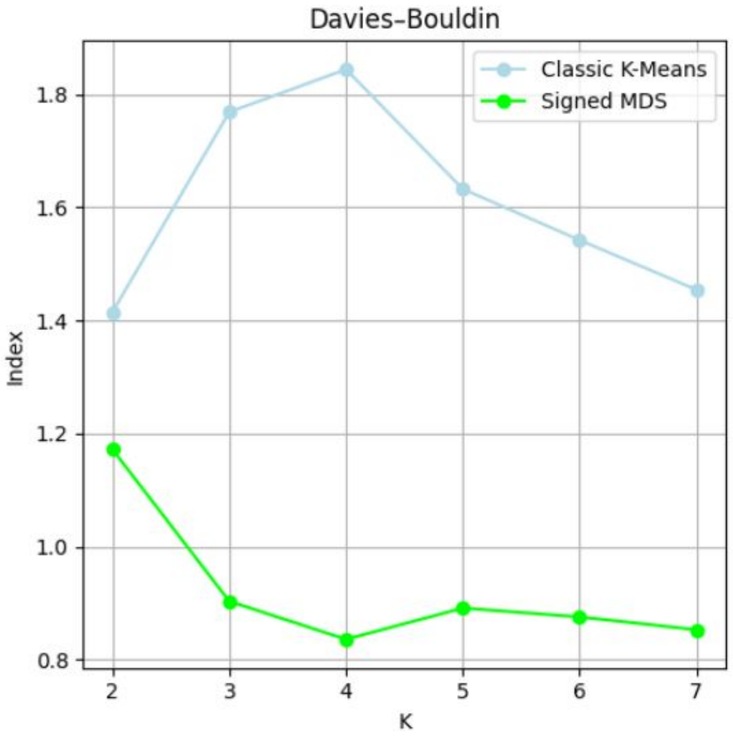


- Traditional ML algorithms are not always sufficient for geospatial datasets
- Classic K Means merges ore and waste halos
- Clustering in MDS embedded space preserves spatial distances and optimised weights to delineate geologically meaningful domains

Cluster Validity



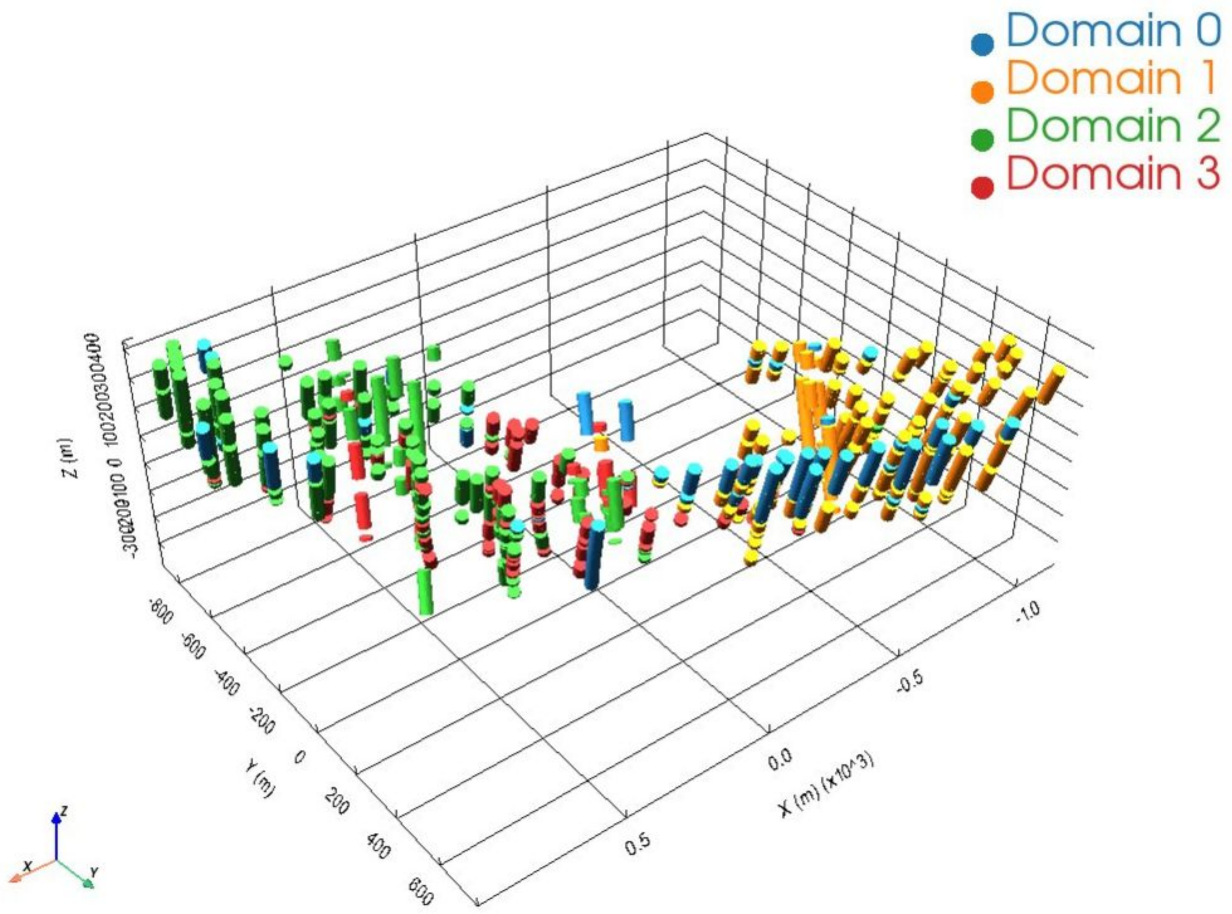


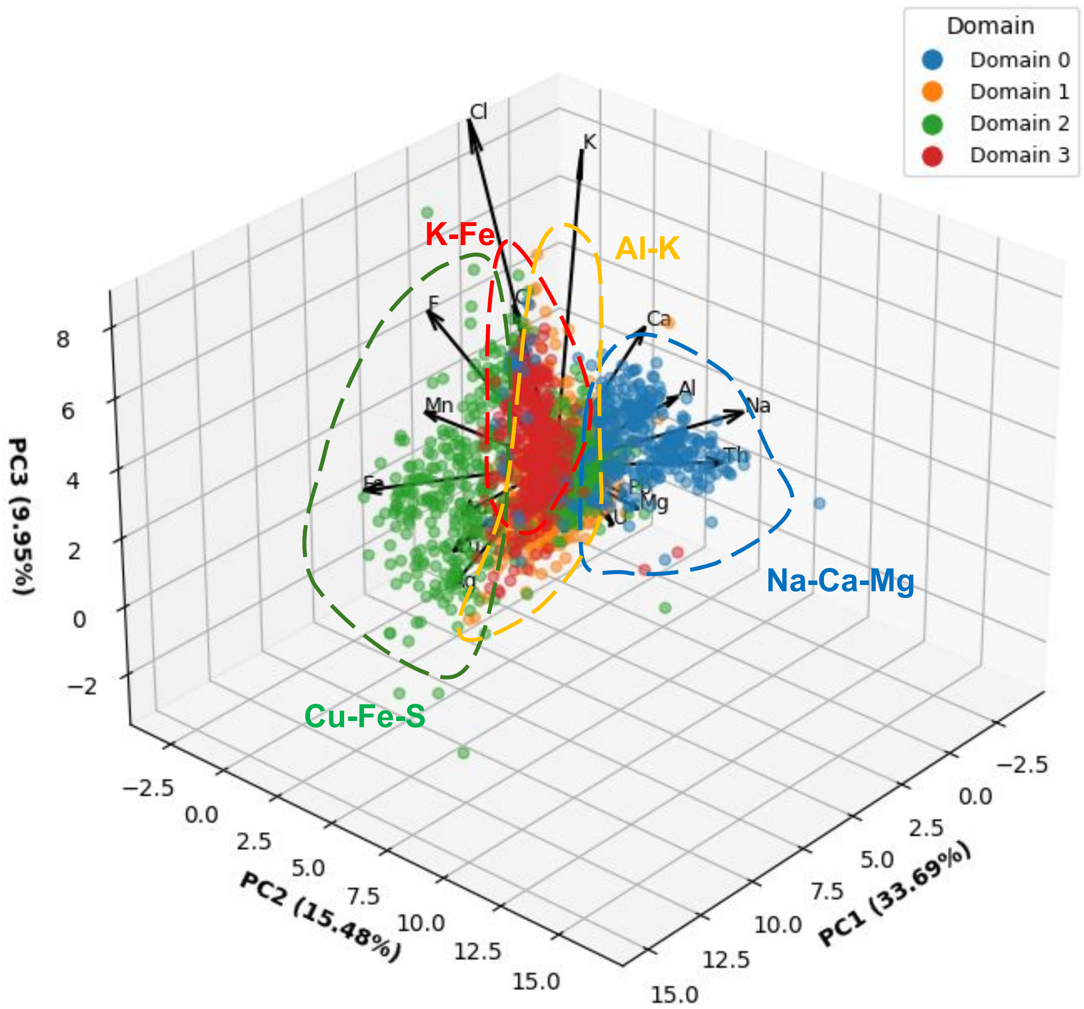


Validity indices measure how well samples are separated from neighbouring clusters.

- MDS K means curve points to K = 4 across all three indices.
- Silhouette and Calinski-Harabasz peak at K = 4,
- Davies-Bouldin reaches its minimum around K = 4
- The four clusters were stable with < 5% reassignment on reseed

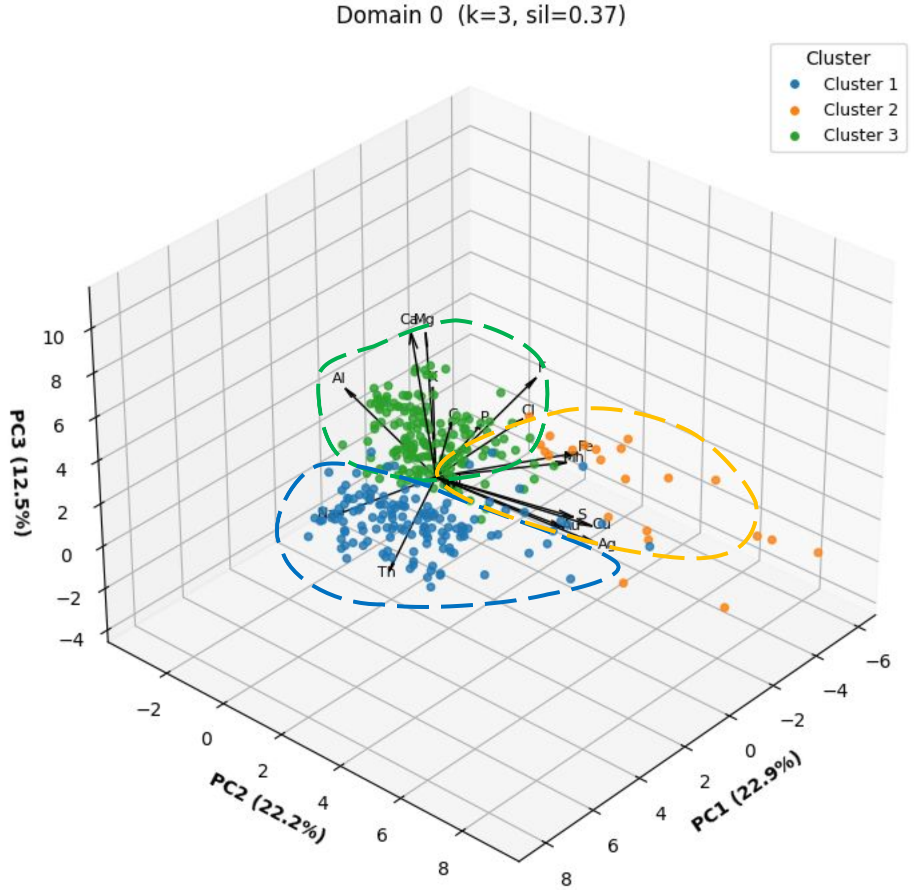
Geological Domains

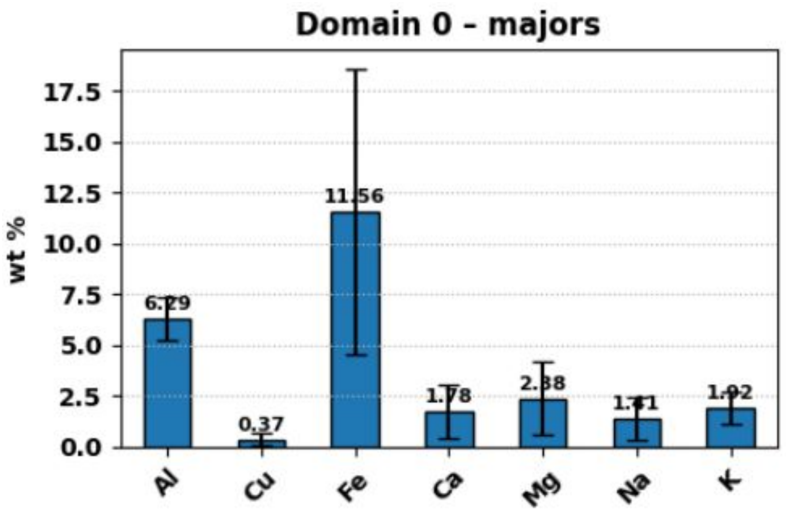


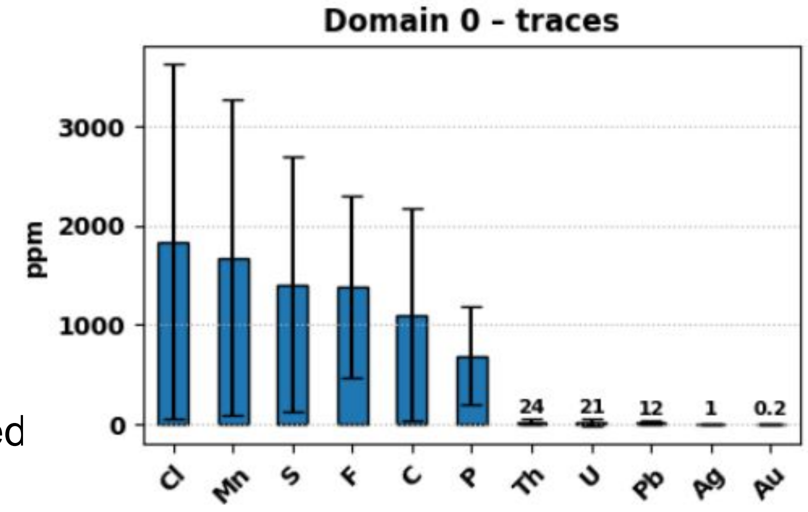


- MDS clusters reveal four primary geological domains based on geochemical analysis
- Principal Component Analysis analysed global and intra-domain geochemical signatures

Geological Domain Classification



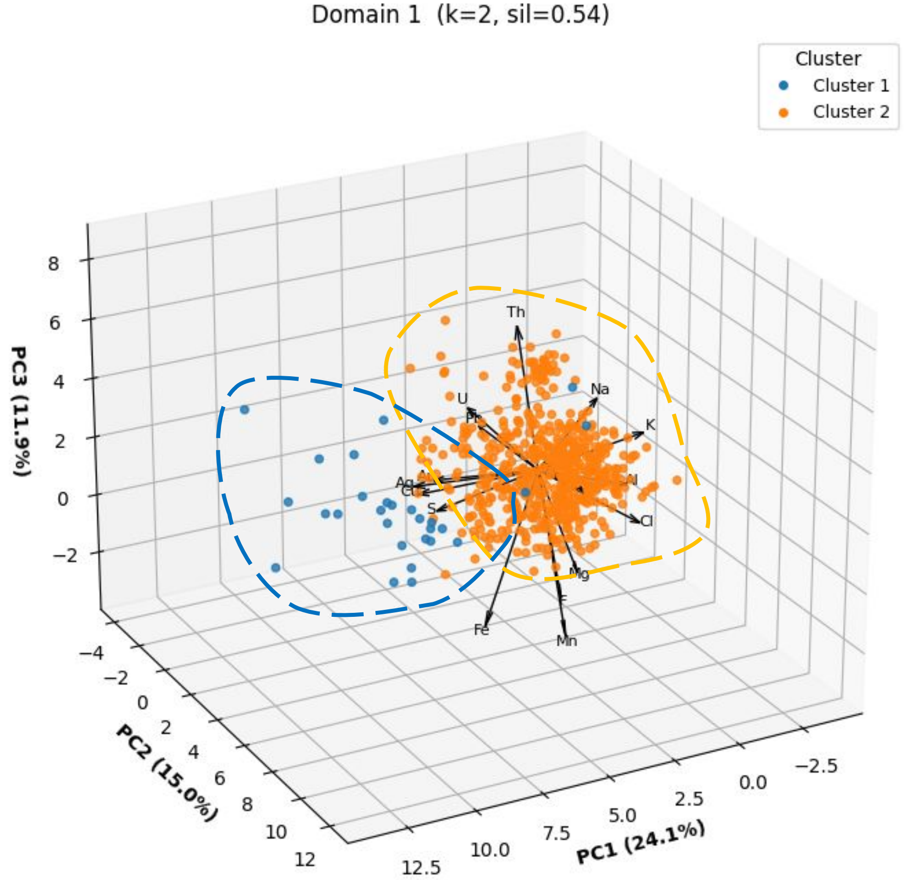


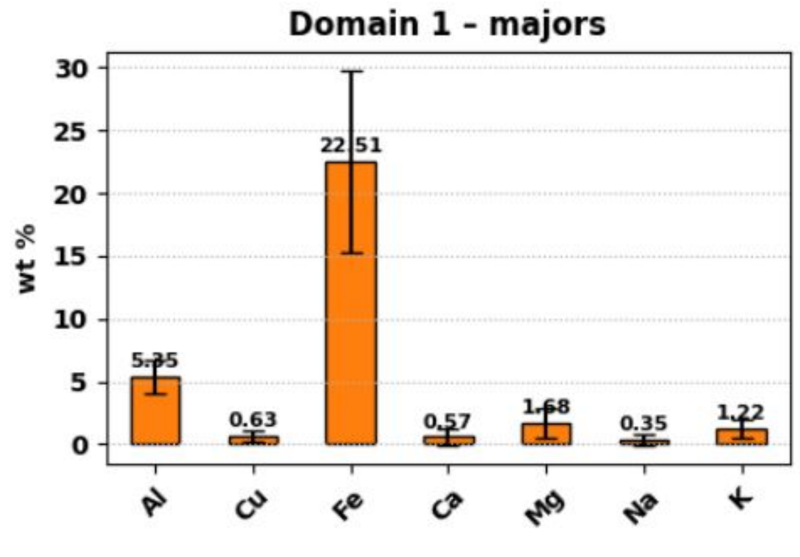


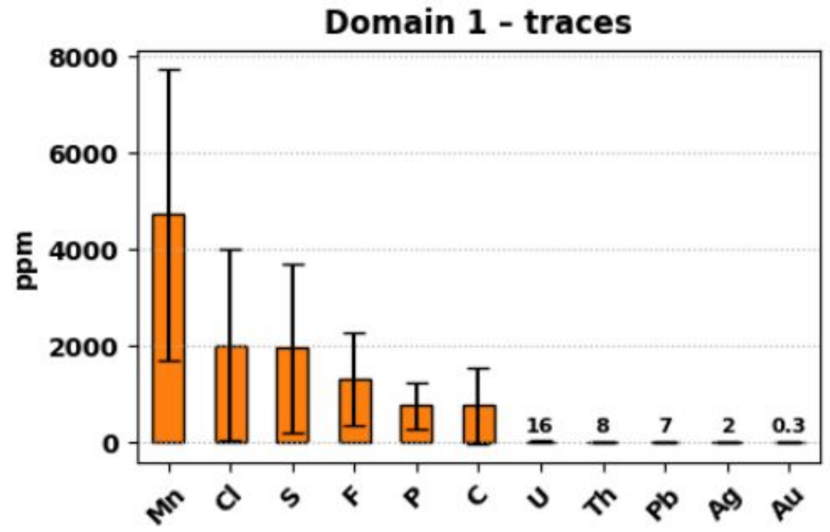
- Enriched in Ca, Na, and Mg, with moderate Fe comparatively low Cu (0.4 wt%), S (0.14 wt%) and Au-Ag
- Points to intact plagioclase and epidote-chlorite alteration
- Elevated Cl and Mn and higher Th-U, are typical of less intensely altered host rock

Facies Classification: **Propylitic zone**

Geological Domain Classification



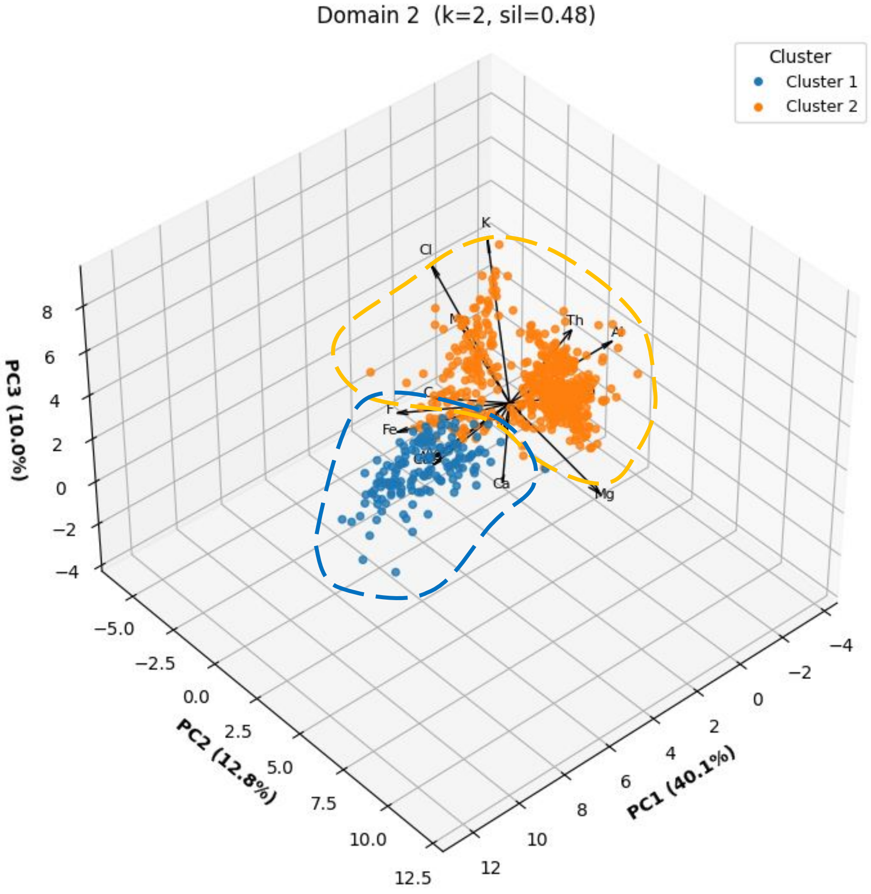


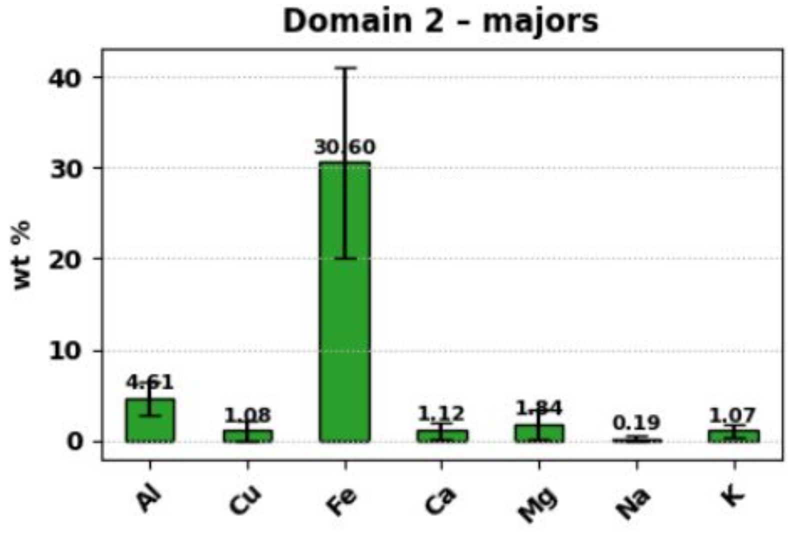


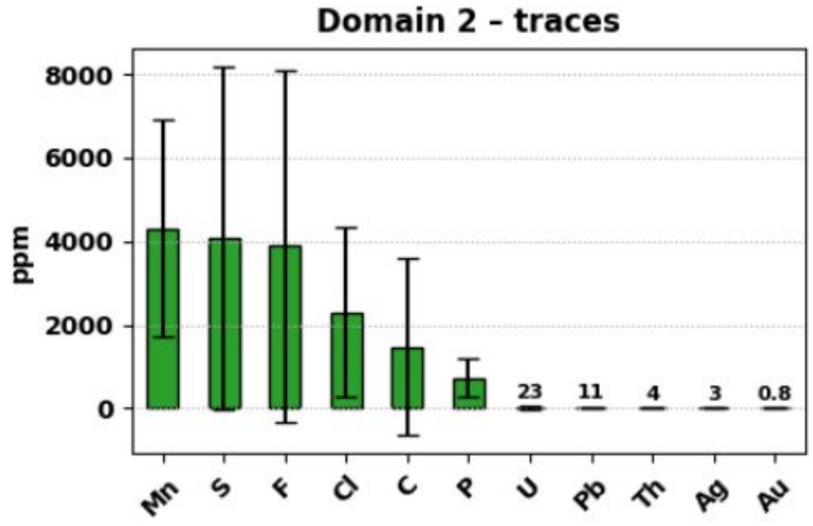
- PCA splits into two variants a clay-sericite-rich cluster and a more mineralised transition cluster trending toward the Cu-Fe-S vectors
- Al is high (~5 wt%), Fe ~22 wt%, Cu ~0.6 wt%, S ~0.20 wt %
- Ca-Na depleted and K moderate (~1.2 wt%) - consistent with plagioclase destruction and sericite/clay addition.

Facies Classification: **Argillic to early phyllic transition zone**

Geological Domain Classification



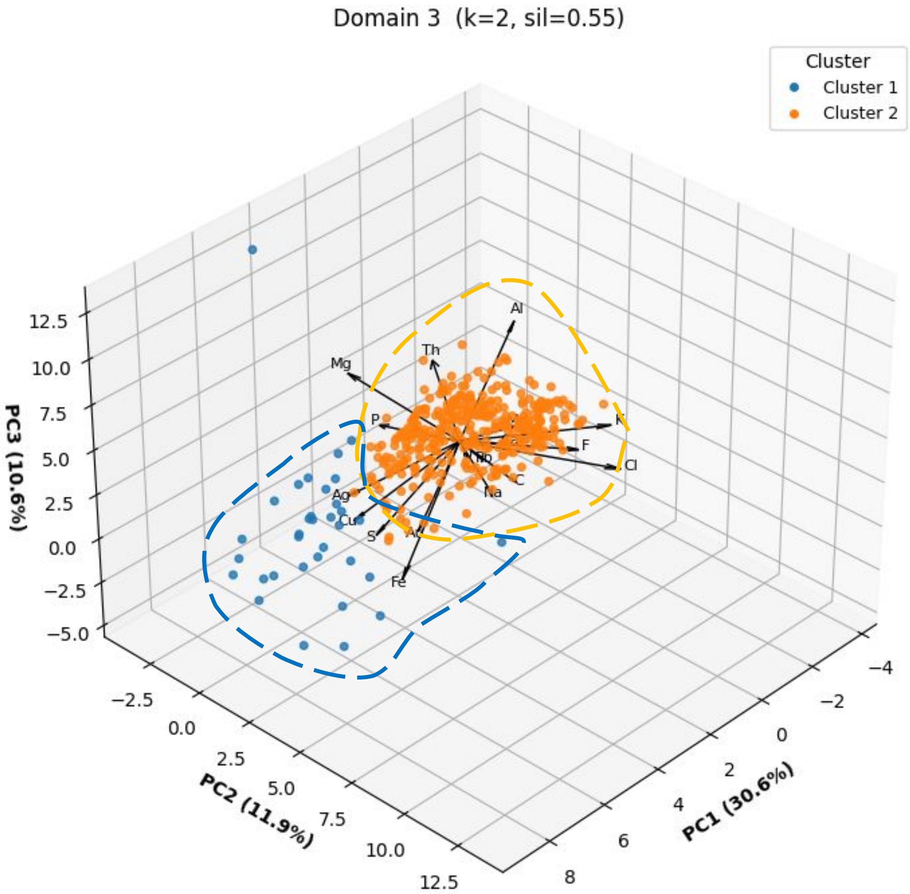


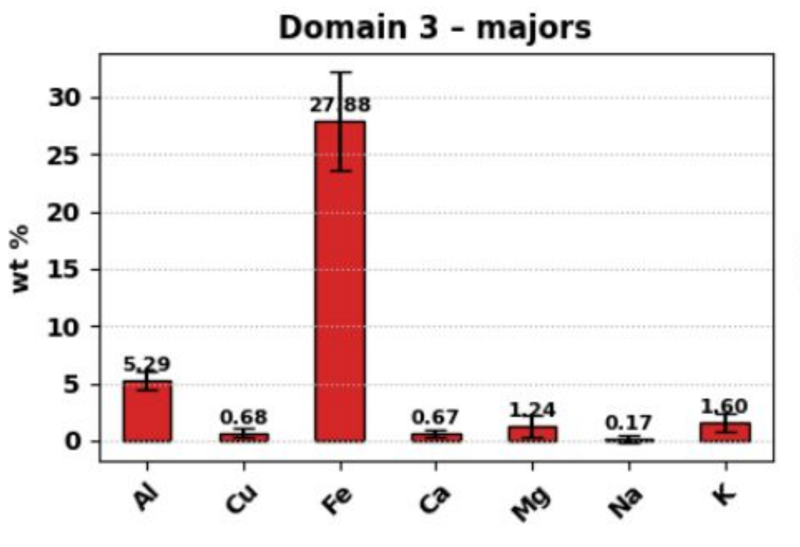


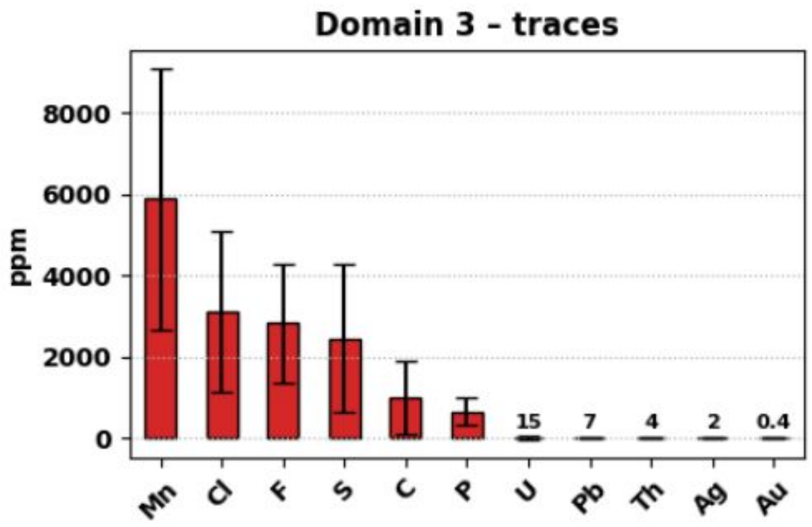
- Highest Cu (1.1 wt%) , S (0.41 wt%) and Au-Ag content, indicating abundant chalcopyrite and pyrite.
- Depletion in K and Ca-Na consistent with intense sericitic replacement of feldspars
- Geochemically well defined high-sulfide signature.

Facies Classification: **Phyllic zone** (high sulfide ore zone)

Geological Domain Classification



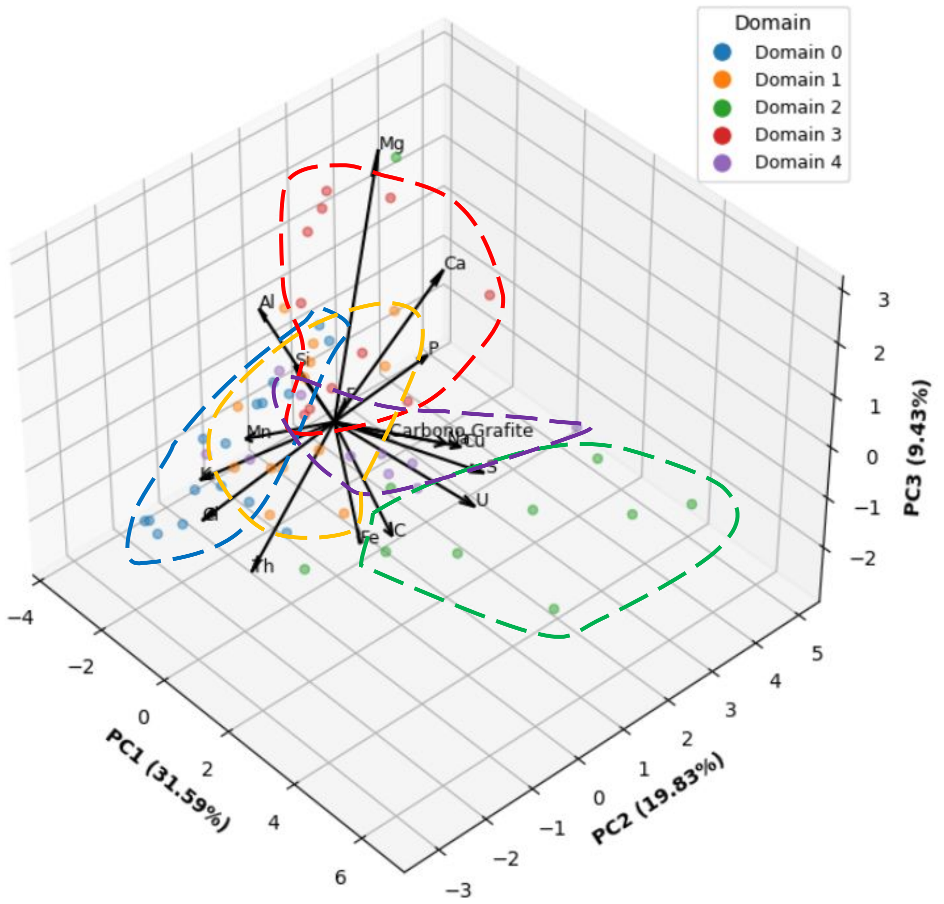


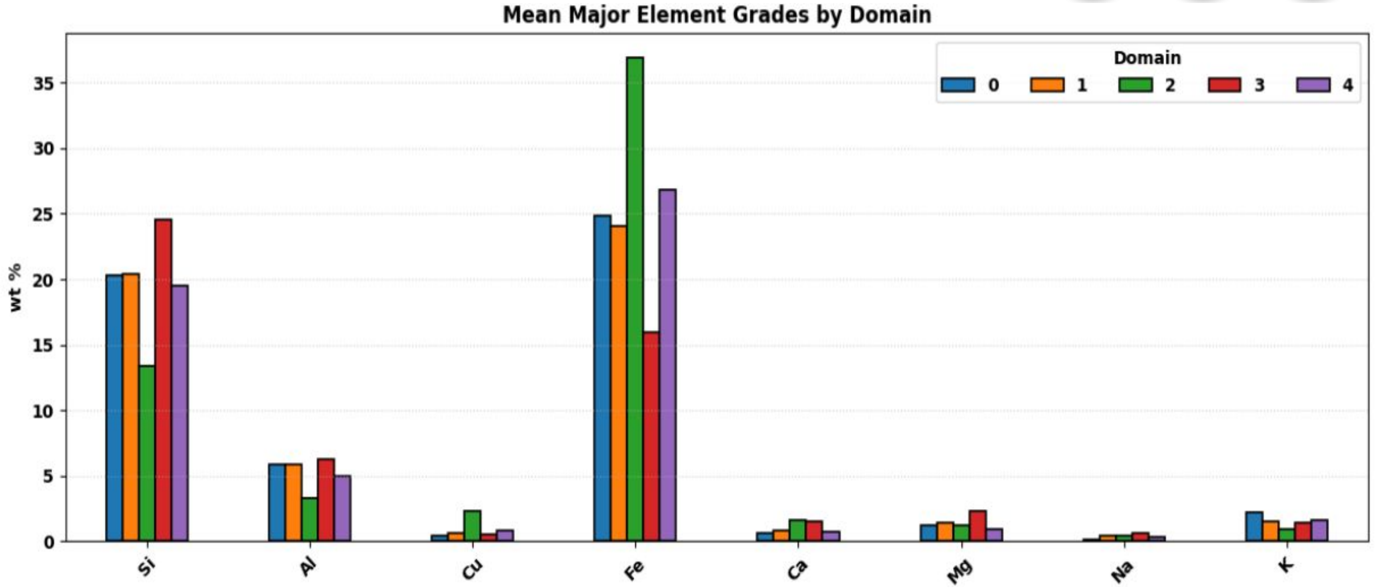


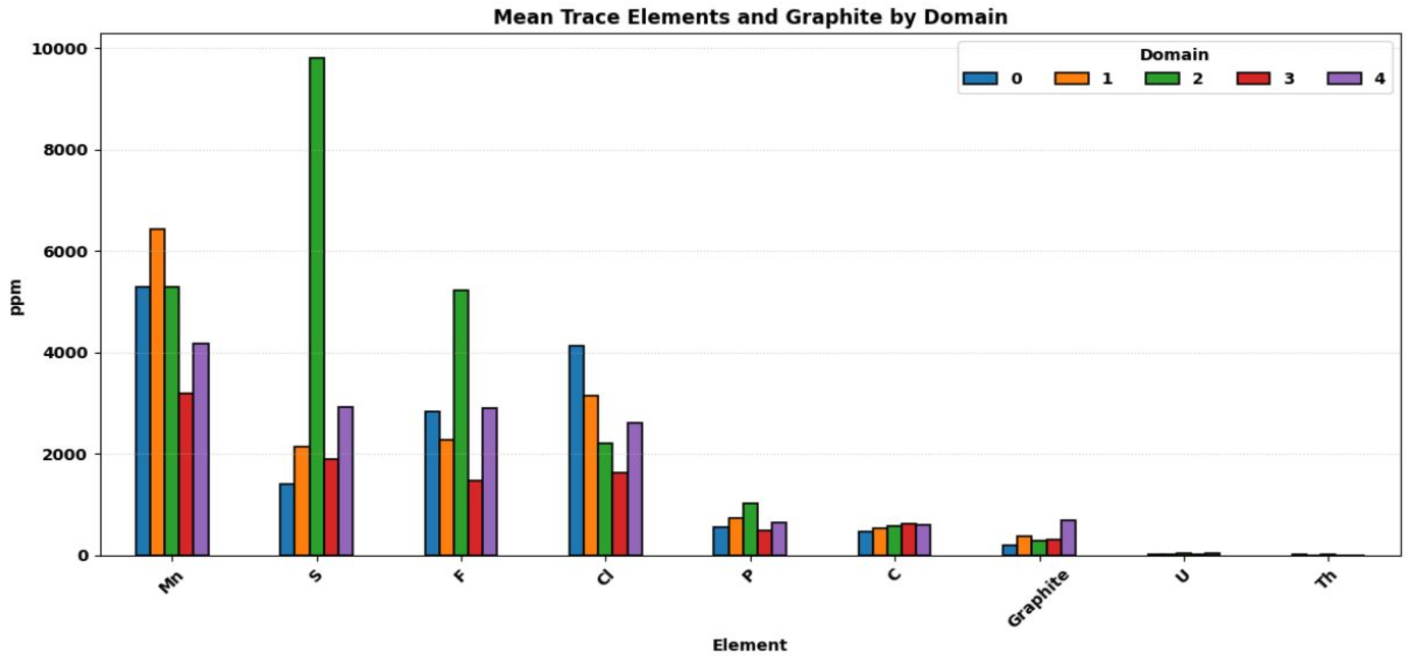
- Elevated K (~1.6 wt%), with moderate Cu (~0.68 wt%) and Fe (~28 wt%).
- Intra-domain: Inner potassic subgroup loading with K-Fe (biotite/magnetite rich) and transitional subgroup trending toward Cu-S and slight Pb-Au.

Facies Classification: **Potassic zone**

Comminution Samples

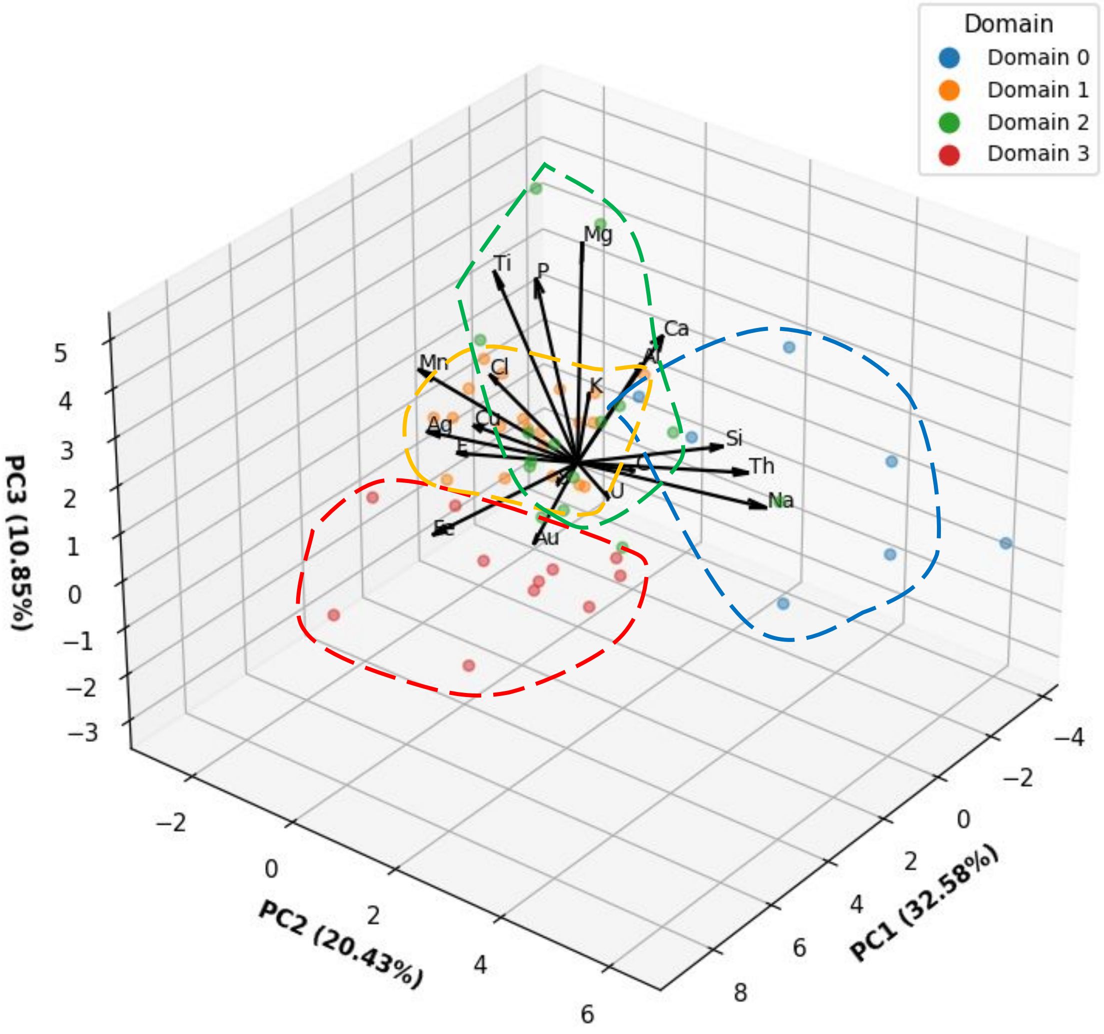






- Added graphitic lens
- Comprising highest graphite C at 688 ppm, Cu 0.8%, S 0.3%, Fe 27% - distinct carbonaceous inclusion

Flotation Samples

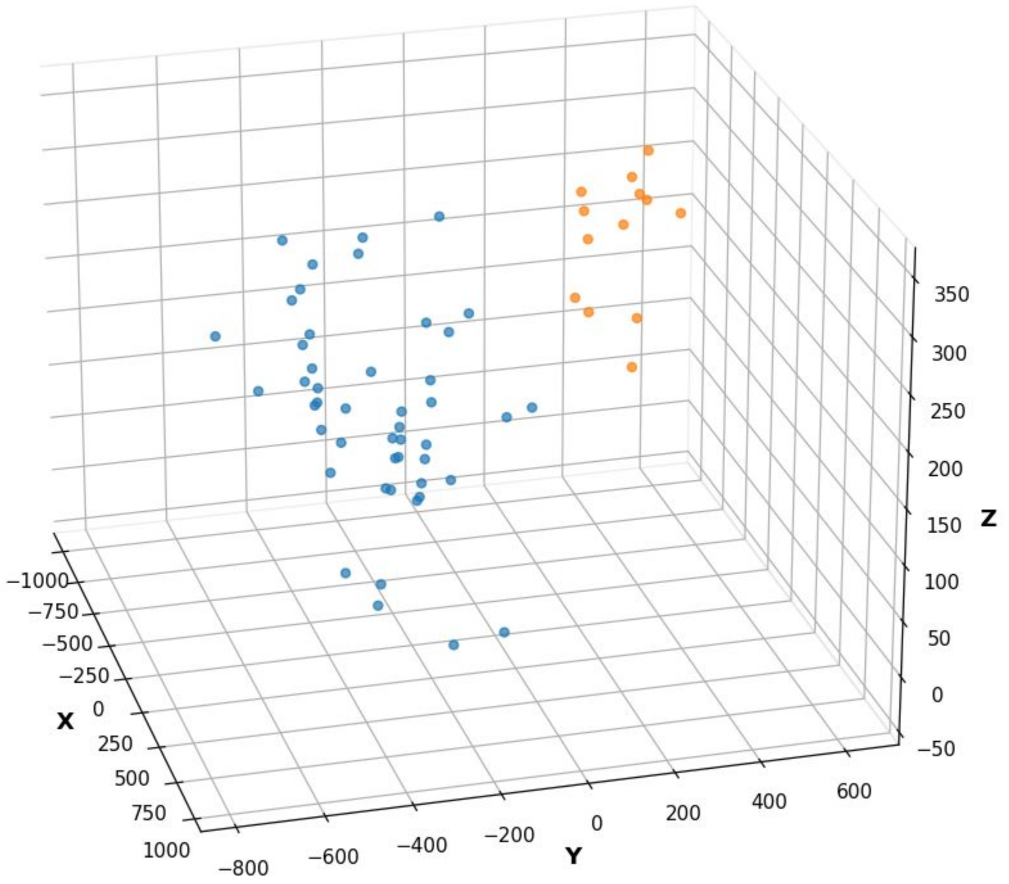


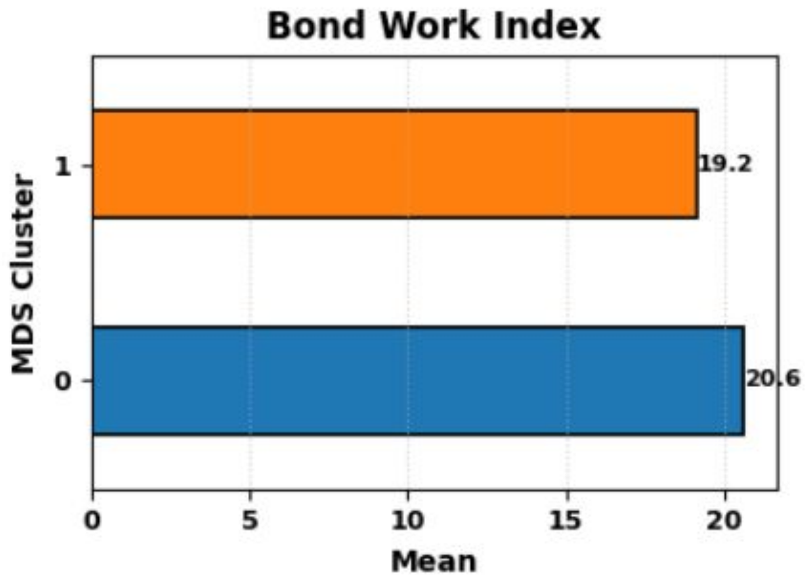
Final Facies Classification:

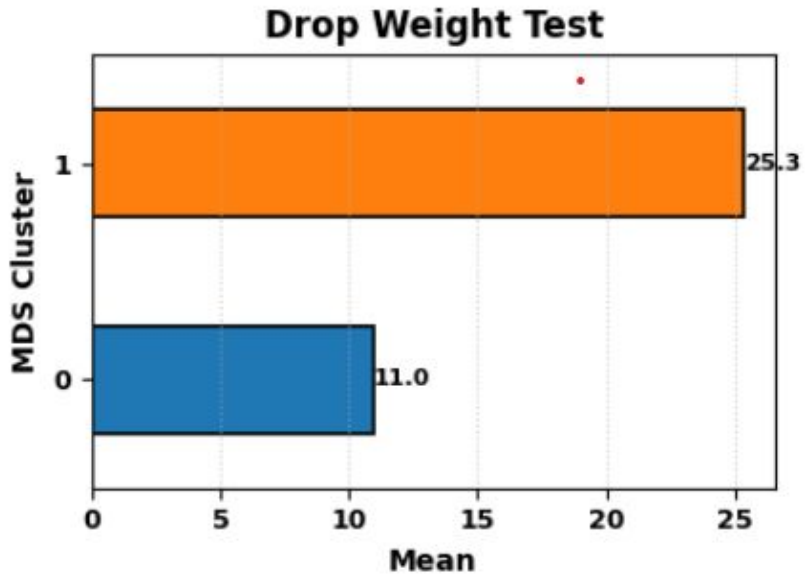
Domain	Facies	Cu %	Key Minerals
0	Propylitic	0.3	Chl + Ep + Carb
1	Argillic-Phyllic	0.6	Ser + Kaol
2	Phyllic	1.1	Qz-Ser-Py
3	Potassic	0.7	Kfs-Bt
4	Graphitic	0.8	C-rich lens

- Natural carbon reports to the sulphide concentrate and lowers Cu grade

Comminution Domains





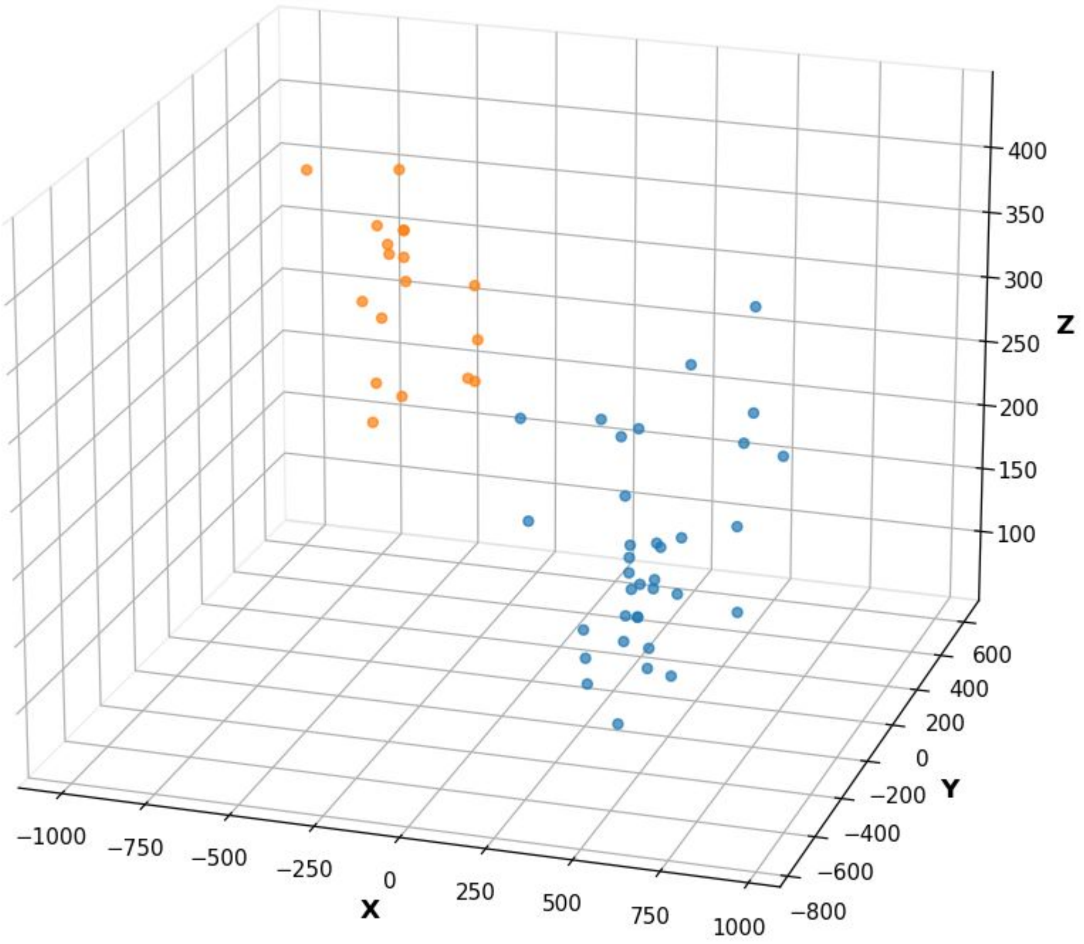


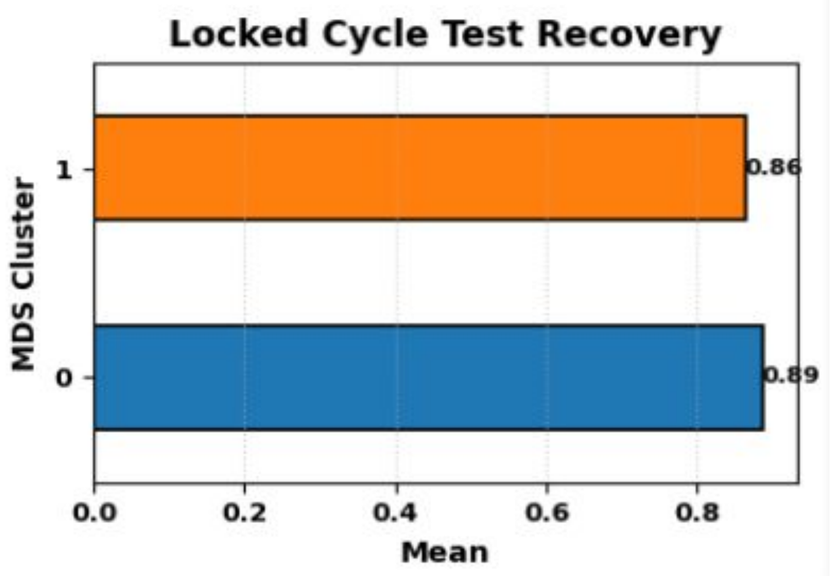
- MDS analysis defined two clusters separated by ~1.5 kWh/t BWI

0: Competent, hard to grind and resists breakage, typical of propylitic, potassic and argillic rocks

1: Softer, easier to break rocks from phyllic and graphitic material

Flotation Domains





- Flotation domains split similarly, with a ~2.4 % Cu recovery difference

0: Averages 88.7% recovery, fr ≈ 24.3%, and Cu x_r ≈ 4.0% cleaner, higher-grade concentrate after first recovery

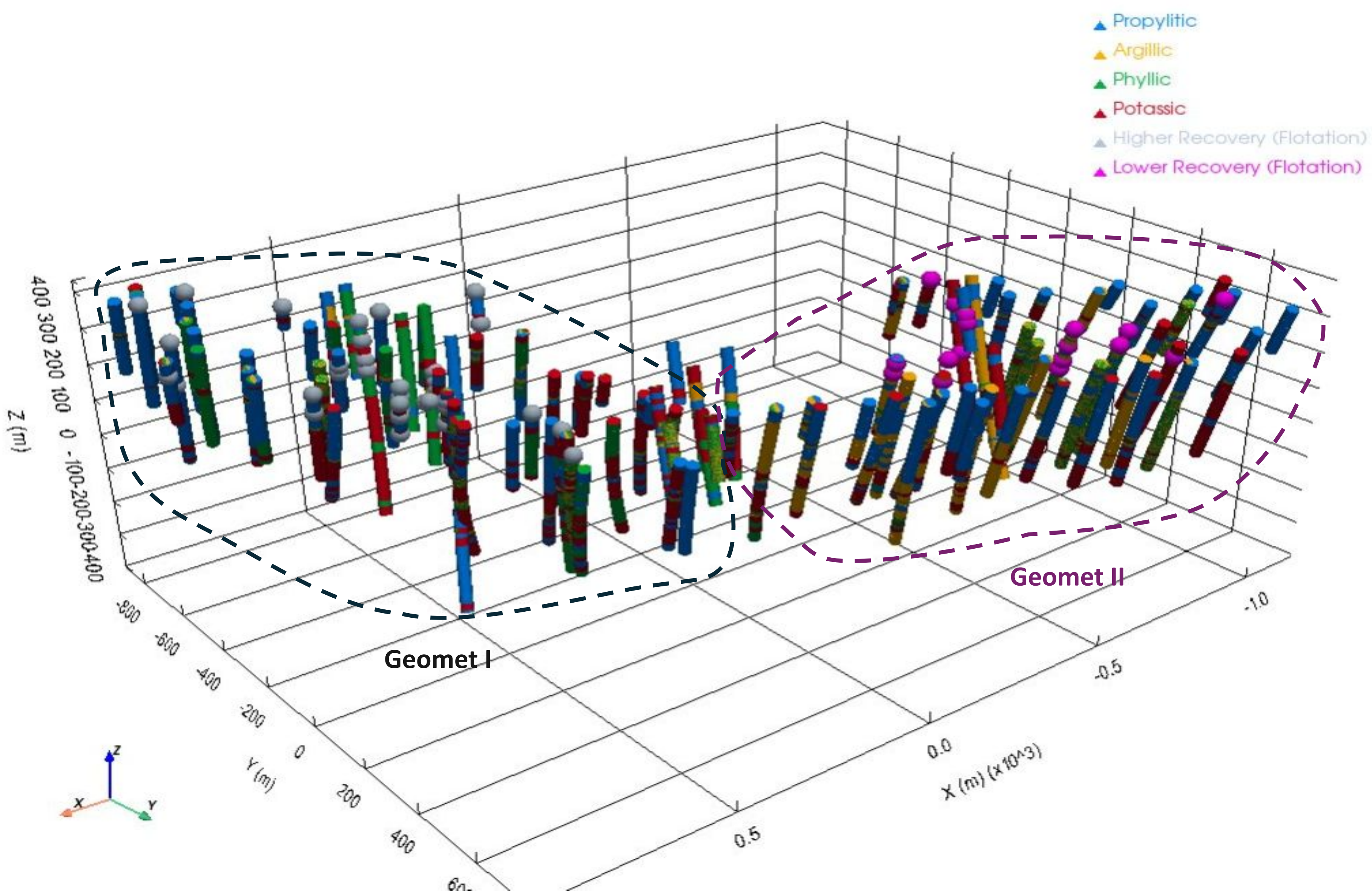
1: Averages 86.3% recovery, fr ≈ 25.7%, and Cu x_r ≈ 3.0% slightly higher rougher pull but lower final recovery and grade, consistent with clay, graphite influence

Geometallurgical domains

Geomet Domain	Geological Domain	Facies	Cu tenor / Sulfides	Net Processing Behaviour
I – hard / high recovery	Argillic-Phyllic	Sericite-clay halo	Moderate Cu, moderate S	Breakage similar to propylitic rock, acceptable Cu recovery
	Potassic	K-silicate inner core	Moderate Cu, high Fe	Hard rock, reliable Cu recovery; useful for blending
	Propylitic	Outer halo / leached cap	Very low Cu, low S	Harder to break; Cu grades too low to influence plant performance
II – soft / low recovery	Graphitic Inclusion	Carbonaceous lens	Moderate Cu, graphite C	Very soft; carbon can dilute concentrate – best managed separately
	Phyllic	High-sulfide core	Highest Cu and S	Breaks easily but loses copper during cleaning; needs closer monitoring

- Two distinct geometallurgical domains.
- Softer samples demand less specific energy but lose ~2% Cu to cleaning.
- Even moderate shifts in hardness (1.5 kWh t^{-1}) or recovery carry substantial economic consequences.
- Blending soft and hard feeds can therefore balance throughput and sustain Cu output.

Geometallurgical Domains



Takeaways

- Using spatially aware algorithms ensures clusters remain geologically meaningful.
- Analysing multiple data scales together adds context and exposes hidden patterns.
- The integrated domains explain both geological zonation and processing behaviour, providing a direct link between rock type and metallurgical response.
- Accurate domain definition forms the foundation for reliable resource estimation, plant forecasting and metal reconciliation.

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