CONVENTION QMEA XPLOR

Application of Powder X-Ray Diffraction to Determining Ore Hardness

Presented by Craig R. McClung

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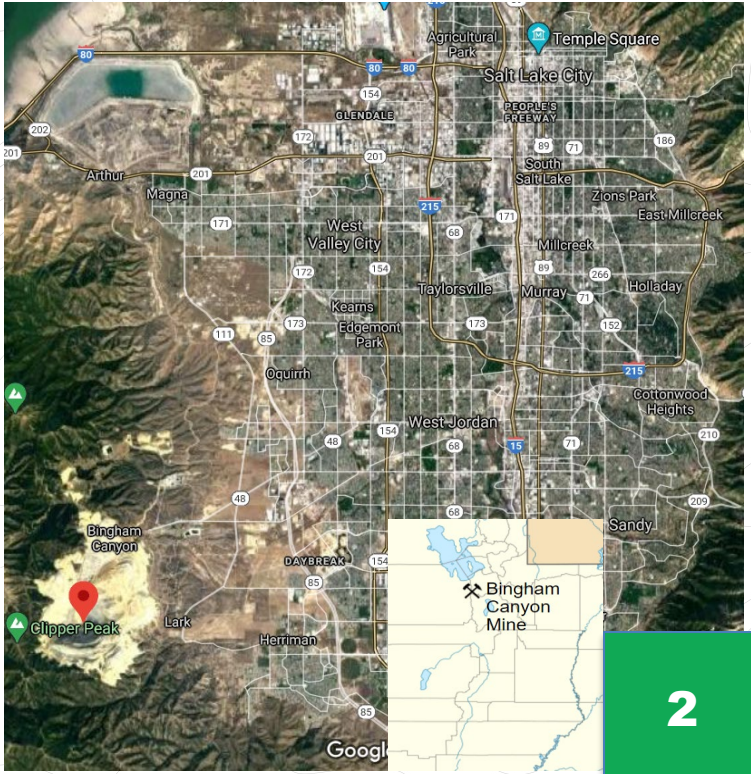
Where and What is Bingham Canyon?

- Located roughly 30 km southwest of Salt Lake City, Utah
- Largest man-made hole and deepest open-pit mine in the world
    - Pit measures over 1 km deep, 4 km wide & covers 7.7 km^2
- Well endowed porphyry system
    - Over 3 Bt of metal produced;
    - Continuously mined since 1906



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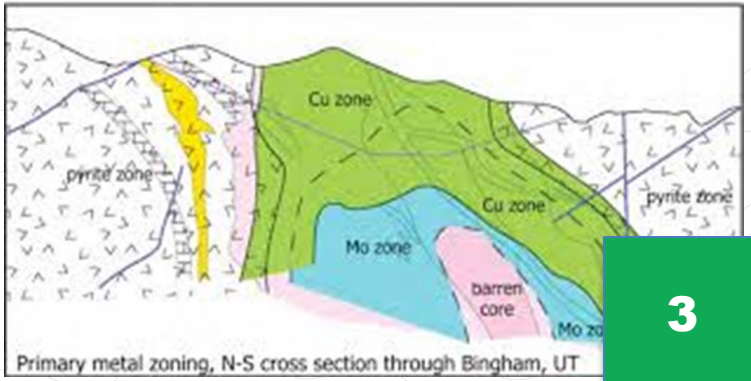
Geology of Bingham Canyon

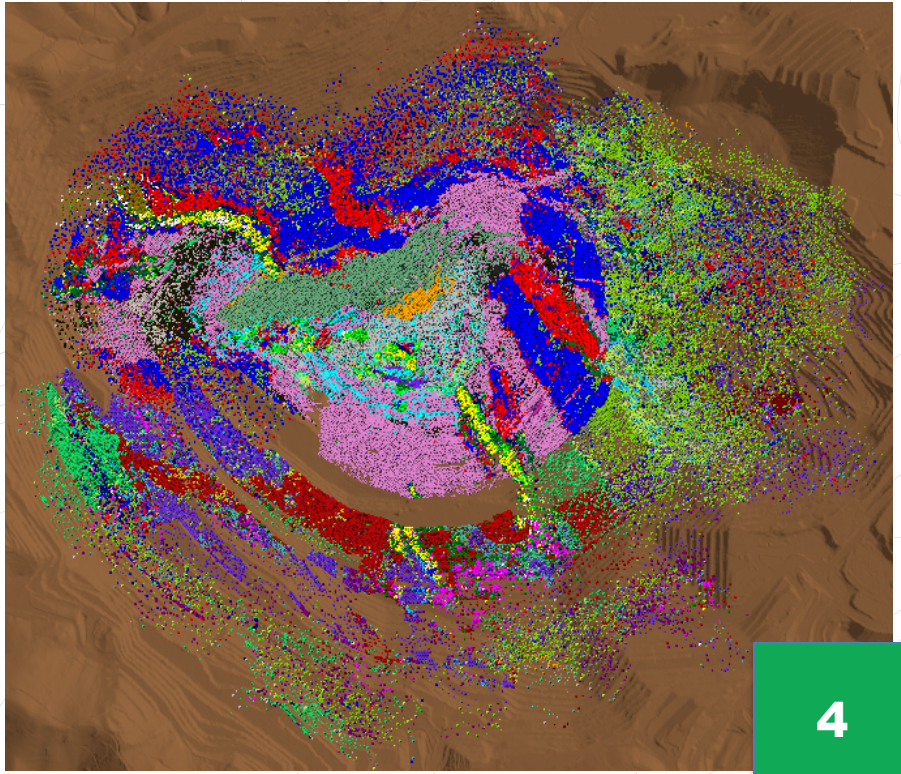
- World-class porphyry Cu-Mo-Au-Ag deposit with lesser amounts of Pb-Zn & other metals
- Centered on the Bingham Stock
    - Steeply dipping suite of mid-Eocene intrusions emplaced into a succession of folded Paleozoic meta-sedimentary rocks.
- Mineralization displays traditional concentric zonation
    - Barren core -> Moly -> High-grade Bn-Cpy-Cc-Au -> Py-Cpy -> Barren Py zone
    - Outermost Pb-Zn-Ag and distal Au-As zones



Primary metal zoning, N-S cross section through Bingham, UT

Ore Types and Geometallurgy

- Intrusive-hosted ores
  - Quartz Monzonite Porphyry (QMP)
  - Monzonite (Mz)
  - Hard Monzonite
  - Moly-rich QMP-Mz
  - Au-rich Mz
  - As-rich Mz
- Sediment-hosted ore
  - Quartzites (Lower, Upper, Ohio & Parnell)
  - Various Skarns
- Late Fissures



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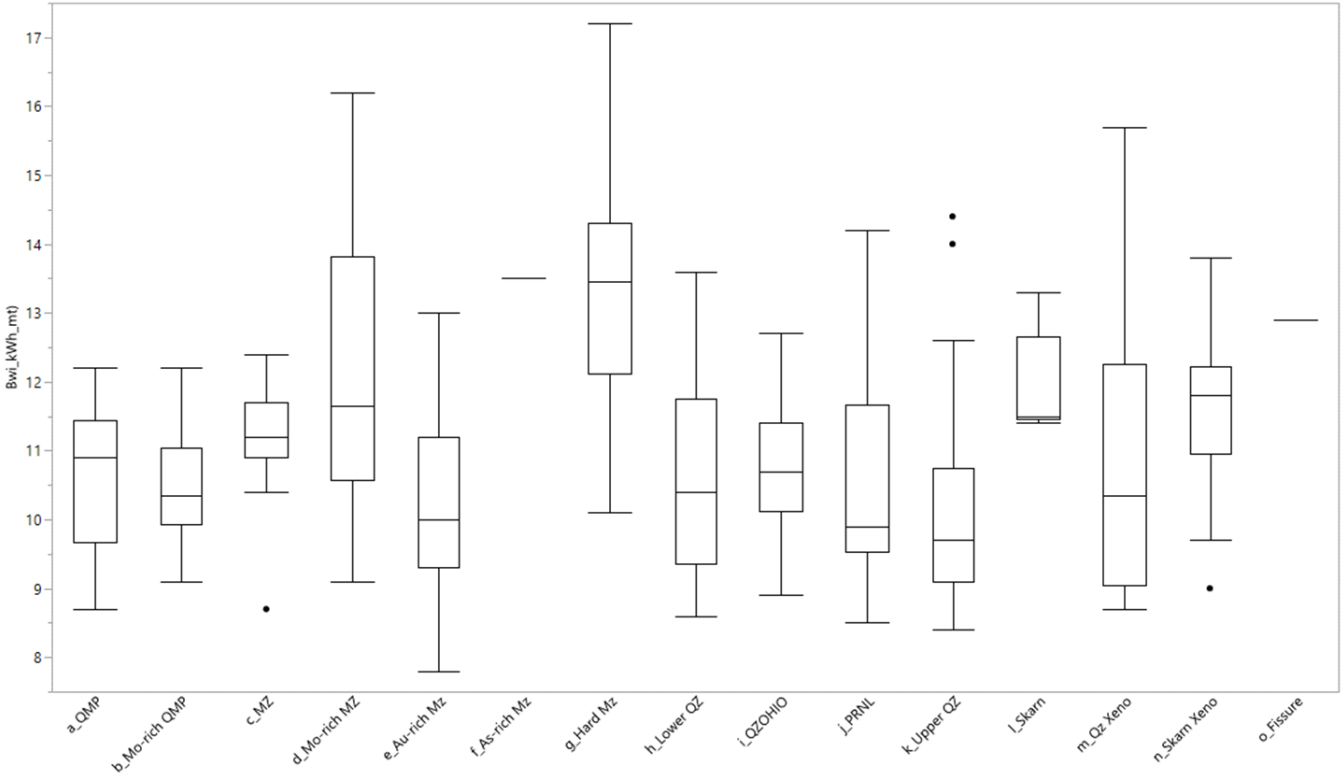
Statement of the Problem

- Natural variations in ore hardness, both internal and external, impact operational performance, i.e. throughput, recovery, grade, etc.
- In the mill, crushing and grinding are the greatest value drivers
    - Highest operating costs, i.e. equipment wear, electricity, etc.
    - Primary control to metal unit production, i.e. throughput & retention time
- Understanding ore hardness at the blasthole level can:
    - Provide planners and operators more accurate throughput information
    - Optimize and improve operational efficiency
    - Enable better delineation of geometallurgical or ore boundaries
- Ultimately, understanding variations in hardness will improve operational profitability

Hardness by Ore Type



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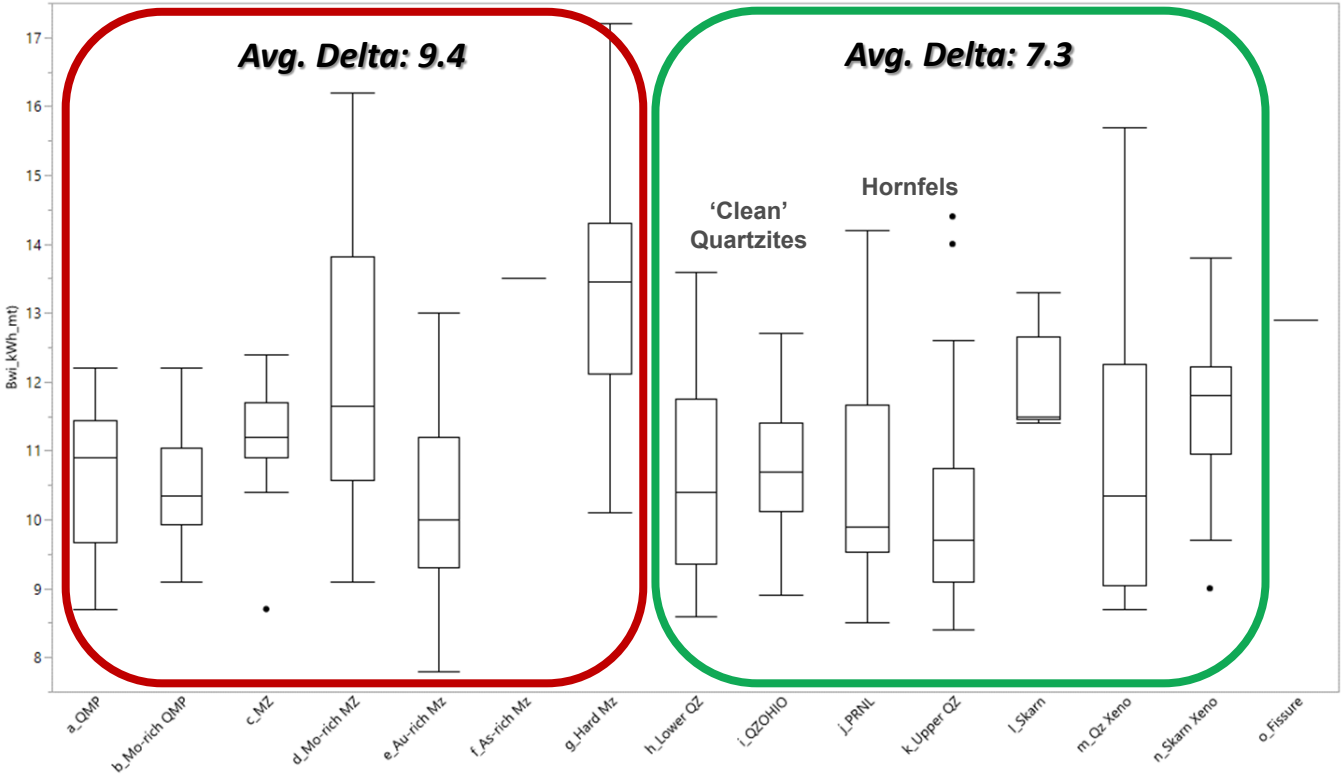
Hardness by Ore Type



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Possible Solutions

- Measure While Drilling
  - Penetration rate, speed, torque, etc.
  - Not correlated to ore type
- Physical metallurgical testwork
  - Regular testing necessary; requires lots of sampling
- Mean average
  - Requires lots of test results to improve accuracy; ignores variability
- Mineralogical + geochemistry of blastholes
  - Better and more accurate ore control
  - Correlate with Measure While Drilling
- Guess and/or ignore

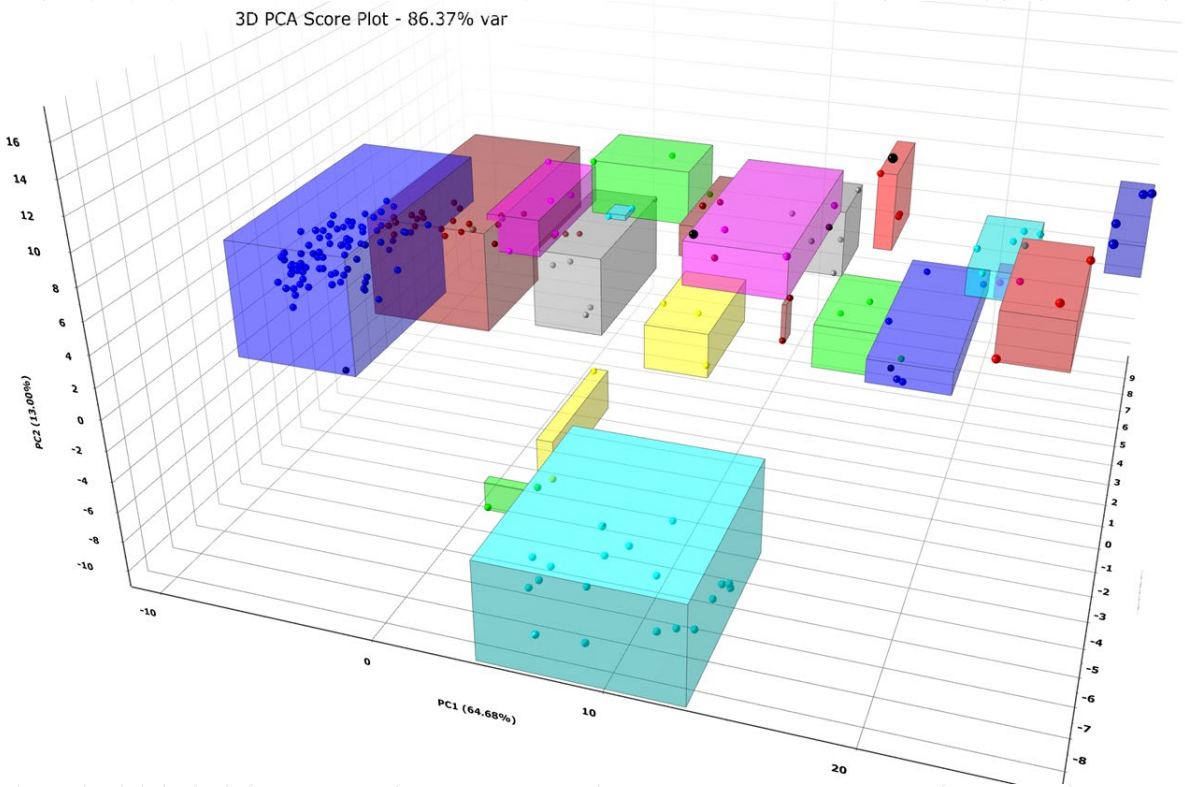
Proposed Methodology

- Collect data from various sources, i.e. physical metallurgy, geochemistry, mineralogy, etc.
    - 63 samples with physical metallurgical testwork results
    - 130 blastholes & ore type samples without testwork & limited geochemistry
- Using the Clustering Analysis feature in HighScore Plus™ to create clusters including all samples, as well as by lithology
- Evaluate clusters and define attributes, including hardness
- Correlate hardness to mineralogy and geochemistry
- Develop predictive model using multiple data analysis techniques

Initial Findings

- Assays and XRD-based mineralogy are cheap, they should not be left out to save on cost.
    - Might not use it today, but one day you will wish you had the data.
- QA/QC of ore type easily performed by XRD
    - Slight changes in mineralogy have significant impacts on performance.
- Assays critical for determining sample value, i.e. worth testing???
- Upfront cost-savings can costs more in the long term.

Principle Component Analysis (PCA): All Data



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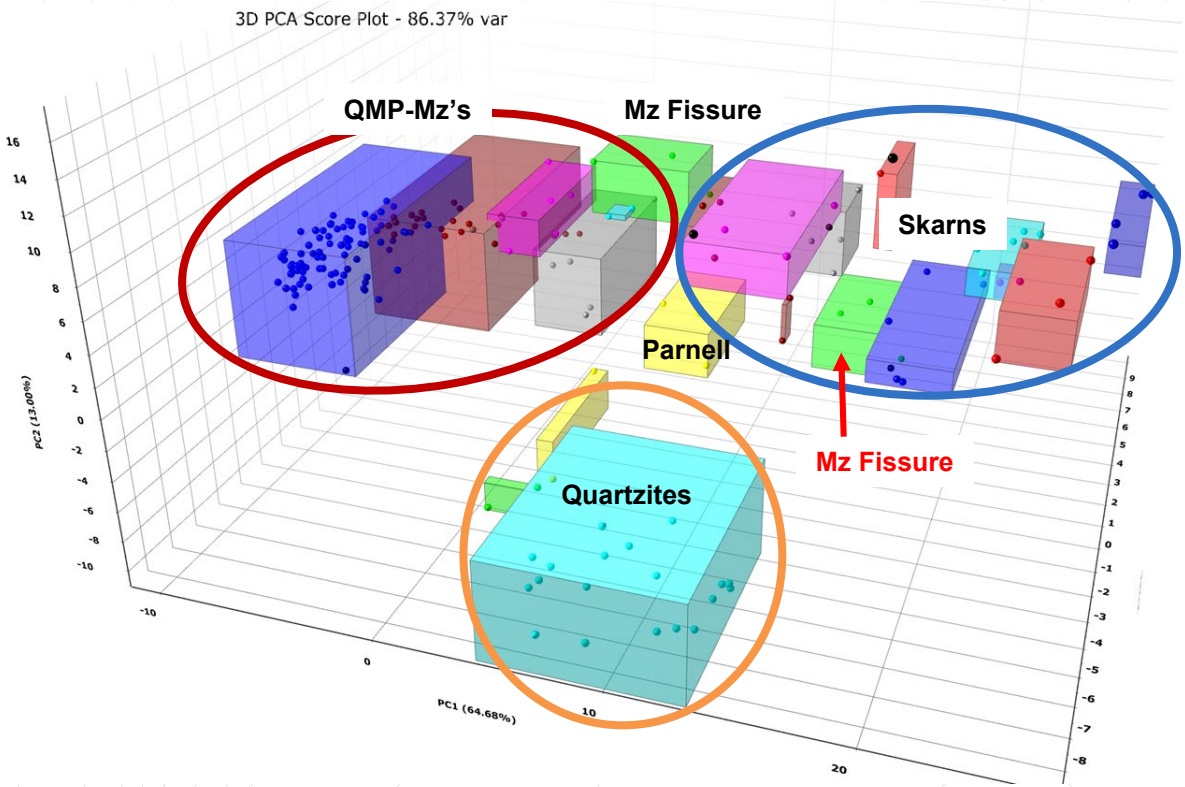
Principle Component Analysis (PCA): All Data



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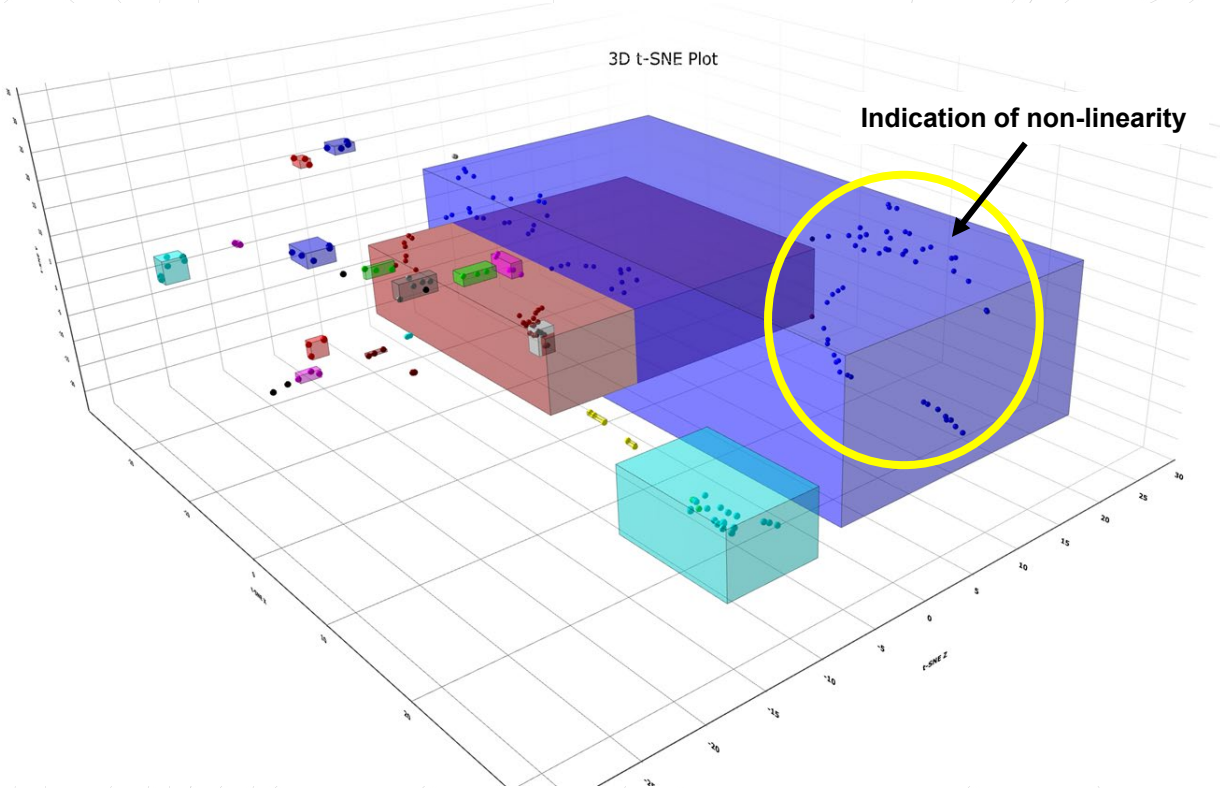
t-distributed Stochastic Neighbor Embedding (t-SNE): All Data



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What does it all mean?

- Easy way of quickly and easily identifying ore type(s)
    - Identify misclassified samples before mining, i.e. Mz Fissure in skarn ‘space’
- Natural internal variations exist within individual ore types
    - Ore type boundaries must be dynamic, not static
    - Ore types are highly variable (Six components = 95% of variability)
    - t-SNE confirms data is non-linear
- *Routine statistical-based methods of analysis will not work for predicting hardness*
- Skarns exhibit most variability (40% of clusters)
    - Impact to performance predications and operating strategies

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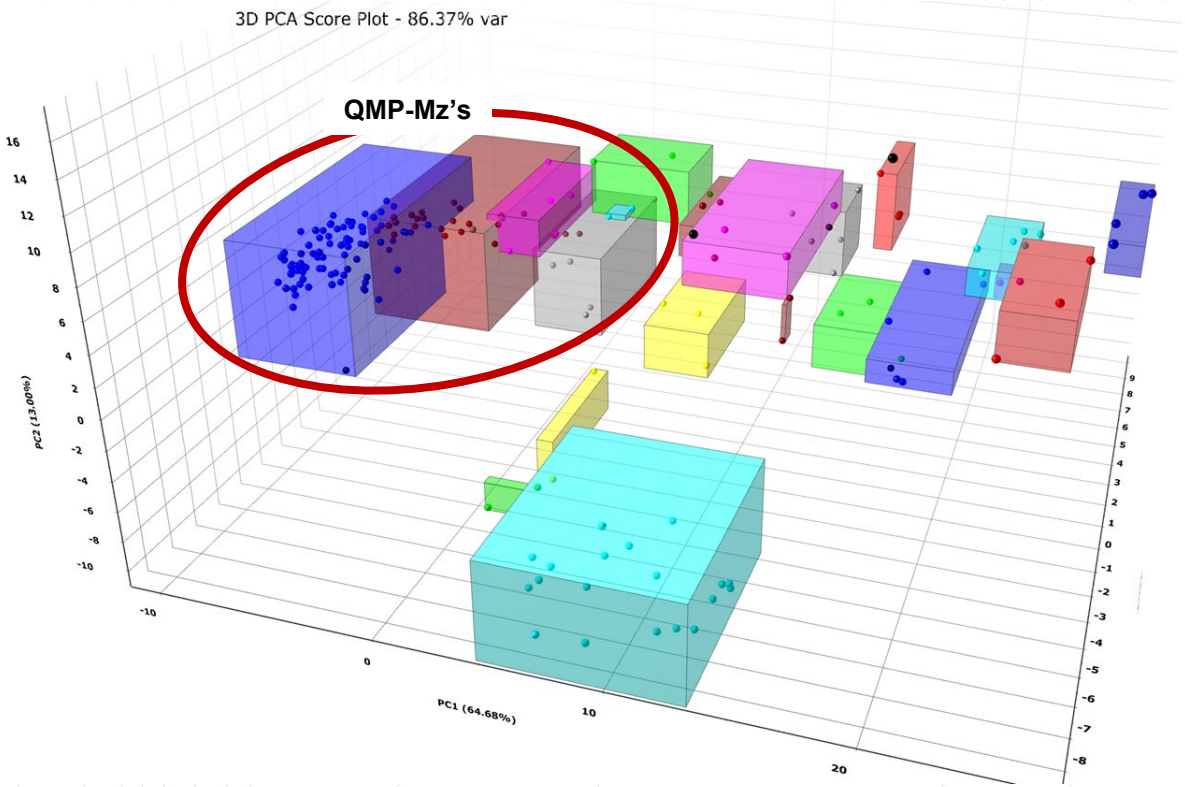
Principle Component Analysis (PCA): All Data



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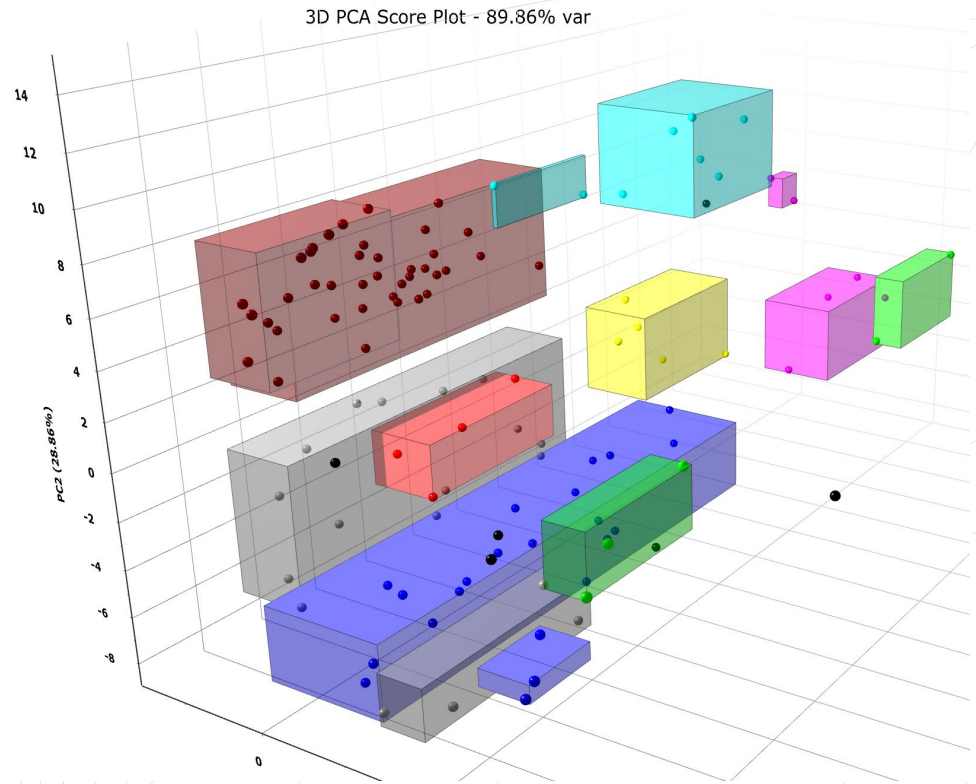
Principle Component Analysis (PCA): Intrusion-hosted Ores



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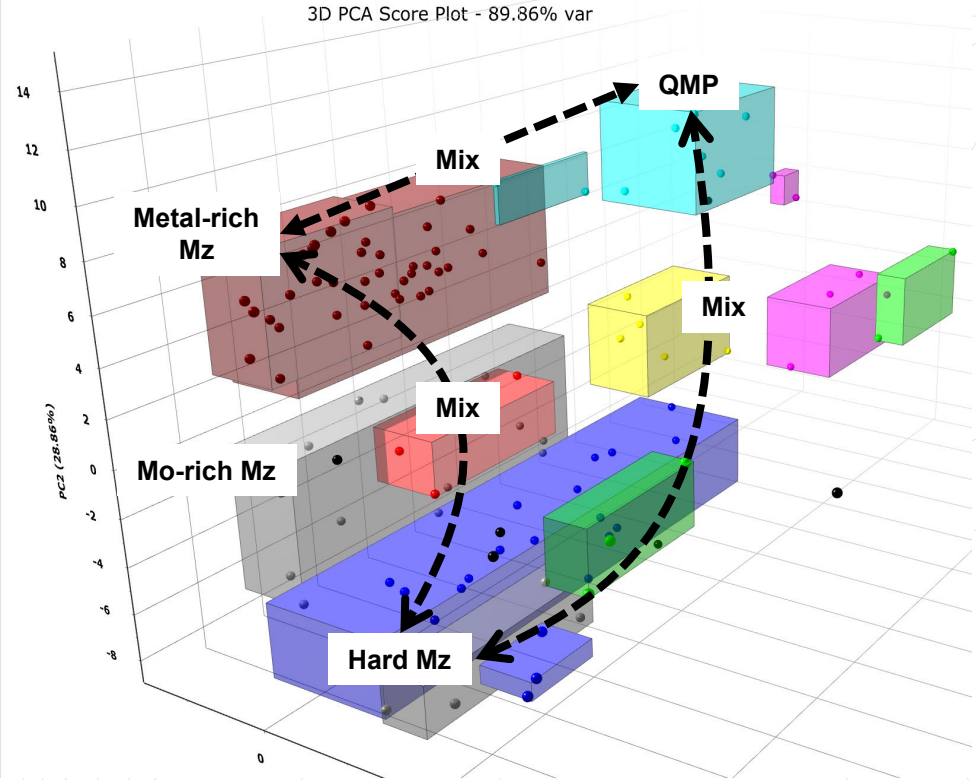

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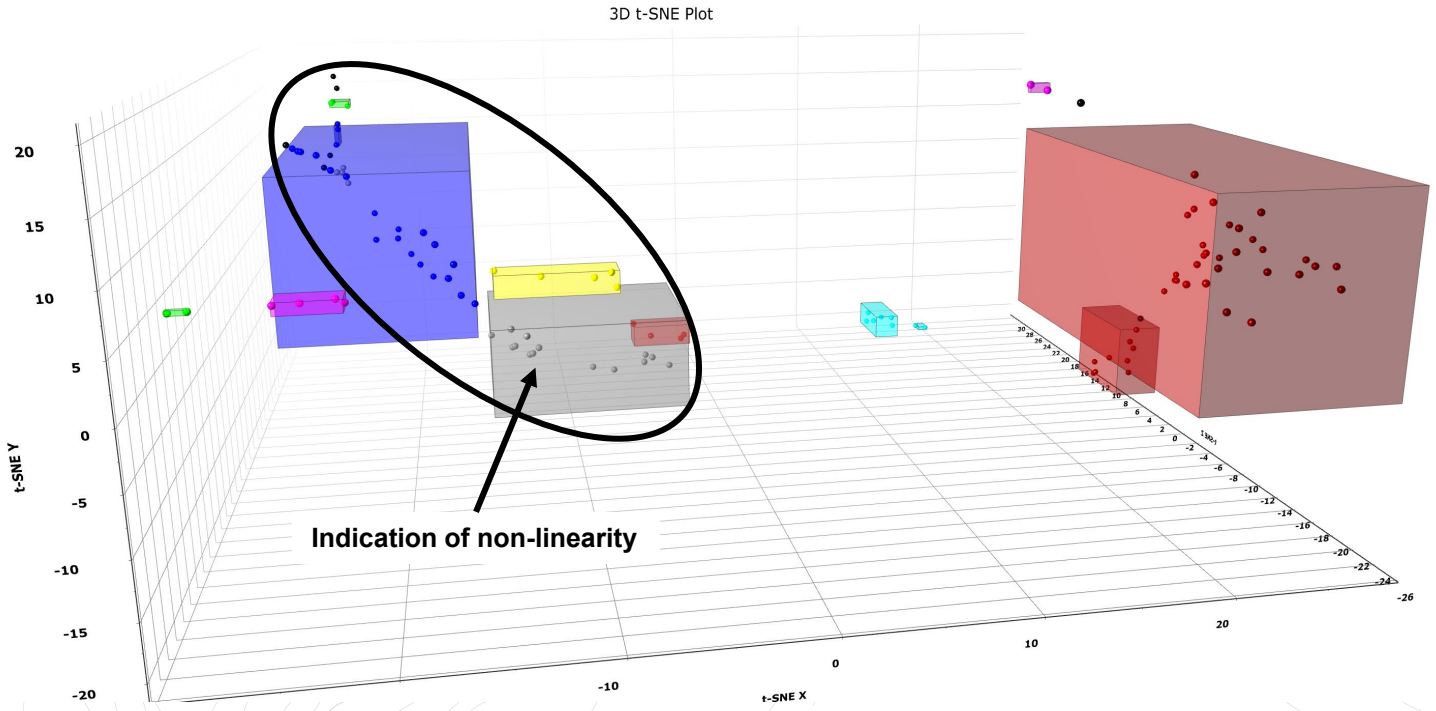
t-distributed Stochastic Neighbor Embedding (t-SNE): Intrusion-hosted Ores



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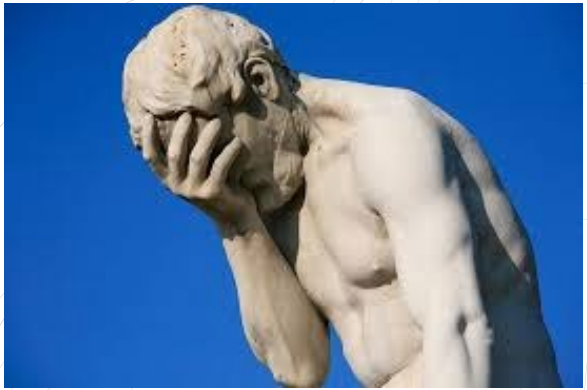
Implication for Intrusion-hosted Ores?



- Multiple end-members and intermediate types of intrusion-hosted ores exist with well clustered end-members
- Ore types not easily compartmentalized due to intermediate phases
    - Intermediate or mix ores represent roughly 33% of the samples
    - High variability (Five components = 95%)
    - t-SNE confirms data is non-linear
    - Impact to performance predications and operating strategies
- *Routine statistical-based methods of analysis not appropriate for predicting hardness*

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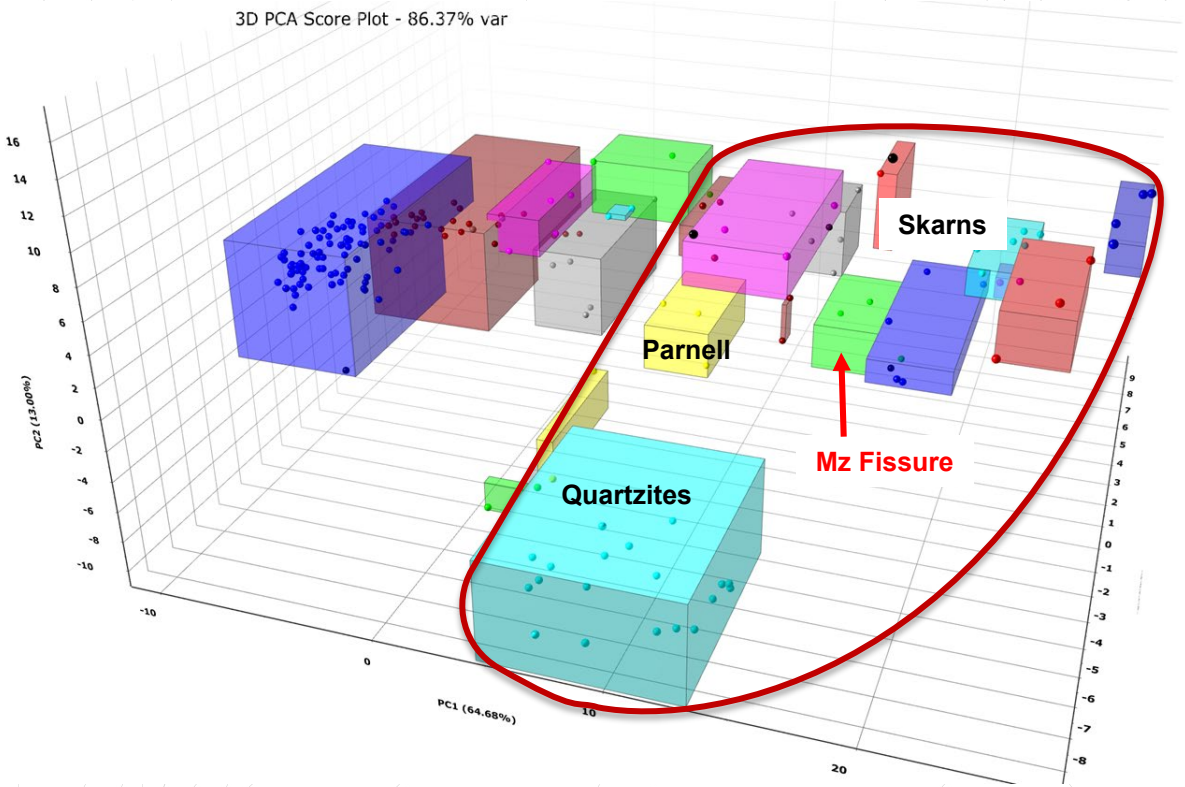
Principle Component Analysis (PCA): All Data



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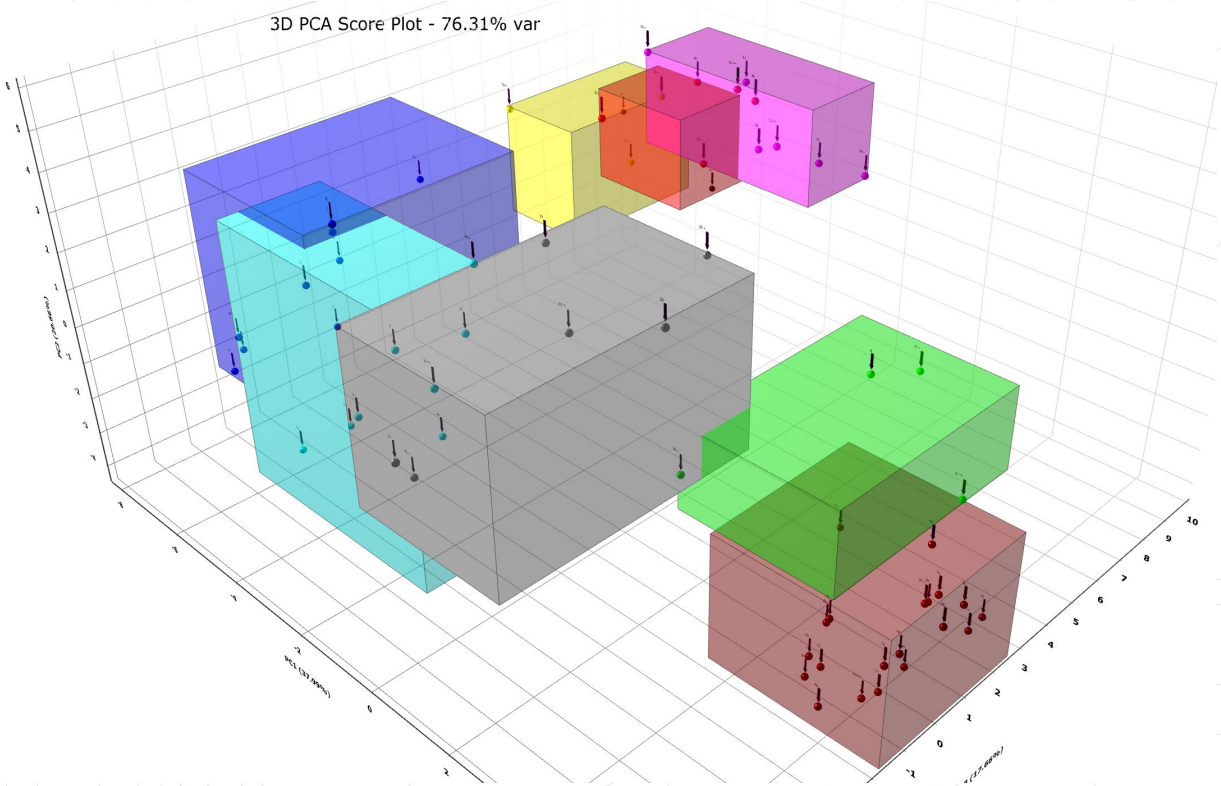
Principle Component Analysis (PCA): Sediment-hosted Ores



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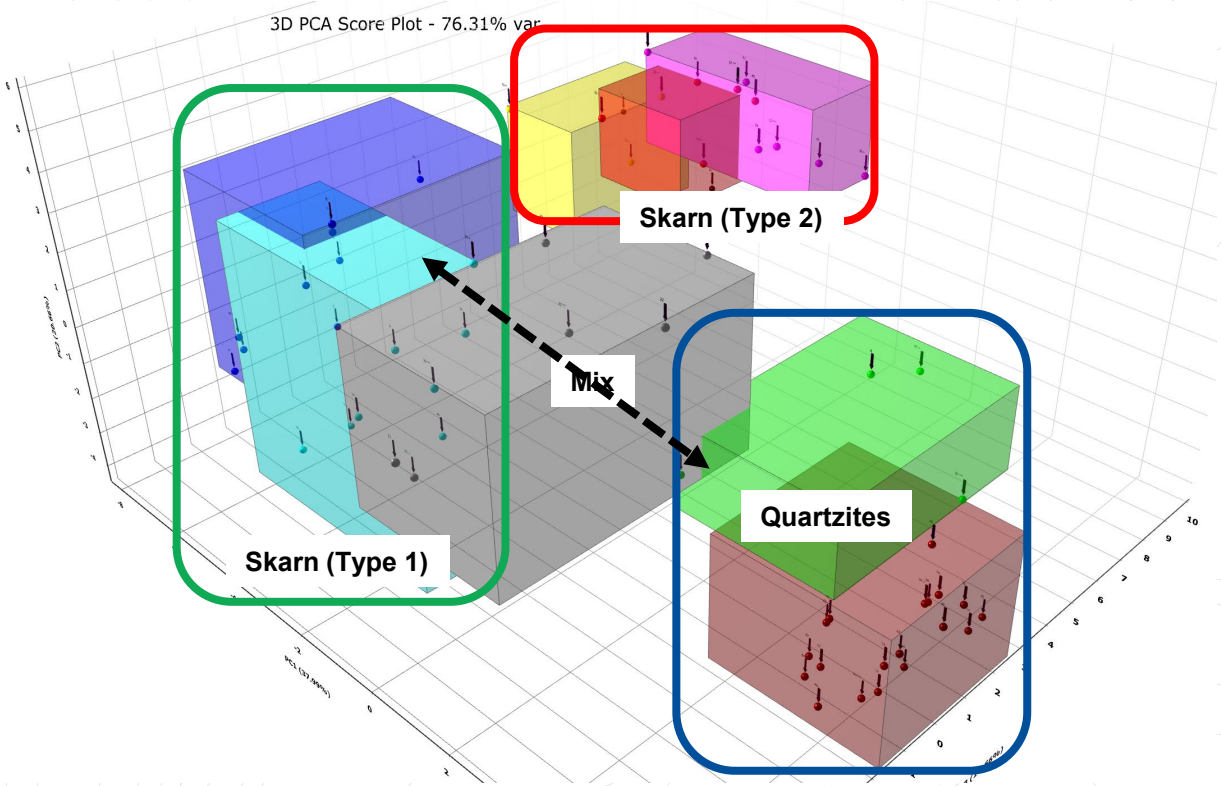
Principle Component Analysis (PCA): Sediment-hosted Ores



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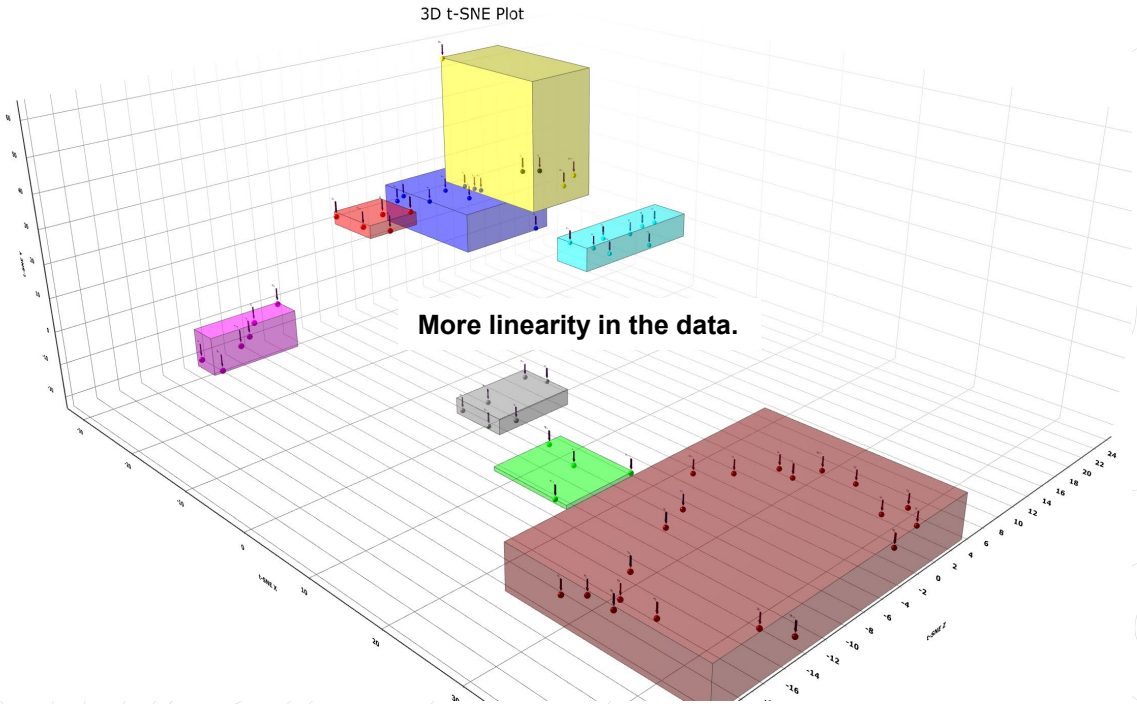
t-distributed Stochastic Neighbor Embedding (t-SNE): Sediment-hosted Ores



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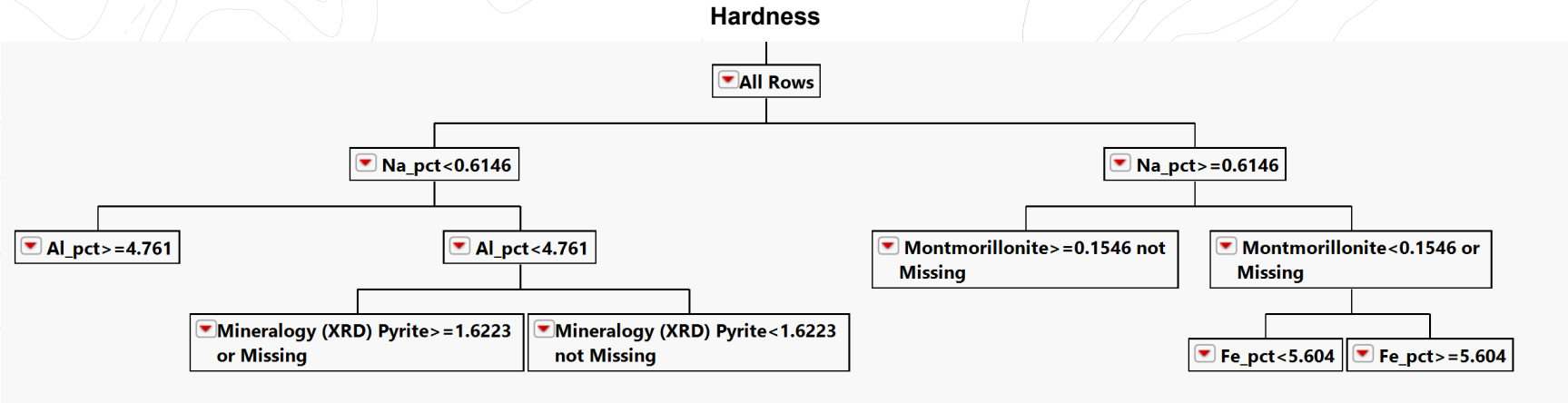
Sediment-hosted Ores?

- Quick and easily technique for identifying internal variability
    - Two distinctly different types of skarn
    - Implications for performance predications and operating strategies
- Ore types more variable than intrusion-hosted ores (Eight components = 95)
    - t-SNE shows higher likelihood of linearity
- *Higher probability that routine statistical-based methods for predicting hardness will work*
- Understanding mineralogical variations critical for improving performance

Hierarchical Classification



- QMP
- Mo-rich QMP
- Au-rich Mz

- Skarns

- Quartzites

- Mz Mixture
- Mo-rich Mz

- Hard Mz

- Higher average metal grades
- Relatively softer ores (quartzites variable)
- ***Plagioclase in QMP & Mz ores intensely clay altered***

- Intermediate to lower metal grades
- Relatively intermediate to harder ores
- ***Plagioclase intact or weakly clay altered***

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Observation and Interpretation

- Powder XRD provides an easy way to identify ore type misclassifications
  - Potential negative impact to operational performance - $$$ loss
- Predicting hardness by XRD more complicated than assumed
  - Alteration mineralogy has a significant impact on clustering
- Correlations are non-linear, i.e. traditional statistical methods ineffective
  - Non-linear nature caused by varying degrees of alteration and alteration type
- Understanding alteration mineralogy critical!
  - Clay alteration controls hardness in Mz and skarn ores
  - Alteration creates lots of intermediates complicating clustering
  - Intense [clay] alteration associated with higher metal grades

Conclusion

- Cutting out assays and XRD during metallurgical testing is a bad idea
- XRD good for ore type classification QA/QC – How are you doing?
- Predicting hardness by mineralogical clustering alone is difficult due to alteration
    - Is compartmentalizing really the best approach for big, complex systems?
- Correlations are non-linear due to varying degrees and types of alteration
- Plagioclase content appears to be a good indicator of hardness
    - Low plagioclase = softer ore, i.e. strongly altered
    - High plagioclase = moderately to hard ore, i.e. weakly alteration
- Understanding alteration mineralogy critical to successful operation

QUESTIONS

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