CIM 2015
The Art and Science of Geology

Resource Models – More than just grades stuffed into blocks

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What is Geostatistics? Why is it Special?

Geostatistics could be considered equal parts MATH / SCIENCE / ART

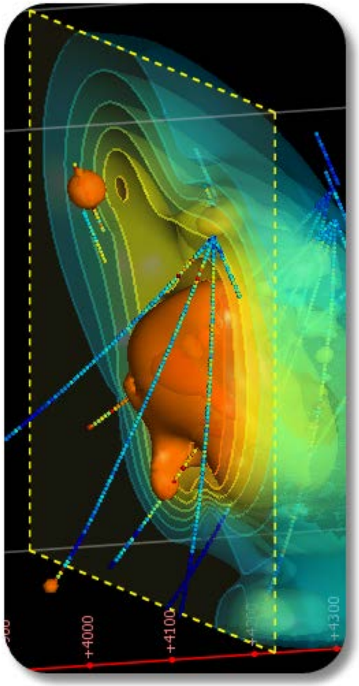
MATH – because it is founded on statistics and calculus

SCIENCE – because it incorporates physics, chemistry, and geologic principles

ART – *because subjectivity and opinion are a requirement (QP has ultimate control)*

Why Geostatistics?

Because thanks to Mother Nature. Geological features are NOT considered random



Therefore mineral concentrations, related to geological features, can be predicted

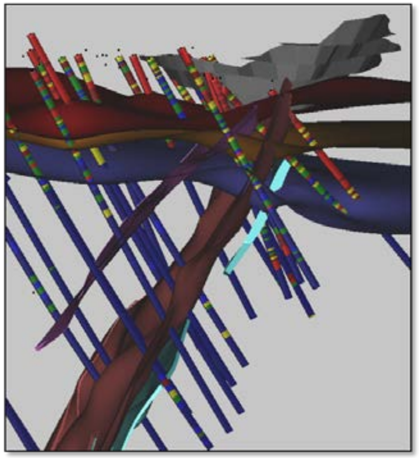
The underlying measureable continuity, allows for the interpolation of values, into unsampled areas, using available samples

Geostatistics Alone is not Enough

Five Fundamentals of Resource Estimation

1. Proper sampling of deposit
2. Integrity of the digital database
3. **Understanding of the deposit geology and proper use in resource estimation procedures**
4. *Use of appropriate estimation techniques*
5. *Use of appropriate classification methodologies*

Geostatistics Alone is not Enough



Five Fundamentals of Resource Estimation

1. Proper sampling of deposit
   1. Is the deposit drilled and sampled appropriately?
   2. Are important geological contacts preserved in assay intervals?
      1. Are grades “smeared” across contacts? If so, is it important for the scale of the model being constructed?
   3. Are appropriate and necessary geological data points captured during logging?
   4. Are appropriate analytical methods used for assaying?

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Geostatistics Alone is not Enough

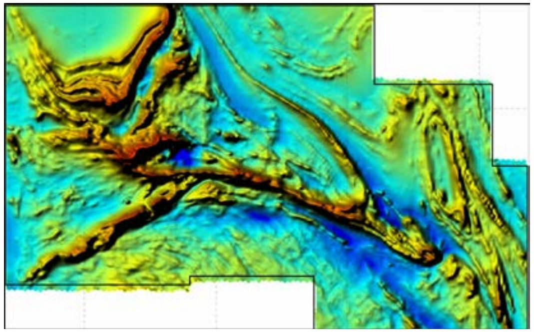
COLLAR | SURVEY | ASSAY | ALT | LITH | MIN | DEN | STRUCT

	U	SAMPID	FROM	TO	LENGTH	CUT
1	C.	703867	40.30	42.00	1.70	0.0850
2	C.	703868	42.00	44.00	2.00	0.1280
3	C.	703869	44.00	46.00	2.00	0.1010
4	C.	703870	46.00	48.00	2.00	0.0900
5	C.	703871	48.00	50.00	2.00	0.0720
6	C.	703872	50.00	52.00	2.00	0.0640
7	C.	703873	52.00	54.00	2.00	0.0580
8	C.	703874	54.00	56.00	2.00	0.0550
9	C.	703875	56.00	58.00	2.00	0.0660
10	C.	703876	58.00	60.00	2.00	0.1290
11	C.	703877	60.00	62.00	2.00	0.0820

Five Fundamentals of Resource Estimation

1. *Proper sampling of deposit*
2. Integrity of the digital database
    1. Has the digital data been validated?
        1. Checked for assays greater than hole depth, overlapping intervals, erroneous downhole deviation, appropriate collar locations, etc…
    2. Does the digital database contain all available information, or simply a predefined subset?
        1. If a predefined subset, is the subset appropriate?
    3. Are special fields appropriately identified and understood?
        1. Below and above detection limits are accurately defined?
        2. Are gaps or unsampled intervals understood? How should they be handled?

Geostatistics Alone is not Enough



Five Fundamentals of Resource Estimation

1. *Proper sampling of deposit*
2. *Integrity of the digital database*
3. **Understanding of the deposit geology and proper use in resource estimation procedures**
    1. Are geological controls of primary mineralizing events understood?
        1. Lithological, alteration, structural, etc..
    2. Are post primary mineralization controls understood?
        1. Faulting causing displacement, volumetrically important barren intrusives, weathering controls, etc…
    3. *What about geological controls, not “required” for grade estimation but needed for geomet, geotech, density, etc…*

Geostatistics Alone is not Enough

Five Fundamentals of Resource Estimation

1. Proper sampling of deposit
2. Integrity of the digital database
3. **Understanding of the deposit geology and proper use in resource estimation procedures**
4. *Use of appropriate estimation techniques*
    1. What estimation method is most applicable?
        1. ID, OK, SK, Simulation
    2. Is the chosen estimation method applicable to underlying grade distribution, grade variability, spatial continuity, and account for volume variance relationships?
    3. Are you choosing the appropriate estimation parameters, to match the estimation method?

Geostatistics Alone is not Enough

Five Fundamentals of Resource Estimation

1. Proper sampling of deposit
2. Integrity of the digital database
3. **Understanding of the deposit geology and proper use in resource estimation procedures**
4. *Use of appropriate estimation techniques*
5. *Use of appropriate classification methodologies*
    1. Are chosen confidence criterion applicable to deposit style
    2. Do they appropriately account for the QP's judgement of the quality of sampling, database, geological continuity and understanding, and grade estimation quality and continuity?
    3. Are other necessary data points missing?
        1. Density, Oxidation state, etc..

Geostatistics Alone is not Enough

If the fundamental inputs to resource estimation are ignored, done incorrectly, or not understood…

They can never be compensated for, nor corrected by geostatistics alone

***Errors** in the underlying data, database, geological assumptions **will be** reproduced in the model*

Where to Start

Interpretation

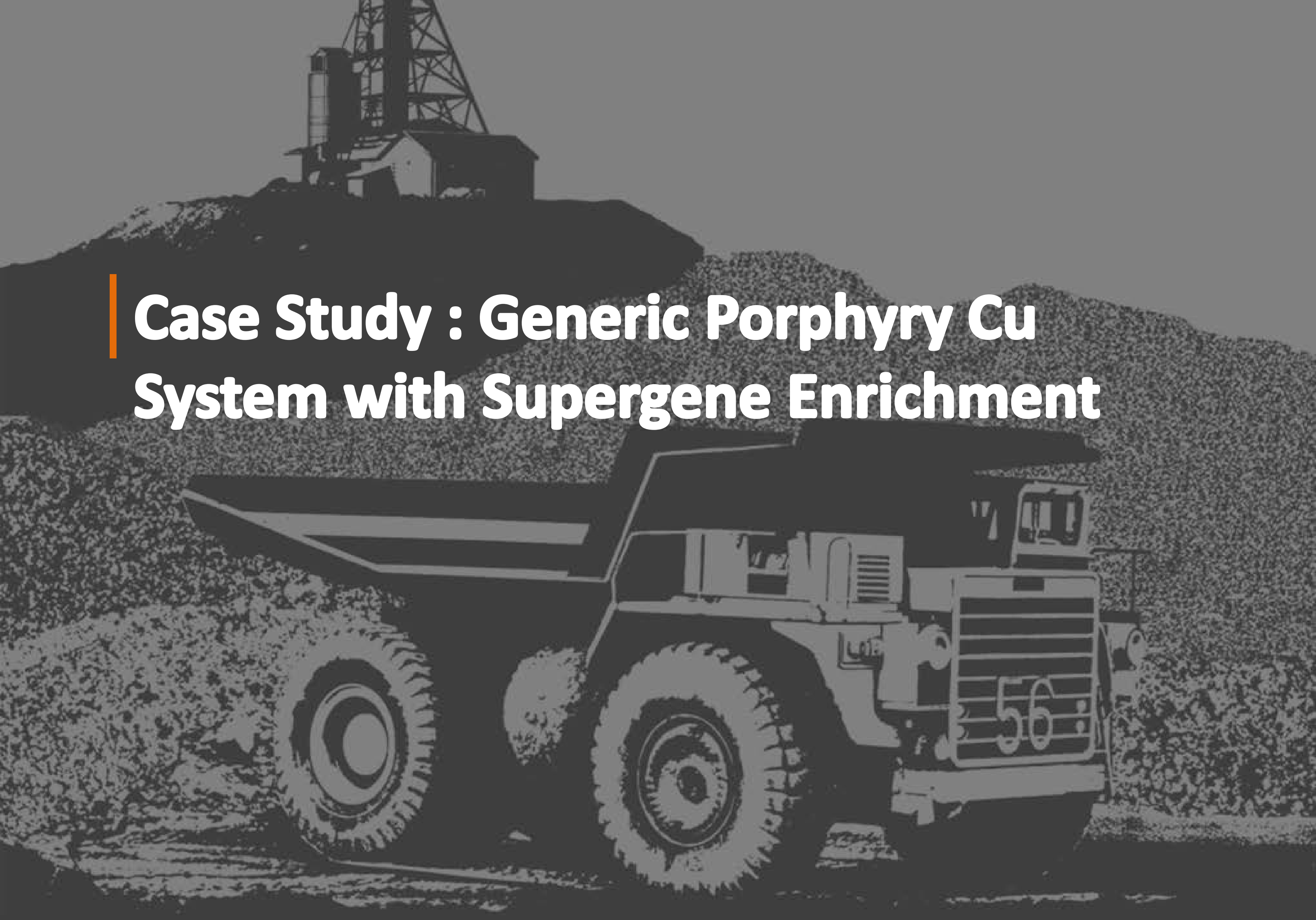
As geologists we are are tasked with interpreting the data and “understanding” the geology of our deposits.

My Advice:

Build your concept with paper, computers, your knowledge

Don’t let the computer build your concept

You are the operator. You are in Control. Make the computer do what you want!



Case Study : Generic Porphyry Cu System with Supergene Enrichment

Porphyry Copper / Supergene Enrichment

- Mineralized Porphyry Copper Deposit
- Intrusive Stock
- Rain water & Ground water precipitating through ground, channeled by fractures

Copper Mineralogical Zonation

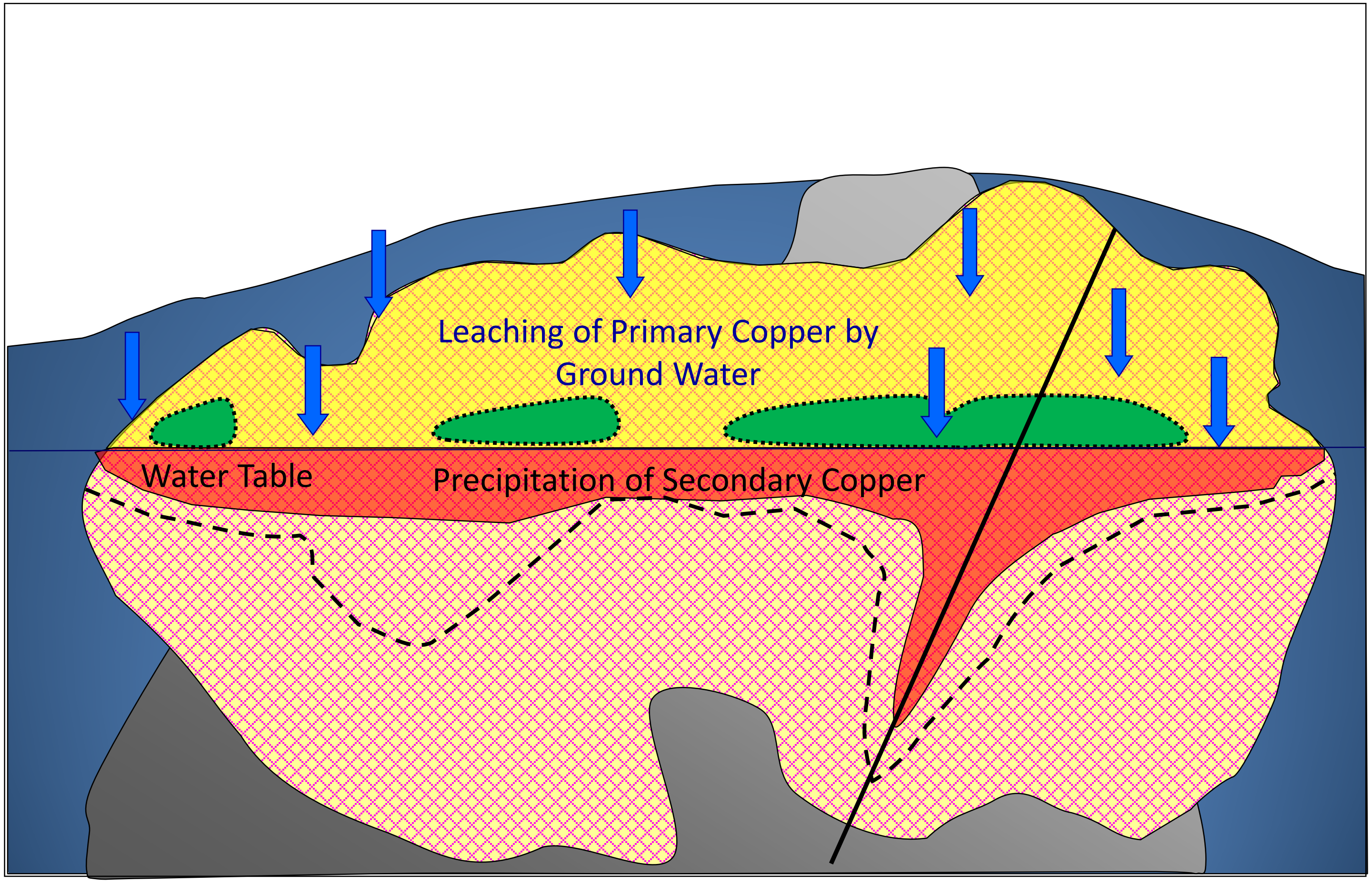
Leached Cap
metals removed, perched zones

Oxide Minerals
(chrysocolla, brochantite, etc..)

Supergene Enrichment
(chalcocite, covellite > chalcopyrite)

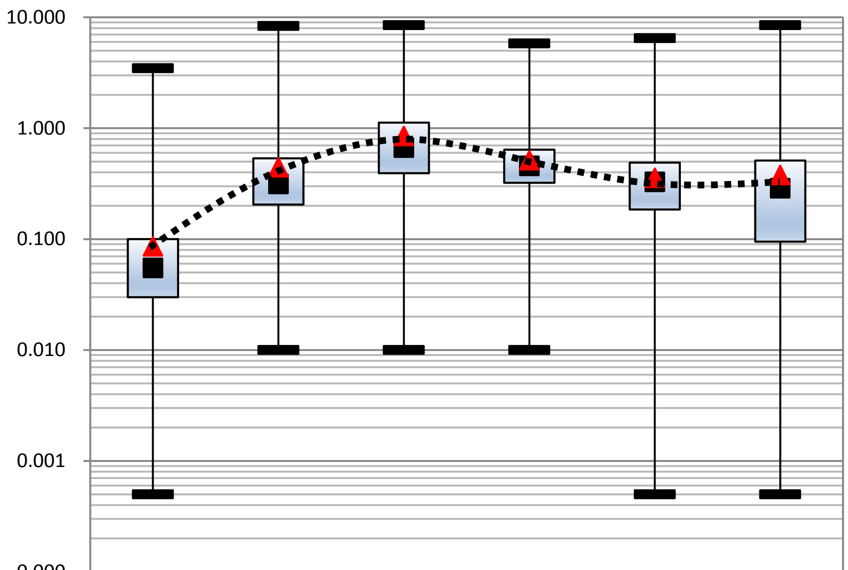
Transition
(chalcopyrite > chalcocite)

Hypogene
(chalcopyrite, bornite – no visible secondary copper minerals)



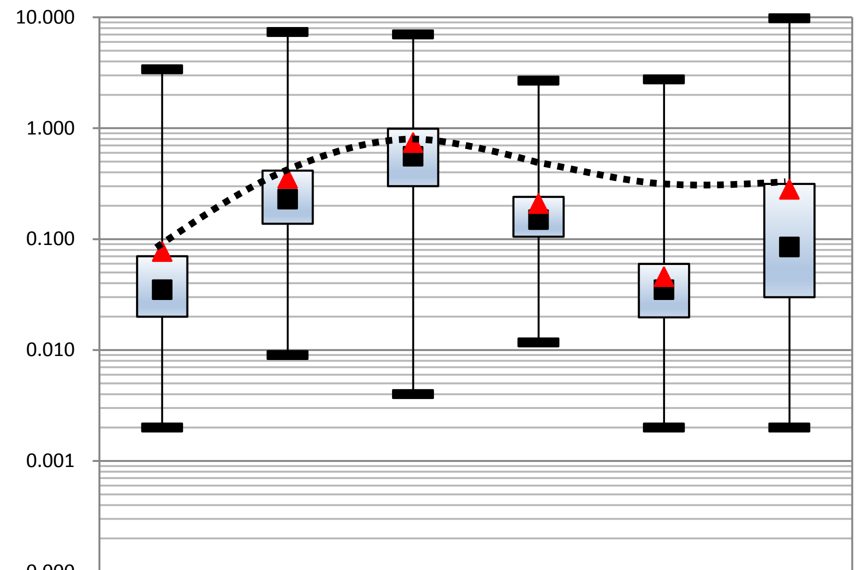
Data Statistics Change by Geology

Total Copper



	leach	oxide	enr	trans	prim	all
Q1	0.03	0.21	0.39	0.32	0.18	0.09
Min	0.00	0.01	0.01	0.01	0.00	0.00
Median	0.06	0.31	0.67	0.46	0.33	0.29
Mean	0.09	0.44	0.85	0.51	0.36	0.38
Max	3.48	8.35	8.48	5.82	6.50	8.48
Q3	0.10	0.54	1.12	0.64	0.49	0.51
NSamples	17,425	2,836	14,836	6,673	47,815	95,964
CV	1.42	1.12	0.77	0.60	0.67	1.09

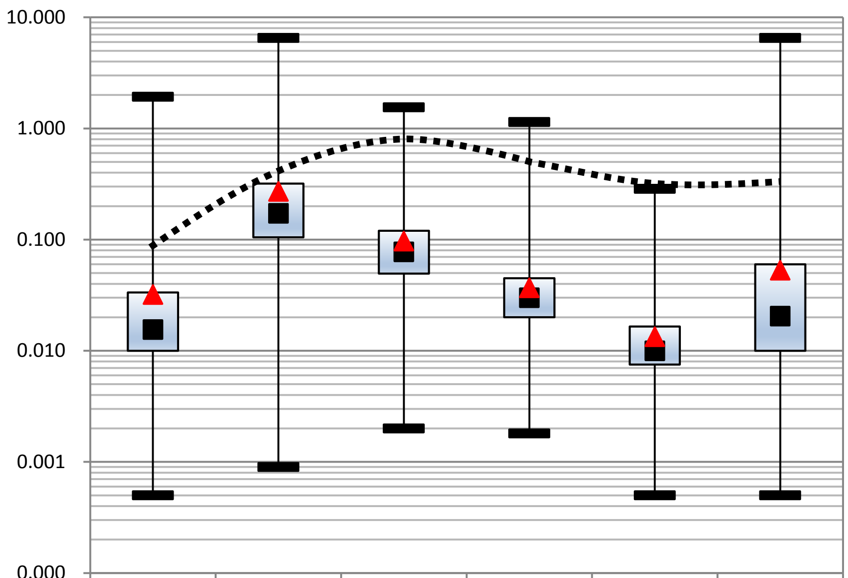
Sequential Copper



	leach	oxide	enr	trans	prim	all
Q1	0.02	0.14	0.30	0.11	0.02	0.03
Min	0.00	0.01	0.00	0.01	0.00	0.00
Median	0.04	0.23	0.56	0.15	0.04	0.08
Mean	0.08	0.35	0.74	0.21	0.05	0.28
Max	3.39	7.36	7.00	2.69	2.75	9.80
Q3	0.07	0.42	0.99	0.24	0.06	0.32
NSamples	6,759	2,663	14,431	6,476	19,548	51,950
CV	1.95	1.27	0.84	0.94	1.19	1.66

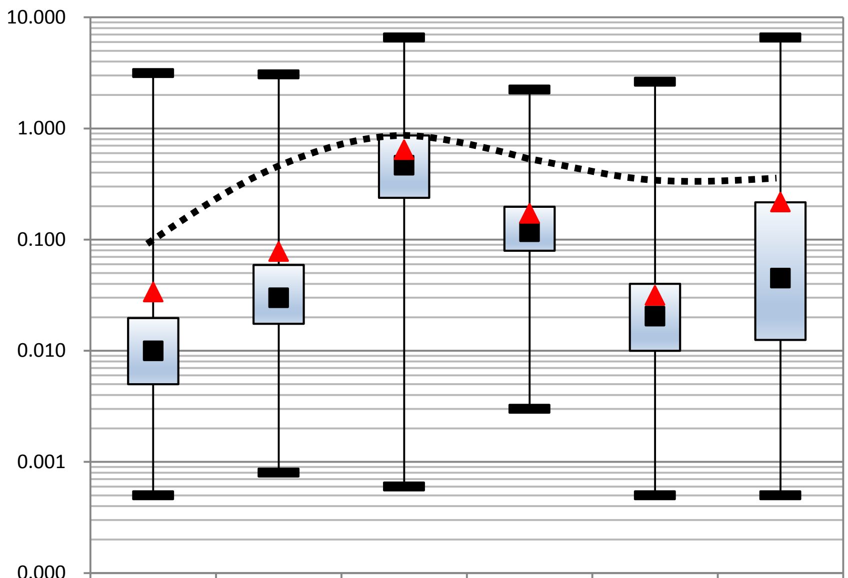
Data Statistics Change by Geology

Acid Soluble Copper



	leach	oxide	enr	trans	prim	all
Q1	0.01	0.11	0.05	0.02	0.01	0.01
Min	0.00	0.00	0.00	0.00	0.00	0.00
Median	0.02	0.17	0.08	0.03	0.01	0.02
Mean	0.03	0.27	0.10	0.04	0.01	0.05
Max	1.93	6.52	1.55	1.14	0.29	6.52
Q3	0.03	0.32	0.12	0.04	0.02	0.06
NSamples	10,785	2,700	14,704	6,562	21,282	58,790
CV	2.11	1.31	0.85	0.88	0.82	2.07

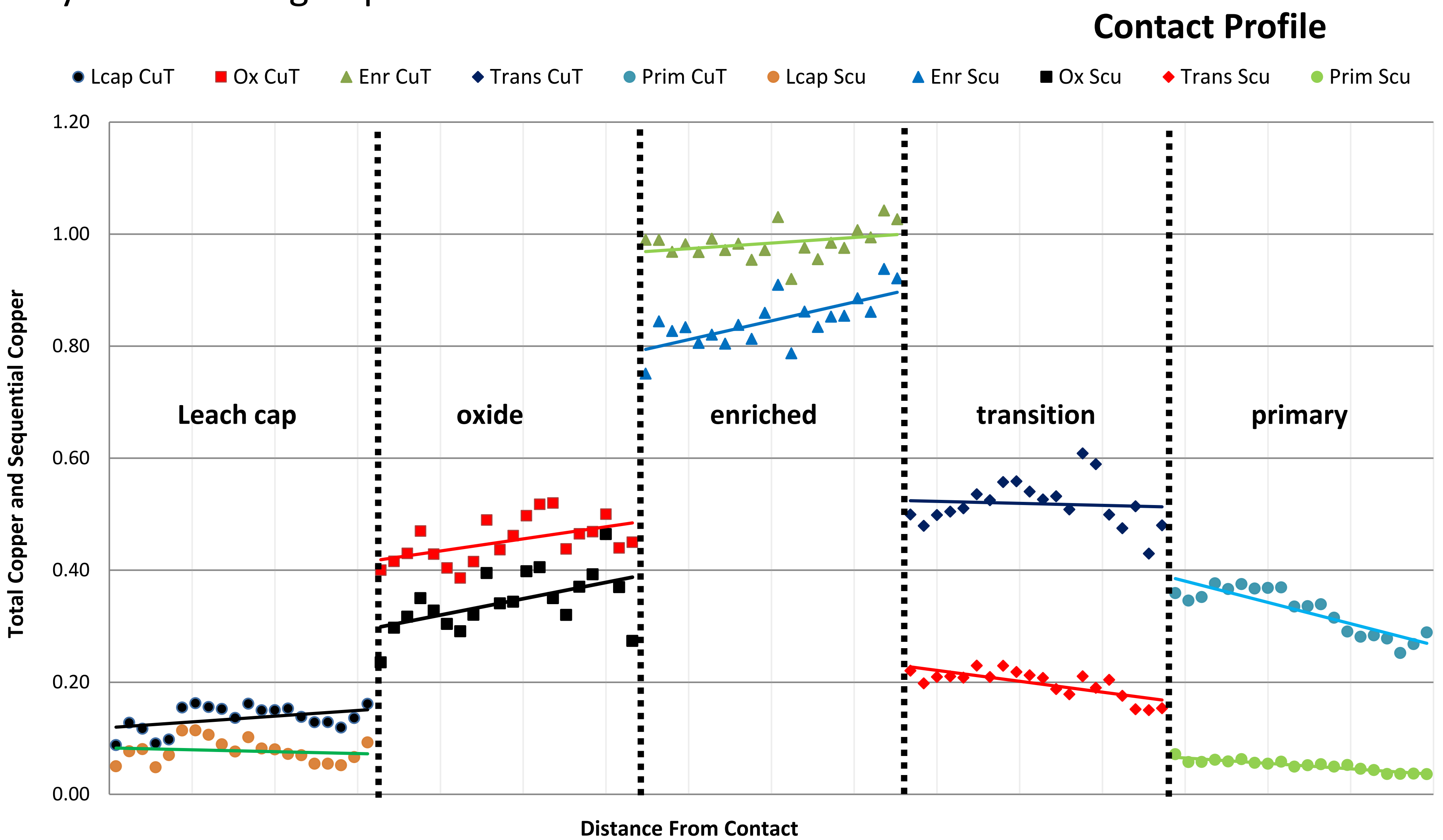
Cyanide Soluble Copper



	leach	oxide	enr	trans	prim	all
Q1	0.01	0.02	0.24	0.08	0.01	0.01
Min	0.00	0.00	0.00	0.00	0.00	0.00
Median	0.01	0.03	0.47	0.12	0.02	0.05
Mean	0.03	0.08	0.64	0.17	0.03	0.22
Max	3.15	3.07	6.59	2.24	2.63	6.59
Q3	0.02	0.06	0.87	0.20	0.04	0.22
NSamples	7,255	2,663	14,433	6,478	19,966	53,157
CV	3.22	2.34	0.90	1.04	1.47	1.88

Data Statistics Change by Geology

Why is Domaining Important?



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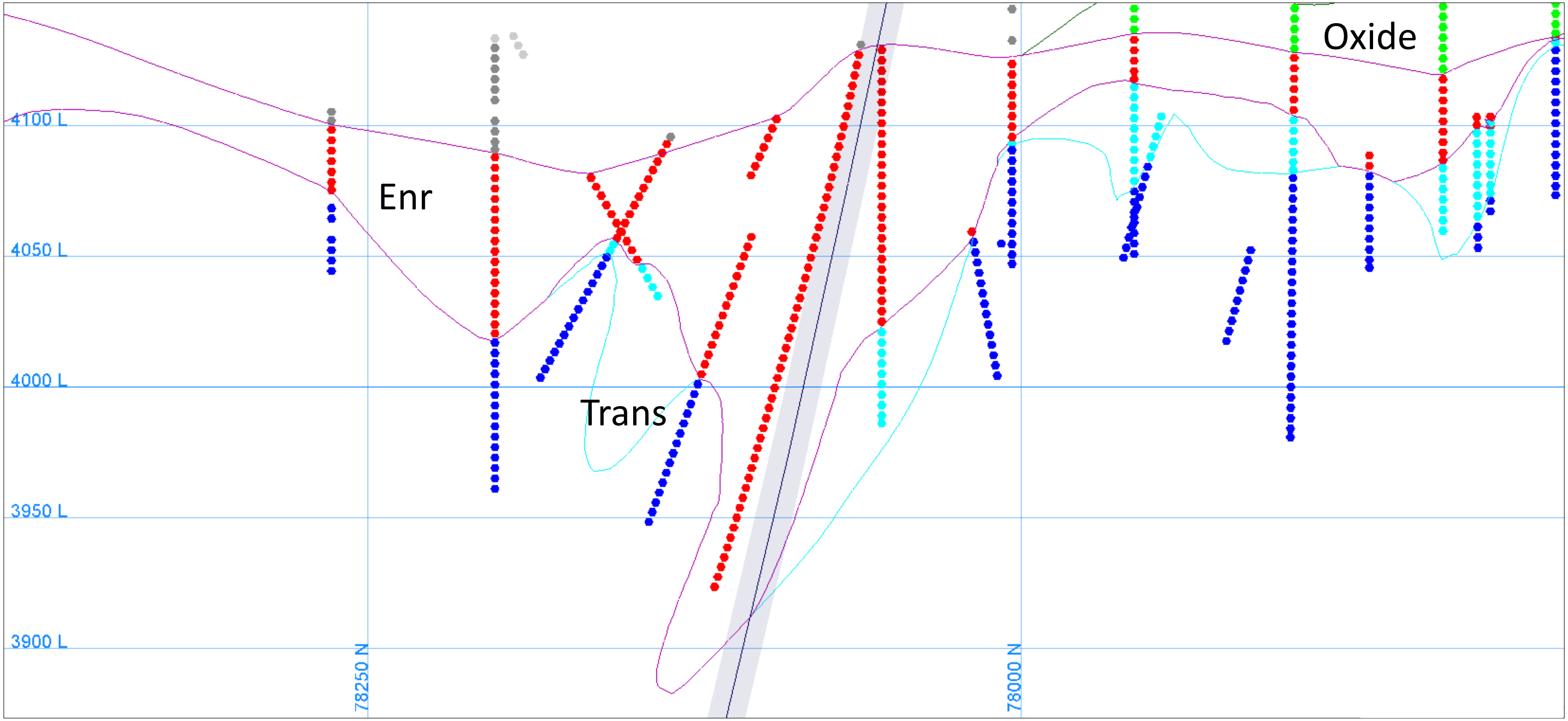
The Model

Cross Section View through the deposit



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Truth (Domained) vs UnDomained

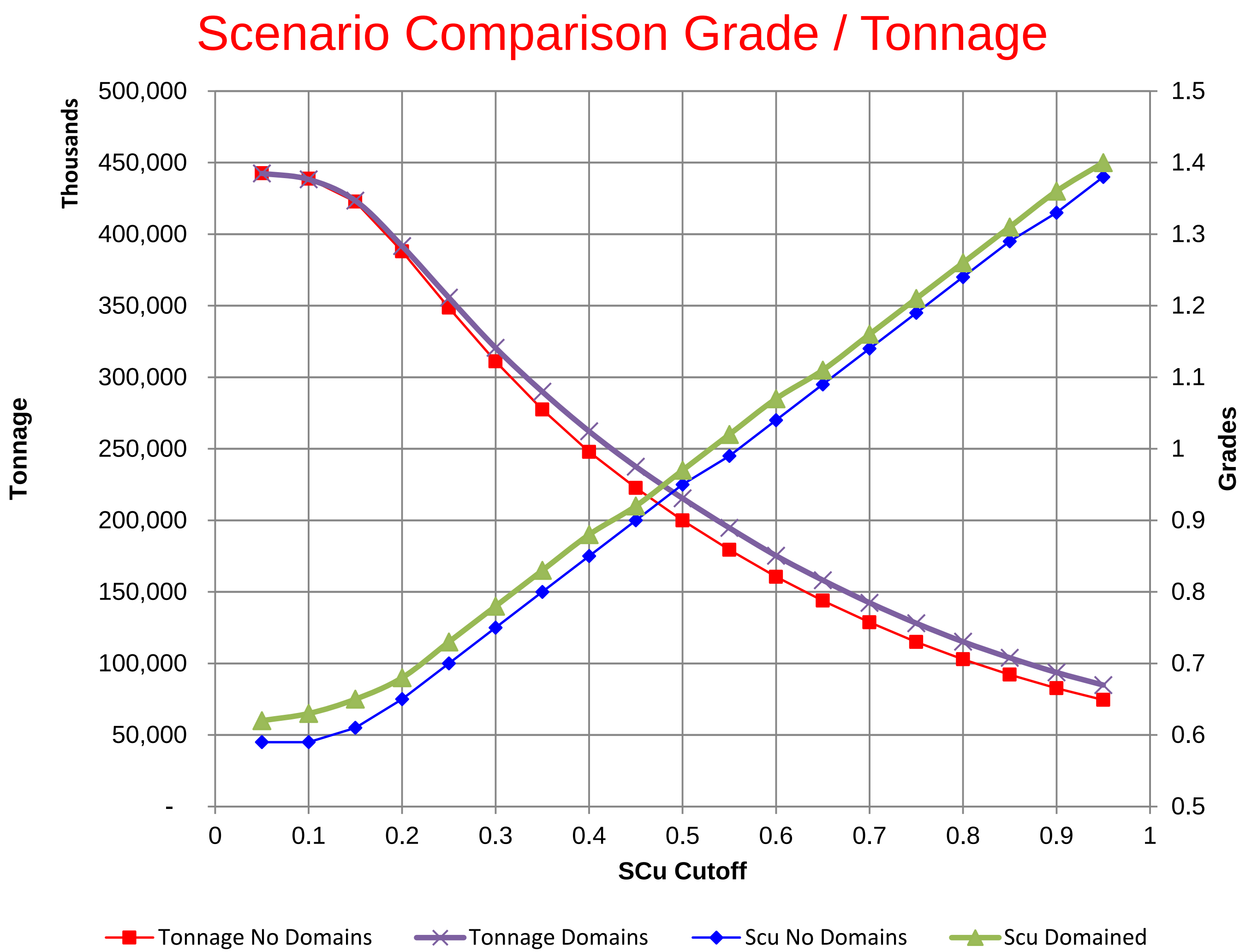
Two estimations were completed using the same estimation parameters (search, sample count, etc..)

First estimation considered geological domains

Second estimation considered NO geological domains

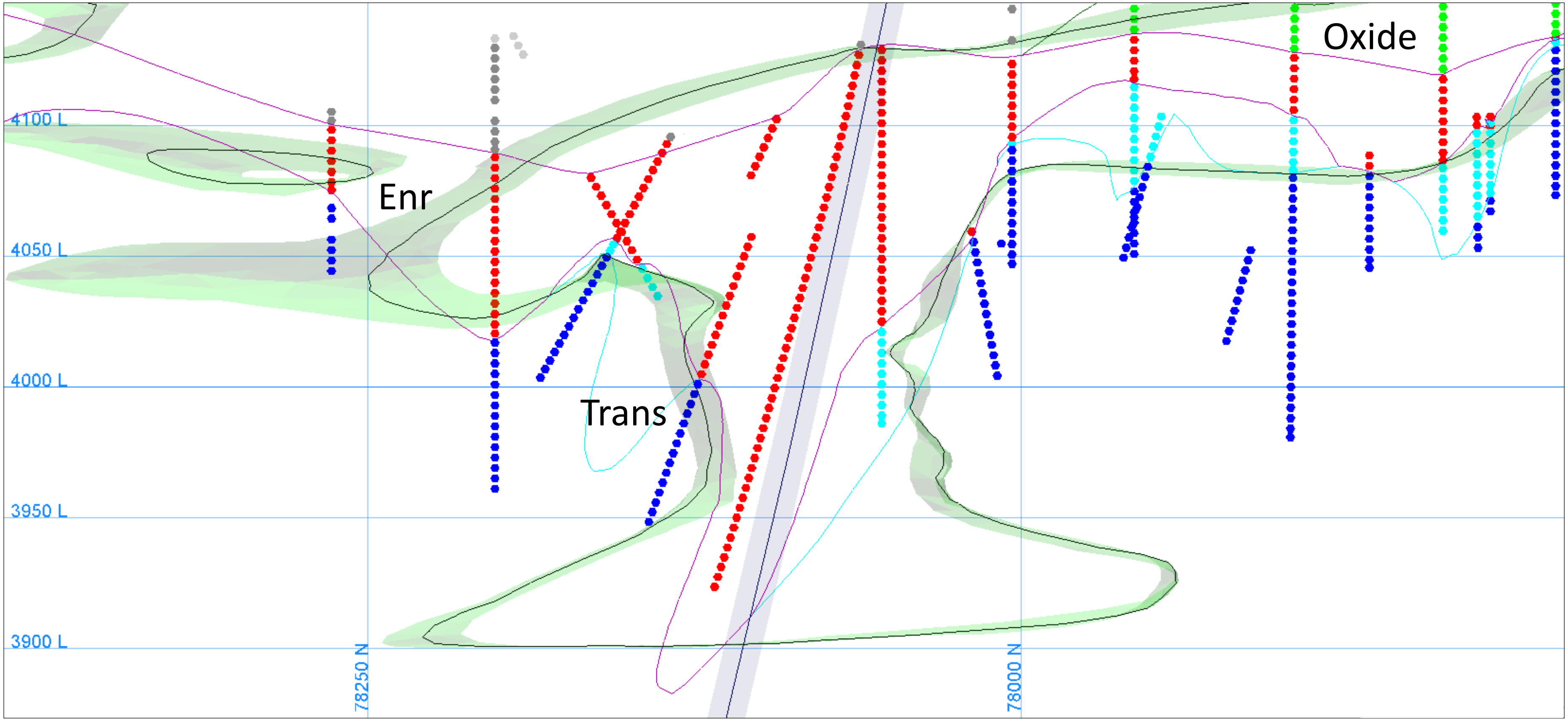
At 0.15% Scu cut-off the Undomained model predicts -6.5% less metal

At $2.50/lb Cu this equates to ~$950M Difference



The Model Compared to Grade Shell

Cross Section View through the deposit



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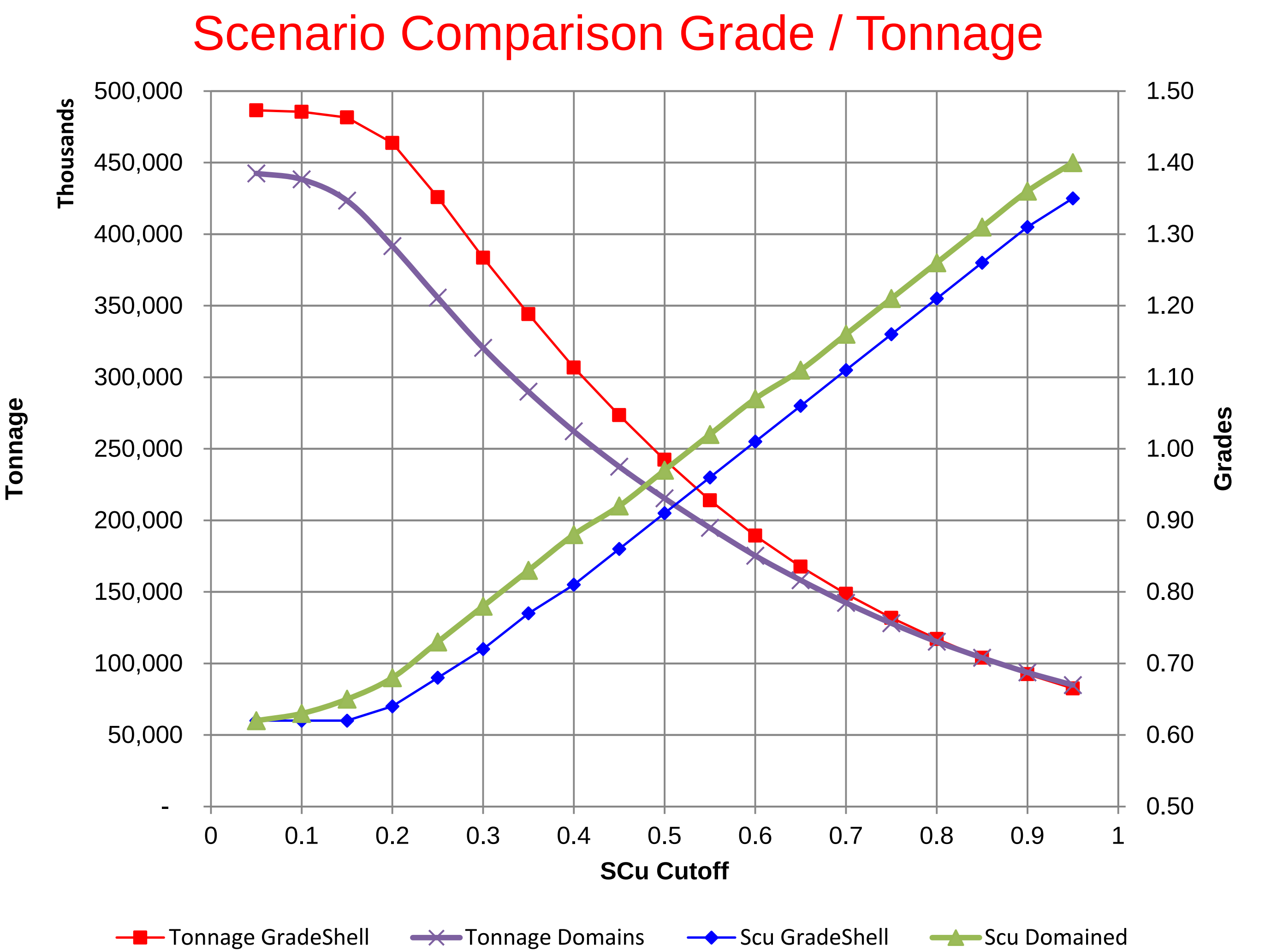
Truth (Domained) vs Grade Shell

Here we compare the original domained model, to an implicit grade shell model

A 0.15% Scu cut-off grade shell was produced via implicit techniques

At 0.15% Scu cut-off the grade shell model predicts 8.5% more metal

At $2.50/lb Cu this equates to ~$1.3B Difference



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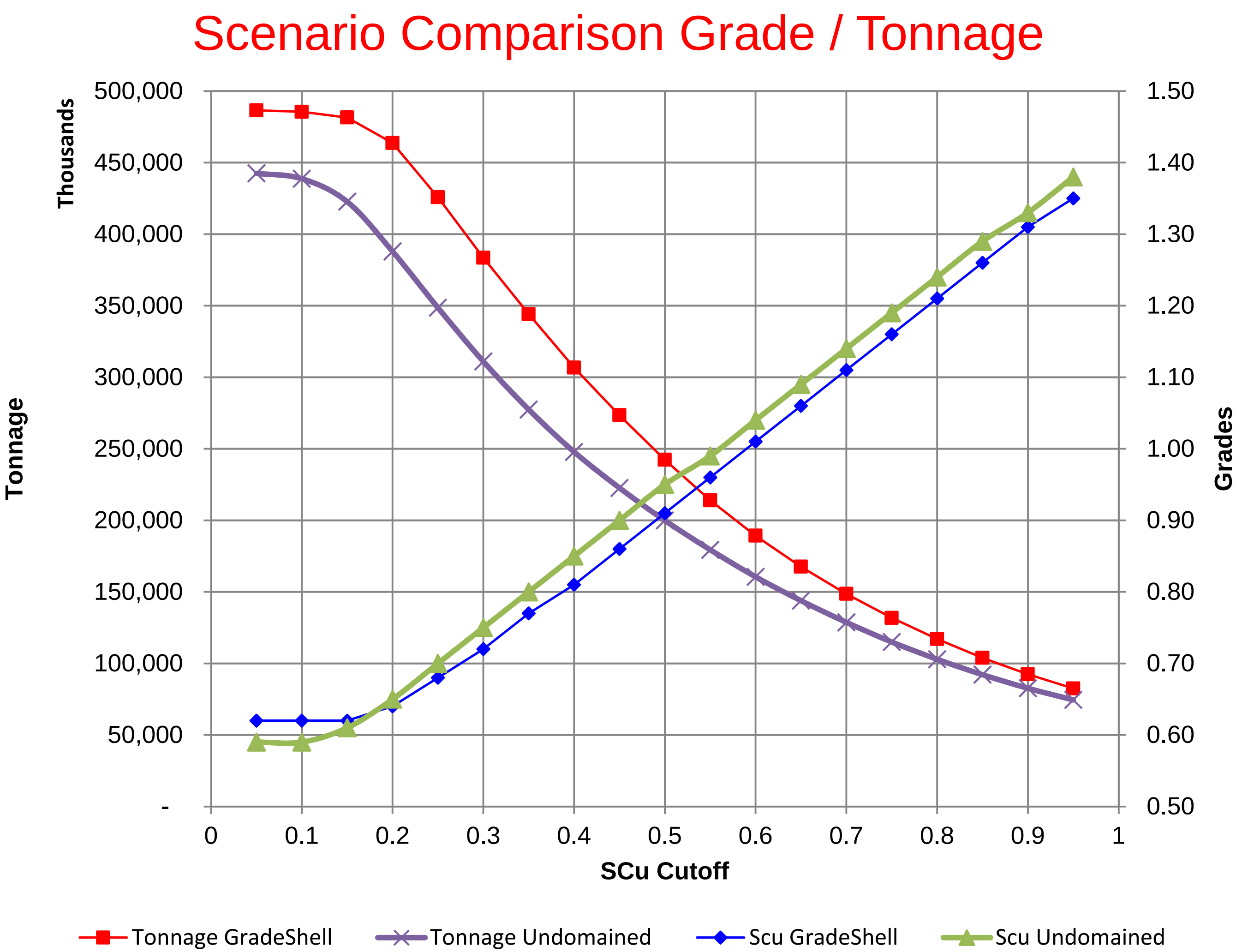
Undomained vs Grade Shell

To show the difference between the geology model (although undomained) and the gradeshell

At 0.15% Scu cut-off the grade shell model predicts 15% more metal

At $2.50/lb Cu this equates to ~$2.2B Difference



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Proposed Ideas Going Forward

Include write-up on Geological / Domain model validation

many reports contain very little back up / justification to parameter choices in geological model, and / or domain choices

Include volume / tonnage sensitivity information

test multiple methods (explicit, implicit parameter option A, implicit parameter option B, etc…)

Include a comparison of the block proportion summary from 3D geological model to a NN declustered model of data

has any volume bias been introduced?

Conclusion

Geostatistics requires an artistic component

Geological features are NOT random

Grades can be interpolated IF geological features are understood

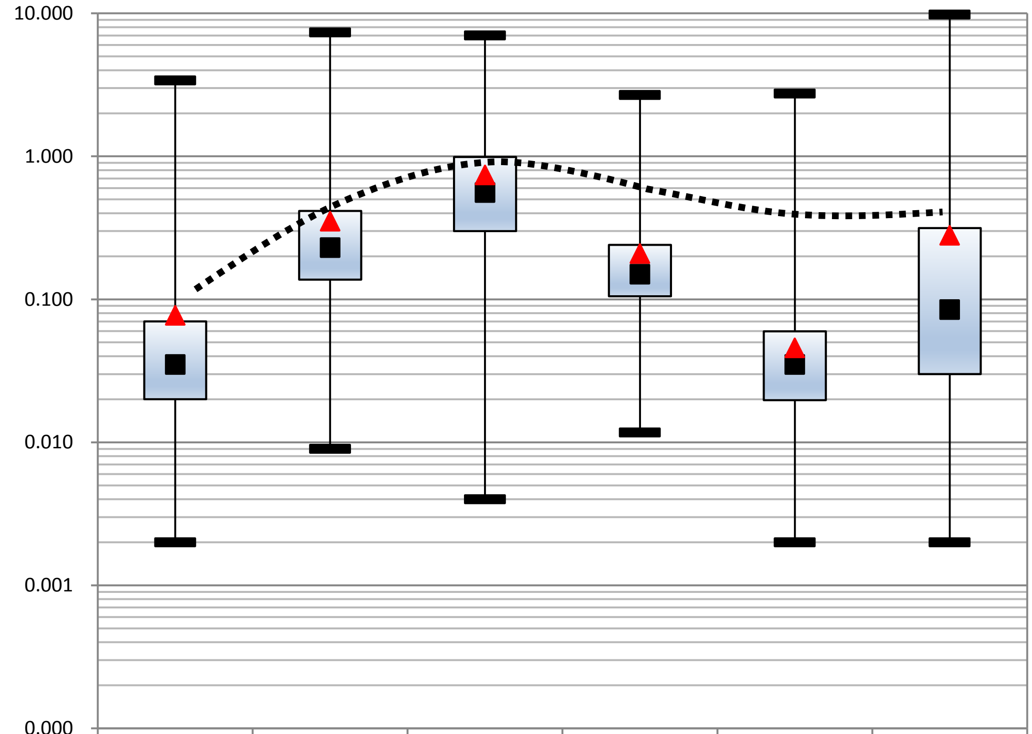
Computers & Software should not be expected to do all the work, the input and guidance must come from the geologist

BUT the use of computers & software gives geologists power and control, like we have never seen before

Ore grades often change considerably from zone to zone, so overall contained metal will be directly correlated to volume representation of the high grade geological features

Test multiple methods to understand the uncertainty associated to model

Models are expected to be reproducible, so parameter choices must be disclosed



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Thank You