Extracting Value from Downhole Data using Quantitative Analytical Techniques

ASEG Downhole Logging Workshop

Perth WA, February 14, 2015

Outline

- Importance of Rock properties
- Where is all the petrophysical data?
- Importance of data quality and consistency
- Quantitative data analysis: benefits and applications
- Examples and case studies of extracting value from quantitative data
  - Nickel example
  - Iron ore
  - Gold

Importance of Physical Rock Properties

- Physical properties are the quantitative link between geology and geophysics.
- Respond to lithology, mineralization, alteration, porosity, and mechanical rock properties
- Capable of providing key insights into ore grade, ore delineation, geometallurgy, geotechnical properties and hydrogeology.
- Can be used for unbiased classification into rock property domains and establish proxy relationships.
- Applications include:
  - Objective rock type classification – assist with core logging
  - Providing inversion constraints
  - Reliably “in fill” and predict values for expensive or time consuming ex-situ tests
  - Estimating ore grade, recovery, and geometallurgical parameters

Where is all the Petrophysical data?

- The missing link?
- Why are rock properties rarely measured in mineral exploration?
- Standard practice in the oil and gas industry – 100% of drill holes are logged with petrophysics
- DGI estimates in-situ rock properties are measured on only 2% - 5% of drilled metres in Canada
- Often completed as an afterthought – rarely proactively planned for, or considered as part of an exploration budget

Drill Program Costs for Advanced Exploration in North America

Recent Poll of North American Projects (multiple sources):

Typical “all in” Drill Program Costs = $600/m

Includes: camp, supervision, drill contractor, core logging, geochemistry/assay costs

Geochem analysis typically $65-100/sample for 64 element suite or 10% of “all in” drilling budget.

200 hole program with average depth of 400m x $600/m = $48 million total cost

Including an estimated $5.2 million on geochem analysis

What are the typical borehole logging costs for such projects????

The 2-4C Process: Overview

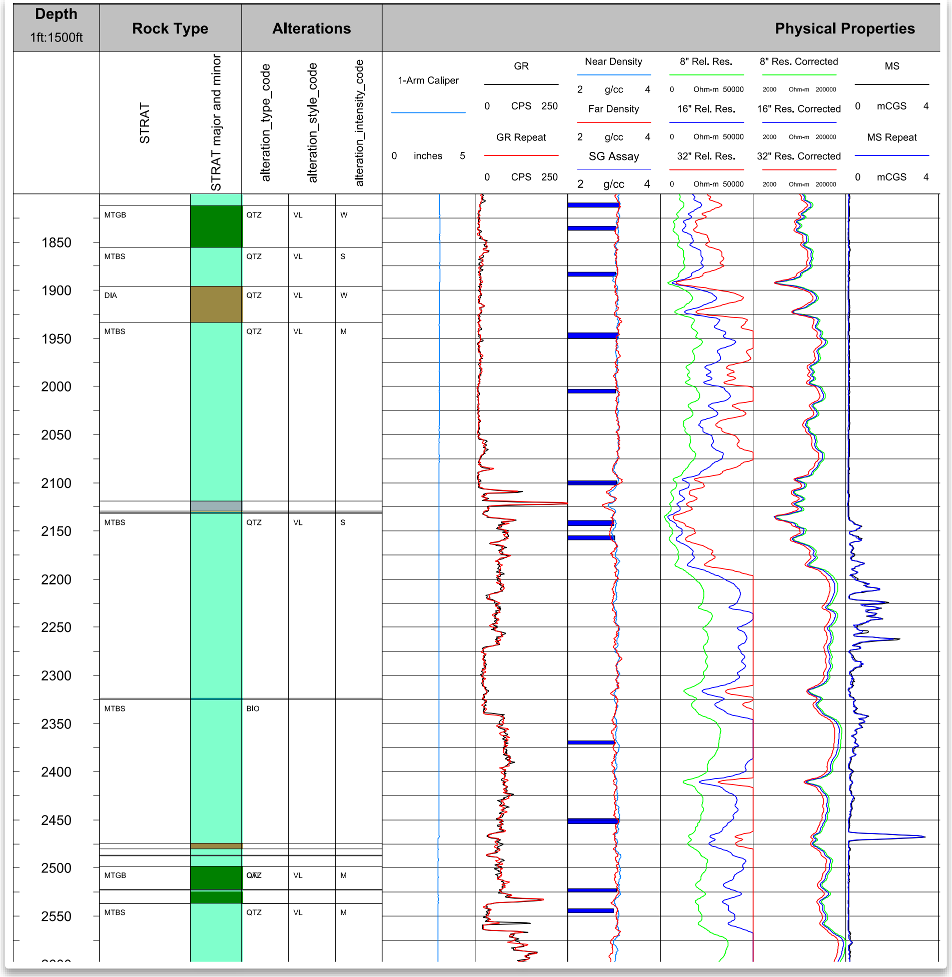
- Robust, data-driven technique.
- Uses a combination of data validation, machine learning, cluster analysis and conventional statistics.
- Creates unbiased classification schemes and builds proxy relationships from disparate datasets.

INPUTS (DRILLING)		OUTPUTS (2-4C PROCESS)		KEY APPLICATIONS
Lithology Geochemistry Geometallurgy Geotechnical Physical Rock Properties	→	Unbiased classification schemes Proxy relationships between traditionally isolated datasets.	→	Objective rock type classification. Intelligent survey design. Linking geology and geophysics. Providing inversion constraints. Estimating ore grade, recovery, geotechnical and geometallurgical parameters.

Why 2-4C?: Integration v. Isolation

- No definite visual correlation between core-logged lithology and individual physical properties.
- Rather than looking at each parameter in isolation, consider them together (clustering!).

Integration v. Isolation



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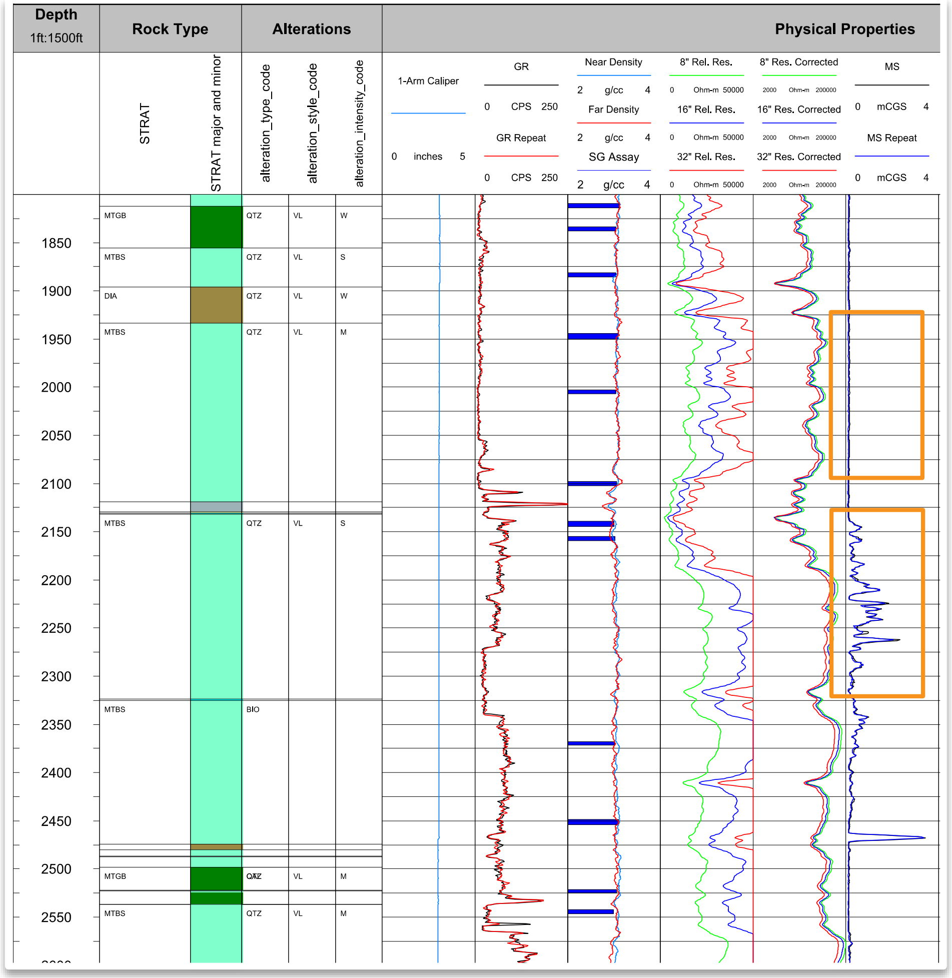
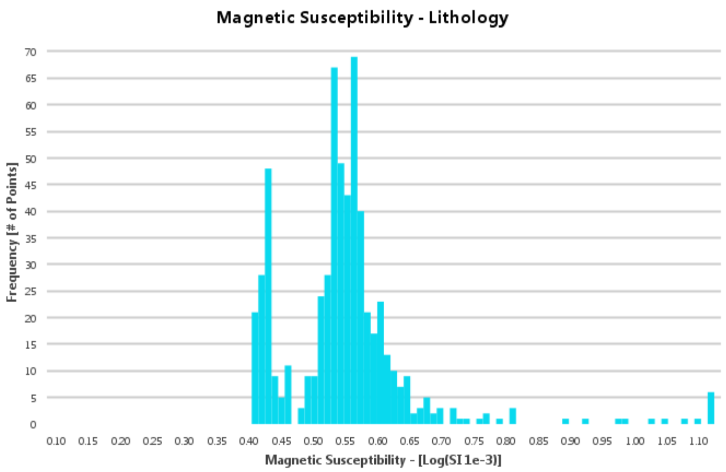
Why 2-4C?: Integration v. Isolation

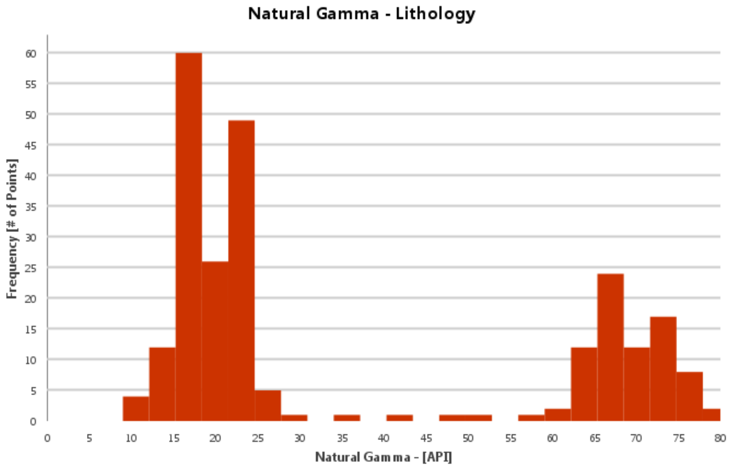
- For example:
  - Same core logged lithology (indicated by box) has distinctly different magnetics signature.
  - Considering just magnetics data for identification would have been insufficient.
  - Lithologies often have multiple physical rock properties signatures.



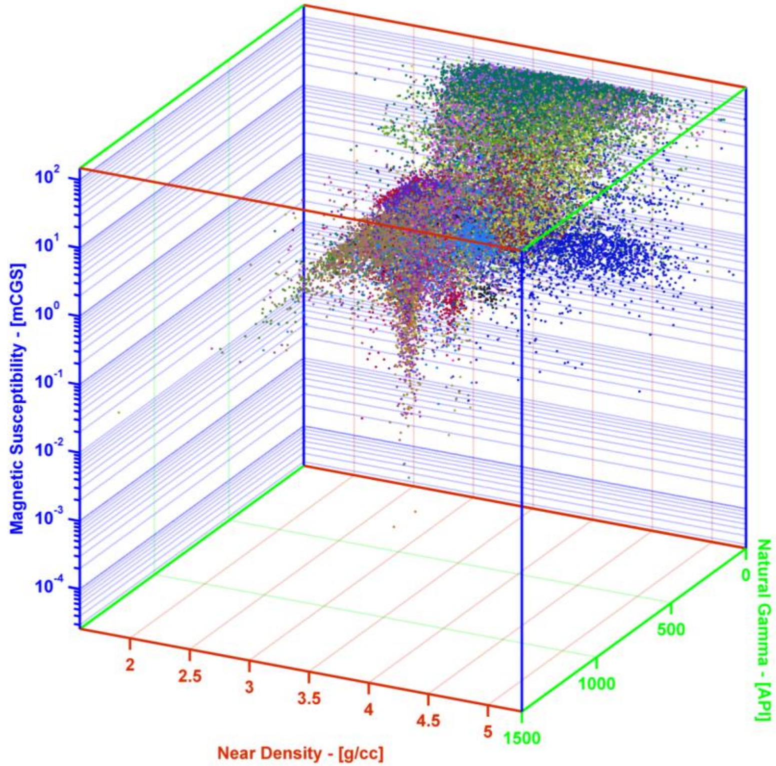
Why 2-4C?: Multi-Modal Distribution Problem

- Correlating subjective core-logged geology with individual physical properties parameters often results in multi-modal distributions – undesirable.
- Classifying the rock quantitatively using the 2-4c process eliminates this problem resulting in a robust and consistent classification scheme.
- Better at mapping variation and classifying the rock into domains that are more relevant to geometallurgy, geotechnical, and geophysical applications.

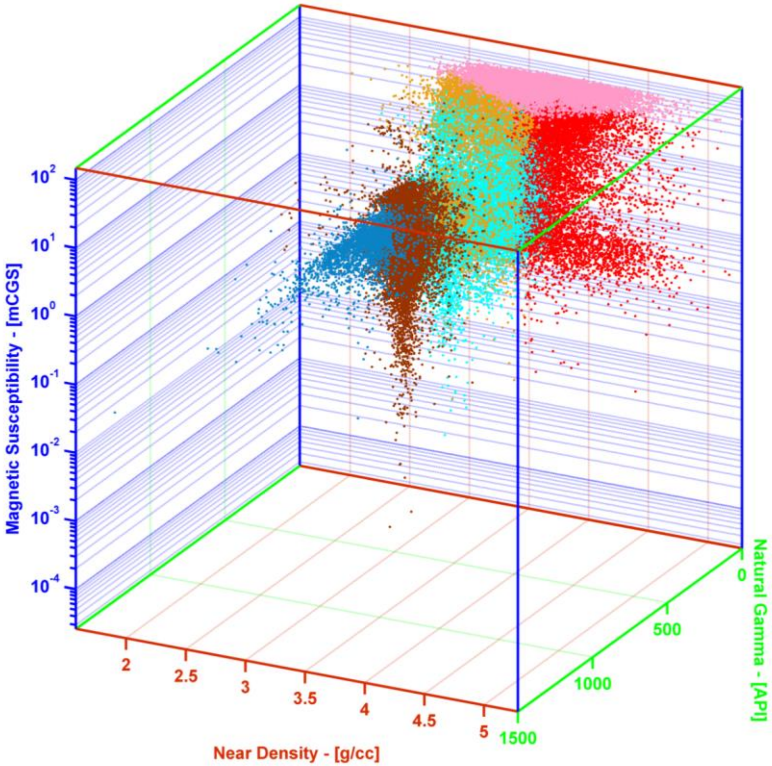




3D Cross Plot of Rock Property Data



classified by core-logged geology



classified by rock property domains

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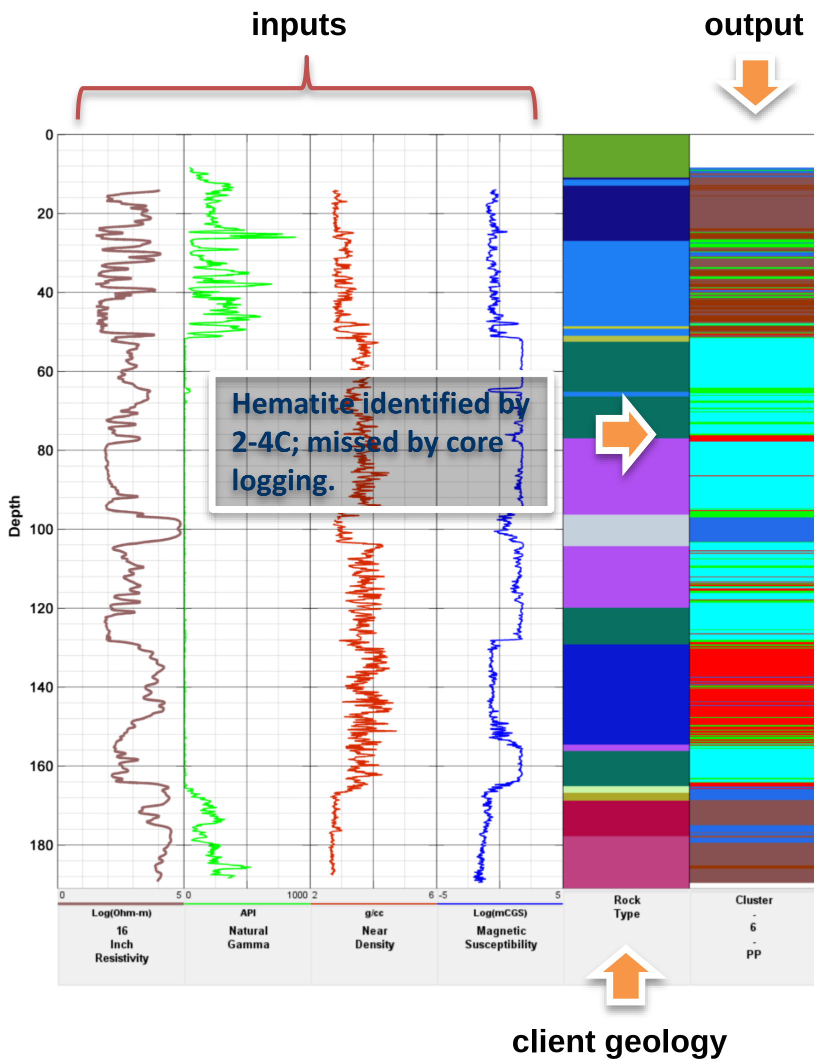
Iron Ore Case Study: Introduction

- Iron Ore deposit in Eastern Canada.
- 70 boreholes of data; physical properties logged by DGI.
- Inputs:
  - Physical properties
  - Logged geology from client
  - Geochemical assay results
- Outputs
  - Petrophysical domains created using physical rock properties
  - Proxy data and infilling of missing data

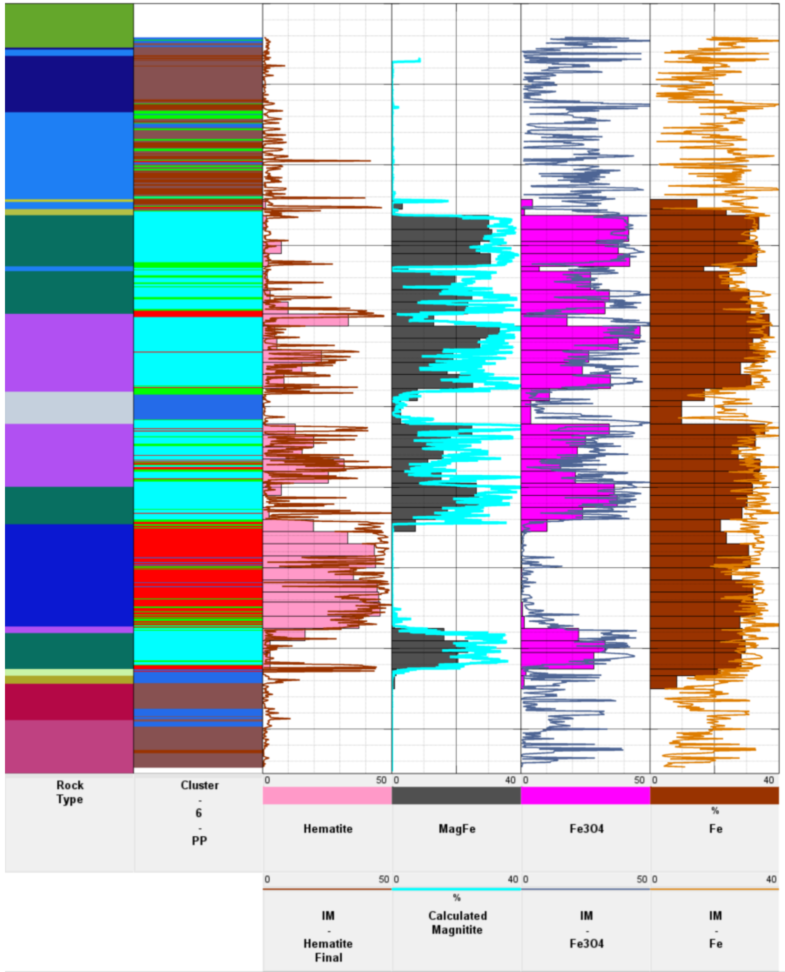
Iron Ore Case Study: Physical Rock Property Domains



- 4 physical rock properties on 70 boreholes analyzed to create statistical clusters.
- Correlation between clusters and logged geology.
- Hematite zone identified from physical properties, missed by core logging (later confirmed by assay results).

Iron Ore Case Study: Proxy Relationships

- Same four rock properties have been used to produce proxies for various parameters.
- Proxies created using a robust, empirical correlation matrix.
- Bars: assay values.
- Lines: DGI prediction.



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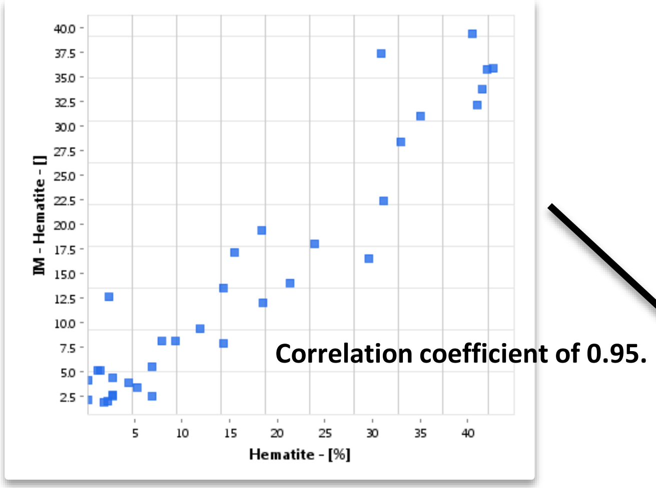
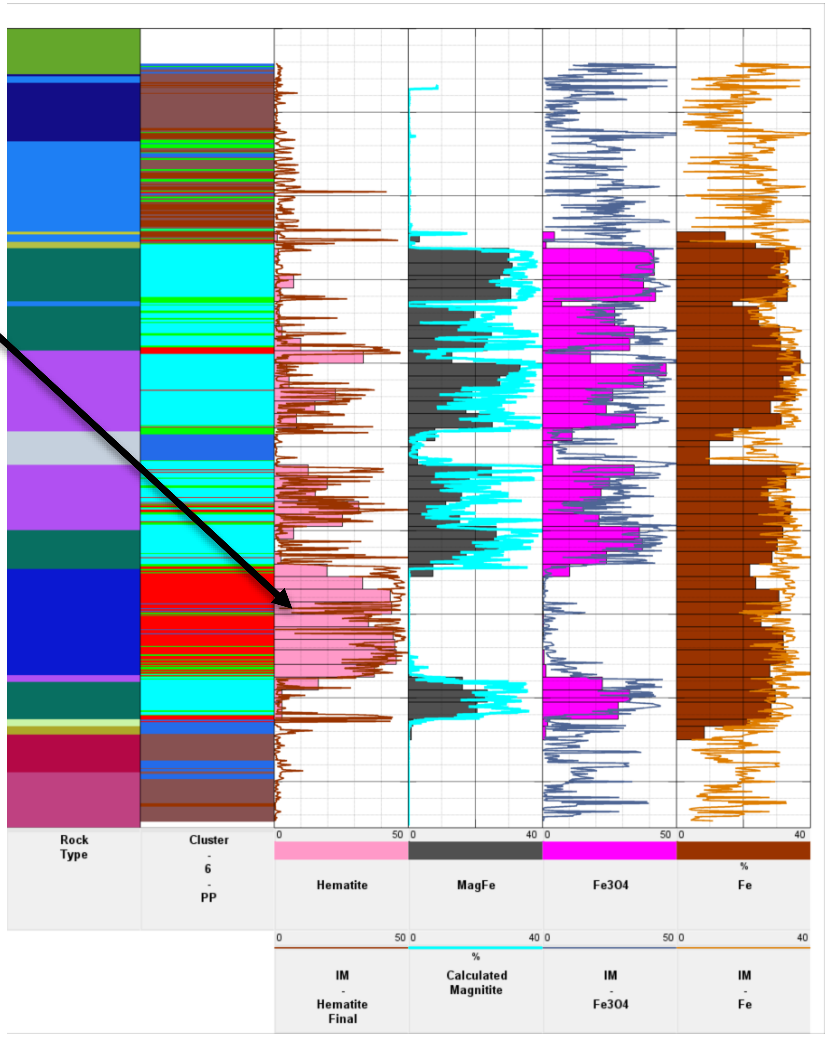
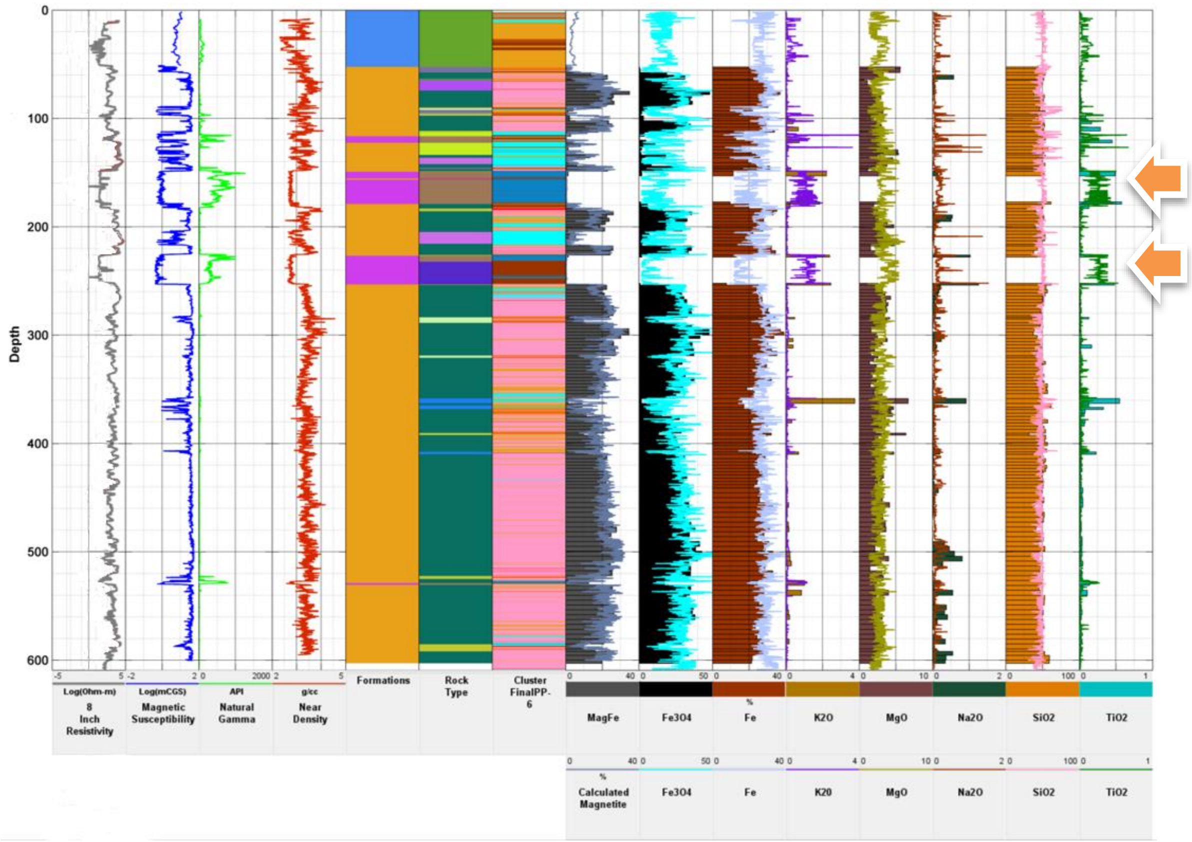
Iron Ore Case Study: Proxy Relationships





- Illustrated is a cross-plot of predicted and assayed hematite values.
- Correlation coefficient of 0.95.

Iron Ore Case Study: Proxy Relationships



- Assay values missing for regions of low core recovery (indicated by the arrows).
- Able to fill in missing data using proxy relationship results.

Kami Project - Alderon Resources

Initial Deliverables for DGI Participation

- Interpreted optical televiewer (OTV) for complex structural geology
- Quantitative magnetic susceptibility for % magnetite estimates
- Near focus density for specific gravity
- Initial geotechnical assessment with acoustic televiewer (ATV) and full waveform sonic

Additional Drivers

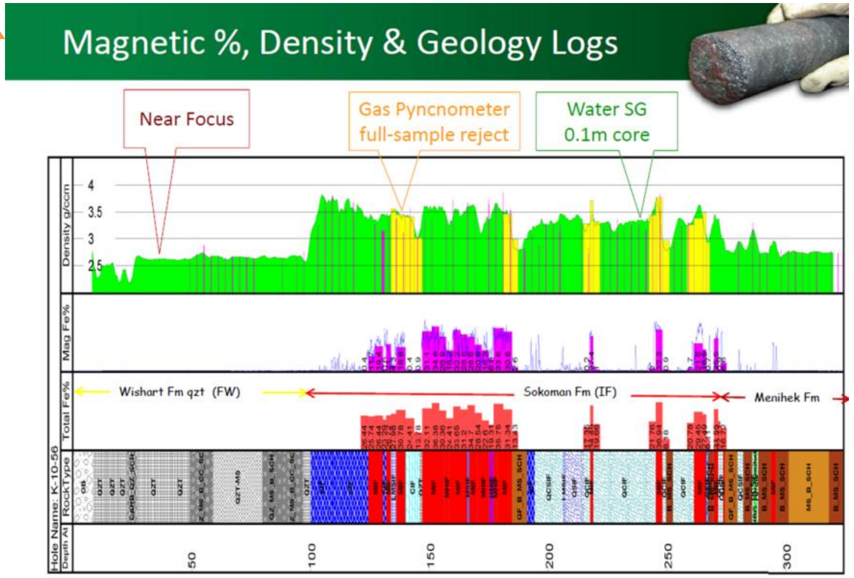
- Maximize the amount of data to leverage the drilling investment
- Compress timelines

Accomplished

- 120 Boreholes surveyed over 2 years
- Quantitative physical rock properties data taken in 10 cm intervals for a statistically robust dataset

Results

- All deliverables accomplished
- Prediction of assay results through the 2-4C Process – i.e. understanding sooner
- Saved 9 months and 17 boreholes for the geotechnical program (approx. $4 million in cost savings)



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Decar Project

- Low grade/high volume disseminated Nickel - Awaruite
- Physical Properties acquired in-situ
- Goal - quantitative characterization of ore and host rock
  - Describe rock types quantitatively with physical properties
  - Augment traditional geologic logging and geochem/assay sampling
  - Maintain or improve quality and accuracy
  - Increase speed, data density and relevance
  - Applications in sequence: Resource, Structural, Geometallurgy, Rock Mechanics, Geotechnical, Mine Planning, Production Optimization
- Optical and Acoustic Televiewers acquired in-situ
- Ultimate application = Ni recovery prediction

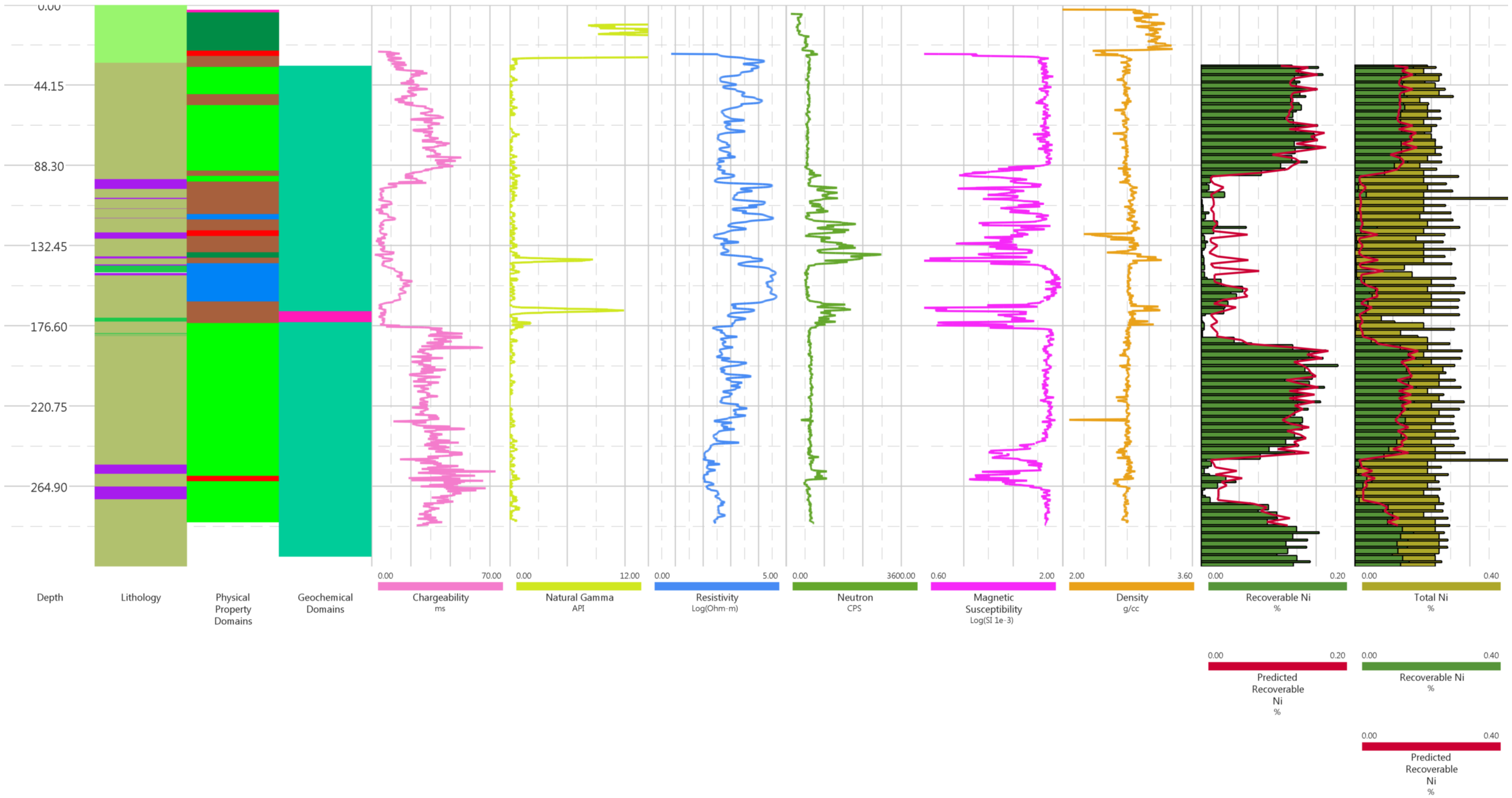
Decar Preliminary Observations

- Geologically indistinct
  - >90% Peridotite; varying degrees of Serpentinization – non-visual
  - Not relevant to recoverable Nickel
- Geochemically indistinct
  - Closed system - homogeneous from a geochemical perspective
  - Not relevant to recoverable Nickel
- Physical Properties Domains reveal variation
  - Reveals variation in Peridotite
  - Maps to recoverable Nickel
- Televiewers
  - Dyke corrected orientation for true thickness and volume contribution

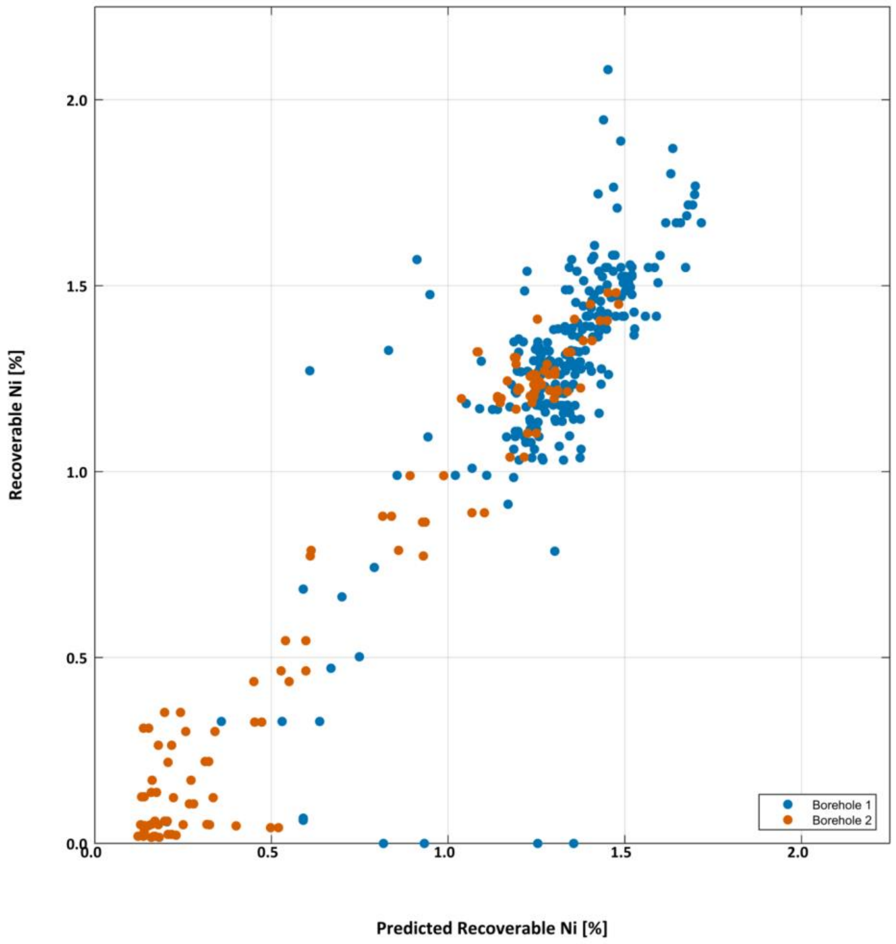
Decar program data acquisition summary

- Approximately 25,000 metres; 69 boreholes
- 54 boreholes surveyed – partially or completely
- 3 attempted in 2010; 25 of 31 in 2011; 29 of 35 in 2012
- Physical Properties acquired:
  - Density, Magnetic Susceptibility, Resistivity, Induced Polarization, Neutron, Natural Gamma
- Optical and Acoustic Televiewer acquired
- Gyro for x,y,z positional accuracy acquired

Borehole #2: Recoverable Ni Prediction Results



Recoverable Ni (Lab Measurement) vs Recoverable Ni Prediction from Rock Property Data Boreholes # 1 and 2



- $R^2=0.9216$

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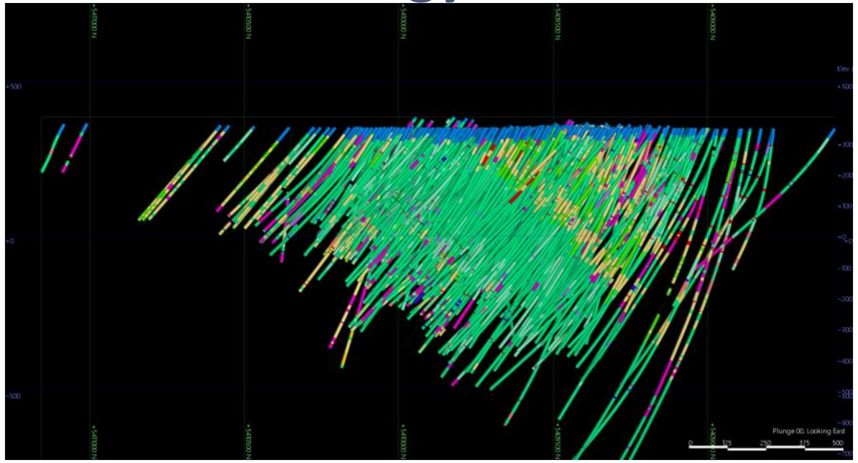
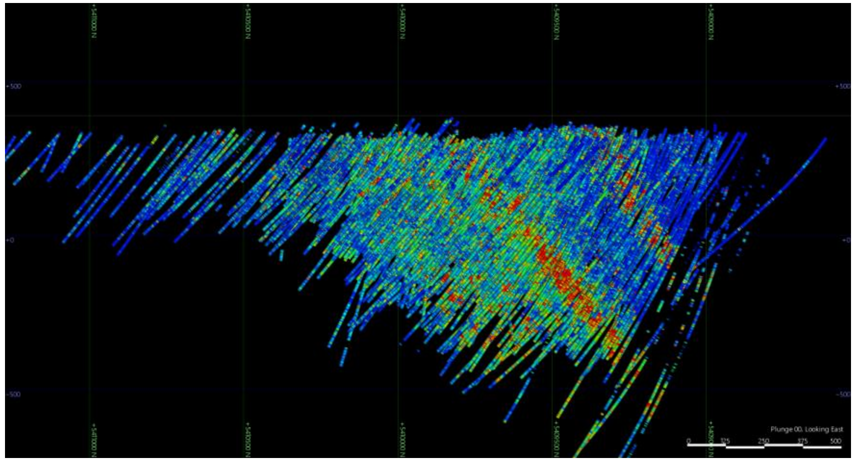
Physical Properties Correlation Table

	DTR Ni	DTR Ni Prediction	Chargeability	Density	Magnetic Susceptibility	Natural Gamma	Resistivity
DTR Ni	1.00	0.97	0.17	-0.19	0.41	-0.18	-0.35
DTR Ni Prediction	0.97	1.00	0.18	-0.23	0.43	-0.17	-0.33
Chargeability	0.17	0.18	1.00	-0.32	0.30	-0.11	-0.19
Density	-0.19	-0.23	-0.32	1.00	-0.23	0.38	0.15
Magnetic Susceptibility	0.41	0.43	0.30	-0.23	1.00	-0.34	0.23
Natural Gamma	-0.18	-0.17	-0.11	0.38	-0.34	1.00	0.05
Resistivity	-0.35	-0.33	-0.19	0.15	0.23	0.05	1.00

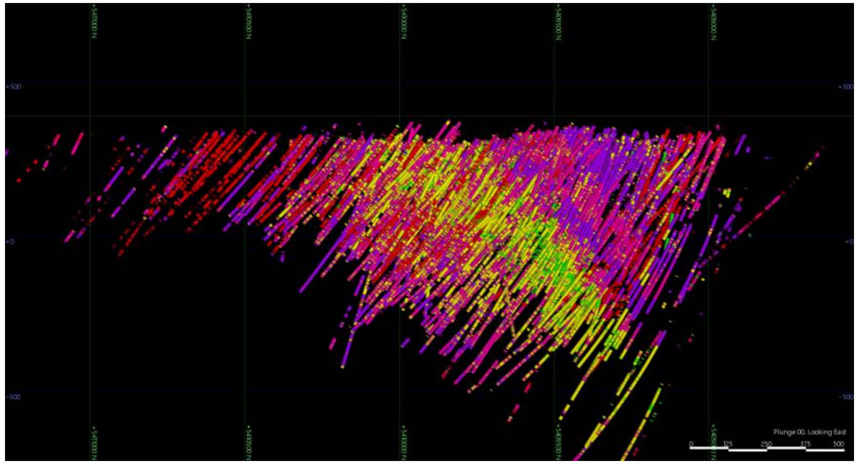
Lithology compared to 2-4c Classification Au

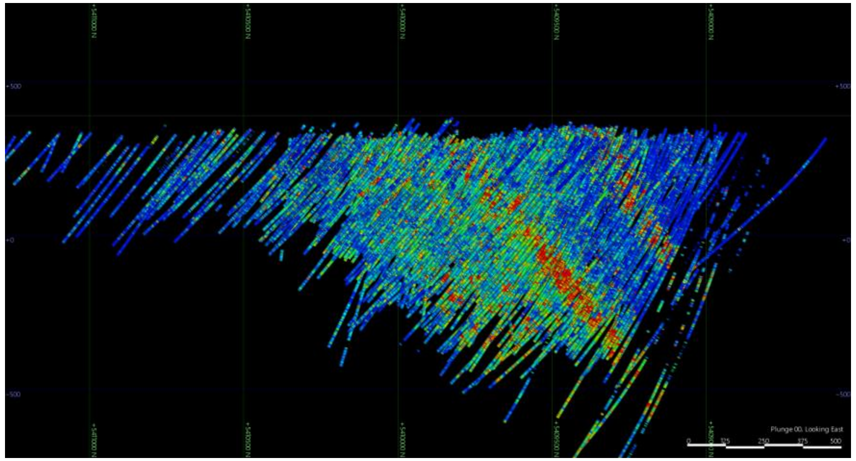
Lithology vs Au



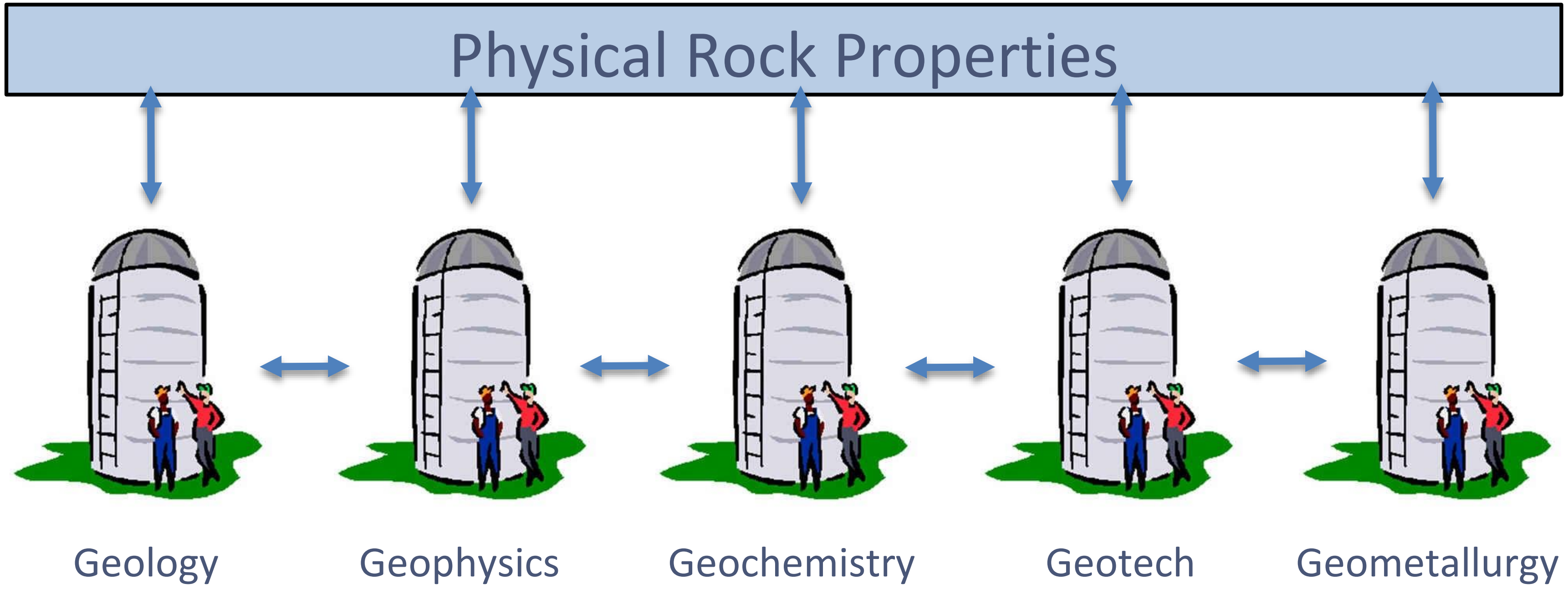


2-4c Classification vs Au





Data Integration through Physical Rock Properties



Challenges with Data

- Inconsistent data: quality, calibrations, format
- Adhock acquisition programs – missing parameters etc
- Data preparation challenges

- New York times article – Aug 17, 2014 "***For Big-Data Scientists, 'Janitor Work' Is Key Hurdle to Insights***"
- "… 80 percent of their time mired in this more mundane labor of collecting and preparing unruly digital data, before it can be explored for useful nuggets."
- "It's an absolute myth that you can send an algorithm over raw data and have insights pop up,"

Raise the Bar on data Quality and Consistency

- Good for all stakeholders – Mineral exploration and mining companies, service providers, equipment suppliers, entire industry
- We can increase the value of downhole logging to any project in the way we plan, execute, and analyze results.
  - The best data in the world is useless if it sits on the shelf
  - inconsistent data is limited in value
  - poorly designed / ad-hock surveys do not provide the robust data sets required for advanced multivariate analytics
- Requires all stake holders to work together
- Workshops like today are a great start

THANK YOU!