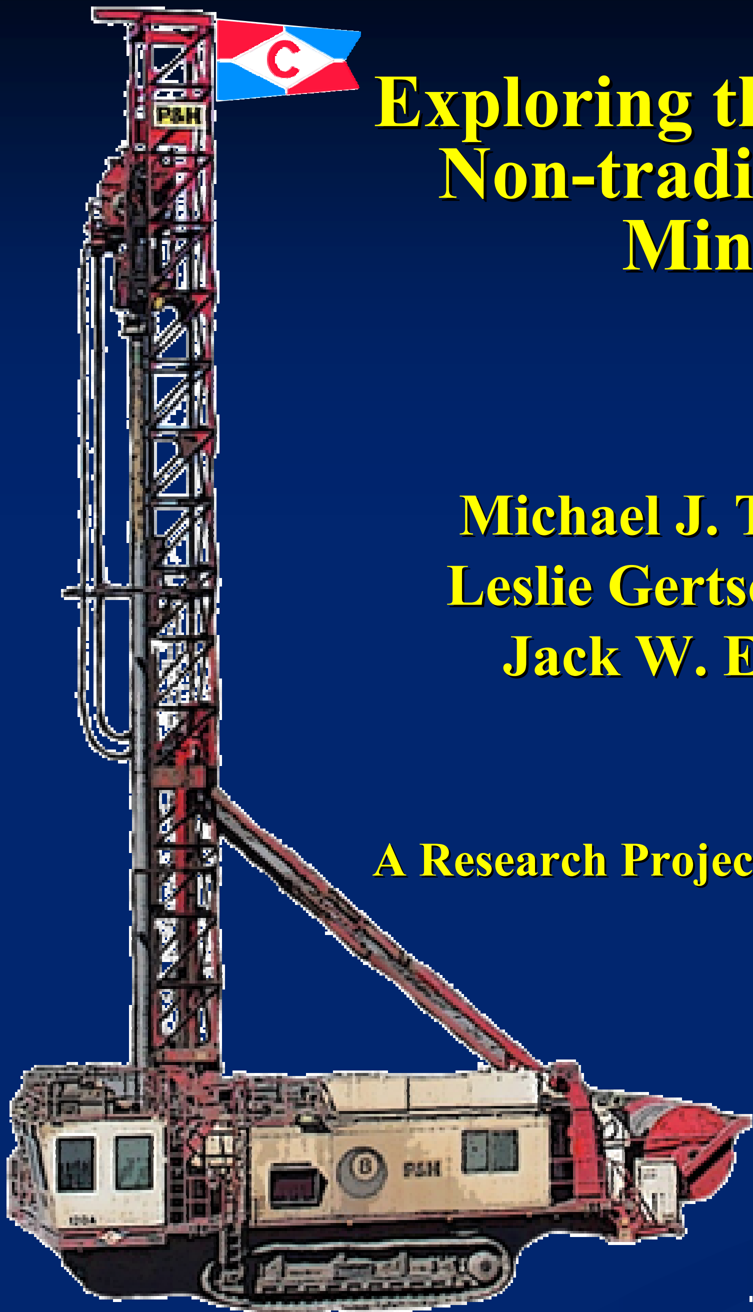


Exploring the Data – Adding Value with Non-traditional Geologic Initiatives on Minnesota's Mesabi Range

Michael J. T. Orobona, Cleveland-Cliffs Inc.
Leslie Gertsch, University of Missouri – Rolla
Jack W. Eloranta, Eloranta & Associates

A Research Project Funded by U.S. Department of Energy and Supported by Industry

Total Ore Process Integration and Management – Project Partners

Iron Ore Mines:

Hibtac, Cleveland-Cliffs
Minntac, US Steel

Supporting Companies:

Wipware: Size Analysis Imaging
Eloranta & Associates: Blasting and Comminution
Mount Sopris Instruments: Blasthole Geophysics
Thunderbird Pacific: Drill Monitoring
Viking Explosives: Blasting Analysis
Mintec: Orebody Modeling
Minnesota Explosives & Dyno Nobel: Blasting Analysis
Modular Mining: Ore Control & Drill Monitoring
Queens University: Ore Hardness Behavior

Funded by the US Department of Energy

Towards A New Approach

OBJECTIVE:

Increase Efficiency By Optimizing the Entire Mining and Processing System

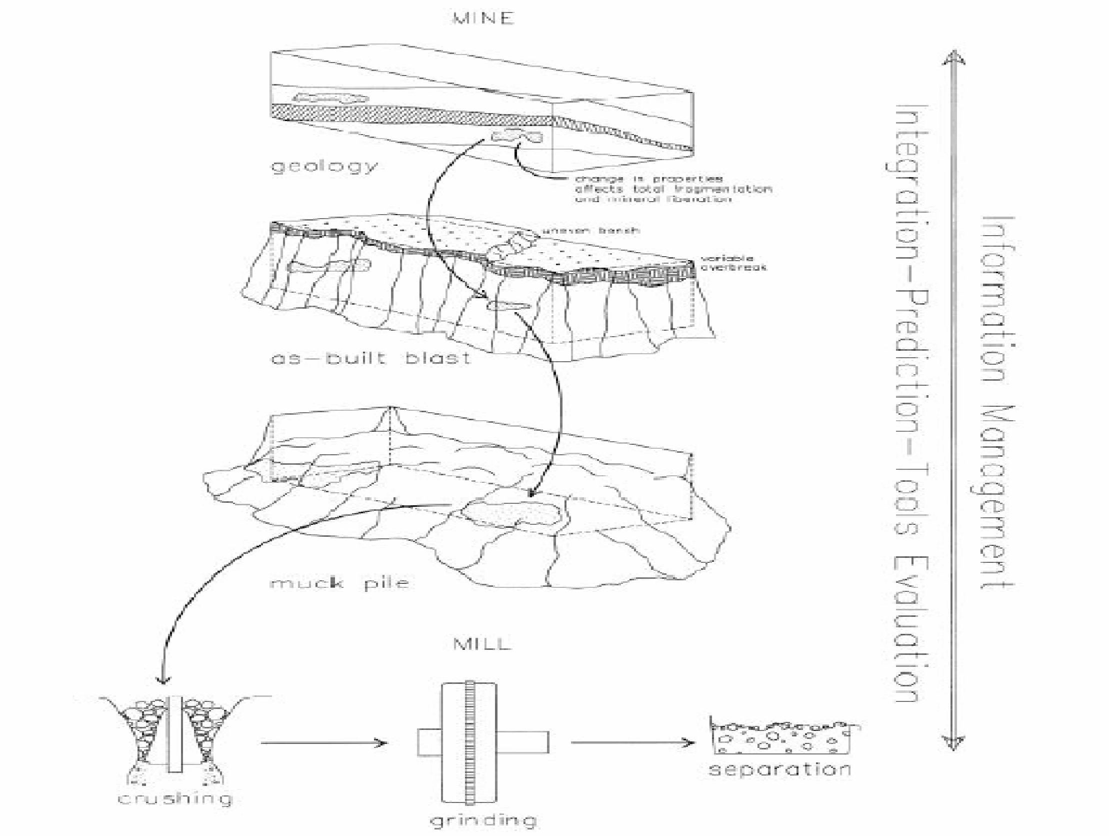
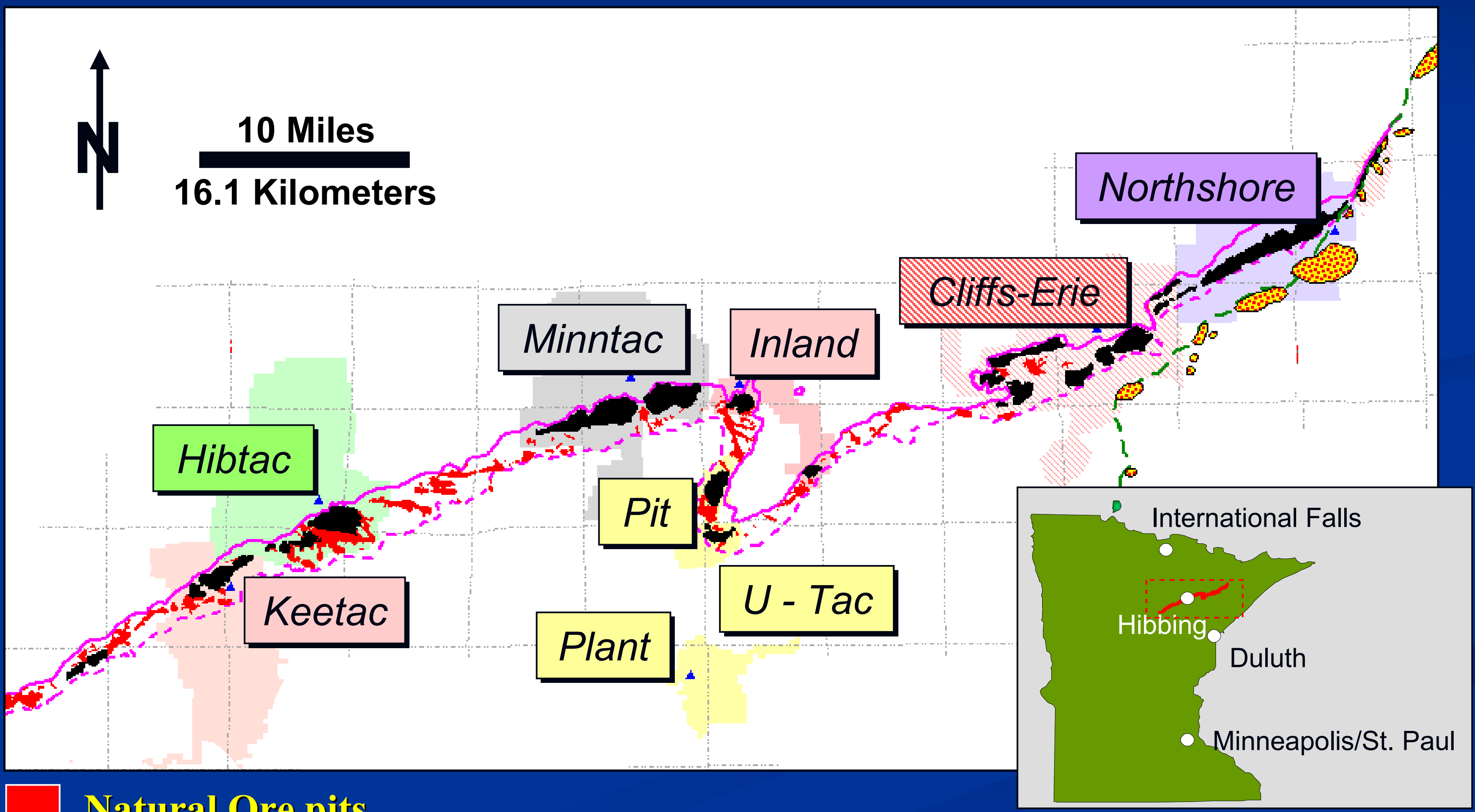


Figure 1. Schematic diagram of the the TOPIM System concept. TOPIM will provide mine and mill personnel with the means to identify areas in the geology that affect downstream outcomes, in time to react before the ore reaches the sensitive processing step.

STRATEGY:

1. **Baseline Current Practices and Knowledge**
2. **Propose Hypotheses**
3. **Make Changes to the Process and *Measure* the Effects**
4. **Increase Understanding and Then Control**

Mesabi Iron Range:

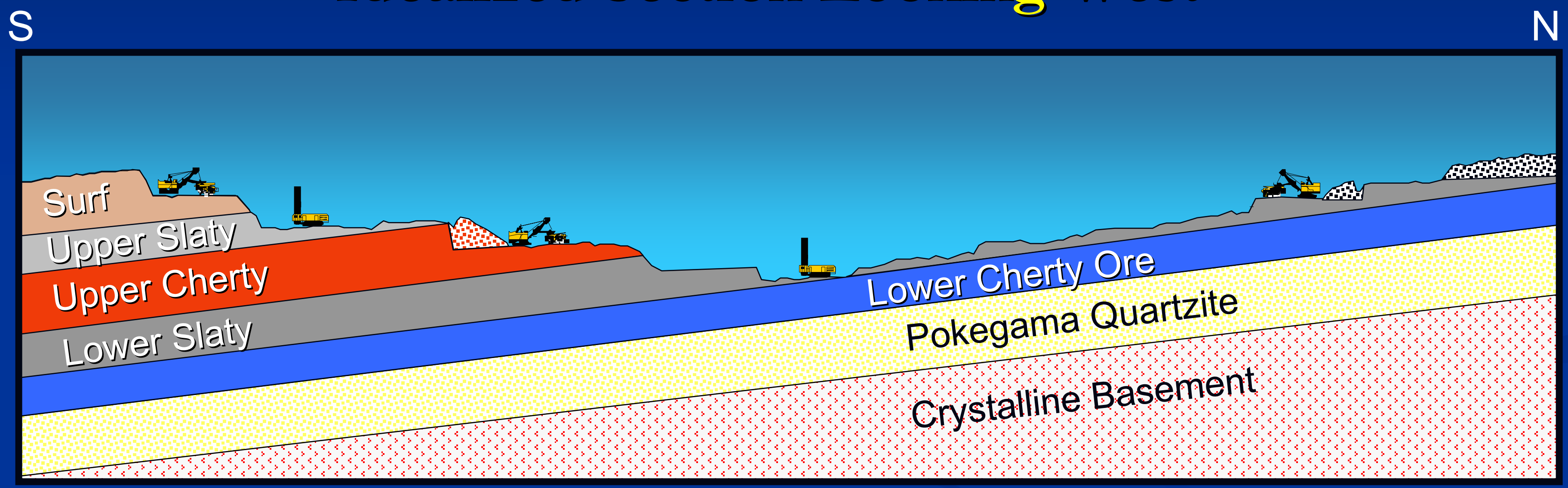


Natural Ore pits

Taconite mines

Central Mesabi Range - Taconite Mine Development

Idealized Section Looking West



- Dipping benches average 4% slope for blending – slightly askew to geology
- 40 foot (13 m) average bench height – typically 3 benches of ore
- Simple geologic framework with a complex metallurgical response

Autogenous crushing and grinding circuit

- Single stage crushing
  60” (1.5 m) gyratory crushers
  set to 9” (23 cm) opening
- Single stage grinding
  36’ (11.0 m) autogenous mills
  concentrate 75-85% -325 mesh

Exploring the Data…the Challenge

- Underutilized data offer mine geologists a value creation opportunity that should be explored much the same as prospective ground
- Large amounts of data are collected by, but not always evaluated by the geology department
- In this computer age – staggering amounts of data are compiled in relational databases, but unexamined
- Many physical rock properties are considered “engineering” variables
- The mine geology function is too often task-oriented
- Though well positioned to address downstream processing issues, geologists commonly have little or no contact with ore dressing

PROCESS CONTROL

- Already Know Where the Metal is
- What Else Controls the Process?

  Chemical Properties

  Physical Properties

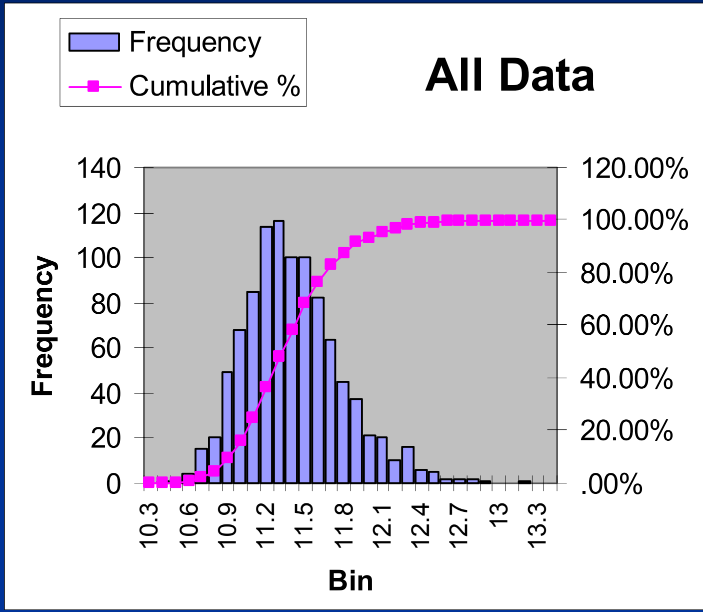
  $$W = 10W_i\left(\frac{1}{\sqrt{P_{80}}} + \frac{1}{\sqrt{F_{80}}}\right)$$ Bond's Equation (1952)

- Add New Control Properties to the Orebody Model

Tonnage Factor

- Imprecise bulk density is the most common error found in ore reserves
- Geologists – those most qualified to characterize tonnage – are often detached from what is considered an engineering function
- A few hand samples commonly quantify multi-million ton deposits
- Often "historic" precedents – little or no documentation

Tonnage Factor Estimations

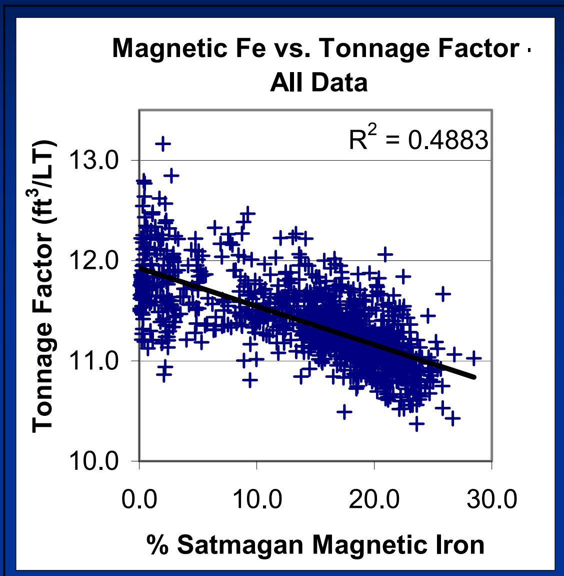


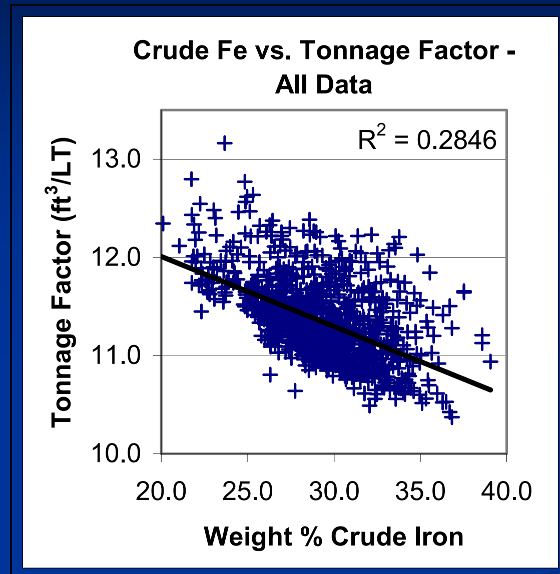
	CF/TN
Mean	11.36314
Standard Error	0.01222
Median	11.31687
Mode	11.15471
Standard Deviation	0.384112
Sample Variance	0.147542
Kurtosis	0.999521
Skewness	0.714137
Range	2.789576
Minimum	10.37282
Maximum	13.16239
Sum	11226.78
Count	988
Largest(1)	13.16239
Smallest(1)	10.37282
Confidence Level(95.0%)	0.023981

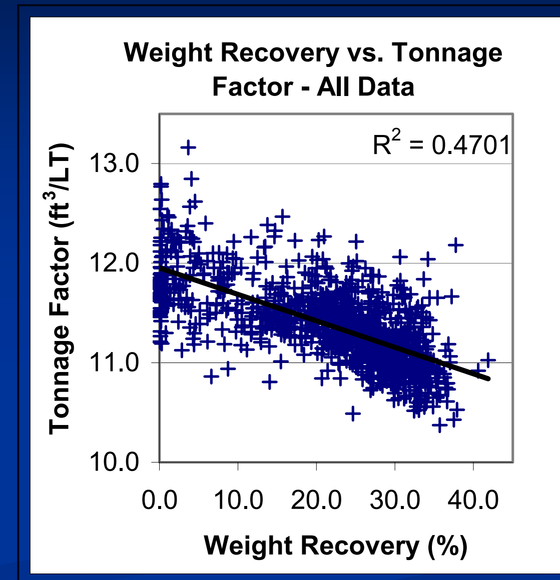
$$S.G. = \frac{Weight\ \ in\ \ air}{Weight\ \ in\ \ air - Weight\ \ in\ \ water} \qquad \text{i.}$$

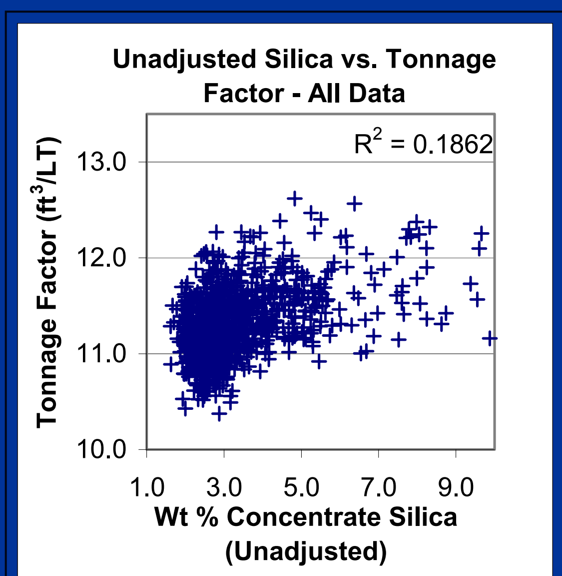
$$Tonnage\ \ \ factor = \frac{2240}{S.G. \times 62.4}\left(\frac{CF}{Ton}\right) \qquad \text{ii.}$$

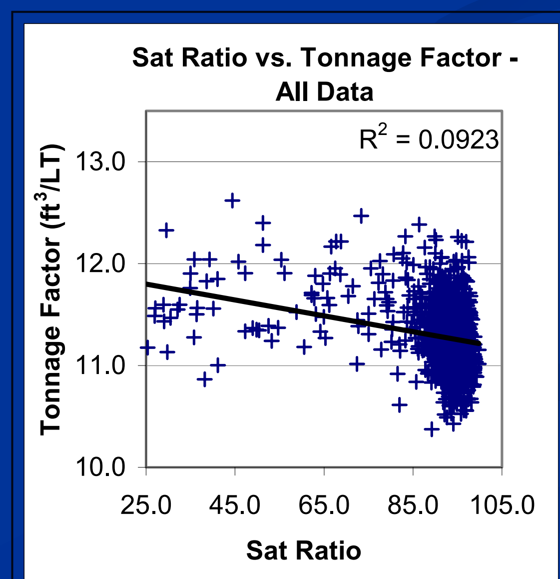
Tonnage Factor Modeling







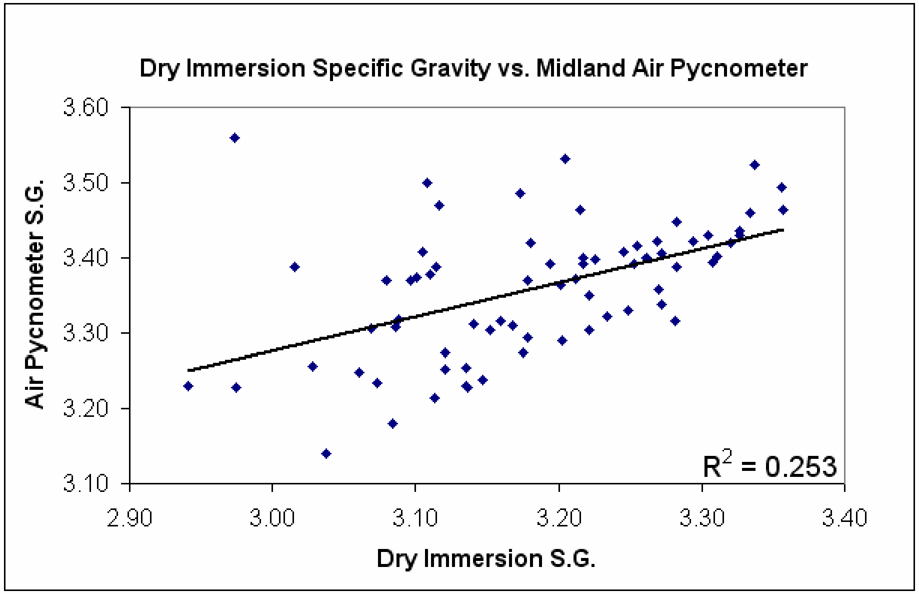


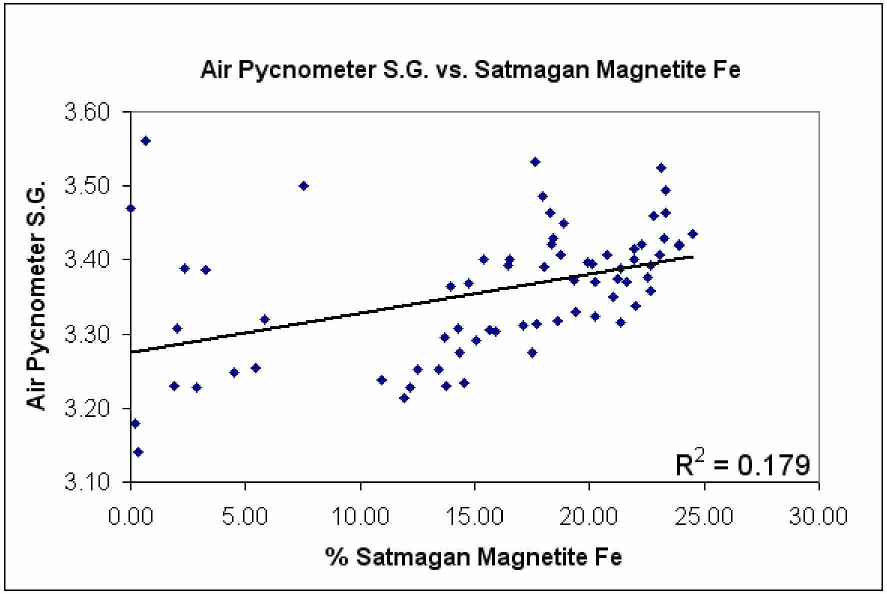


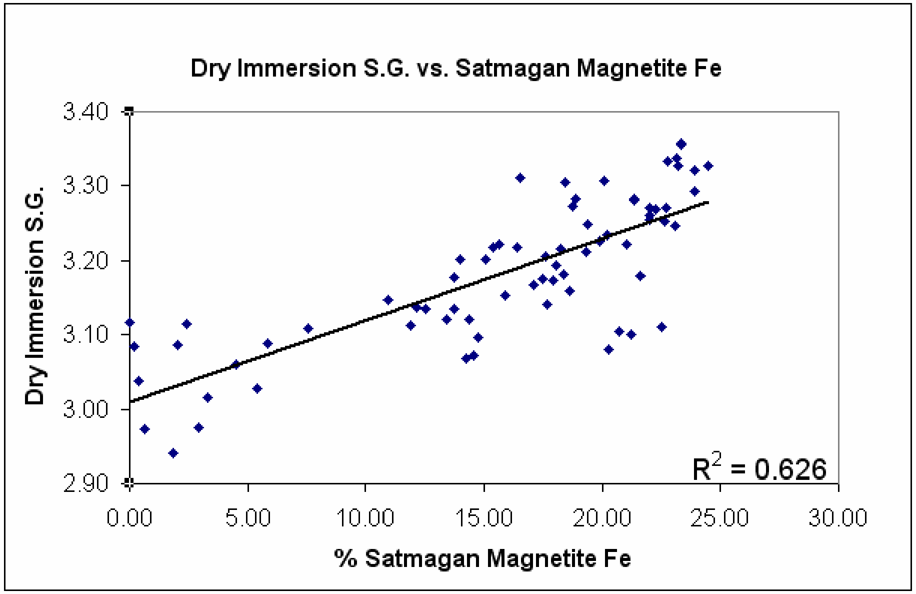
Model by…

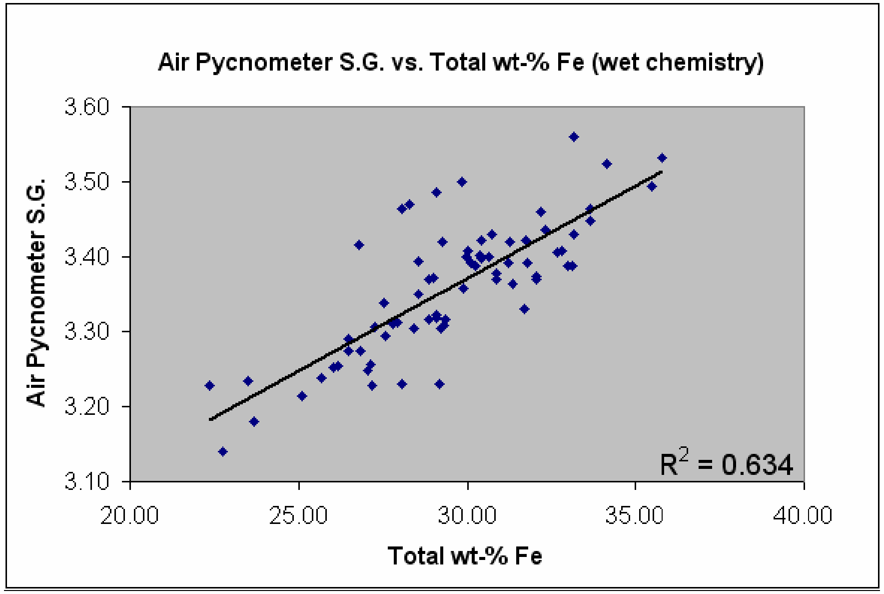
- Geology
- Location
- Met variable
- Ore/waste

Comparison of Sampling Methods

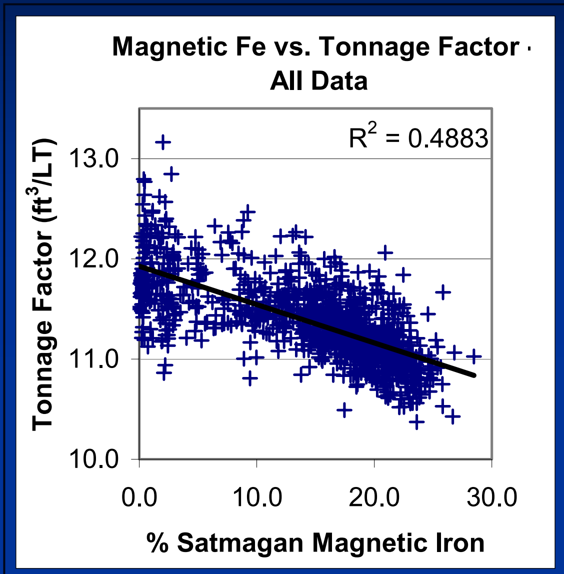


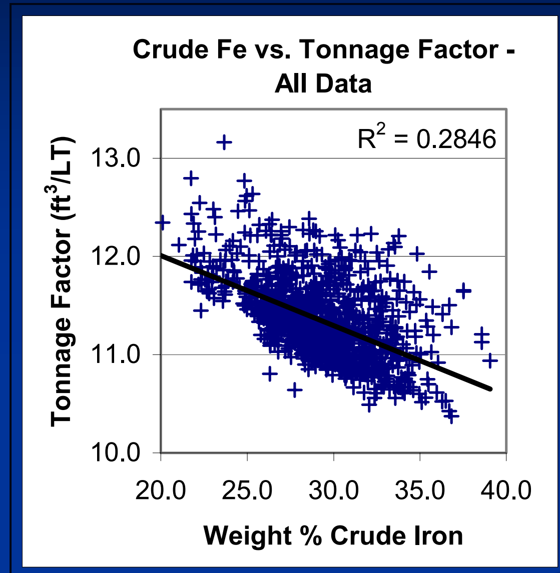


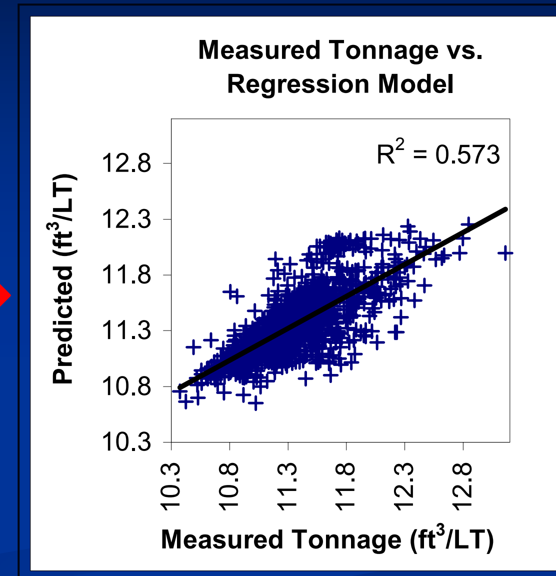




Tonnage Factor Modeling







Regression Statistics									
Multiple R	0.7570								
R Square	0.5730								
Adjusted R Square	0.5722								
Standard Error	0.2543								
Observations	1104								
ANOVA									
	df	*SS*	*MS*	*F*	*Significance F*				
Regression	2	95.5675	47.7838	738.7793	3.4744E-204				
Residual	1101	71.2120	0.0647						
Total	1103	166.7795							
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*	
Intercept	13.0557	0.0785	166.3588	0	12.9017	13.2096	12.9017	13.2096	
Sat Mag Fe	-0.0318	0.0012	-27.2702	1.5643E-125	-0.0341	-0.0295	-0.0341	-0.0295	
Crude Fe	-0.0420	0.0028	-14.7775	3.24325E-45	-0.0476	-0.0365	-0.0476	-0.0365	

Model by…

- Geology
- Location
- Met variable
- Ore/waste

Tonnage Determination

Benefits:

- Better ore reserve estimation and blast grading
- Improved blast pattern loading
- Royalties paid on a per-modeled ton basis reduced for leaner ore blasts
- Reduced discount between mine predicted and plant weight recovery
- Improved deliverables from drill core

Cost

- Summer intern 2.5 weeks, bucket, scale, hydrometer
- Lab costs for check samples

Measure. *Then* Control

Hypothesis: Need a Range of Sizes for AG Mills

Measure How Fragmentation Affects Autogenous Mill Performance

What Mix of Muck Sizes Work Better?

Measure What affects Fragmentation

Geology

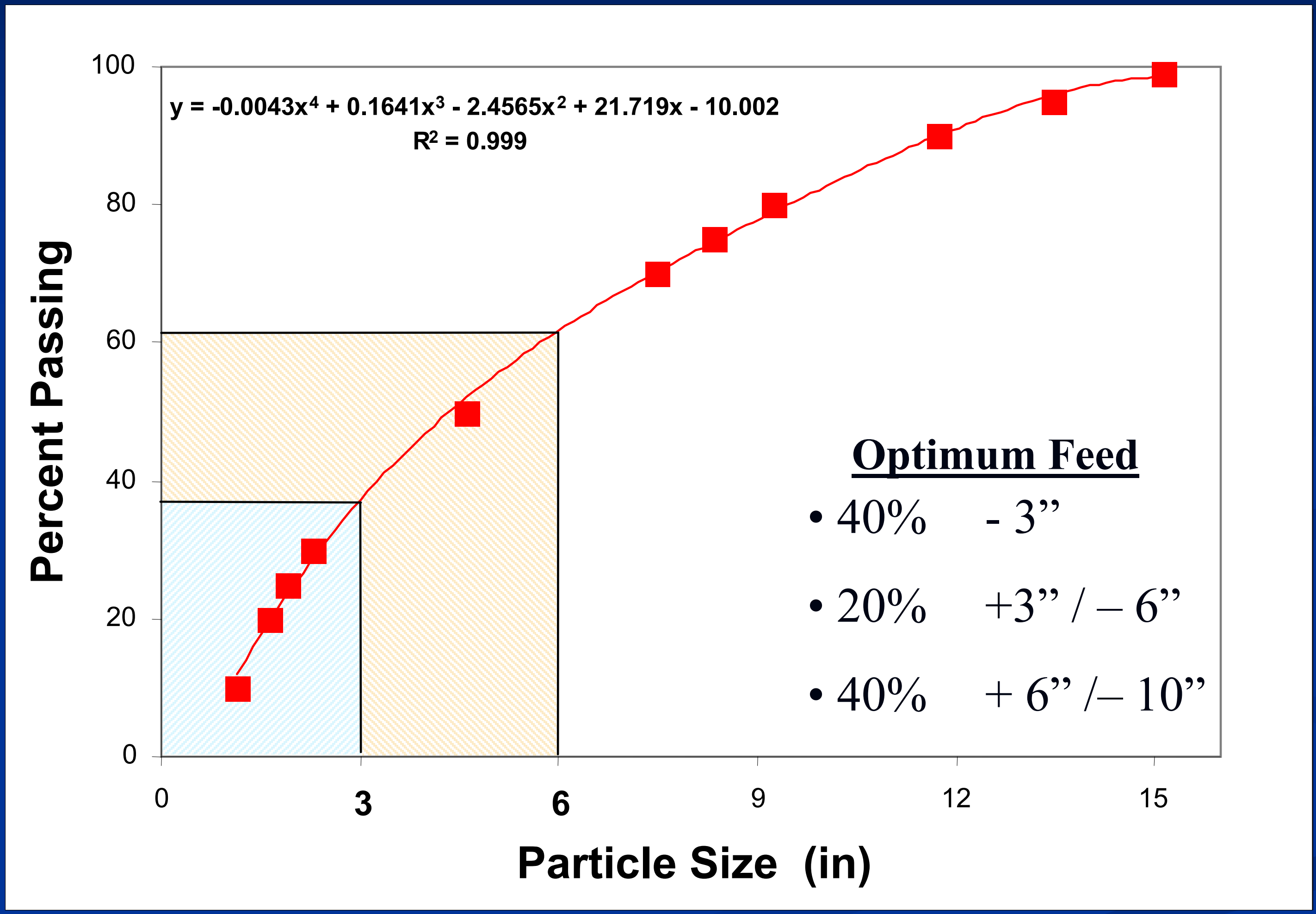
Powder Factor

Blast Design

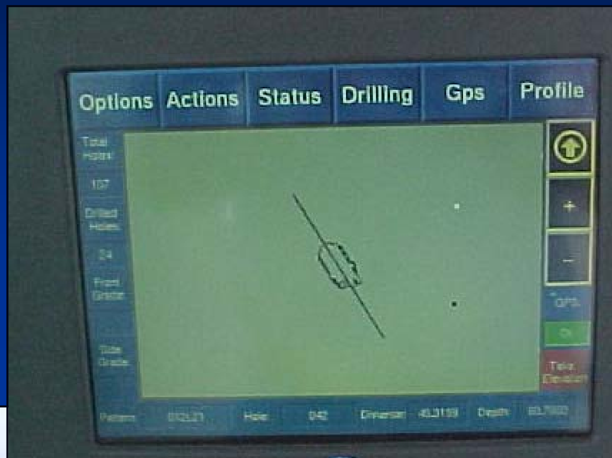
Feed Size Distribution - tools

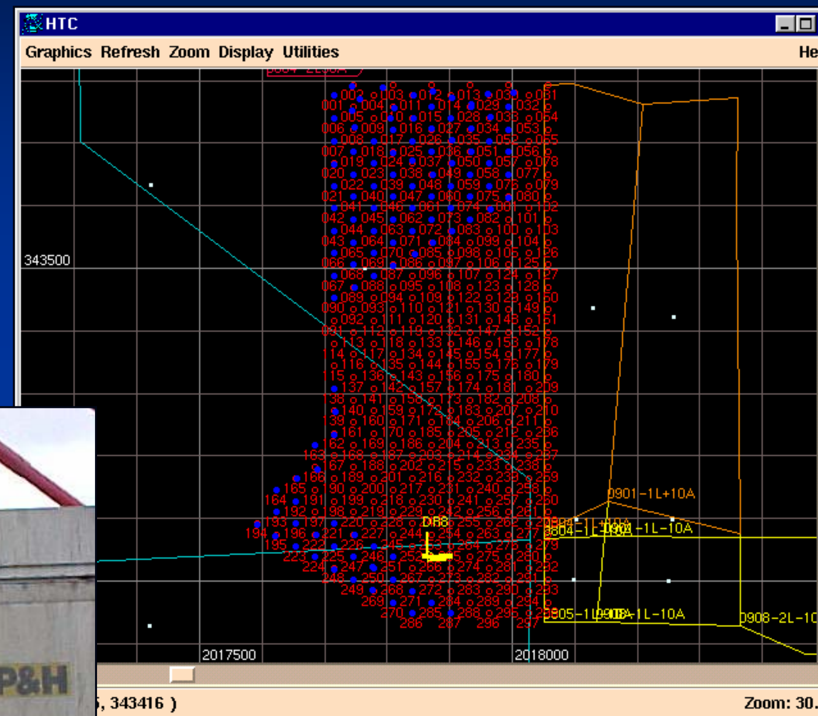
- Production drill performance
- Drill core geotechnical measurements

CRUSHER PRODUCT SIZES



Drill Monitoring Systems





- Engineers use systems to improve productivity and fragmentation
- Used to much lesser extent for geologic classification
- Many production drills come pre-equipped to record performance indicators – “free” data

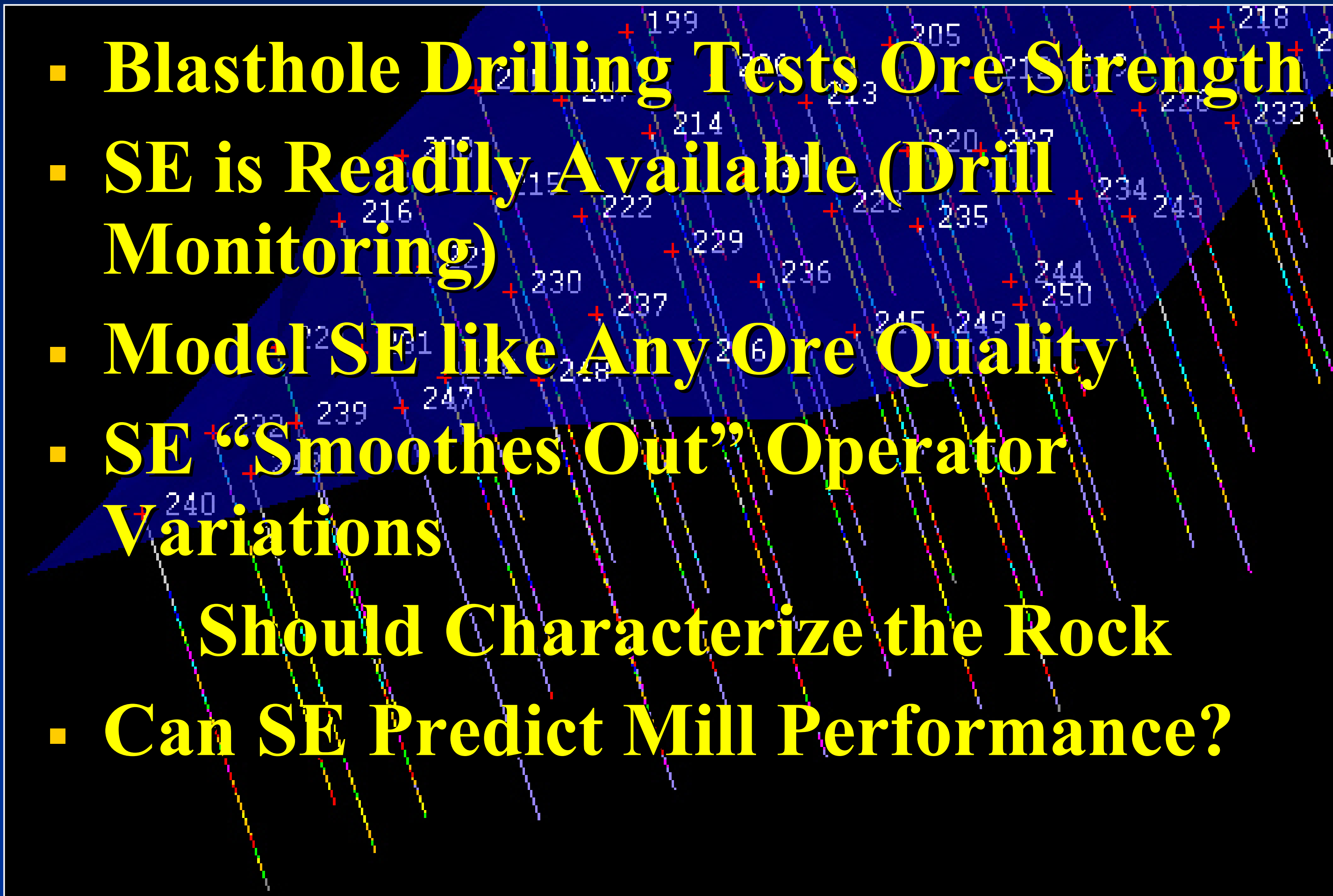
Definition of Specific Energy

SE = Energy per Unit Volume Excavated

$$SE = \left(\frac{F}{A}\right) + \left(\frac{2\pi}{A}\right)\left(\frac{NT}{ROP}\right)$$ lbf/in^2 (Teale, 1964)

- **Energy: Torque (*T* lb in.) RPM (*N*), Pulldown (*F* lb) and ROP (ft./min)**
- **Volume: Bit Area and ROP ($A \cdot ROP$ ft·in^2) in one minute**

Drilling Specific Energy

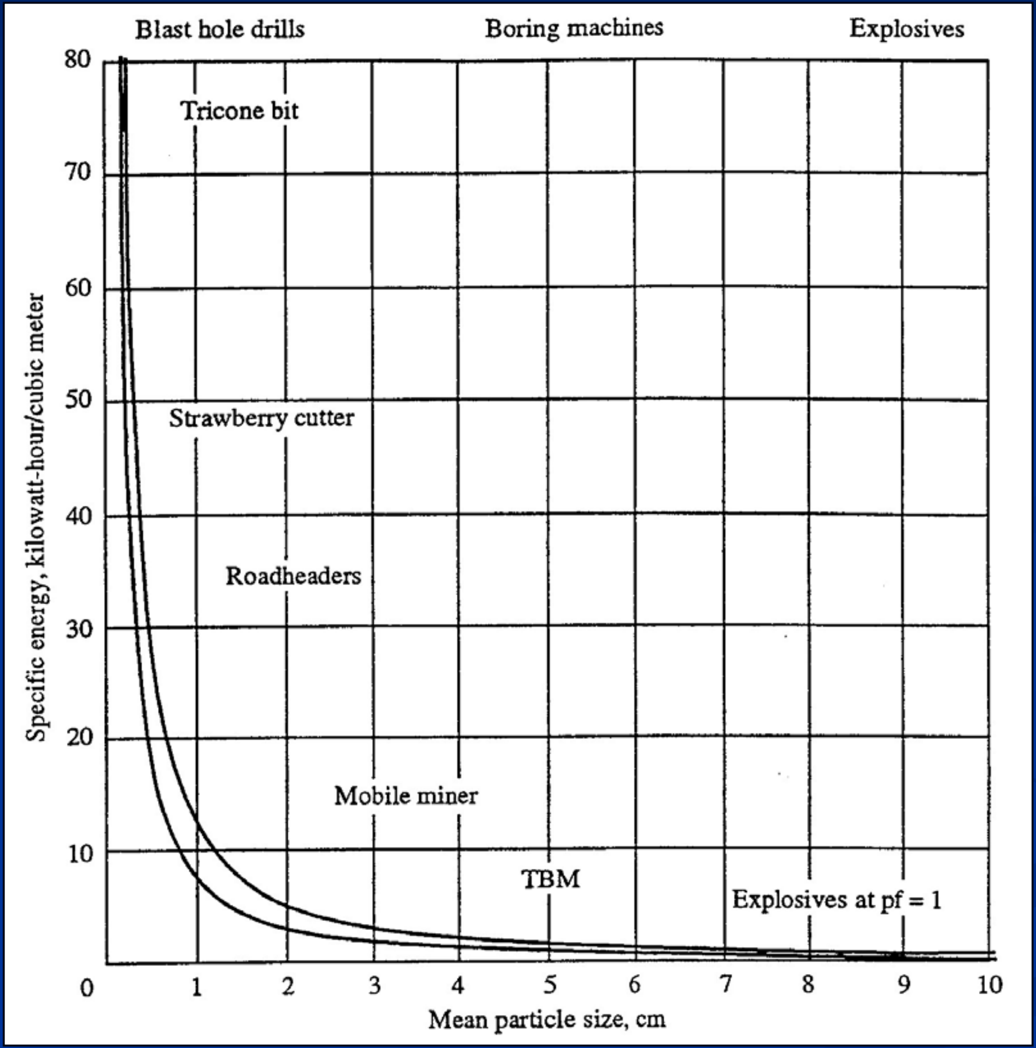


- Blasthole Drilling Tests Ore Strength
- SE is Readily Available (Drill Monitoring)
- Model SE like Any Ore Quality
- SE "Smoothes Out" Operator Variations

Should Characterize the Rock

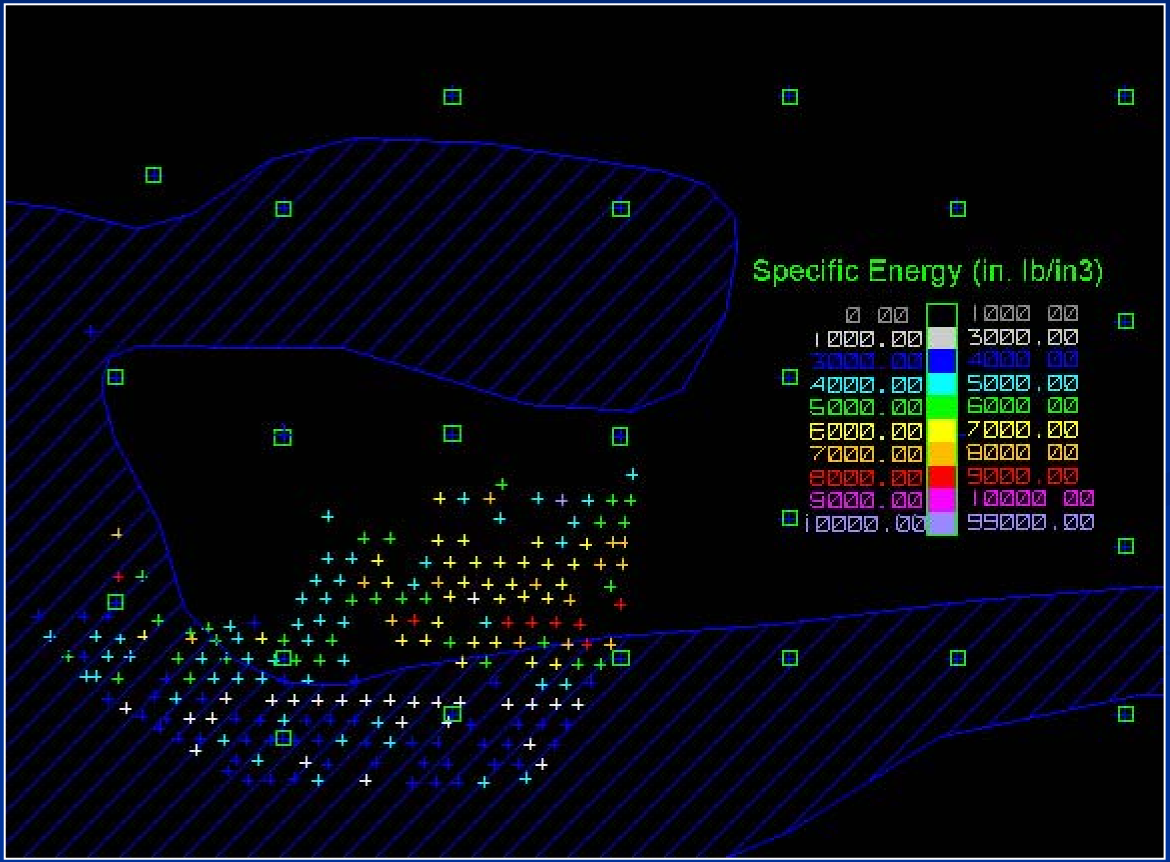
- Can SE Predict Mill Performance?

SE is Tool and Rock Specific



From Gertsch (1991)

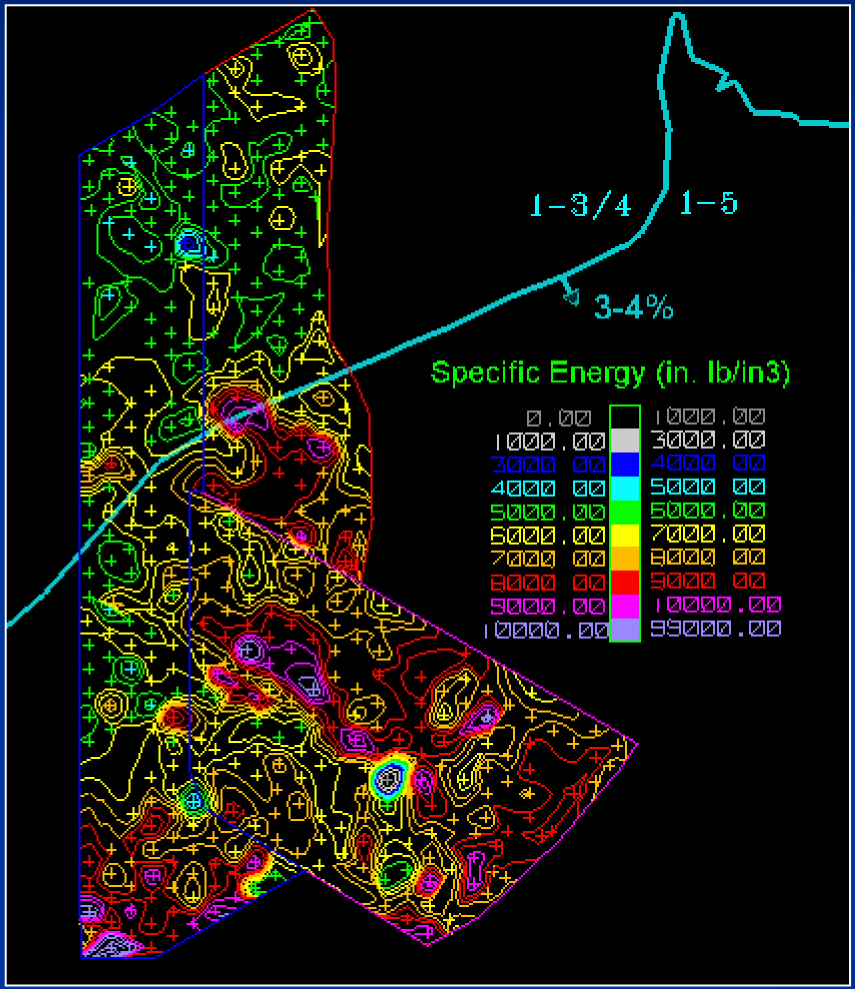
Bench Composites of SE



- **Map boundaries between zones of contrasting strength**
- **Fill in gaps between wide-spaced DDH**
- **Minimize impact of subdrill or overbreak**

Bench composites vs. modeled oxidation

Contoured Bench Composites of SE



- Map lithologic contacts
- Reflect bed thickness and *in situ* fracture frequency
- May also show variations in hardness/work index
- Identify sources of potential rock bridges/ crusher plugs
- Distinct zones cross pattern progression
- Some boundaries may reflect tool changeout

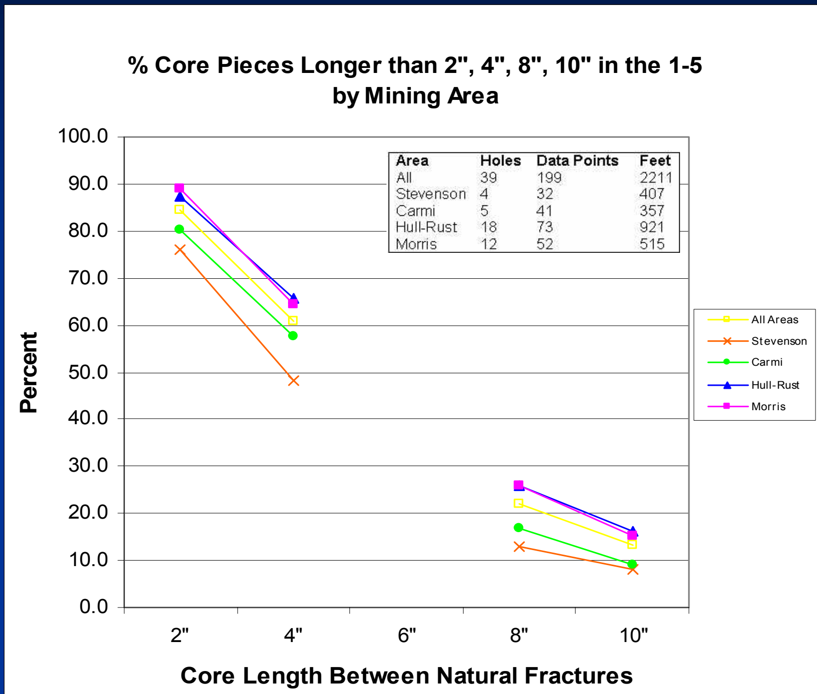
CHALLENGES

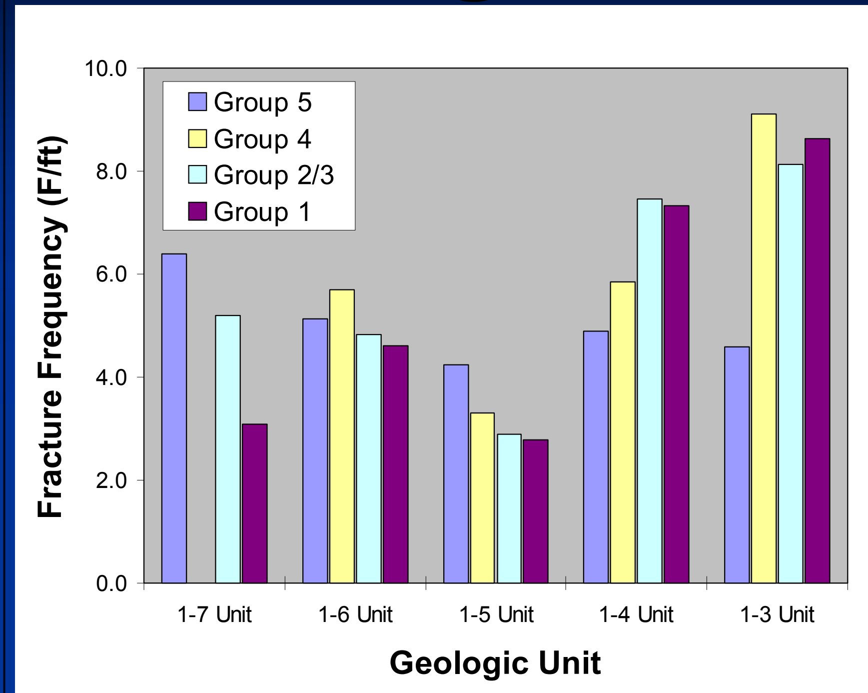
- Equipment Breakdowns:
  - No Data
  - Loss of Blend
- What Does SE Measure? (Laminations)
- Operator Training
- SE Tool Dependent (Bit wear?)
- Too Late in Process for Predictions
- Core Data are Better for Modeling

Drill Core Geotechnical Data

- Typically used for engineering ground stability studies
- No data collected by the geologist are used so infrequently – by the geologist
- No buy in → possibly suspect quality → loss of customer support
- Data are often not digitally compiled and are lost

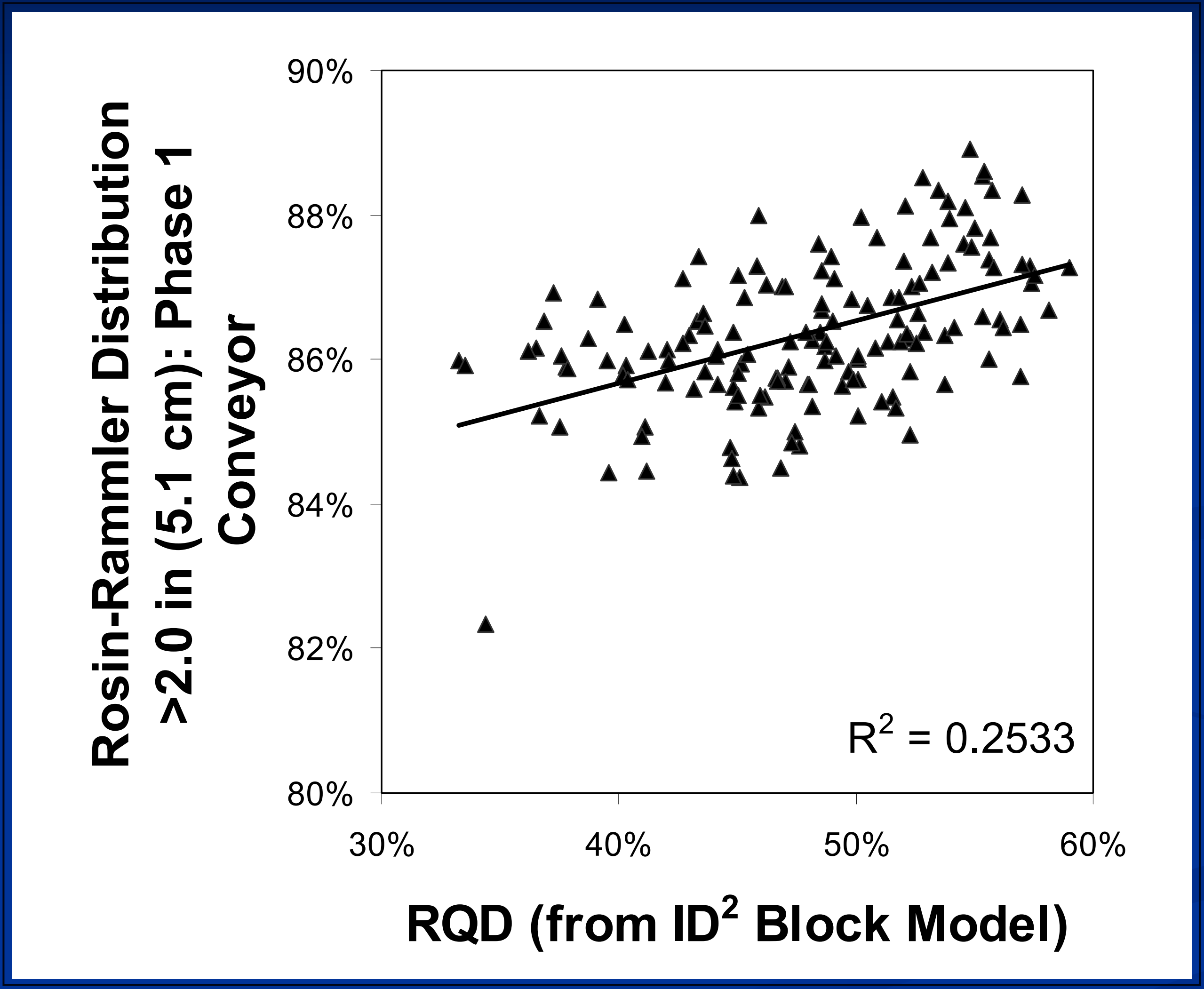
Geotechnical Core Logs





GEOTECHNICAL/METALLURGICAL CORE LOG														
FR	TO	FT.	Bit	Recovery %	Modified RQD (2", 4", 8", 10")				FF	% Slaty	Joint Angle	S.G.	Unit(s)	NOTES
					2"	RQD	8"	10"						
0	11	11	ATW	97	61.8	22	6.1	0	5.5	13	85	3.15	1-6	Rough, irregular joint @ 85 degrees.
11	20	9	ATW	100	95.6	95.6	62.2	57.8	1.6	8		3.36	1-5	
20	40	20	ATW	100	93	82	44.5	27.7	2	15	90	3.28	1-5	Undulating, rough jt @ 38.5'; Cc on jt.
40	60	20	ATW	100	93.8	79.8	25.1	10.8	2.4	15	60	3.3	1-5	Rough, planar jt @ 47'
60	76	16	ATW	100	92.2	68.4	21.9	12.9	2.9	15		3.17	1-5	
76	805	9	ATW	100	75.6	55	17.2	0	3.7	13	85	3.09	1-4	Irregular planar jt @ 76'
85	105	20	ATW	100	48.5	21	7.4	0	13	45		3.05	1-3	
105	111.5	6.5	ATW	100	53.4	38.9	10.8	0	10	75		2.99	8-3	
111.5	115	3.5	ATW	98	77.1	52.9	0	0	3.7	20		2.99	8-3	

Preliminary Size Distribution Index



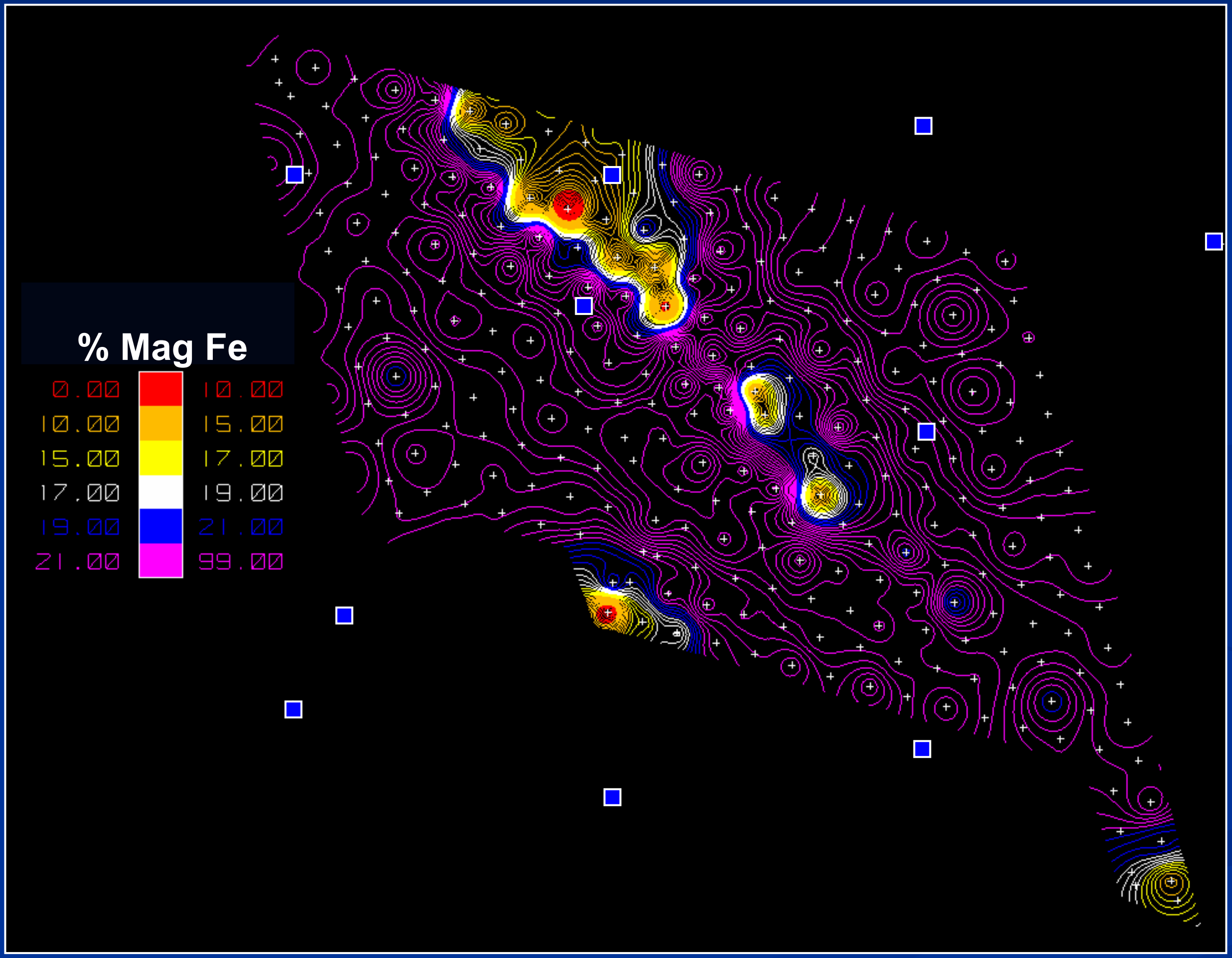
<u>Even though</u>…

- RQD based on only 80 DDH in 4 loose clusters across property
- Core size fractions measured in box – not split tubes
- Mill feed blasted and crushed to –10 inch (25.4 cm) prior to WipFrag©

<u>Why</u>?

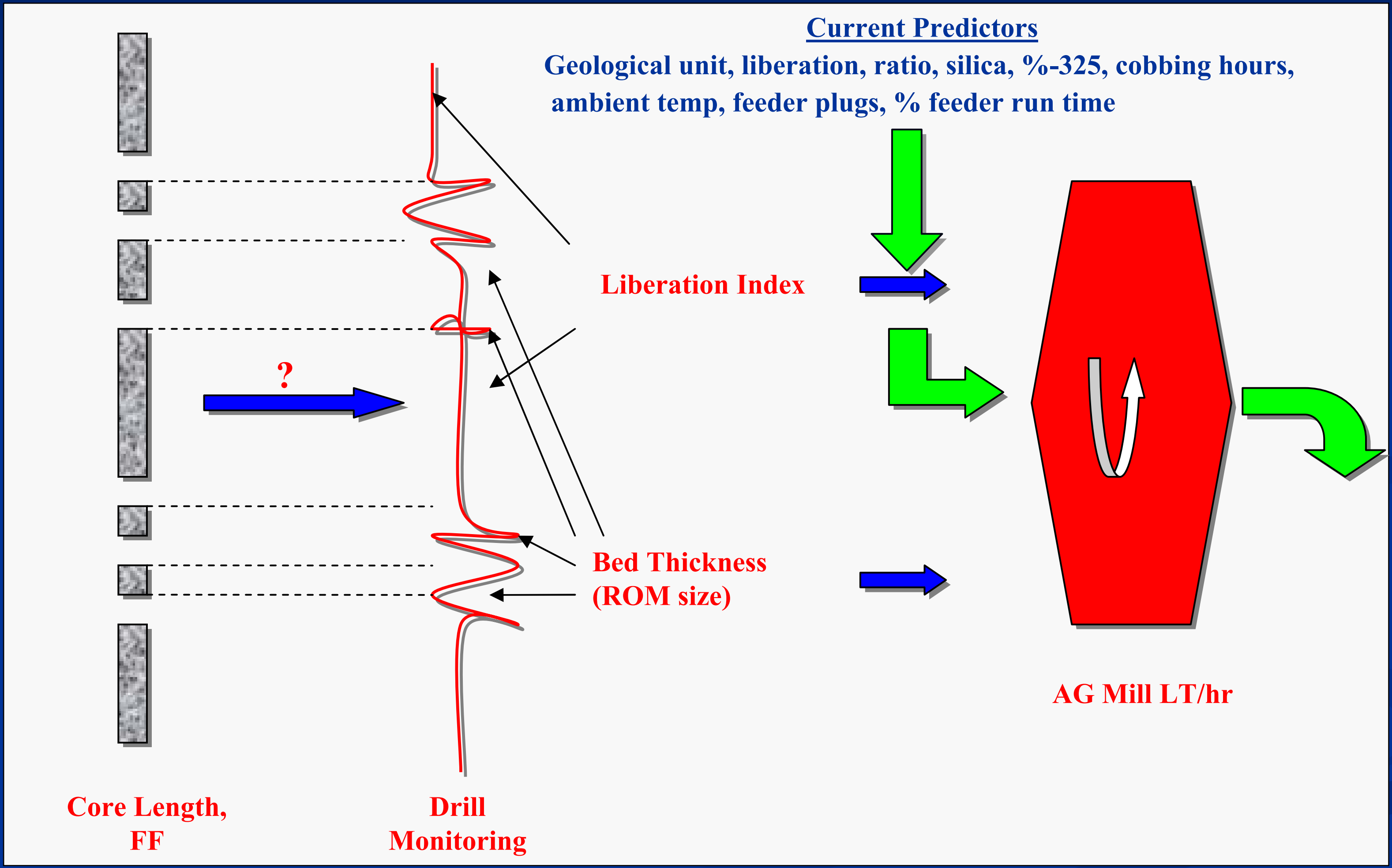
- Blasting exploits pre-existing fractures
- Crusher acts as chute – does not produce fines

Improved Magnetic Susceptibility Mapping and Ore Grading - Through Geotech Logging



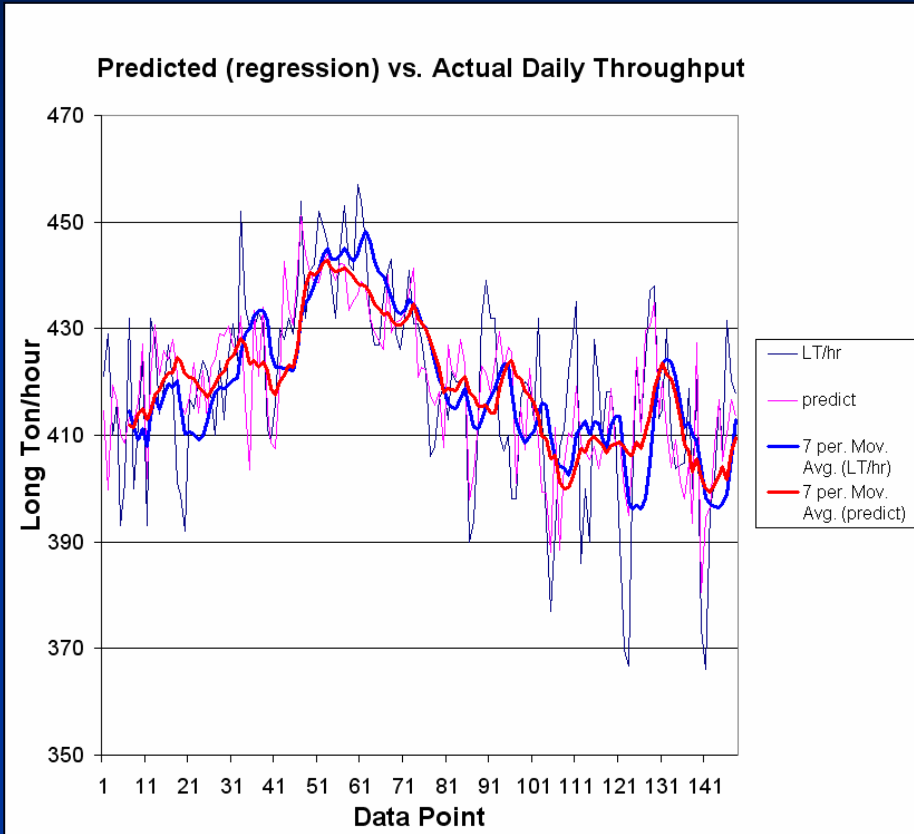
- Probed blast holes are calibrated to nearest DDH core samples
- Poor core recovery typically due to non-magnetic, oxidized fines washed into formation
- Remaining DDH sample → block model bias, poor recovery reconciliation
- Poor recovery intervals now not used for probe calibration. Polygons are flagged as zones of potential discount between DDH and plant weight recovery. Improved DDH sampling.

Incorporate Geotechnical Data into Mill Performance Predictions



$$W = 10W_i\left(\frac{1}{\sqrt{P_{80}}} + \frac{1}{\sqrt{F_{80}}}\right)$$ Bond's Equation

Mill Throughput Predictions



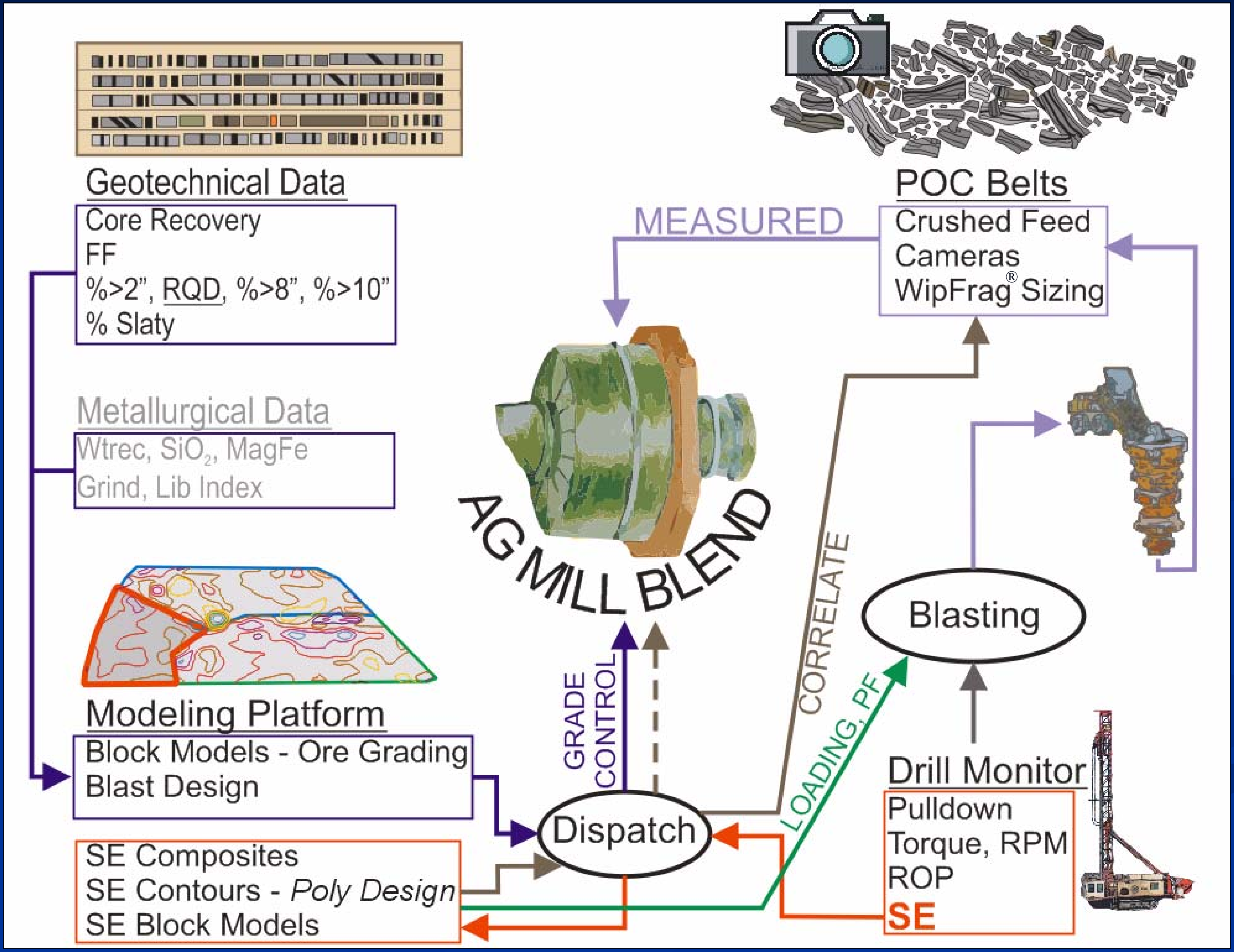
Throughput Calculator		
	Input	*Coefficients*
Intercept		947.660
Powder Factor	0.72	40.085
RQD	50	-0.626
% > 8" core pieces (SLAB8)	13	2.191
kW-hr/LT (LIB Index)	11.8	-6.633
Predicted Crude MagFe (Smgfe)	20.2	5.016
Predicted Total Fe (Ciron)	30	-11.927
Liberation wtrec pred (Liswt)	28.7	2.192
Ratio	95.9	0.240
Pred %-325 (P325m)	71.1	-1.687
DSC	19182	-0.003
%-1-3/4	13	0.736
%-1-7	2	1.264
Average Daily Temp	53	0.070
Cobbing hours	69	0.145
%fdr_runtime/milltime	98	-1.777
Total Feeder Plug	0	0.965
	LTPH	**400.8**

- Ore-dominated milling variables – Geologist is person best suited to validate inputs for plant performance estimates
- Garbage in → garbage out: surge maintenance, grading discrepancies, poor met balance – all can weaken regression models if un-vetted

Communication

- Daily interaction between geologist and mill
- Weekly interdepartmental ore quality meetings
- Monthly geometallurgical reconciliation reports

DATA INFORMATION FLOW



In Conclusion…

- Engineering and ore dressing are the mine geologist's customers – so start liking numbers.
- Computers allow cheap and easy storage of data.
- Mine databases can be 'elephant country'.
- Physical properties of ore fall within the domain of the mine geologist.
- More value can be squeezed from drill core.
- Failed initiatives lead to successes.
- The geologist sees the extractive process from the beginning and is best suited for reconciling predictive estimates with the end product.
- The geologist must participate fully in downstream ore processing decisions.