Introducing Bulk Sorting: its Enablers, Application, and Potential

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IPCC 2018

Outline

- Bulk Sorting Defined
- Mass Mining and Heterogeneity
- Heterogeneity Analysis
- Bulk Mineral Sensing
- Bulk Ore Diversion
- Application Scenarios
- Conclusions

Bulk Sorting Defined - Terminology

- Sensor-based Ore Sorting
  - Mineral Sensing
    - Surface Sensing
    - Penetrative Sensing
  - Mineral Sorting
    - Particle Sorting
    - Bulk Sorting
      - Batch Sorting
      - Ore Routing

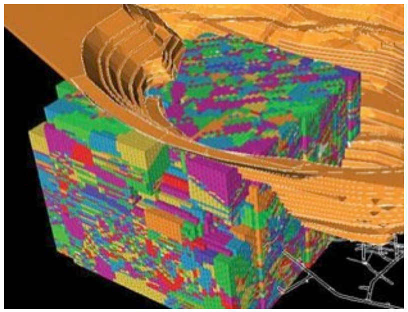
Heterogeneity

- Is there sufficient difference in materials to be separated?
- Improvement with size reduction?
- How does size fraction matter?

Source: McCarthy, 2014

Heterogeneity/Opportunity at Every Length Scale

Mine Planning



Today Mining Ignores Mid-Scale Heterogeneity

Grinding / Flotation

Bulk Sorting

Particle Sorting

Length Scale

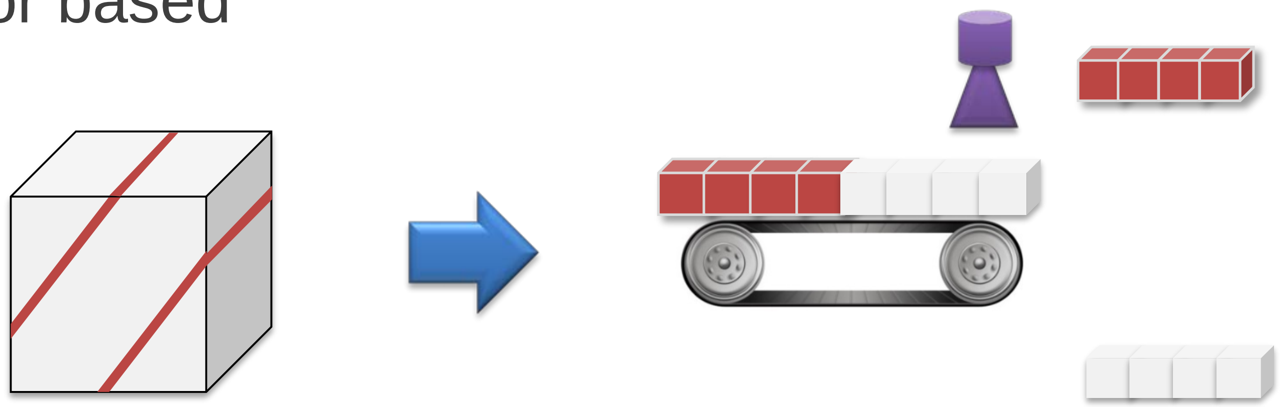
>10m >1000T	1m	10cm	<1cm <0.1kg

Source: Modified from Bamber, 2017

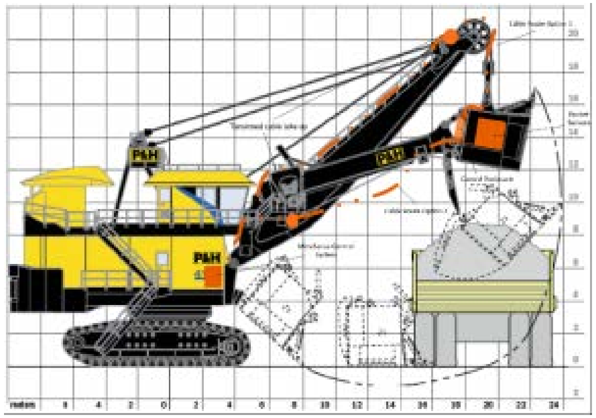
Bulk Sorting Defined

Bulk Sorting

- Conveyor based



- Shovel based



From MineSense

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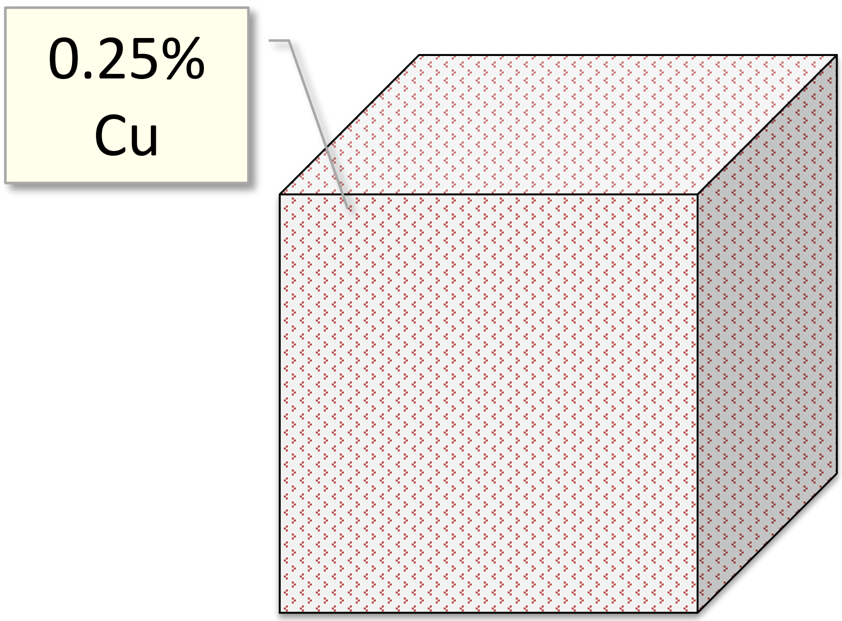
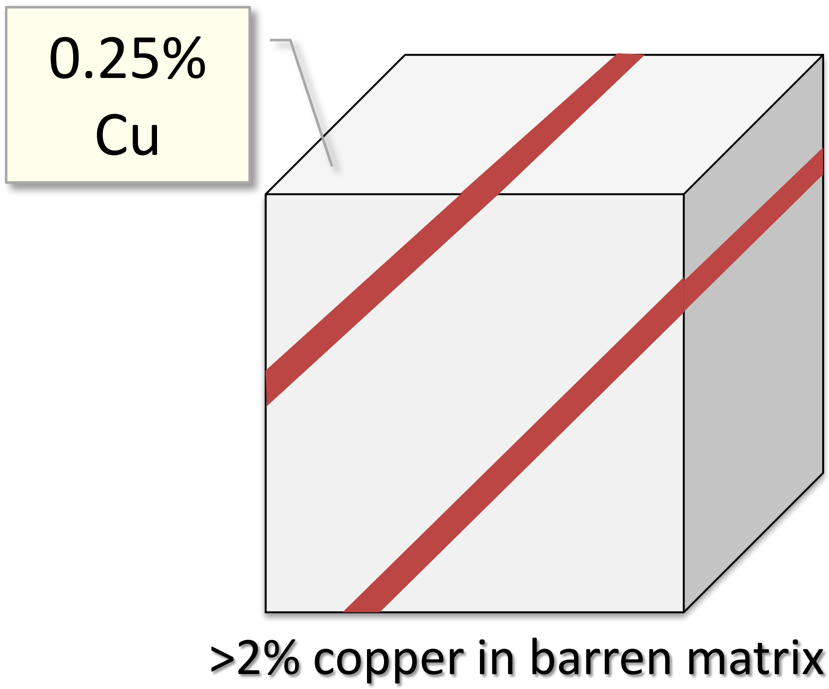
Heterogeneity



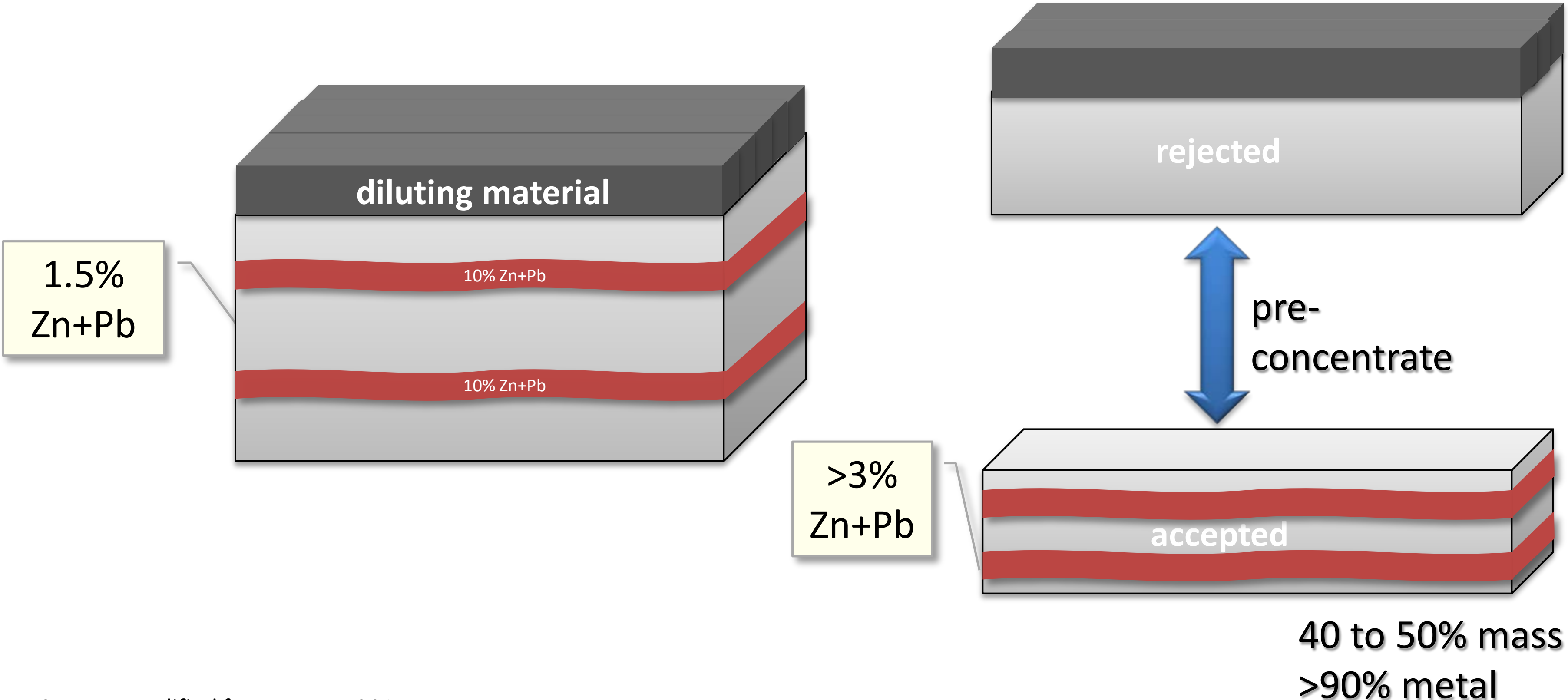
Homogenous



Heterogeneous

Pre-Concentration – Waste Rejection

A combination of in-situ heterogeneity and dilution



Source: Modified from Dance, 2015

Heterogeneity

Inherent in ore deposits

Scale varies

Enabler for sorting

Masked in block modeling

Decreases through the mining value chain

SMU size/block size increases for mass mining

- Smoothing of grade
- Reduction of grade
- Masking of heterogeneity

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Down Hole Heterogeneity

- Down hole analysis technique:
  - Aggregating lengths
  - A “rolling composite” down the hole
  - Every sample point can be interpreted in the context of multiple aggregation lengths (similar to composites)
  - The sample point is tested as to whether it is in an aggregate of “ore” or “waste” for varying cut-offs

- Heterogeneity Calculation:

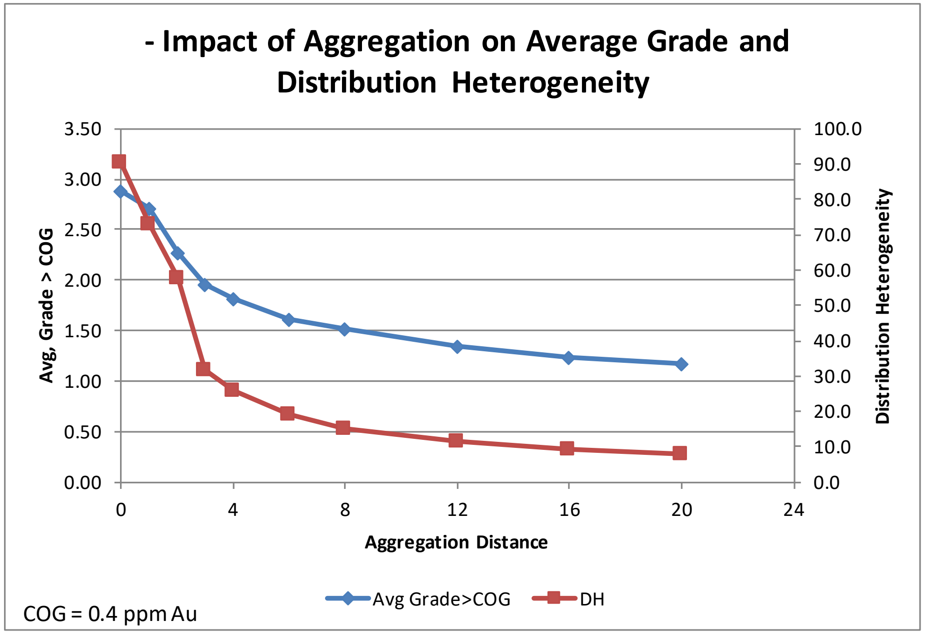
$$DH^{*} = N_g * (\Sigma (a_i - a_L)^2 \times M_i^2) / (a_L^2 \times M_L^2)$$

Where N_g is the number of groups (aggregations), α_i and α_L are the grades of group *i* and lot, respectively, while M_i and M_L are the masses of group *i* and the lot.

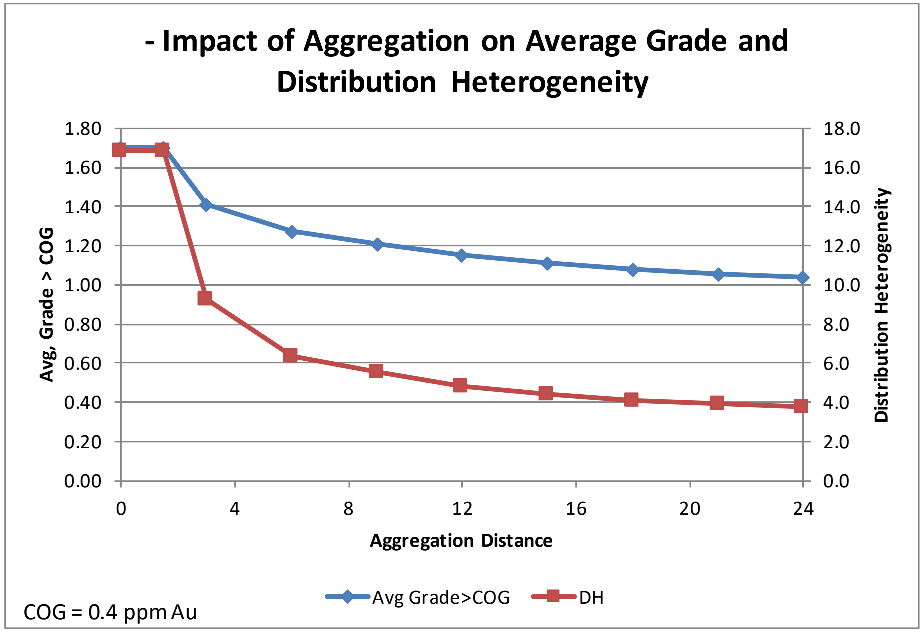
* - Distribution Heterogeneity for a dimensionless lot (per Gy, described by Pitard, 1993)

Aggregation Impact on Grade

Gold Property A



Gold Property B

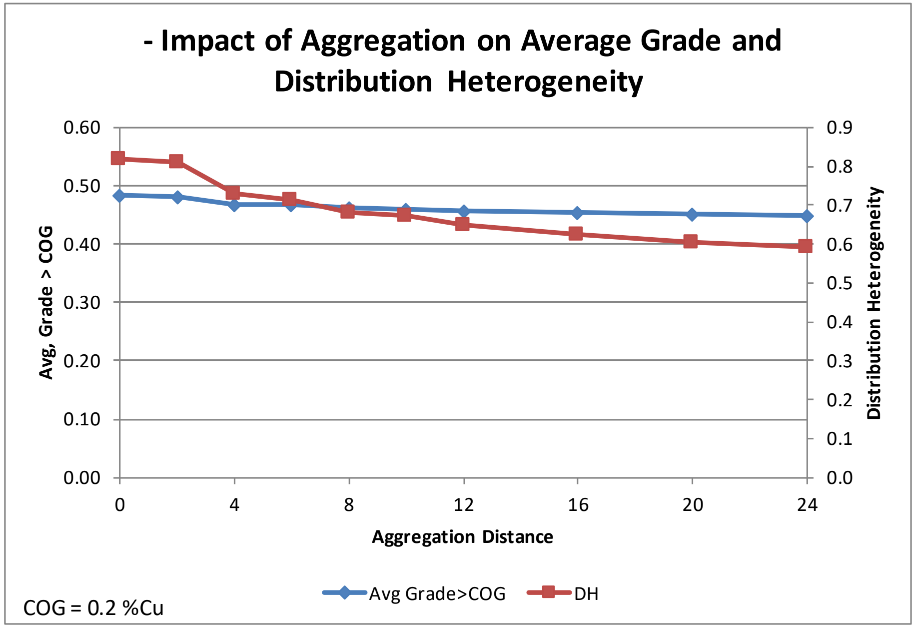


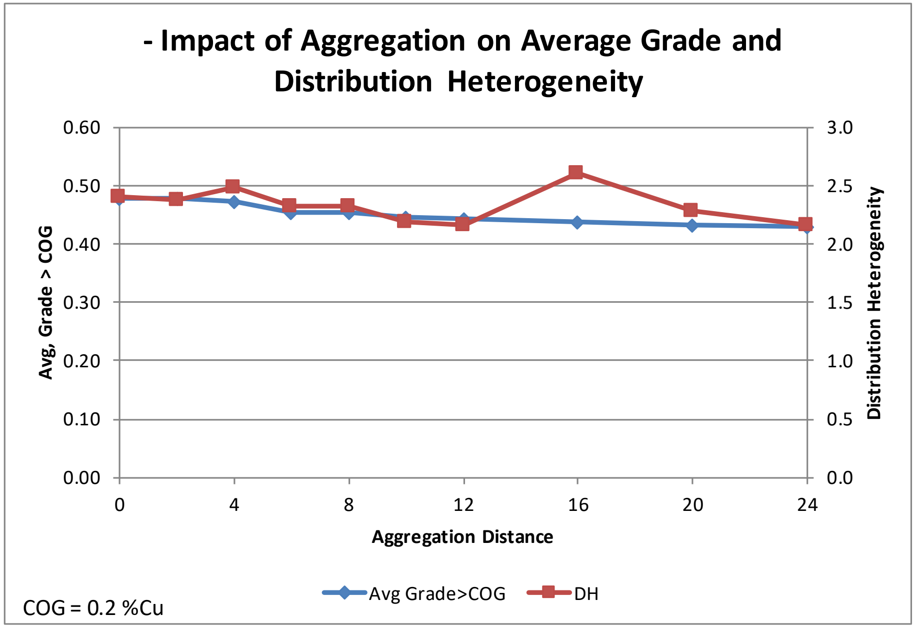
Source: McCarthy, 2017

Aggregation Impact on Grade

Copper Property A

Copper Property B

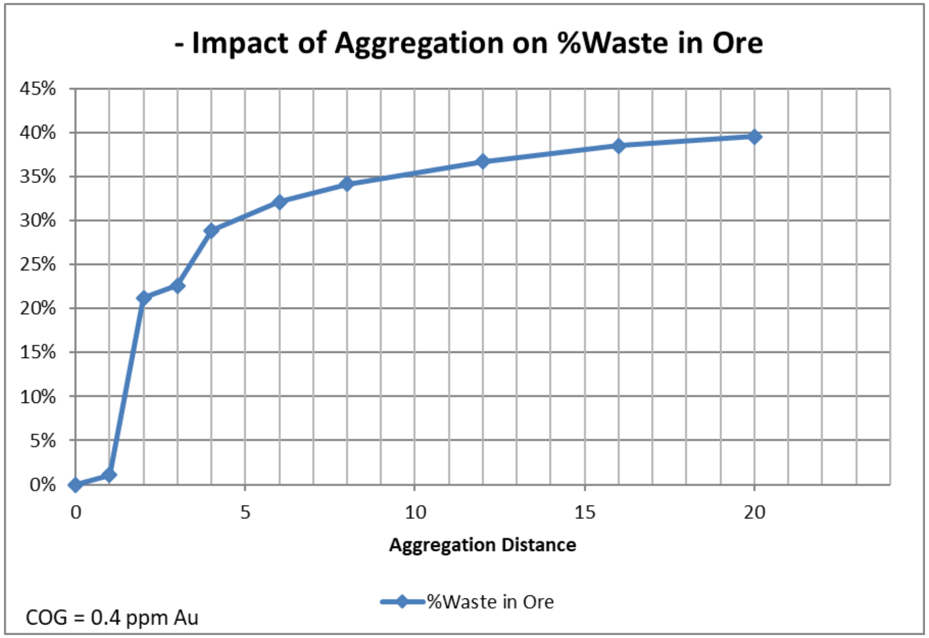




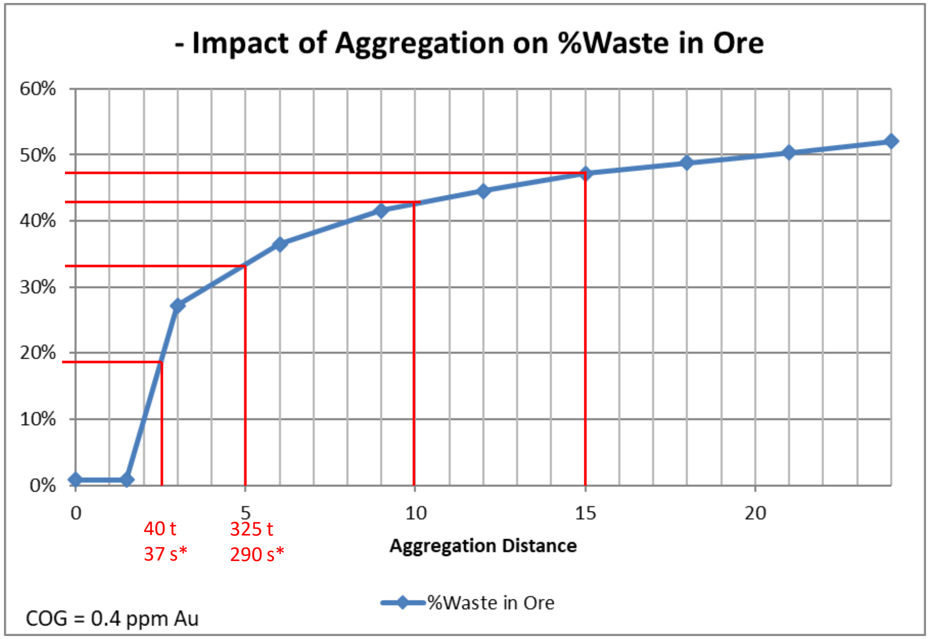
Source: McCarthy, 2017

Aggregation and Waste in Ore

Gold Property A



Gold Property B



* - Assumes 100,000 tpd ore feed

Source: McCarthy, 2017

Aggregation and Waste in Ore

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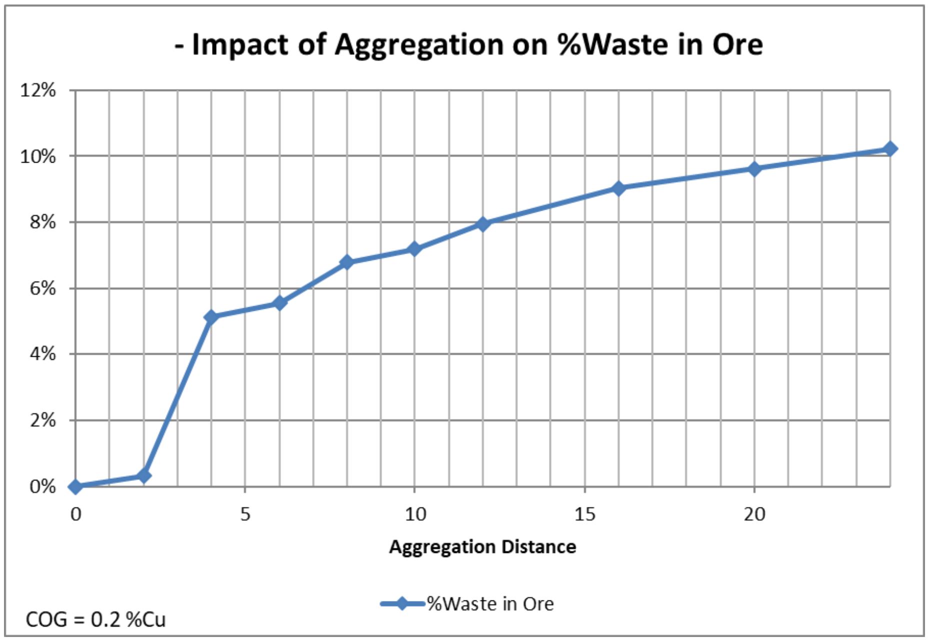
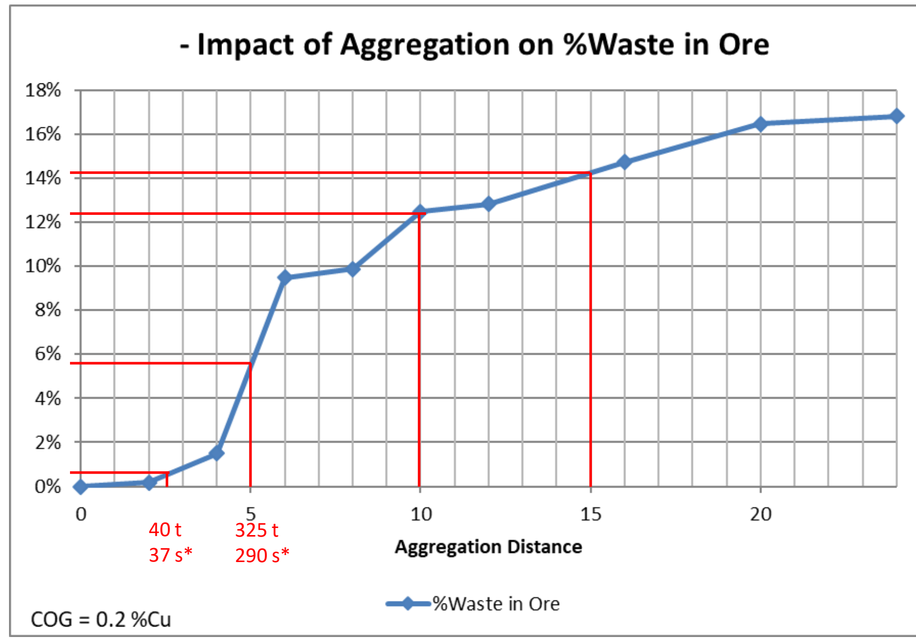


Copper Property B

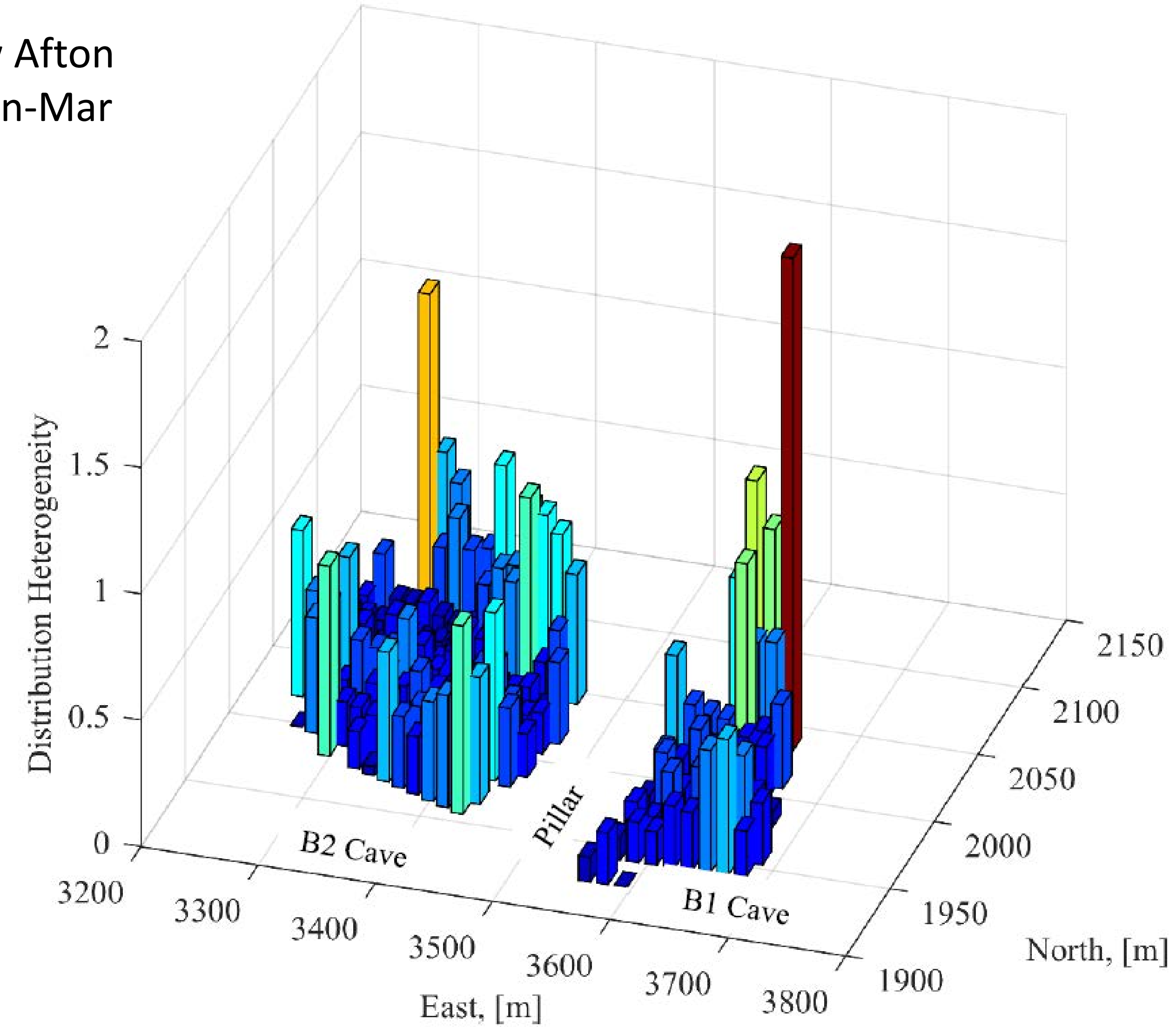


* - Assumes 100,000 tpd ore feed

Source: McCarthy, 2017

Heterogeneity of a Cu Porphyry Block Cave

Cu DH for New Afton Drawpoints, Jan-Mar 2014



Source: Nadolski, 2018

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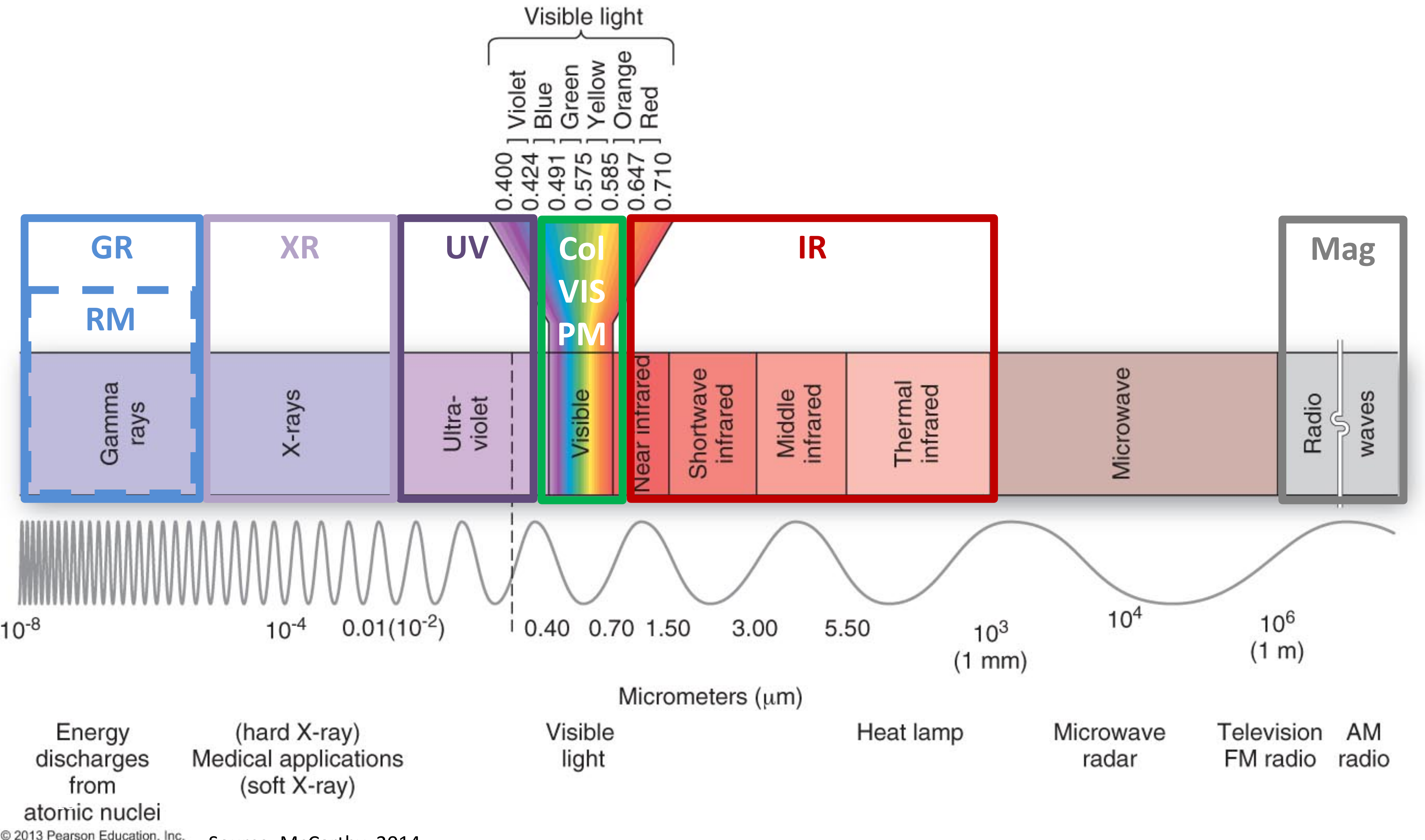
Mineral Sensing



Source: McCarthy, 2014

Mineral Sensing Technology

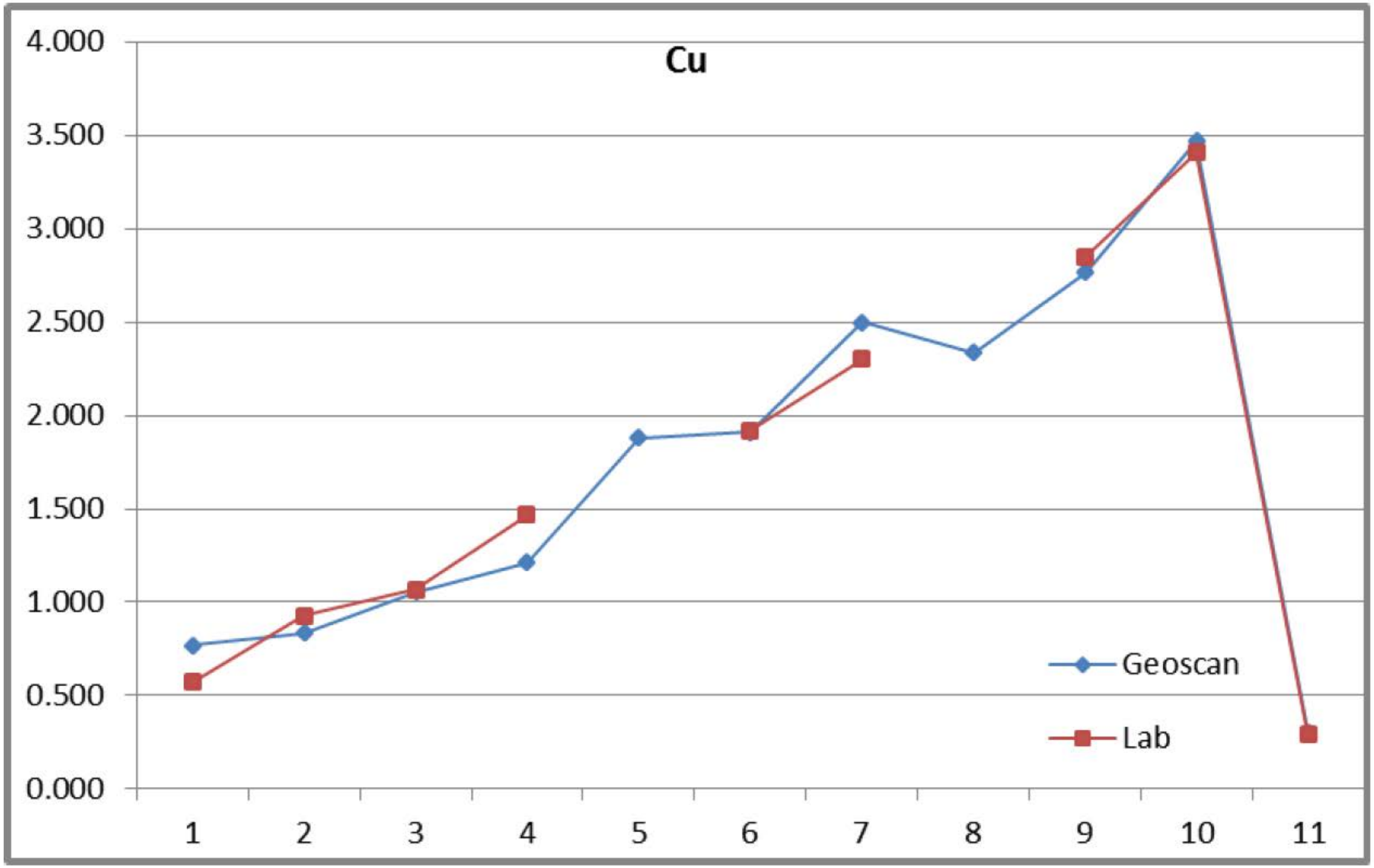
Method	Sensor Type	Sort Type	Materials	Limits
PGNAA	Penetrative	Bulk	Limestone,Fe,Al,Ph,Mn,Cu,Zn	1-2 min. avg, <500mm rock, >20-30 kg/m, sub 1% detection
NITA II	Penetrative	Bulk	Coal,C,H,O,Fe,K,Ca,S,Al,Cu,Ni,Mn,Si,Ti	1-2 min. avg, <300mm rock, <350mm depth, need >1% for detection
PFTNA	Penetrative	Bulk	Ni,Fe,Co,Mg,Si,Al,Mn,Cr,C,H,O,	<90mm rock, <280mm depth, 50-150kg/m
RM	Penetrative	Both	U	Only for radioactive minerals
XRT	Penetrative	Particle	Base metals, industrial minerals, coal, diamonds, Au/Ag indirect	2-300 mm rock, <300 tph, >4-5 A.N. diff.
XRF	Surface	Particle	Ni, Cu, Zn, Au, Ag, Fe, Cr, Mn, U, W, Sn, Al	Requires long exposure time, limited to A.N.>20, 30-250 mm rock, 20-50 tph
XRL	Surface	Particle	Diamonds, fluorite, sphalerite, kunzite	
UV	Surface	Particle	Scheelite	Few minerals naturally respond to UV excitation
VIS	Surface	Particle	Quartz, limestone, dolomite, feldspar, fluorite, gems, Au/Ag indirect	
RGB	Surface	Particle	Industrial minerals, gemstones, Cr, Au, Ni, Pt, Cu oxides, Au/Ag indirect	5-250 tph,
PM	Surface	Particle	Industrial minerals, diamonds	

Mineral Sensing Technology

Method	Sensor Type	Sort Type	Materials	Limits
LIBS LIF	Surface Surface	Particle Particle	Elemental Analysis, most all elements	Sensitive to variations in distance from Laser/detector to target sample Like LIBS, early stage of development few commercial applications
VNIR SWIR MWIR LWIR FIR	Surface Surface Surface Surface Surface	Particle Particle Particle Particle Particle	Industrial minerals, Fe ore	2-120 mm rock, 20-100 tph, surface technique impacted by cleanliness and single perspective (though double sided set-ups exist)
EMS IND	Penetrative Penetrative	Both Both	Fe ore, base metals with magnetic response	8-60 mm rock, 70 tph
MRS	Penetrative	Bulk	Chalcopyrite	300 mm rock, 1300 tph, Not all nuclei are magnetic

Source: McCarthy, 2014

PGNAA on Cu Mineral Sensing



From one Chilean copper mine

Source: Scantech, 2017

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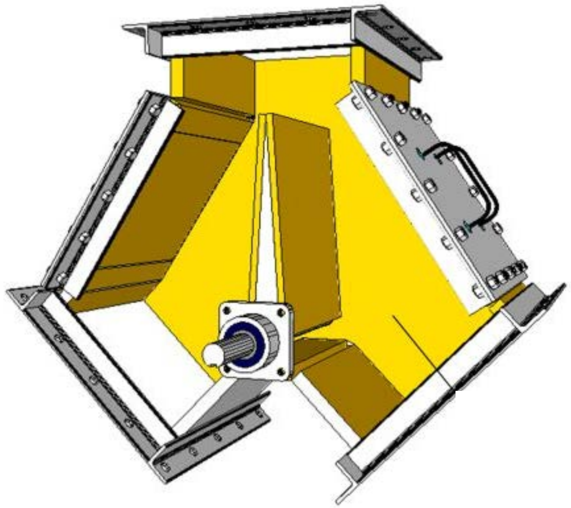
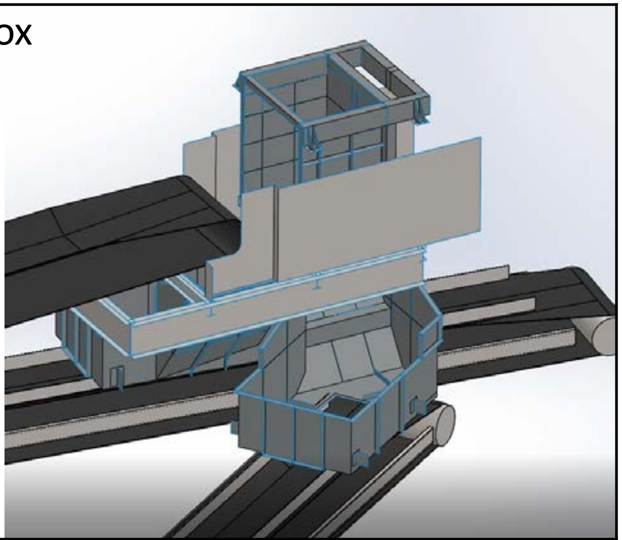
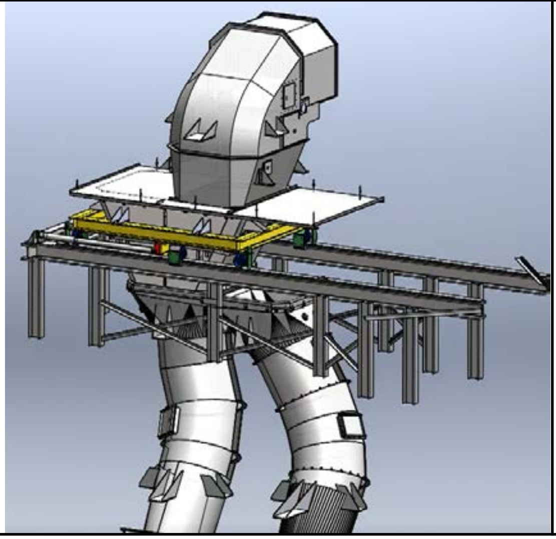
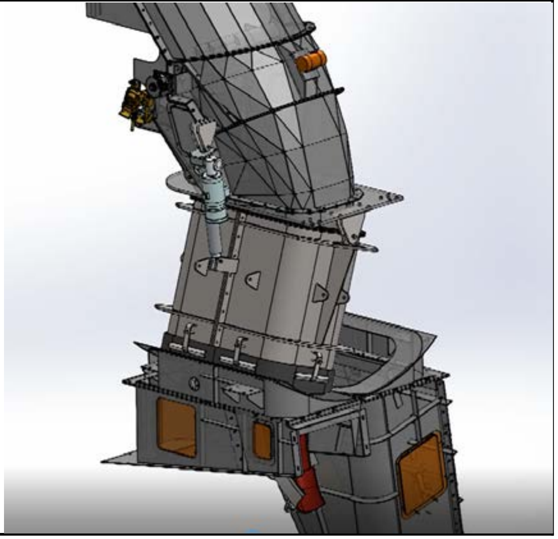
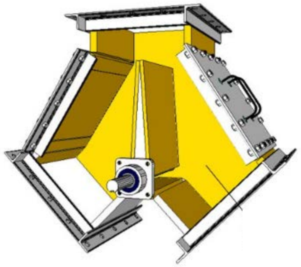
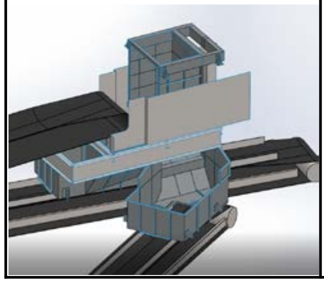
Bulk Diversion Technologies

Flop Gate 	Moving Rock Box 
Linear Traveling Bucket 	Rotating Bucket 

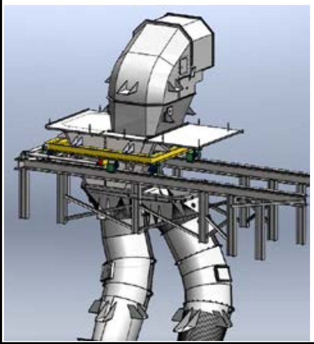
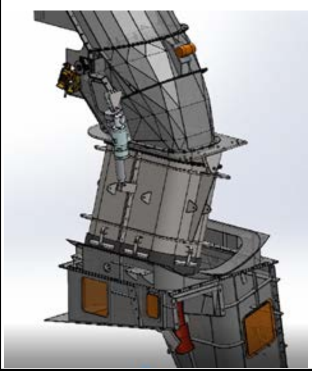
Source: CWA Engineers, 2018

Bulk Diversion Technologies

Diverter	Pros	Cons
Flop Gate 	• Simple • Dust seal around rotating shaft prevents dust escape and spills. • Can be integrated into a controlled flow chute system	• Difficult to switch during material flow • Material buildup can prevent full rotation of gate and allow material leakage into other output chute.
Moving Rock Box 	• Good for abrasive materials • Low vertical transfer height requirement • Different arrangements allow for two or three way transfers.	• Dribbles always end up in one output chute • No sealing in between output chutes • No dust sealing • Shuttle rails and actuator require space around chute to operate • Limited ability to switch outputs during material flow

Source: CWA Engineers, 2018

Bulk Diversion Technologies

Diverter	Pros	Cons
Linear Traveling Bucket 	• Can be switched during material flow • Limited ability to continuously split flow between two output chutes • Can be integrated into a controlled flow chute system	• Complicated sealing arrangement - May allow dust escape and material leakage past seal if improperly adjusted • Shuttle rails and actuator require space around chute to operate
Rotating Bucket 	• Can be switched during material flow • Can be used to switch between more than two outputs • Can be used to continuously split flow between two output chutes. • Actuating mechanism takes up less space than linear traveling bucket mechanism • Can be integrated into a controlled flow chute system	• Complicated sealing arrangement - May allow dust escape and material leakage past seal if improperly adjusted • Precise alignment is required for successful operation

Source: CWA Engineers, 2018

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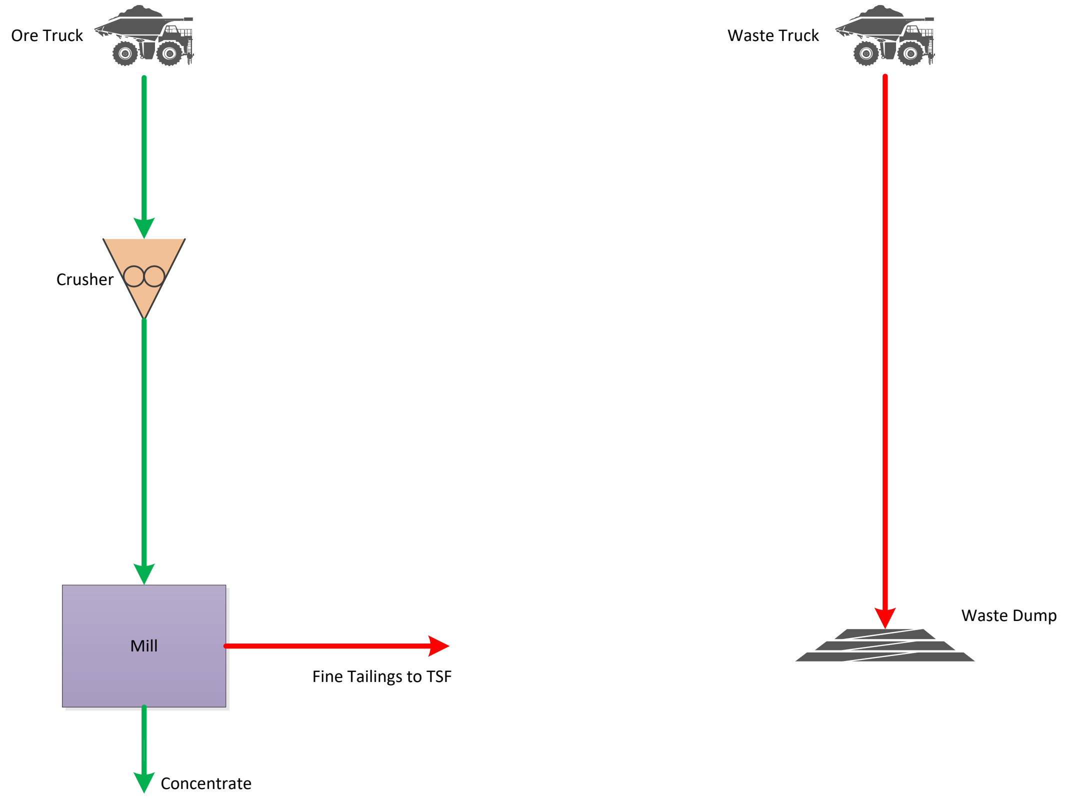
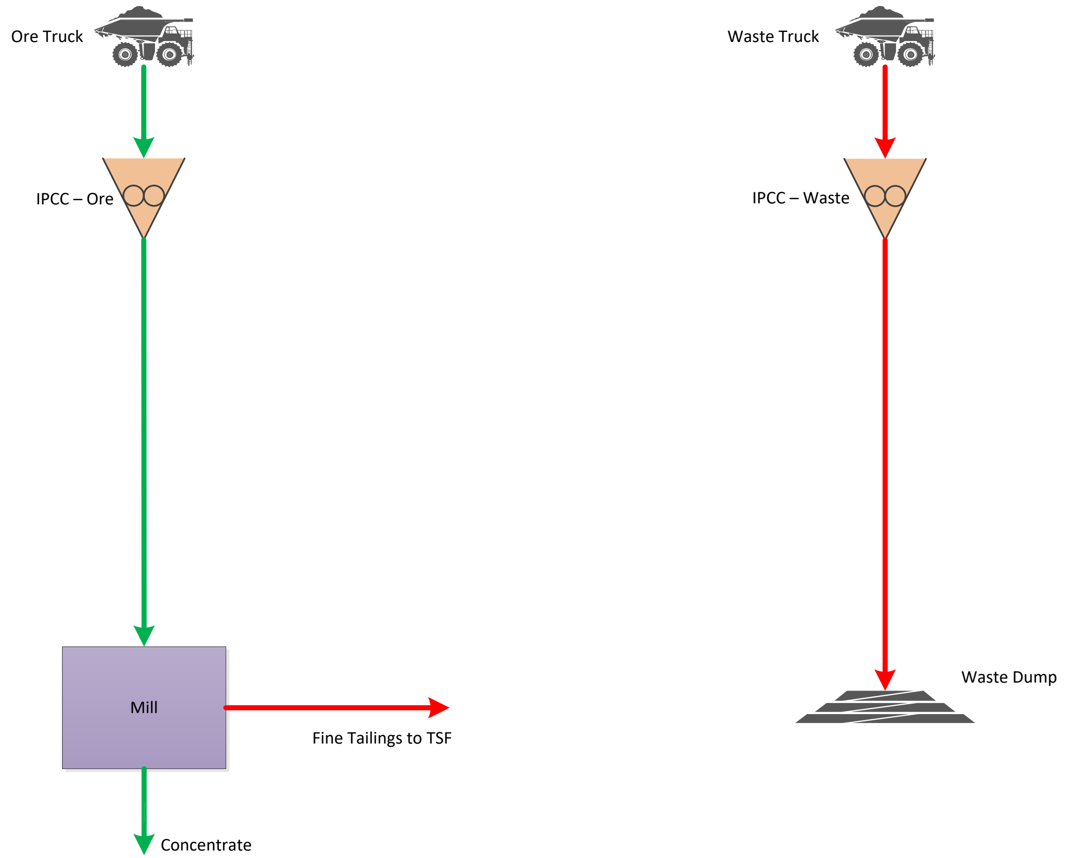
Application Scenarios

Base Case



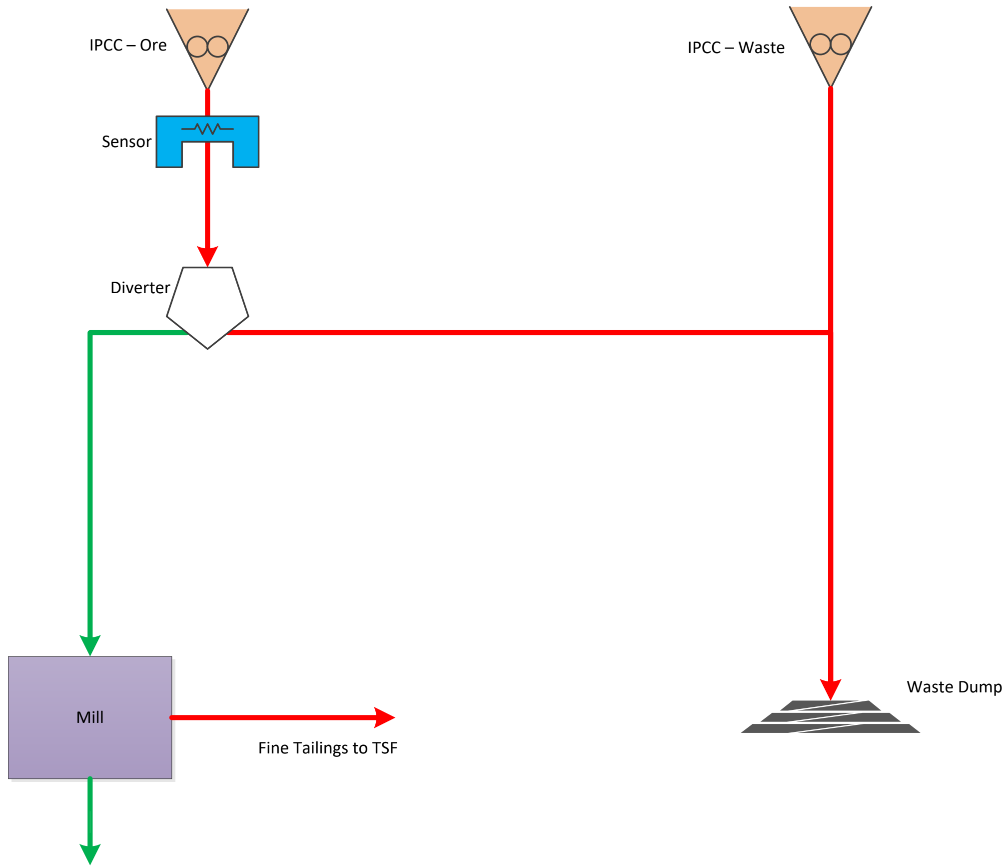
Application Scenarios

IPCC



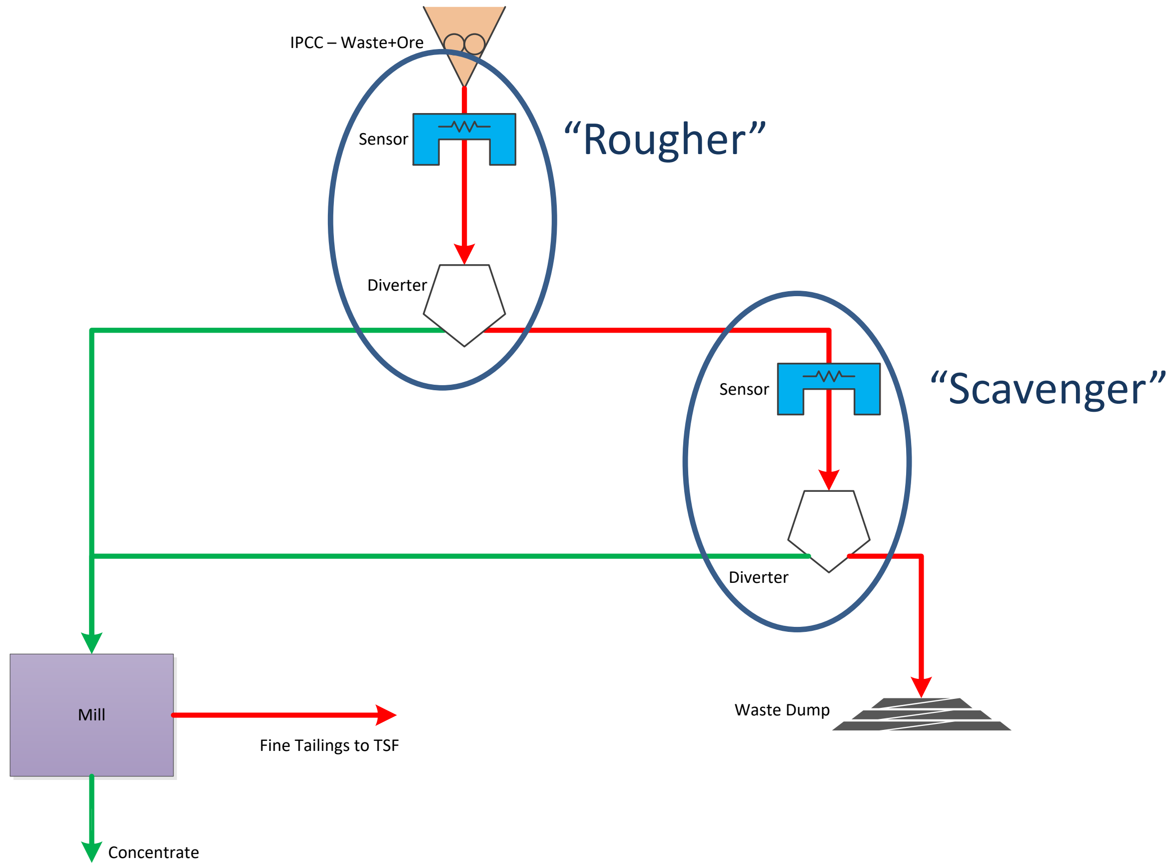
Application Scenarios

Bulk Sort A



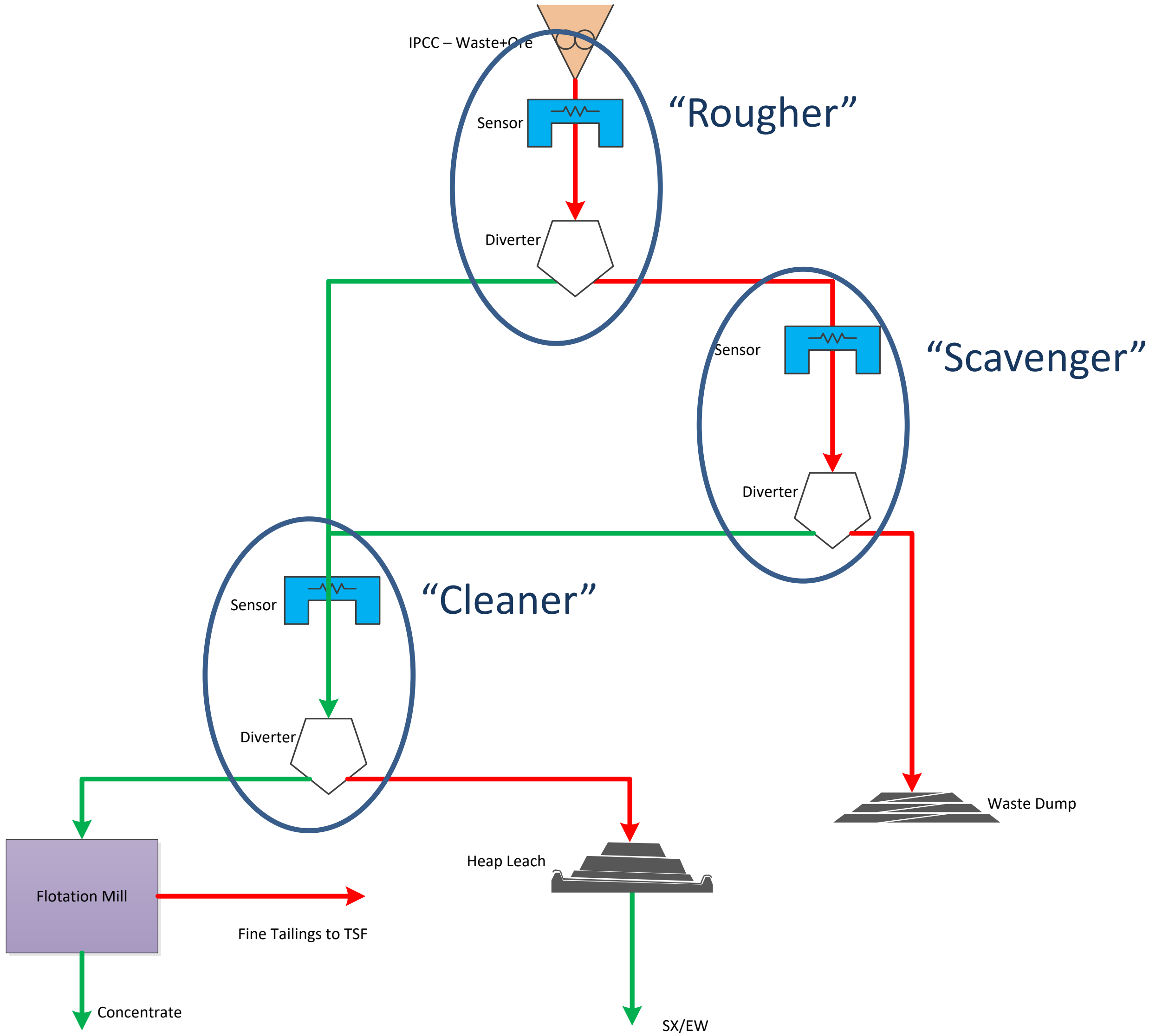
Application Scenarios

Bulk Sort A2



Application Scenarios

Bulk Sort C



Application Scenarios

Based on 100,000 tpd Cu operation

Case	Description	Total Cu Produced, Mlbs	Total Capex, $M	Operating Cost, $/lb Produced	All-in Cost, $/lb	NPV, $M (vs Base)	IRR (vs Base)
Base Case	Base Case Truck-Shovel	4,636	$1,681	$1.67	$2.63	-	-
IPCC	IPCC of Waste and Ore	4,636	$1,808	$1.26	$2.25	$476	56%
Bulk Sort A	IPCC + Bulk Sort - Reject Waste Only	4,522	$1,686	$1.31	$2.28	$432	N/A
Bulk Sort B	IPCC + Bulk Sort - Over-produce to fill mill	4,555	$1,863	$1.30	$2.31	$488	45%
Bulk Sort C	IPCC + Bulk Sort - Fill Mill and Secondary Process	4,649	$2,063	$1.36	$2.39	$495	40%

Positive Change vs IPCC

Negative Change vs IPCC

Equal or Near Equal to IPCC

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Conclusions

- Mass mining results in resource modeling and mine planning with block sizes that mask natural heterogeneity and smooth/reduce grade.
- Ore deposits exhibit heterogeneity to varying degrees, but most possess it.
- Large scale mass mining, such as with IPCC, can take advantage of natural heterogeneity through bulk sorting.
- The closer to the mining face that bulk sorting is implemented, the greater are the opportunities for waste rejection (✓ for IPCC).
- Mineral sensing technology is progressing to the point where bucket-size parcels of mined material can be discriminated.
- Material handling technologies are able to divert materials approaching this size range.
- Bulk sorting can be applied in the pre-concentration process as “rougher”, “scavenger”, and “cleaner”.
- Bulk sorting can be a value-accretive complement to IPCC.

Thank-you!

- For more information:

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