

# A Practical Process Mineralogy Approach to Advancing the Flowsheet for the Kamoia Project

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# Introduction

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## Objectives

- Objective 1:
  - Describe the use a Process Mineralogy centric methodology as a valid predictive tool in flowsheet design
    - *Complex ore bodies can undergo many stages of empirical flotation testing*
    - *Mineralogical data is used in this methodology to eliminate multiple stages of empirical testing and focus on requirements of the ore*
    - *By focusing on ore requirements, we have removed inherent limitations in flotation equipment i.e. building flowsheet around Denver cell for example*
    - *Flowsheet design and simulation is based entirely on mineralogical measurement data collected from simple kinetic flotation test*
- Objective 2:
  - Demonstrate the use of this methodology in advancing and improving the Kamoa Flowsheet as a case study

# Process Mineralogy and Kamoa

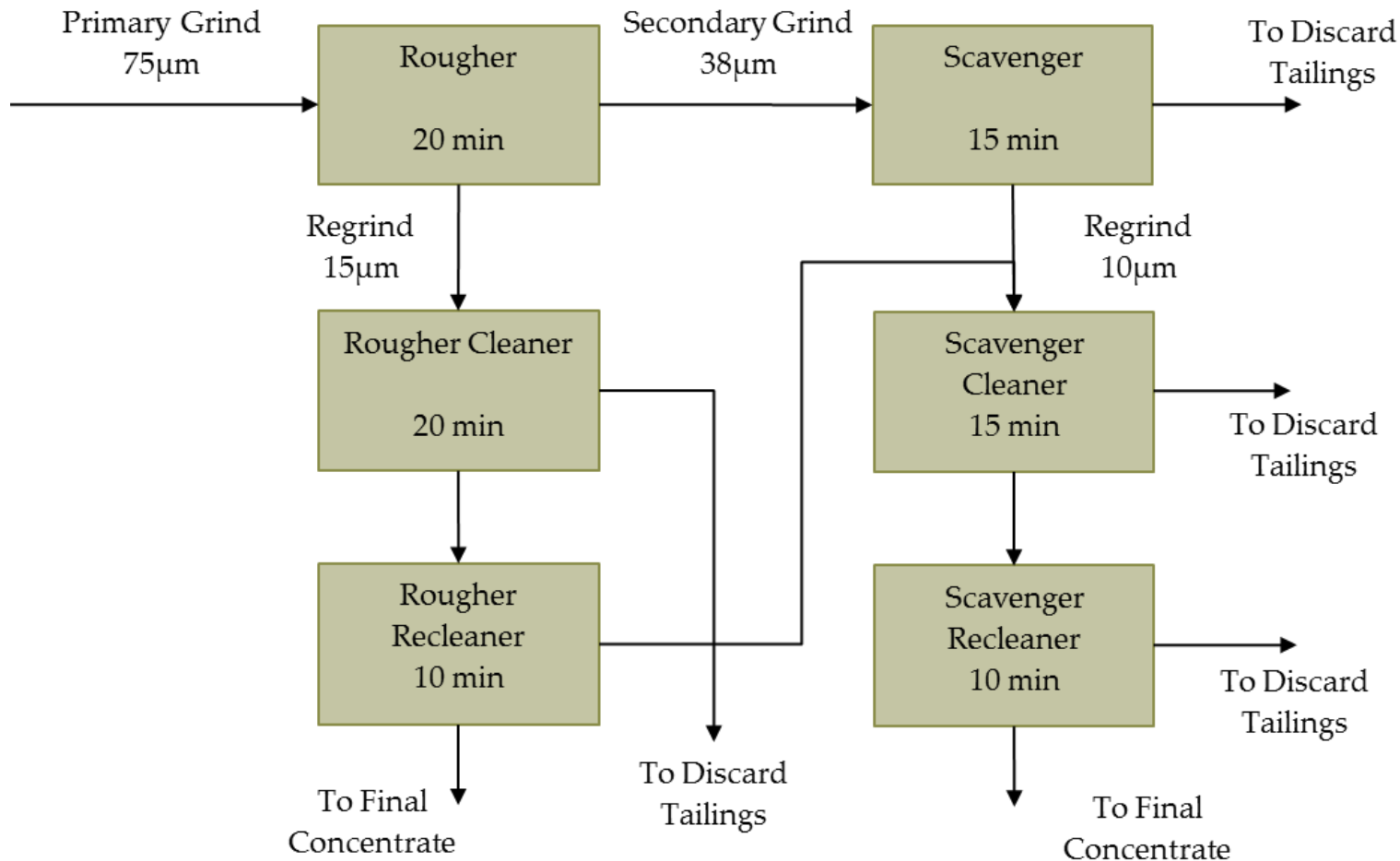
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## What we already know...

- Kamoa is a complex ore body (*owned by Ivanhoe Mines Ltd, and is located in the Katanga Province of the DRC*)...
- Cu mineralogy includes chalcopyrite, bornite, covellite, chalcocite (as well as oxides, carbonates and native Cu)
  - Ratios of sulphide mineralogy change between supergene and hypogene horizons
  - Variability is high within the horizons geospatially
  - Ratios affect feed grade and flowsheet response models and predictions
- Cu mineralogy grain size
  - This is consistent between all ores previously tested
  - Some Cu sulphide mineralogy ~50µm with remainder always around an 8-10µm grain size
- Flowsheet development has targeted fine grinding and mixed collector suite to handle variation in sulphide mineralogy

## Previous Kamoā Work

### Existing MF2 Flowsheet (Lotter et. al. 2013)



## Previous Kamoā Work

### Existing MF2 Flowsheet Typical Results (Lotter et. al. 2013)

- MF2 arrangement complex and \$\$\$ intensive (capex and opex)
- Current Results

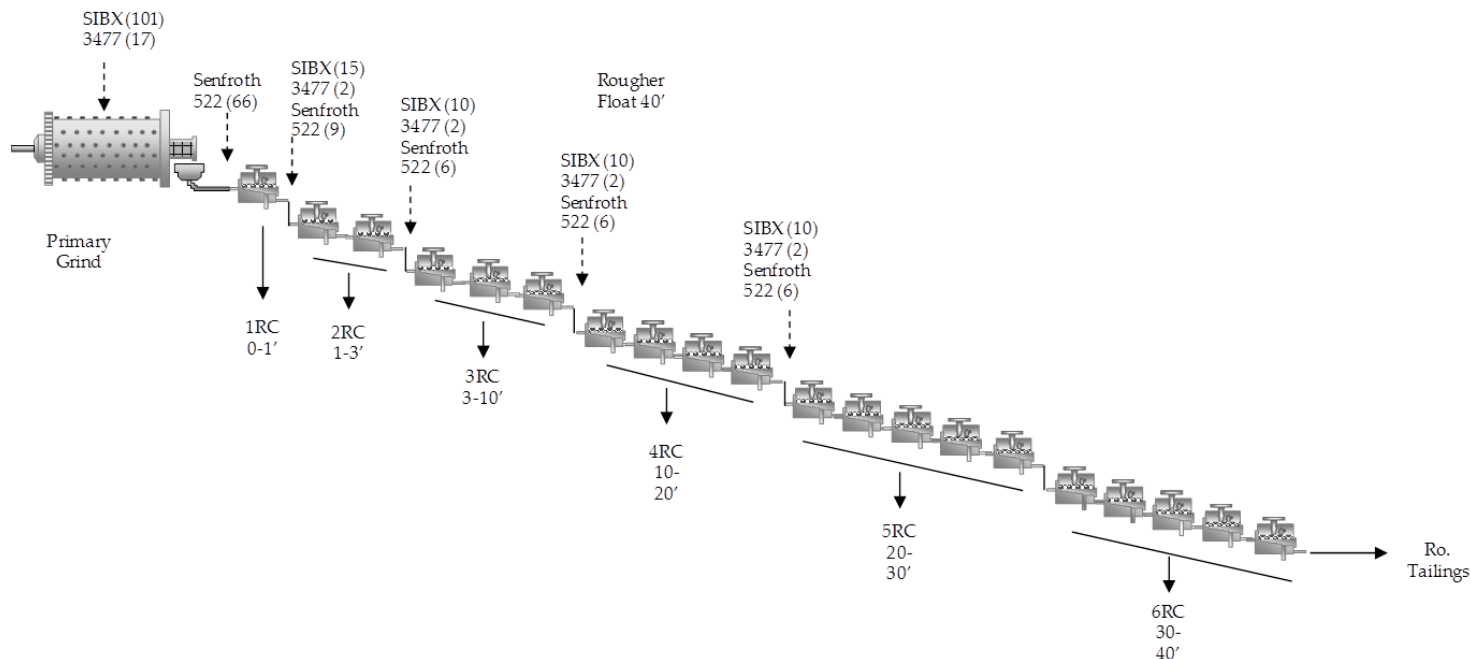
	Cu Grade %	Cu Recovery %	SiO <sub>2</sub> Grade %
Feed	3.3 - 3.9		
Final Concentrate	32 - 45	83 - 85	19 - 26
Scavenger Tails	0.5 - 0.7	11 - 14	

- Required a new approach to answer the following questions outlining new objectives
1. Can we get beyond 83% recovery with high feed grades?
  2. Are there sufficient liberated Cu sulphides in early stages of roughing to warrant a separate cleaner circuit that does not require regrinding?
  3. Can a single stage grind effectively replace the more complex and expensive MF2 arrangement? What would be a suitable primary grind?
  4. Can the SiO<sub>2</sub> dilution be reduced to near 14% and Cu grade maintained above 28% regardless of Cu sulphide mineralogy?
  5. Can tailings grade of 0.4% Cu be achieved? Scavenger Tails are mostly coarse locked Cu sulphides – How do we minimize this?

# Approach

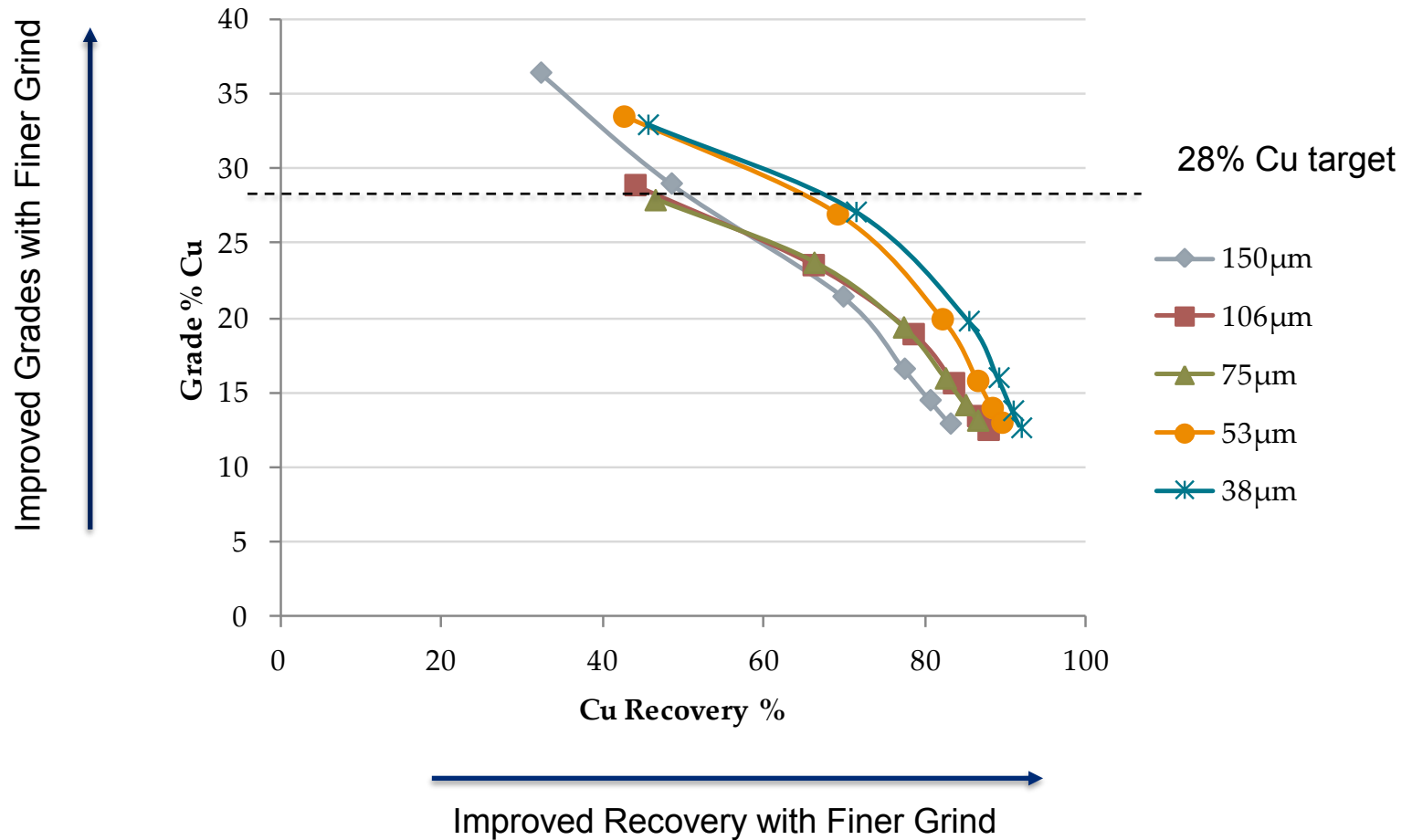
## How to Achieve New Targets?

- New methodology of combining kinetic flotation test with comprehensive mineralogy to effectively design the new flowsheet with no empirical testing
- Kinetic floats at 150 $\mu$ m, 106 $\mu$ m, 75 $\mu$ m, 53 $\mu$ m and 38 $\mu$ m were performed on new composite material
- Mineralogy was completed on three best performers.



# Kinetic Float

## Results

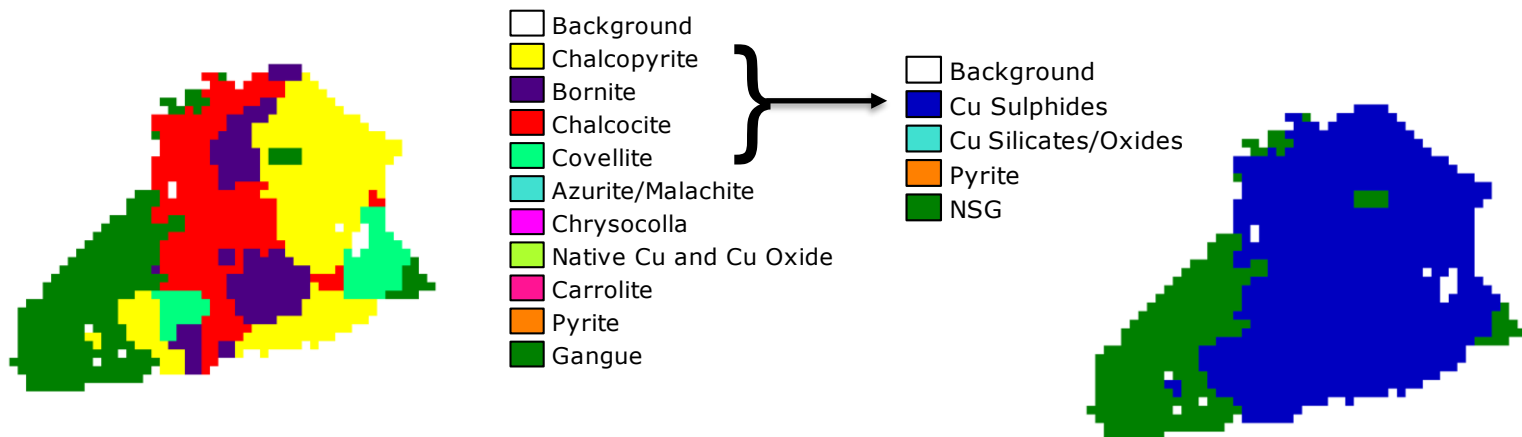


106µm, 53µm and 38µm duplicated for mineralogical measurement

# Mineralogy

## Procedure

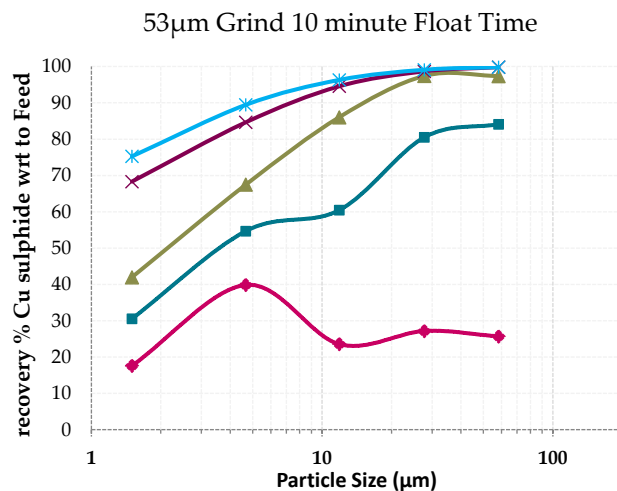
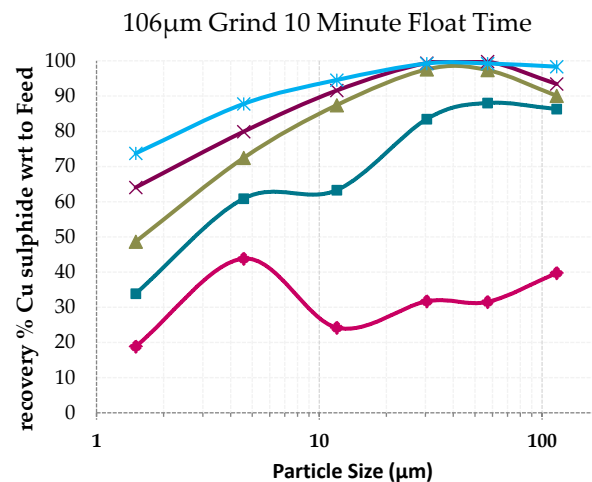
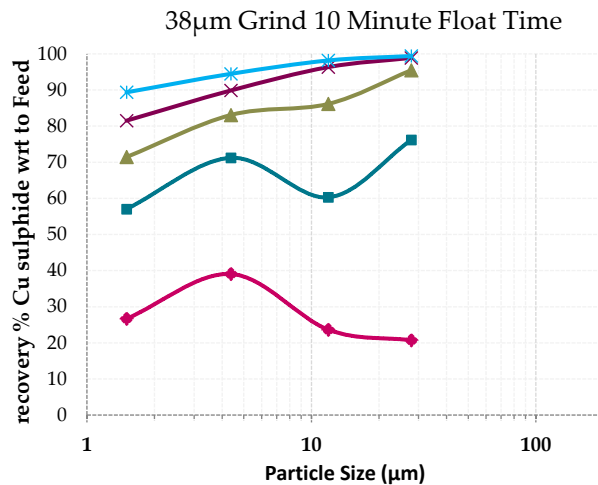
- Each Concentrate and the Rougher Tailing of the 38µm, 53µm and 106µm grind was sized and prepared for mineralogy by QEMSCAN
- Kinetic mass and value balance data was used to calculate size-by-size mineral recoveries
- Given close textural association of the individual Cu sulphide minerals – these were combined into one grouping of “Cu sulphides” which is a true depiction of bulk sulphide liberation required for this ore
  - This also simplifies liberation for subsequent modelling and simulation





# Recovery by Liberation

Are there sufficient liberated Cu sulphides in early stages of roughing to warrant a separate cleaner circuit that does not require regrinding?



- ◆ Locked (<30%)
- Low Grade Middling (30-80%)
- ▲ High Grade Middling (80-95%)
- ✕ Liberated (>95%)
- ✱ Free (100%)

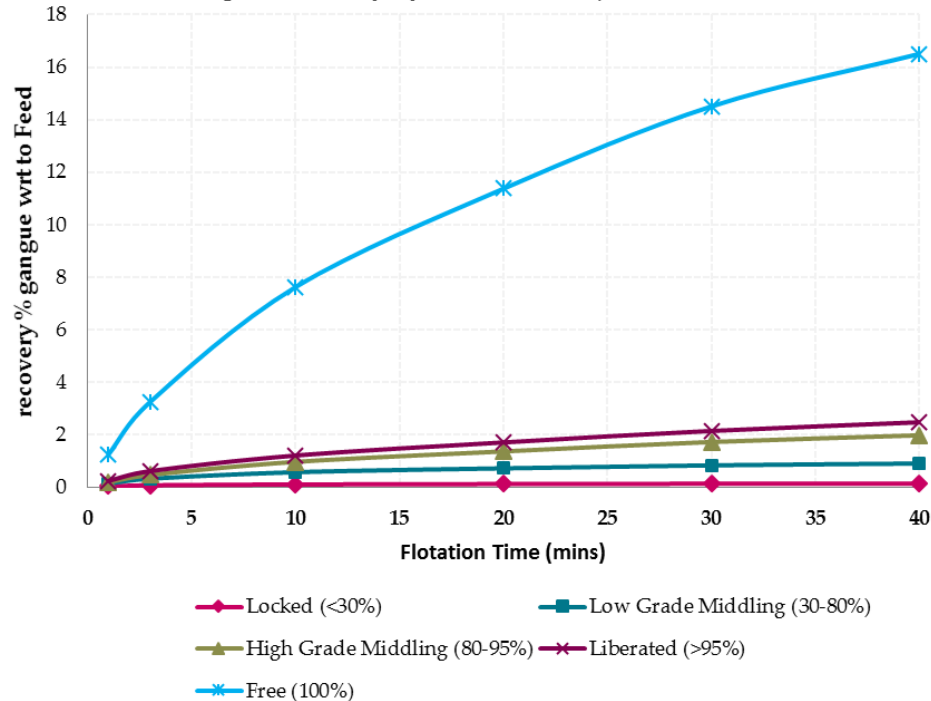
Kinetics are similar between grinds for liberated and free Cu sulphides

>90% of liberated Cu sulphides are recovered by 10 minutes of flotation

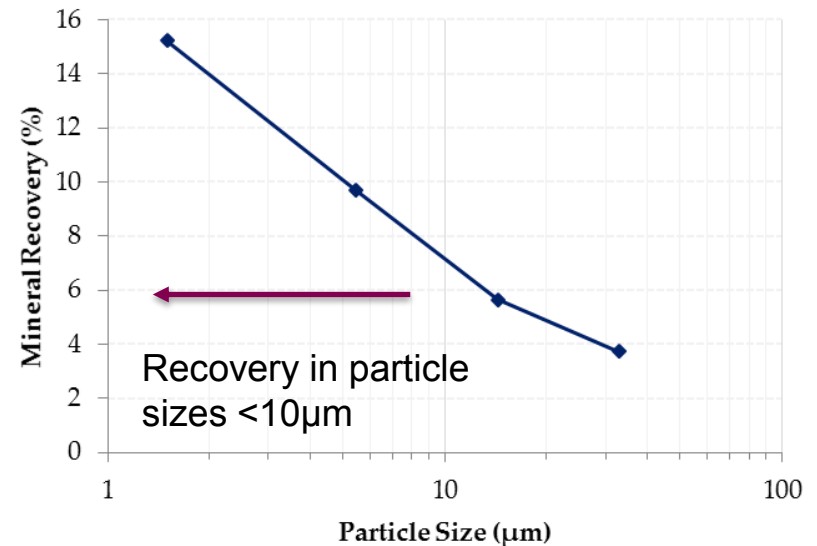
# Recovery by Liberation

Can the  $\text{SiO}_2$  dilution be reduced and Cu grade maintained above 28% regardless of Cu sulphide mineralogy?

Gangue Recovery by Liberation 38 $\mu\text{m}$  Grind

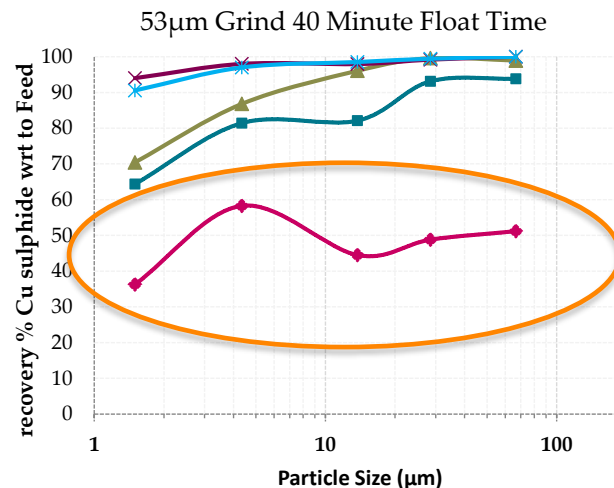
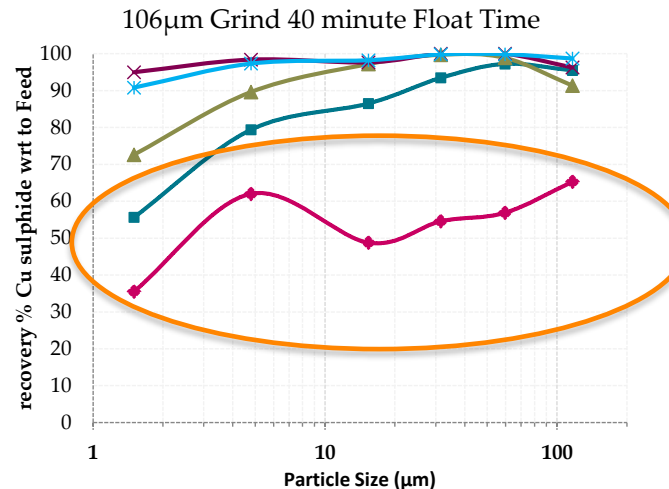
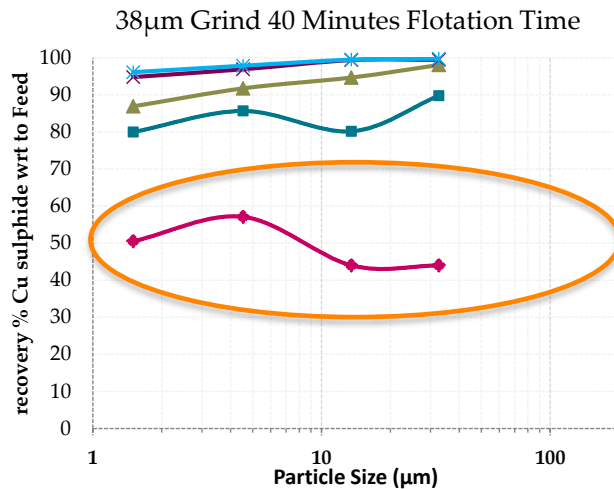


38 $\mu\text{m}$  Grind Liberated Gangue Recovery by Size (10 minutes)



# Recovery by Liberation

Can tailings grade of 0.4% Cu be achieved? How do we minimize coarse locked Cu sulphide losses?



- ◆ Locked (<30%)
- Low Grade Middling (30-80%)
- ▲ High Grade Middling (80-95%)
- ✕ Liberated (>95%)
- ✱ Free (100%)

Middling flotation improved to >80% by 40 minutes

Locked Cu sulphide recovery plateaus around 50% regardless of primary grind

Regrind stage still necessary to improve recovery >83% and minimize SiO<sub>2</sub> recovery to concentrate

	38µm	53µm	106µm
% Cu Loss	8.33	10.75	12.56
% Cu Loss >25µm	3.23	6.83	8.58
CuS Grain Size µm	8	8	8

# Flowsheet Simulation

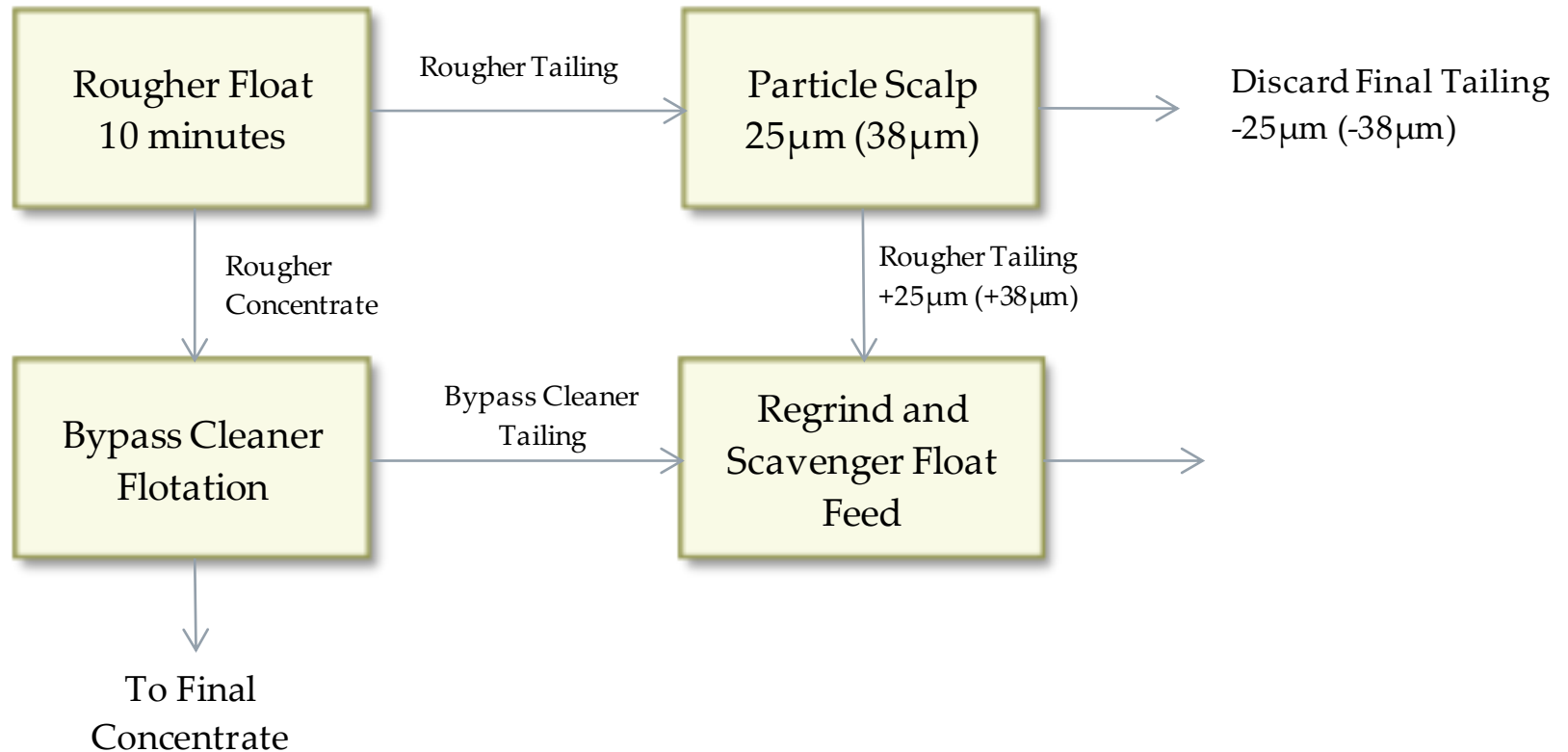
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## Options

- Simulations completed on mineralogical dataset
- Liberation data suggests a bypass without the need for regrinding is possible
  - Simulation looks at 3 minute and 10 minute bypass concentrate
- Can tailings grade of 0.4% Cu be achieved? How do we minimize coarse locked Cu sulphide losses?
  - Finer primary grinding than 38µm not economical
  - Simulation assesses scalping of coarse particles for reprocessing and subsequent tailings grade
- Can the SiO<sub>2</sub> dilution be reduced to near 14%?
  - Simulation assesses SiO<sub>2</sub> recovery by liberation and particle size and models bypass concentrate cleaning potential
- Can a single stage grind effectively replace the more complex and expensive MF2 arrangement? What would be a suitable primary grind
  - Simulation assesses all of the above options at the 3 grinds of 106µm, 53µm and 38µm

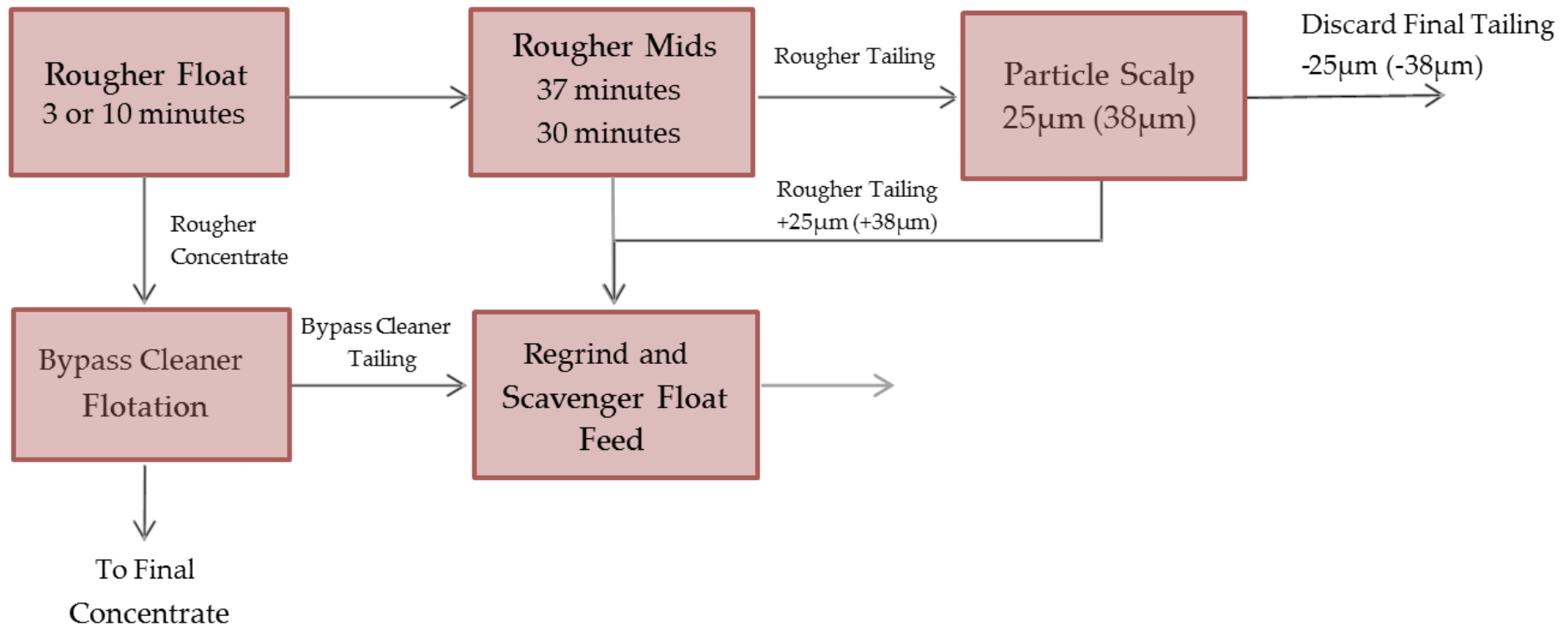
# Flowsheet Simulation

## Simulation 1



# Flowsheet Simulation

## Simulation 2 and 3



# Flowsheet Simulation

## By Pass Concentrate

- Target for final concentrate increment:
  - >28% Cu
  - <14% SiO<sub>2</sub>

### 3 minute concentrate

	% Cu	% SiO <sub>2</sub>	% Cu Recovery
38μm	25	31	71
53μm	29	26	65
106μm	20	38	77

### 10 minute concentrate

	% Cu	% SiO <sub>2</sub>	% Cu Recovery
38μm	19	39	84
53μm	22	35	81
106μm	20	38	77

- Remember SiO<sub>2</sub> recovery is all liberated and <10μm indicating entrainment

### 3 minute modelled concentrate

	% Cu	% SiO <sub>2</sub>	% Cu Recovery
38μm	40	9	66
53μm	42	7	59
106μm	39	10	54

### 10 minute modelled concentrate

	% Cu	% SiO <sub>2</sub>	% Cu Recovery
38μm	37	13	77
53μm	40	10	70
106μm	38	12	63



# Flowsheet Simulation

## Rougher Middling and Tail

- Target for final scavenger/rougher discard tails:
  - <0.4% Cu
  - <11% Cu Loss

### Rougher Tail After 10 minutes

	% Cu	% Cu Loss
38µm	0.7	16
53µm	1.0	20
106µm	1.1	23

### Rougher Tail after 40 minutes

	% Cu	% Cu Loss
38µm	0.5	9
53µm	0.7	11
106µm	0.7	12

- Remember Cu losses are mostly locked in coarse particle sizes

### 10 minute Rougher Tail -25µm

	% Cu	% Cu Loss
38µm	0.5	10
53µm	0.7	8
106µm	0.8	9



### 40 minute Rougher Tail -25µm

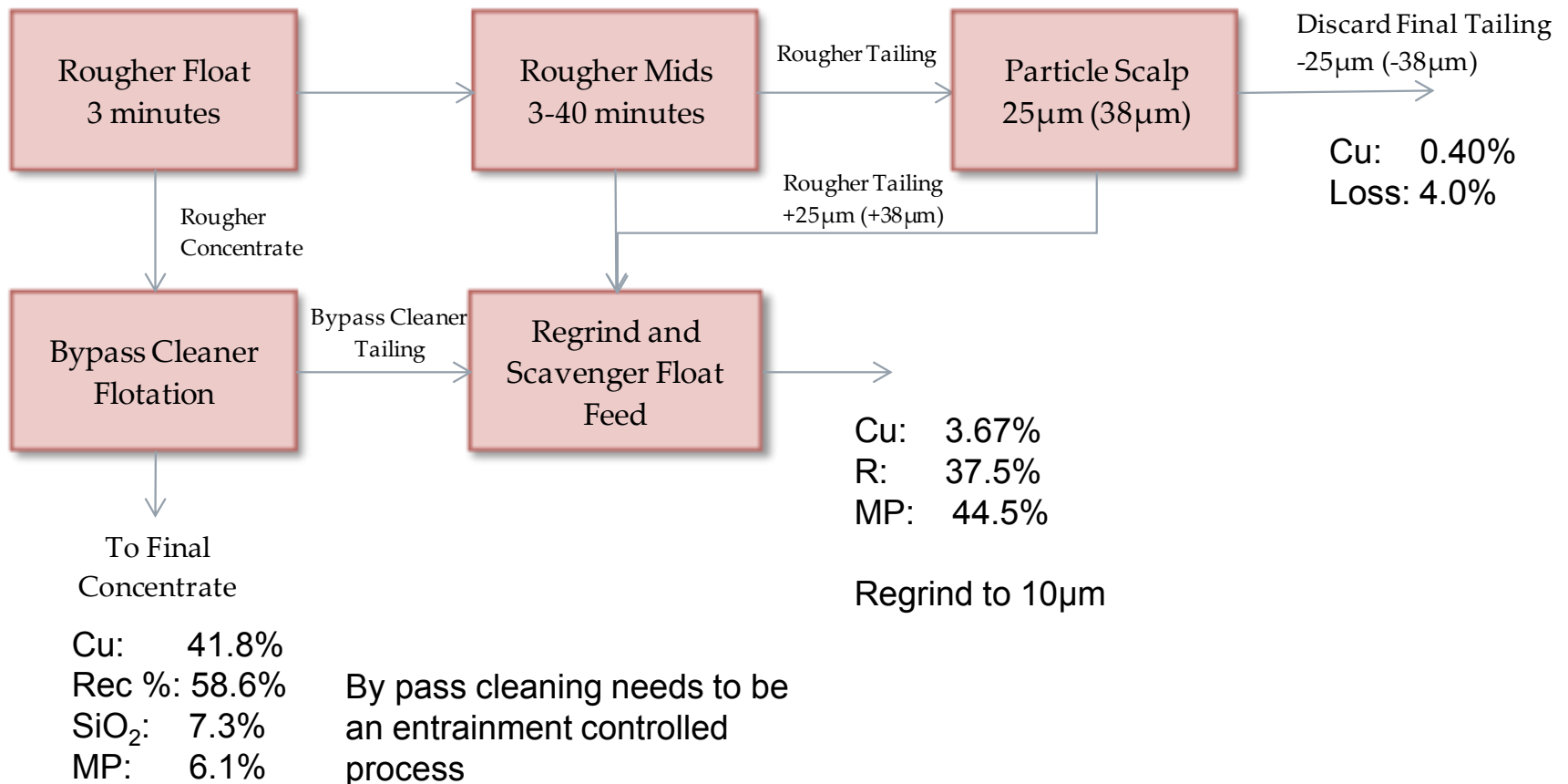
	% Cu	% Cu Loss
38µm	0.4	6
53µm	0.4	4
106µm	0.4	4



# Flowsheet Simulation

## Recommendations from mineralogy

53µm Primary Grind



## Flowsheet Simulation

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**Did we achieve our project goals with this mineralogical design method?**

Can we get beyond 83% recovery with high feed grades?



Is there sufficient liberated Cu sulphides in early stages of roughing to warrant a separate cleaner circuit that does not require regrinding?



Can a single stage grind effectively replace the more complex and expensive MF2 arrangement? What would be a suitable primary grind



Can tailings grade of 0.4% Cu be achieved? How do we minimize coarse locked Cu sulphide losses?

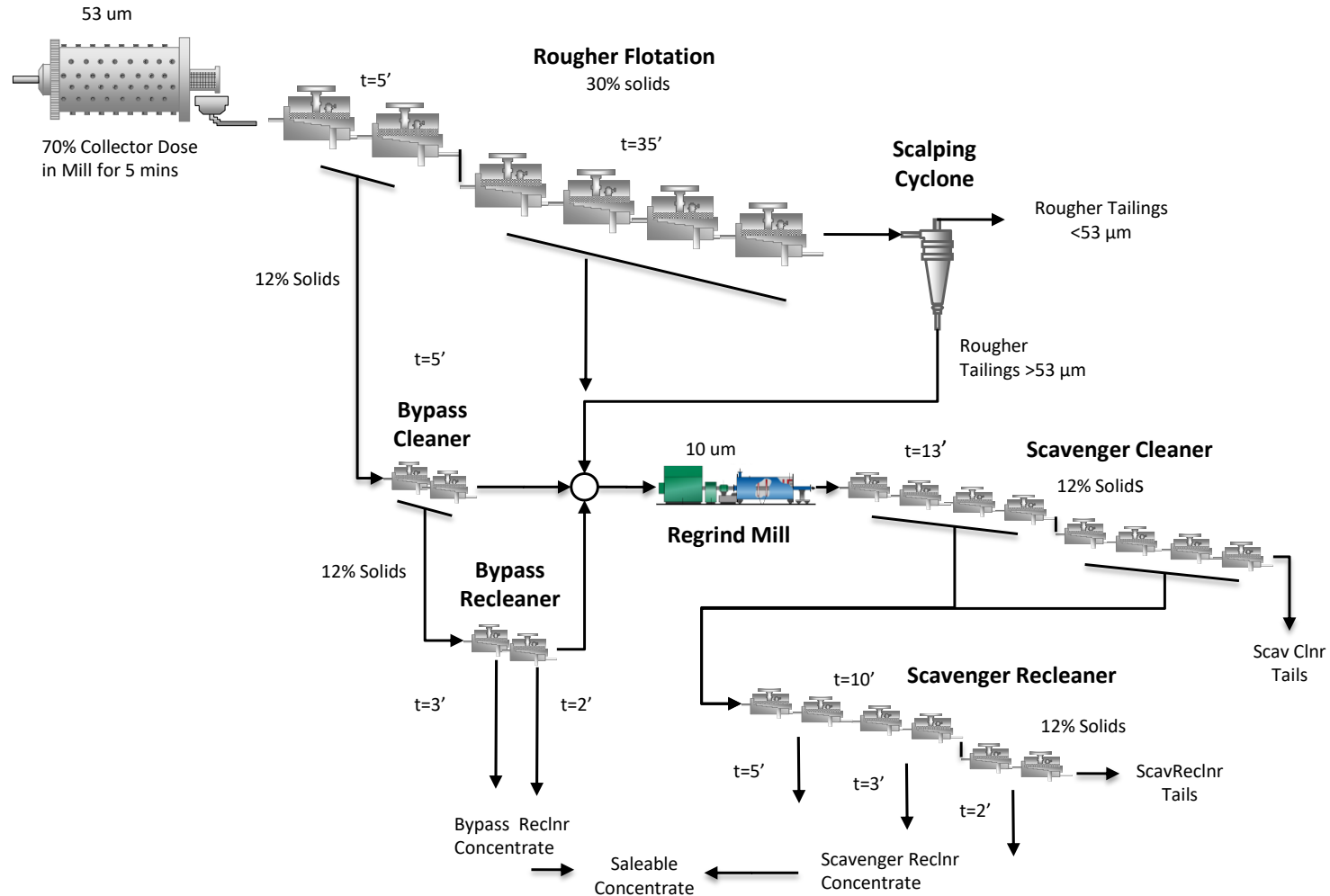


Can the SiO<sub>2</sub> dilution be reduced?



# Actual Flowsheet

Single-Stage Grind to optimum  $d_{80}$  size 53  $\mu\text{m}$



# Actual vs. Simulation

## How do they compare?

- Actual Flowsheet Results
  - 5 minute by-pass concentrate followed by low density cleaning
  - Middling flotation to 40 minutes
  - 53µm scalp with oversize to regrind feed

	Cu Grade %	Cu Recovery %	SiO2 Grade %	MP %
5 min By-pass Concentrate	41.34	65.3	10.9	8.57
Final Concentrate	38.99	88.3	14.56	
Rougher Tails	0.35	4.9		

- Simulated Flowsheet Results from Mineralogical Data
  - 3 or 10 minute by-pass concentrate
  - Middling flotation to 40 minutes
  - 25µm scalp with oversize to regrind feed

	Cu Grade %	Cu Recovery %	SiO2 Grade %	MP %
3 min By-pass Concentrate	41.8	58.6	7.3	6.1
10 min By-pass Concentrate	39.5	70.3	10.3	7.8
Final Concentrate	-	-	-	
Rougher Tails	0.4	4.0		

## Conclusions

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- A simple combination of kinetic floats with size-by-size mineralogy was used
- Designed a flowsheet based on the mineralogical data and the kinetics of key minerals by particle size and liberation
- Enhanced laboratory testwork by:
  - Effectively replacing empirical flotation testing and accurately predicting the physical response of the ore at set target grind
  - Removed inherent laboratory equipment limitations and identified the process required
  - Guiding physical testing to begin at demonstration and optimization rather than discovery
- Process mineralogy can be used as a valid predictive tool in process design

## Acknowledgements

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- Management of XPS Consulting & Testwork Services
- Management of Ivanhoe Mines Ltd