# Sensor-Based Sorting: Base Metals

Mike McCubbing, Manager
Geoanalytical Laboratories
Saskatchewan Research Council (SRC)

# SRC Overview

***SRC is Canada's second largest research and technology organization and has worked with industry, government and communities around the world for over 75 years.***

**Role as a Treasury Board Crown Corporation**

SRC is governed by The Research Council Act. It is overseen by an independent Board of Directors and is accountable to the Minister Responsible for SRC.

We receive a portion of our funding from government with the remainder coming from contract research and fee-for-service work.

## OVERVIEW 2021-22

**$277** MILLION IN ANNUAL REVENUE

CANADA'S 2ND LARGEST RESEARCH & TECHNOLOGY ORGANIZATION

23 — 1,400 CLIENTS IN 23 COUNTRIES

OVER **300** EMPLOYEES

**+75** YRS OF RD&D EXPERIENCE

## ECONOMIC PERFORMANCE 2021-22

**$13.6** BILLION IN IMPACTS SINCE 2003

TOTAL IMPACTS ON PROVINCIAL ECONOMY: **$1.8** BILLION

**$1.2** BILLION IN DIRECT ECONOMIC BENEFITS

**$627 MILLION** VALUE OF JOBS CREATED/MAINTAINED

59x — 59-TIMES RETURN ON PROVINCIAL INVESTMENT



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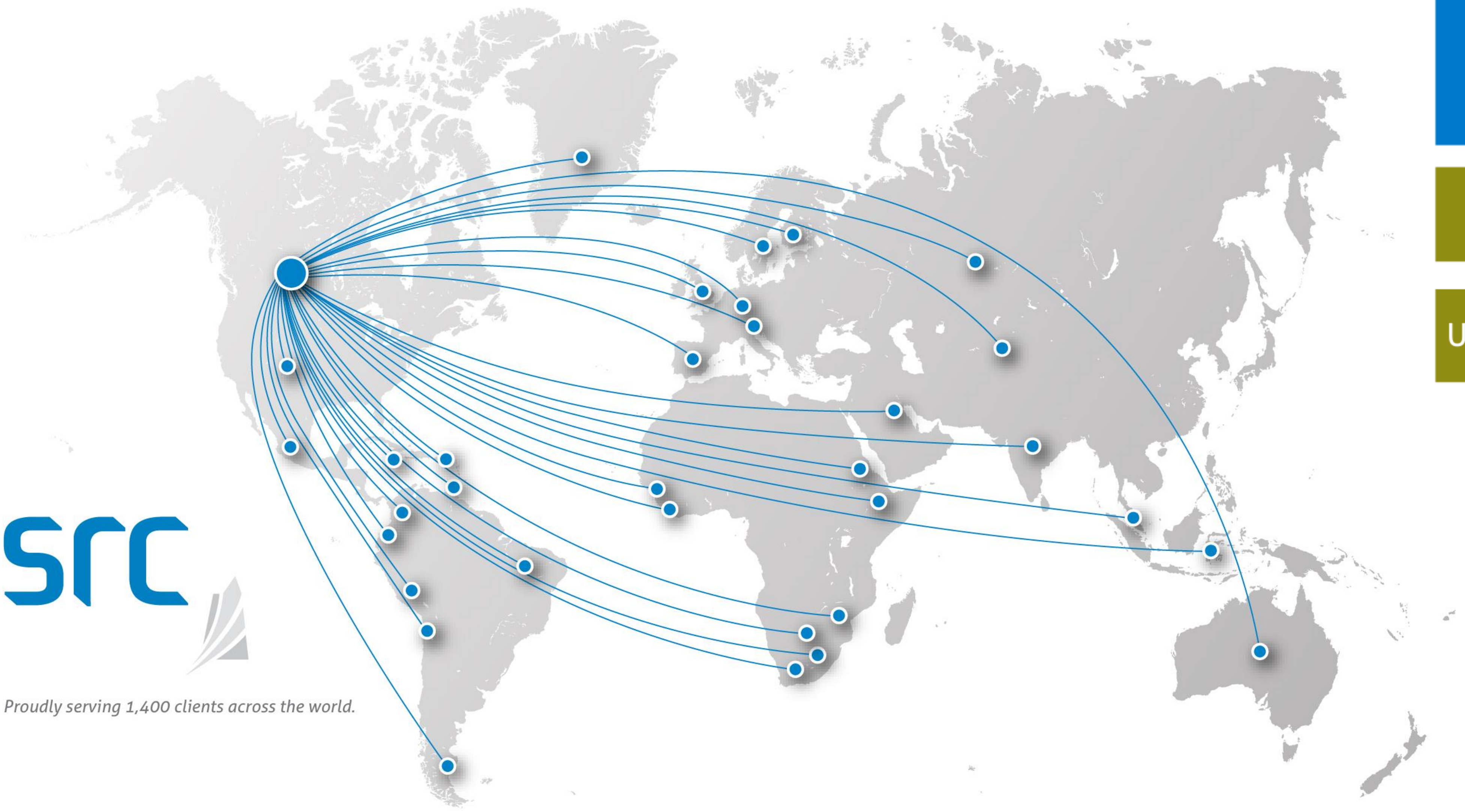


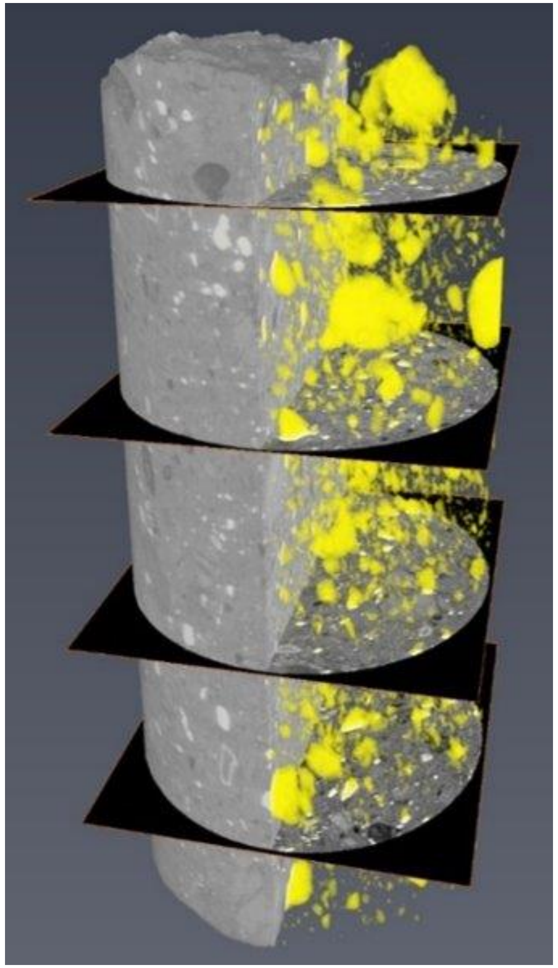
SRC HAS LOCATIONS IN

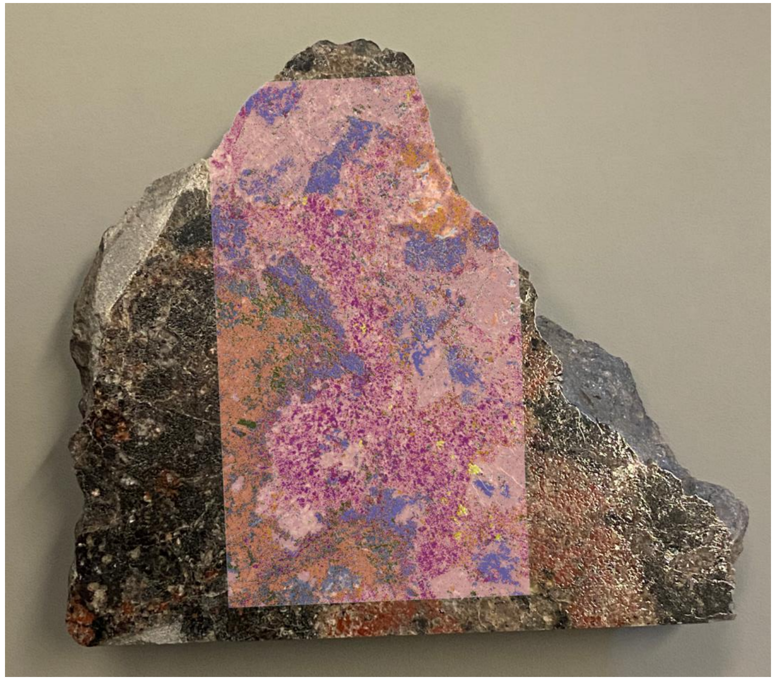
- Saskatoon, Sask. (Headquarters)
- Regina, Sask.
- Uranium City, Sask.

*Proudly serving 1,400 clients across the world.*

# Why is Sensor-Based Sorting Testwork Important?

- Identifies physical mineral properties
- Quantitative data
- Small samples can provide useful information
- Theoretical and actual data can be used
- Standardization of testing methodology







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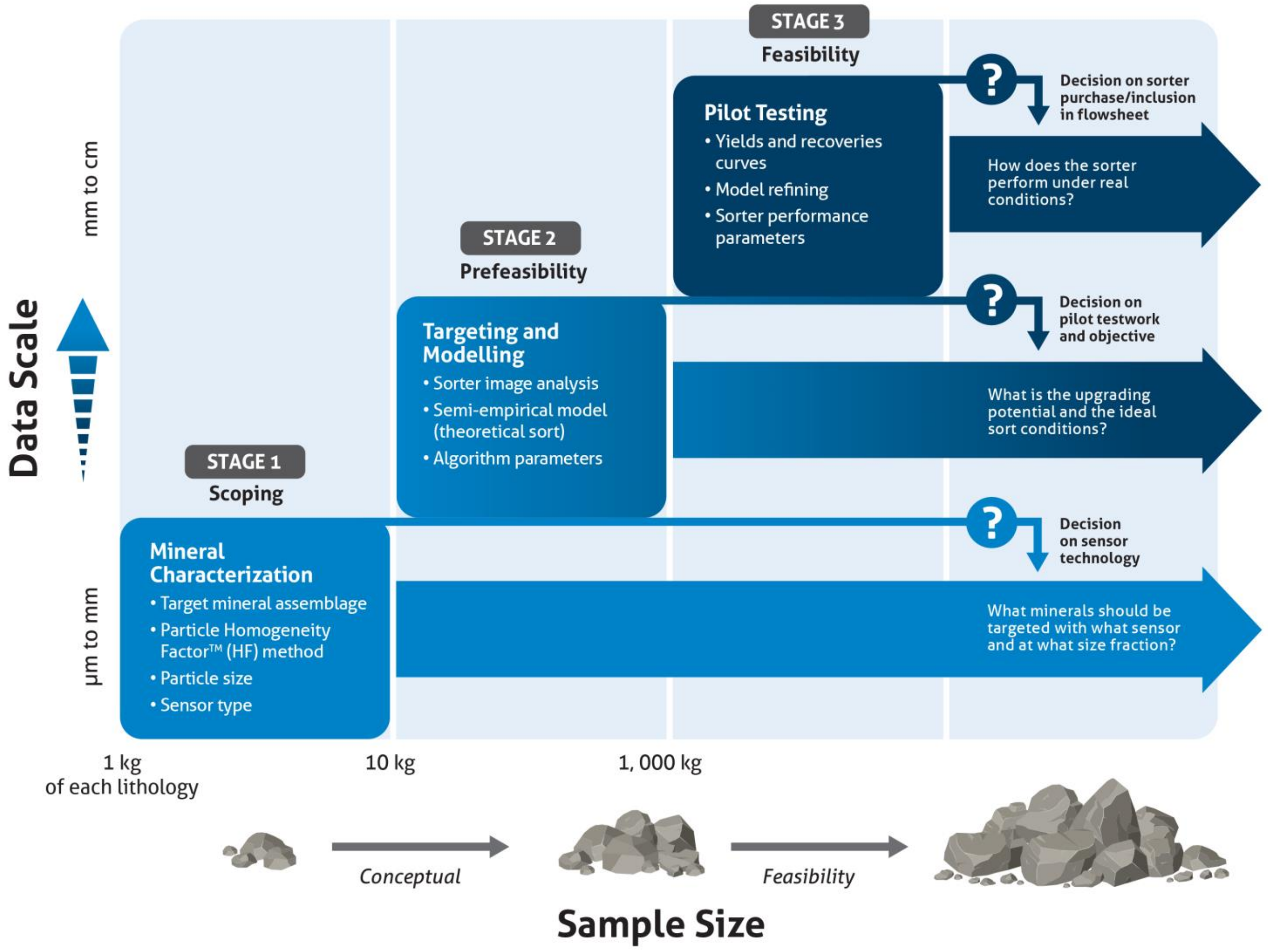
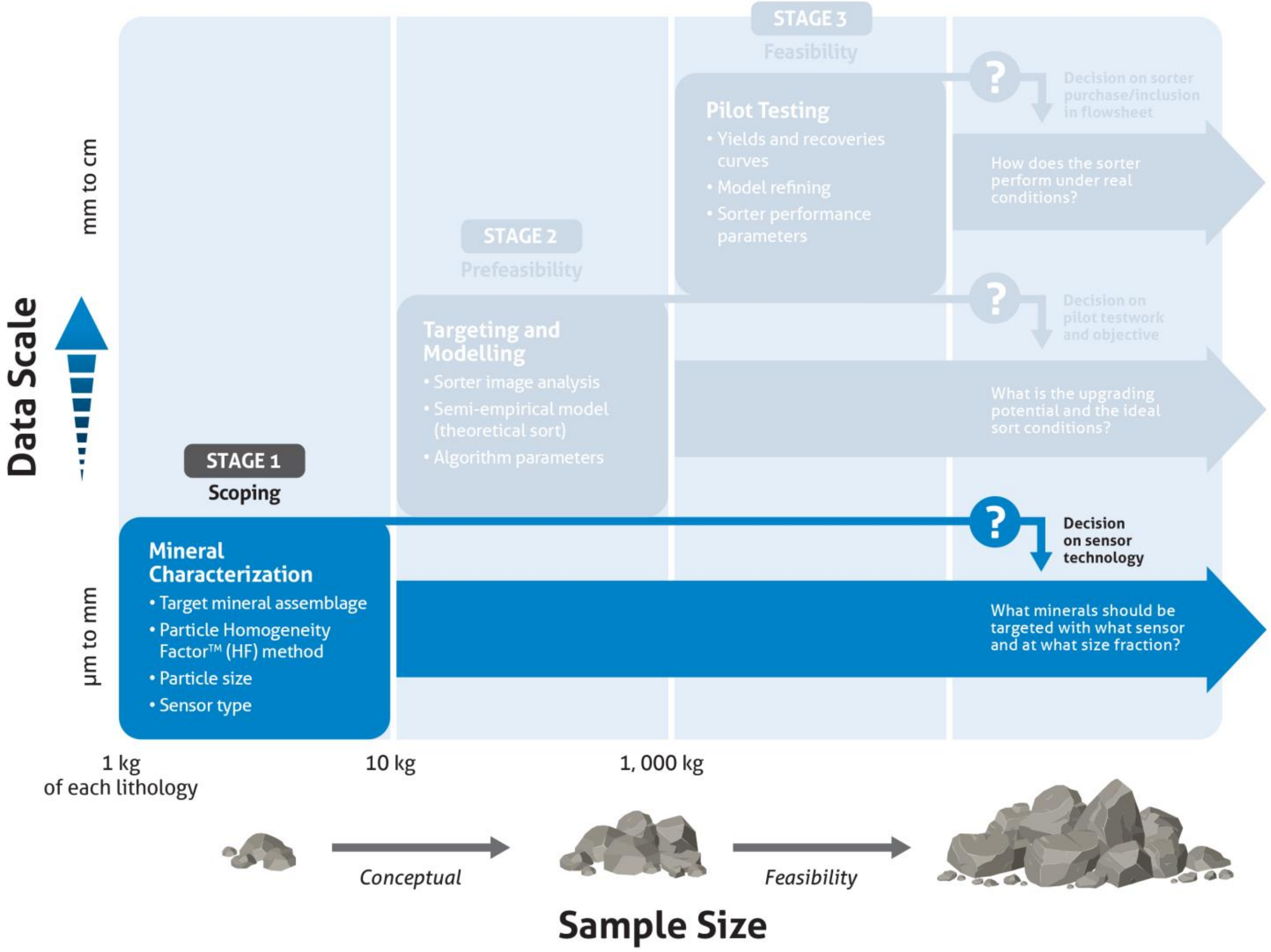
# Testing Stages for Sensor-Based Sorting



# STAGE 1

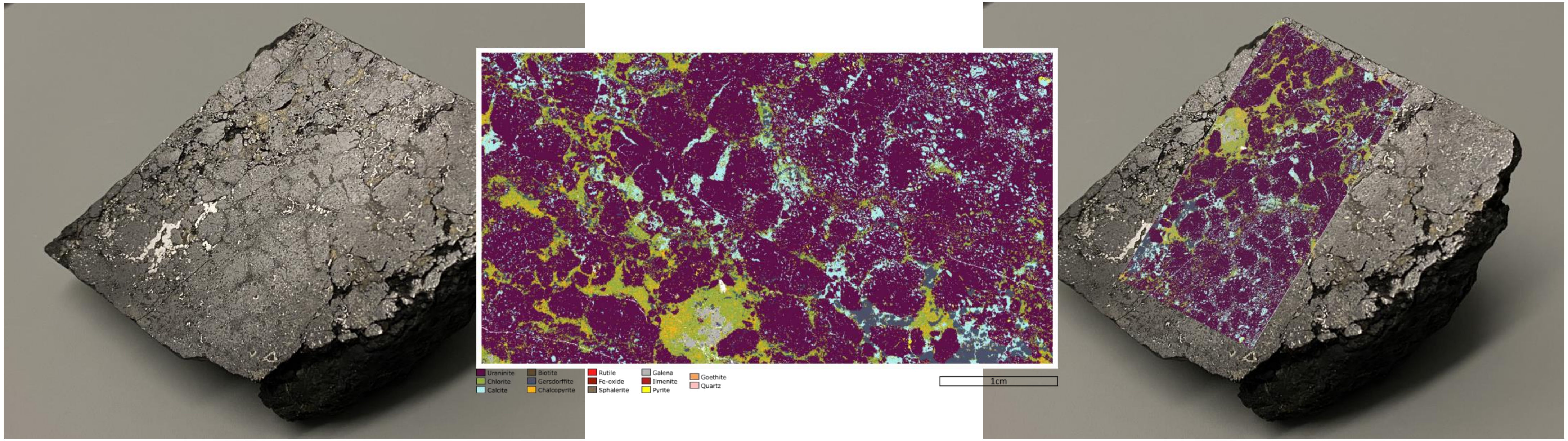
## Testing Stages for Sensor-Based Sorting



# STAGE 1: Scoping

Goal:

Identify target mineral assemblage and ideal particle size for sensor-based sorting



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# Characterization

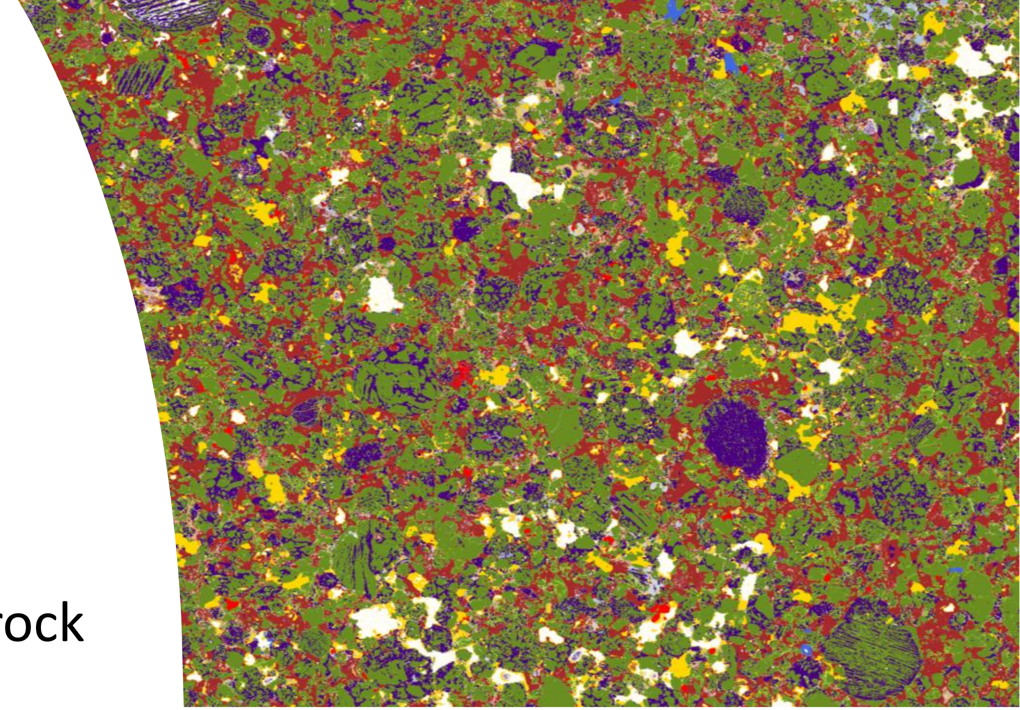
*What is characterization?*

**Sorter Amenability Work:**

- Sample selection – fully representative of mineralization, barren host-rock and country rock
- Modal mineralogy determination
- Mineral properties as they relate to sensor selection
- Optimal particle size determination

**Initial Sorter Testwork:**

- Test sheets of all determined mineralogy
- Assays to confirm sorter efficiency
- Model predictions for further bulk testwork



# Homogeneity and Sortability

- Ideally a large sample can be supplied to assess liberation
- Often sample size is at a premium
- Characterization can be determined on core samples (~20 cm) in length
- Representativity is very important
- SRC has developed the Homogeneity Factor$^{TM}$ (HF) when only a smaller sample size is available
- Creates a first estimate on ideal particle size



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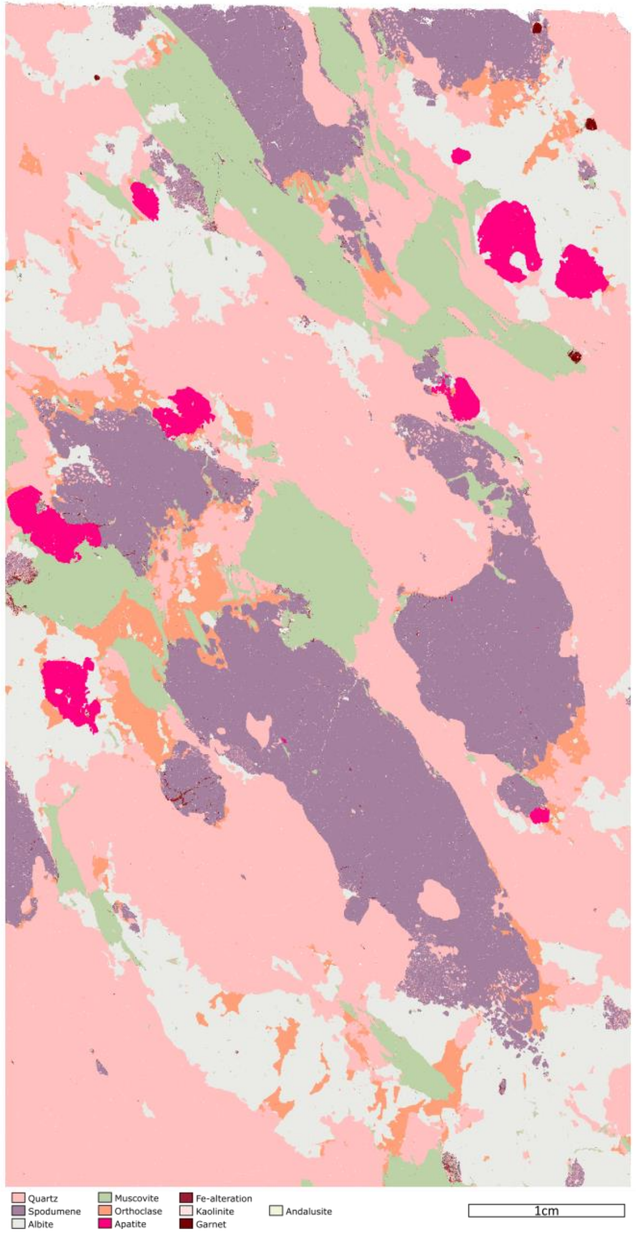
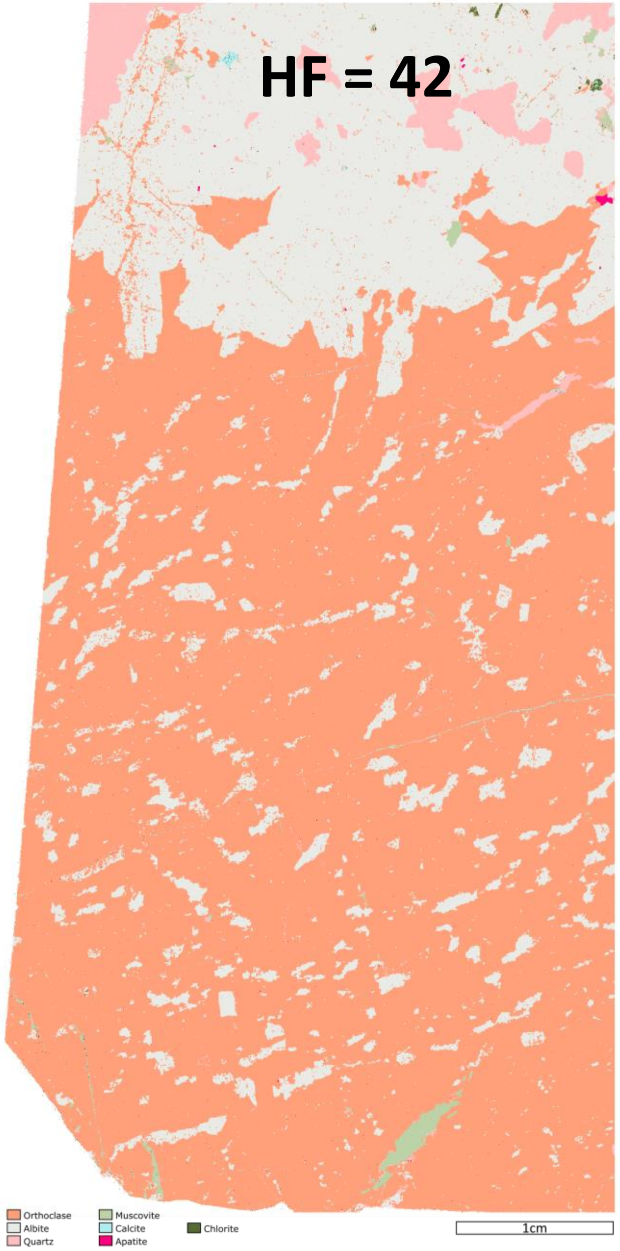
# High Homogeneity

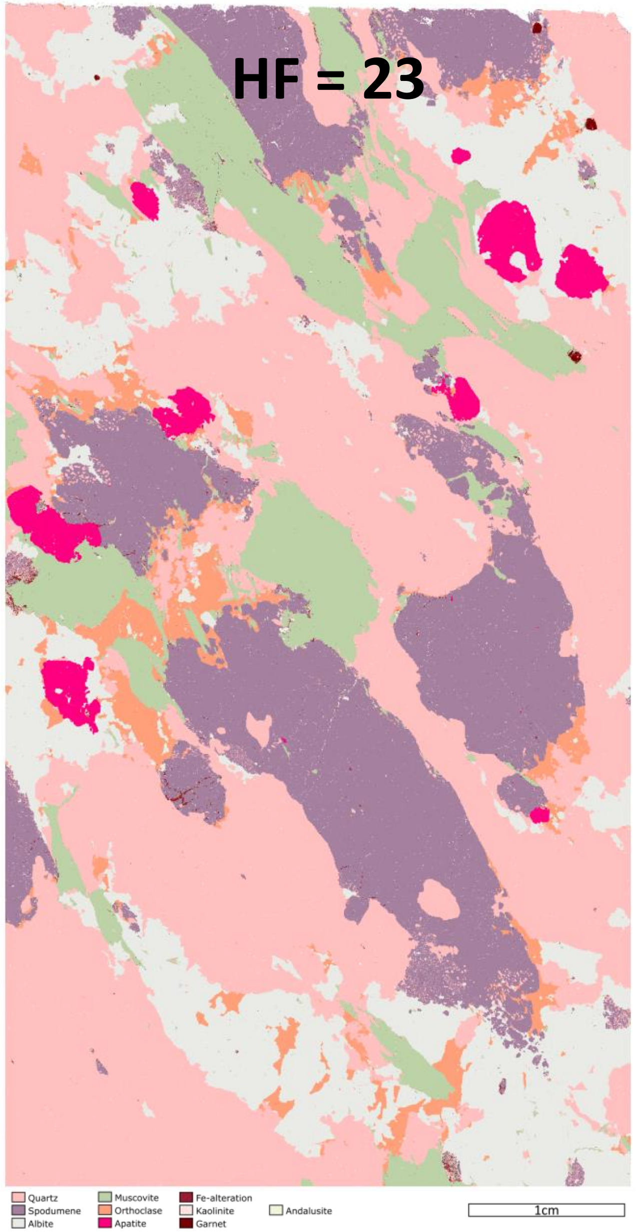

# Low Homogeneity



## High Homogeneity




## Low Homogeneity



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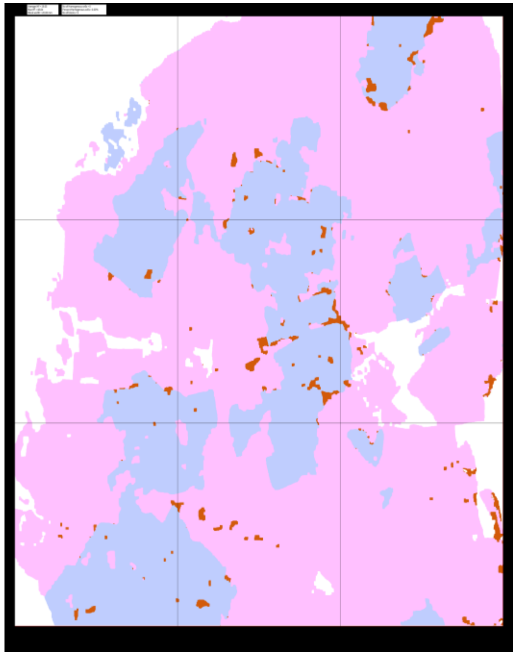
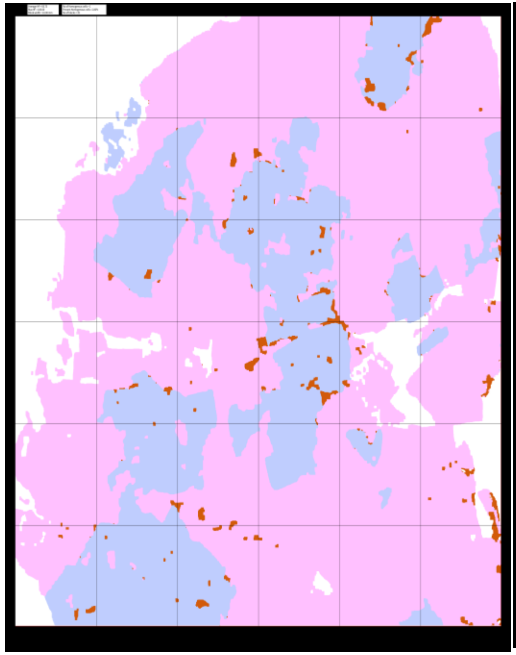
# HF Size Grid

**Modelling HF increase in by reducing particle size:**



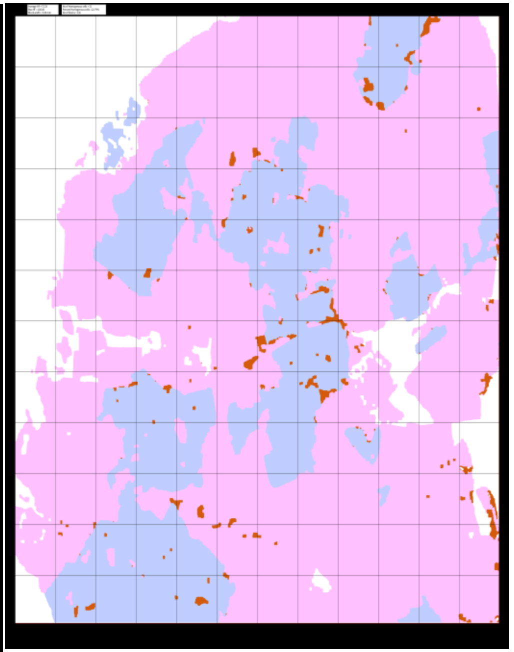
**20 mm**

**HF = 9.8**



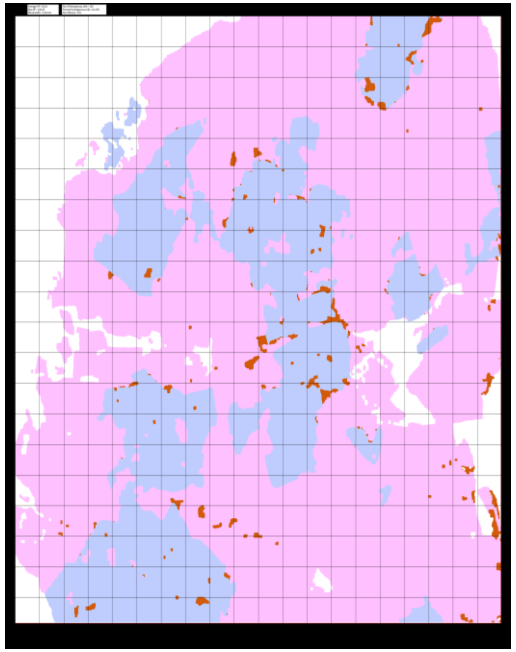
**10 mm**

**HF = 39.7**



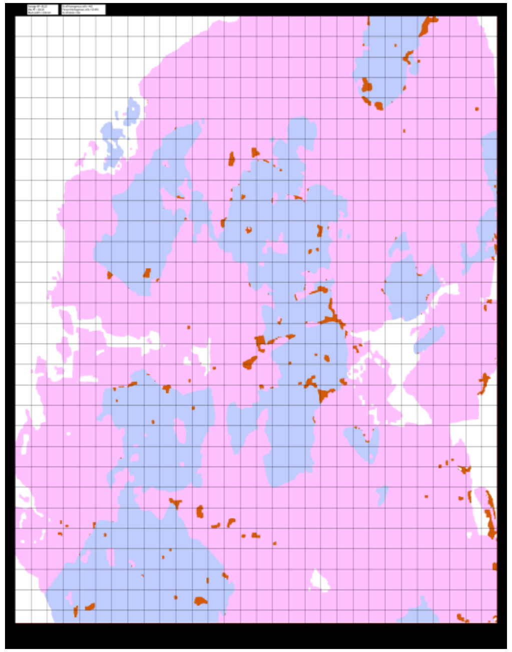
**5 mm**

**HF = 67.7**



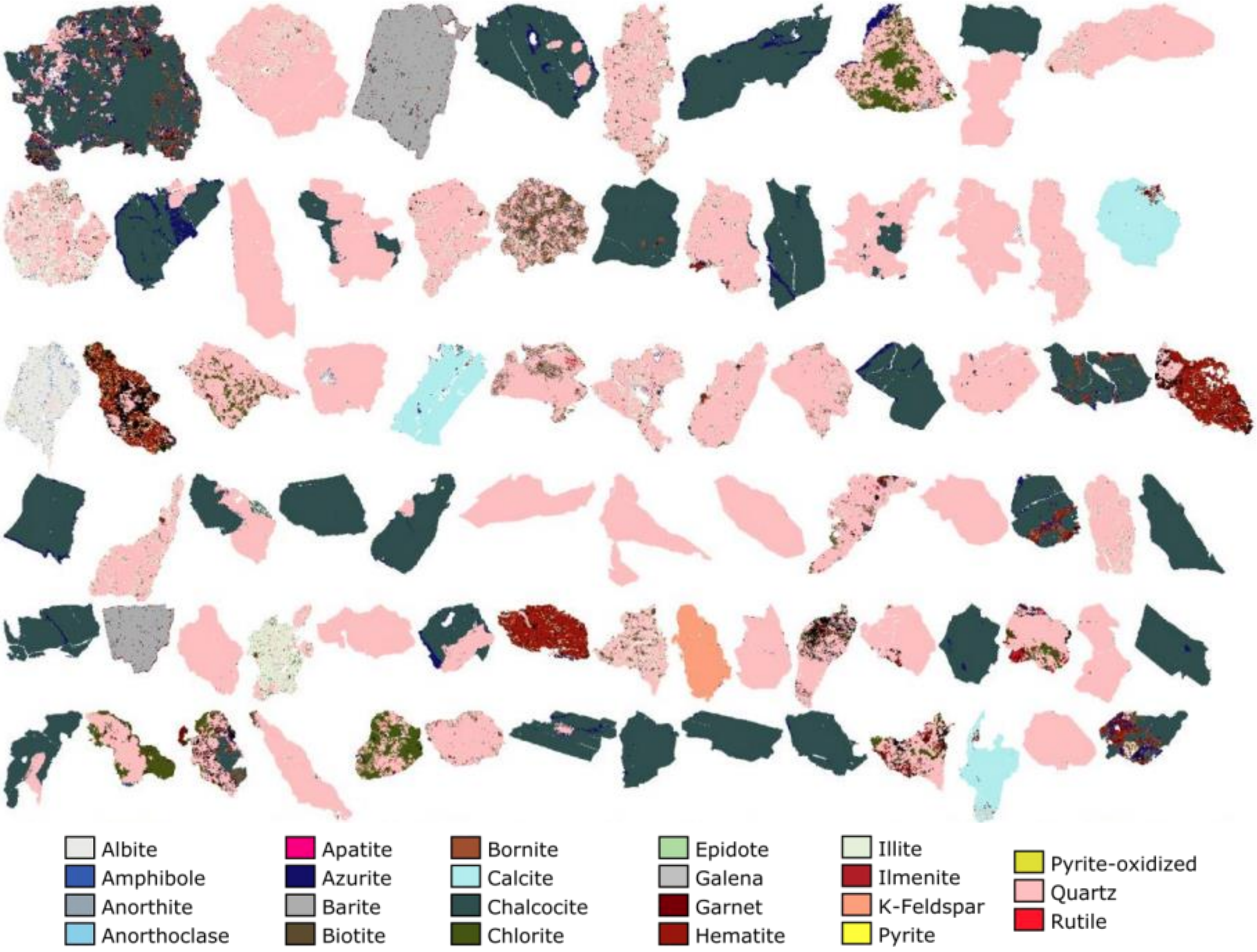
**2 mm**

**HF = 82.1**



**1 mm**

**HF = 90.3**



Albite
Amphibole
Anorthite
Anorthoclase
Apatite
Azurite
Barite
Biotite
Bornite
Calcite
Chalcocite
Chlorite
Epidote
Galena
Garnet
Hematite
Illite
Ilmenite
K-Feldspar
Pyrite
Pyrite-oxidized
Quartz
Rutile

# Case Study

## Gold and Silver Bearing Ore

- Example of a sample that has both minerals of interest and minerals which would be problematic.

# Stage 1 Deliverable: Characterization Table



| Mineral Name | Ore/ Waste Rock | Chemical Formula | Modal % | Average Size Range (cm)* | Major Associations | Mineral Group/ Species | Approx. Au% Au% | Hardness (MOH) | Specific gravity ($kg/m^3$) | Electron Density (gm/cc) | Molecular Weight (gm) | Atomic Density (N) | Colour | Luster | Transparency | Luminescence | Magnetic Susceptibility |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Electrum | Ore | AgAu | 34 | 1-3 | Tth/Ttp/Ccp | Alloy | 60 Au 40 Ag | 2.5-3 | 12.5-15 | 12 | 304.83 | 2.37E-24 | pale yellow | metallic | opaque | Non-fluorescent | Nonmagnetic |
| Tetrahedrite/ Tennantite | Waste Rock | $(Cu,Fe)_{12}(Sb,As)_4S_{13}$ | 24 | 3-5 | Pyg/Prs/Elc | Sulphide | - | 3.5-4 | 4.6-5.2 | 4.3-4.52 | 1471.40-1643.31 | 1.71E-25 | Black Steel grey | metallic | opaque | Non-fluorescent | Nonmagnetic |
| Chalcopyrite | Waste Rock | $CuFeS_2$ | 10.5 | 2-5 | Elc/Qz | Sulphide | - | 3.5-4 | 4.1-4.3 | 3.98 | 183.52 | 1.31E-24 | Brass yellow | metallic | opaque | Non-fluorescent | No (yes on heating) |
| Pyrargyrite | Ore | $Ag_3SbS_3$ | 8.5 | 4-5 | Prs/Tth/Ttn | Sulphide | 59 Ag | 2.5 | 5.85 | 5.19 | 541.56 | 5.77E-25 | Deep red | sub metallic | opaque to translucent | Non-fluorescent | Nonmagnetic |
| Silver | Ore | Ag | 6.5 | 2-5 | None | Native Element | 100 Ag | 2.5-3 | 10-11 | 9.15 | 107.87 | 5.11E-24 | Grey | metallic | opaque | Non-fluorescent | Nonmagnetic |
| Sphalerite | Waste Rock | (Zn,Fe)S | 4.5 | 0.5-1 | Ccp/Elc | Sulphide | - | 3.5-4 | 3.9-4.2 | 3.85 | 96.98 | 2.39E-24 | Black-Brown | resinous-greasy | transparent to translucent | Fluorescent | Nonmagnetic |
| Proustite | Ore | $Ag_3AsS_3$ | 3.75 | 0.5-1 | Pyg/Tth/Ttp | Sulphide | 65 Ag | 2-2.5 | 5.5-5.56 | 4.98 | 494.72 | 6.06E-25 | Reddish grey | sub metallic | transparent to translucent | Non-fluorescent | Nonmagnetic |
| Pyrite | Waste Rock | $FeS_2$ | 2.25 | 0.25-0.5 | Elc/Ccp | Sulphide | - | 6.5 | 5-5.02 | 4.84 | 119.98 | 2.43E-24 | Pale brass yellow | metallic | opaque | Non-fluorescent | No (yes on heating) |
| Quartz | Waste Rock | $SiO_2$ | 2.25 | 2-3 | Ccp | Silicate | - | 7 | 2.6-2.65 | 2.65 | 60.08 | 2.66E-24 | White | vitreous | transparent to translucent | Fluorescent | Nonmagnetic |
| Muscovite | Waste Rock | $KAl_2(Si_3Al)O_{10}(OH,F)_2$ | 1.25 | 0.5-1 | Elc | Mica | - | 2-2.5 | 2.77-2.88 | 2.81 | 398.71 | 4.24E-25 | Silver white | vitreous, silky, pearly | transparent to translucent | Non-fluorescent | Nonmagnetic |
| Kaolinite | Waste Rock | $Al_2Si_2O_5(OH)_4$ | 1.25 | 0.5-1 | Elc | Clay | - | 1.5-2 | 2.6 | 2.62 | 258.16 | 6.11E-25 | Brownish white | dull | transparent to translucent | Non-fluorescent | Nonmagnetic |
| Arsenopyrite | Waste Rock | FeAsS | 0.75 | 0.5-1 | Pyr | Sulphide | - | 5 | 6.07 | 5.7 | 162.83 | 2.11E-24 | Light steel grey | metallic | opaque | Non-fluorescent | No (yes on heating) |
| Gold | Ore | Au | 0.5 | 0.5 | Elc | Native Element | 100 Au | 2.5-3 | 16-19.3 | 15.5 | 196.97 | 4.74E-24 | Yellow | metallic | opaque | Non-fluorescent | Nonmagnetic |
| Separation Technique: | | | | | | | | | DMS | | | XRT | Colour | | laser | UV | Magnetics |

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# Separating Gold/Silver

- **Arsenic bearing minerals could be problematic if not removed**
- **Colour – possible** if focusing on just removing tetrahedrite/tennantite or electrum, or removing some waste rock
- **DMS – minimal return** - density separation for some waste rock removal
- **XRT** – combination of thickness/density/atomic density – **feasible**
- **NIR – not possible**
- **Magnetics – not possible**
- **Luminescence – not possible**



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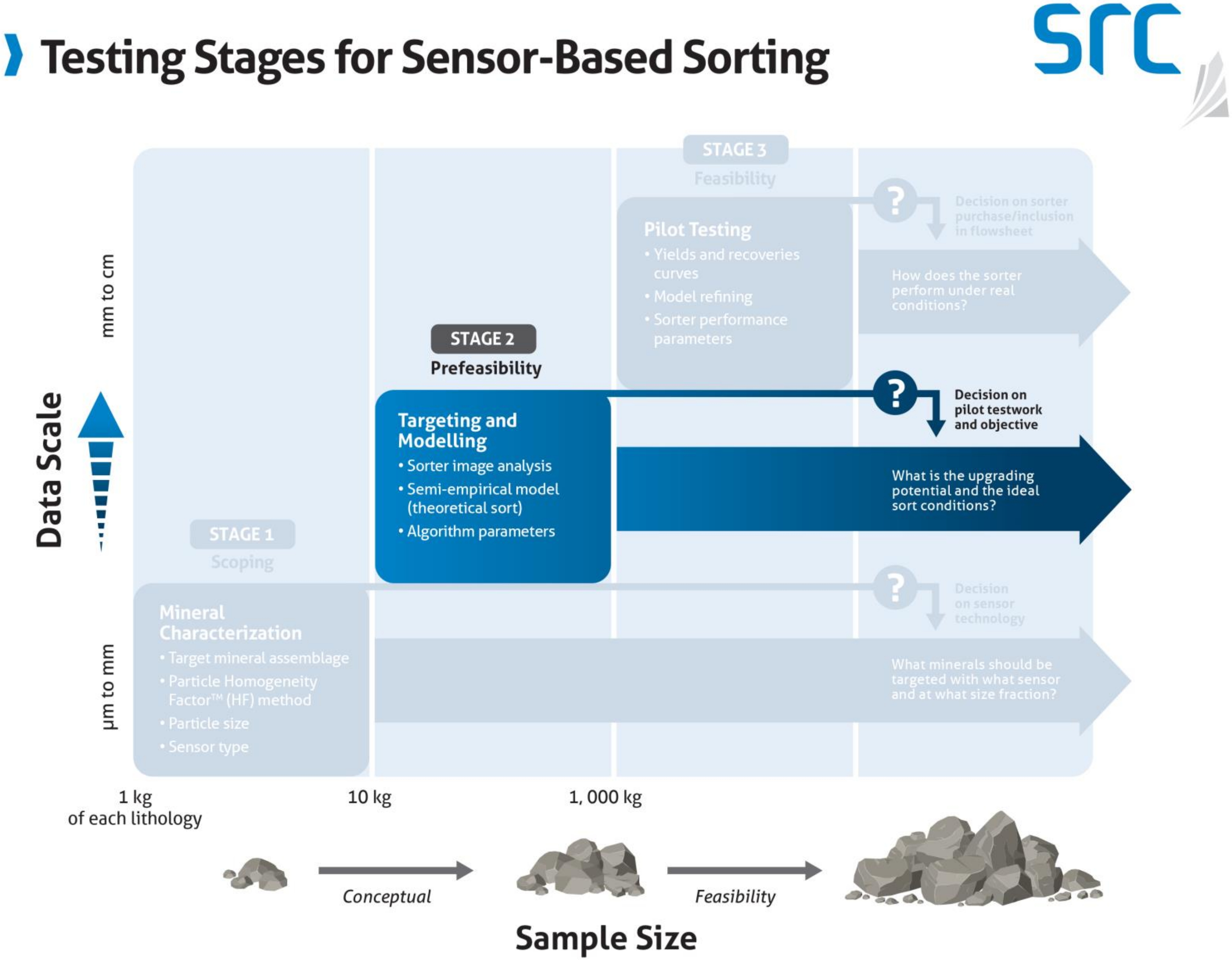
# STAGE 1 Decision

CLIENT DECISION: *What target mineral, sorter and size?*

1. Based on sensor responses of each mineral
2. HF – size tables of each mineral

# STAGE 2


Testing Stages for Sensor-Based Sorting
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STAGE 3
Feasibility
Pilot Testing
• Yields and recoveries curves
• Model refining
• Sorter performance parameters
Decision on sorter purchase/inclusion in flowsheet
How does the sorter perform under real conditions?
STAGE 2
Prefeasibility
Targeting and Modelling
• Sorter image analysis
• Semi-empirical model (theoretical sort)
• Algorithm parameters
Decision on pilot testwork and objective
What is the upgrading potential and the ideal sort conditions?
STAGE 1
Scoping
Mineral Characterization
• Target mineral assemblage
• Particle Homogeneity Factor™ (HF) method
• Particle size
• Sensor type
Decision on sensor technology
What minerals should be targeted with what sensor and at what size fraction?
Data Scale
mm to cm
µm to mm
1 kg of each lithology
10 kg
1, 000 kg
Conceptual
Feasibility
Sample Size

# STAGE 2: Prefeasibility

1. Evaluate the *sorting efficiency* of the identified technology
2. Develop *semi-empirical sorting models* to build flowsheets and test different scenarios
3. Small (but representative) amounts of sample; data is gathered from sorter first inspection, as well as characterization results



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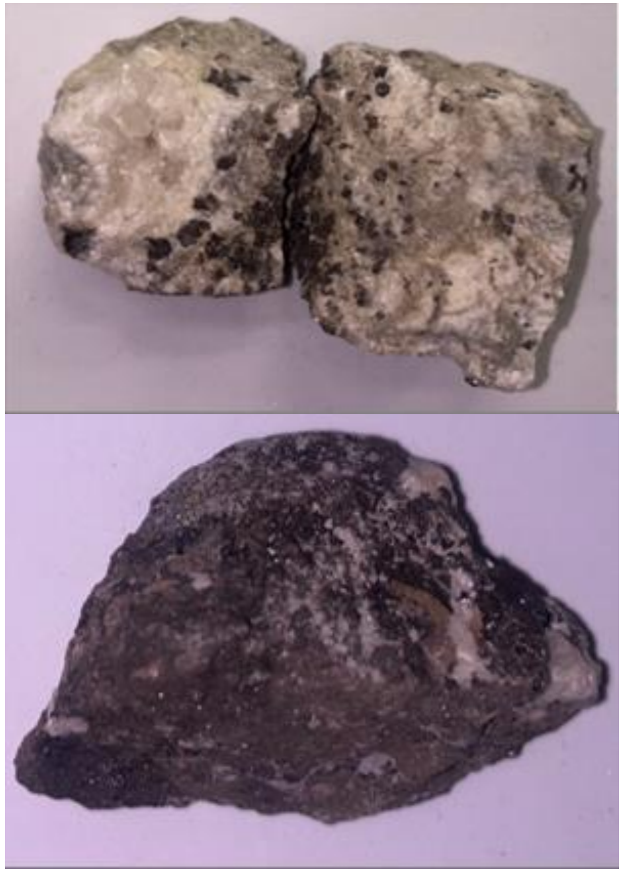
# Case Study: Lead-Zinc

- Carbonate hosted Lead-Zinc.  Dolomite alteration with suphide mineral zonation
- Sphalerite, galena, and minor marcasite mineralization.

High Grade

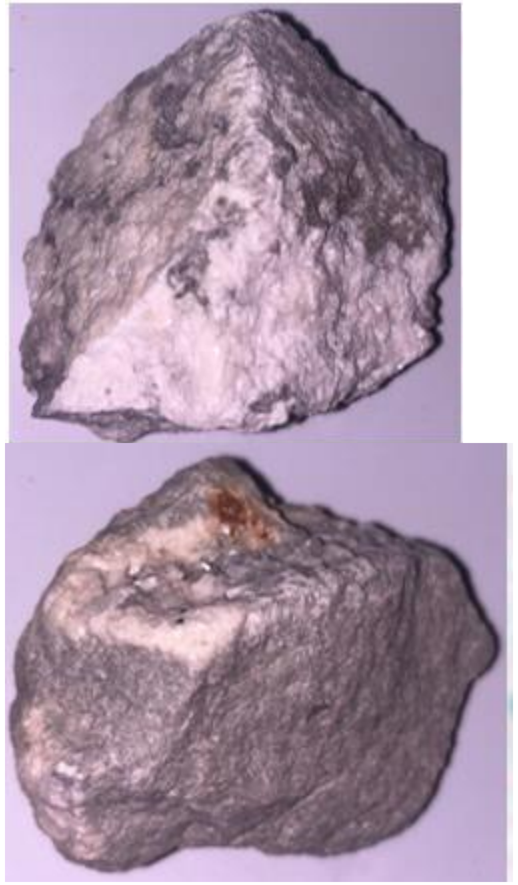


Medium Grade

# Case Study: Lead/Zinc

Low Grade

Barren



# Colour Calibration

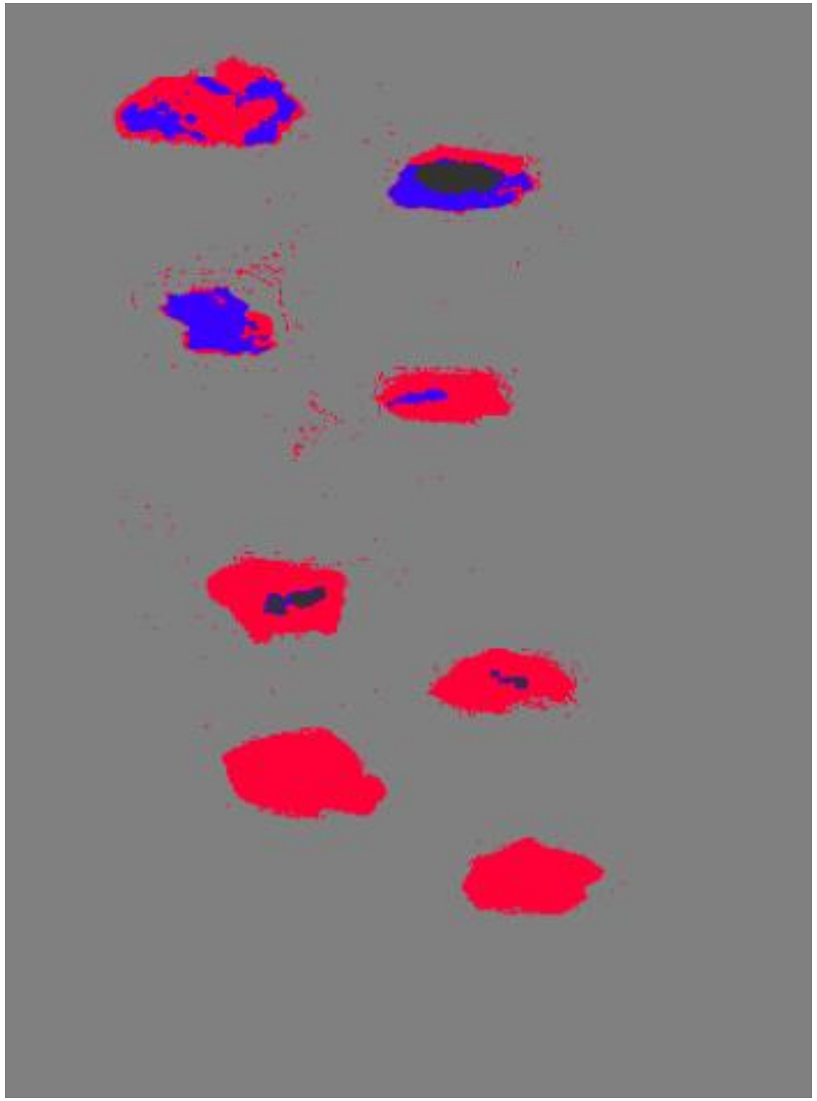
| Data | Red | Green | Blue | Brightness | Hue | Saturation | avg. Brt | Colour |
|---|---|---|---|---|---|---|---|---|
| 1 | 166 | 166 | 168 | 168 | 170.0 | 3.0 | | |
| 2 | 176 | 180 | 181 | 181 | 136.0 | 7.0 | | |
| 3 | 164 | 163 | 160 | 164 | 31.9 | 6.2 | | |
| 4 | 120 | 111 | 101 | 120 | 22.4 | 40.4 | | |
| 5 | 155 | 156 | 158 | 158 | 155.8 | 4.8 | | |
| 6 | 202 | 214 | 214 | 214 | 127.5 | 14.3 | | |
| 7 | 191 | 192 | 194 | 194 | 155.8 | 3.9 | | |
| 8 | 159 | 164 | 160 | 164 | 93.5 | 7.8 | | |
| 9 | 156 | 162 | 162 | 162 | 127.5 | 9.4 | | |
| 10 | 136 | 140 | 141 | 141 | 136.0 | 9.0 | 166.6 | |

# XRT Inspection Tests

- Raw x-ray image
- 50 mm particle size

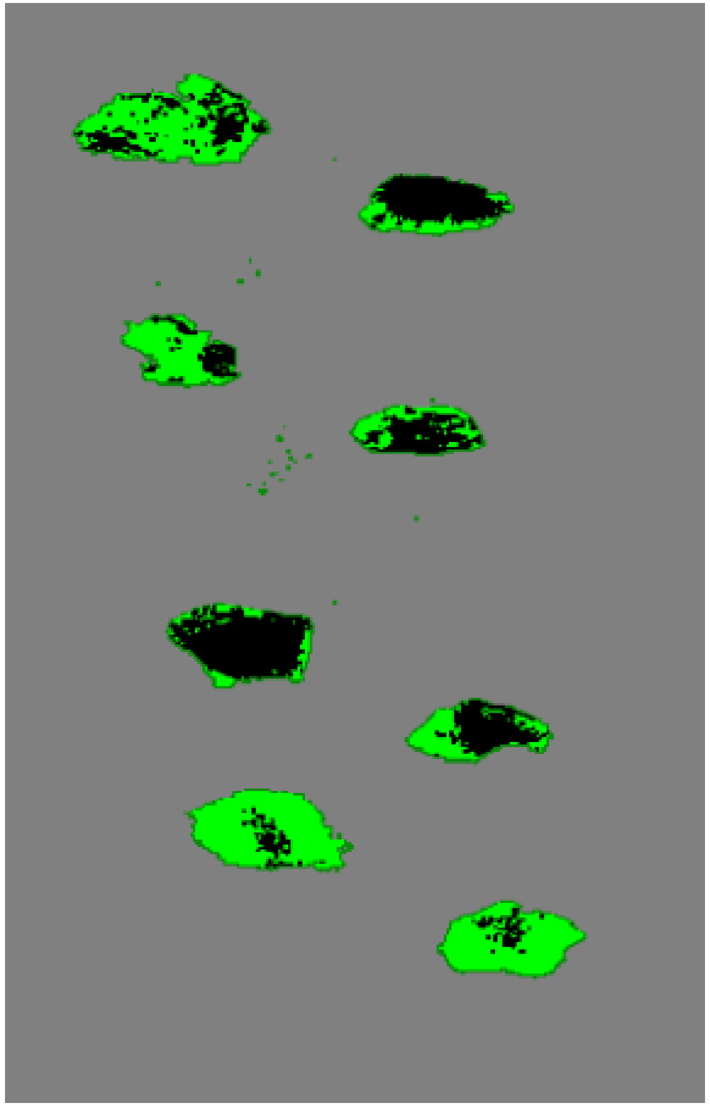
# XRT Inspection Tests

- Red = Low Density
- Blue = High Density



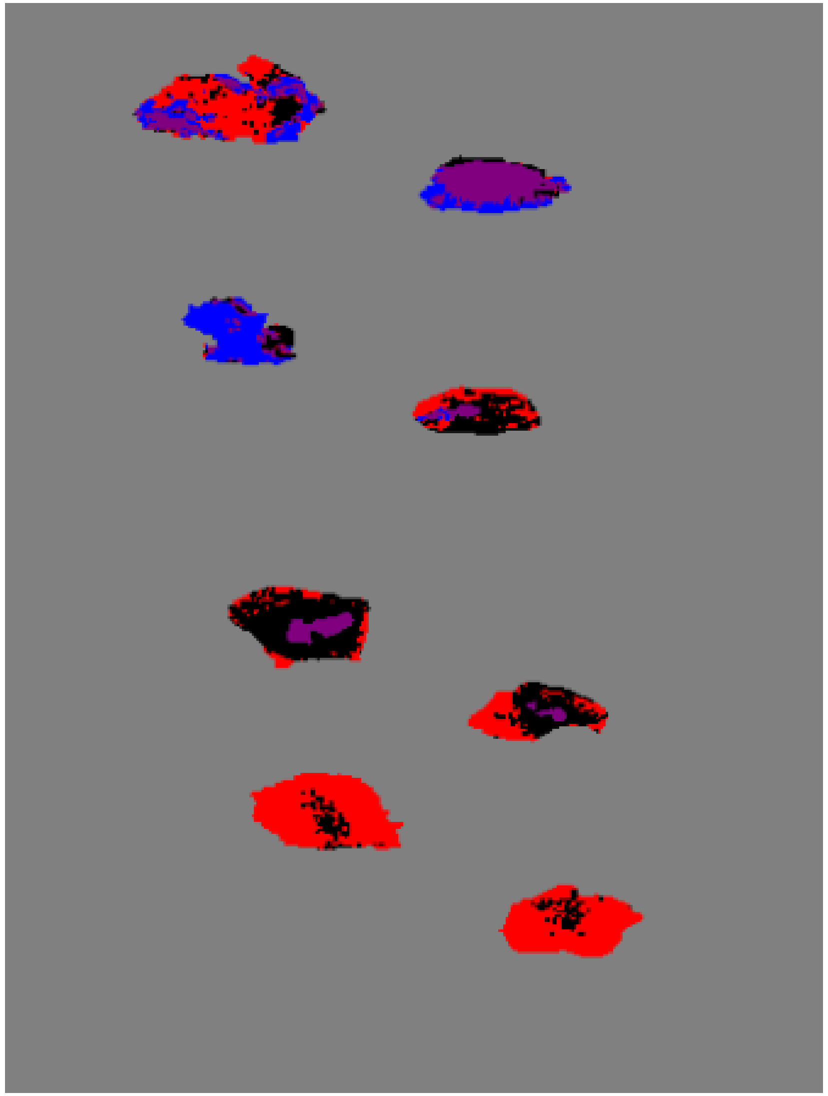
# XRT Inspection Tests

- Inclusion detection

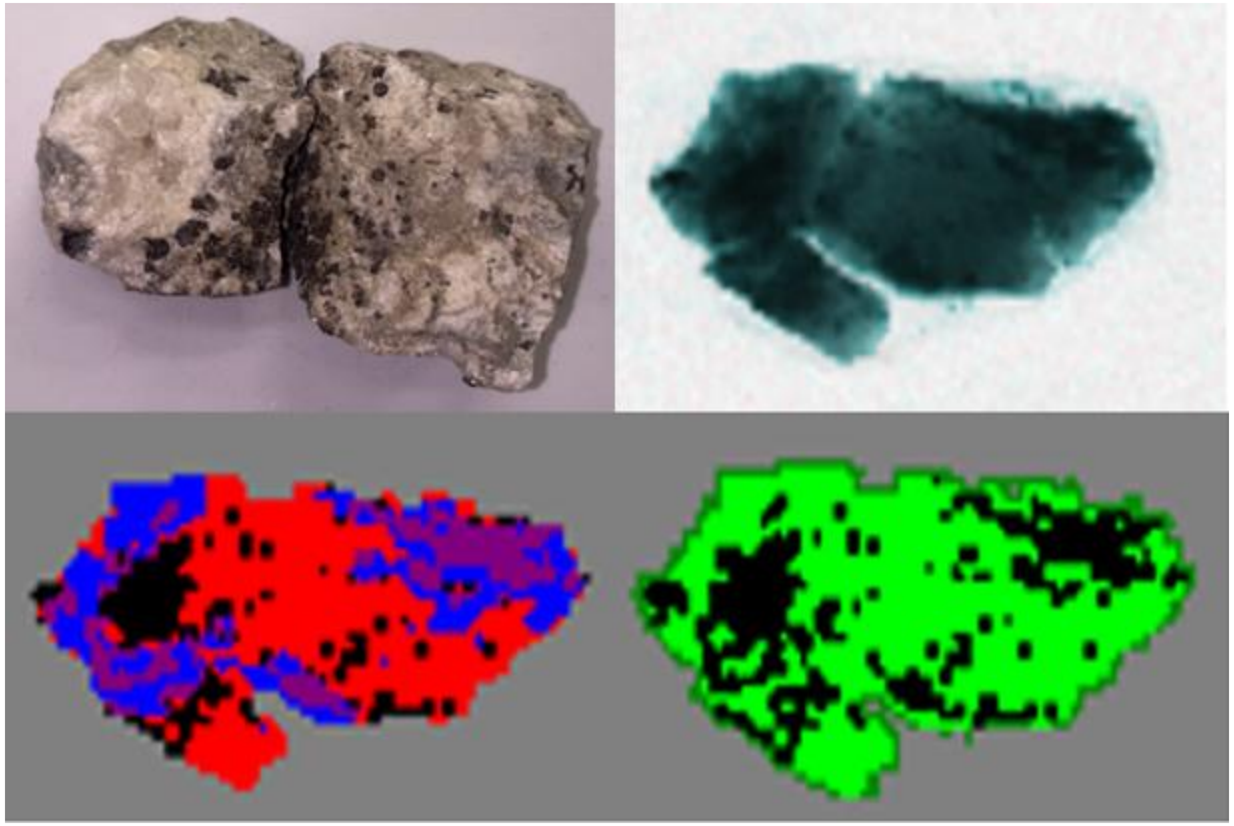


# XRT Inspection Tests

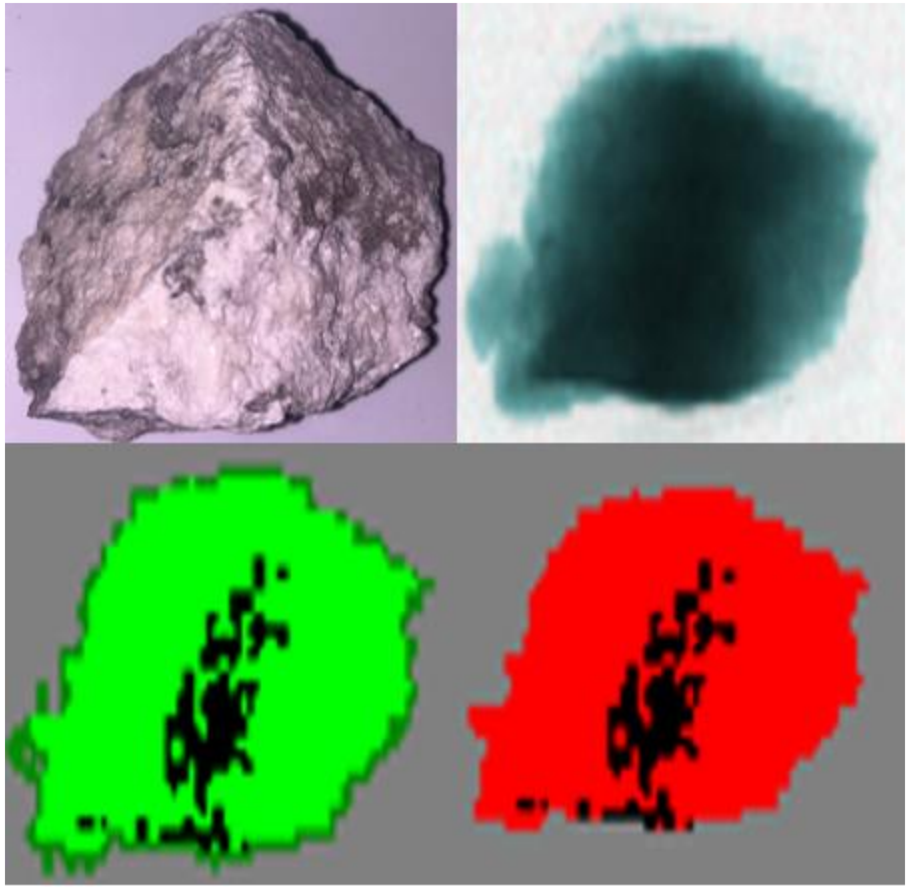
- Red = Low Density
- Blue = High Density
- Purple = Inclusions



# XRT Inspection Tests



High grade



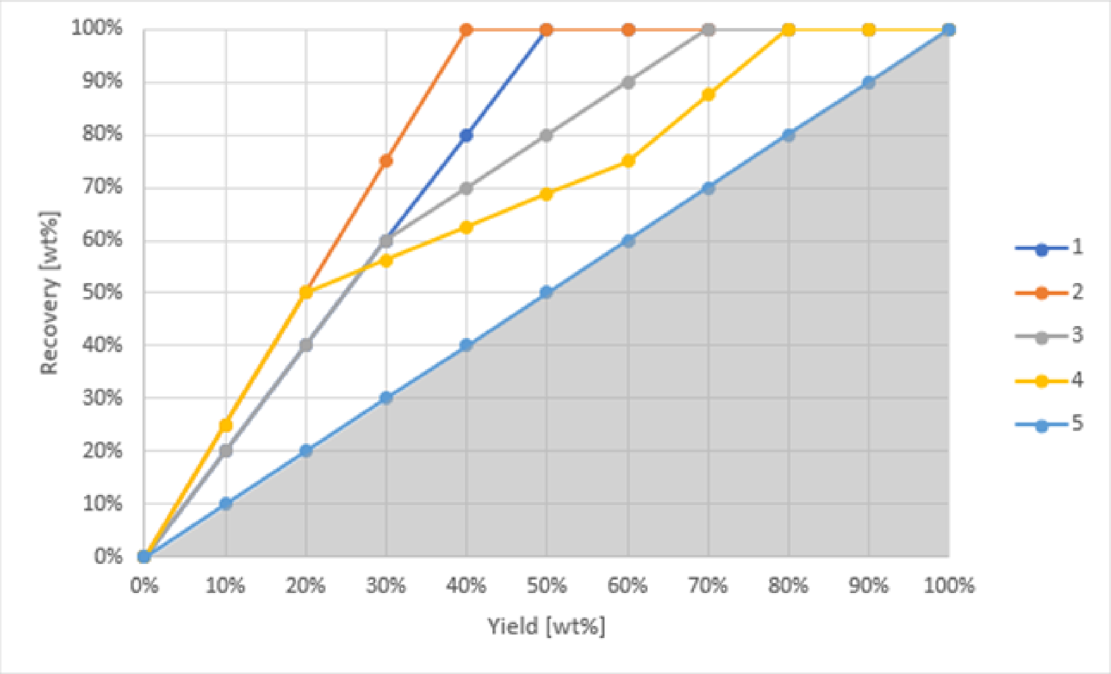
Barren

# XRT Cascading Tests

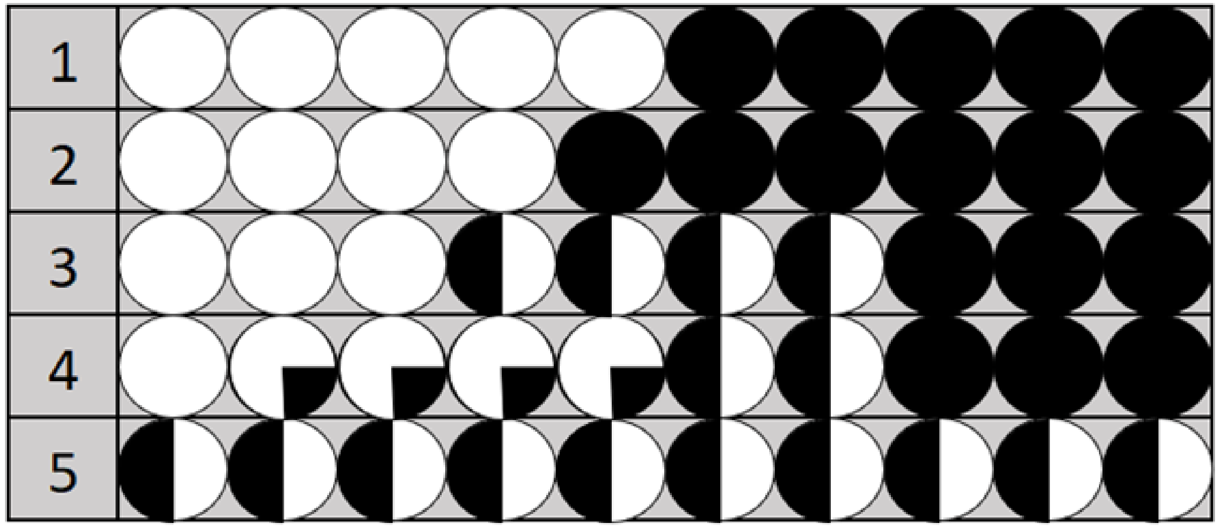
- 10s of kg to 100s of kg required
- Adjusted threshold settings for each run
- Establishes data set
- Splits are submitted for assay on-site




src



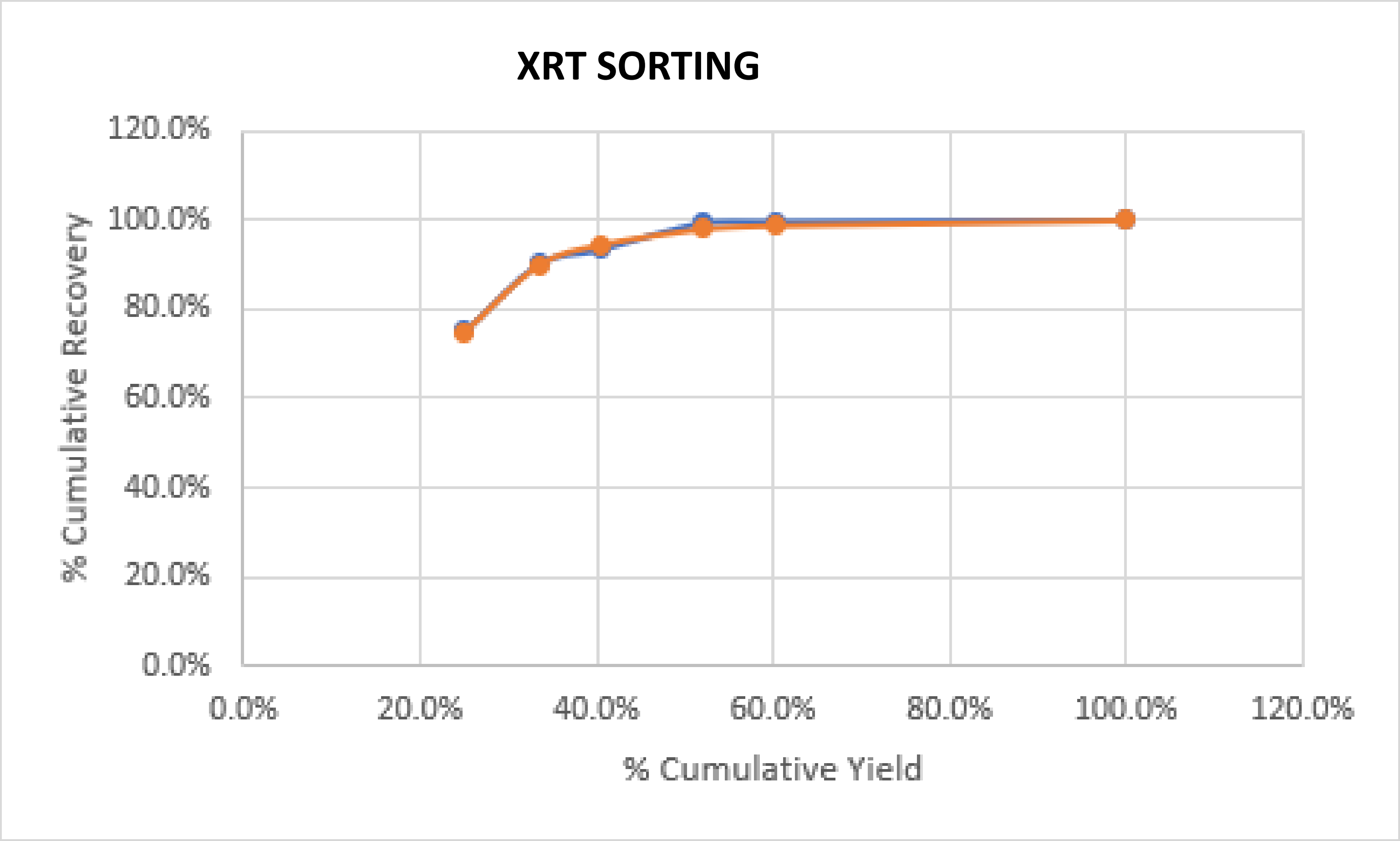
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Recovery [wt%]
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Yield [wt%]
1
2
3
4
5

1
2
3
4
5




src



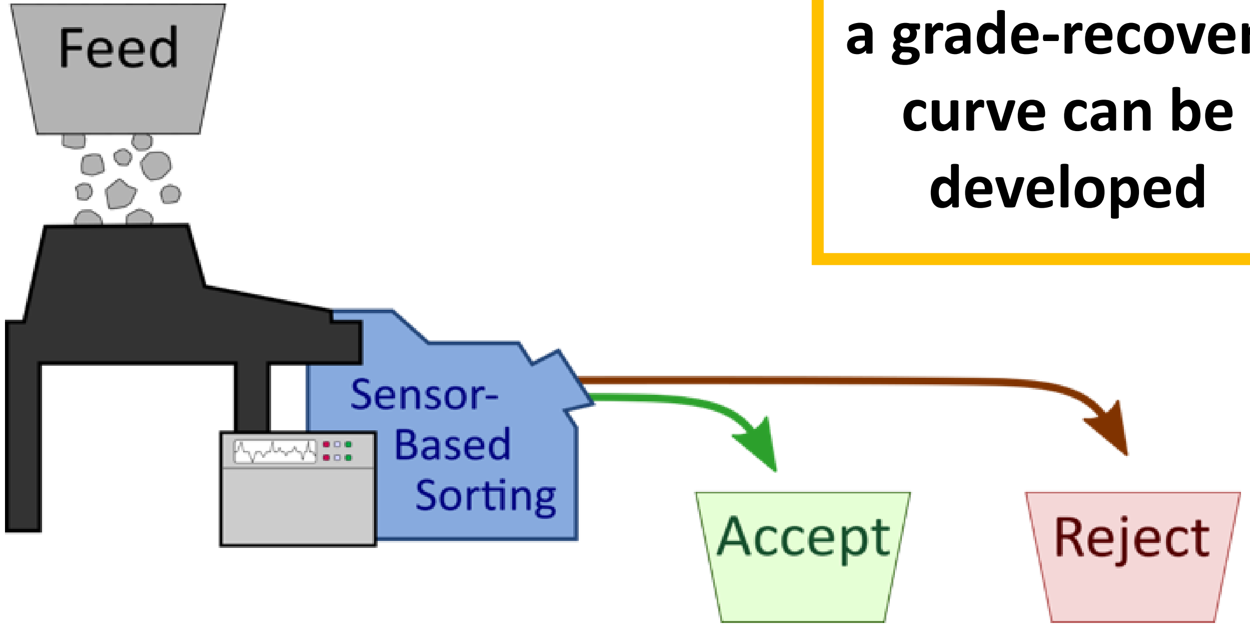

- 60% threshold retains 100% recovery of mineralized ore
- Roughly 40% removal of non mineralized ore

# Stage 2 Deliverable: XRT Model for 50 mm

## XRT SORTING

**Grade cutoff** 0.07

**Feed Grade (wt%)** 0.880
**Feed Mass (kg)** 103.58




| | | |
|---|---|---|
| | **Accept Grade** | **Reject Grade** |
| | 2.780 | 0.050 |
| | **Accept Mass** | **Reject Mass** |
| | 39.53 | 64.05 |
| | 38% | 62% |

Sorting Efficiency 85.0%
Mineral recovery 12.1%
Upgrade Potential 315.9%

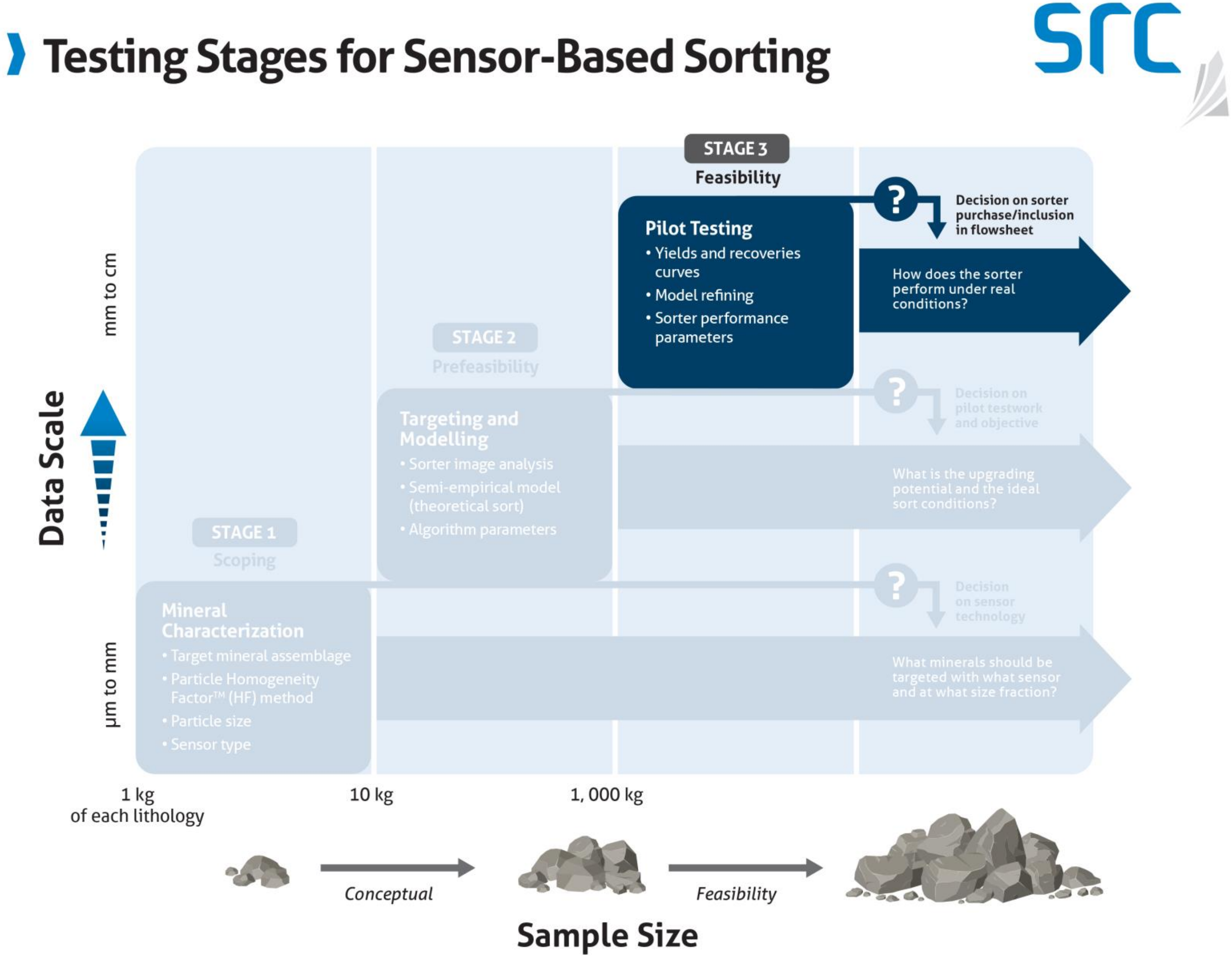
**From this model, a grade-recovery curve can be developed**

# STAGE 2 Decision

CLIENT DECISION: *What are the optimal mass pulls and grade cutoffs?*

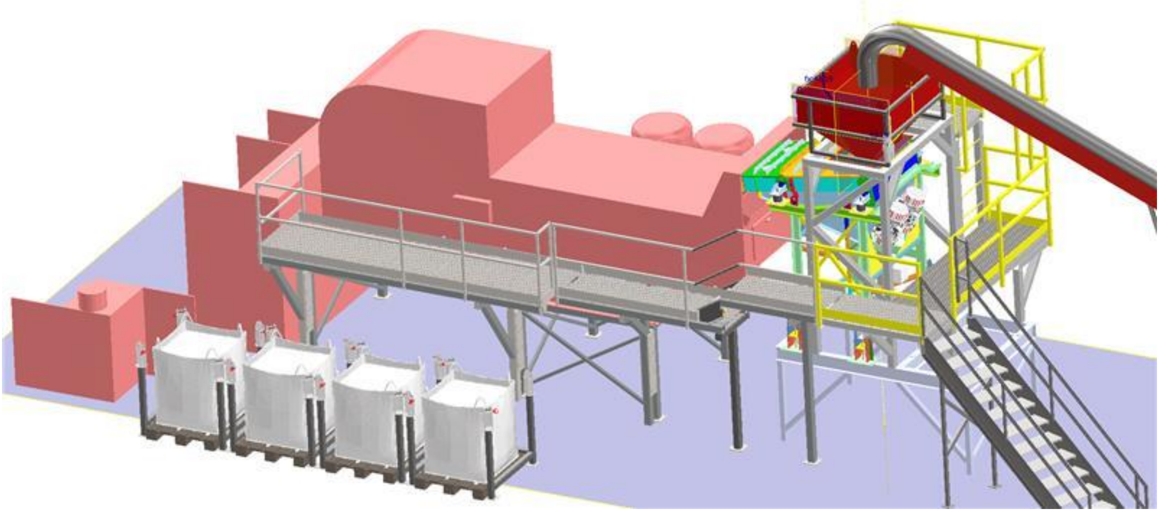
1. Adjust the design criteria
2. Refine modelling for scaled testwork

# STAGE 3


Testing Stages for Sensor-Based Sorting
src
STAGE 3
Feasibility
Pilot Testing
• Yields and recoveries curves
• Model refining
• Sorter performance parameters
Decision on sorter purchase/inclusion in flowsheet
How does the sorter perform under real conditions?
STAGE 2
Prefeasibility
Targeting and Modelling
• Sorter image analysis
• Semi-empirical model (theoretical sort)
• Algorithm parameters
Decision on pilot testwork and objective
What is the upgrading potential and the ideal sort conditions?
STAGE 1
Scoping
Mineral Characterization
• Target mineral assemblage
• Particle Homogeneity Factor™ (HF) method
• Particle size
• Sensor type
Decision on sensor technology
What minerals should be targeted with what sensor and at what size fraction?
Data Scale
mm to cm
µm to mm
1 kg of each lithology
10 kg
1, 000 kg
Conceptual
Feasibility
Sample Size

# STAGE 3: Feasibility

- Larger volume testwork based on previous stages
- Verification of equipment specifications
    - Sorter performance (real vs. semi empirical model)
    - Maximize throughput
    - Determine efficiency
- Optimizes flow sheet and design criteria
- 1,000's of kg to 10,000's of kg of material needed



# Key Points

- Mineral characterization can provide first indications of sortability and potential sensors
- Standardized testwork combined with assay can be used to develop a semi-empirical model
- Scaled testing can provide validation of equipment for flow sheet design
- Quantitative data and modelling might be used for feasibility studies and compliance reporting (e.g., NI 43-101)

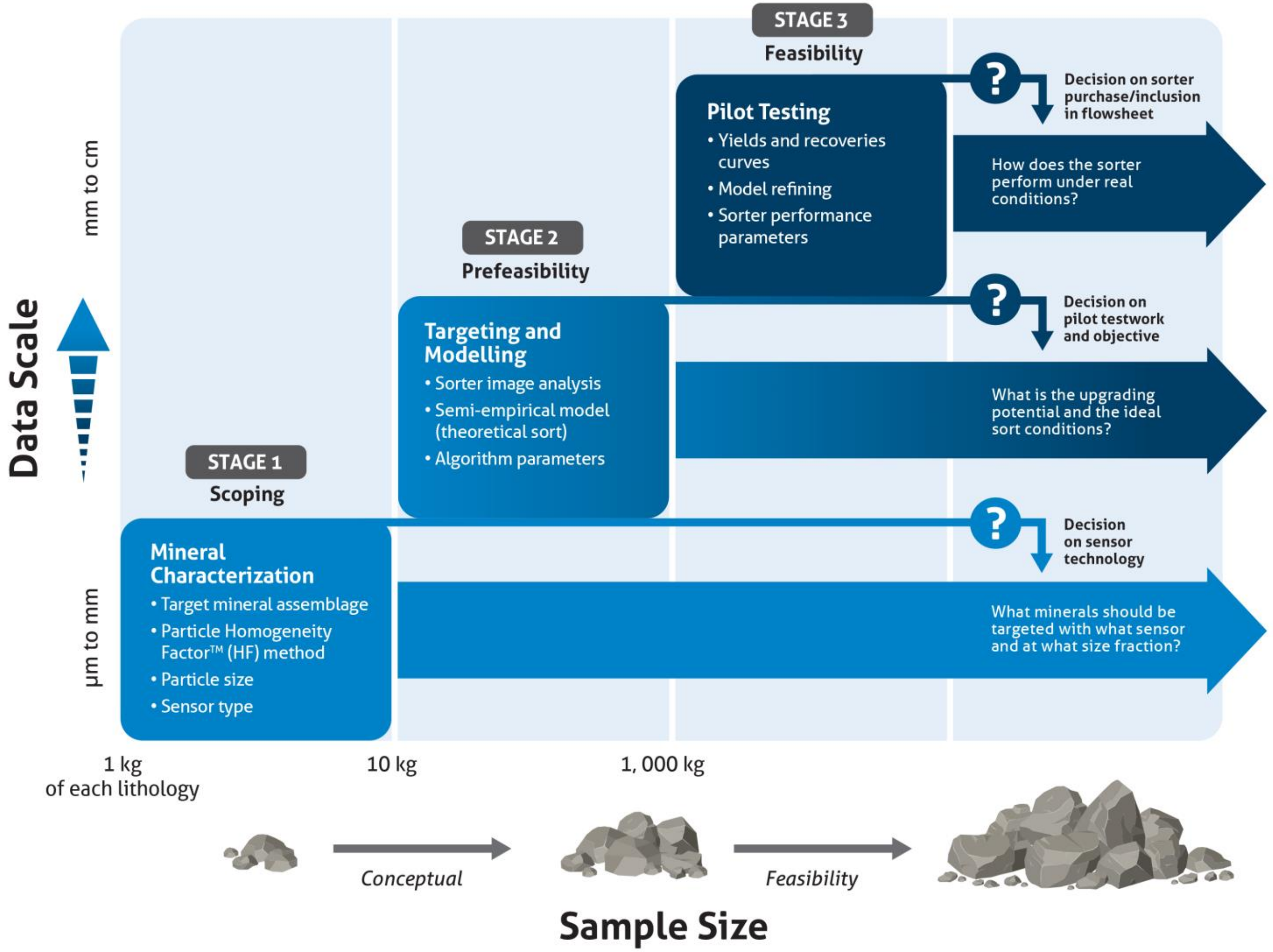
# Sensor-Based Sorting at SRC

- Independent
  - Work directly with mining companies
  - Work with equipment suppliers
  - Work with contractors
- On-site analyses at SRC Geoanalytical Laboratories
  - Assay, microanalyses, CT scanning, magnetic susceptibility and UV testing.
- SRC Mineral Processing
  - Crushing
  - Sizing
  - Heavy Liquid Separation
  - Dense Media Separation
  - Bench and Pilot Scale Hydrometallurgy



SRC

# Testing Stages for Sensor-Based Sorting



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