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# Ore Sorting in Mining

## Association of Mining Analysts

20th April, 2016

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# Acknowledgement

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TOMRA SORTING SOLUTIONS | MINING

Tomra Sorting Solutions have provided considerable materials and support in preparing this presentation.

# Content

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- Introduction to Sorting
  - Application to Mining
  - Benefits and Limitations
- Principles & Technology
  - Sensors
- Testwork and Optimisation
- Economics
- What an Analyst should look at

# Introduction to Sensor Based Sorting (SBS)

# What is Sorting?

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- Ore sorting is a mineral concentration process where **individual** ore particles are separated from the unwanted material based on some physical (or chemical) property
- Ore Sorting can be used for:
  - Pre-Concentration / Waste Rejection
  - Ore-type diversion
  - Concentration to product
- Sensor Based Sorting is the automation of this process

# Long History




Hand Picking Ore in Agricola's 1556 "De Re Metallica"

Source: Tomra

# Long History

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Hand sorting ore at Sullivan Mine circa. 1915

Source: Wills' Mineral Processing Technology

# Long History

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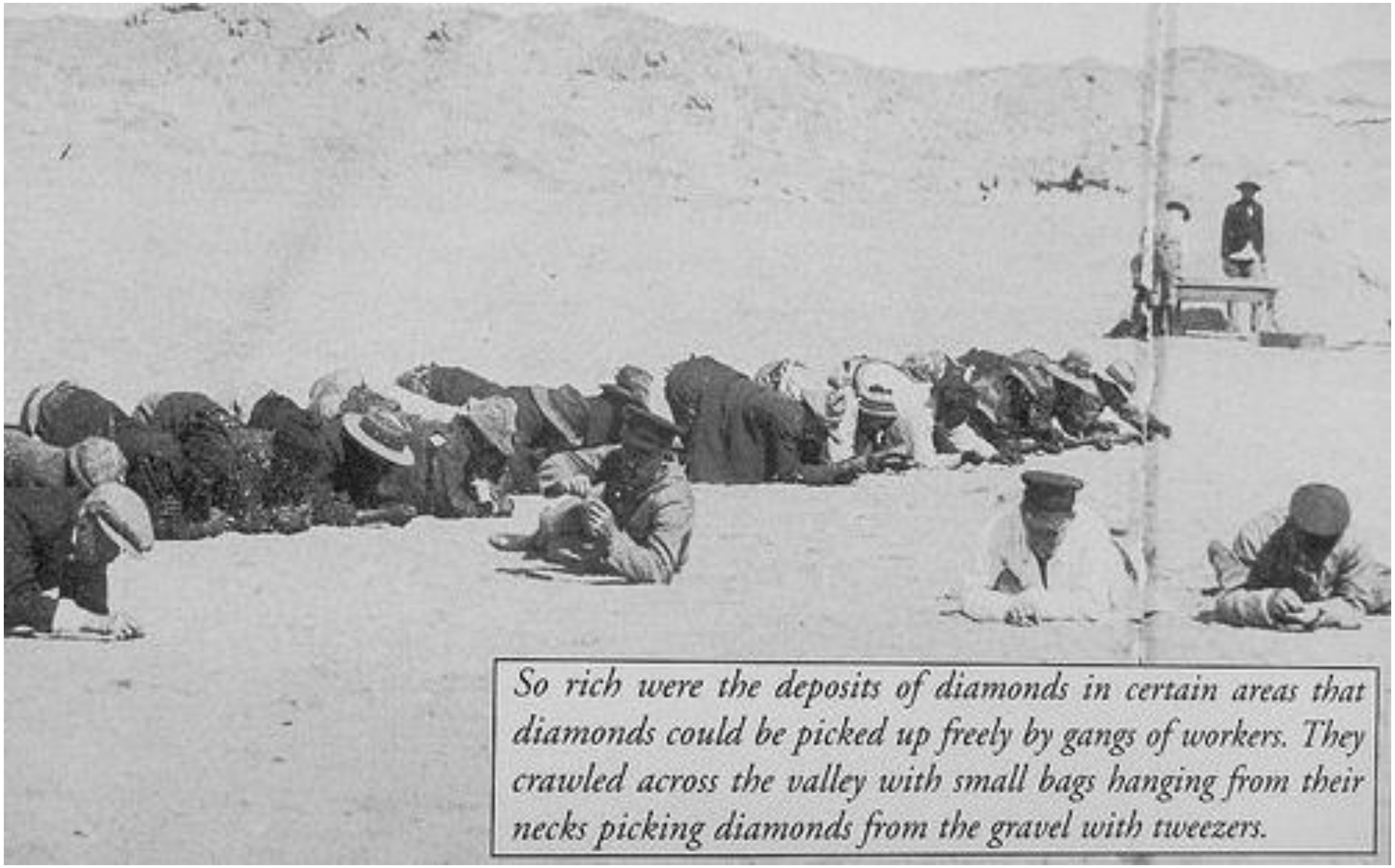
Hand sorting ore at a mine in Turkey 2012
Source: Tomra

# Diamond sorting – early days




Namibian diamond rush - circa. 1908
Hand "sorting" diamonds in the Sperrgebiet

# Diamond sorting - today

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Tomra large diamond recovery (LDR) machine using XRT sensors at Karowe Mine, Botswana.

# Diamond sorting - today

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1,111 carat diamond recovered by a Tomra large diamond recovery (LDR) machine using XRT sensors at Karowe.

# History of Sorting in Mining

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- 1940’s Radiometric Sorters
- 1950’s Photometric Sorter
  - Mary Kathleen U mine, Australia
- 1970’s Photometric Sorter
  - GFSA Doornfontein Gold Mine (RTZ Ore Sorters)
  - Looked at difference in colour between lighter “reef” and darker “waste”
  - First to use laser technology
  - First high tonnage sorters

# Why the slow uptake?

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- Historically poor throughput rates
  - Computer processing power
- Misconception of robustness of this technology in mining environment
- Aversion to new technology
  - Unlike the oil industry, mining has been slow to adopt new technologies
  - Mining companies and the financiers promote "tried and trusted, traditional technologies"

# Sorting is widespread

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About 250

About 10,000

## Mining

**Applicable for:**

Precious metals

Base metals · Diamonds

Coal · Ferrous metals

Copper · Platinum · Slag

Industrial minerals · Gold

Tailings · Gemstones

commodas ultrasort

## Recycling

**Applicable for:**

E-scrap · CRT Glass · Wood

Single Stream · Paper

Packaging · Wire · C&D waste

Car shredder · Plastics

Organic · MSW · Metals

RDF monitoring

TITECH®

## Food

**Applicable for:**

Dried fruit · Fresh cut · Fruit

Nuts · Seeds · Processed potato

Whole potatoes · Seafood

Meat/Process Analytics

Vegetables · Whole products

Peeling solutions

ODENBERG BEST

## Specialty Products

**Applicable for:**

Raw Materials

Virgin plastics · Synthetic rubber

Virgin wood chips · Pharmaceuticals

Tobacco

Treshing stems · Oriental leaf

Primary lamina · Primary stems

Cigar · Recon · OTP · Additives

ODENBERG BEST

Common development of core components

# Mining Applications

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**INDUSTRIAL MINERALS**

COLOR · XRT · NIR

Calcite, quartz, feldspar, magnesite, talc, dolomite, limestone, rock salt, phosphates, potash

**GEMSTONES**

COLOR · XRT · NIR

Diamonds, emeralds, rubies, sapphires, tanzanite

**FERROUS METALS**

XRT · EM · NIR

Iron, manganese, chromite

**NON-FERROUS METALS**

XRT · COLOR · EM · NIR

Copper, zinc, gold, nickel, tungsten, silver, platinum group metals

**FUEL**

XRT

Coal, oil shale

**SLAG**

XRT · EM

Stainless steel slag, carbon steel slag, ferro silica slag, ferro chrome slag, non ferrous slag

# Wet Mineral/Ore Processing

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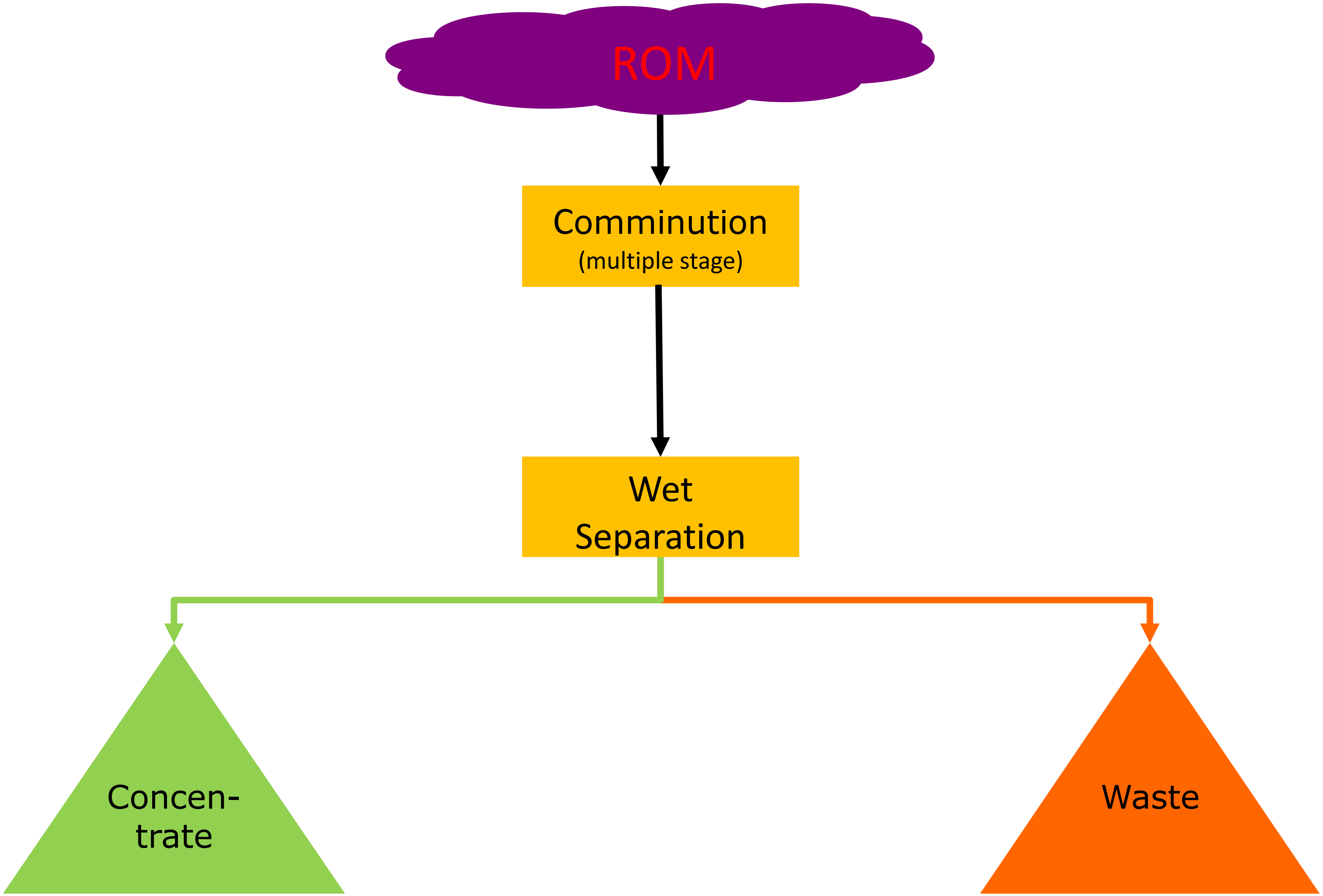

# And Waste is here

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Syncrude Tailings Dam - Mildred Lake

# Avoidable costs

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- Every single tonne in that tailings pond has had costs for:
  - Crushing
  - Screening
  - Milling
  - Process water
  - Flotation reagents: frothers, collectors, modifiers
  - Pumping and pipes
  - Water treatment: filters, thickeners, flocculants
  - Ponds' erection, dams, and lining
  - Pond monitoring
  - Use of land; local and environmental permits
  - Etc.

# An alternative approach

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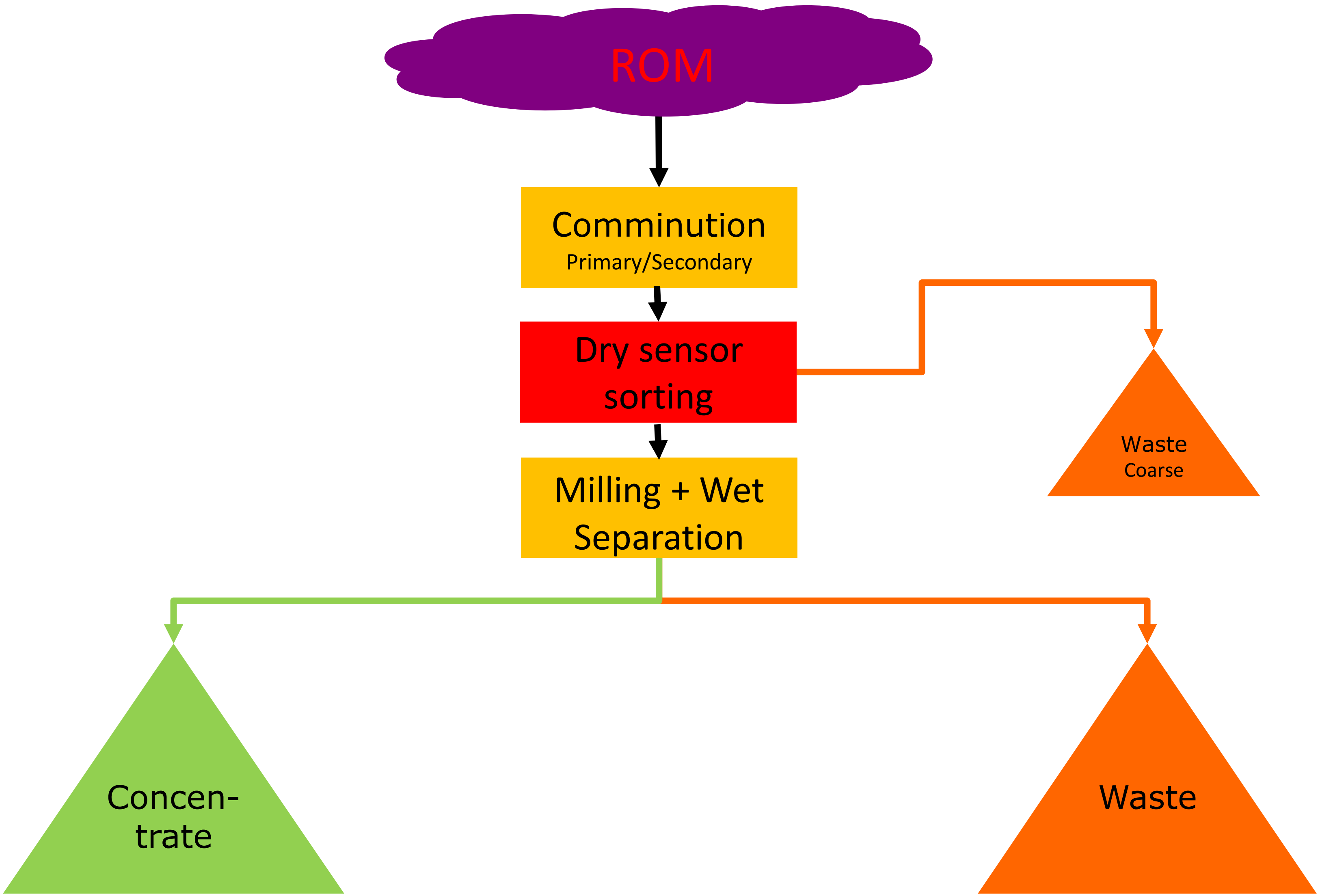

# Value throughout the Mining Cycle

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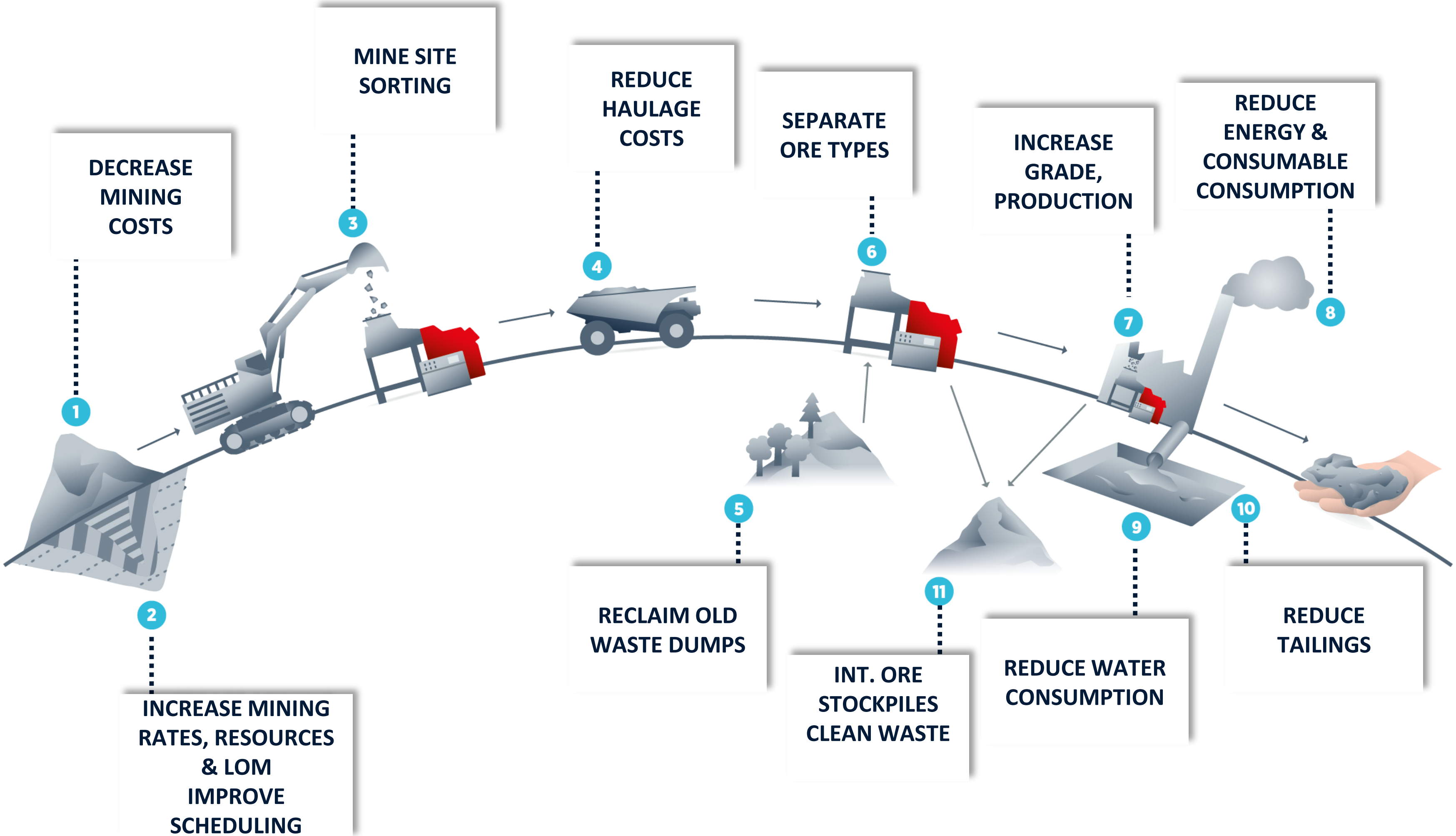

# Limitations of Ore Sorting

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- Sorting only effective within certain particle size ranges:
  - Too fine, and the throughput decreases
    - Throughput decreases with particle size
    - +10mm is typical lower economic limit
  - Too coarse, and dilution increases
    - Upper size determined by ore characteristics and sensor
      - e.g. 40 - 50mm is average penetration depth of XRT
    - Generally less than 100mm
- Every deposit is unique; not all ores amenable to sorting
  - Style of mineralisation, mineralogy and liberation

# What can be achieved?

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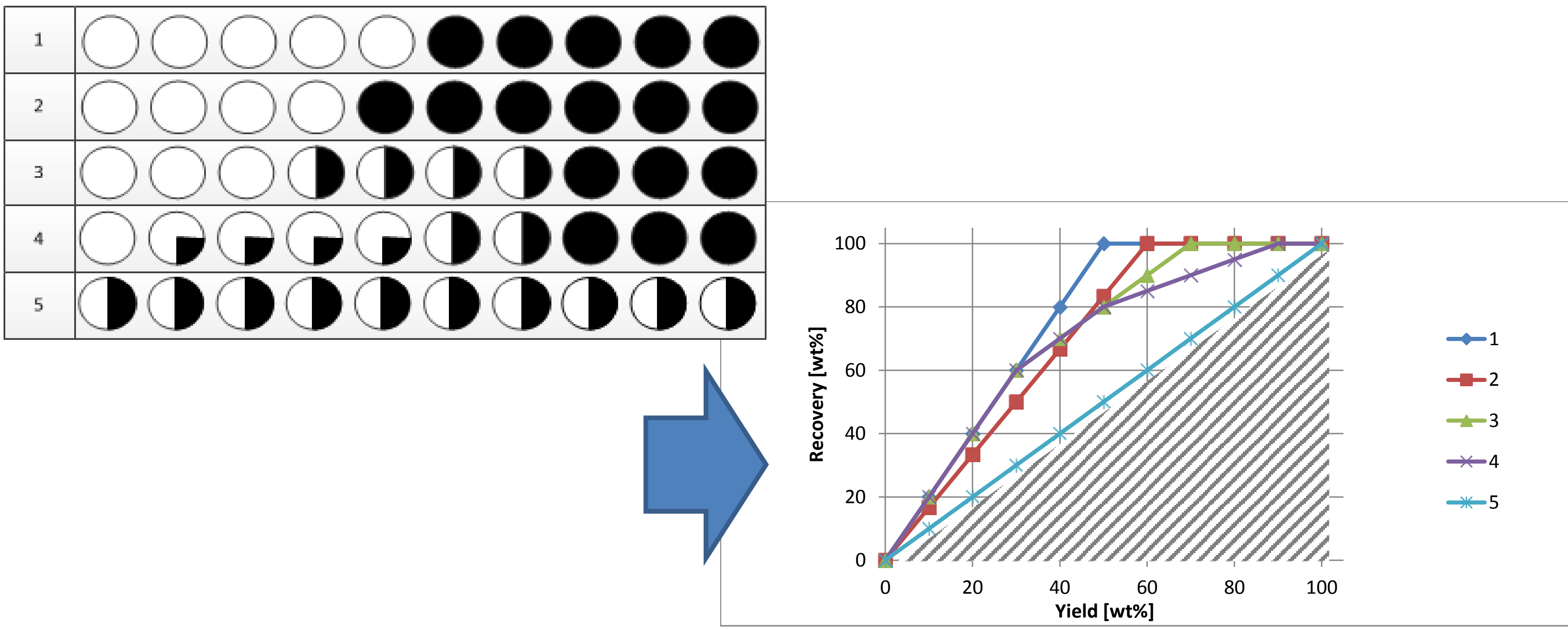
- Variations in LIBERATION make physical separation possible – e.g. mining dilution, ore type, grade
- A distinct difference in the physical property must be DETECTABLE – contrast, sensor resolution



# Principles and Technology of Sensor Based Sorting

# Stages of sorting

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- Feed Preparation
  - Crushing
  - Screening – uniform particle sizes
- Presentation of feed
  - Chute & Belt types
  - Clean / Wet / Dry?
- Sensing & Processing
  - Particle Identification & Location
  - Particle examination
  - Classification according to machine settings
- Separation
  - Air jets vs mechanical

# Material Presentation

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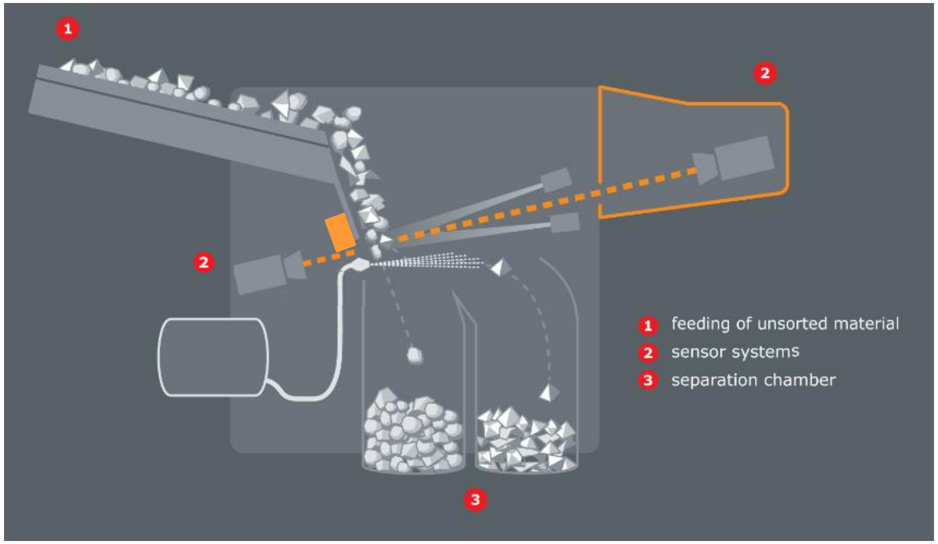
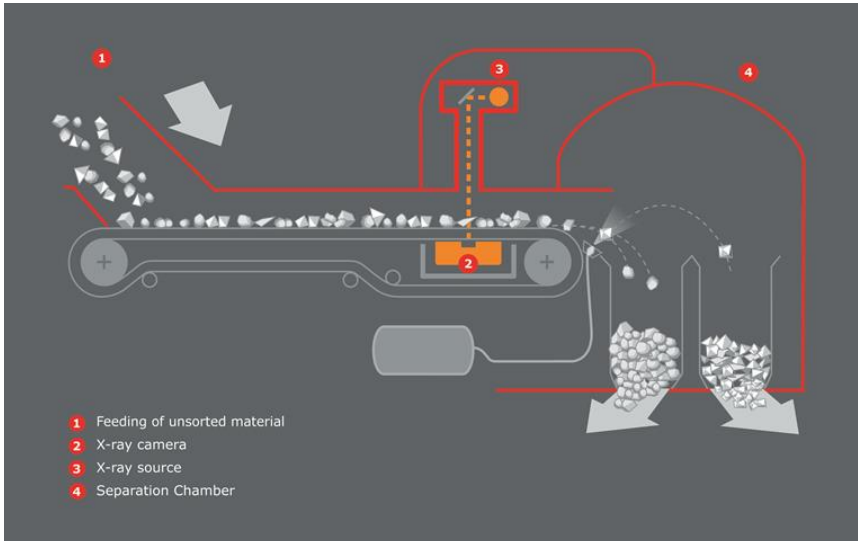
## Particles presented as a MONOLAYER

- **Chute Feed**
  - Surface detection
  - Freefall material
  - Multiple Face Sensors
- **Belt Feed**
  - Internal detection
  - Stable particles
  - Single Sensor Position



# Separation

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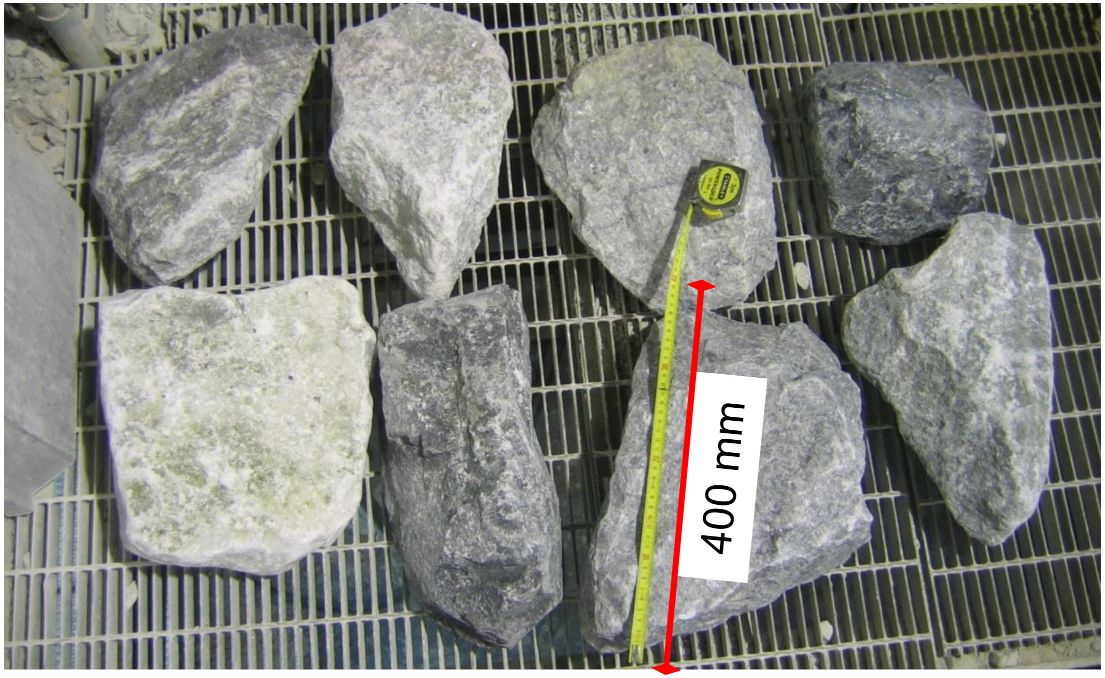
- High pressure air jets
  - Air jets can eject large rocks up to 15kg
  - Up to 10% "Overshoot" – particle collisions etc.




- Mechanical sorters used by RADOS

# Clean / Dry / Wet Samples?

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| Sensor Technology | Surface detection | Subsurface detection | Comment |
|---|---|---|---|
| Gamma radiation | | Yes | Not really applicable on Industrial Minerals |
| X-Ray transmission | | Yes | Very successful |
| Color camera | Yes | Very limited | Very sensitive to surface coating (dust, clay) |
| Laser Scattering | Yes | Limited | Using the near surface minerals |
| Near Infrared | Yes | Limited | Using the near surface minerals |
| Electro-magnetic | | Yes | Based on conductivity<br>Not really applicable on IM |

**All technologies with full or limited sub-surface detection capabilities could be used without washing water**

# Sensors available for sorting

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## X-RAY TRANSMISSION (XRT)

*Material property detected:* specific atomic density irrespective of size, moisture or pollution level

## VISIBLE LIGHT SPECTROMETRY (VIS)

*Material property detected:* visible spectrum for transparent and opaque materials

## ELECTROMAGNETIC SENSOR (EM)

*Material property detected:* electro-magnetic properties like conductivity and permeability

## COLOR CAMERA (COLOR)

*Material property detected:* color properties in the color are as red, green and blue

## RADIOMETRIC

*Material property detected:* natural gamma radiation

## IR CAMERA (IR); TRANSMISSION (IRT)

*Material property detected:* heat conductivity and heat dissipation
*Material property detected (IRT):* light absorption

## X-RAY FLUORESCENCE (XRF)

*Material Property detected:* elemental composition

## NEAR-INFRARED SPECTROMETRY (NIR)

*Material property detected:* specific and unique spectral properties of reflected light in the near-infrared spectrum

## LASER REFLECTION/SCATTERING/FLUORESCENCE

*Material property detected:*
+ Monochromatic reflection / absorption
+ Scattering of laser light Fluo or bio-luminescence, Super K

# Optical Sensing – Colour/VisibleLight

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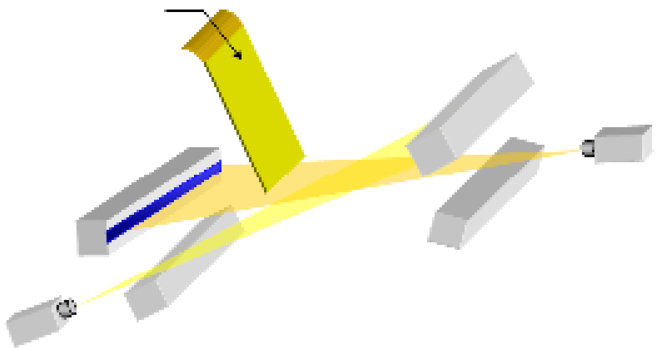
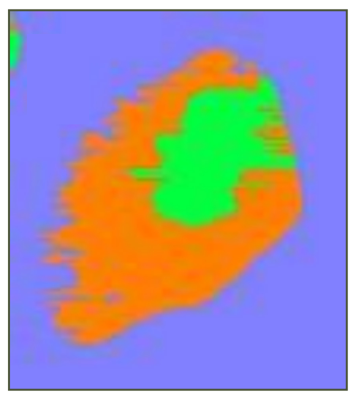


- Most popular sorting technology (industry & industrial minerals)
- Detects surface colour differences – clean/wet
- Each particle is photographed and the image processed and classified according to the calibrated colours
- Requires stable and high quality illumination

Input fraction (Talc)



Output fractions:

**Accept**

**Reject**

# Optical Sensing - Wet vs Dry?

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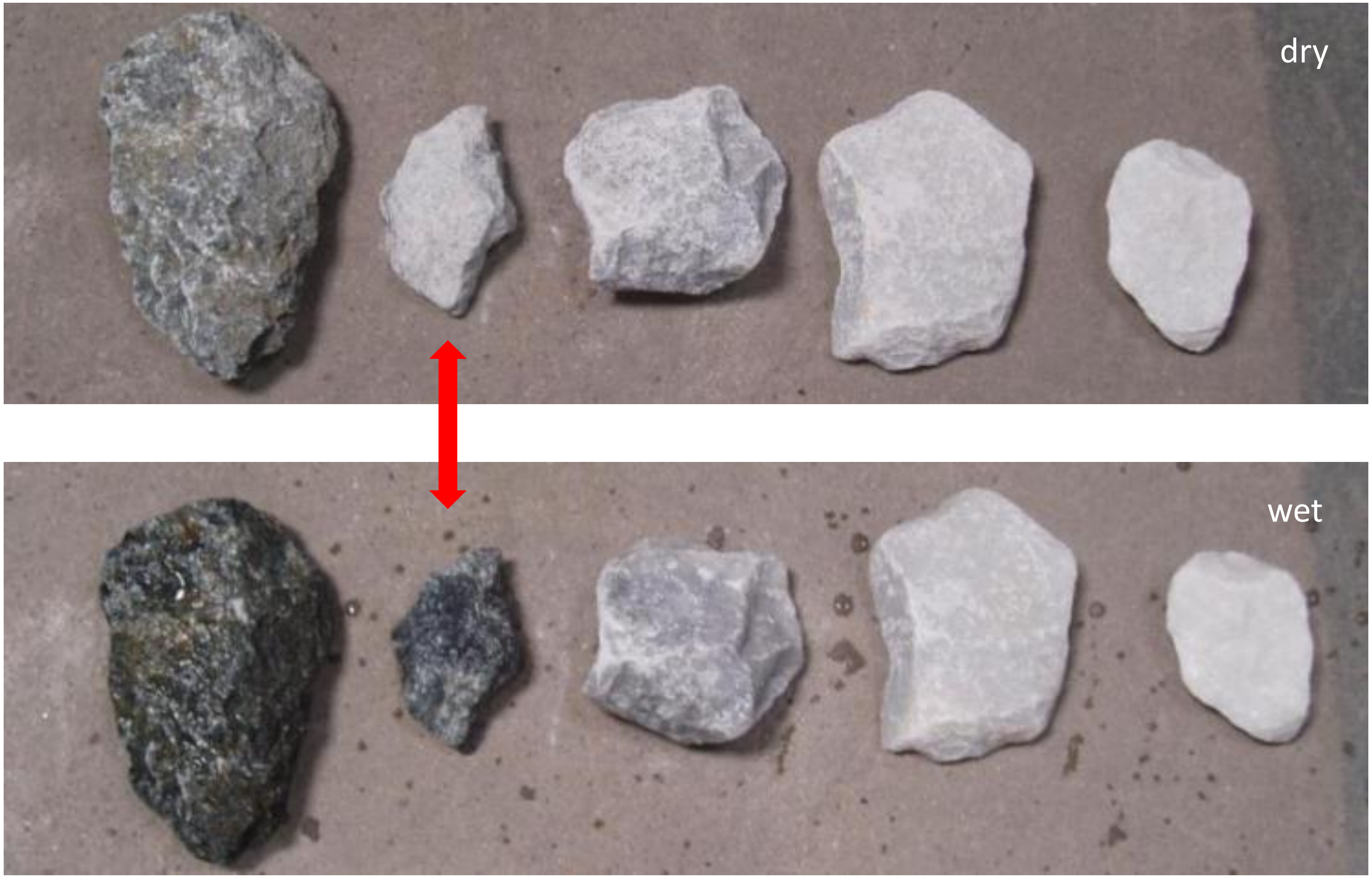

# Near Infrared (NIR) - principle

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## ➢ Principle

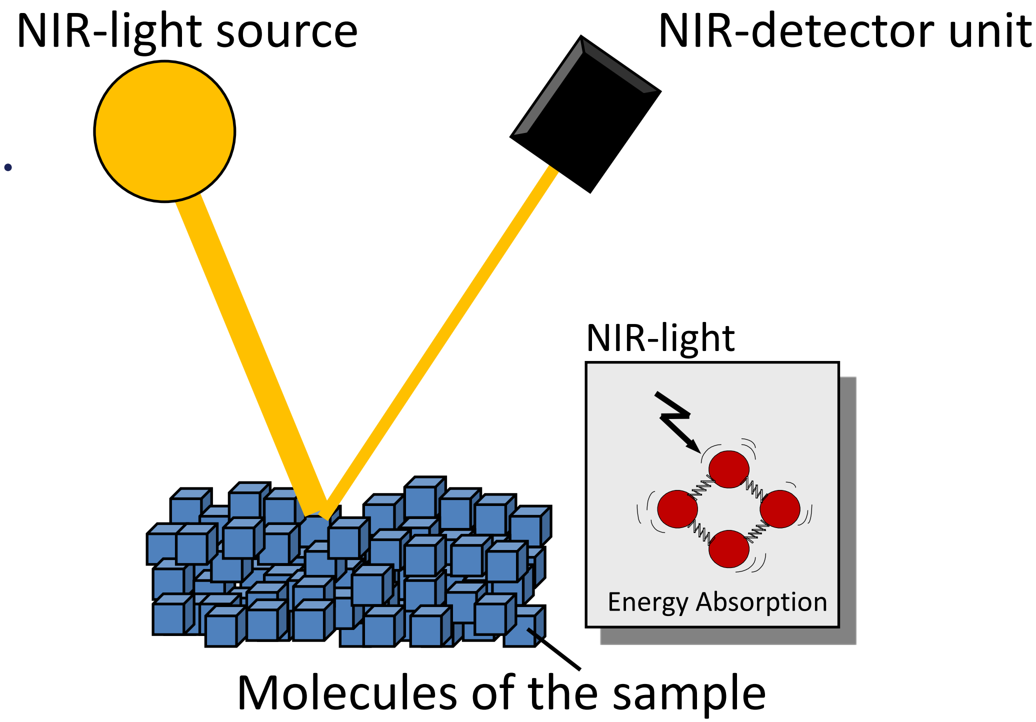
Certain NIR frequencies excite sample molecules to oscillate – these energy levels are predominantly absorbed.

Other energy levels of the light are diffusely reflected.

This light is directed to the detector unit and analyzed.

## ➢ Result

Spectrum of the reflection intensity against the wavelengths.



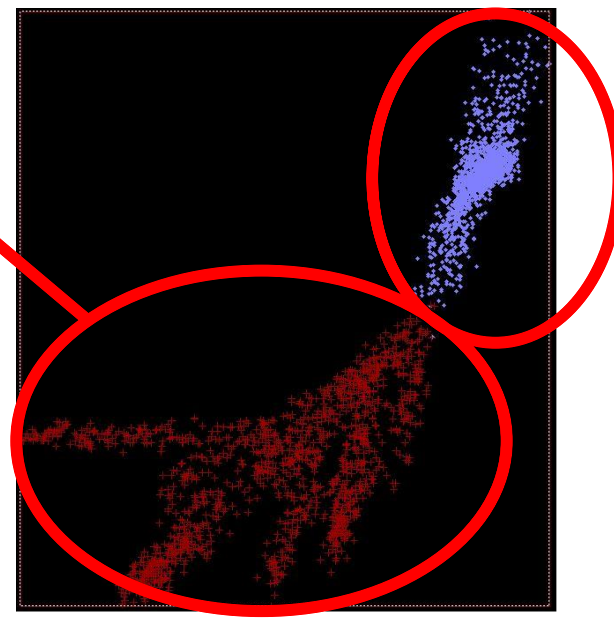
# NIR-sorting of magnesite



Unfortunately it is difficult to demonstrate invisible effect in photos, …

**Magnesite** – low Si

**Magnesite** – high Si containing particles from low Si pieces



… but the grades are clearly visible for the scanner

**Magnesite** – high Si

# LASER – Principal

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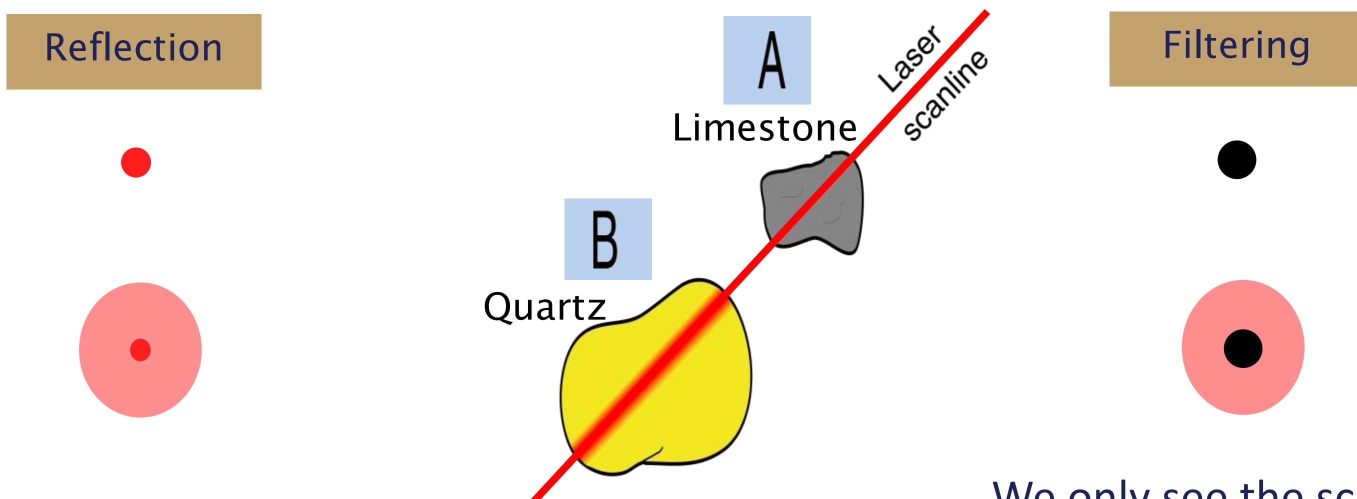
- A laser is permanently scanning the material
- Sorting is based upon the 'penetration' of laser light, which depends on the product structure.
- A 'glow' or 'scattering'-effect is triggered…




We only see the scatter, not the laser point any more.

# Laser Images

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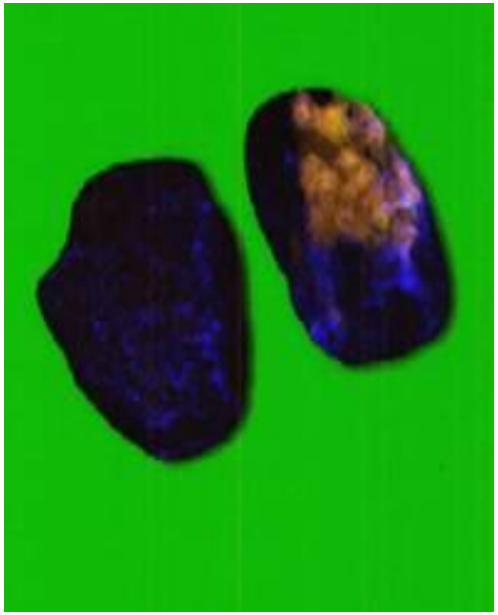
Picture



Raw data Image

Classified data Image

With color one can see no difference between both rocks, whereas using Laser the sorter gets a great signal from the scattering effect inside the Quartz. And the quartz is an indicator for gold....

# LASER – Quartz vein hosted Au

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- Host Tonalite

- Quartz vein

Material generally needs to be washed

# Electromagnetic Sensor (EM)

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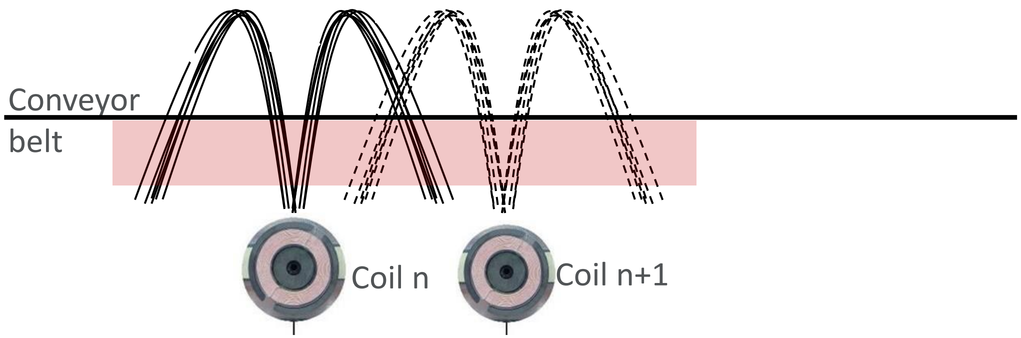


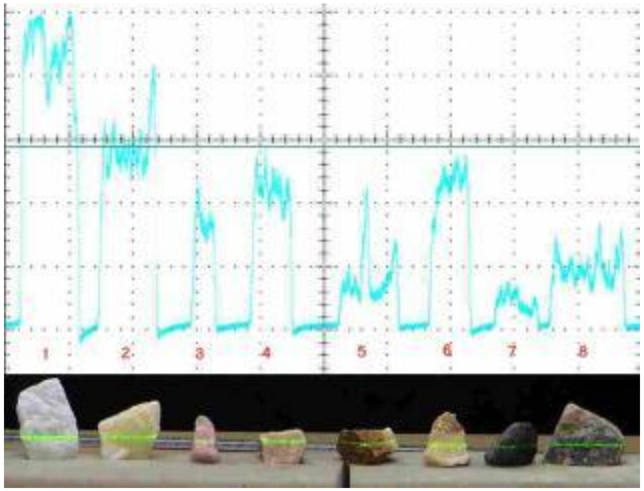


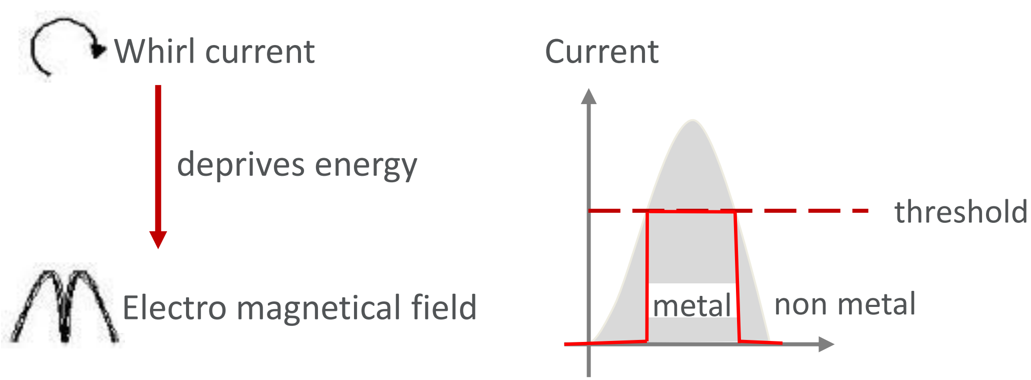


- Feed rates up to up 300Tph
- Material size down to 5mm
- More faster and accurate sensors

# EM - Base Metals, Sudbury

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- EM ore pre-concentration before further processes (e.g. milling, flotation, hydrometallurgy, etc.)
- The challenge: Remove low grade ore (<0.5% Ni) and waste from feed material

| Feature | Value |
|---|---|
| Sorting Task | Remove all particles <0.5% Ni |
| Feed rate | approx. 60 t/h |
| Size range | 25..50mm |
| Feed grade | 1.4-1.6% |
| Sorter concentrate | Product 2.0-2.7% Ni<br>Waste 0.1-0.2% Ni |
| Reject rate | Up to 40% |

ROM Secondary EM Sorter

# X-Ray Transmission

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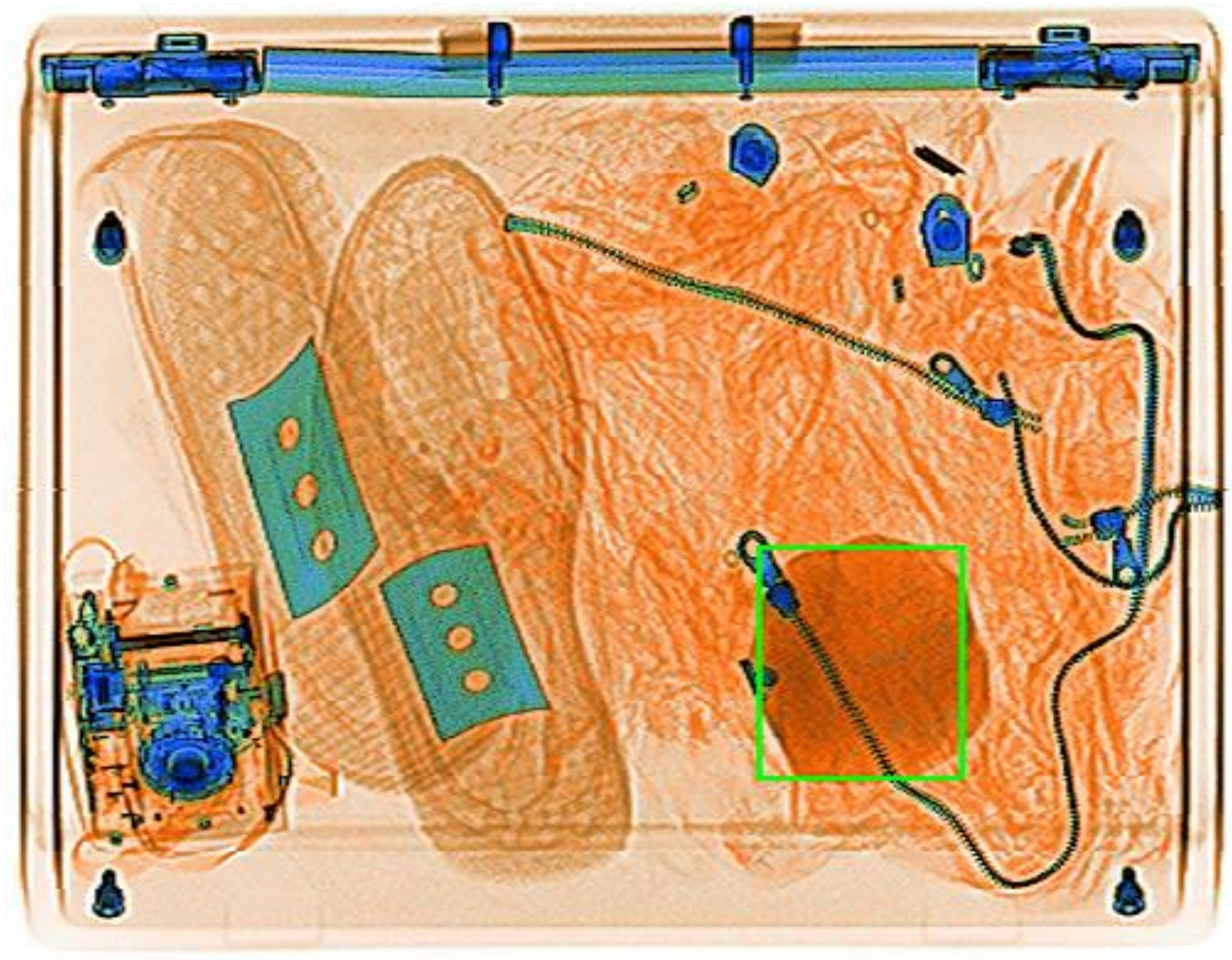

# What is the challenge?

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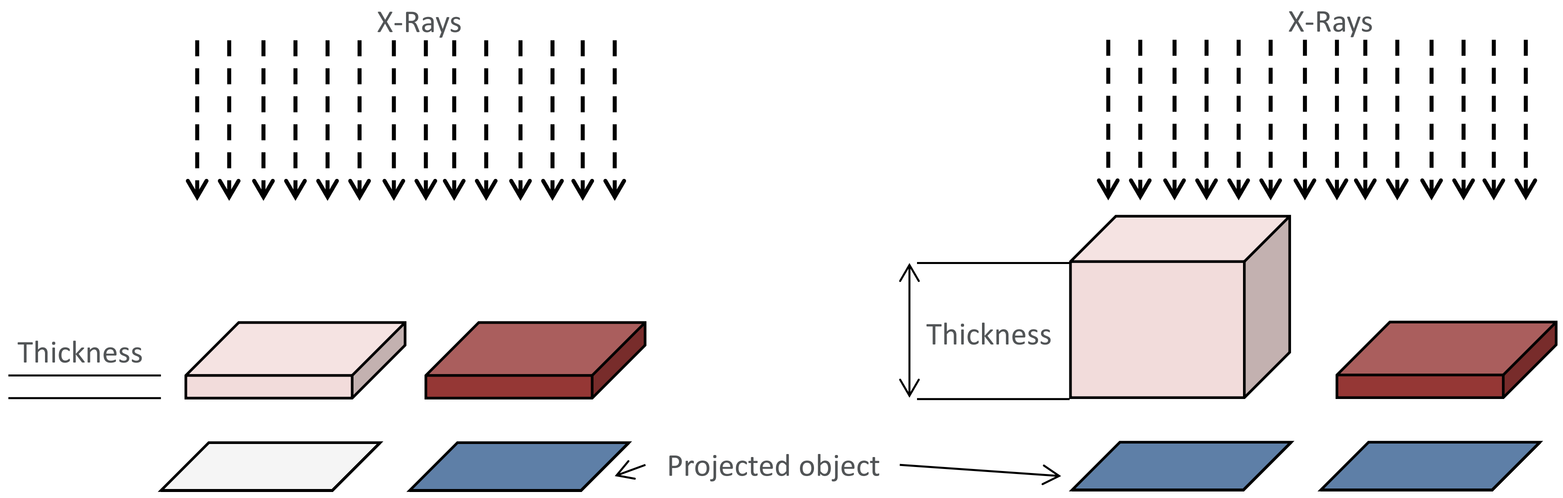
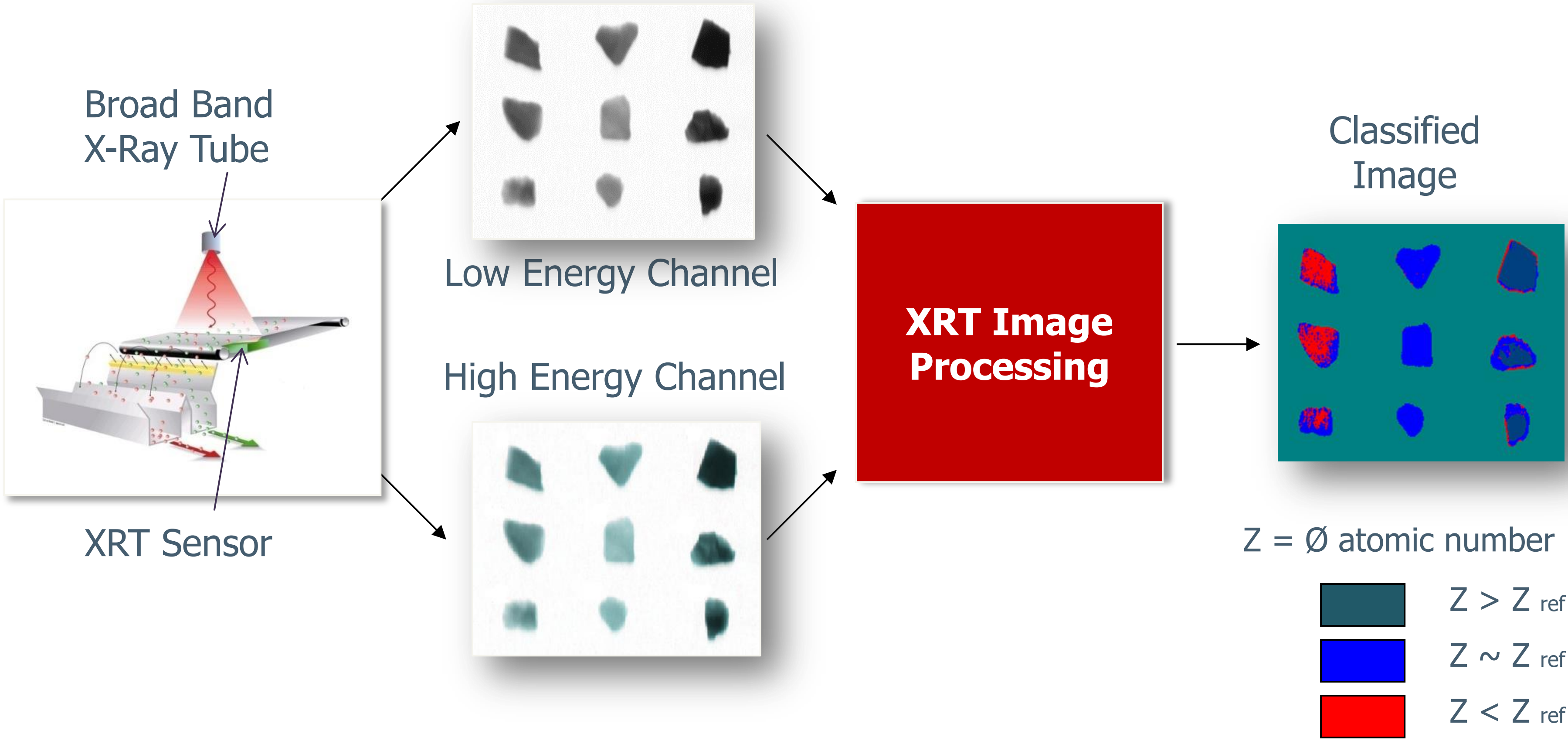
XRT-technology measures the level of x-ray energy after the rays have passed through an object. This level of attenuation is directly dependent on atomic density **and** thickness of the object.

XRT works to a particle thickness of ~40mm (35mm iron ore, 80mm coal)




This means: Two pieces of different materials can create the same projected picture. So use the Dual Energy technology (DE-XRT).

# XRT – Dual Energy image processing




- An image transformation of the density images of the two bands then makes it possible to classify each pixel according to atomic density.
- Classification proceeds relative to a reference density, to which the system has been calibrated.

# XRT – Nickel ore

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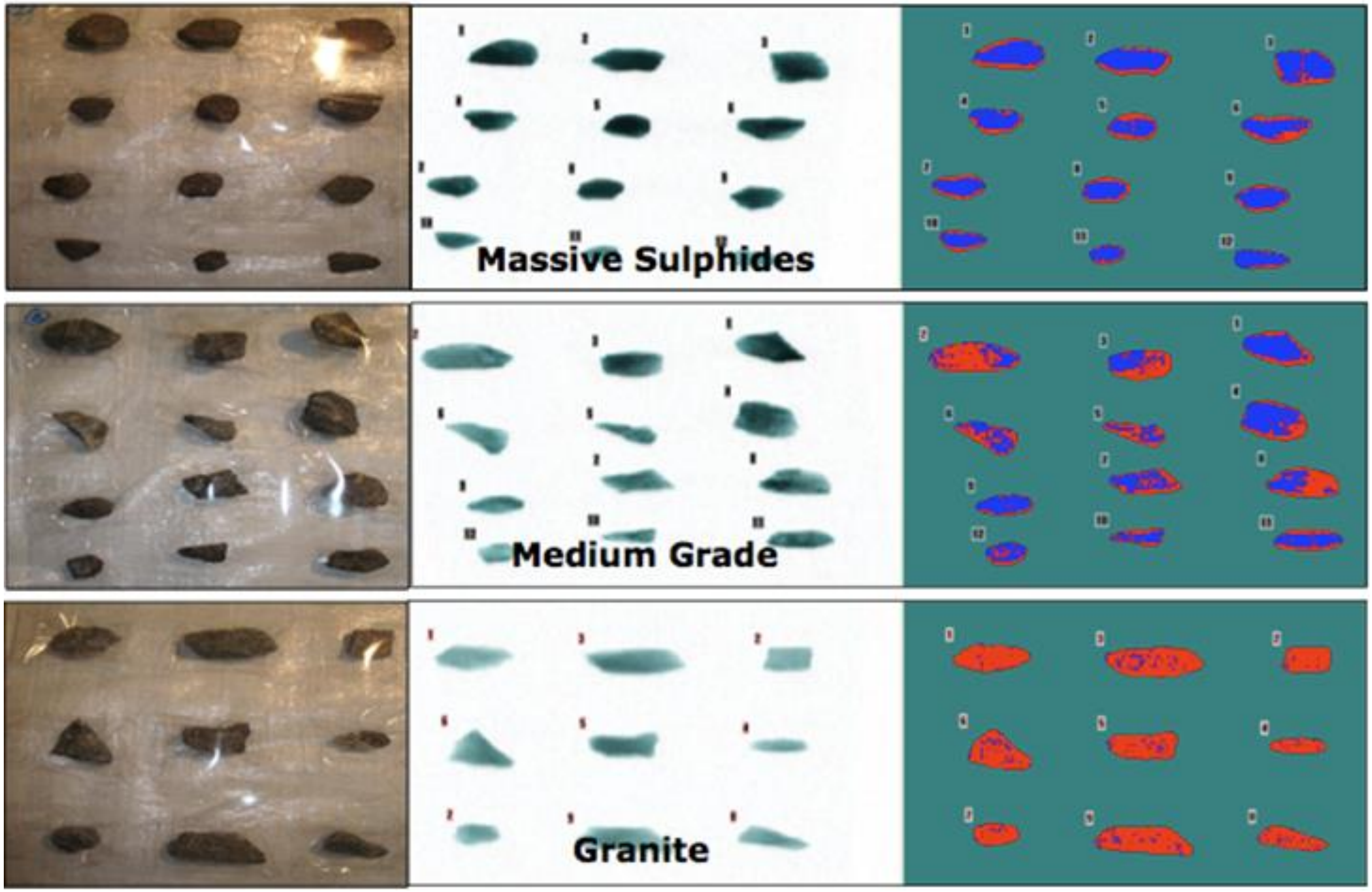
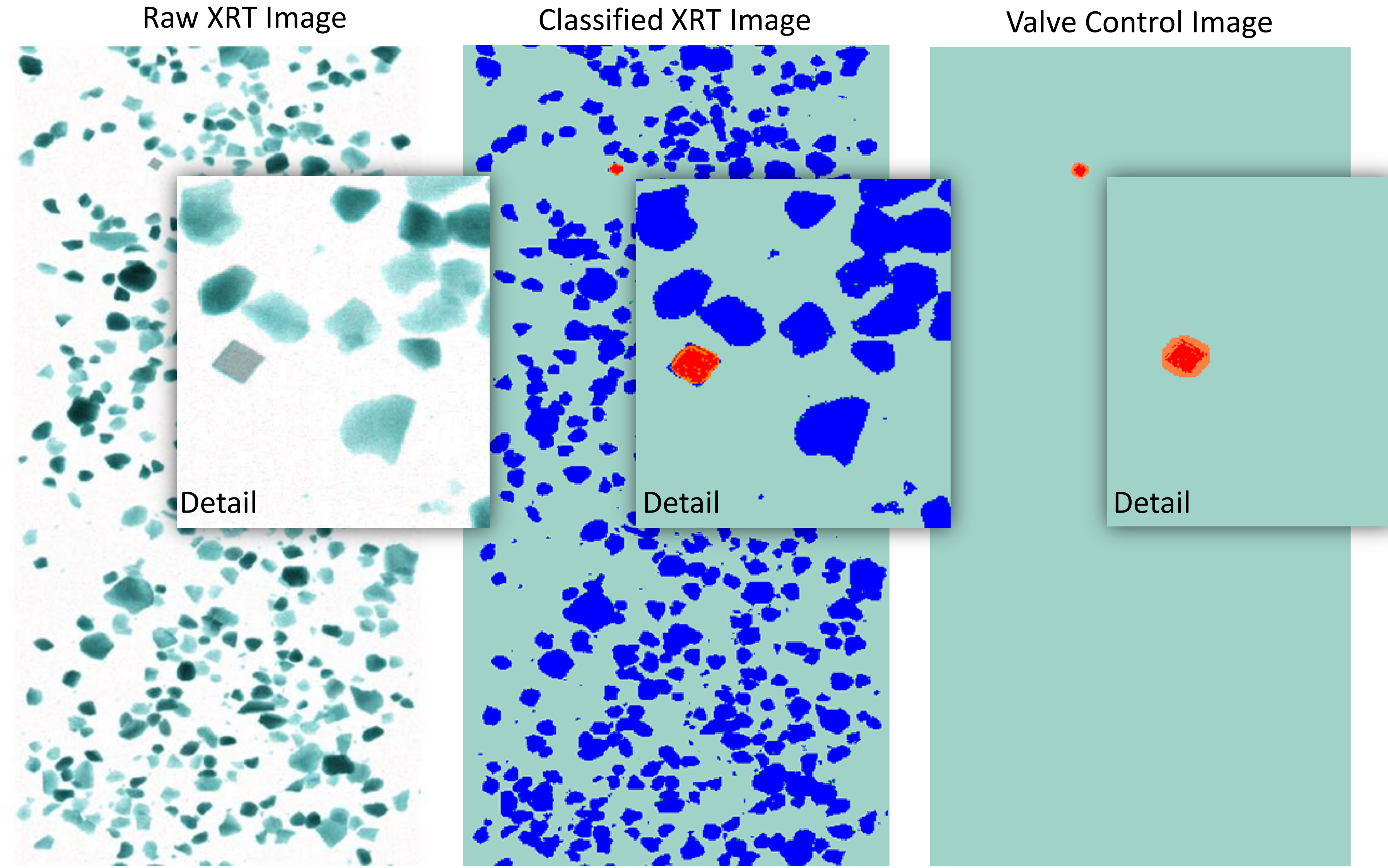


# XRT – Diamonds



# Commercial XRT Sorter

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2 x 1.2 m XRT Sorters

# Tungsten - Austria

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- **Mittersill Scheelite Mine (WBH)**
  - Opened in 1976 with a head grade of 0.7% $WO_3$
  - Mining up to 500,000 t/y
  - Head grade is now 0.2% $WO_3$
  - Processing plant requires 0.3% $WO_3$
  - Limited capacity of tailings pond

- **2 Parallel XRT sorters to pre-sort scheelite**
  - 70 tph; 16-30mm & 30-60mm
  - Grade of feed to the processing plant: 0.38% $WO_3$
  - 50% of sorted material goes straight to waste
  - Over 100,000 tpa no longer needs to be processed and disposed of in the tailings pond
    - Extended the mine life
  - XRT waste rock is sold as aggregate for road construction

# Commercial XRT Sorter


2.4 m XRT Sorter

# Phosphate – Saudi Arabia

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- Waad Al Shamal Phospate Project
  - ROM: 13.5 million tonnes per annum
  - 70% of ROM will be sorted
  - Nine 2.4m wide XRT sorters
  - Currently in construction phase: 2017 start-up?
- Benefits include:
  - Downsizing the downstream process
  - Smaller plant footprint
  - Reduced consumption of energy, water and chemicals per ton of final product
- Throughput of sorters is no longer an issue

# Testwork and Optimisation
# Application to a project

# Testwork Programme for Sorting

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## Testwork is Relatively Cheap

- Sample Preparation
  - Sampling (representative?)
  - Crushing
  - Screening
    - Material washing?
- Sorting
  - Machine calibration
  - Geologist input
- Assaying
  - Mass Balance Calculations

# Crushing & Screening

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- Objective is to maximise the material which goes through the sorter
- Crushing generates fines which bypass the sorters
  - Upgrade / downgrade of material?
- Minimise fines (-10mm)
  - Poor crushing and/or screening
  - Avoid oversize
- Screening
  - Consistent across tests
  - Represent screening in a production scenario
    - Single crush

# Example of fines generation

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| | 2013 Sample | 2014 Sample | 2015 Sample 1 | 2015 Sample 2 | 2015 Sample 3 |
|---|---|---|---|---|---|
| 1st Crush & Screen Lab1 (-8mm) | 9.4% | | | | |
| 1st Crush & Screen Lab1 (-10mm) | | 12.4% | 13.9% | 8.9% | 11.3% |
| 2nd Crush & Screen Lab2 (-10mm) | | 5.9% | | | |
| Re-Screen Tomra (-8mm) | | | 12.5% | 9.5% | 8.6% |
| Slimes Lab1 | | | 4.7% | 1.8% | 2.2% |
| **Total Fines %** | **9.4%** | **18.3%** | **31.1%** | **20.2%** | **22.1%** |

Proportion of Fines generated with each crushing and/or screening
Poor screening requires more handling

# Screening

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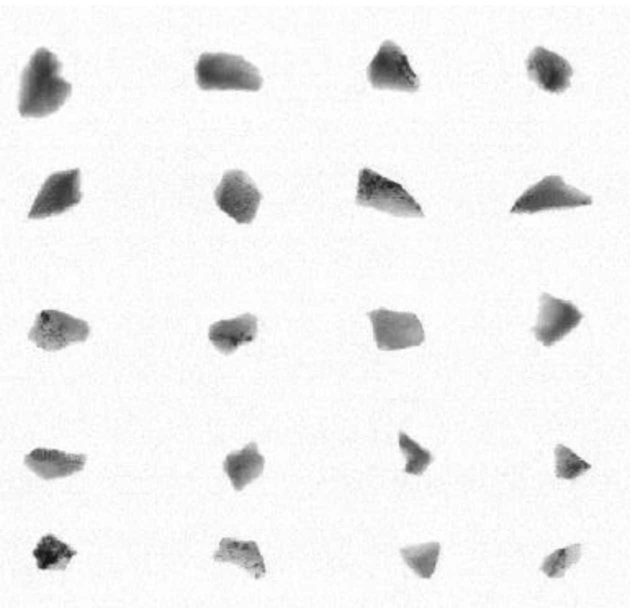
- Min:Max of range should be <3
- Typically 2 size ranges

  e.g.
  - -10mm = Fines
  - +10-20mm
  - +20-40mm
- Liberation analysis?
  - QEMSCAN

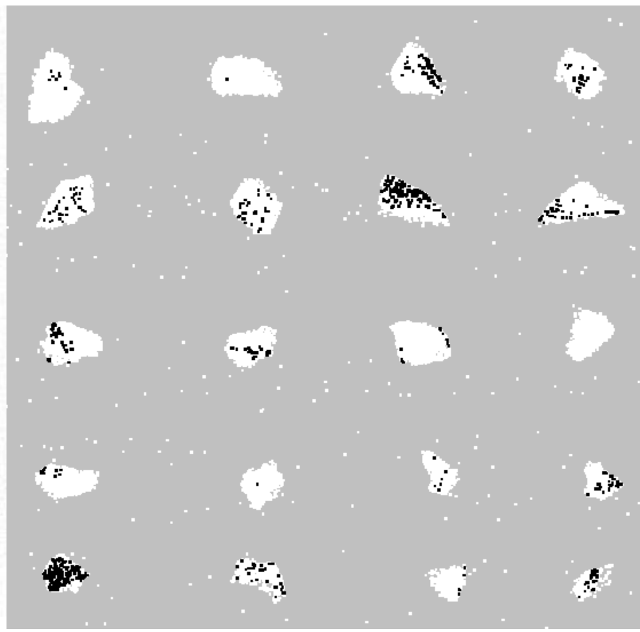
Sizes based on narrowest particle dimension passing through screen

# Machine Settings?

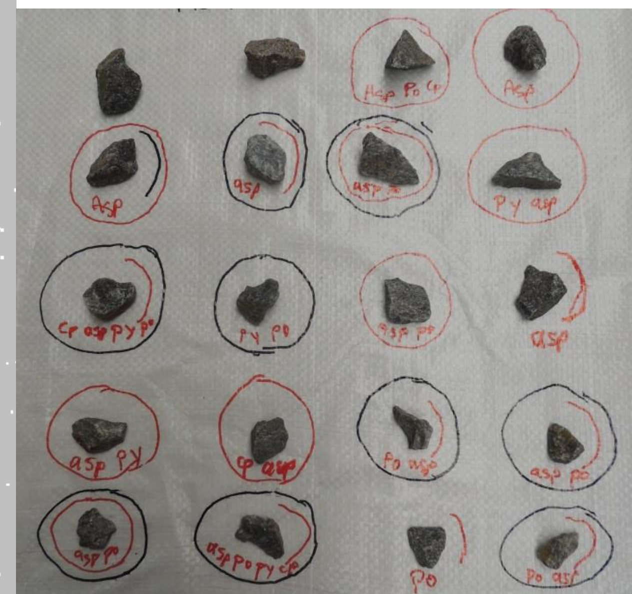
Raw XRT Image



Classified XRT Image



Geologists View



**Geologists input is important to determine ore types and to calibrate the sorter and selection thresholds**

# Optimising the process

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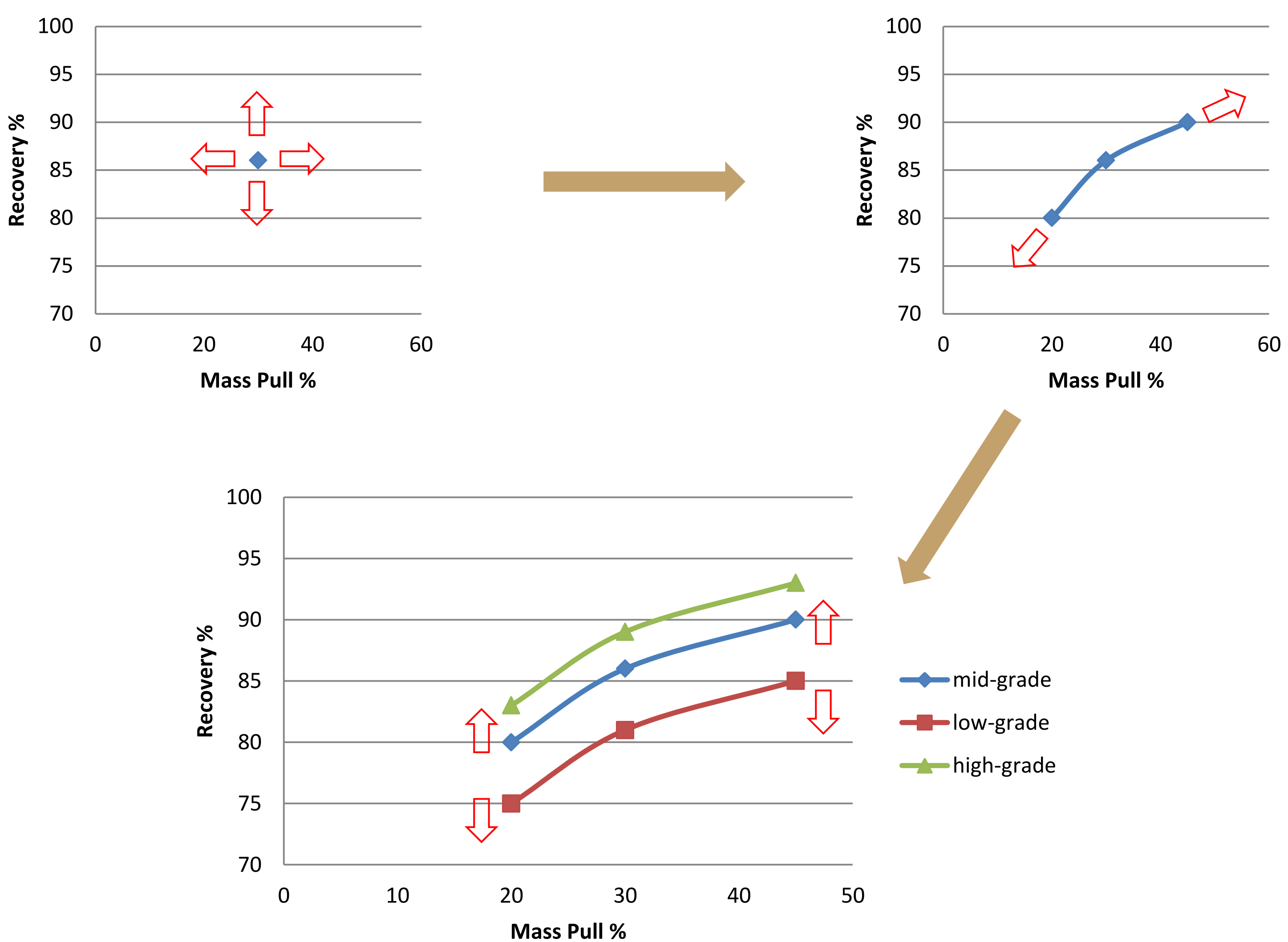
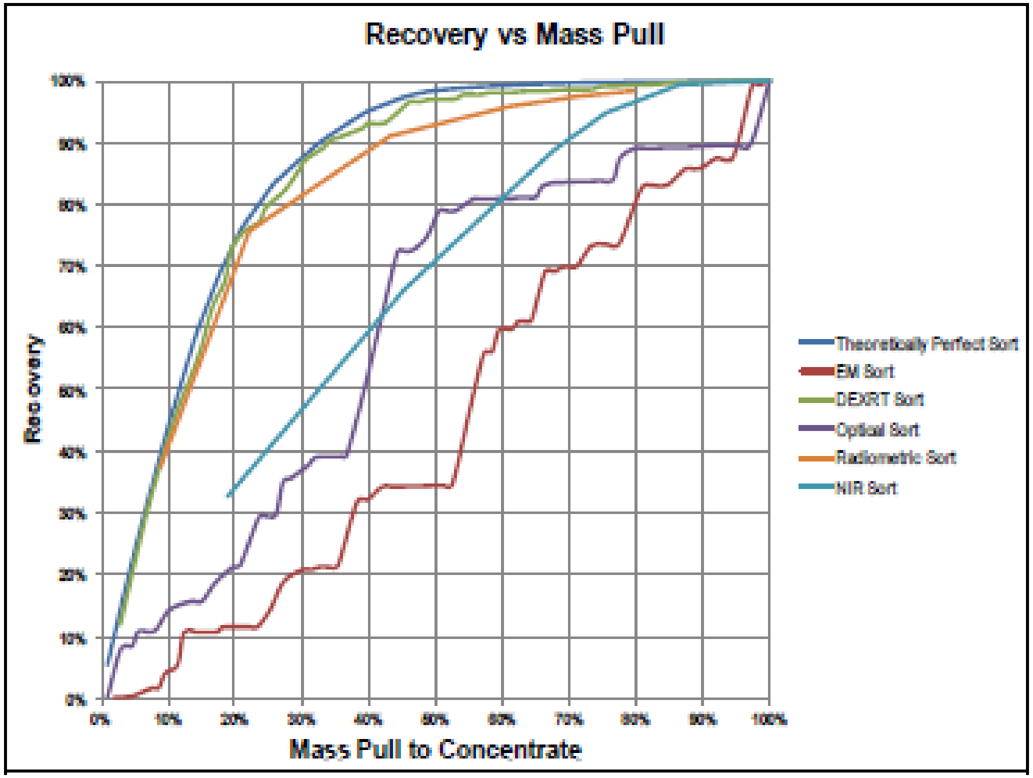
- What are we trying to do?
  - Determine how the efficiency of sorting (recovery:mass pull) varies with
    - different feed types (ore type, grade etc.)
    - machine settings (thresholds)
  - Quantify the sorting efficiency in such a way that this information can be applied to a block model
    - Geometallurgy
  - Improve confidence

# Essential Data Collection



# Bokan Mountain, HREE - Alaska

- Studies looked at different sensors
  - XRT and Radiometric most effective
- Sorting will lead to 50% rejection to waste



# Bradshaw Au deposit, Timmins

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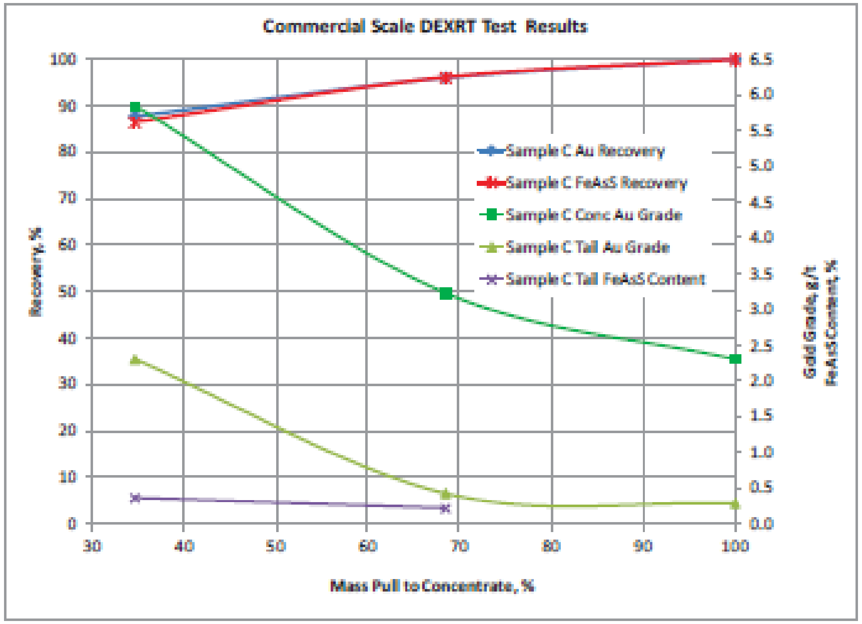
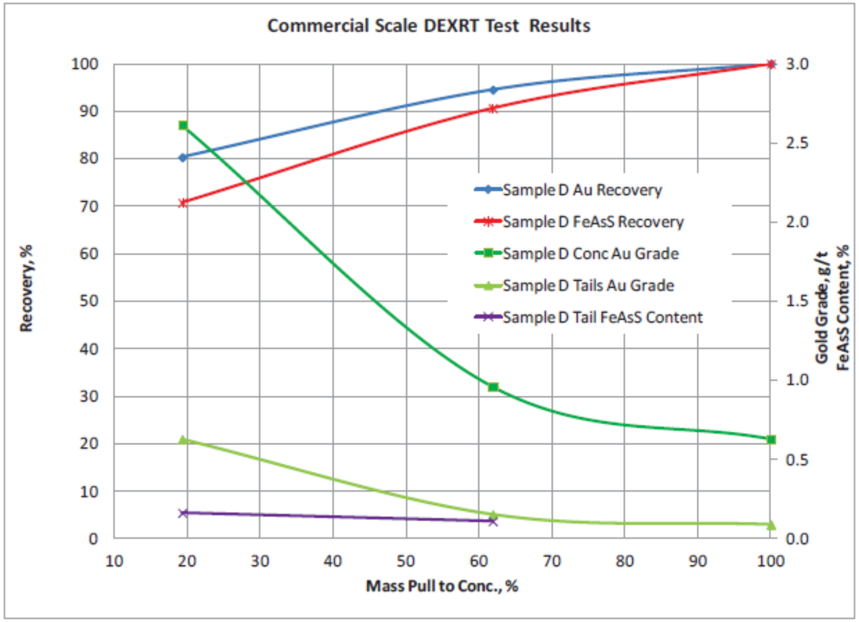
- ## Gowest Gold - 2015 PFS
  - 2 XRT Sorters: 10-25mm, 25-75mm
  - 53% mass pull for 98% Au recovery (incl. fines)
  - Ore upgraded from 4.8 g/t Au to as high as 9g/t

High Grade Samples




Low Grade Samples



# Economic Considerations

# Containerised Installation

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# Underground installation?

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- Industrial Minerals
  - Rock Salt
  - Underground colour sorting to remove impurities in Germany, Morocco and Canada
  - Historically in a fluorspar mine
- Requires considerable space
  - Conveyors, removal of waste etc
- Not practical in most metal mines

# Capital Costs

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- Very rough ballpark figures:
  - Each 1.2m sorter is ~ € 0.5 million
  - Annual Maintenance costs of 10%

- Number of machines depends on configuration and throughput rates
  - Throughputs depend on material density and particle sizes

**Rule of Thumb:**
10-20mm particles of 2.7 g/cm$^3$ density 15 tph/sensor m

# Running Costs

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- **XRT Energy Consumption:**
  - 10 – 26 KW per sorter
  - Variation due to width (1.2m or 2.4m) and power of different x-ray tubes and motors
- **Compressed Air for Ejection:**
  - Depends on feed/hit rate and particle size
  - For 1.2m XRT, processing 60 tph of 30-50mm with a hit rate of 25-30% will need 40-50KW compressor power

# Overall Project Economics - Example

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- Belvedere Resources Kopsa AuCu Deposit
  - Constrained by pre-existing Ni mill infrastructure
  - 20 km transport from mine to mill
  - PEA looked at 6 scenarios with and without sorting
    - Based on the same block model
  - XRT Sorting:
    - 65% mass rejection
    - 90% Au recovery
    - 75% Cu recovery
- Savings throughout the mine cycle

# Comparative project economics

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| Scenario | | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| Production Rate | (Mtpa) | 0.5 | 0.75 | 1.0 | 1.0 | 1.2 | 1.2 |
| Sorting | | | | | Sorting | | Sorting |
| | | | | | | | |
| LOM | (years) | 19 | 13 | 10 | 10 | 9 | 9 |
| Tonnes to Hitura Plant | (Mt) | 9 | 9 | 9 | 3.2 | 9 | 3.2 |
| Hitura plant head grade | (Cu %) | 0.15% | 0.15% | 0.15% | 0.32% | 0.15% | 0.32% |
| Hitura plant head grade | (Au g/t) | 0.91 | 0.91 | 0.91 | 2.34 | 0.91 | 2.34 |
| Total Op Costs /t ROM | (USD /t) | 30.1 | 27.1 | 27.9 | 19.1 | 27 | 18.2 |
| Total Op Costs (incl contingency) | (M USD) | 273 | 245 | 253 | 173 | 244 | 165 |
| Total Cap Costs (incl contingency) | (M USD) | 54 | 55 | 69 | 49 | 70 | 48 |
| Undiscounted cashflow | (M USD) | -6.6 | 19.4 | -1.4 | 58.2 | 5.6 | 65.5 |
| Post-tax NPV @8% | (M USD) | -11.5 | 1.2 | -11.5 | 21.8 | -8 | 26.4 |
| Post-tax IRR | (%) | - | 10% | -5% | 31% | -1% | 36% |

# Questions to ask?

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- Extent of studies
  - Quantification of sorting efficiency
- Is the sample representative?
  - Different ore types? (Liberation; disseminated ore)
  - Different grades?
- Crushing and Screening?
  - Have fines been suitably accounted for?
- Economics
  - Throughput rates?
  - Costs
  - Realistic expectations?

# Conclusion

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- Proven technology
  - Diamonds, Industrial Minerals
- Multiple benefits
  - Project economics
  - More complete exploitation of a deposit
  - Environmental
- Not just for new projects
  - Cost savings
  - Extend resources, lower grade ores become accessible
  - Extending mine life
- Not a “silver bullet”
  - All deposits are unique, not all are amenable to sorting

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