So you have it crushed and on a conveyor – Now what?
Optimizing value through ore sorting

Bob McCarthy
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Johannesburg, South Africa
Outline

• What and Why
• Terminology
• Current technology
• Technology providers
• Applications
• Potential and limitations
• SRK assistance
• Conclusions
What and why?

• Ore-Sorting: sensor-based concentration, pre-concentration, or scavenging
• For pre-concentration, reject the waste before treating unnecessarily (money and resources)
  • Natural heterogeneity
  • Planned dilution – internal and external
  • Unplanned dilution
• Advances in recycling and food industries have increased the options in sensing technology, most of which are equally applicable to mineral sensing
• Advances in computing power for mineral sensing algorithms
• Crushed material, on a conveyor, is a prime candidate for ore sorting
• Ore sorting is almost wholly applied to conveyed materials
**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?
Current Technology – Mineral Sensing

Energy discharges from atomic nuclei
Medical applications (soft X-ray)
Visible light
Heat lamp
Microwave radar
Television FM radio
AM radio

<table>
<thead>
<tr>
<th>Energy sources</th>
<th>Wavelengths (μm)</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma rays</td>
<td>10^{-8}</td>
<td>Energy discharges from atomic nuclei</td>
</tr>
<tr>
<td>X-rays</td>
<td>10^{-4}</td>
<td>Medical applications (soft X-ray)</td>
</tr>
<tr>
<td>Ultrasound</td>
<td>0.01(10^{-2})</td>
<td></td>
</tr>
<tr>
<td>Visible light</td>
<td>0.40</td>
<td>Heat lamp</td>
</tr>
<tr>
<td>Thermal infrared</td>
<td>3.00</td>
<td>Microwave radar</td>
</tr>
<tr>
<td>Microwave</td>
<td>5.50</td>
<td>Television FM radio</td>
</tr>
<tr>
<td>AM radio</td>
<td>10^{4}</td>
<td></td>
</tr>
<tr>
<td>Microwaves</td>
<td>10^{6}</td>
<td></td>
</tr>
</tbody>
</table>

Visible light:
- Violet (0.400)
- Blue (0.424)
- Green (0.491)
- Yellow (0.575)
- Orange (0.647)
- Red (0.710)
# Current Technology – Mineral Sensing

<table>
<thead>
<tr>
<th>Method</th>
<th>Sensor Type</th>
<th>Sort Type</th>
<th>Materials</th>
<th>Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>PGNAA</td>
<td>Penetrative</td>
<td>Bulk</td>
<td>Limestone, Fe, Al, Ph, Mn, Cu, Zn</td>
<td>1-2 min. avg, &lt;500mm rock, &gt;20-30 kg/m, sub 1% detection</td>
</tr>
<tr>
<td>NITA II</td>
<td>Penetrative</td>
<td>Bulk</td>
<td>Coal, C, H, O, Fe, K, Ca, S, Al, Cu, Ni, Mn, Si, Ti</td>
<td>1-2 min. avg, &lt;300mm rock, &lt;350mm depth, need &gt;1% for detection</td>
</tr>
<tr>
<td>PFTNA</td>
<td>Penetrative</td>
<td>Bulk</td>
<td>Ni, Fe, Co, Mg, Si, Al, Mn, Cr, C, H, O, U</td>
<td>&lt;90mm rock, &lt;280mm depth, 50-150kg/m</td>
</tr>
<tr>
<td>RM</td>
<td>Penetrative</td>
<td>Particle</td>
<td>Base metals, industrial minerals, coal, diamonds, Au/Ag indirect</td>
<td>Only for radioactive minerals</td>
</tr>
<tr>
<td>XRT</td>
<td>Penetrative</td>
<td>Particle</td>
<td>Ni, Cu, Zn, Au, Ag, Fe, Cr, Mn, U, W, Sn, Al</td>
<td>2-300 mm rock, &lt;300 tph, &gt;4-5 A.N. diff.</td>
</tr>
<tr>
<td>XRF</td>
<td>Surface</td>
<td>Particle</td>
<td>Diamonds, fluorite, sphalerite, kunzite</td>
<td>Requires long exposure time, limited to A.N.&gt;20, 30-250 mm rock, 20-50 tph</td>
</tr>
<tr>
<td>XRL</td>
<td>Surface</td>
<td>Particle</td>
<td>Scheelite</td>
<td>Few minerals naturally respond to UV excitation</td>
</tr>
<tr>
<td>UV</td>
<td>Surface</td>
<td>Particle</td>
<td>Quartz, limestone, dolomite, feldspar, fluorite, gems, Au/Ag indirect</td>
<td></td>
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<tr>
<td>VIS</td>
<td>Surface</td>
<td>Particle</td>
<td>Industrial minerals, gemstones, Cr, Au, Ni, Pt, Cu oxides, Au/Ag indirect</td>
<td>5-250 tph,</td>
</tr>
<tr>
<td>RGB</td>
<td>Surface</td>
<td>Particle</td>
<td>Industrial minerals, diamonds</td>
<td></td>
</tr>
</tbody>
</table>
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<tr>
<th>Method</th>
<th>Sensor Type</th>
<th>Sort Type</th>
<th>Materials</th>
<th>Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIBS</td>
<td>Surface</td>
<td>Particle</td>
<td>Elemental Analysis, most all elements</td>
<td>Sensitive to variations in distance from Laser/detector to target sample</td>
</tr>
<tr>
<td>LIF</td>
<td>Surface</td>
<td>Particle</td>
<td></td>
<td>Like LIBS, early stage of development few commercial applications</td>
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<tr>
<td>VNIR</td>
<td>Surface</td>
<td>Particle</td>
<td>Industrial minerals, Fe ore</td>
<td></td>
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<tr>
<td>SWIR</td>
<td>Surface</td>
<td>Particle</td>
<td>2-120 mm rock, 20-100 tph, surface technique impacted by cleanliness and single perspective (though double sided set-ups exist)</td>
<td></td>
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<tr>
<td>MWIR</td>
<td>Surface</td>
<td>Particle</td>
<td>2-120 mm rock, 20-100 tph, surface technique impacted by cleanliness and single perspective (though double sided set-ups exist)</td>
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<tr>
<td>LWIR</td>
<td>Surface</td>
<td>Particle</td>
<td>2-120 mm rock, 20-100 tph, surface technique impacted by cleanliness and single perspective (though double sided set-ups exist)</td>
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<tr>
<td>FIR</td>
<td>Surface</td>
<td>Particle</td>
<td>2-120 mm rock, 20-100 tph, surface technique impacted by cleanliness and single perspective (though double sided set-ups exist)</td>
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<tr>
<td>EMS</td>
<td>Penetrative</td>
<td>Both</td>
<td>Fe ore, base metals with magnetic response</td>
<td>8-60 mm rock, 70 tph</td>
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<tr>
<td>IND</td>
<td>Penetrative</td>
<td>Both</td>
<td>Fe ore, base metals with magnetic response</td>
<td>8-60 mm rock, 70 tph</td>
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<tr>
<td>MRS</td>
<td>Penetrative</td>
<td>Bulk</td>
<td>Chalcopryrite</td>
<td>300 mm rock, 1300 tph, Not all nuclei are magnetic</td>
</tr>
</tbody>
</table>
Current Technology – Mineral Sorting

Particle Sorting Process

1. Material Conditioning
   - Sizing and washing (depending on sensing technology)
2. Feed and Presentation
3. Detection and Evaluation
4. Mechanical Ejection
Current Technology – Mineral Sorting

Chute sorter

I. Conditioning
II. Separation
III. Emitter-detector
IV. Data processing
V. Product stream
VI. Reject stream

Current Technology – Mineral Sorting

Conveyor belt sorter

I. Conditioning
II. Emitter-detector
III. Separation
IV. Data processing
V. Product stream
VI. Reject stream

Current Technology – Mineral Sorting

Mechanical ejection

• Compressed air jets
  • 2 ms response

• Paddles/flaps
  • Pneumatic or hydraulic
  • 20 ms response – 5 m/s movement = 100 mm req’d. separation

• Water jets
Current Technology – Mineral Sorting

Bulk Sorting

- Conveyor based
  - Telescopic conveyor
  - Reversible conveyor
  - Flop gates
  - Trippers
- Shovel bucket

From MineSense
## Sensing Technology Providers

<table>
<thead>
<tr>
<th>Company</th>
<th>Electromagnetic</th>
<th>Infrared</th>
<th>Optical</th>
<th>Ultraviolet</th>
<th>X-Ray</th>
<th>Gamma</th>
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<tr>
<td>Comex</td>
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<td>NIR</td>
<td>Colour</td>
<td>UV</td>
<td>XRT</td>
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<td>CSIRO</td>
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<td>MRS</td>
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<td>EVK</td>
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<tr>
<td>LLA Instruments</td>
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<td>MineSense</td>
<td>EMS</td>
<td>LIBS</td>
<td>XRF</td>
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<td>NITA II</td>
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<td>Multotec</td>
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<td>XRF</td>
<td>PFTNA</td>
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<td>PANanalytical</td>
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<td>NIR, SWIR</td>
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<td>XRF</td>
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<td>Rados</td>
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<td>NIT</td>
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<td>XRF</td>
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<td>ScanTech</td>
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<td>Induction, Magnetic</td>
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<td>XRT</td>
<td>PGNAA, DUET</td>
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<td>Steinert</td>
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<td>Thermo Scientific</td>
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<td>PGNAA</td>
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<td>Tomra</td>
<td>EMS</td>
<td>NIR, IR, MWIR</td>
<td>VIS, Colour, PM</td>
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<td>XRT</td>
<td>XRF, XRL, RM</td>
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<td>IMA Engineering</td>
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<td>SGS/CoreScan</td>
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<td>Specim</td>
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<tr>
<td>Spectral Evolution</td>
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</tbody>
</table>

- **Company also provides sorting**
- **Surface sensing**
- **Penetrative sensing**
Technology Providers

- Primarily from recycling industry, dabbling in minerals
- Some dedicated to mining
- Sensing companies – many
- Sorting companies – few
- Secretive – some

- Opportunities – many!
Applications

- Material characterization
  - Drill logging
  - Core scanning
Applications

- **Sorting**
  - Concentration (finished product) vs pre-concentration (waste removal) vs scavenging (product from waste)
  - Waste Rejection: at face or post primary crushing
    - Waste use potential – road material, stemming, aggregate
  - Underground pre-concentration
    - Save on hoisting, transport
    - Provide backfill
  - PAG material removal (sulphides)
  - SAG/AG pebbles
  - Multi-stage and multi-technology
    - Remove material in stages to reduce throughput for technologies that require throughput limiting computational analysis or limiting mechanical separation
    - Multiple sensors on same built to identify waste; first technology tags particle as waste so that subsequent sensors/algorithms do not have to process
Applications

Ore Crusher

-250 mm

Waste

Crusher

Mineralized material

Sensors

-250 mm

Flop gate/conveyor distribution

Waste

Particle Separators

-30 mm

30mm x 85mm

85mm x 250mm

NAG

Truck load out

PAG

NAG trucked to Waste Dump

PAG Conveyed to TSF

Fine Tailings to TSF

Mill

Product
Applications

Ore Sorting

-250 mm

Cross belt sensor

Flop Gate

Reject stream

-30 mm

30mm x 90mm

90mm x 250mm

Particle Separators

Mill

Product

Truck load out

PAG trucked to backfill or used as blast stemming

Fine Tailings to TSF
Potential and Limitations

Potential

- Consider 3 hypothetical mining operations:
  - A Zn open pit mine, 10 Mtpa
  - A Au open pit mine, 10 Mtpa
  - A Au underground mine, 2 Mtpa
- All have 10% dilution
- OP mines have similar milling costs; UG has scaled higher milling unit costs
- Consider material rejection (10-25%) in 2 scenarios:
  - In mine (“at face”)
  - After primary crusher
Potential and Limitations

Impact of Sorting on OP Zn Mine

Impact of Sorting on OP Au Mine

Impact of Sorting on UG Au Mine - Selective Mining Method
Potential and Limitations

Potential – cont’d

• Consider impact of increasing dilution in UG Au mine in adopting a less selective mining method
• Mining cost of $70/tonne (vs $100/tonne)
• 25% dilution (vs 10%)
• All else remains the same
Potential and Limitations

Impact of Less Selective Mining and Ore Sorting

- Mass Mining, At Face Rejection
- Mass Mining, After Crusher Rejection
- Selective Mining, At Face Rejection
- Selective Mining, After Crusher Rejection
- Mass Mining - No Sorting
- Selective Mining - No Sorting
Potential and Limitations

Limitations

• General
  • Analysis complexity – limiting algorithms
  • False negatives
  • Lack of heterogeneity
  • Deposit variability

• Particle sorting
  • Feed presentation – one or two sides, clean
  • Requires consistency of particle size (<3:1 variation)
  • Maintainability of compressed air ejection systems
  • Max 300 tph/m sorter width for particles 200-300 mm (XRT, Opt, NIR) vs 10-30 tph/m for XRF

• Bulk sorting
  • Conveyor-based: minimum batch size
  • Entrained good material
Potential and Limitations

Realized Examples

• Iron ore
  • 56% Fe / 0.15% S sorted to 62% Fe / 0.04% S DSO by multi-stage XRT and Optical

• Tungsten-moly-bismuth
  • XRT rejected 50% of feed as waste to double the plant capacity

• Limestone
  • Low quality material, previously wasted, is upgraded such that only half the total material previously mined is now mined
SRK Assistance

Sensor testing program

Heterogeneity analysis

Process route options

Reserve/COG analysis

Economic evaluation

IPCC-sorting integration

IPCC mine planning

Pebble Assessment

Size Fraction Analysis

* - member of ICS (Intelligent Conveyor Systems) Consortium
Conclusions

- Sorting is a concept and technology that has been around for a while and continues to develop
- Able to pre-concentrate ores by rejection of waste materials
- Pre-concentration reduces demands on water, energy, etc.
- Pre-concentration enables lower cost, less selective mining methods
- Pre-concentration can reduce mill opex and capex
- Can reduce cut-off grade to extend reserves and mine life
- Sensing technology is now able to detect most all elements and minerals in real time and at high speed
- Sorting technology can be throughput limiting
- Multi-stage sorting, including mix of bulk and particle sorting, can improve throughput
- Scope of potential applications is extensive
Thank-you!

- For more information:

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