Automated mineral mapping in optical ore microscopy

Accuracy and limitations

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Automated Mineral Mapping

- Sampling
- Imaging
- Mineral Identification
Automated Mineral Mapping

- **Imaging**
  - Spatial Sampling
    - A random point sampling gives an unbiased estimator of the volume proportion of a phase ($\alpha$) in a solid
    
    $1^{st}$ Principle of Stereology (Delesse, 1848)

    $$P^\alpha_P = A^\alpha_A = V^\alpha_V$$

    Systematic sampling on a “random” section

    “Do more less well”
Automated Mineral Mapping

- Sensing the mineral target
  - Sensing principle
    » Ex. X-ray fluorescence; light absorption; atomic force; ...
  - Signal processing and interpretation
    » Database of spectra; Characteristic rays ($K_{\alpha}$,...)
Automated Mineral Mapping

- **Whiskbroom imaging mode**
  - Scanning beam
    - or moving sample

Ex. Scanning Electron Microscopy

Result of EDX mapping © QEM SCAN
Automated Mineral Mapping

- **Pushbroom imaging mode**
  - Scanning linear sensor

- Industrial vision of « marble » tiles

- Diffuse reflectance imaging

- Specular reflectance imaging
• Array imaging mode
  - CCD/CMOS camera

Reflected Light Microscopy

Typical Quantum Efficiency for an Si-detector
Photonic Ore Microscopy

- Photons
- Filters
- Reflectance database
• MultiSpectral Imaging
  • Conventional Ore Microscope
    » Objective transmittance >50% @ 1100nm
  • Scientific grade CCD camera
    » Spectral sensitivity 350nm-1000nm
  • Filter wheel
    » Interference filters @ 50 nm spacing

Typical Quantum Efficiency Curve for an Si-detector

Multispectral Image
Photonic Ore Microscopy

- **MultiSpectral Imaging**
  - Calibration
    - Correction for uneven illumination
    - Measure of reflectance standard
  - Correlation with Specular Reflectance Database
    - Quantitative Data File - QDFIII (Criddle & Stanley, 1993)
    - Extension to 1000 nm (Brea et al., IMA, 2010)

**COVÉLITÉ**

**CR 286**

Enhanced Pyrrhotite-Cubanite discrimination
**MultiRadial Imaging**

- Rotating incident polarizer
  - “Information” about crystal anisotropy

\[ B = \text{Max}\{P_{x,y}^\theta\} - \text{min}\{P_{x,y}^\theta\} \]
Applications

- Epithermal Cu-Au
- Stratiform Cu
- Carbonate rocks
Wavelength Selection

- Phalaborwa: Cu-Ni Sulphides
  - @ 437nm; 489nm; 591nm; 692nm (10nm FWHM)

Pentlandite
Chalcopyrite
Violarite
Pyrrhotite
Cubanite
Chalcocite
Covellite
Bornite
Magnetite

Criddle & Stanley QDFIII, 1993

Califice A., 2008
Chelopech: Epithermal Cu-Au Paragenesis

False Colour Image

Maximum Likelihood Classification

Pyrite
Chalcopyrite
Bornite
Covellite
Résine

Pyrite
Résine+gangue
Covellite
Enargite
Chalcopyrite
Galène
Tennantite
Bornite

After Conditional Geodesic Propagation
Modal Analysis

- **Kansanshi: Stratiform Cu**
  - Supergene (mixed) zone
    - Secondary Cu sulphides,
    - Malachite,...

489nm, 590nm, 690nm

Chalcopyrite (A)
Chalcopyrite (B)
Copper
Cuprite
Digenite
Malachite
Chalcocite
Rutile
Molybdenite
Pyrite

Siebels K., 2012
Modal Analysis

- **Kansanshi: Stratiform Cu**
  - Supergene (mixed) zone
    - Secondary Cu sulphides,
    - Malachite,...

![Modal Analysis Diagram](image)

**Curva de Liberación Ccp RoCo**

- **Cp1**
- **Cp2**
- **Cc**
- **Mal**
- **Py**

**Composition**

- **Ss-Cu** 11.1%
- **Ox-Cu** 3.0%
- **Hem** 1.7%
- **S-Fe** 25.1%
- **Gg** 4.6%
- **Other** 0.3%
- **Cp** 54.2%

**EMC2012 Frankfurt**

Dufrasne Fl., 2010; Perez-Barnuevo L., 2011
Microstructure Analysis

- Carbonate Rock

Multiradial Image

Porosity

Grain Boundaries (gradient)

Jaimes Contreras R., 2011
- Carbonate Rock

Percentiles of Intercept Length (Crystal Size Distribution)
Accuracy & Limitations

- Visual check
- Chemistry, XRD
- Comparison with SEM
- Round Robin
Accuracy & Limitations

- **Validation**
  - Visual
    » Point counting; Time Consuming; Subjective;...
  - Chemistry
    » Balance; Limited mineralogy; ...
  - XRD
    » Major minerals;...
  - Round Robin Test
    » Interlaboratory test on « similar samples »
    » Detailed statistics of inter/intra variability
    » Initiative of IMA-CAM
• Comparison with Automated EM-based Mineralogy
  - QEM-SCAN/MLA
    • High resolution (PGE, Au)
    • Non-stoechiometric minerals (Lcx)
    • Trace / Precious elements partitioning
    • Gangue mineralogy
    • Process mineralogy oriented software

  - Optics
    • Cheap technology
    • Fast imaging
    • Large samples (do more less well!)
    • Good discrimination in some critical ores
      » Iron oxide; Ni-Cu sulfides; ...
    • Multiradial imaging
      » Grain size analysis
      » Crystal orientation (EBSD for the poorest)
EMERALD Erasmus Mundus

- European Master Degree in Georesources Engineering

- Innovative education in « Geometallurgy »
  - Mineral Resources Characterization - Processing - Modelling - Management

- Worldwide network of associated universities
  - Moscow, Queensland, Capetown, Hacceteppe, Minas Gerais, UChile, Kazakhstan, ...

- Supported by major mining companies

Application Deadline
31 Dec 2012
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