Tescan

Maximizing Throughput of Ore Characterization by Means of Automated Mineralogy

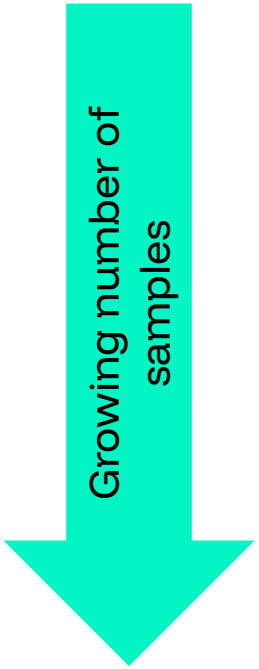
Marek Dosbaba

Geometallurgical characterization

- **Geological Characterization**
  – lithology, alteration, and mineralization.
- **Mineralogical & Textural Analysis**
  – quantify of minerals, grain size, associations, and elemental deportment
- **Geochemical Analysis**
  – Perform assays for economic and environmentally significant elements
- **Geotechnical & Metallurgical Testing**
  – hardness, density, magnetic/electrical properties, abrasion index
- **Proxy Variables & Multivariate Data Analysis**
  – Collect fast-measurable attributes to predict recovery, energy, and reagent use
- **Spatial Modeling & Domaining**

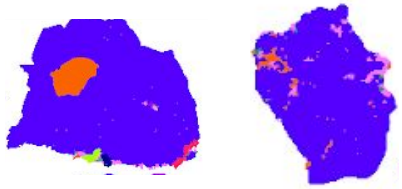
Scale of geometallurgical characterization

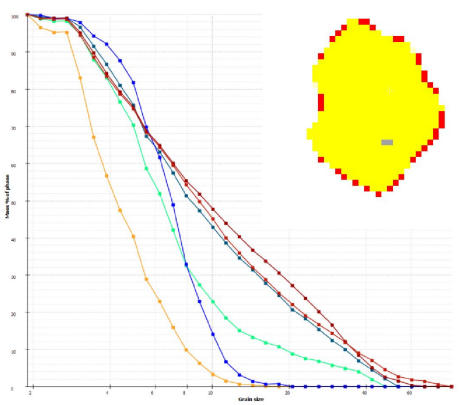
- **Exploration Stage** – Early identification of ore variability and preliminary mineralogical assessment
- **Resource Definition Stage** – Quantification of spatial variability and establishment of geometallurgical domains
- **Project Development / Feasibility Stage** – Detailed testing and model development to predict processing performance
- **Operational Stage** – Continuous data collection, model refinement, and process optimization



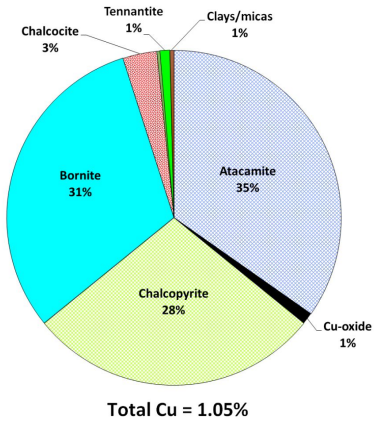
Possible mineralogy related challenges

- Modal mineralogy
- Liberation and locking
- Grain size
- Mineral associations
- Mineral chemistry
- Surface chemistry
- Coatings and rimming
- Magnetic properties





- Specific gravity
- Dissolution kinetics
- Cyanides and oxygen demand
- Refractoriness (sulfide minerals)
- Preg-robbing (carbonaceous materials)
- Deleterious or toxic elements (As, Sb, Te …)
- Deleterious minerals (AG and AC minerals)



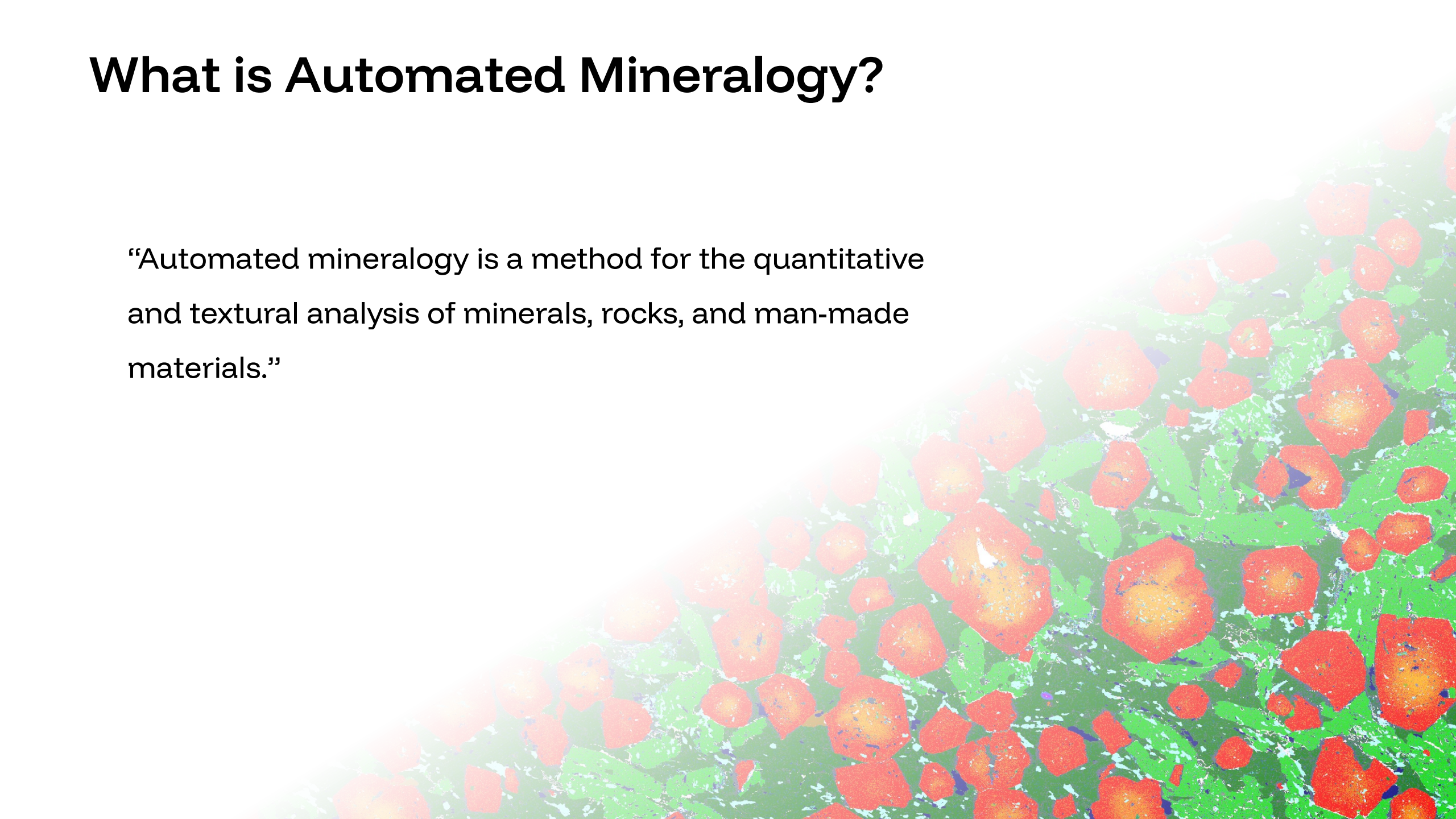
Total Cu = 1.05%

Joe Zhou Mineralogy Ltd.

- **Modal mineralogy**
- **Mineral associations and locking**
- **Grain size distribution (mineral by mineral)**
- **General liberation degree**
- **Elemental deportment**

What is Automated Mineralogy?

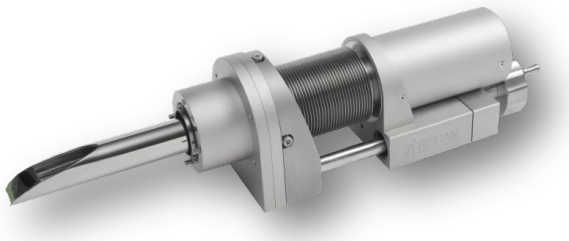
“Automated mineralogy is a method for the quantitative and textural analysis of minerals, rocks, and man-made materials.”

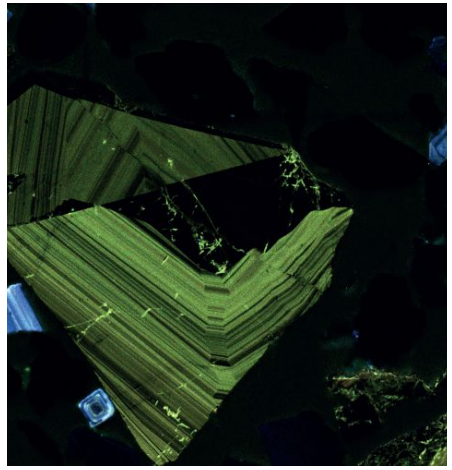


What options there are to deliver mineralogical information?

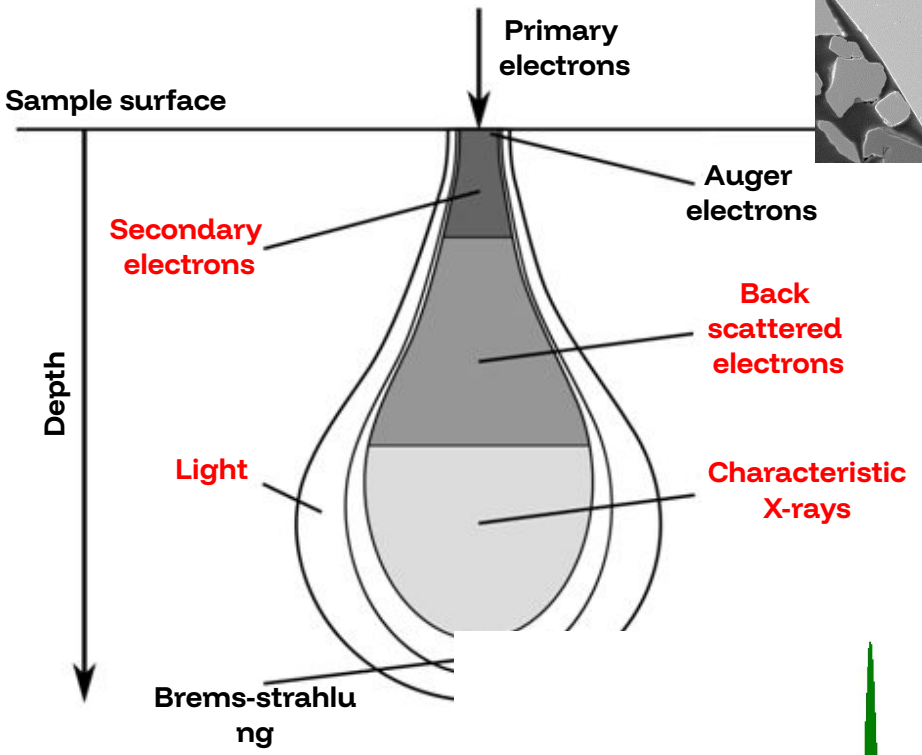
Method	Modal Mineralogy	Associations & Locking	Grain Size Distribution	Liberation Degree	Elemental Deportment
XRD	Yes (>1-2 %)	No	No	No	Yes (inferred from phases)
Hyperspectral Imaging	Yes (incomplete)	Not reported	Not reported	Not reported	No
LIBS	Yes (>X00 ppm)	Not reported	Not reported	Not reported	Yes
Raman Spectroscopy	Yes	Not reported	Not reported	Not reported	No
MicroXRF Mapping	Yes (X0 – X00 ppm)	Yes	Yes (>20 microns)	Yes (>20 microns)	Yes
SEM - Automated Mineralogy	Yes (>X00 ppb)	Yes	Yes (<1 µm)	Yes	Yes (quantitative, mineral-by-mineral)

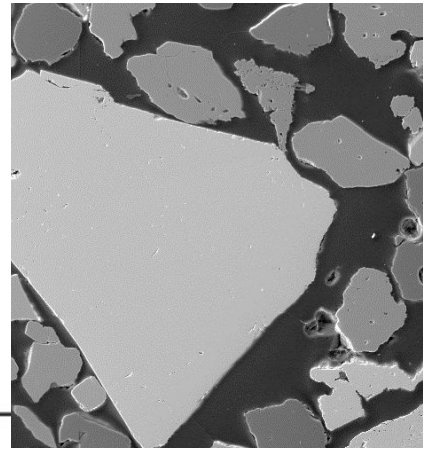
How does SEM-AM work?





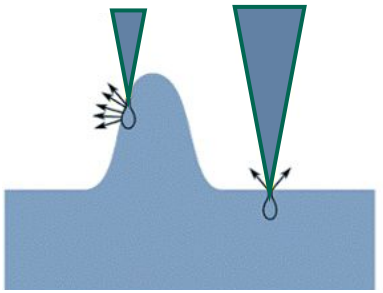
Cathodoluminescence

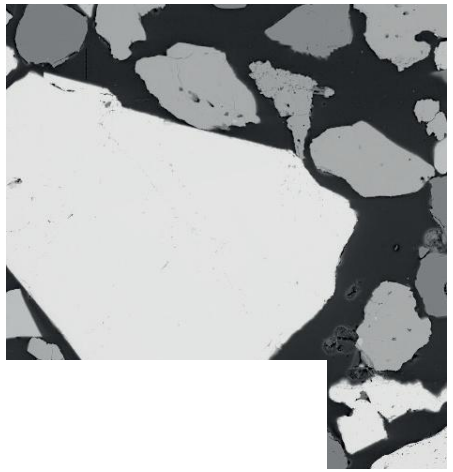




SE

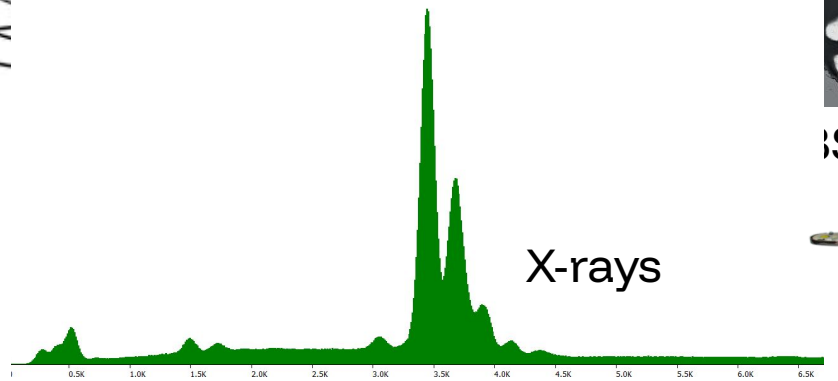
Surface topography



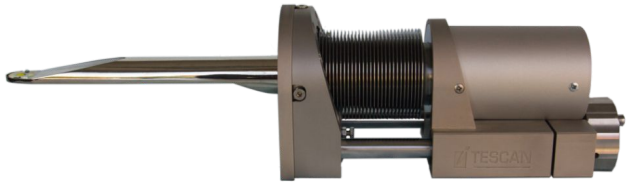


BSE

Material contrast

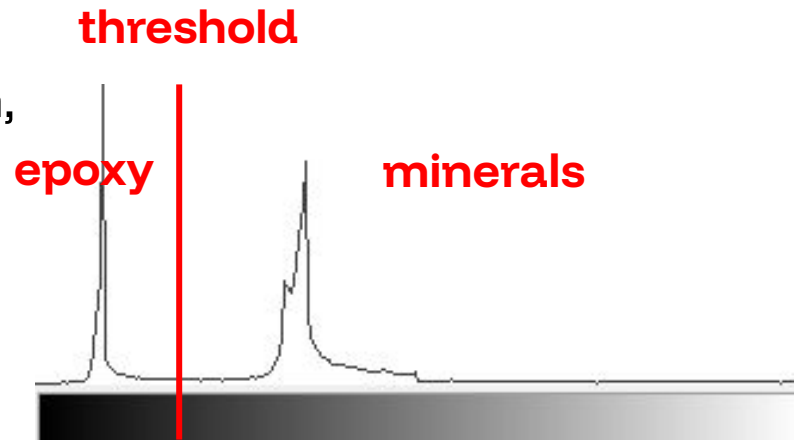


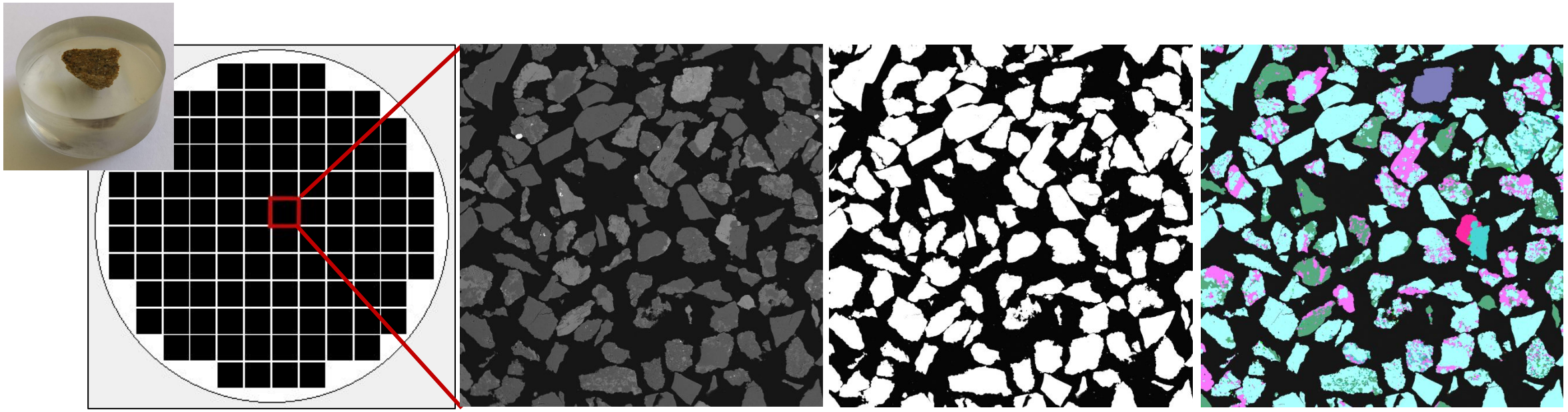
X-rays



Automated mineralogy data collection

- Typical working conditions: HV 15 - 25 kV, working distance 15 mm, beam current 5 – 12 nA
- BSE signal thresholding to tell minerals from background
- Multiple analytical modes

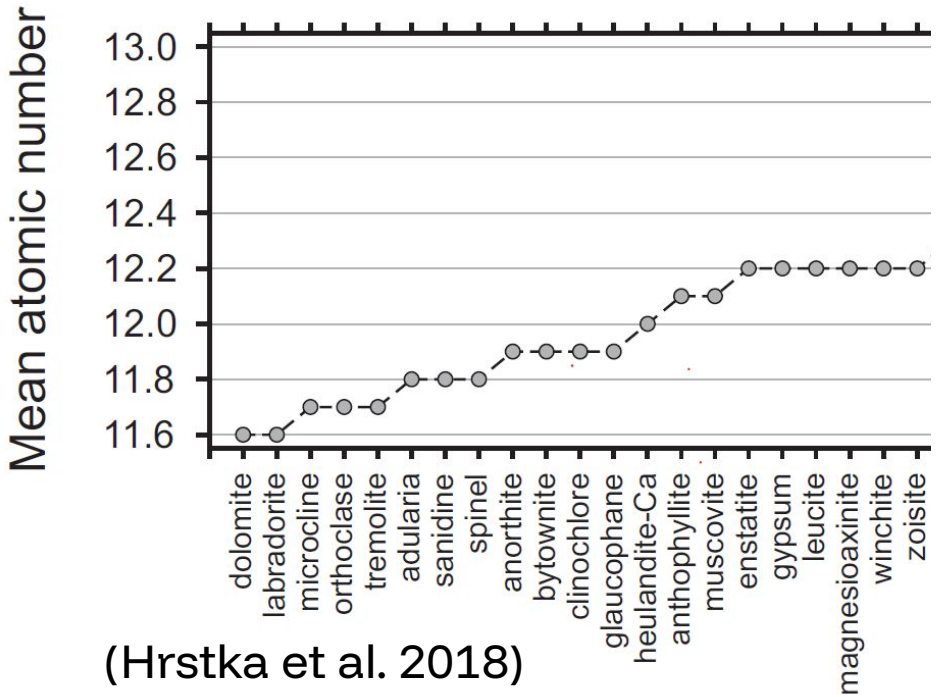




fields BSE particles/background

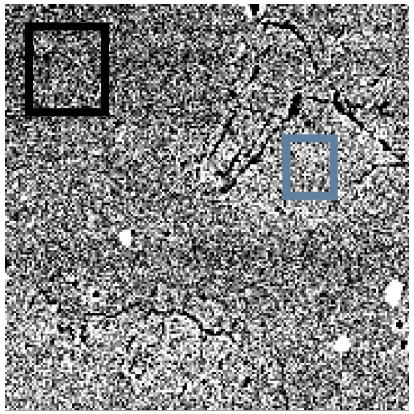
Backscattered electron signal and its limitations

- Resolution expressed in atomic number ~ 0.1 Z
- Scanning speed
- Frequent overlaps of phases
- Surface quality

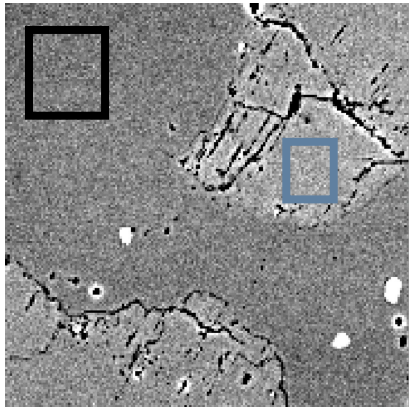


(Hrstka et al. 2018)

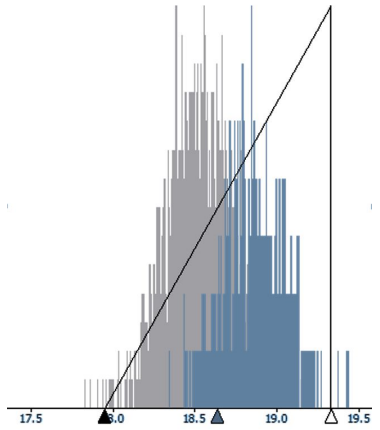
Quartz (Z=10.8) vs Albite (Z = 10.7)

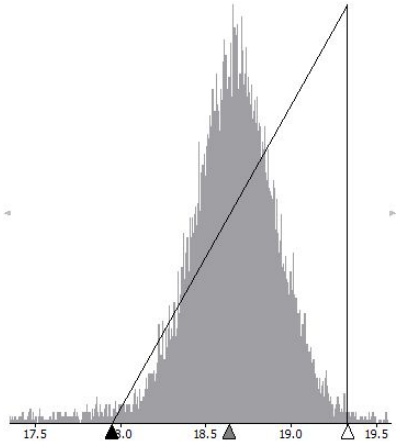


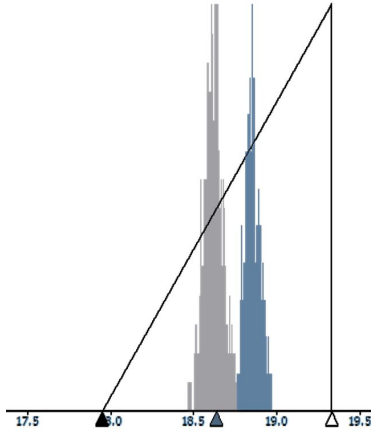
1 µs

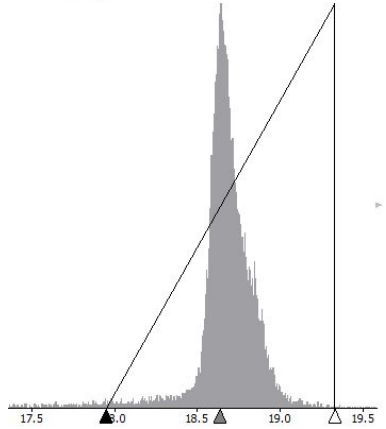


20 µs



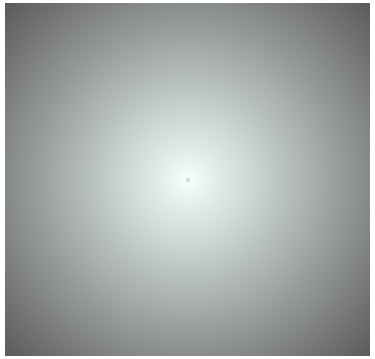


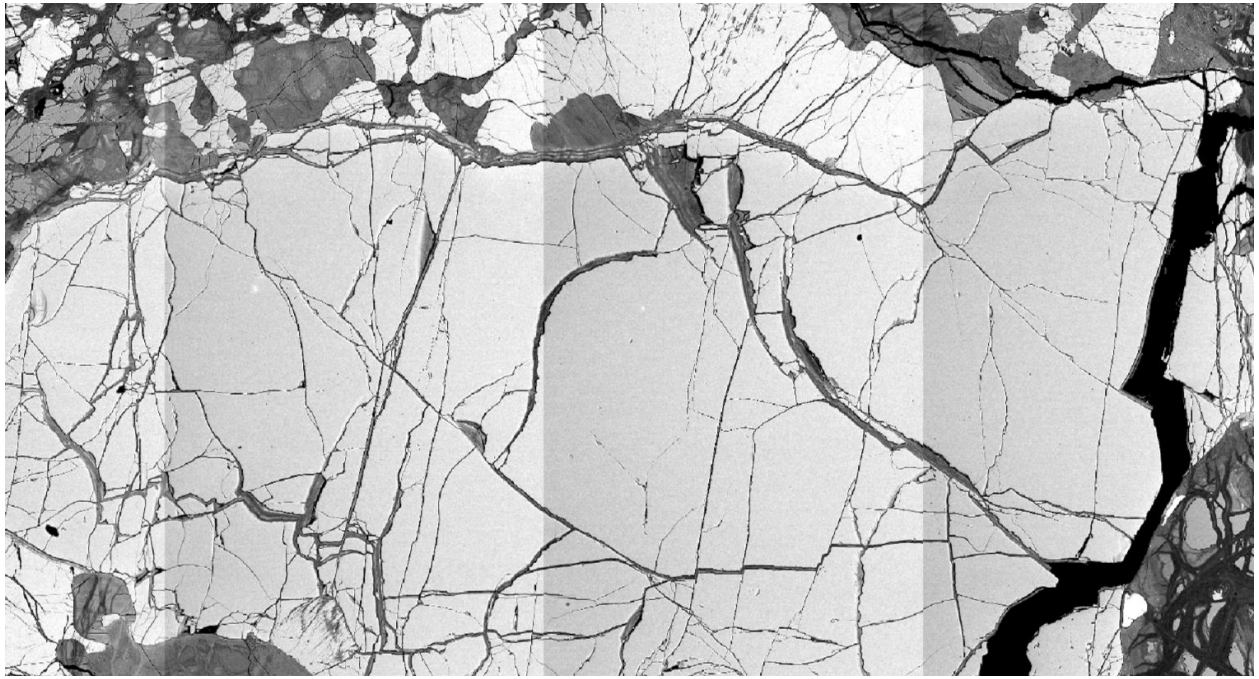




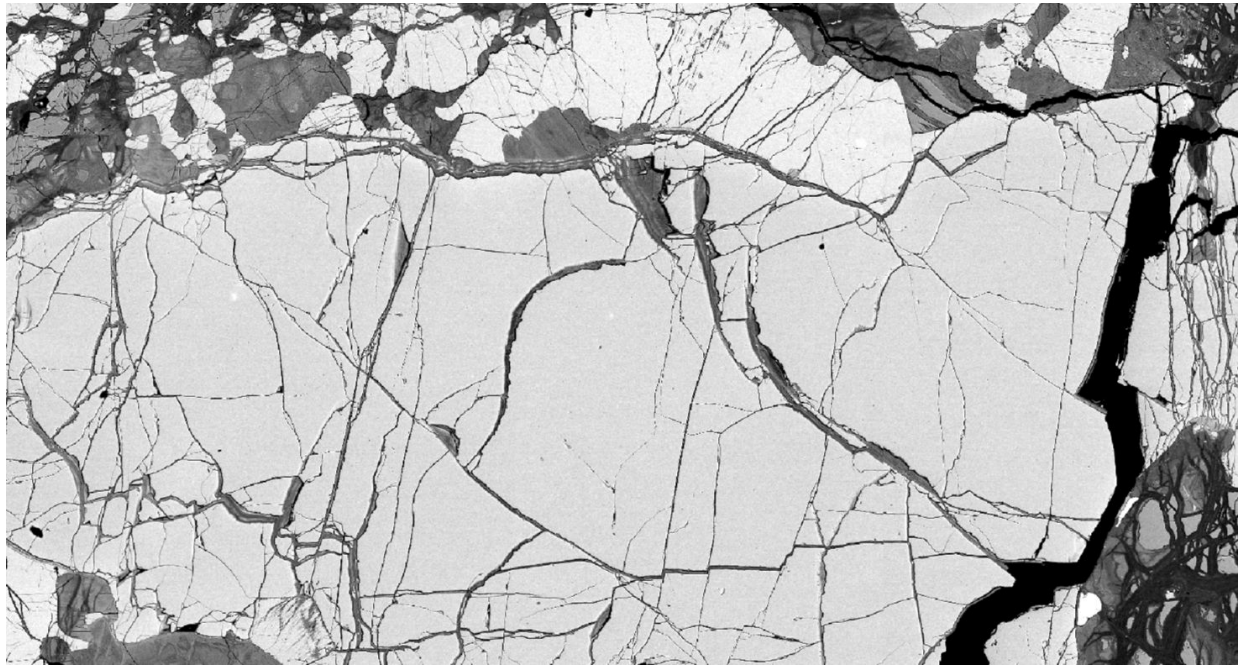
Backscattered electron signal and its limitations

- BSE geometrical effeciency





Uncorrected

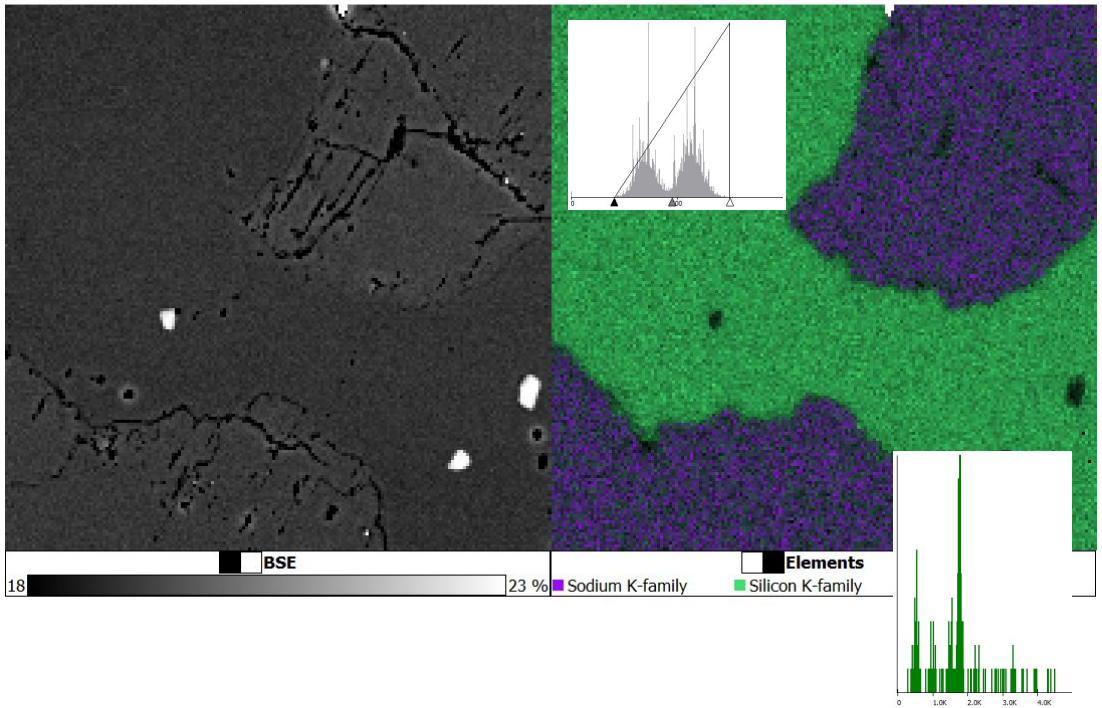


Corrected

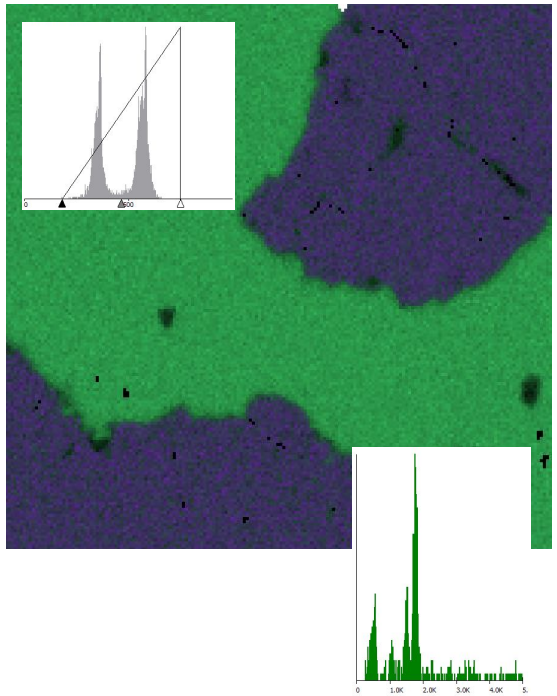
EDS signal – the slower the better

- Optimized for fast analysis – high throughput lower resolution
- Impact of dwell time
- Collection X-ray spectra is on the order of milliseconds

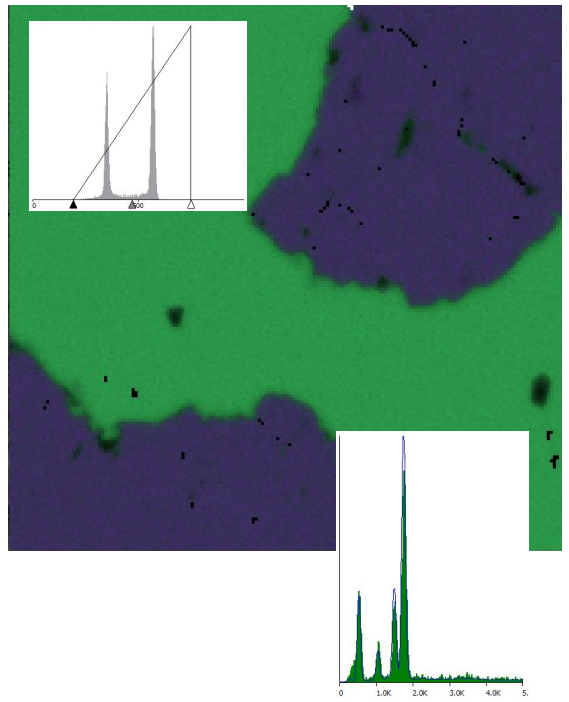
100 counts/pixel



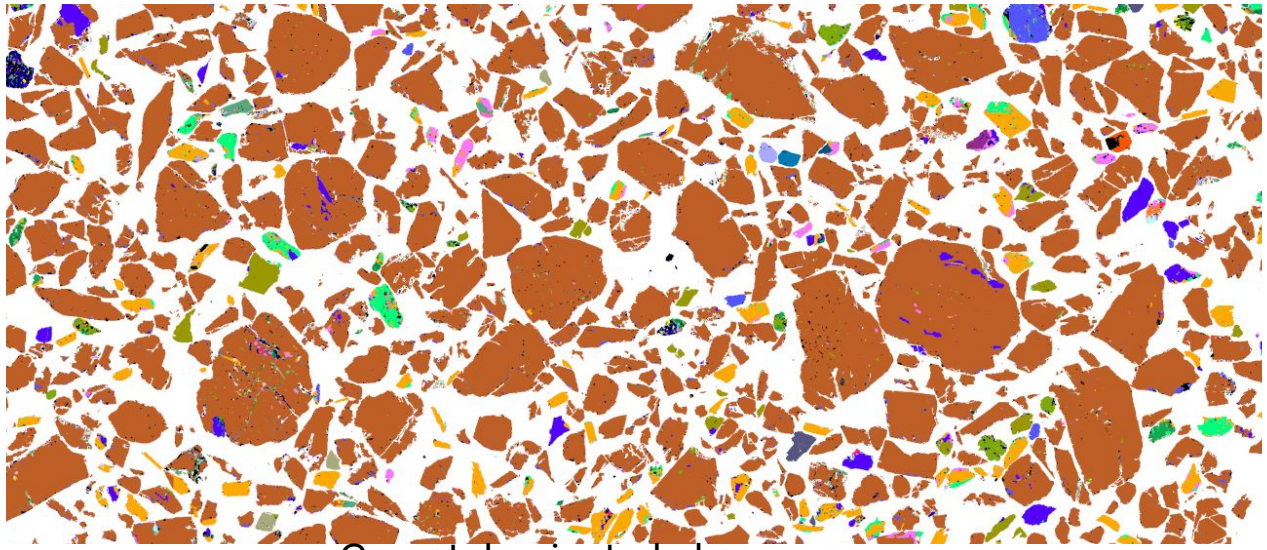
1000 counts/pixel



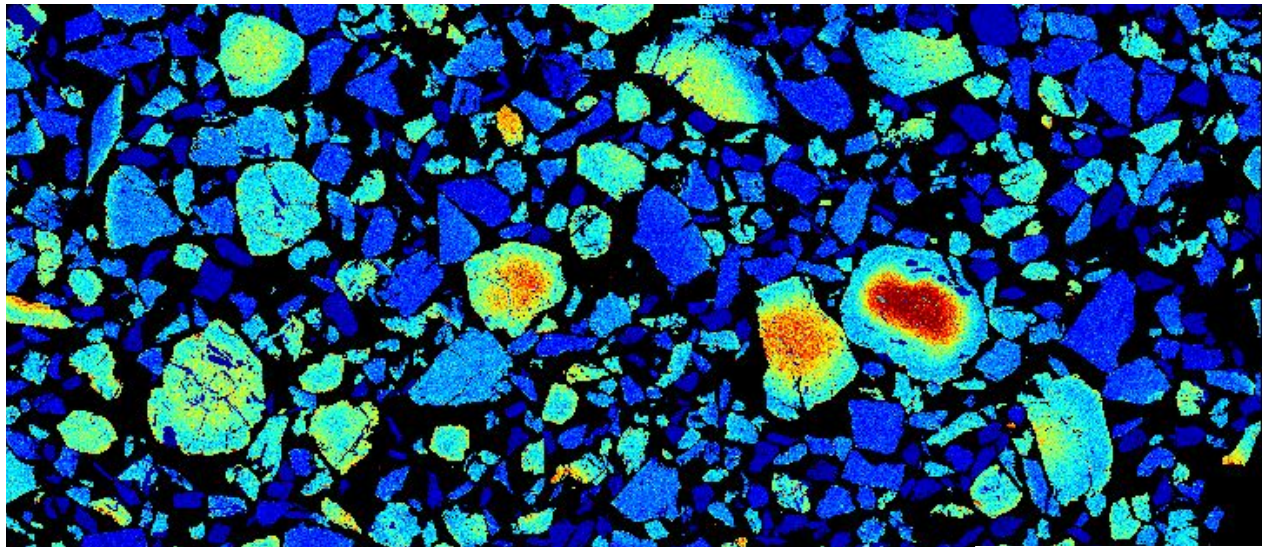
10 000 counts/pixel



Quality spectra or quality elemental maps?



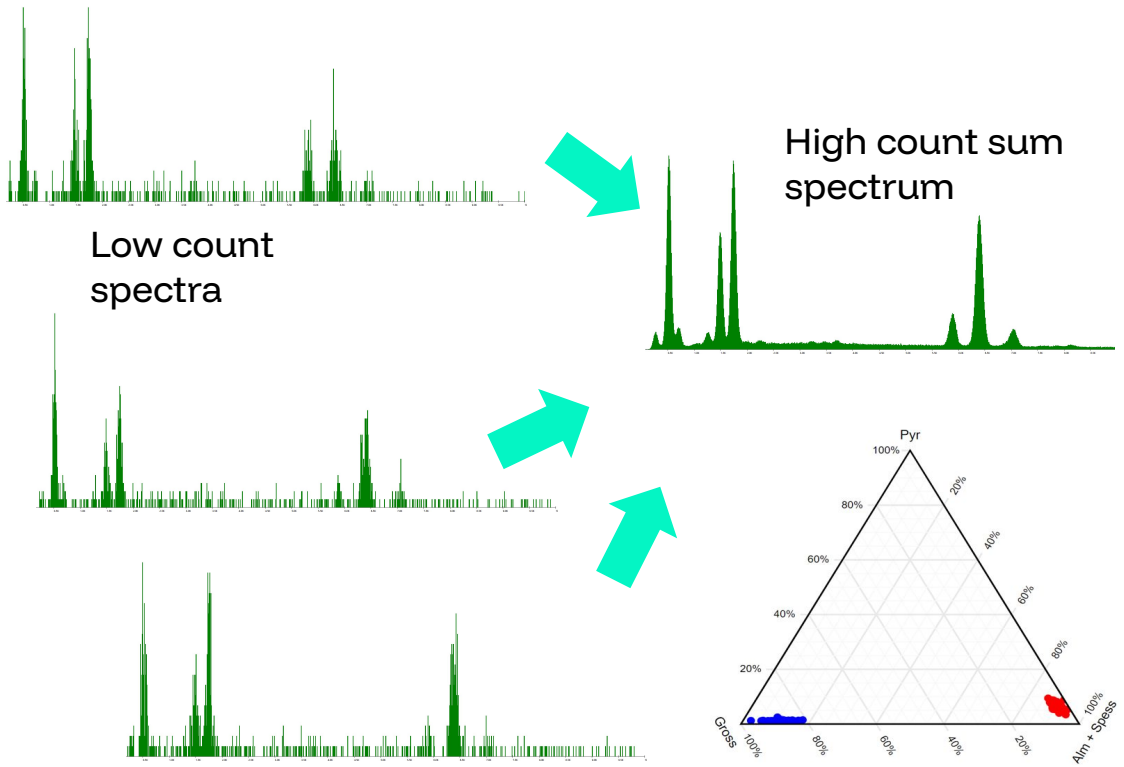
Garnet dominated phase map



Mn – elemental map

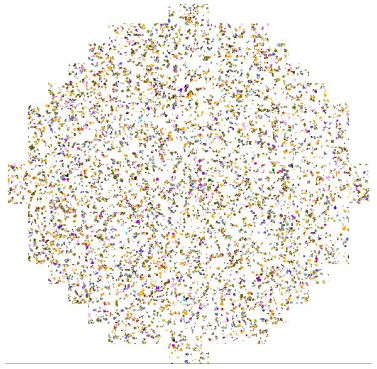
1 mm

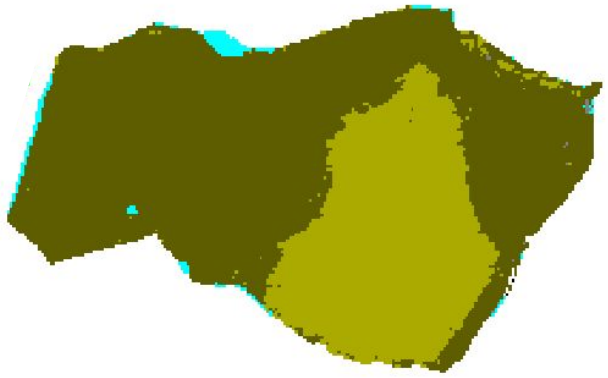
- Centroid vs high resolution mapping
- Segmentation merging low count spectra within mineral grain
- Better suitability for element quantification



Characterizing potential REE resource

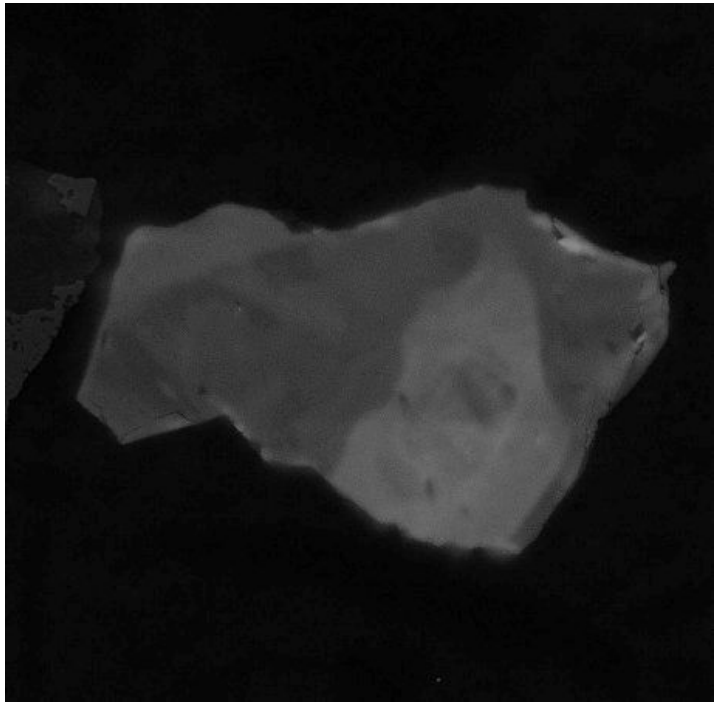
- REE hosted by two types of apatite, britholite, monazite etc.
- REE potentially hosted by other gangue phases as well (e.g. pyroxenes)
- Deliverables: grain size distribution, liberation degree, elemental deportment, bulk mineralogy





Phase map

BSE



Cathodoluminescence

How long will the analysis take?

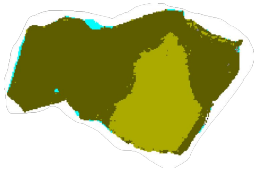
Lab capacity

Natural variables:

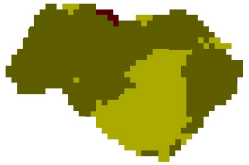
- Grain size distribution
- Mineralogy of the sample
- Content of target phase/element

Variables optimized:

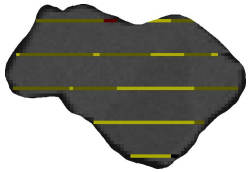
- Analytical modes (10+ options)
- Pixel spacing
- Number of counts
- Scanning speed
- Segmentation strictness
- Field size



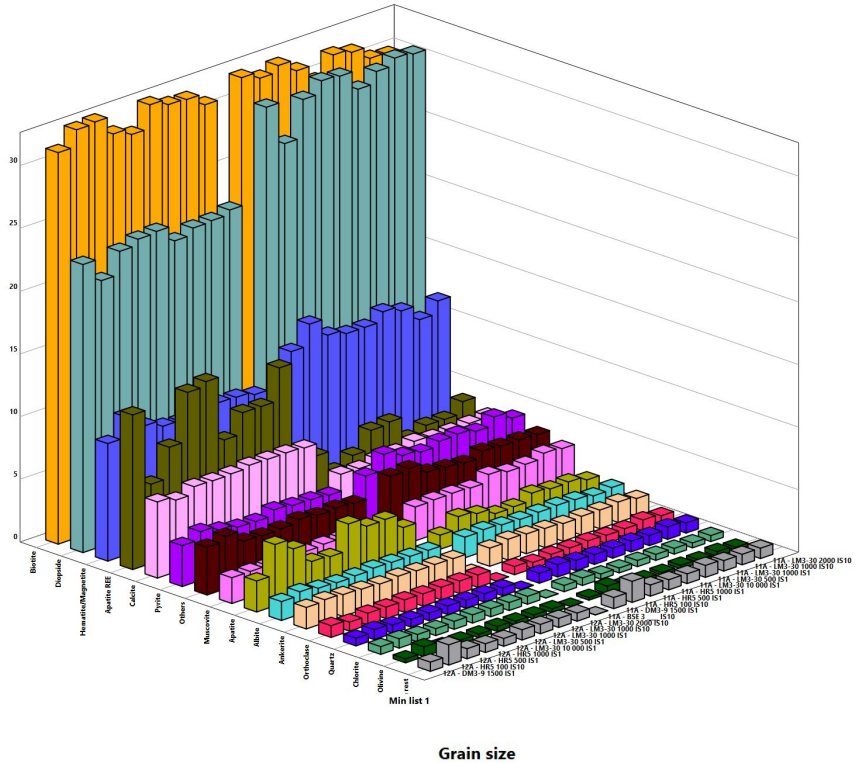
17 h



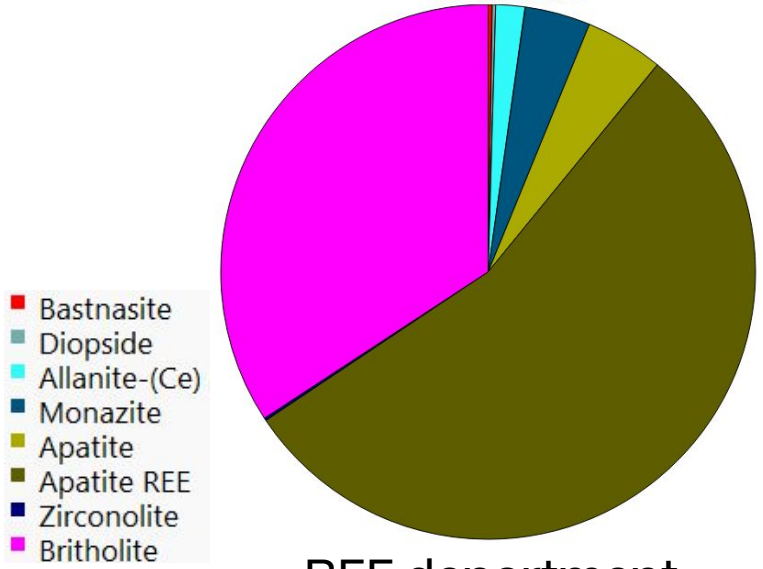
45 min



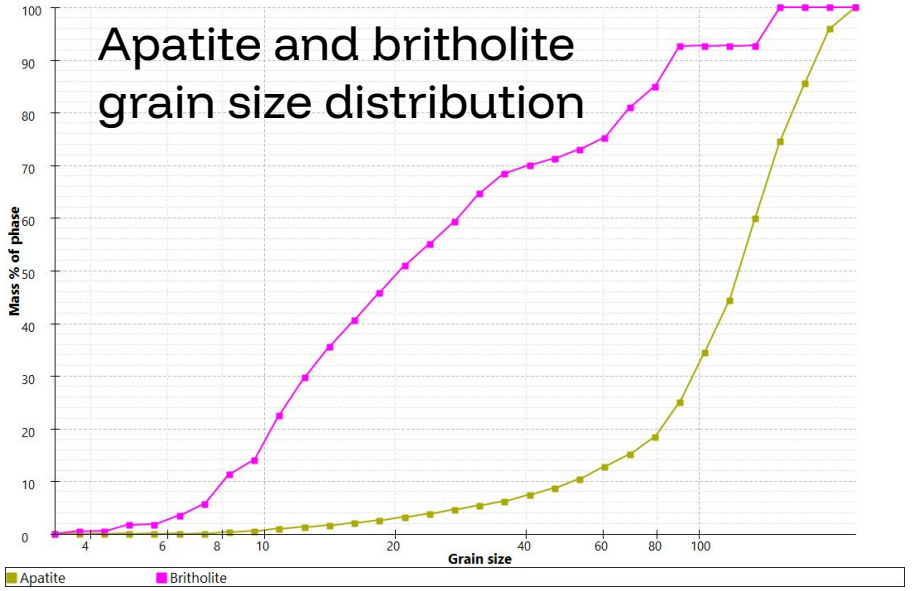
21 min



Grain size

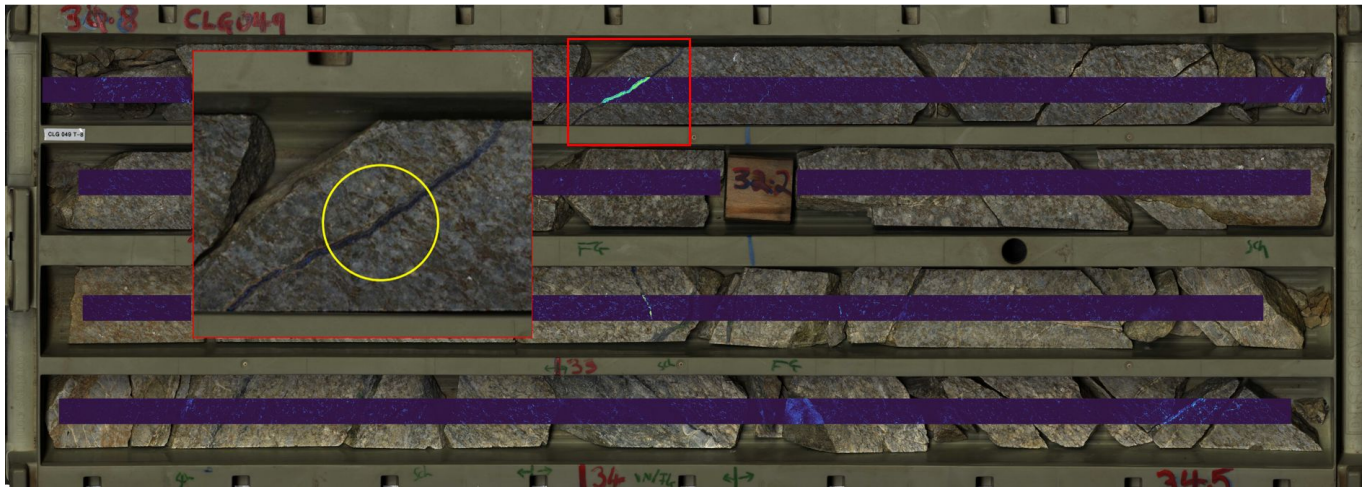


REE deportment

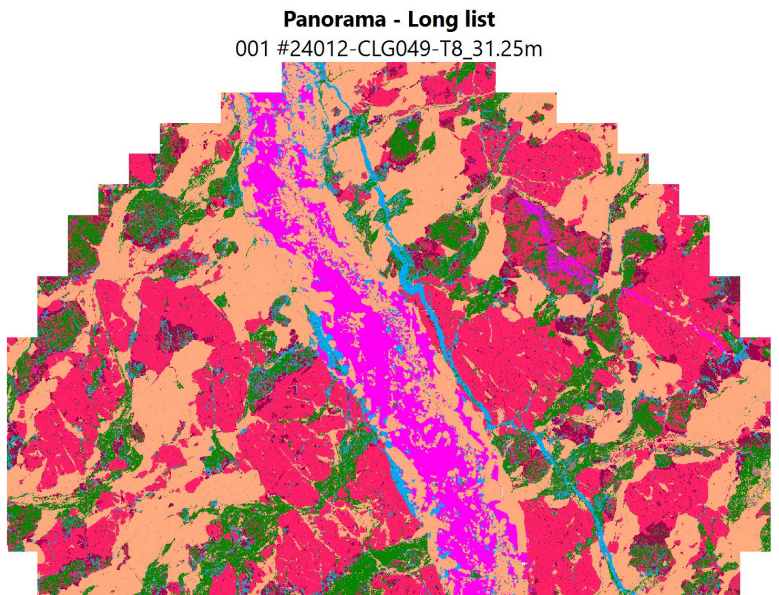


AM does not exist on its own

- Core scanning techniques help targeting mineralogical sampling
- AM helps covering blind spots of hyperspectral mapping or LIBS

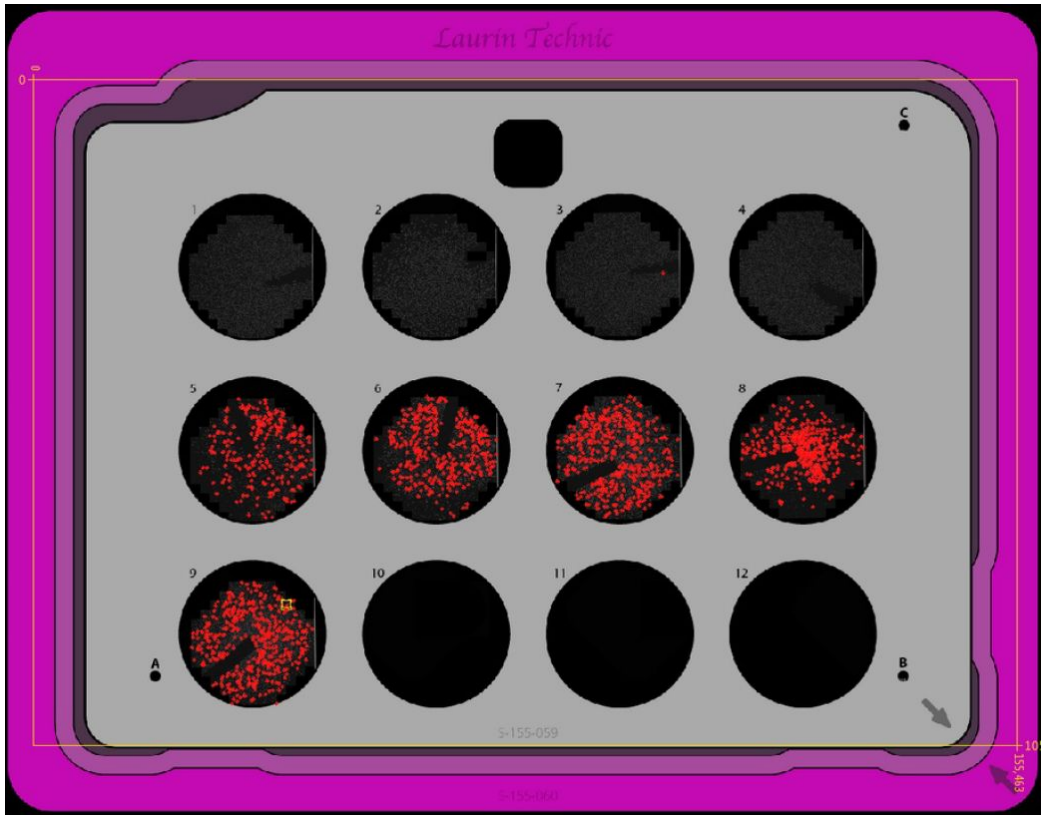


Core tray with overlaid LIBS distribution of Sb (courtesy of Automated Mineralogy Incubator, Australia).

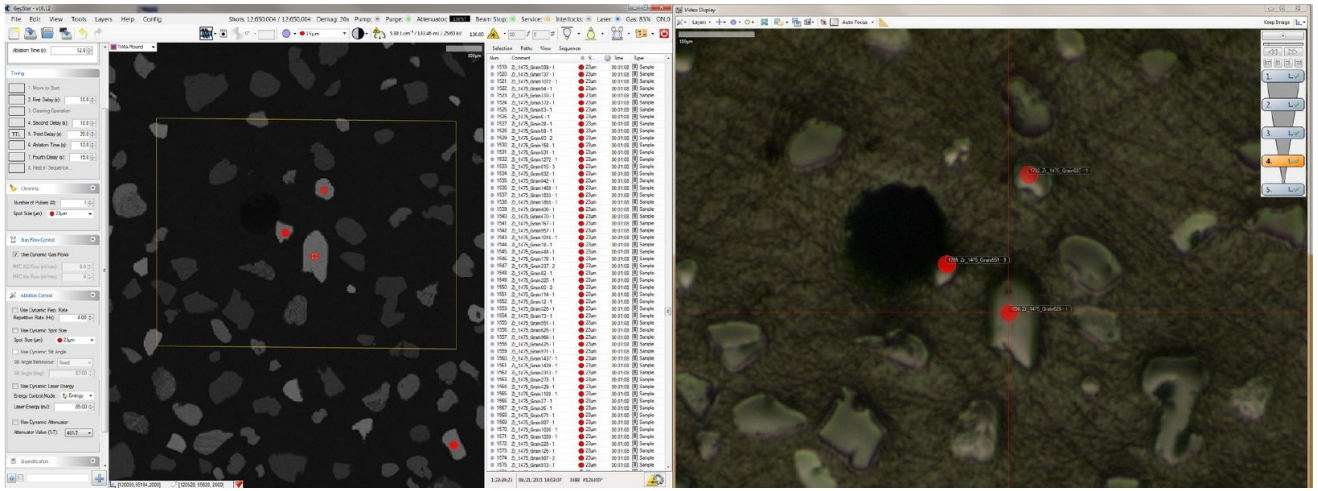


AM as a part of correlative workflows

- Delivering coordinates for more detailed methods



Screenshot of dedicated holder with sample overviews and coordinates selected for LA analysis (in red).



Summary

- SEM-based AM provides **highest lateral resolution** and **lowest phase detection limits**
- The only technique routinely used to address **mineral liberation, association and elemental deportment**
- There is always room for **measurement time optimization**, but texture of the samples has to be considered
- AM can **ease interpretation** of data from other techniques (e.g. LIBS)
- **Coordinate export** can make subsequent application of other microanalytical techniques more efficient

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Accelerating the Art of Discovery

Automated Mineralogy as a part of geometallurgical test programs

Thank you