Advanced Automated Mineralogical and Petrological Analysis

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ZEISS Mineralogic Global Presence - Mining
Focus commodities Fe – Cu – Mo – Zn – Ag – Au – Ni – P – Coltan – Qz – O&G – Steel

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ZEISS

BGR

LULEÅ UNIVERSITY OF TECHNOLOGY

NORGES GEOLOGISKE UNDERSØKELSE - NGU -

National Mineral Development Corporation (NMDC)
राष्ट्रीय खनिज विकास निगम में 'अपरेंटिस' के पदों पर भर्ती

BCSIR

Freie Universität Berlin

THE UNIVERSITY OF UTAH

BGS British Geological Survey

GEUS Geological society of Denmark and Greenland

NTNU Norwegian University of Science and Technology

Universiteit Utrecht

LIÈGE université

Council for Geoscience

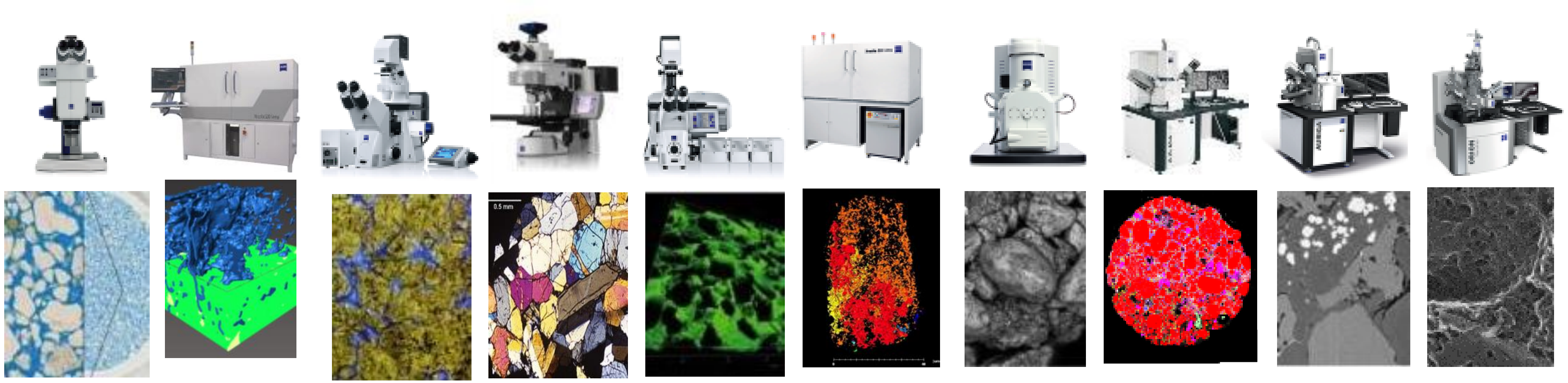
ENERGI DAN SUMBER DAYA MINERAL

UNIVERSITY OF LEICESTER

Durham University

Advanced Geoscience Research spans multiple length scales and requires a Connected Microscopy

Correlation, Contextual & Quantitative
Multi-modal, Multi-scale, Multi-microscope



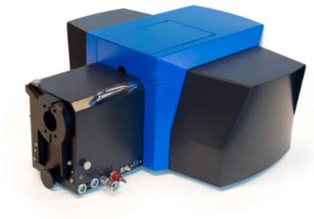
Stereo	X-ray	Widefield	Polarized	Confocal	X-ray	Scanning Electron	Automated Mineralogy	Focused Ion Beam	Helium Ion
1 µm	700 nm	250 nm	200 nm	200 nm	< 50 nm	< 2 nm	< 2 nm	< 1 nm	< 0.5 nm

EM in Geosciences

Imaging and quantitative analysis, flexible detector solutions

Petrologist toolbox

Imaging, chemical and structural analysis

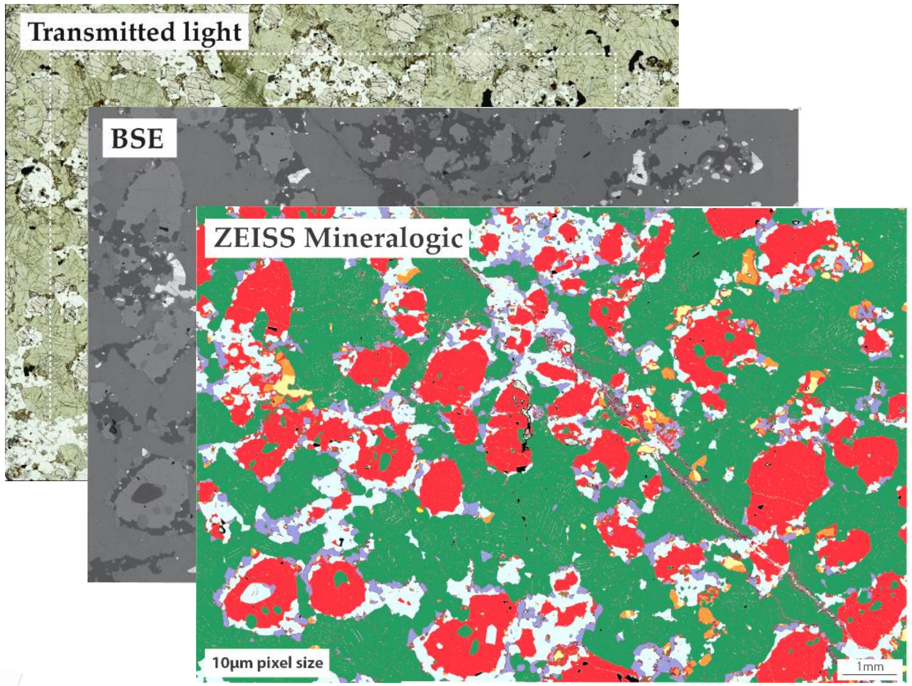


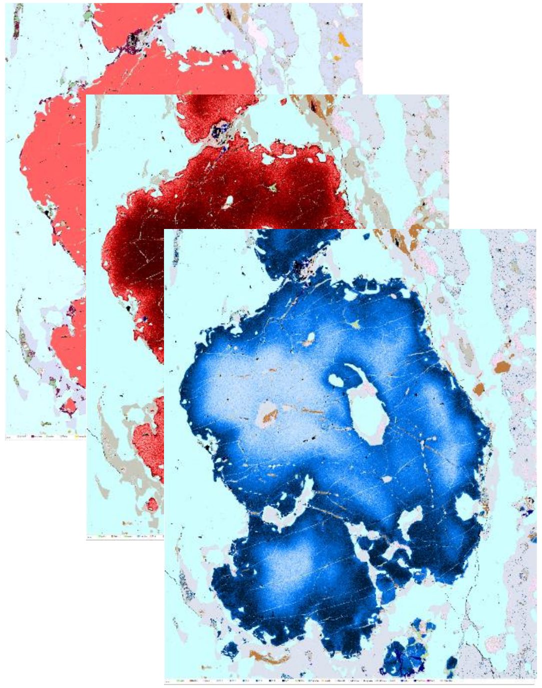
CL

WDS

EBSD

Mineralogic



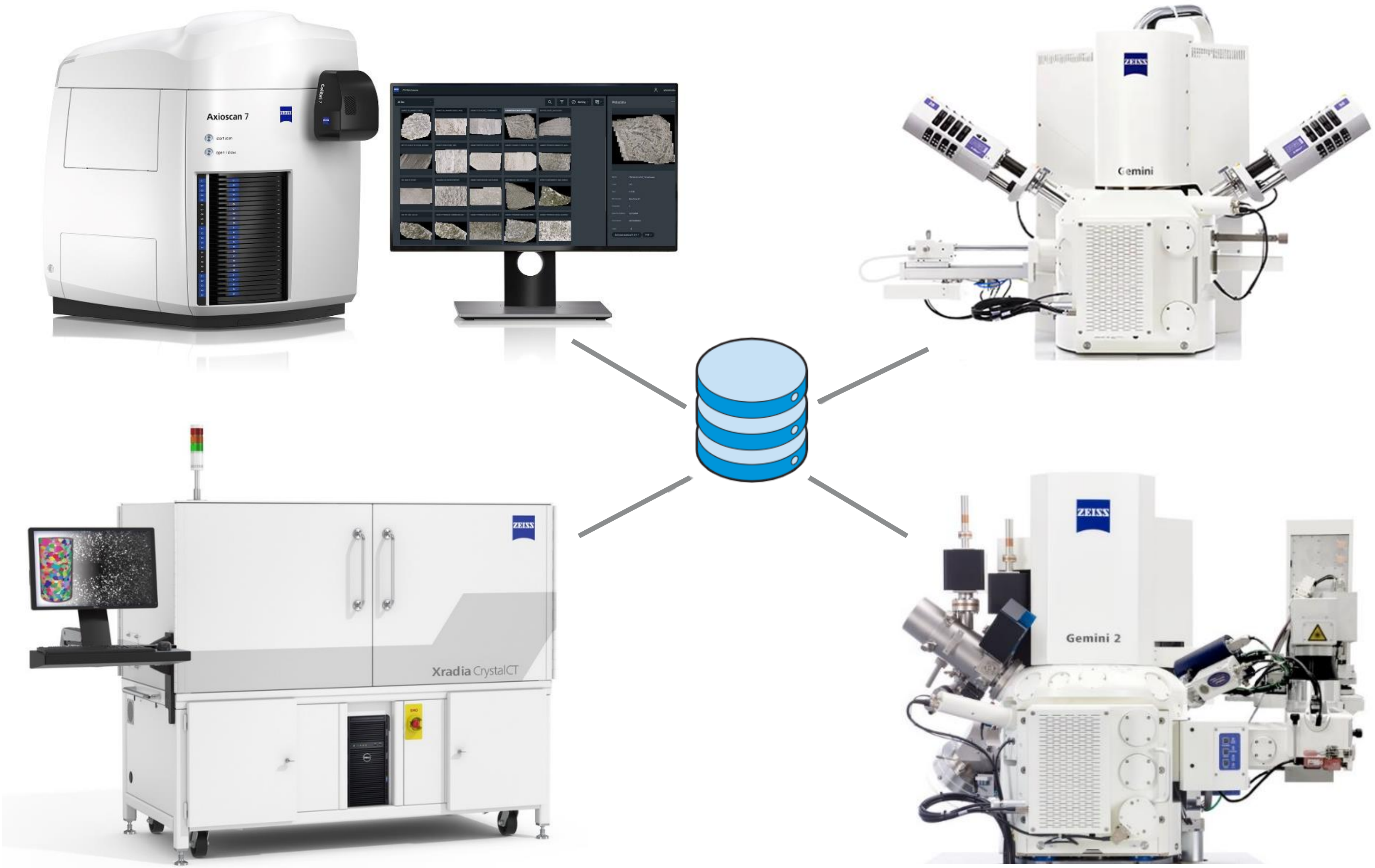


Automated mineralogy

Quantitative geochemistry

Flexible platform

Correlative Microscopy at ZEISS



2 key points

1. Class leading instruments

2. Correlation makes data greater than the sum of its parts!

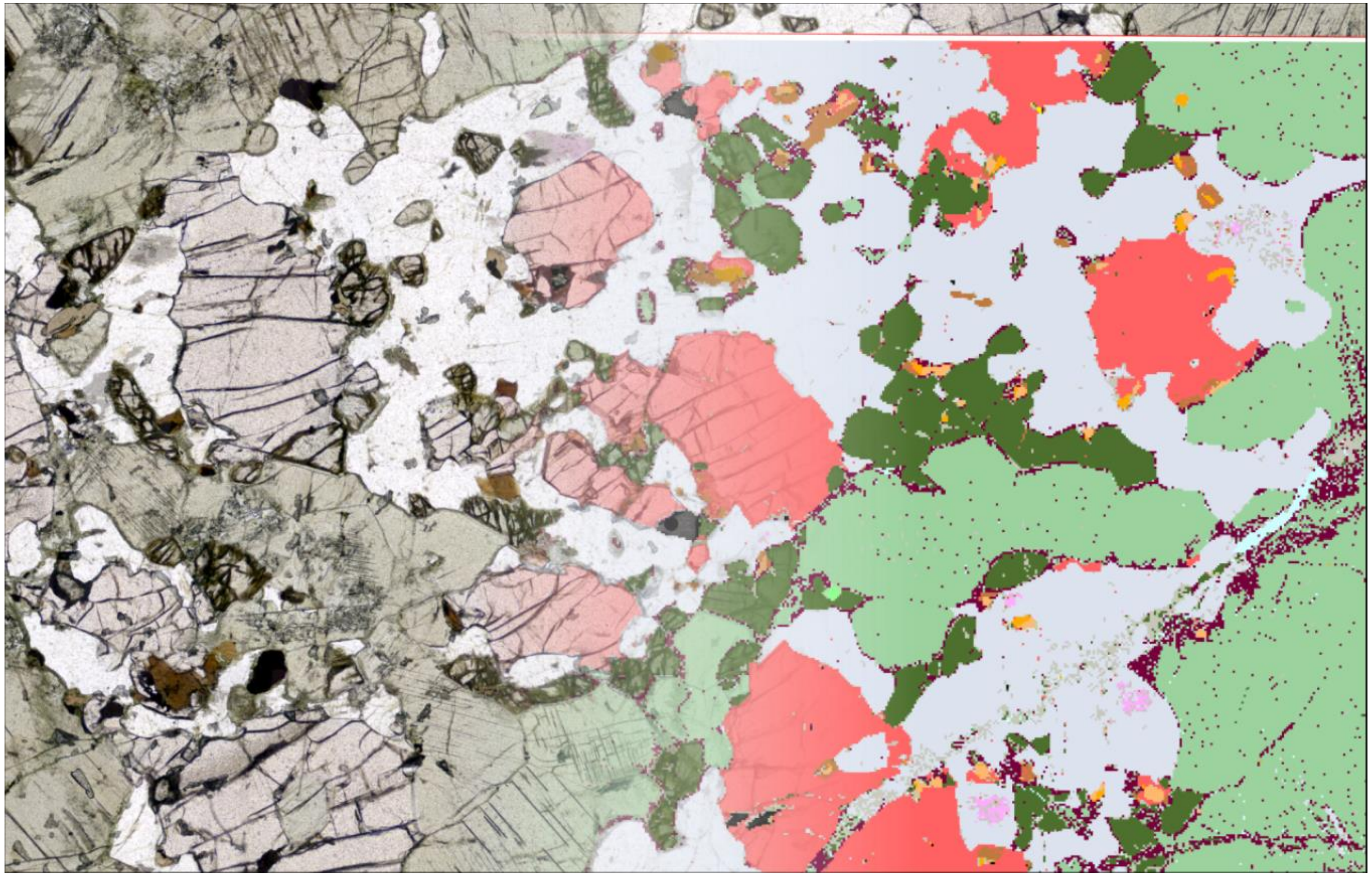
Correlating Chemistry With Optical Mineralogy

Optical microscopy is:

- Familiar
- Fast
- Combined with machine learning provides a new level of understanding

Electron microscopy is:

- Automated
- Detailed
- High resolution mineralogy
- Provides chemical as well as morphological information

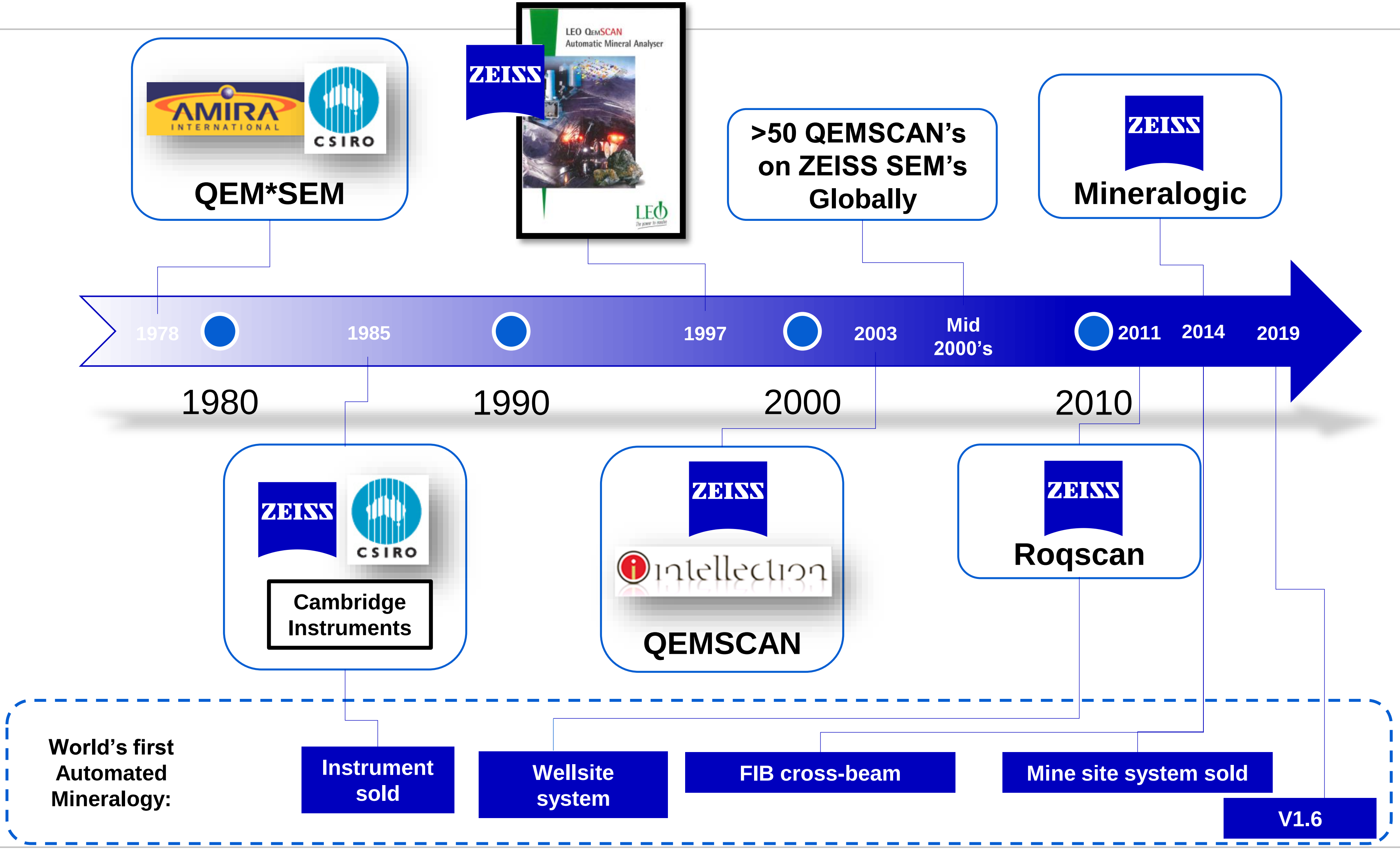


Correlate LM + EM for enhanced mineralogical understanding

Supported Platforms

- Available on:
  - Sigma 300 and 500
  - EVO
  - GeminiSEM 360/460/560
- No restrictions on accessories or available detectors other than those imposed by the configurator
- 1 or 2 EDS up to 100mm^2

ZEISS, Automated Mineralogy and Mineralogic
An Introduction & History



What is Automated Mineralogy (AM)

Specific outputs with a long history

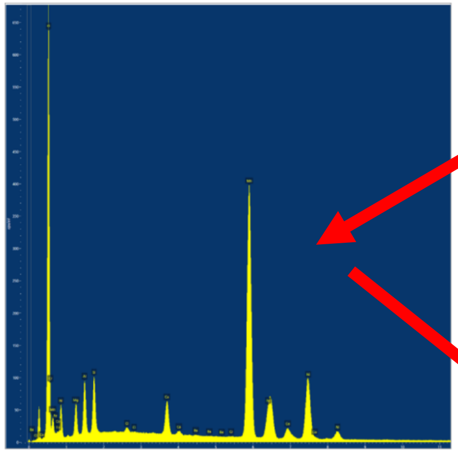
Automated Mineralogy serves two parallel purposes that must operate in tandem

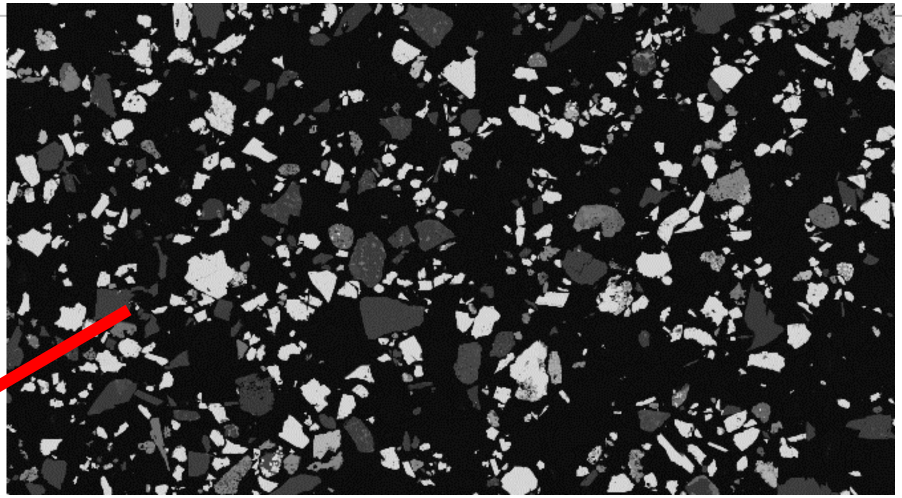
Quantitative textural analysis

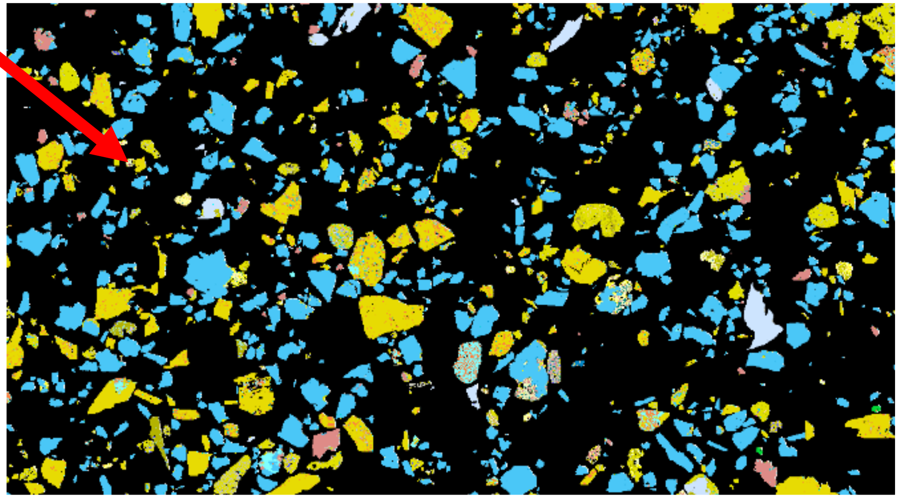
- Image based
- Grain shapes/morphology
- Grain sizes
- Liberation
- Locking
- Associations

Phase ID

- Apply mineral labels to textures
- You have to know who is who!







Strengths

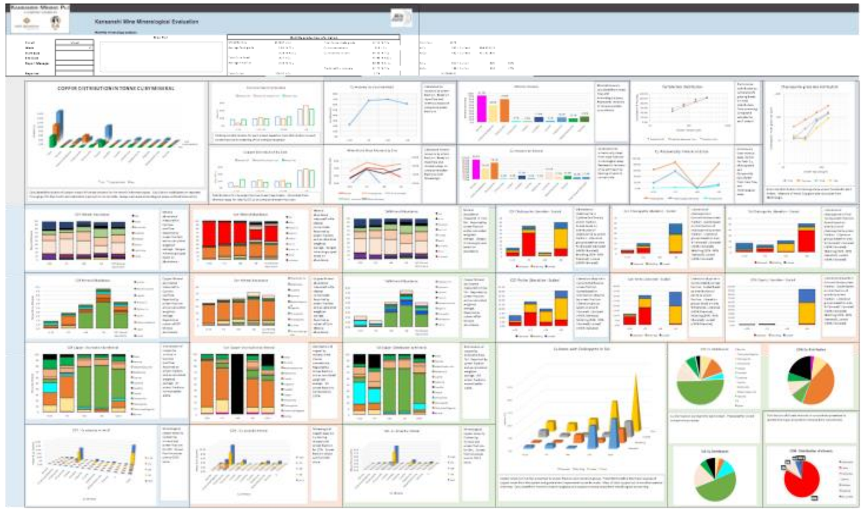
- It's fast! It works!

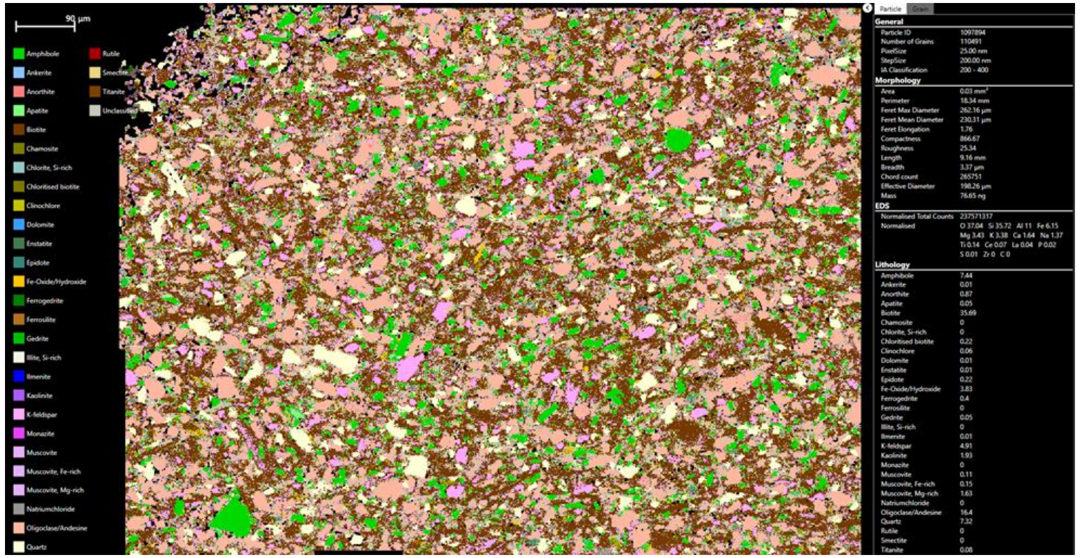
Weaknesses

- Complex black box approach
- Non-transferrable

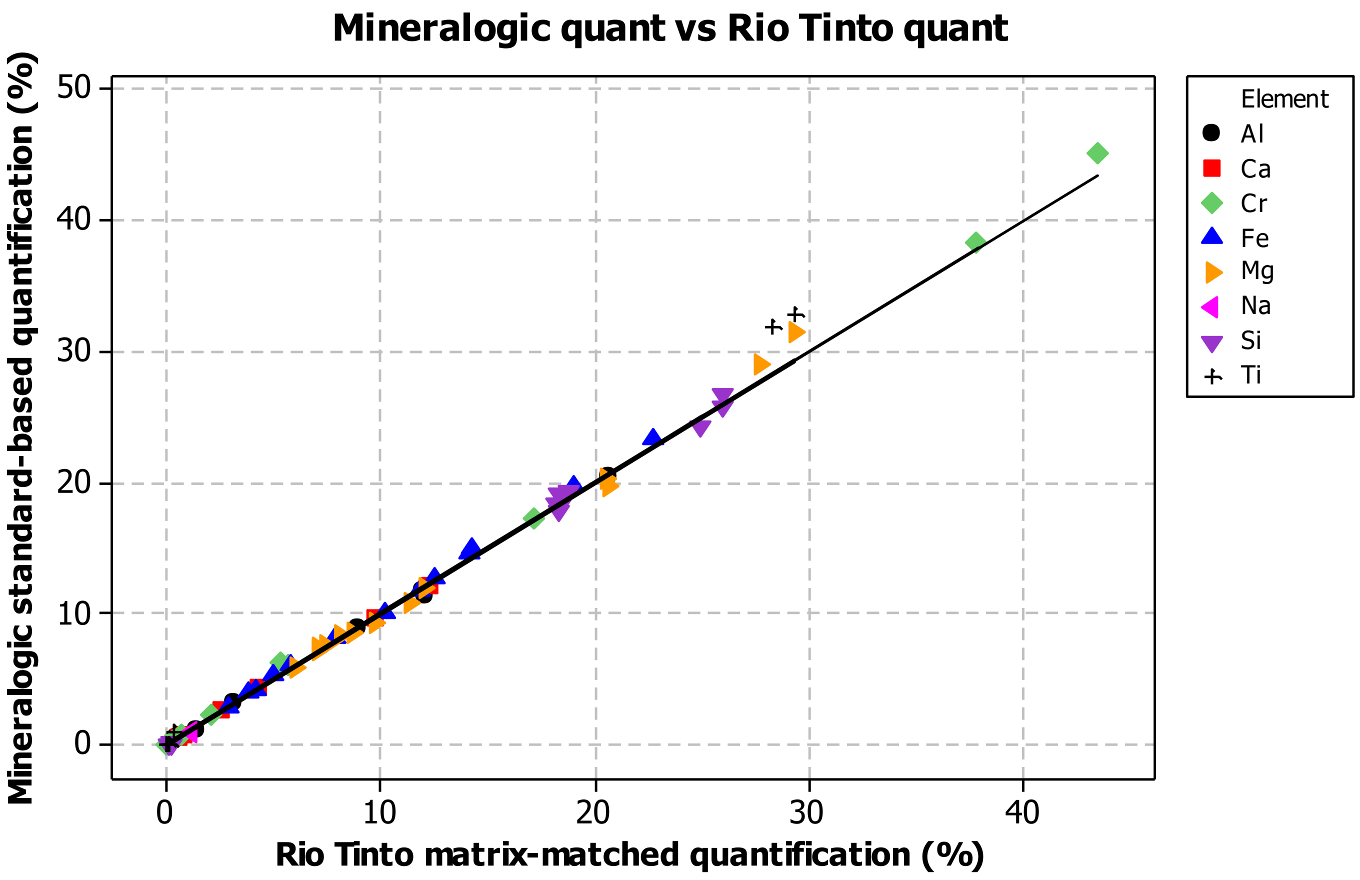
Mineralogic Automated Quantitative Mineralogy

- **Bulk Chemistry to 1000ppm without the need for XRF nor EMP**
- **From nm to cm imaging and analytical resolution**
- **Mineralogy**
- **Grain morphology, including density and mass**
- **Chemical Assay**
- **Element Deportment**
- **Mineral Associations**
- **Liberation**
- **Acid Consuming Gangue Deportment**
- **Soluble Vs Insoluble Mineral Distribution**
- **Theoretical Grade Recovery Curve**
- **Environmentally Toxic Mineral Deportment**





Analyses With Energy or With Standards Calibration



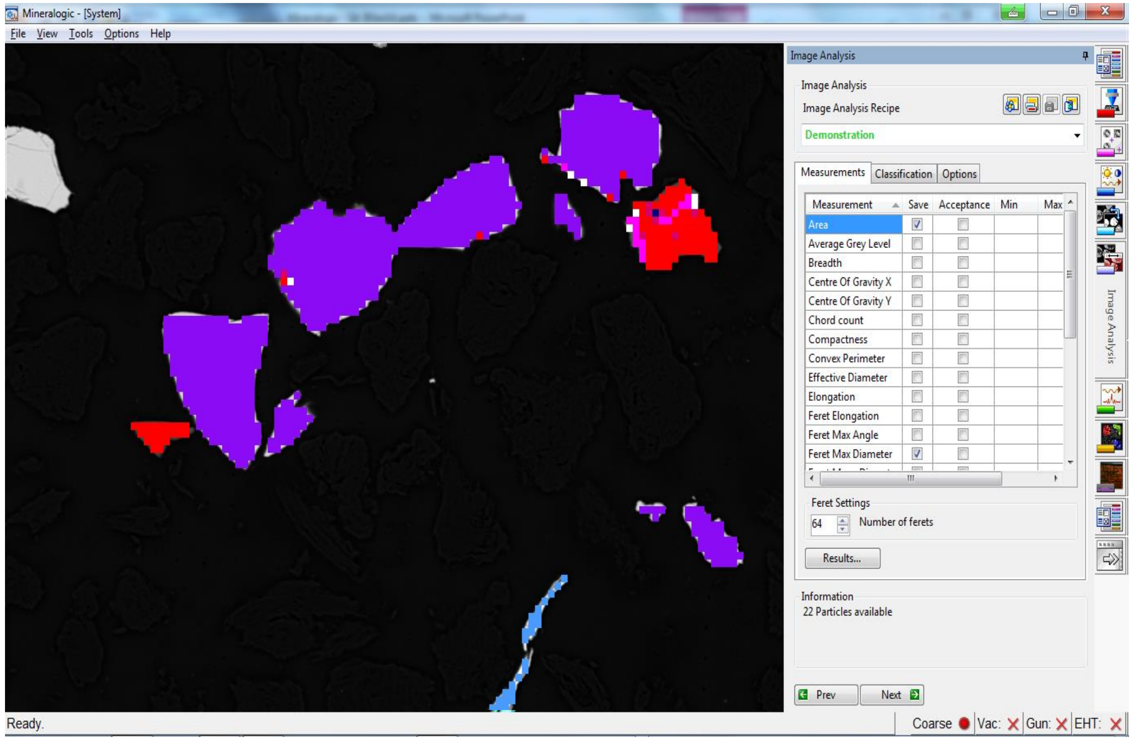
ZEISS Mineralogic 2D
A short demo

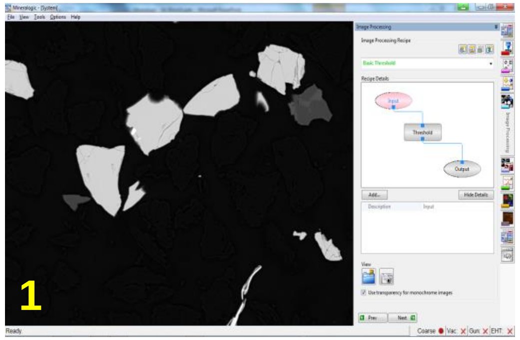
1. **Input image**

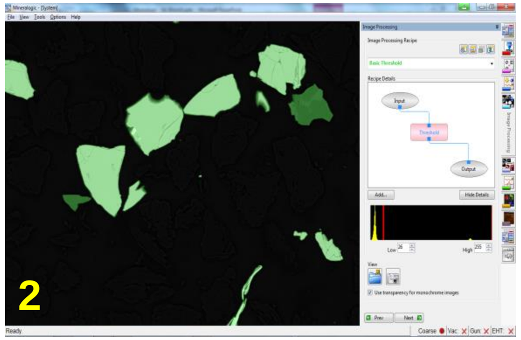
2. **Identify areas of interest to measure**

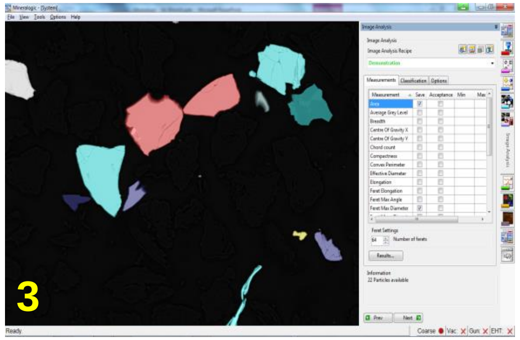
3. **Image Analysis**

4. **EDX Quantification & Classification**





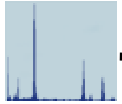




Key Mineral Classification Features

Mineral Classification Options

- Quantitative EDS – classification is independent of the system being used and is solely based on stoichiometry.

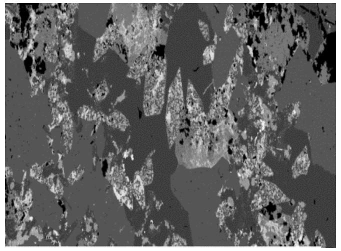
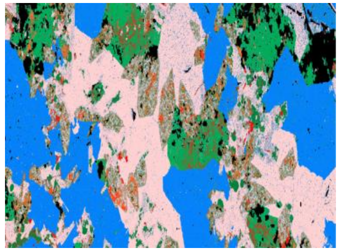
 → Cu:Fe:S = 35:30:35 wt% (chalcopyrite)

- Elemental ratios – as the system quantifies, mineral classification can be further discriminated by relative abundances of elements.

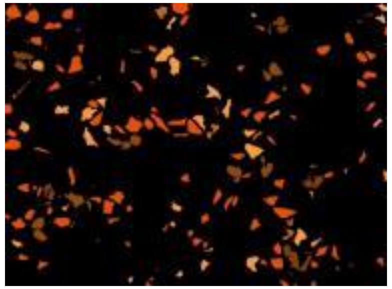
$\frac{As}{Sb}>1$ enargite

$\frac{Sb}{As}>1$ famatinite

- BSD greyscale – the ultra high contrast backscatter detector from ZEISS enables discrimination of minerals with a Δa.m.u. ~ 0.07.

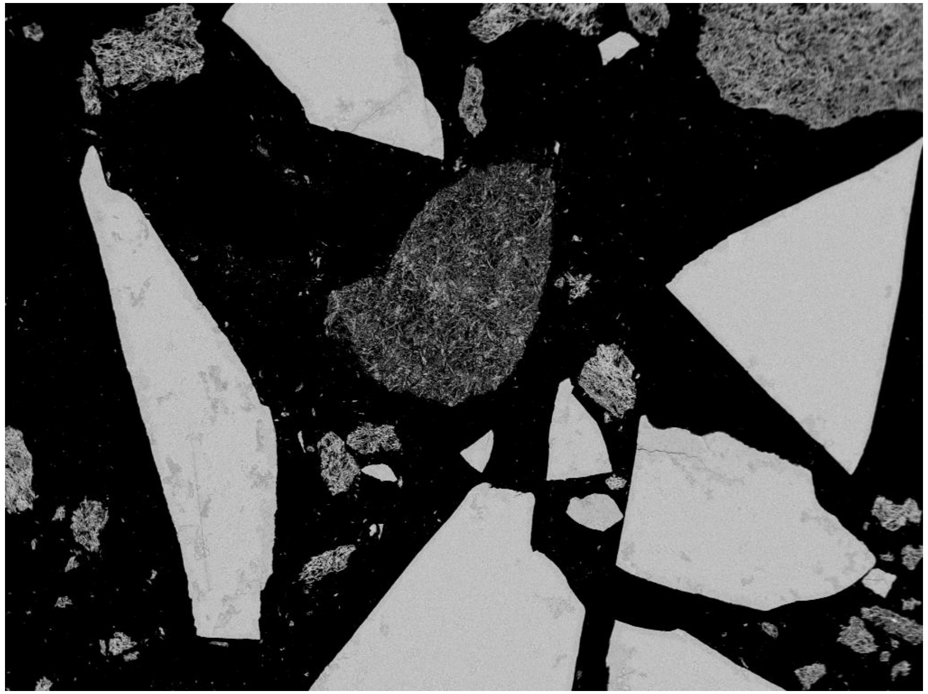
 → 

- Morphology – mineral shape characteristics can be included in the classification for ultimate mineral discrimination.

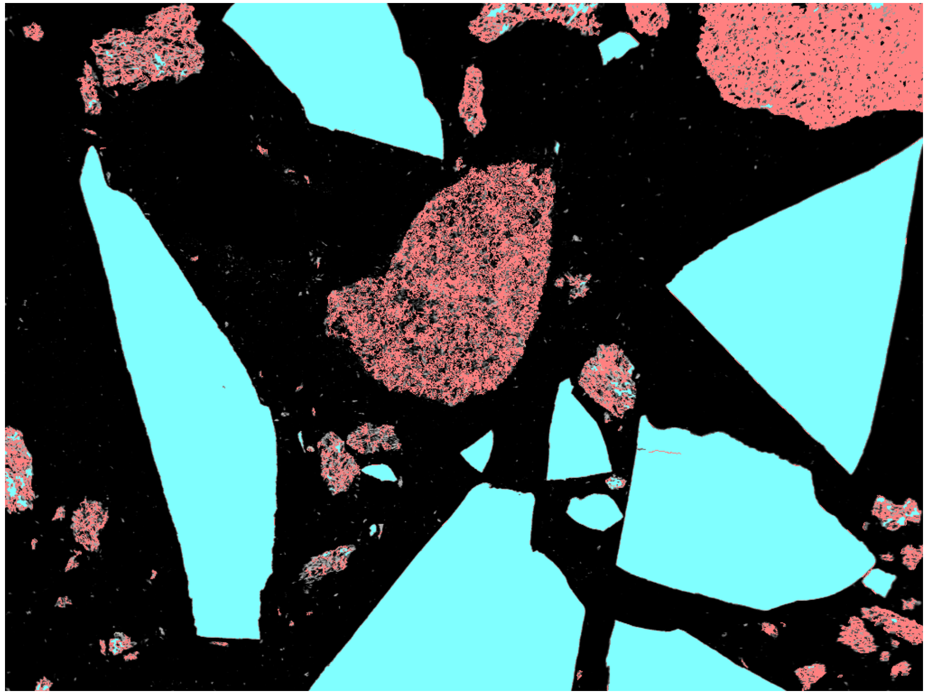


Automated Morphochemical Classification
Create classifiers using morphology and chemistry

Backscattered Electron Image



"Mineralogic" Classified Image



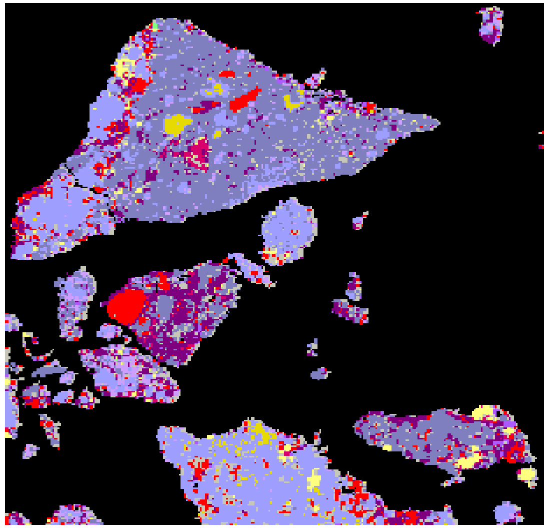
Vitreous Goethite

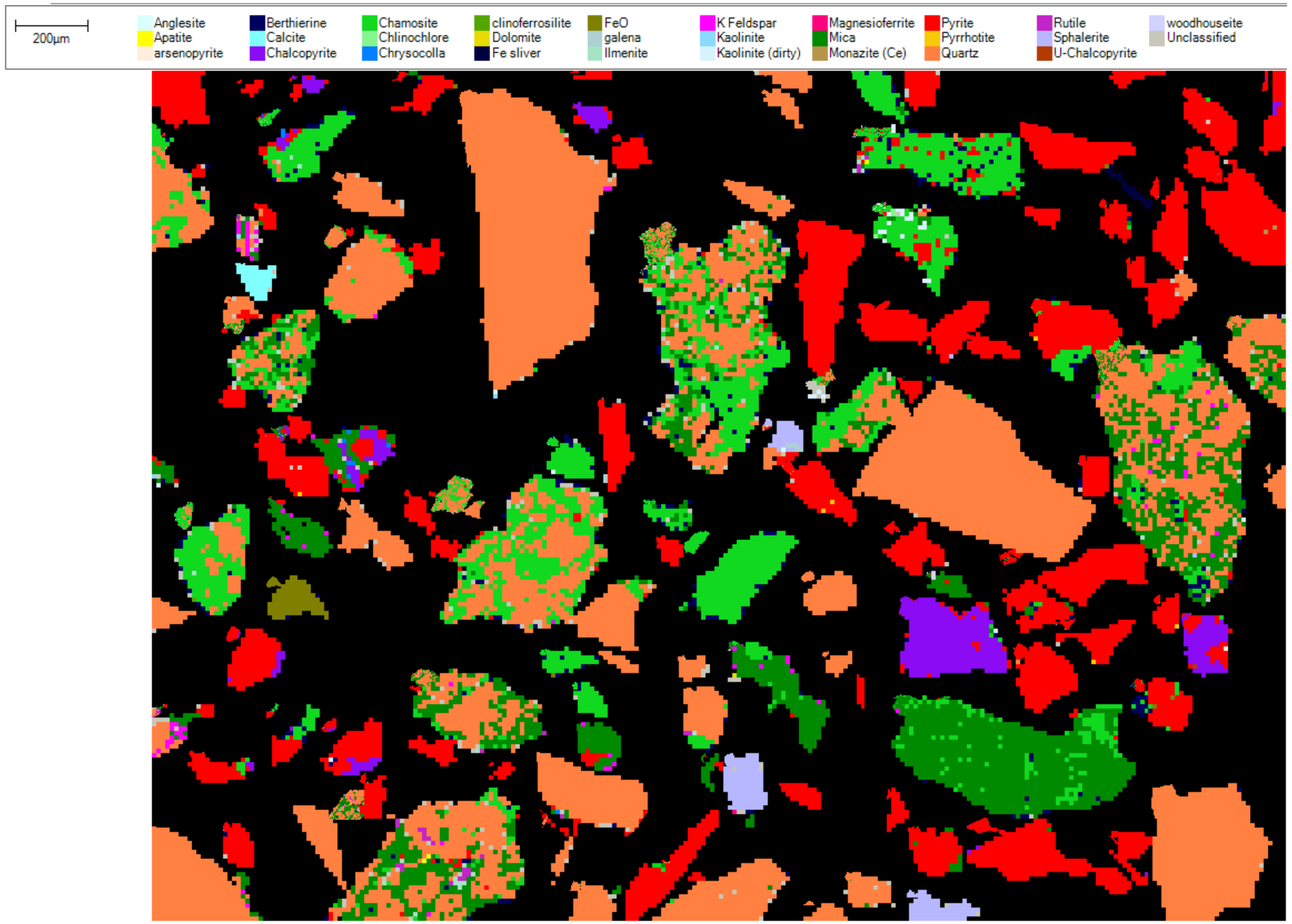
Ochreous Goethite

Analysis Modes
Mapping

Full Mapping

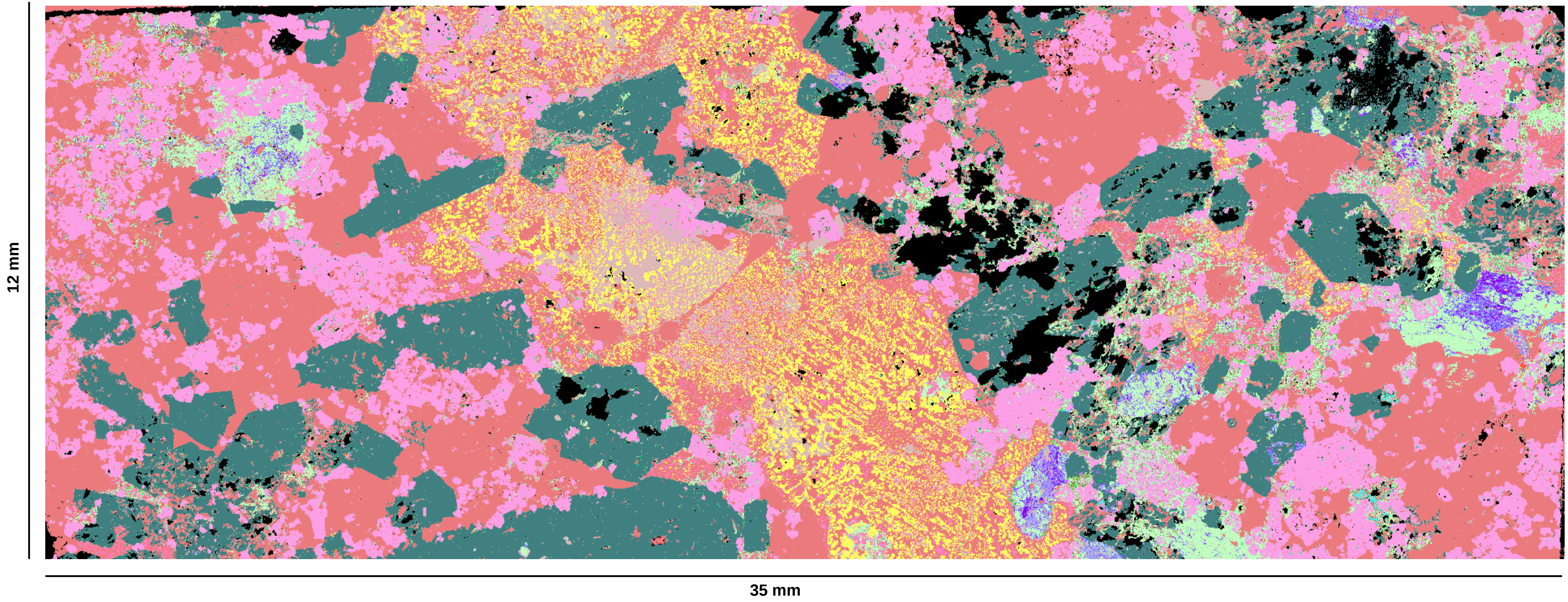
Place a grid over the entire sample and perform quantitative EDX at each point. Assign mineralogy to a pixel of a user defined size (down to nanometre scale)





Grains are classified by their chemical composition with each colour representing a distinct phase and each pixel an analysed point

Analysis Modes
Mapping



- Highest resolution
- Pixel by pixel chemical analysis and classification
- Illuminate chemical zonations and transitions

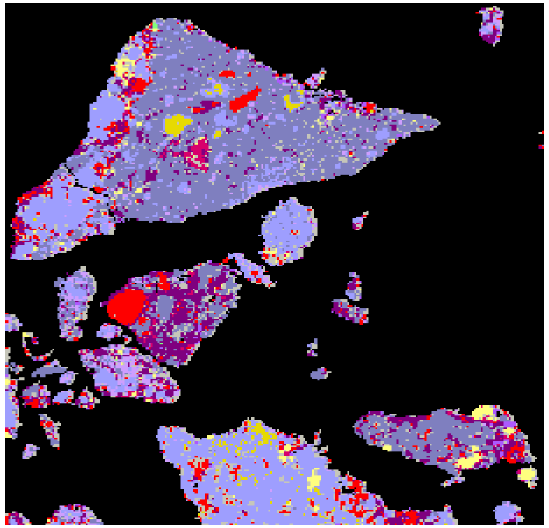
Analysis Modes
Spot centroid

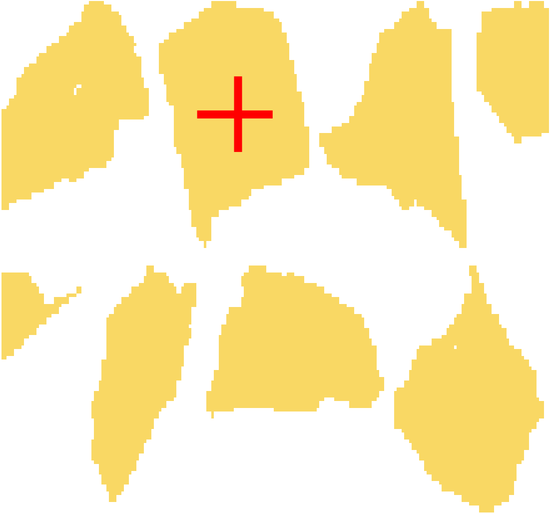
Full Mapping

Place a grid over the entire sample and perform quantitative EDX at each point. Assign mineralogy to a pixel of a user defined size (down to nanometre scale)

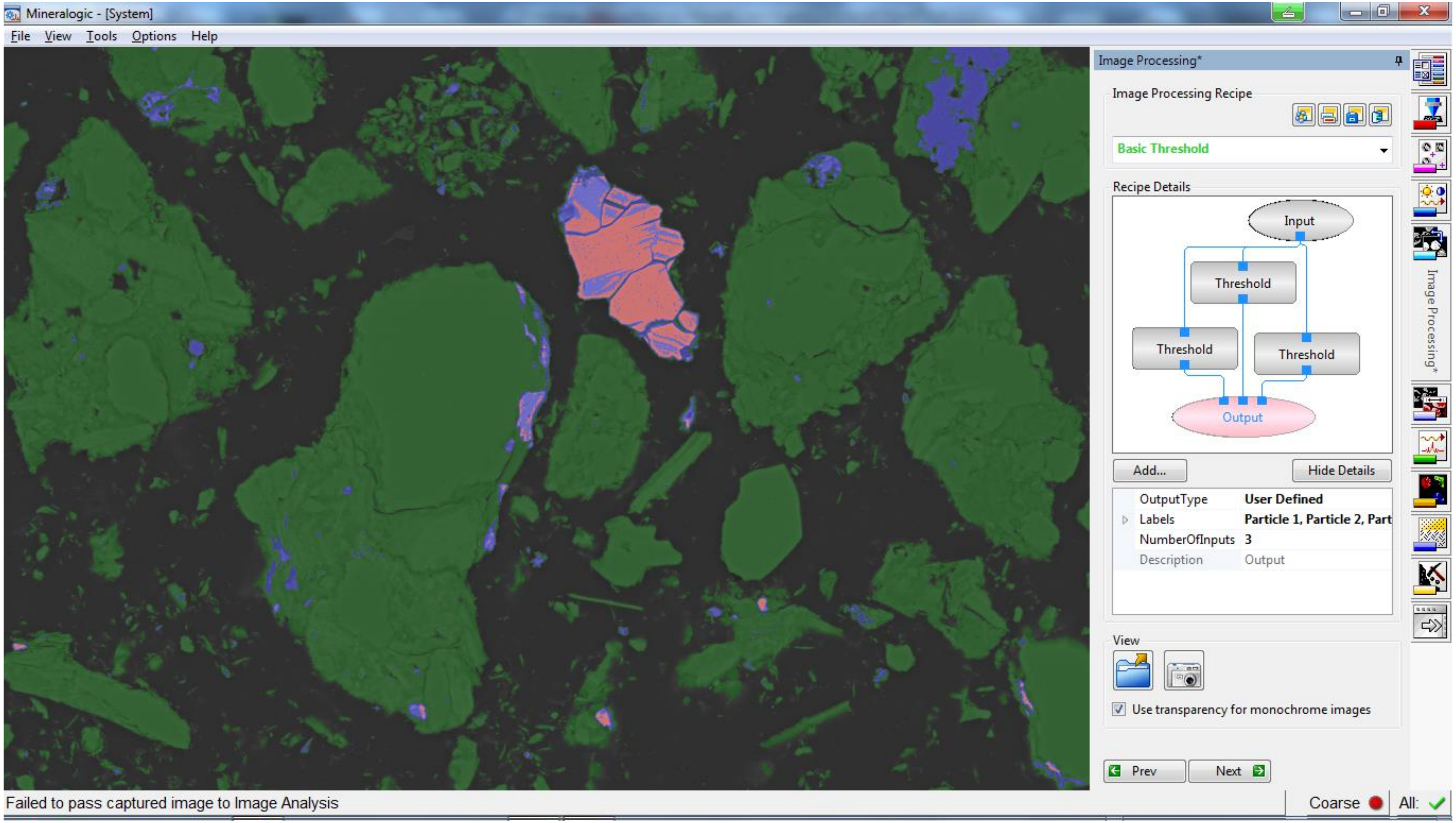
Spot Centroid Analysis

Quantitative EDX analysis at the geometric centre of the grain. Assign the mineralogy measured at the centre to the entire grain.



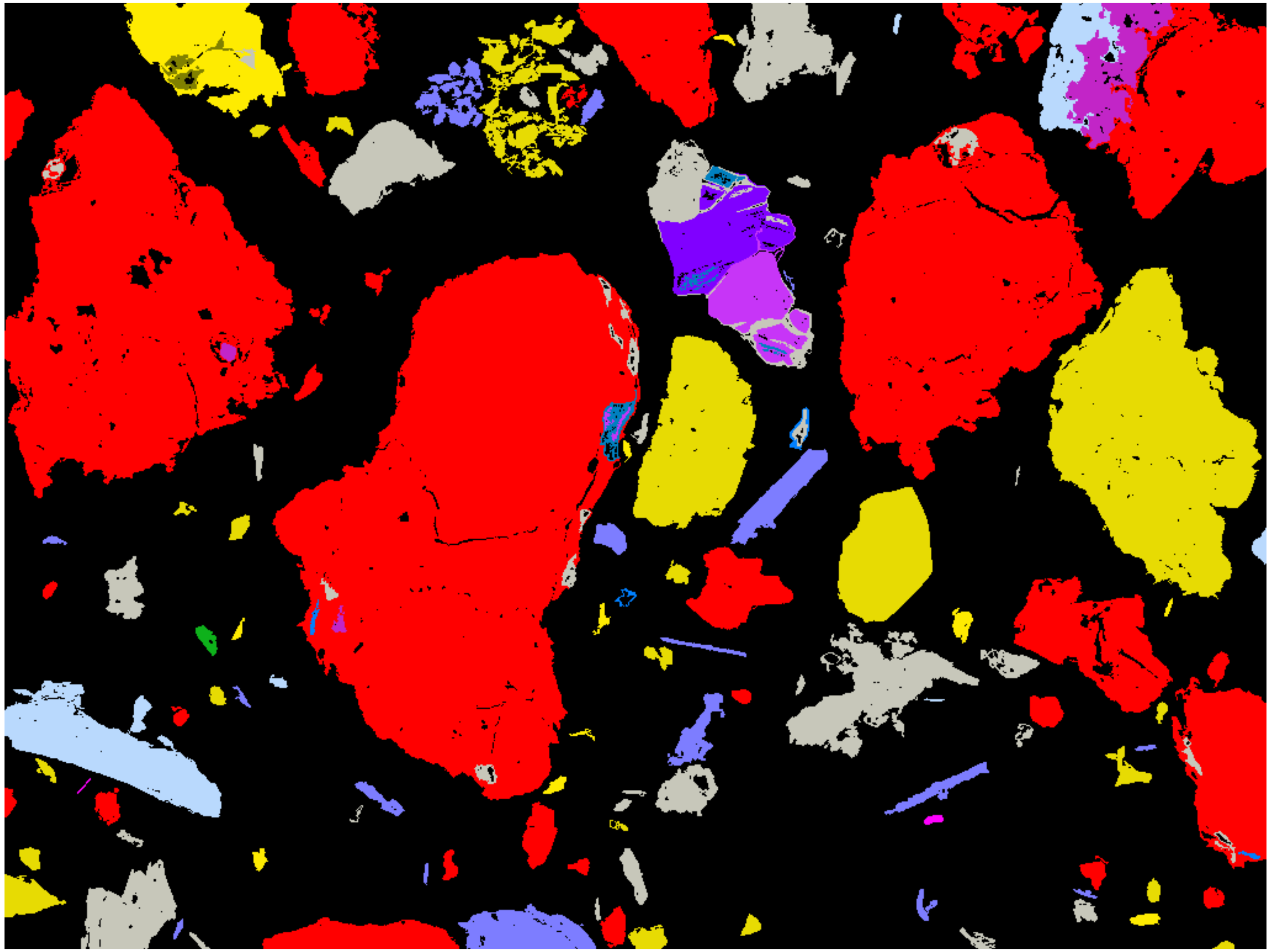


Analysis Modes
Spot centroid improved analysis with image processing



Analysis Modes
Spot centroid

- **Fast and efficient**
- **One composition assigned to particle**
- **Image processing allows analysis of grains**



Analysis Modes
BSE

Full Mapping

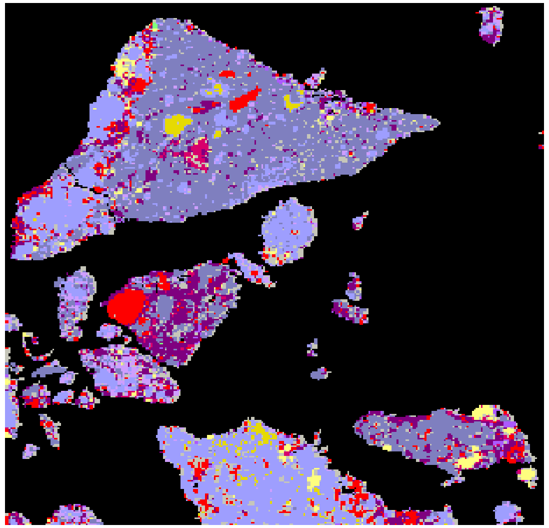
Place a grid over the entire sample and perform quantitative EDX at each point. Assign mineralogy to a pixel of a user defined size (down to nanometre scale)

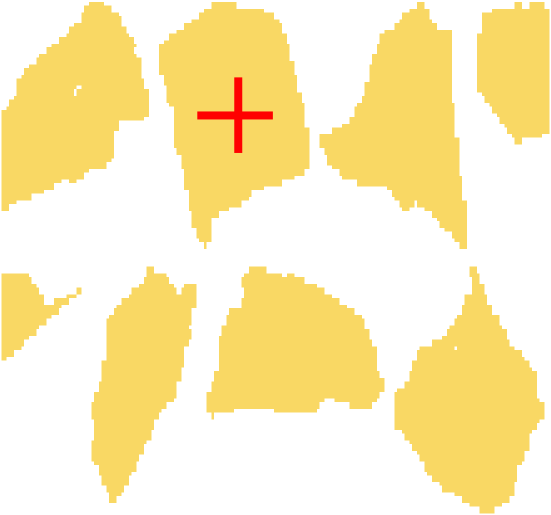
Spot Centroid Analysis

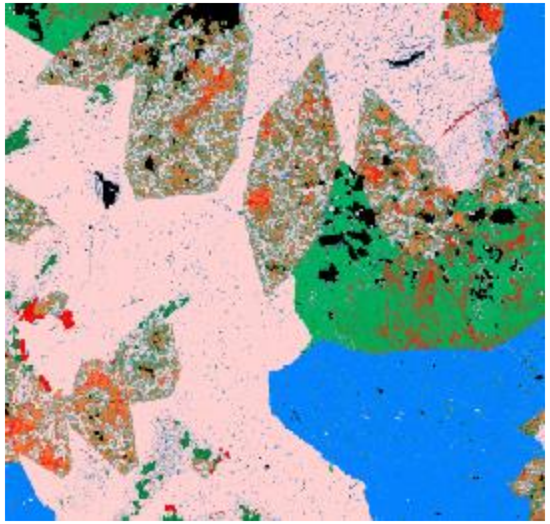
Quantitative EDX analysis at the geometric centre of the grain. Assign the mineralogy measured at the centre to the entire grain.

BSE

- Use BSE brightness to classify minerals
- Very fast, no need for EDX
- Resolution of BSE imaging

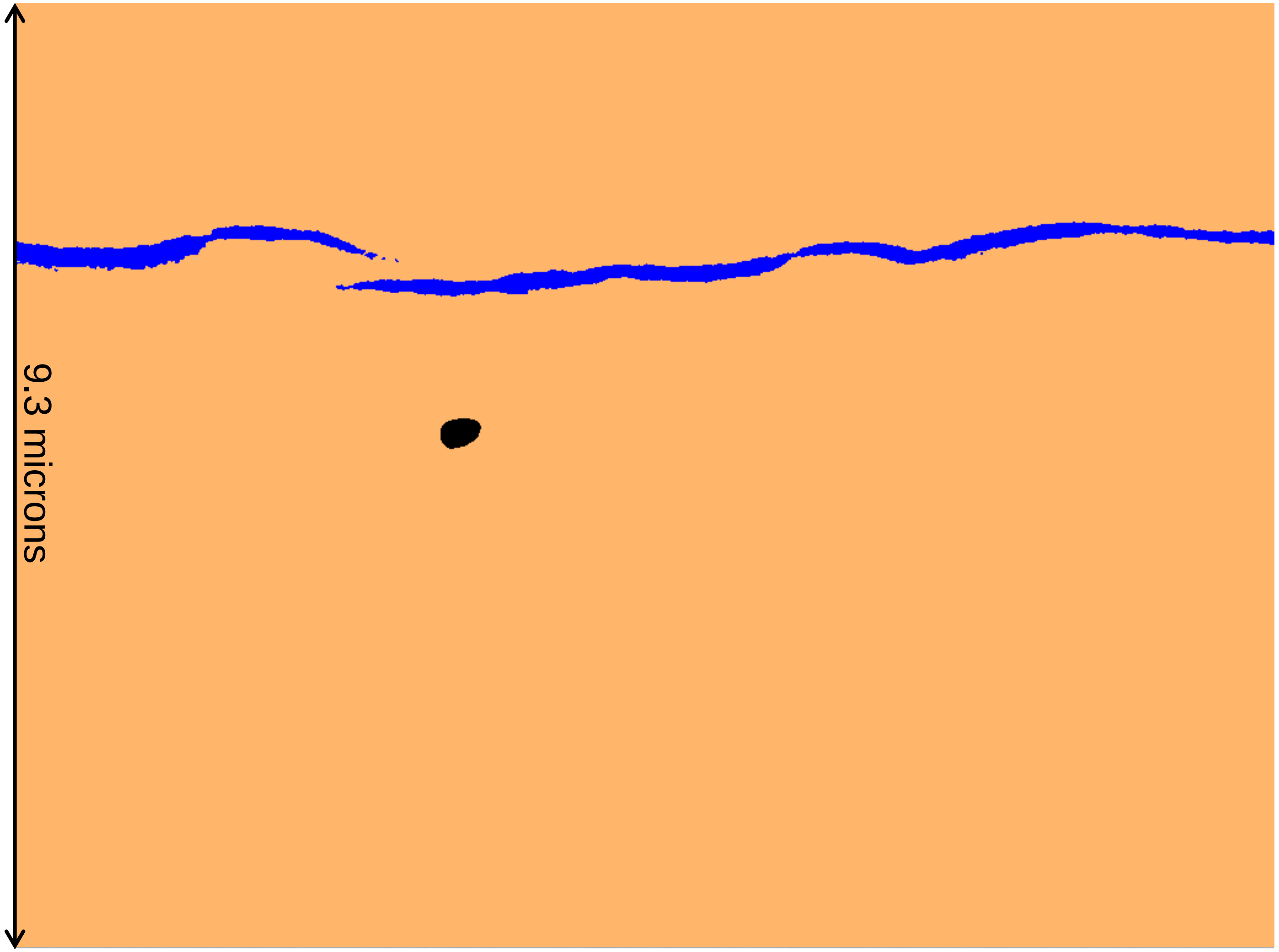




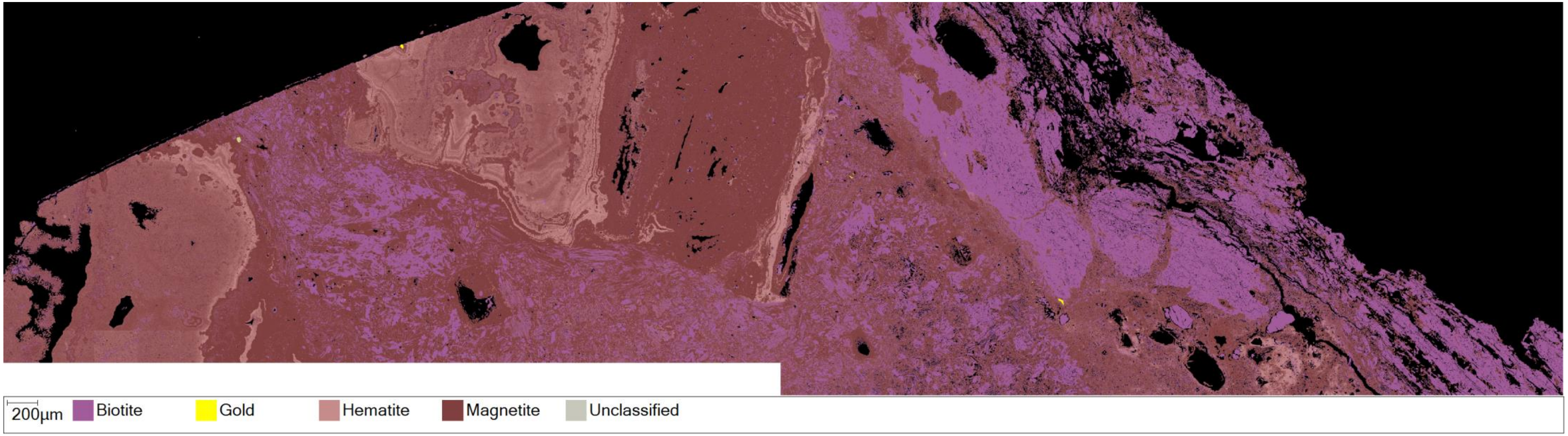


Analysis Modes
BSE

- **Analysis and classification at image resolution**
- **Fastest analysis mode per data provided**
- **Improved BSD offers image capture at 220ms per frame**



Analysis Modes
BSE



- **Easy discrimination between hematite and magnetite by BSE grey level**
- **No need to stretch BSE histogram**
- **Bulk mineralogy results at the speed of imaging**

Analysis Modes
Line scan

Full Mapping

Place a grid over the entire sample and perform Standards Based and Standardless EDX at each point. Assign mineralogy to a pixel of a user defined size (down to nanometre scale)

Spot Centroid Analysis

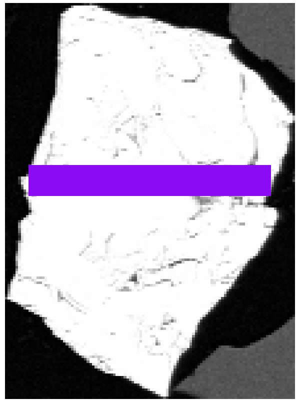
Standards Based and Standardless EDX analysis at the geometric centre of the grain. Assign the mineralogy measured at the centre to the entire grain.

BSE Only

BSE analysis is designed to be a quick analysis whereby minerals are classified on their BSE grey level. Precious metals (Au, Pt, Pd etc.) have a high BSE (Z value) coefficient.

Line Scan

A line is drawn across the centre of the particles where an analysis is carried out. Designed to gather a fast idea of the bulk mineralogy of the sample



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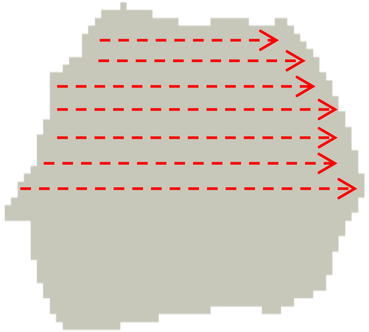
Feature Scan

The beam is rastered over a mineral grain and the resulting EDX spectrum is quantified and the mineralogy is assigned to the entire grain.



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Feature Scan

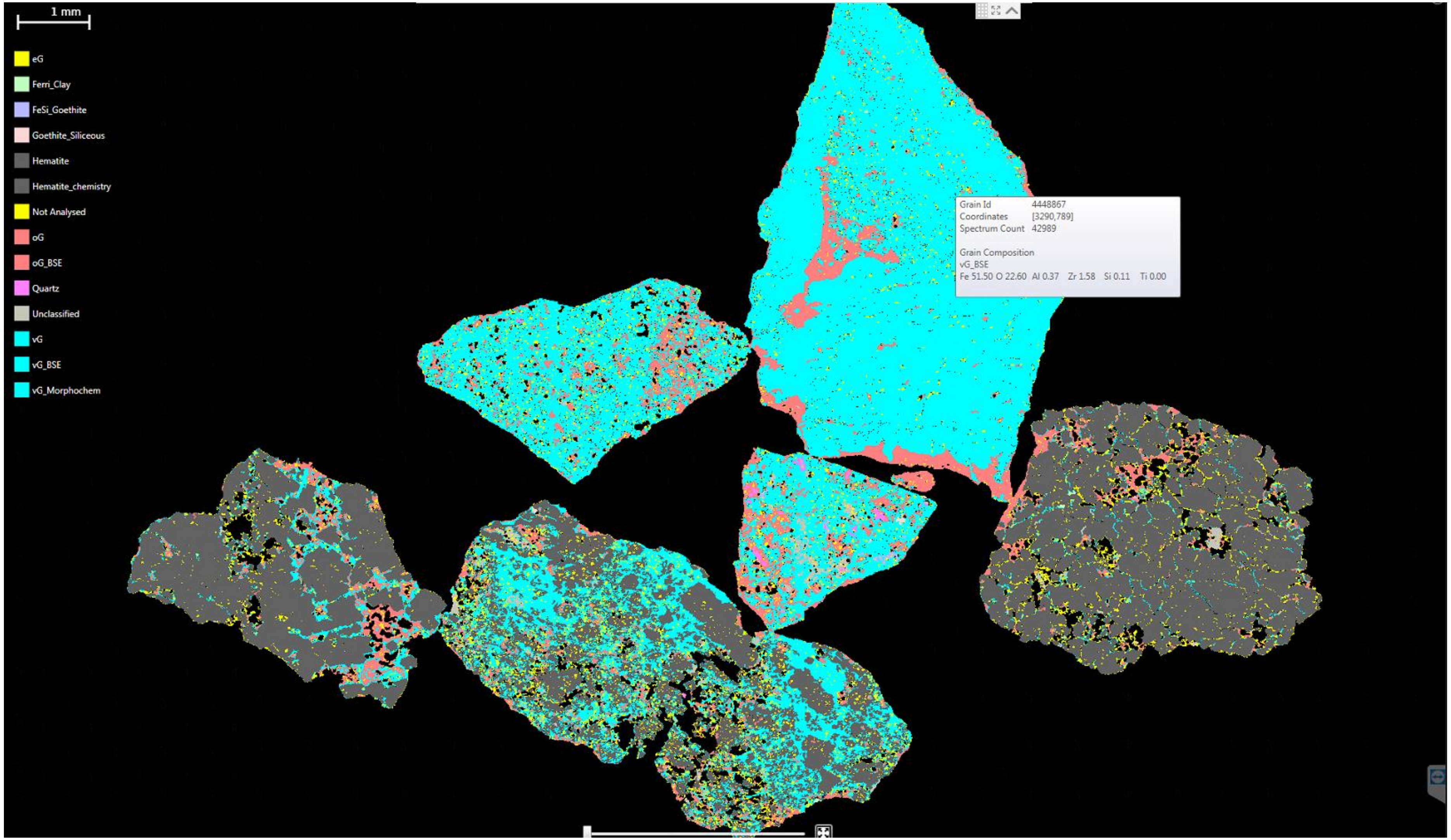
The beam is rastered over a mineral grain and the resulting EDX spectrum is quantified and the mineralogy is assigned to the entire grain.

Fast Scan

A faster way to obtain a quick scan of a grain. Several point analysis can be performed on each grain with larger grains analysed at more points than smaller grains

Live Particle Images

Chemistry, classification, and morphology revealed as you move over the image



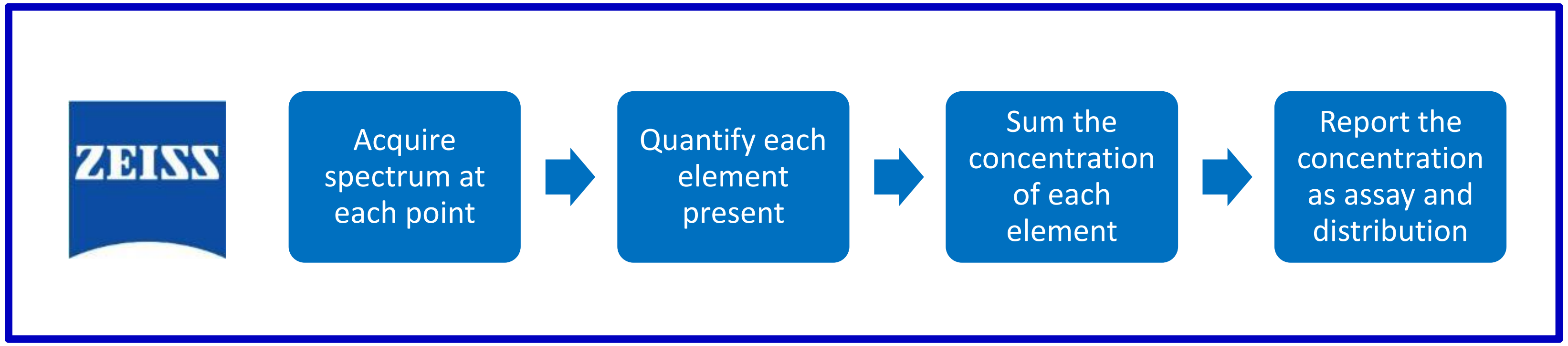
Mineralogic Outputs
Bulk data

Bulk Data

Bulk data includes the modal mineralogy that can be sorted by area %, weight %, average grain size, grain size standard deviation and also includes average composition of the mineral classification based on the quantified chemical analyses.

Target Mineral	Number	Area %	Weight %	Grain Size (µm)	Grain Size Std Dev (µm)	Average Composition
Pyrite	103790	32.9	46.2	27.96	24.66	Fe 50.63; S 49.28; Zn 0.09;
Quartz	61663	35.1	26.4	36.48	37.04	Si 56.61; O 42.48; Al 0.91;
Chamosite	54144	10.2	8.70	19.22	25.01	O 32.43; Fe 30.75; Si 16.49; Al 14.09; Mg 6.18; Mn 0.05; Ca 0.01; Cr 0;
Mica	92813	9.84	8.38	14.33	19.63	O 38.41; Si 27; Al 19.34; K 7.57; Fe 6.6; Mg 0.97; Cl 0.05; F 0.03; Na 0.02;
Chalcopyrite	15125	2.33	2.77	18.42	19.02	Cu 36.39; Fe 33.2; S 30.42;
Sphalerite	8348	1.17	1.35	16.53	19.32	Zn 67.59; S 28.55; Fe 3.86;
Berthierine	75686	1.27	1.22	6.09	4.86	Fe 38.6; O 25.74; Si 20.43; Al 15.23;
K Feldspar	50623	1.67	1.21	9.01	9.88	O 41.16; Si 35.06; Al 15.01; K 7.79; Fe 0.81; Ba 0.11; Na 0.04; Ca 0.02;

Mineralogic Outputs
Assay and Distribution



Target Mineral	Weight %	Assay(S)%	Assay(Ti)%	Assay(Cu)%	Assay(As)%	Assay(Ag)%	Assay(Sn)%	Assay(Sb)%	Assay(Au)%	Assay(Pb)%
Sample		23.48	0.22	1.42	0.05	0.01	0.03	0.01	0.004	0.33
Chalcopyrite	2.77	0.83	0.0001	0.99	0.0001	0.0003	0.0002	0.0003	0.00001	0.0001
Pyrite	46.22	21.76	0.02	0.20	0.04	0.01	0.004	0.01	0.001	0.01
Bornite	0.15	0.04	0.000102	0.09	0.00004	0.00001	0.00001	0.0001	0.0000004	0.00001
Chalcocite (Fe)	0.03	0.01	0.000007	0.03	0.000002	0.000002	0.000001	0.000002		
Enargite	0.05	0.01	0.000003	0.02	0.01	0.000004	0.0000003	0.002		0.00004
Covellite (Fe)	0.02	0.01	0.000014	0.01	0.00001	0.000004	0.0000004	0.00001		

Target Mineral	Weight %	Distibution(S) %	Distibution(Ti) %	Distibution(Cu) %	Distibution(As) %	Distibution(Ag) %	Distibution(Sn) %	Distibution(Sb) %	Distibution(Au) %	Distibution(Pb) %
Sample										
Chalcopyrite	2.77	3.52	0.04	69.68	0.26	2.45	0.79	2.40	0.20	0.04
Pyrite	46.22	92.67	7.98	14.21	65.24	64.55	13.83	40.27	36.54	3.79
Bornite	0.15	0.16	0.05	6.10	0.07	0.11	0.02	0.60	0.01	0.004
Chalcocite (Fe)	0.03	0.03	0.003	1.77	0.003	0.02	0.003	0.01		
Enargite	0.05	0.05	0.002	1.45	14.86	0.04	0.001	14.07		0.01
Covellite (Fe)	0.02	0.02	0.01	1.03	0.02	0.04	0.002	0.04		

Nickel Mineral Assay and Distribution
A selection of elements

	As	Co	Cr	Cu	Fe	Ni	P	Ti	Zn
Sample Assay (wt%)	0.012	0.003	0.042	0.047	29.807	17.366	0.0003	0.005	0.012

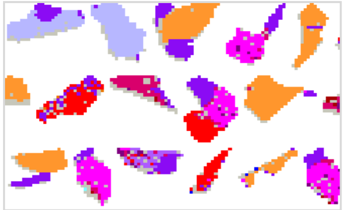
DISTRIBUTION	As	Co	Cr	Cu	Fe	Ni	P	Ti	Zn
Cobaltoan Gersdoffite Mo	0.7	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cobaltoan Gersdoffite	60.1	91.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gersdoffite	28.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dwornikite	0.1	0.0	0.0	0.0	0.1	0.2	0.0	0.1	0.0
Pentlandite	0.7	1.8	0.8	0.0	29.7	51.0	3.2	1.1	0.8
Violarite	0.9	1.2	0.1	0.0	11.1	35.1	1.7	0.0	2.1
Horomanite	0.0	0.0	0.2	0.0	0.9	0.6	0.0	0.3	0.0
Godlevskite	0.0	0.1	0.0	0.0	0.1	1.1	0.0	0.0	0.0
Polydymite	0.1	0.0	0.0	0.0	0.0	2.3	0.0	0.0	0.0
Vaesite	0.1	2.2	0.0	0.0	0.0	1.8	0.0	0.0	0.2
Millerite	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0
FeNiS+Silicate	1.5	0.0	0.7	0.0	1.7	3.8	0.0	0.6	0.9
FeNiS+O	1.0	0.0	1.1	0.0	2.3	1.7	0.0	3.0	2.6
NiS-Silicate	0.1	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.5
Bravoite	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
Taenite	0.0	0.0	0.0	0.0	0.4	0.8	0.0	0.0	0.0

Mineralogic Outputs
Liberation

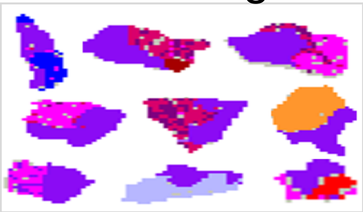
Liberation

User defined parameters to grade locked, middling and liberated minerals

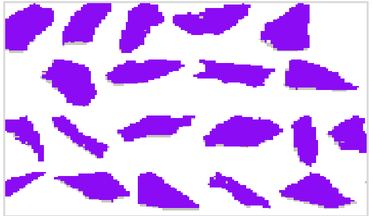
Locked



Middling



Liberated



Target Mineral	Liberated	Middling	Locked	< 10%	< 20%	< 30%	< 40%	< 50%	< 60%	< 70%	< 80%	< 90%	< 100%	100
Chalcopyrite	53.3	26.1	20.5	8.6	6.3	5.6	4.1	4.6	4.5	5.6	7.2	10.8	37.6	5.2
Sphalerite	52.7	26.7	20.6	9.5	5.9	5.1	4.7	5.2	4.9	6.0	5.6	9.0	33.6	10.3
Bornite	7.1	31.2	61.7	20.4	21.7	19.5	11.1	5.0	3.9	6.9	4.5	4.1	2.7	0.2
Ludjibaite	0.0	0.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Covellite	0.0	0.0	100.0	55.7	37.7	6.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copper	0.0	0.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chalcocite (Fe)	0.0	33.3	66.7	18.9	24.7	23.1	18.0	7.9	6.7	0.7	0.0	0.0	0.0	0.0
Chalcocite	0.0	0.0	100.0	24.2	24.2	51.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Digenite	0.0	0.0	100.0	62.4	37.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Covellite (Fe)	0.0	10.2	89.8	49.8	24.4	15.6	5.1	1.7	3.4	0.0	0.0	0.0	0.0	0.0
Chrysocolla	0.0	0.7	99.3	88.2	8.8	2.3	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tenorite	0.0	0.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Zn-Chalcopyrite	0.0	0.1	99.9	90.2	8.9	0.8	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Tennantite	0.0	0.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Particle Liberation and Modal Mineralogy
With respect to Pentlandite containing particles

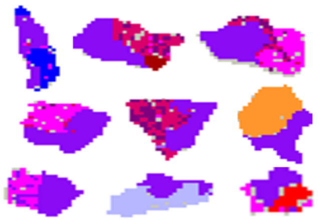
Composition of Particle	0%	< 10%	< 20%	< 30%	< 40%	< 50%	< 60%	< 70%	< 80%	< 90%	< 100%	100%
Number of Particles	218986	455	121	184	161	68	341	100	56	18	0	180
Average Effective Diameter (µm)	11.3	113.5	23.8	17.6	13.5	17.8	11.5	17.6	27.2	27.3	0.0	7.2
Average Max Diameter (µm)	17.8	173.6	35.7	26.2	19.2	25.5	15.4	24.5	37.9	37.0	0.0	9.6
Average Density	2.3	3.2	3.8	4.0	4.1	4.2	4.4	4.5	4.6	4.7	0.0	4.8
Average Porosity	0.1	3.7	0.4	0.1	0.1	0.0	0.0	0.0	0.2	0.0	0.0	0.0
Particle Distribution (%)	88.1	11.4	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.0
Distribution of Mineral (%)	0.0	23.3	5.7	9.3	5.4	4.3	12.5	12.1	19.1	5.6	0.0	2.8
Cum. Dist. of Mineral (%)	100.0	100.0	76.7	71.0	61.7	56.3	52.0	39.5	27.4	8.4	2.8	2.8

Modal Analysis (Area%)	0%	< 10%	< 20%	< 30%	< 40%	< 50%	< 60%	< 70%	< 80%	< 90%	< 100%	100%
Pentlandite (%)	0.0	0.6	13.9	24.3	33.4	43.0	53.1	64.1	74.1	82.9	0.0	100.0
Bravoite (%)	0.0	0.0	0.1	0.1	0.2	0.1	0.0	0.0	0.1	0.0	0.0	0.0
Dolomite (%)	1.3	0.8	1.4	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dwornikite (%)	0.0	0.0	0.1	0.1	0.2	0.0	0.1	0.1	0.0	0.0	0.0	0.0
Enstatite (%)	69.3	71.6	21.8	15.5	6.4	6.8	4.1	1.1	2.4	0.2	0.0	0.0
FeNiS+Silicate (%)	0.1	1.3	2.5	4.2	2.2	2.8	1.4	0.7	1.3	1.1	0.0	0.0
Godlevskite (%)	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Haapalite (%)	0.0	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Horomanite (%)	0.0	0.0	0.3	0.3	0.8	1.0	0.5	0.5	0.8	0.9	0.0	0.0
Magnesite (%)	8.0	7.5	6.2	2.4	1.3	0.3	0.3	0.2	0.0	0.0	0.0	0.0
Magnesite - ferroan (breunnerite) (%)	3.4	4.6	2.6	3.0	1.2	1.4	0.3	0.7	0.1	0.2	0.0	0.0
Magnesite-Si (%)	2.7	5.4	1.0	0.8	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Magnetite (%)	0.8	1.2	2.6	4.8	2.0	2.3	1.5	2.3	1.9	0.9	0.0	0.0
Pyrite (%)	0.2	0.6	14.5	5.8	13.0	5.6	2.5	3.1	2.4	1.3	0.0	0.0
Siderite (%)	0.5	0.9	1.1	1.5	0.9	0.6	0.7	0.8	0.6	0.4	0.0	0.0
Silica 2 (%)	1.6	0.2	0.9	0.9	1.3	0.9	1.4	0.9	0.4	0.2	0.0	0.0
Other (%)	12.0	5.2	30.6	35.9	36.4	35.1	34.0	25.6	15.8	11.9	0.0	0.0

Mineralogic Outputs
Associations

Association

Phase associations are reported as contact associations (example below) and also as locking associations (occur in the same particle but may not have a contact surface)



Target Mineral	Bismuthinite	Bornite	Chalcocite	Chalcocite (Fe)	Chalcopyrite	Covellite	Covellite (Fe)	Digenite	Enargite	Malachite/azurite	Pyrite
Bornite	0.0		0.2	5.2	17.3	0.1	6.4	0.3	0.6	3.3	18.1
Chalcocite		4.2		72.5	0.3	0.1	1.3	8.5	0.1	2.0	0.3
Chalcocite (Fe)		27.0	15.5		3.3	1.0	16.7	11.3	0.0	3.0	4.3
Chalcopyrite	0.0	1.7	0.0	0.1			0.1	0.0	0.3	0.1	25.6
Copper	25.0										
Covellite	0.4	6.4	0.2	9.9			28.9	13.7	1.5	4.6	0.2
Covellite (Fe)		30.4	0.2	15.4	3.8	2.7		3.7	1.2	5.7	5.7
Digenite	0.2	6.6	7.5	47.0	0.2	5.8	16.9		0.1	3.8	0.3
Ludjibaite						12.5	12.5			50.0	
Sphalerite	0.0	0.3			2.2		0.0		0.1	0.0	17.3
Tennantite									37.5		
Tenorite		12.5	37.5							12.5	

Mineralogic Outputs
Particle classifications

Field Images | Particle Images | Particle Data | General Properties | Bulk Data | Assay Data | Liberation | Associations | Lithology Bulk | Lithology Chemistry

Bulk Data

Lithology	Number	Area %	Weight %	Particle Size (µm)	Mineral Area (%)								
					Carbonates	Chalcopyrite	Enargite	Muscovite	Others	Pore	Pyrite	Quartz	Unclassified
Quartz Sericite	737	28.16	25.67	287.03	0.00	0.11	0.02	41.91	3.27	5.86	3.58	44.74	0.51
Quartz Sericite Porous	109	8.43	7.48	436.84	0.00	0.15	0.00	42.10	3.78	14.53	1.40	37.25	0.80
Quartzite	976	13.42	11.78	136.63	0.00	0.04	0.00	3.01	0.99	3.85	0.26	91.66	0.19
Quartzite Porous	72	1.38	1.19	171.61	0.00	0.19	0.00	4.69	2.97	12.45	0.39	78.93	0.39
Sericite	1870	19.75	18.57	128.26	0.00	0.10	0.04	86.84	2.73	5.75	2.46	1.61	0.48
Sericite Porous	327	10.46	9.58	266.88	0.00	0.16	0.00	77.87	4.18	14.45	1.67	1.17	0.51
Skarn	2	0.01	0.01	126.65	99.07	0.00	0.00	0.00	0.00	0.93	0.00	0.00	0.00
Skarn Porous	0												
Sulphide-Ccp	37	0.39	0.50	137.76	0.00	61.55	6.91	2.20	4.85	0.96	15.24	1.89	6.41
Sulphide-En	10	0.36	0.47	237.92	0.00	7.99	68.59	2.73	6.71	1.81	7.01	0.00	5.16
Sulphide-Py	631	14.27	22.01	186.91	0.00	0.91	0.17	9.53	2.54	2.41	82.23	0.66	1.54
Remaining Particles	4486	3.37	2.73	23.02	0.00	1.48	0.28	38.03	12.46	8.67	13.40	3.86	21.82
Sample	9257			103.80									

Mineralogy by lithology, in this sample note how chalcopyrite abundance in porous quartzite is highest, but much lower in the (low-porosity) quartzite. Note also that this mineral appears dispersed across all *gangue* lithologies with no preferential occurrence in any one, however, overall the sample contains mostly quartz sericite and sericite lithologies, quartzite lithology less abundant. Note although some pyrite is dispersed through all lithologies, it most commonly occurs as large nuggetty particles that are dominated by pyrite (lithology = “Sulphite-Py”).

Mineralogic Outputs
Particle chemistry

Field Images | Particle Images | Particle Data | General Properties | Bulk Data | Assay Data | Liberation | Associations | Lithology Bulk | Lithology Chemistry

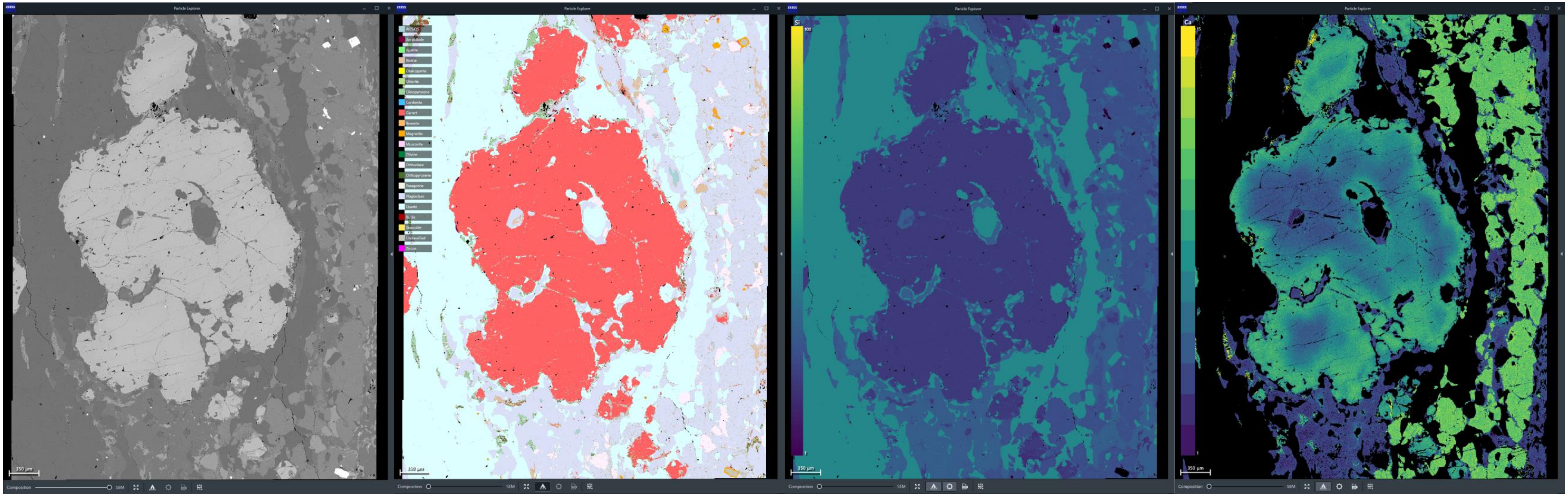
Chemistry Data

Lithology	Number	Area %	Weight %	Average Composition (wt%)									
				Al	As	Ca	Cu	Fe	K	Mg	Mn	S	Si
Quartz Sericite	737	28.16	25.67	8.08	0.00	0.00	0.06	2.26	3.69	0.10		2.09	32.82
Quartz Sericite Porous	109	8.43	7.48	9.02	0.00	0.01	0.08	1.27	3.99	0.08		0.96	32.33
Quartzite	976	13.42	11.78	0.64	0.00	0.02	0.02	0.17	0.25	0.01	0.00	0.17	45.09
Quartzite Porous	72	1.38	1.19	1.26		0.01	0.10	0.36	0.42	0.03		0.36	43.93
Sericite	1870	19.75	18.57	16.48	0.01	0.00	0.07	2.02	7.45	0.14		1.43	21.18
Sericite Porous	327	10.46	9.58	16.26	0.00	0.00	0.08	1.85	7.28	0.22		1.13	21.06
Skarn	2	0.01	0.01			38.64					0.63		
Skarn Porous	0												
Sulphide-Ccp	37	0.39	0.50	0.66	1.47	0.00	27.63	28.32	0.17	0.09		33.86	1.57
Sulphide-En	10	0.36	0.47	0.67	13.75	0.03	37.54	7.89	0.22	0.09		28.47	0.68
Sulphide-Py	631	14.27	22.01	1.86	0.05	0.02	0.58	39.43	0.78	0.03	0.00	45.26	2.55
Remaining Particles	4486	3.37	2.73										
Sample	9257												

Chemistry by lithology, not a surprise, in this example most of the As is associated with the suphide lithologies, but there may be examples of other copper ores where the As deportment is different; this functionality allows the user to determine the lithological host for the deleterious elements such as As and F.

New features – improved Large Particle Viewer
Mineralogic does everything it did before, plus…

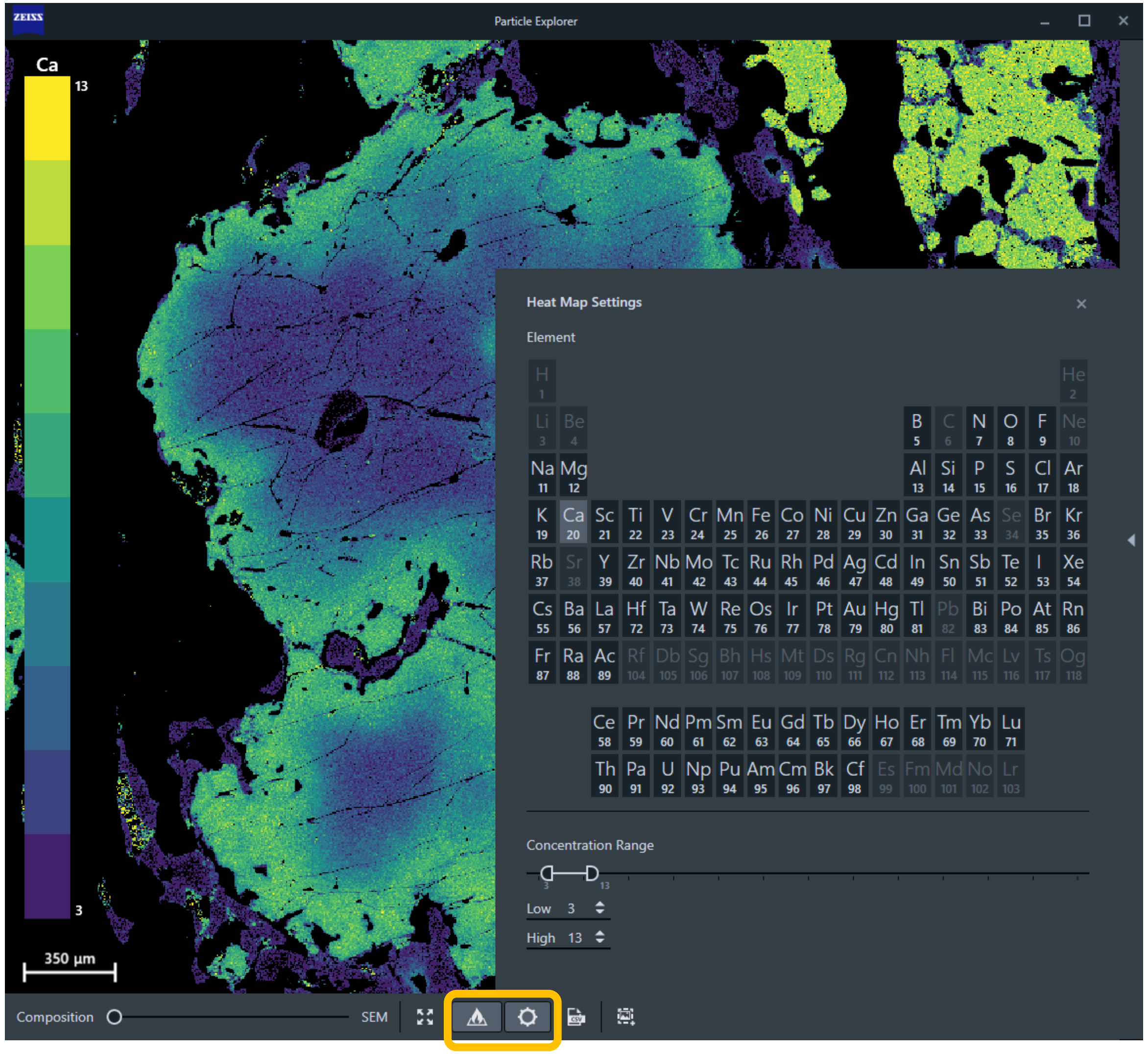
BSE, Phase ID, and new element heatmap view – change in the way the database is accessed

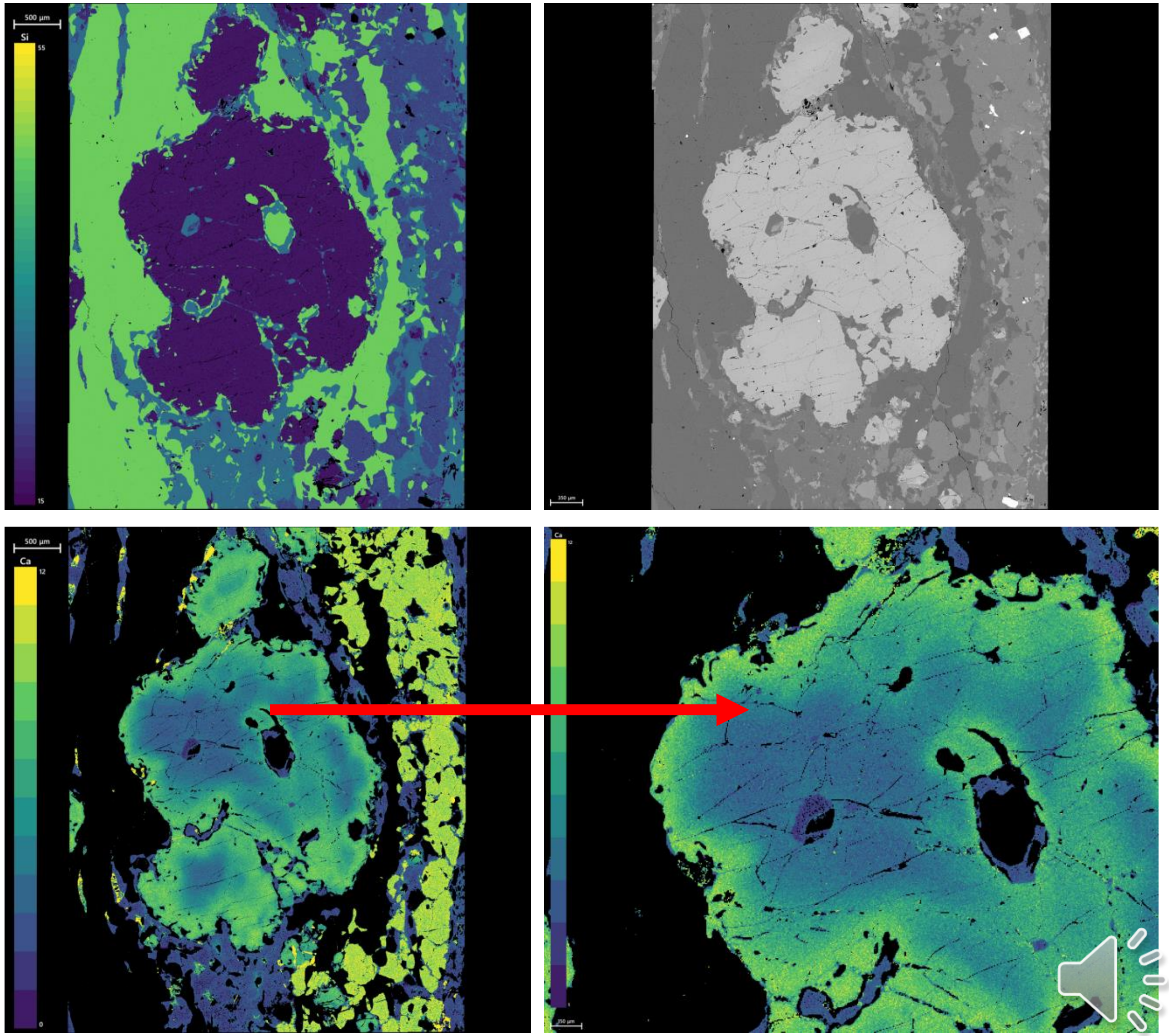


Simple interface allows single click controls for many actions

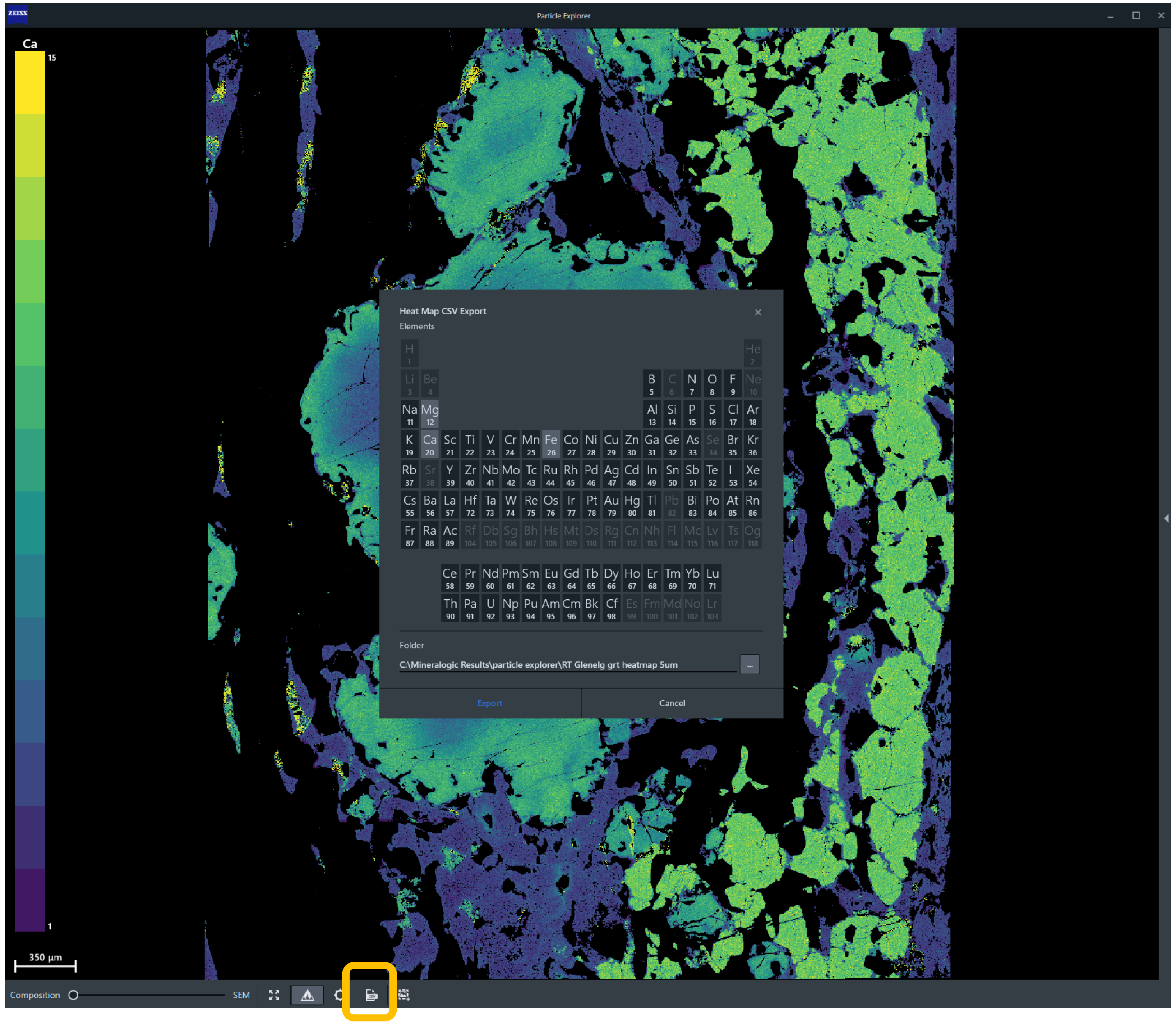
Simple data export
Flexible format for external software

Single click image export – exactly what you see on screen

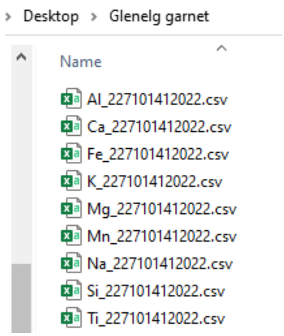


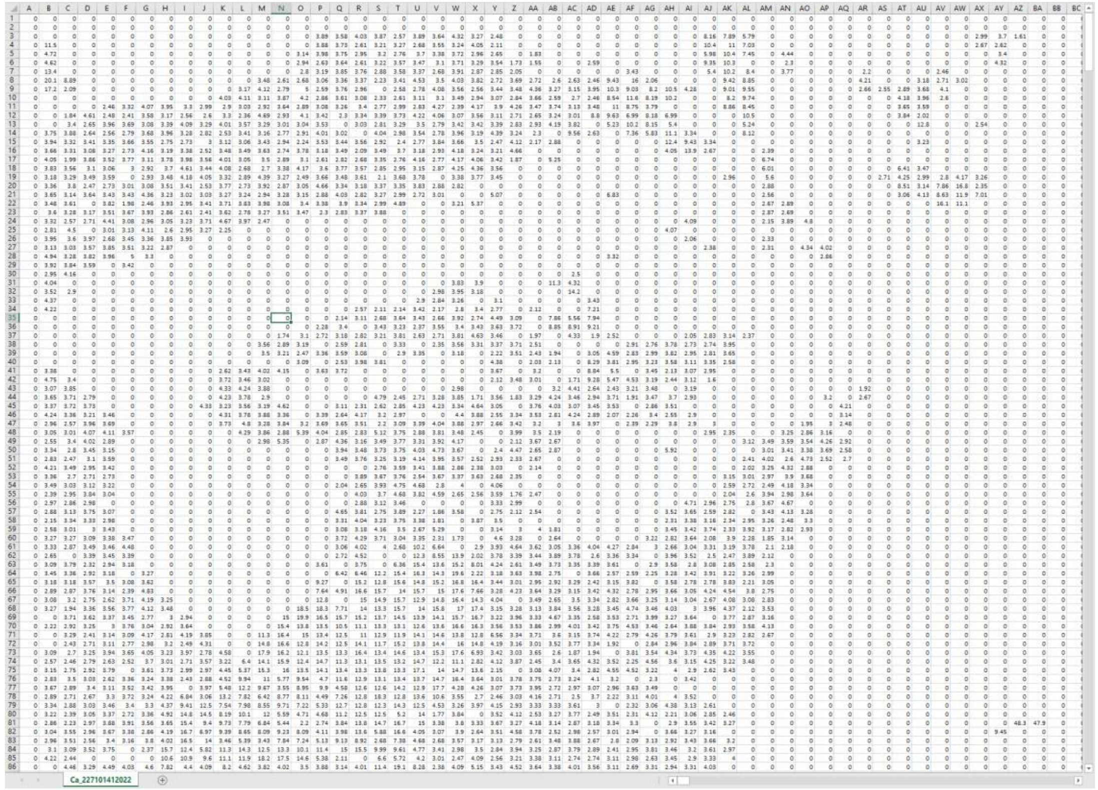


Simple data export
Flexible format for external software



- Select elements of interest
- Select folder
- Entire map exported as .csv

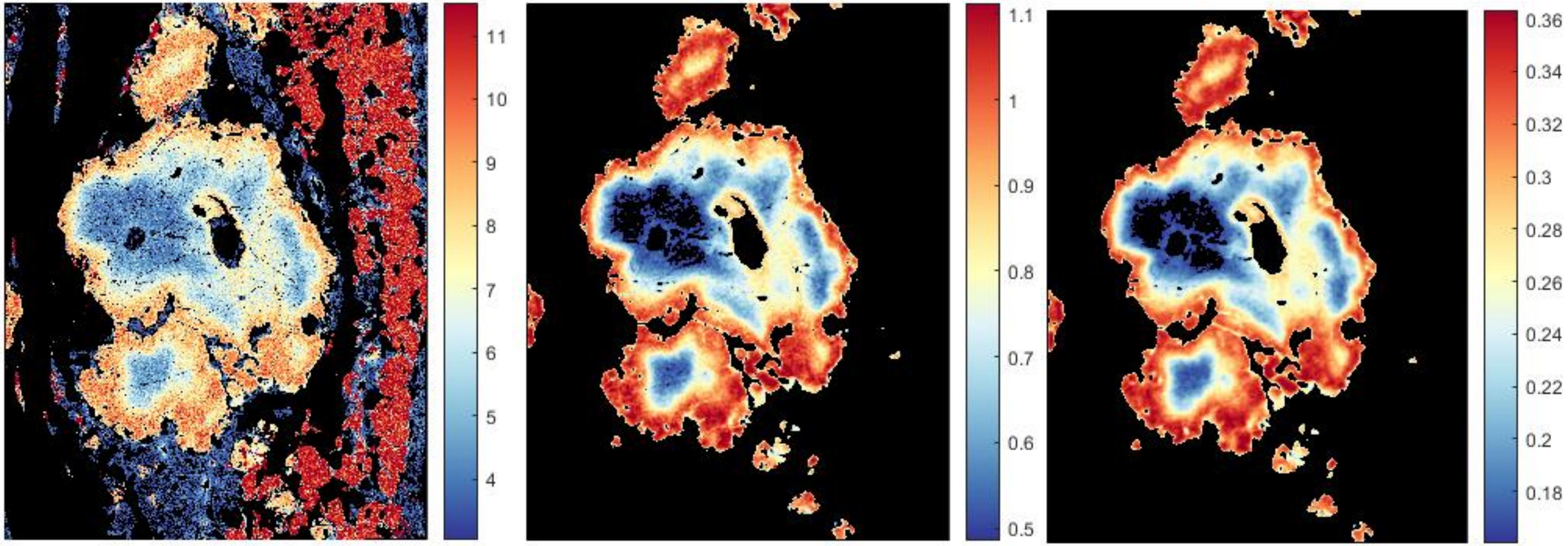


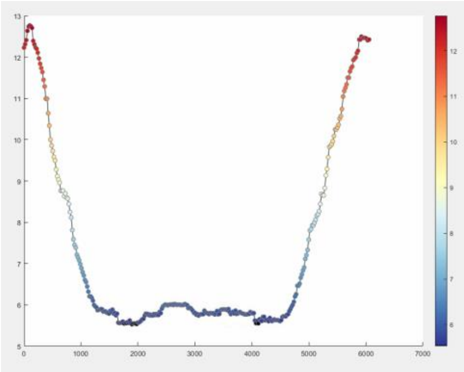


Third party software
Importance of integration and geochemical data

Third party software such as **FIJI/ImageJ** are widely used for image analysis

XMapTools is software designed specifically for geoscience data analysis



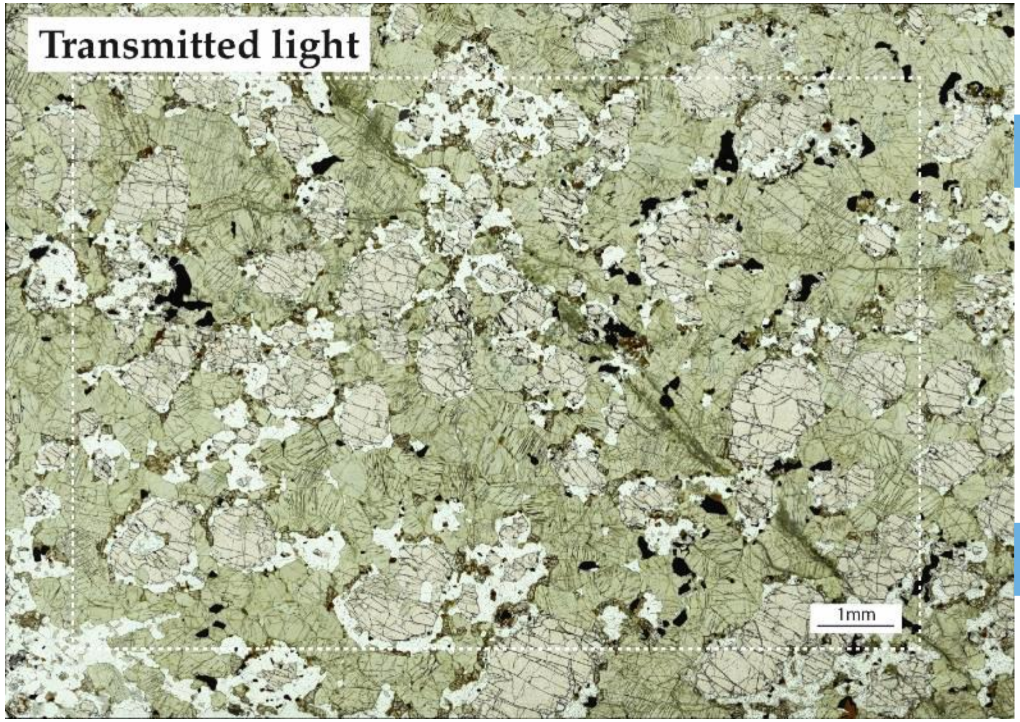


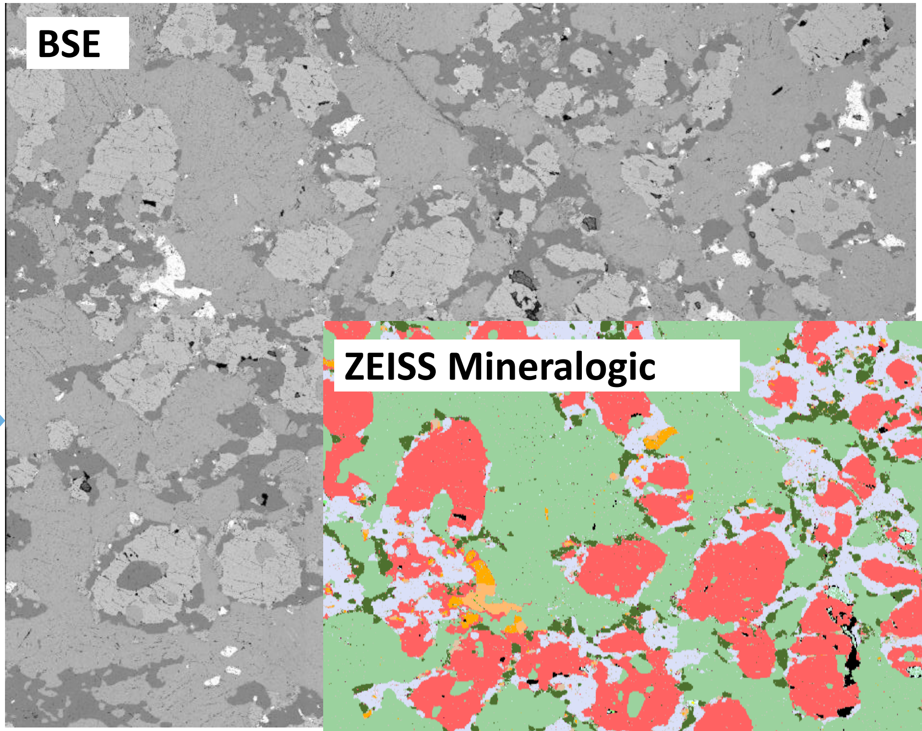
- This is only possible with a **flexible**, data stitched, generic **data** output
- Its only **meaningful** if your data are built on **quantitative geochemistry**

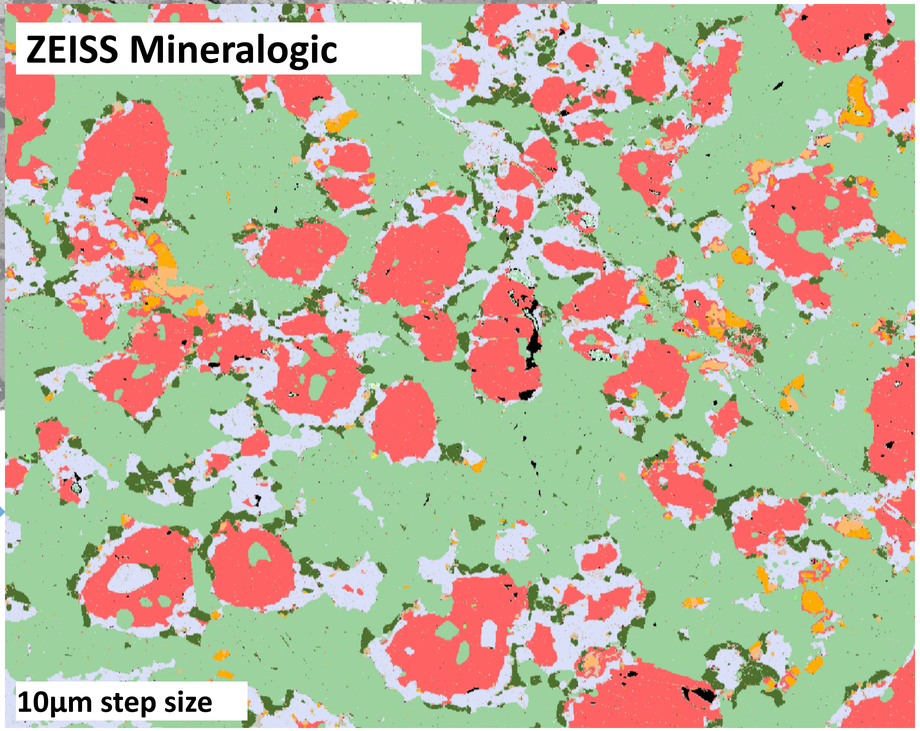
How does ZEISS Mineralogic work
Using quantitative chemistry

Lewisian metagabbro thin section

- Backscattered Electron (BSE) image
- Phase map based on chemistry





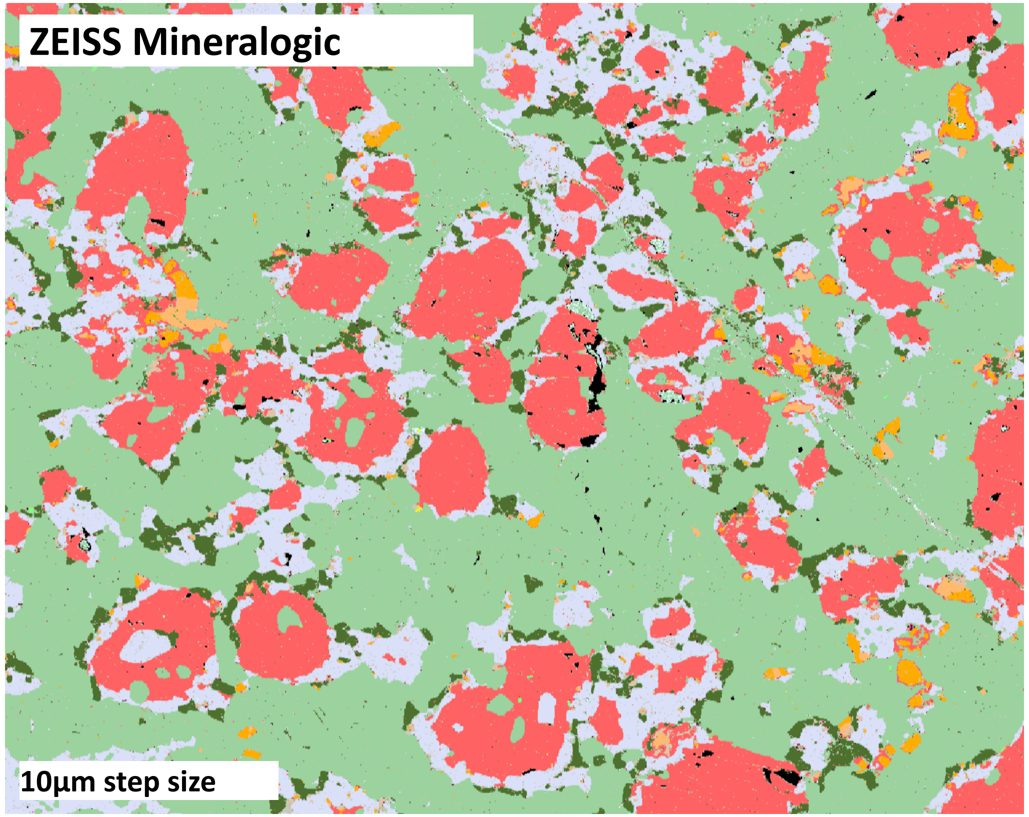


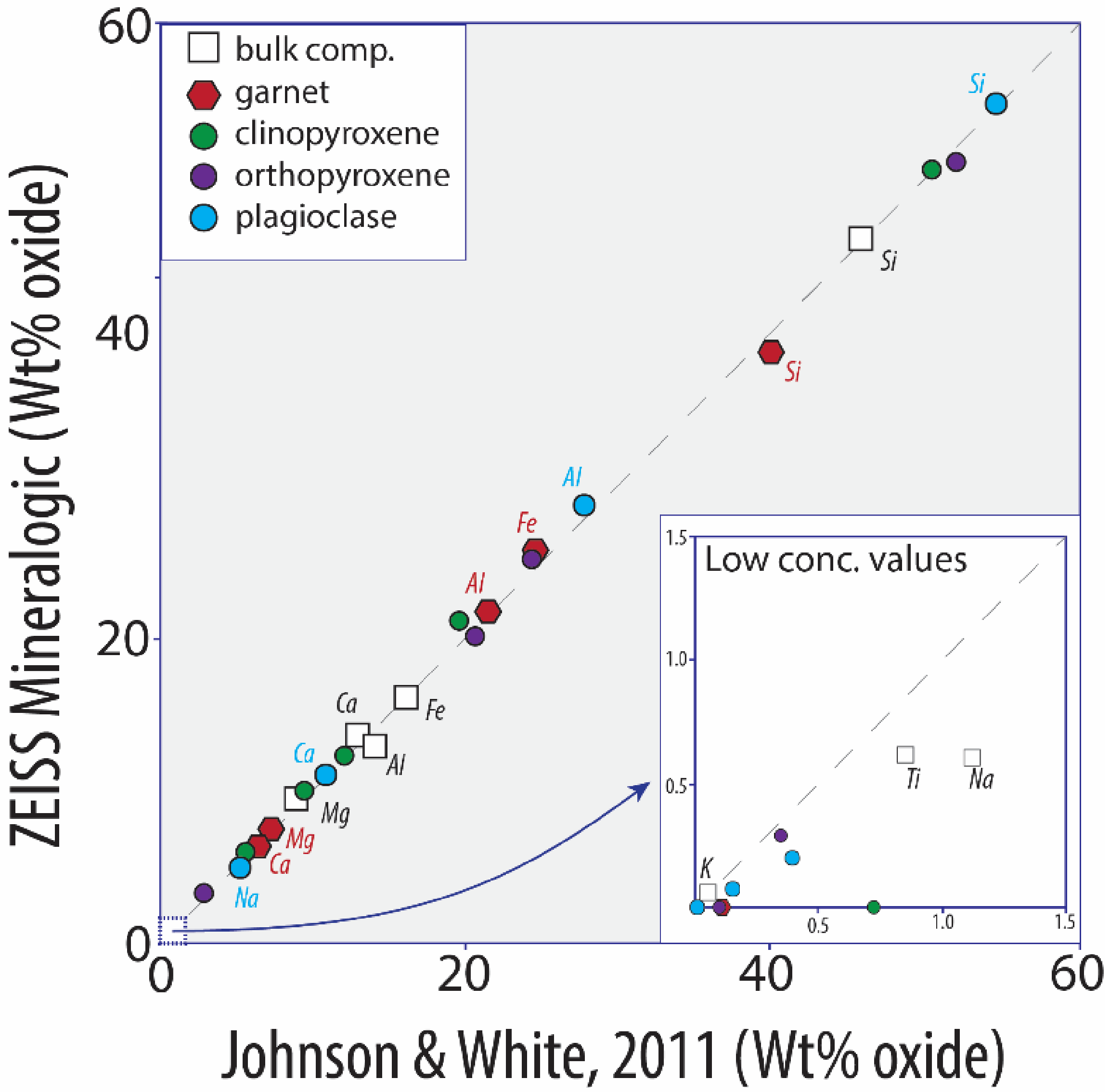
Fundamental purpose – classify mineral phases for further analysis

How does ZEISS Mineralogic work
Using quantitative chemistry

Quantitative thin section geochemistry

- Mineral chemistry
- “Bulk rock” chemistry

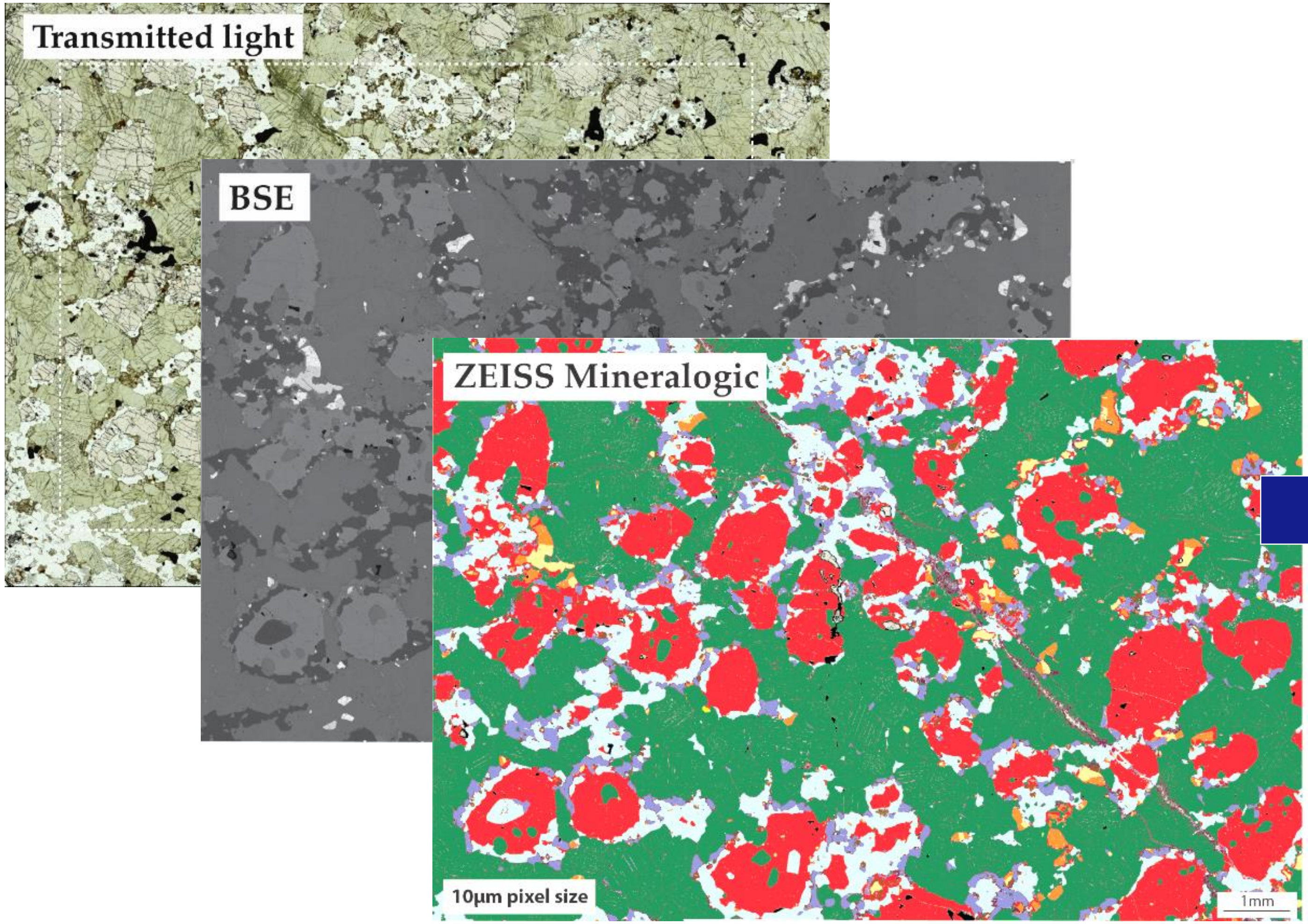


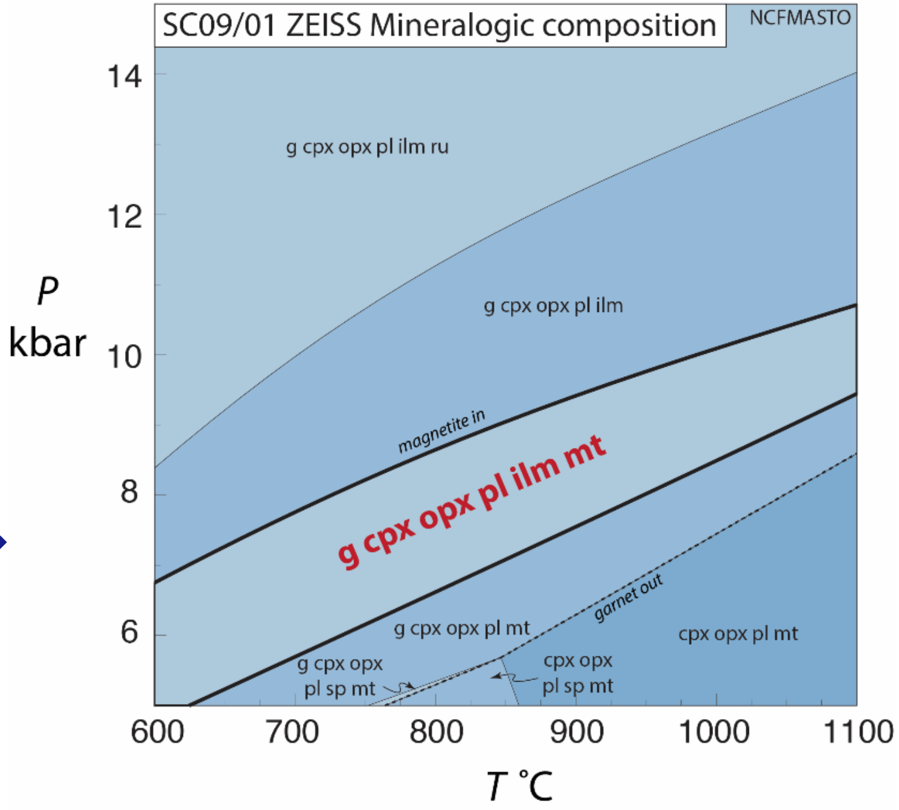


ZEISS Mineralogic

Image analysis – phase identification – quantitative chemistry

Application - Crustal Evolution and Tectonics - Quantitative mineral and sample chemistry



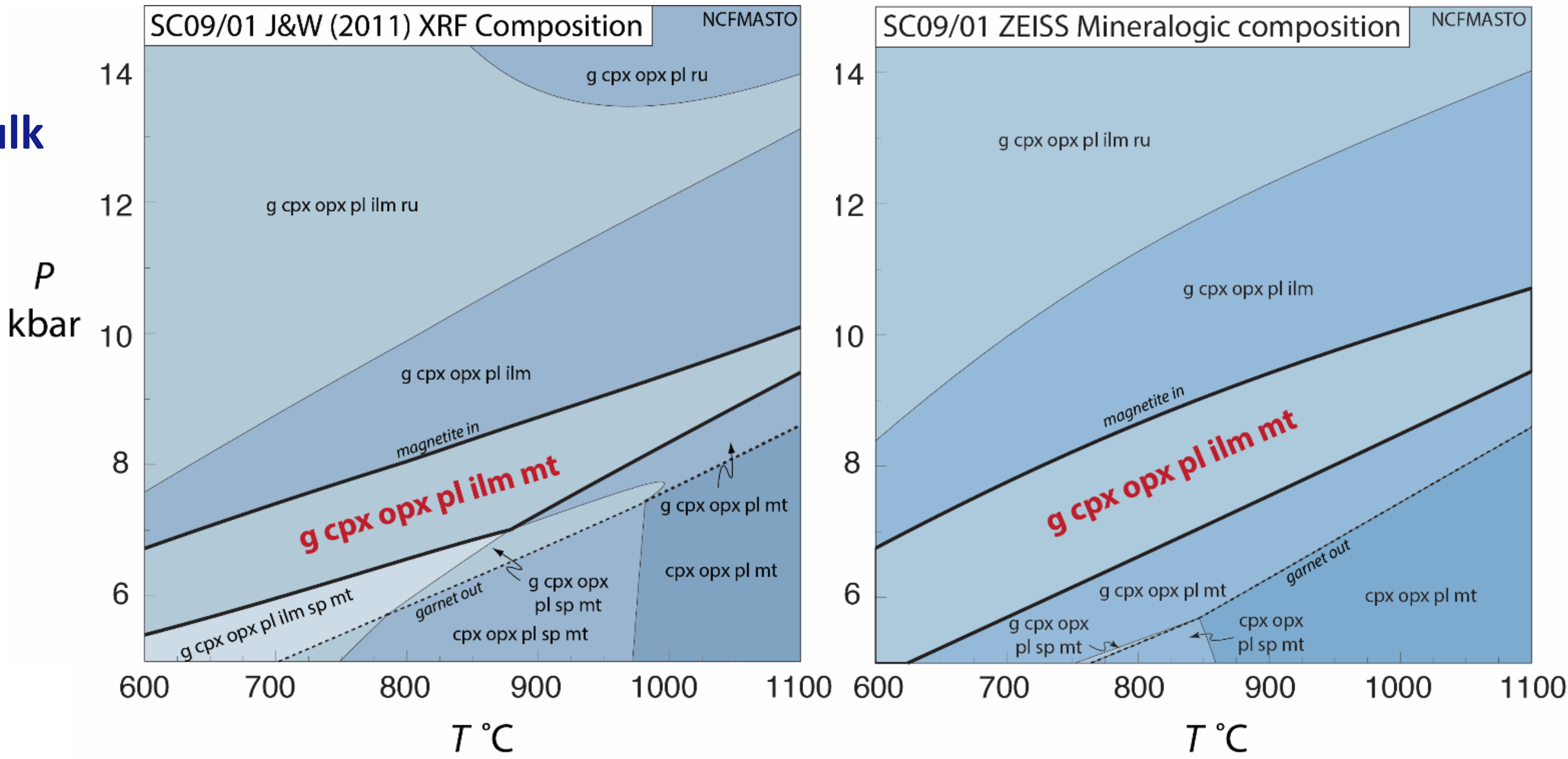


Geological History

Pressure and Temperature calculated from mineral assemblage and bulk chemistry

P-T pseudosection calculated from **Bulk chemistry**

Peak *P-T* constrained from **Mineral assemblage** observations

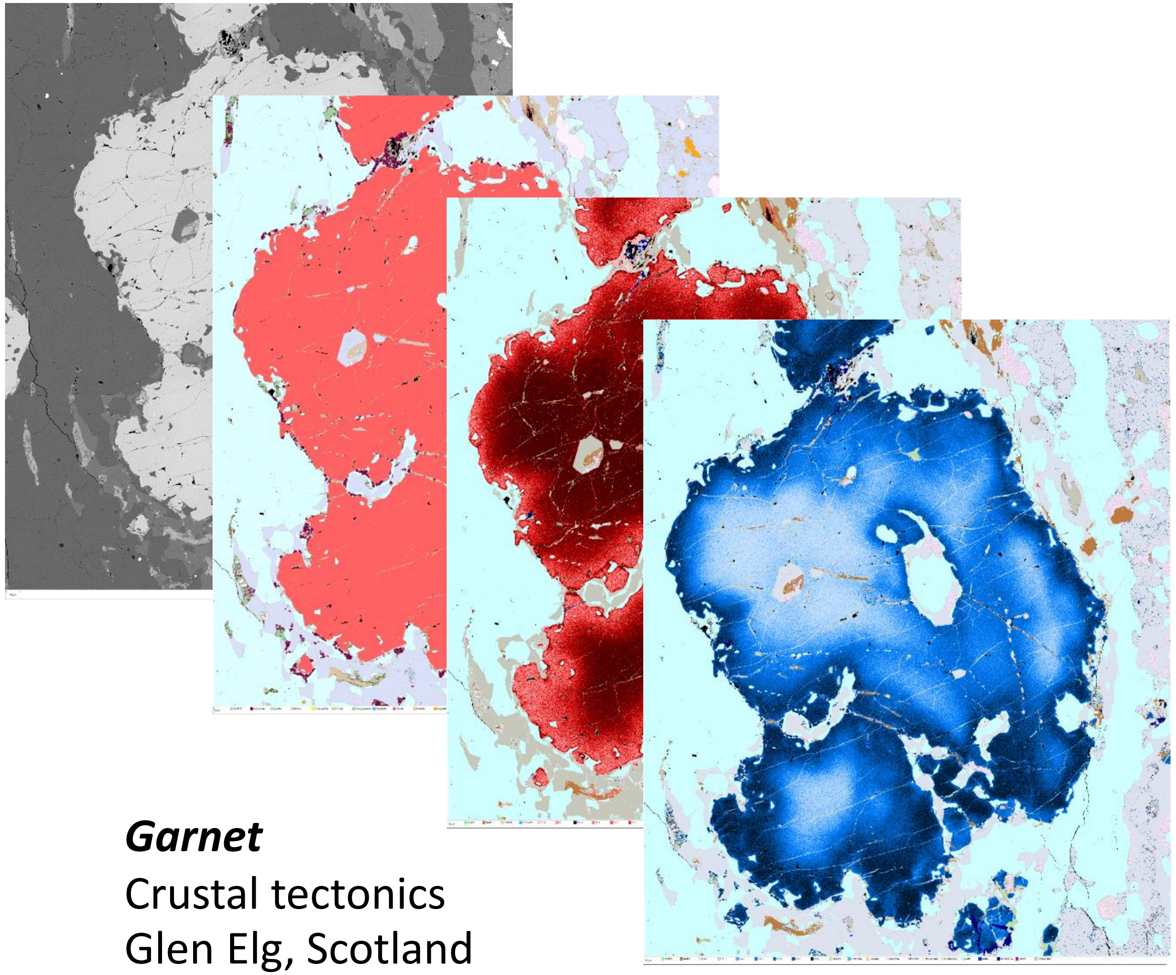


ZEISS Mineralogic

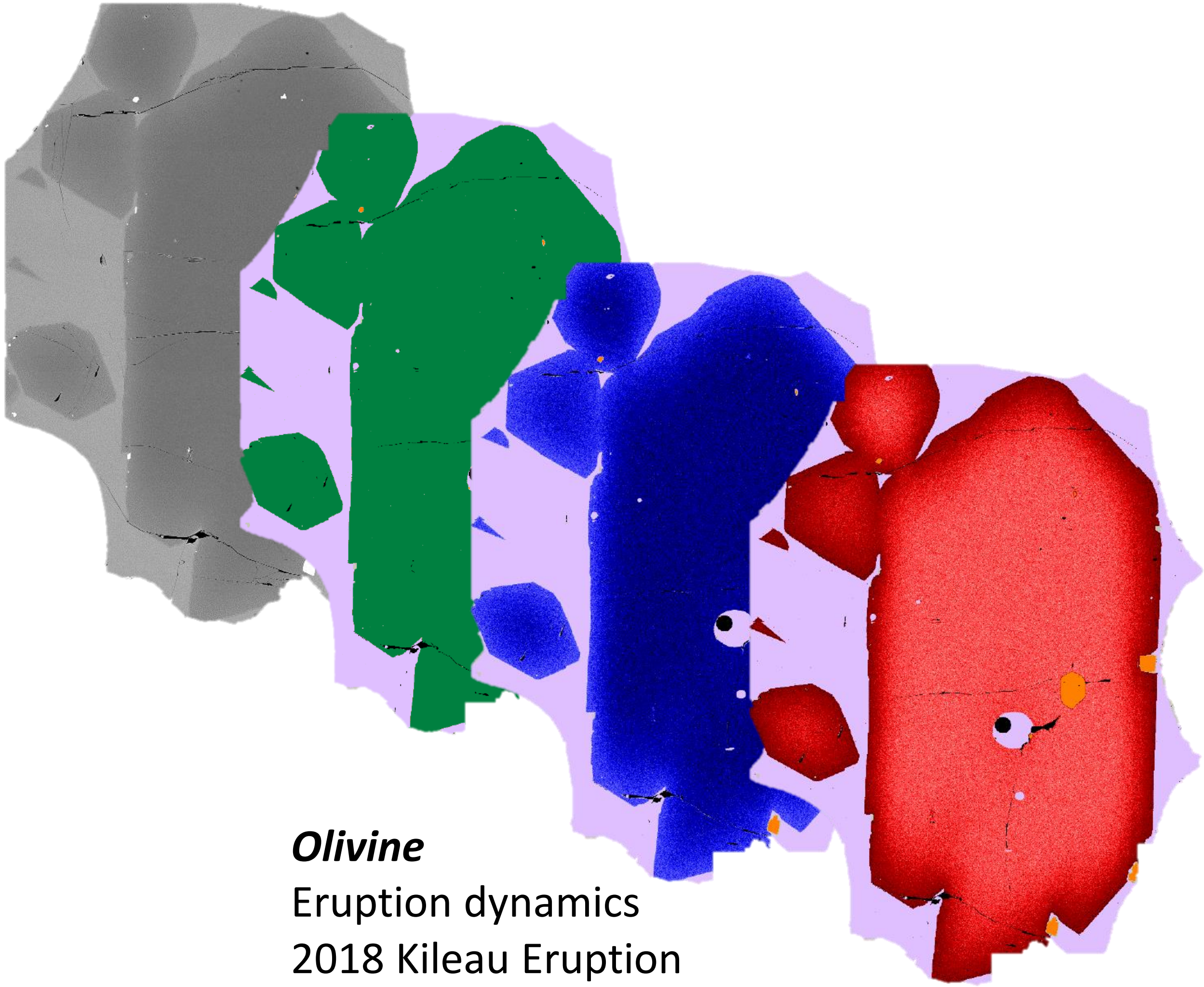
Image analysis – phase identification – quantitative chemistry

Application - Crustal Evolution and Tectonics including volcanism

Internal zonation of minerals



Garnet
Crustal tectonics
Glen Elg, Scotland



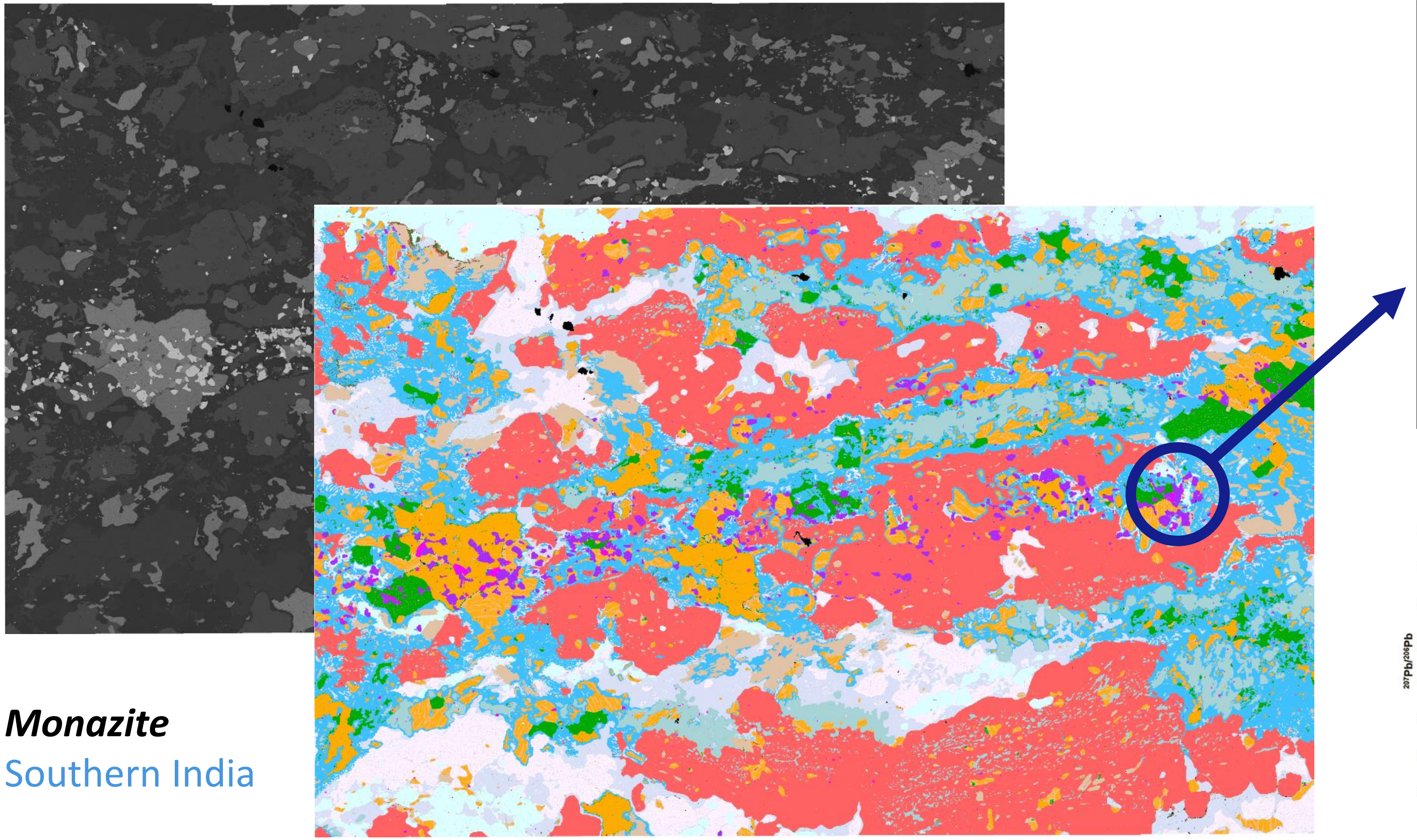
Olivine
Eruption dynamics
2018 Kileau Eruption

ZEISS Mineralogic

Image analysis – phase identification – quantitative chemistry

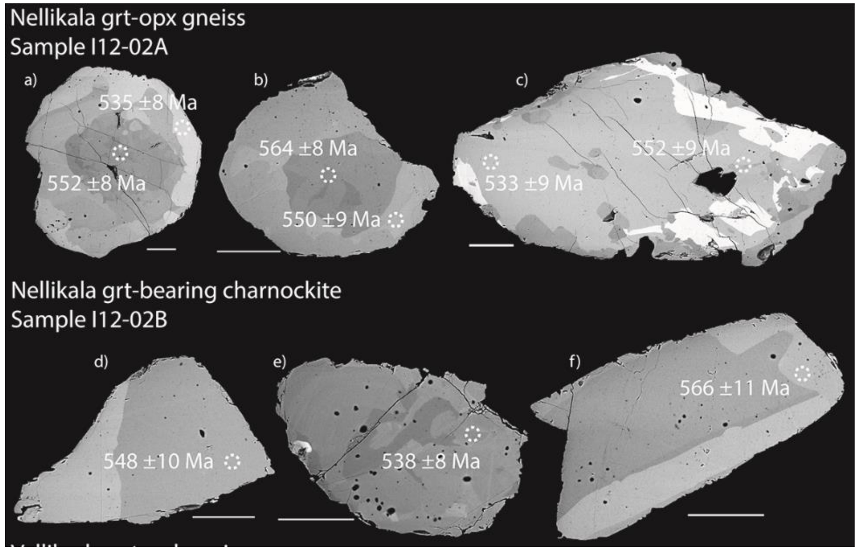
Application – Isotope geology and geochronology

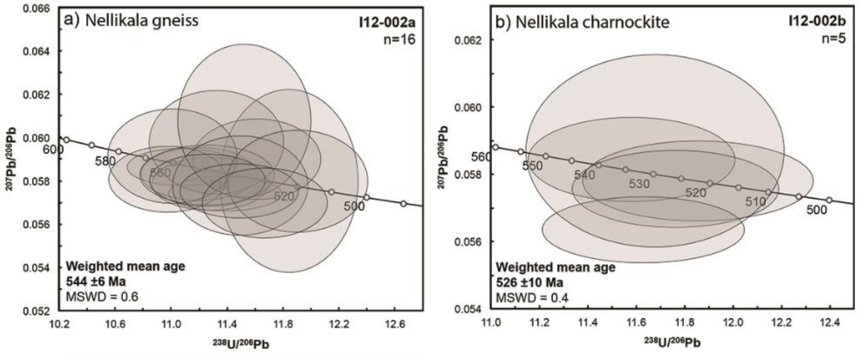
Rapid identification of U-Pb dating accessory mineral in geological context



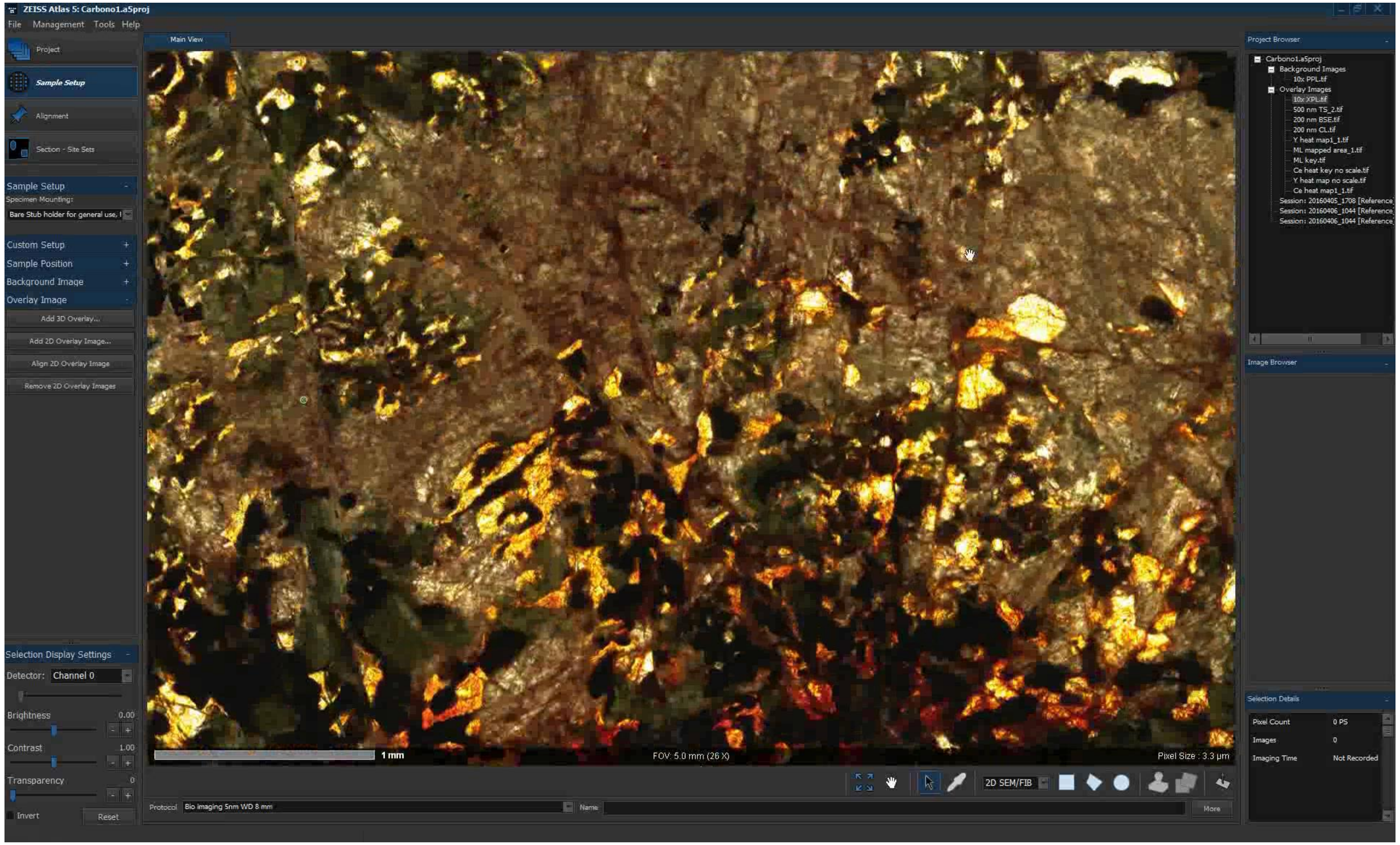
Monazite

Southern India





Multi-instrument Workflow and Multi-scale 2D Characterization
Danish Geological Survey – Carbonatite / REE



Video contains 8 separate large area data layers.

Each data layer has been captured using the latest automated microscopy technology.

Data layer 7 & 8: False elemental concentration maps displaying the element distribution of REE's La & Y.

Data layer 6: False colored Automated Quantitative Mineralogy Map using the Sigma 300 & Mineralogic

Data layer 5: High-resolution CL tiles of the region of interest using the Sigma 300 & Mineralogic

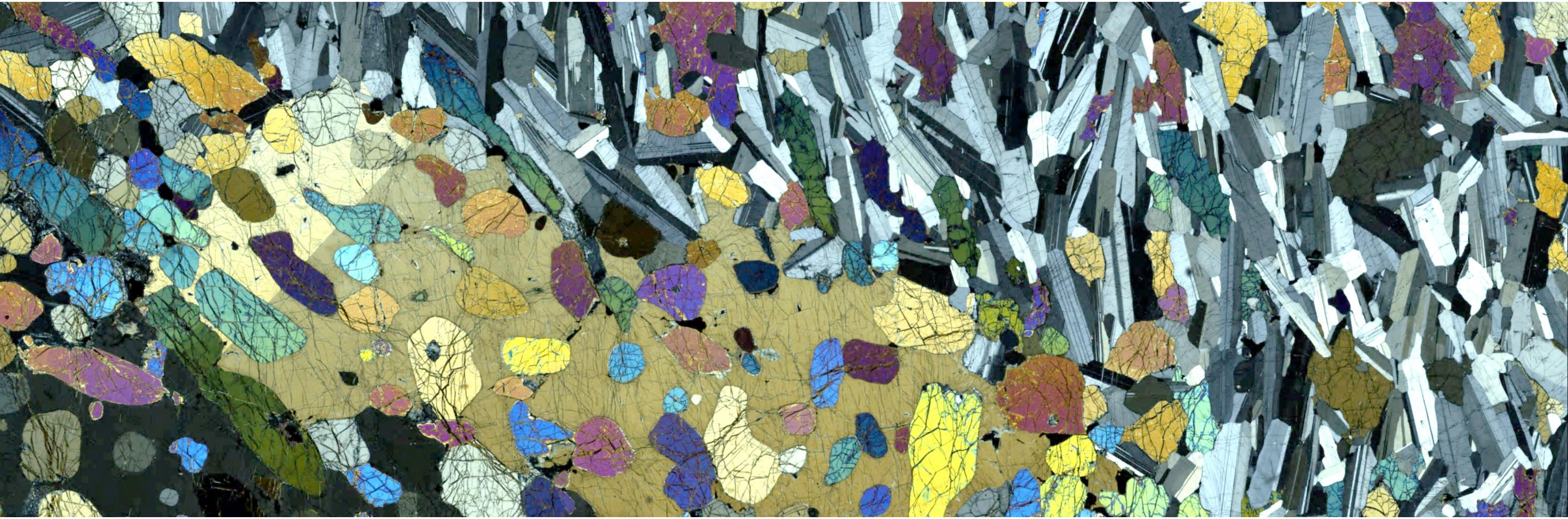
Data layer 4: High-resolution BSE tiles of the region of interest using the Sigma 300 & Mineralogic

Data layer 3: Stitched tiles to produce a large area low resolution BSE image using the Sigma 300 & Mineralogic

Data layer 2: Cross polarized (XPL) light using the automated / motorized stage on a Axio Imager

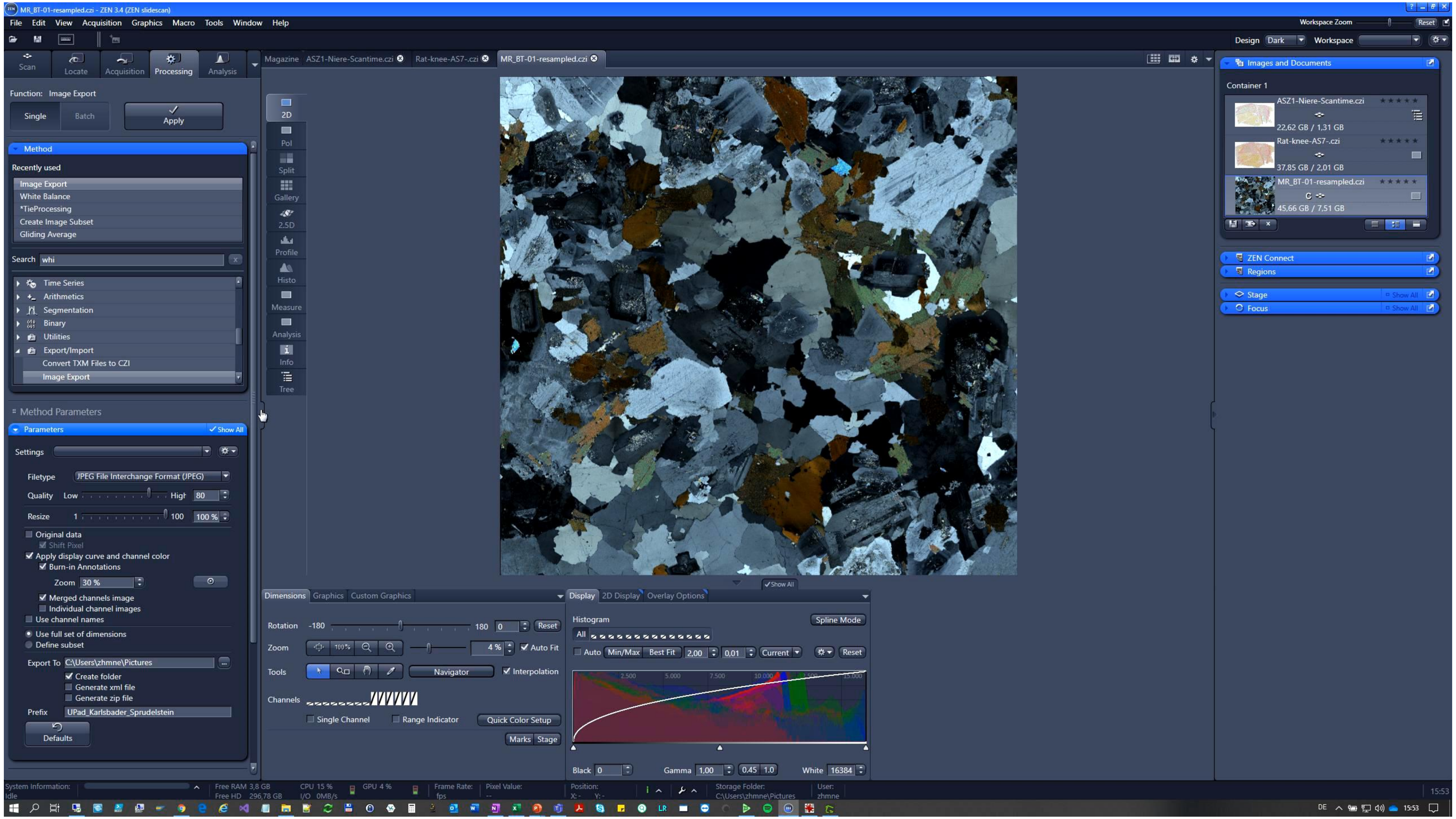
Data layer 1: Plain polarized (PPL) light using the automated / motorized stage on a Axio Imager

Software packages for Axioscan 7 GEO: ZEN Pol Viewer, Data Storage, Intellesis, Image Analysis & the Petrographic analysis toolbox

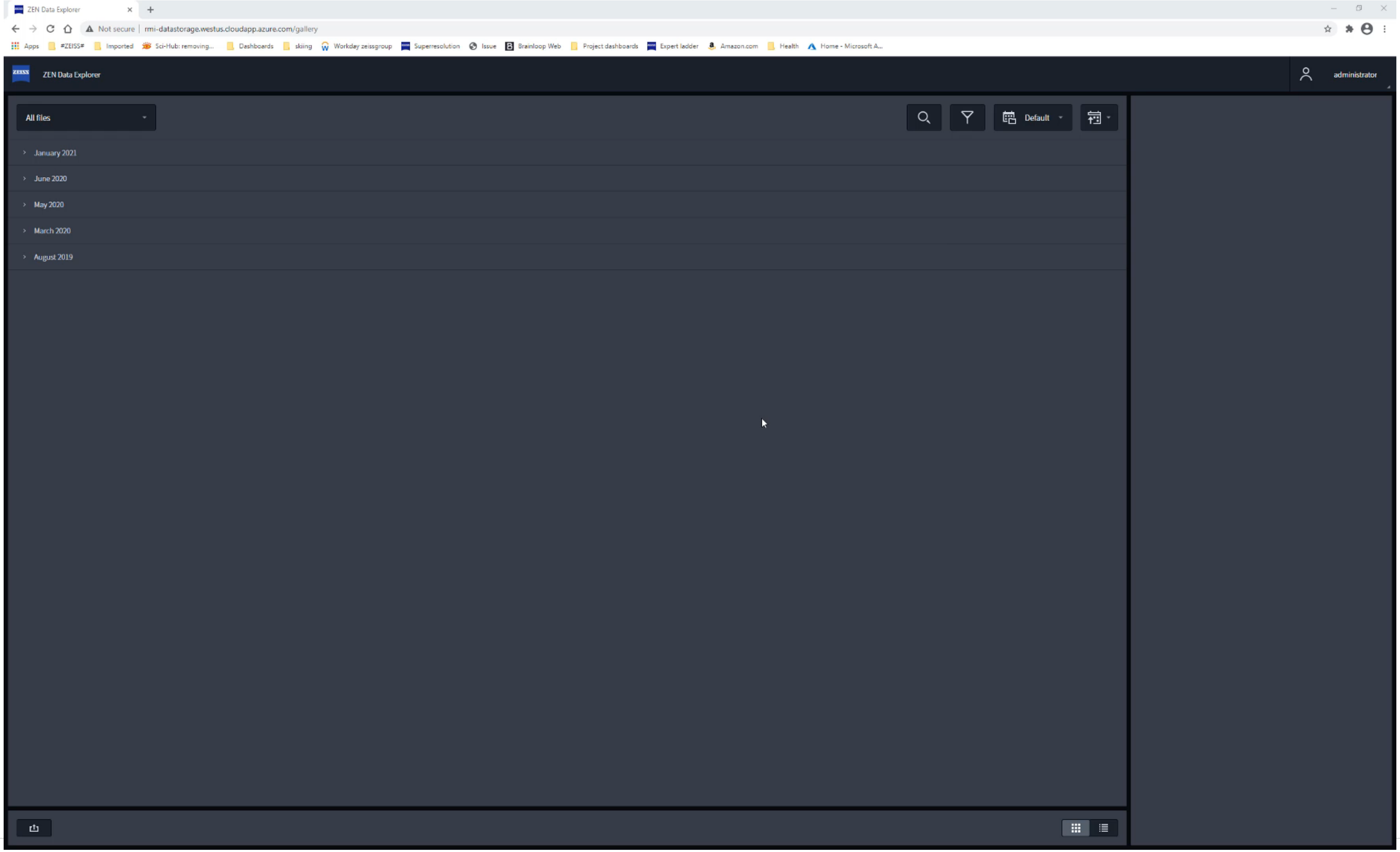


Dr. John S Thella
Raw Materials Sector
Carl Zeiss Microscopy Ltd

Basic & Teaching software 1:
Zen Pol Viewer



Basic & teaching software 2:
ZEN Data Storage



Levels of advanced petrographic analysis

Level 1:

Simple segmentation (e.g. pore vs grain)
Morphological object separation (e.g. watershed)

Pore throat analysis via the petrography analysis toolbox

Input image data: Single channel Plane Polarized light (Ppol)

Software package: ZEN Intellesis, ZEN image analysis, petrography analysis toolbox for pore throat analysis

Level 2:

Mineral classification (multiple mineralogies)

Morphological object separation

Input image data: Multi channel Ppol + circular pol OR Multi channel Ppol + Multi Xpol processed using the petrography analysis toolbox

Software package: ZEN Intellesis, ZEN image analysis, petrography analysis toolbox for processing multi xpol data

Level 3:

Grain identification using multipol data.

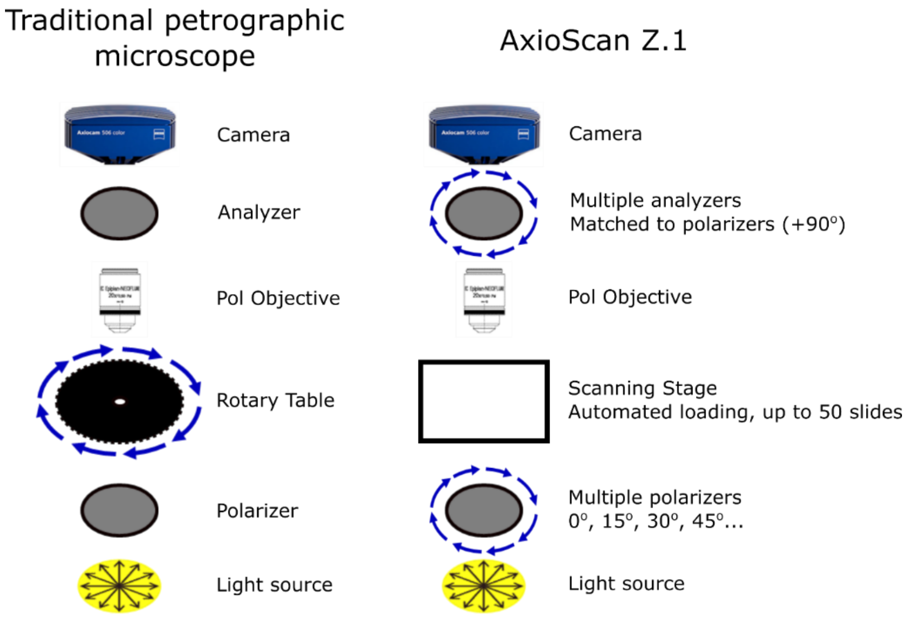
Birefringence solution,

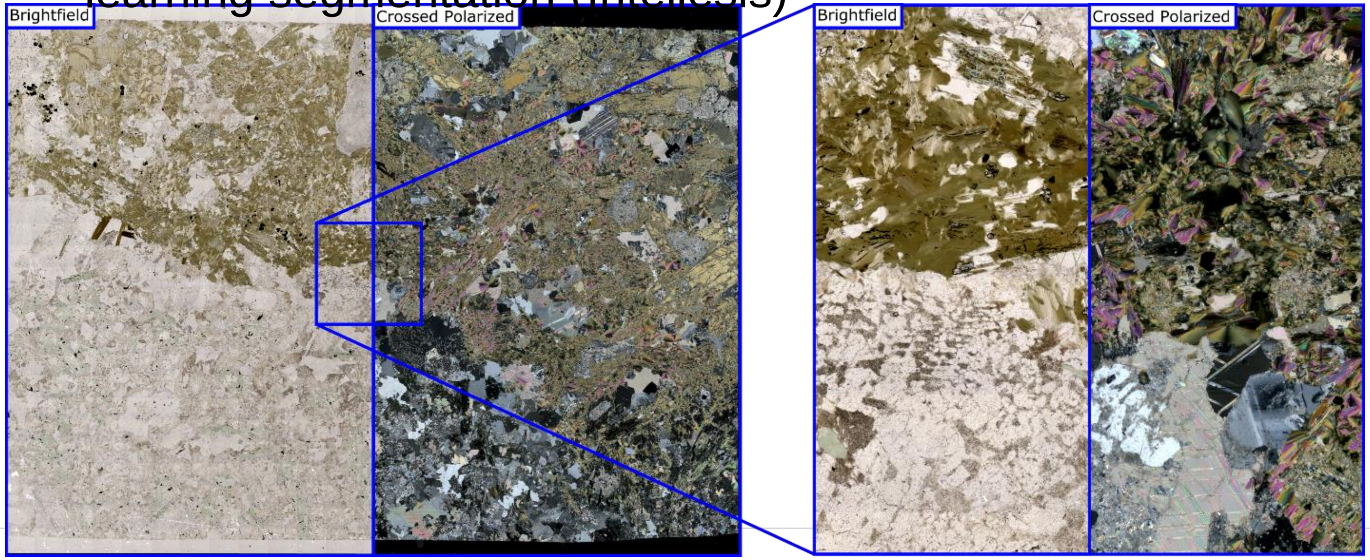
Input image data: Multi channel Xpol

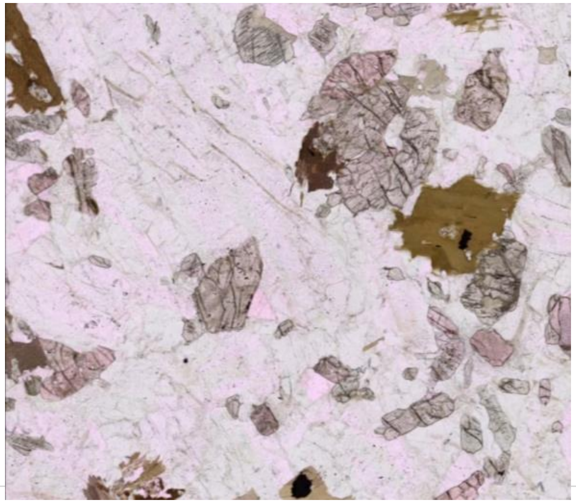
Software package: Petrography analysis toolbox

Digital Petrography
Automated multi-polarization

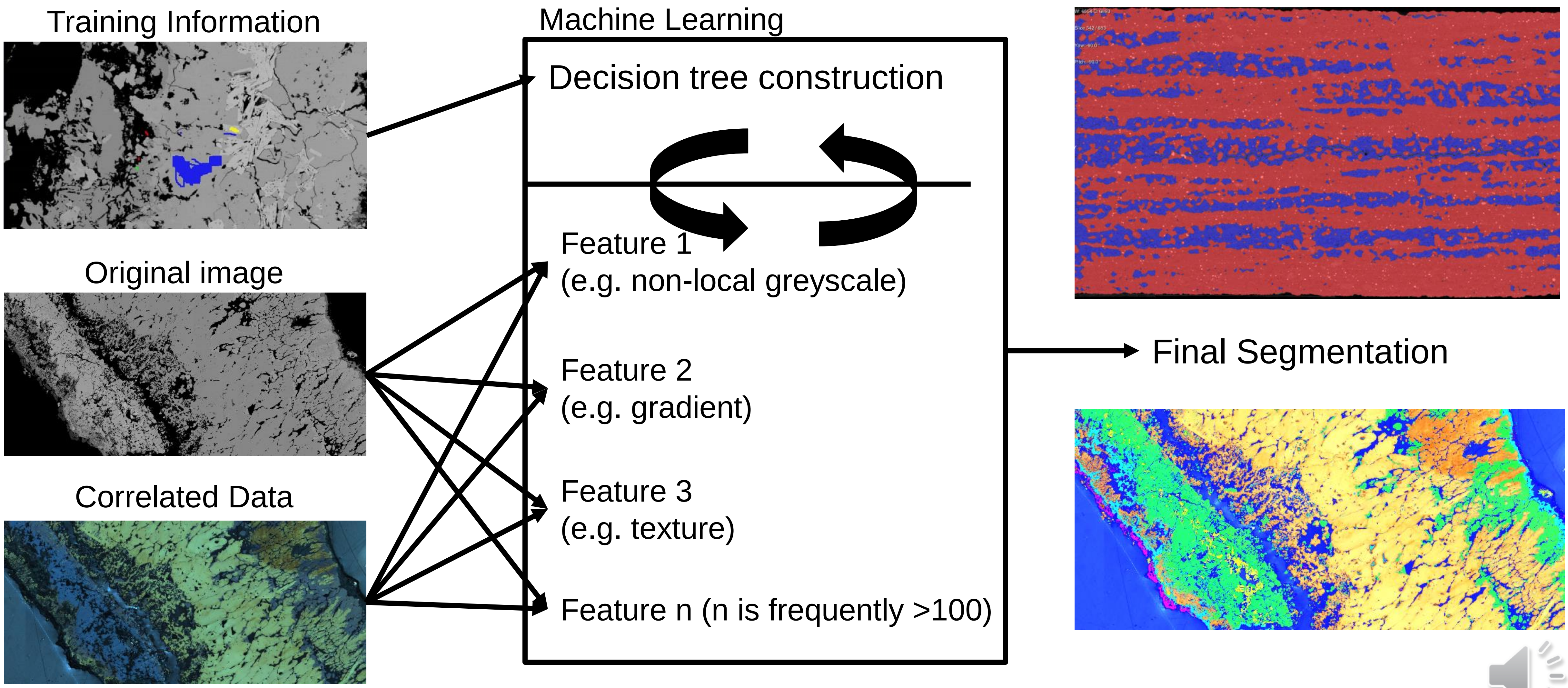
- Multi-slide handling (50-100 slides at a time) with programmatic profile acquisition
- Multimodal acquisition:
  - Multiple spatially registered crossed polarizers (multipol)
  - Brightfield
  - Fluorescence
- Integrated analytical software (ZEN) including power machine learning segmentation (Intellesis)



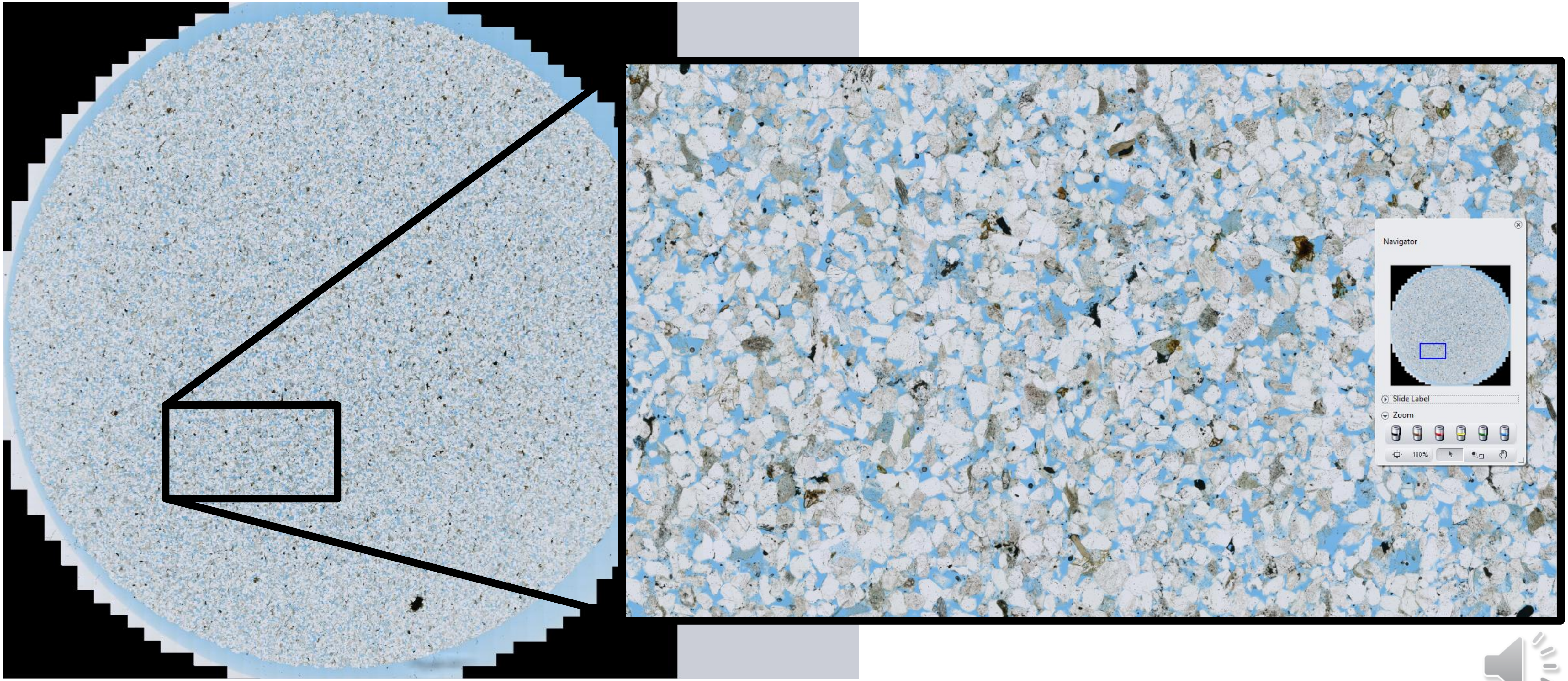




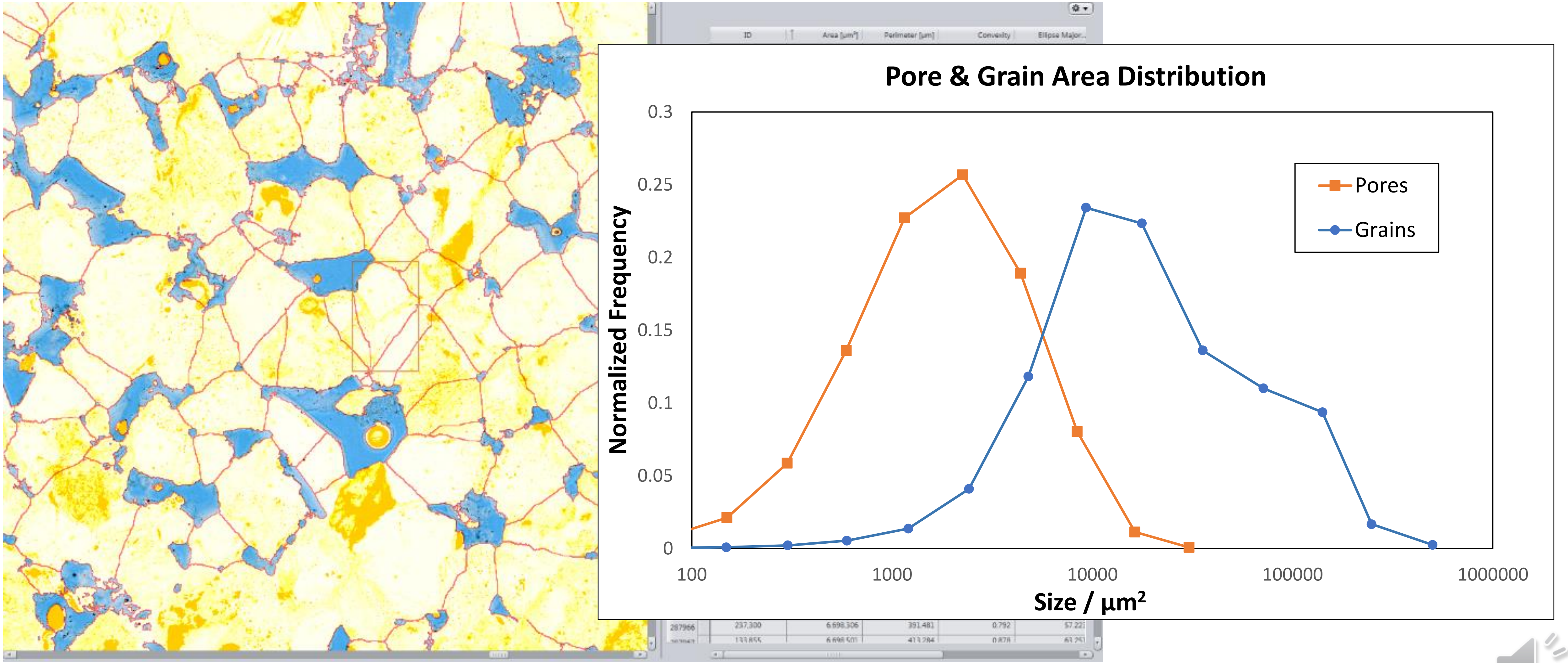
How might we go through this workflow?



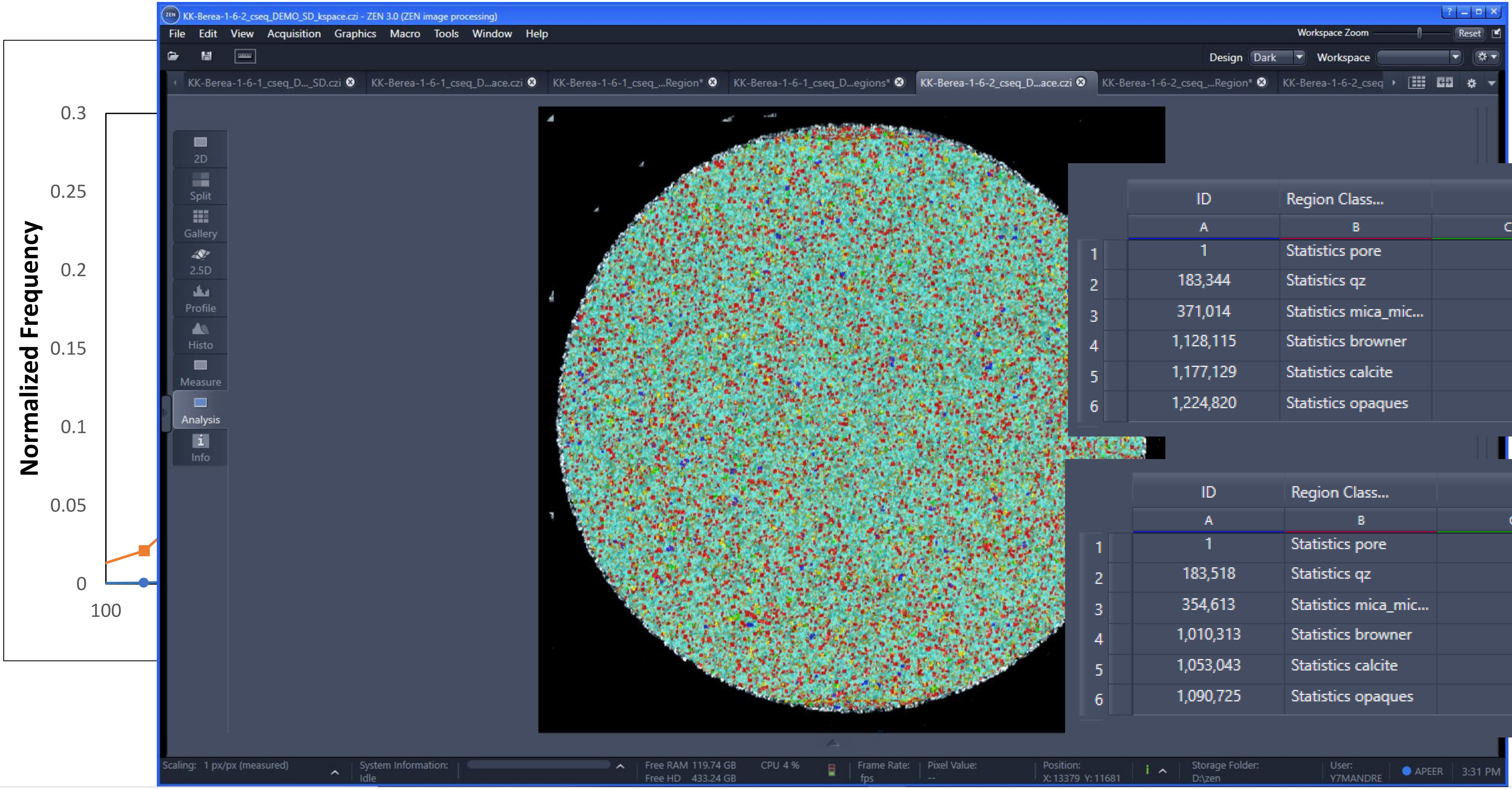
Structural Analysis of Berea Sandstone
Fully Digitized Dataset



Structural Analysis of Berea Sandstone
Level 1 analysis: pore vs grain
Object Separation & Analysis

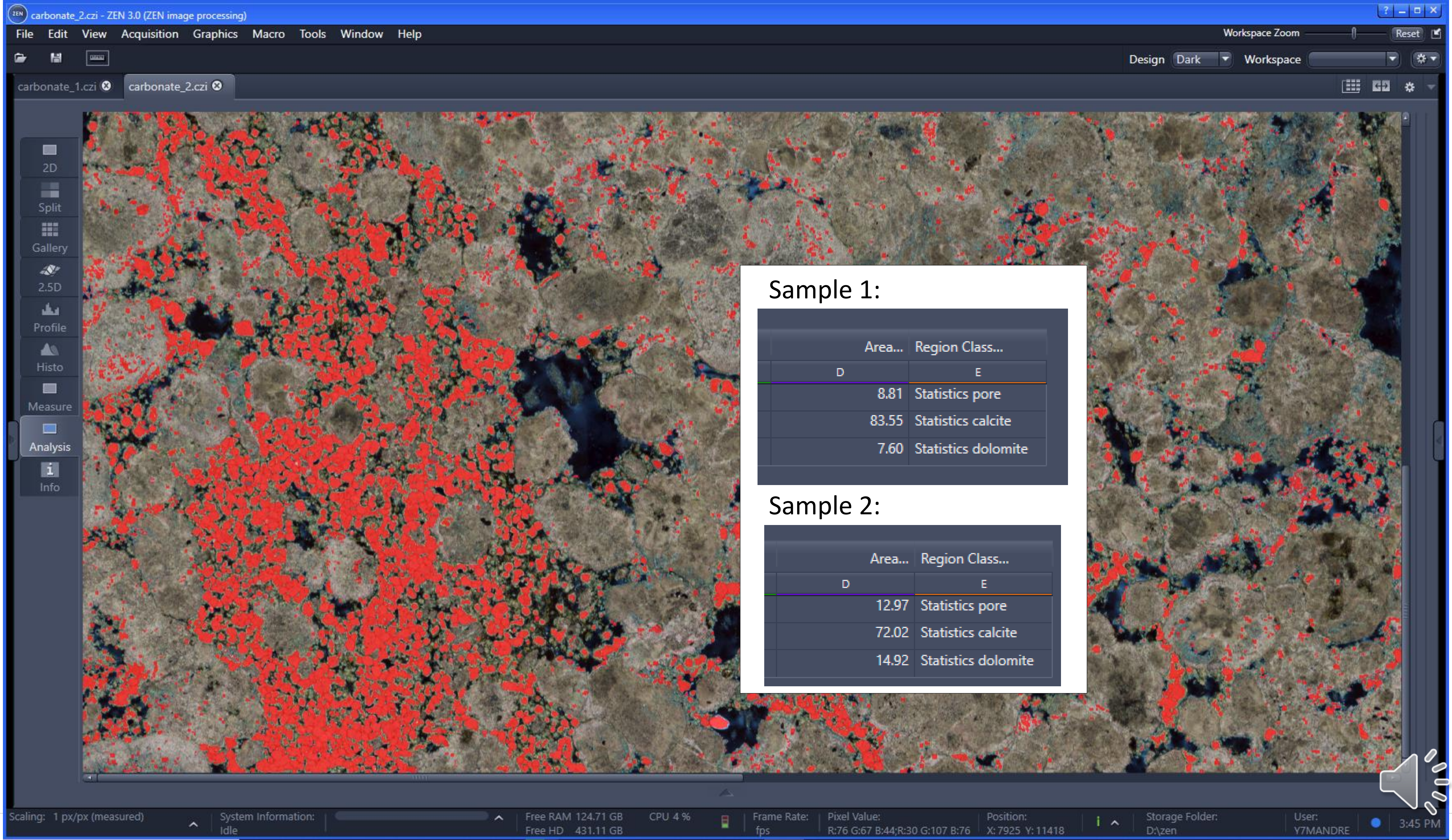


Mineralogical Analysis of Berea Sandstone
Level 2 analysis: Multiple mineralogies



	ID	Region Class...	Area...
	A	B	C
1	1	Statistics pore	19.81
2	183,344	Statistics qz	69.96
3	371,014	Statistics mica_mic...	8.43
4	1,128,115	Statistics browner	0.57
5	1,177,129	Statistics calcite	0.33
6	1,224,820	Statistics opaques	0.89

	ID	Region Class...	Area...
	A	B	C
1	1	Statistics pore	18.38
2	183,518	Statistics qz	72.36
3	354,613	Statistics mica_mic...	7.59
4	1,010,313	Statistics browner	0.50
5	1,053,043	Statistics calcite	0.34
6	1,090,725	Statistics opaques	0.83



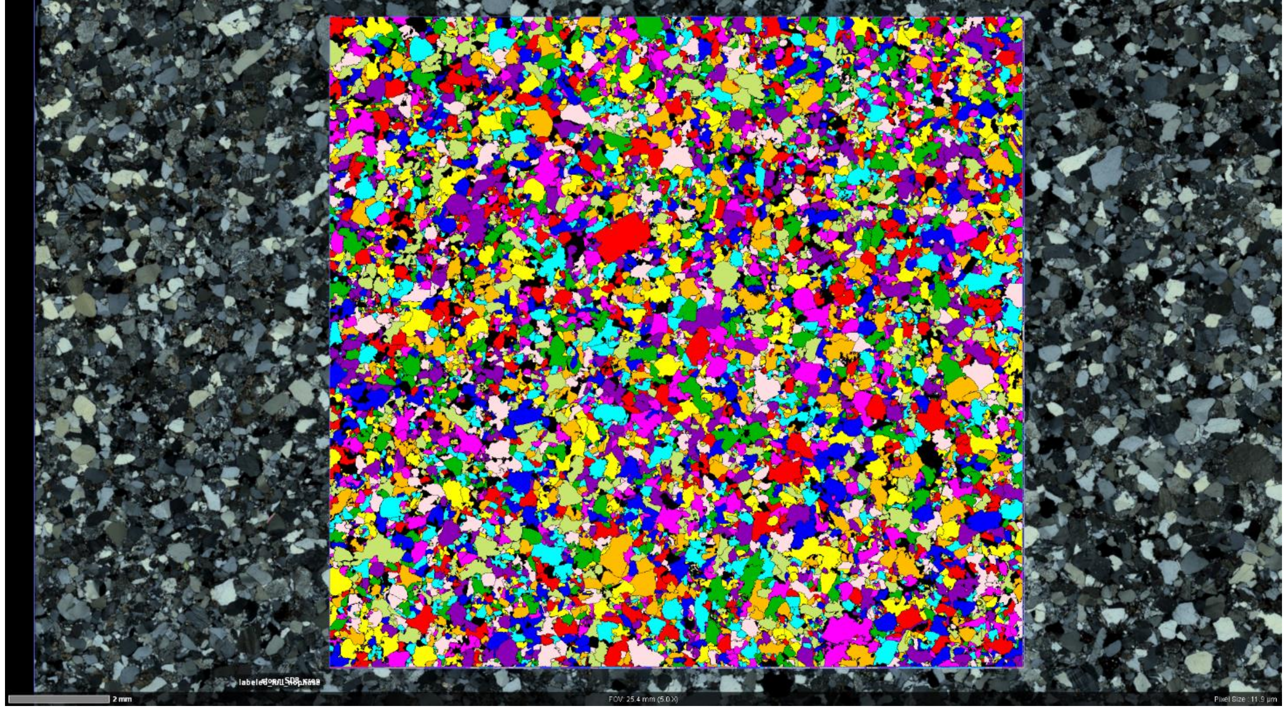
Sample 1:

Area...	Region Class...
D	E
8.81	Statistics pore
83.55	Statistics calcite
7.60	Statistics dolomite

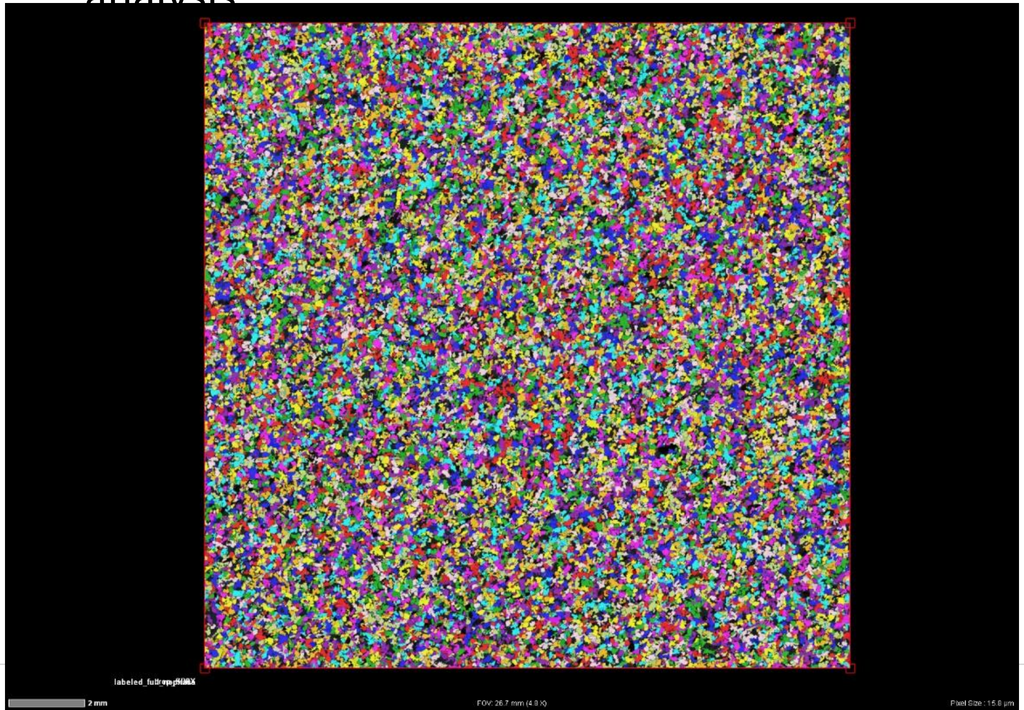
Sample 2:

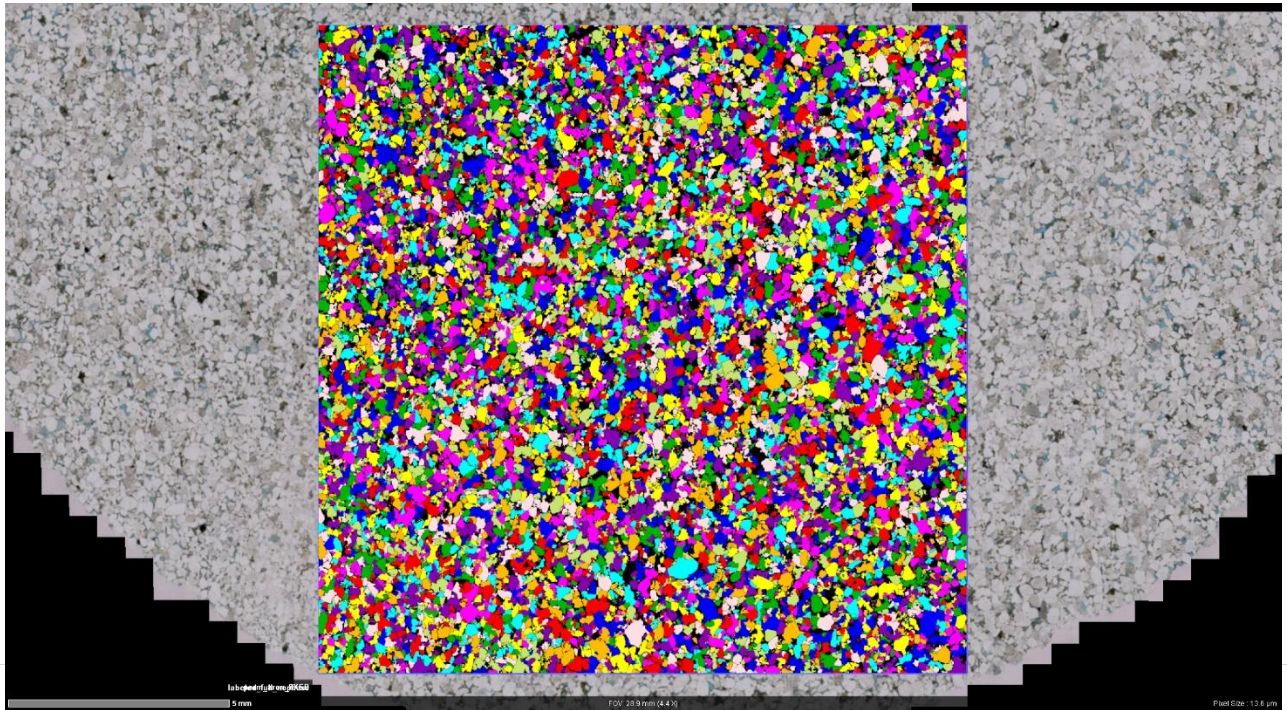
Area...	Region Class...
D	E
12.97	Statistics pore
72.02	Statistics calcite
14.92	Statistics dolomite

Level 3 analysis: Phase fitting
Berea, Stoer, Permian, metaquartzite

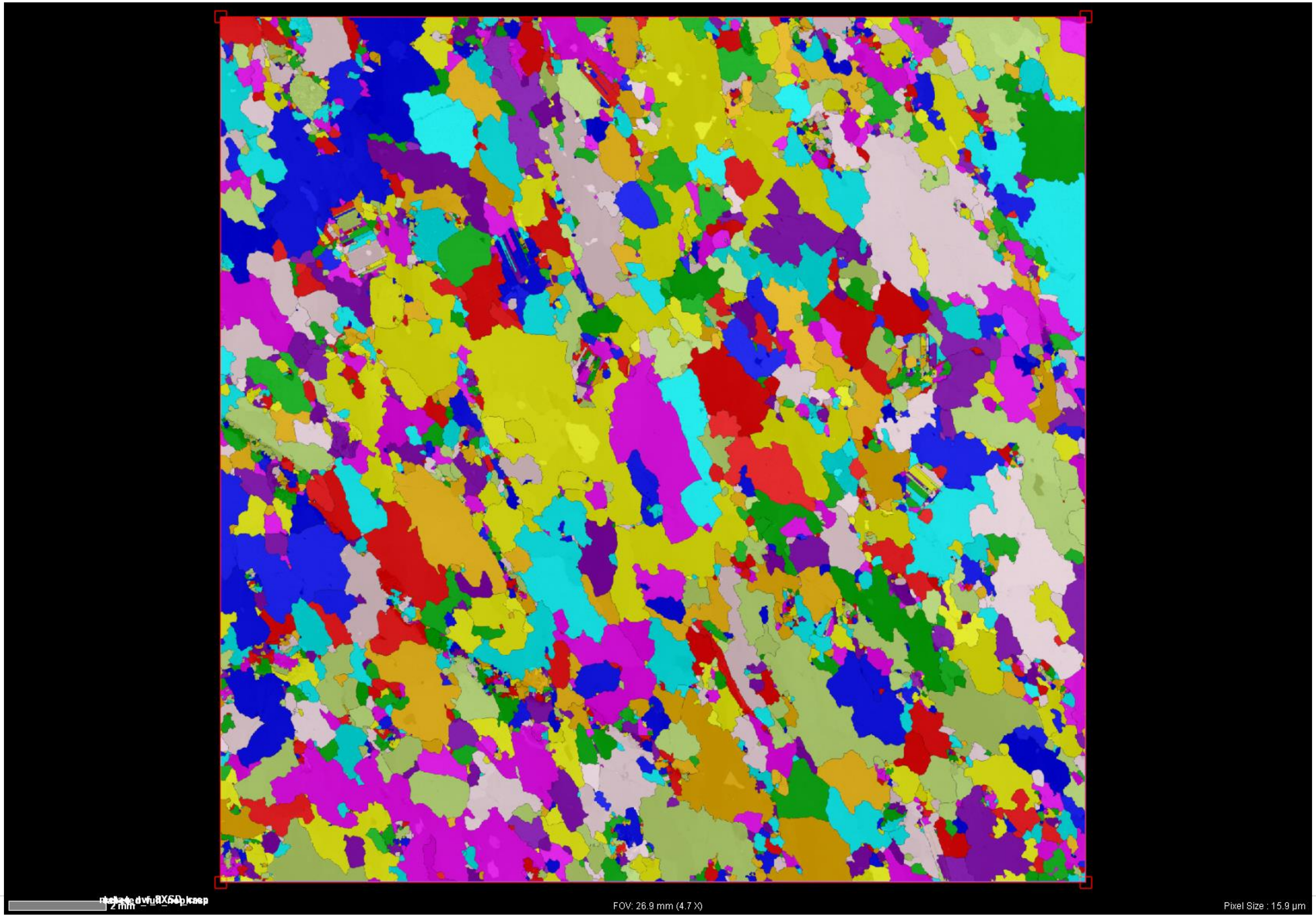


- 200-500Ma
- Completely automated grain identification
- Outputs:
  - Angular solution
  - Separated grain images
  - Grain by grain measurements (size, shape etc)
- Optional level 2 (mineralogy) mask for phase by phase analysis





Level 3 analysis: Phase fitting
Metaquartzite



Acknowledgements

- **MEGECON Organizing Committee**
- **MEAI BH Team**
- **Prof. Vishwanath. U**
- **Dr. Sharath Kumar (VSKDU, Nandihalli)**
- **Rakesh M.M (Co-Founder, Mine Magma)**
- **Carl Zeiss**

ZEISS

Seeing beyond