High Definition Mineralogy by QEMSCAN: From Exploration to Processing

Focus on Automated/Process Mineralogy

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WHEN YOU NEED TO BE SURE

SGS

What is High Definition Mineralogy?

- It is the combination of Experience, Expertise and State of the Art Instrumentation used as a Quantitative tool used for;
  - Defining Geometallurgical Domains
  - Predictive and problem solving tool for metallurgical processing
  - Process Mineralogy; Base metals, PGE, Au, REE, Li etc.
  - Ore Characterization
  - Environmental Mineralogy
  - Forensics
  - Indicator Minerals
  - Upstream Oil and Gas Applications
  - Slags

QEMSCAN Background

- **QEMSCAN:** an acronym for Quantitative Evaluation of Minerals
- Developed as an analytical mineralogical instrument used to obtain high volume, rapid and reproducible analysis for mineral processing industry
- More traditional applications to the mining sector include Base Metal Deposits, PGM's (Au, Pt & Pd) & Heavy Mineral Sands
- Newer Applications include the Industrial Mineral Sector, Environmental Mineralogy, Coal, Oil and Gas Industries and Geometallurgical mapping & modeling

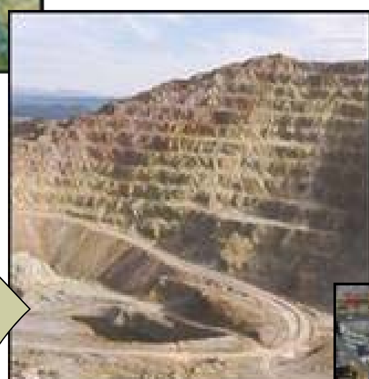
QEMSCAN - Applications

- Exploration (ExploMin™)
- Resource Geometallurgy
- Production forecasting
- Process design and development
- Plant metallurgical quality control
- Plant optimization

Exploration & Development

Grade & volume

Mining



Grade & tonnes

Processing

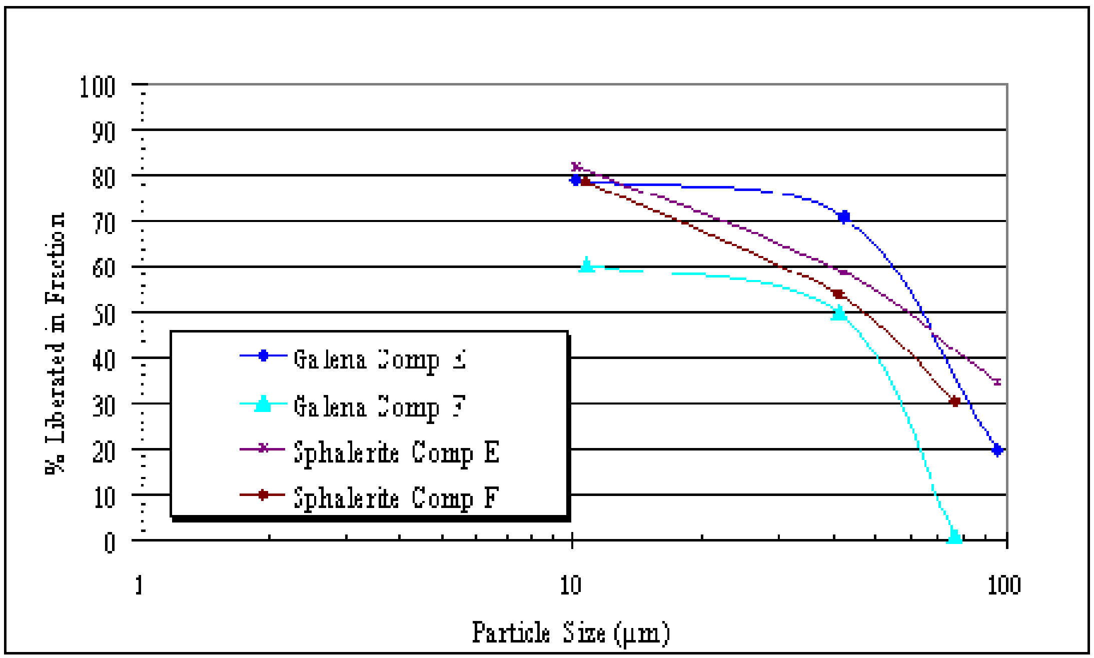
Grade & recovery

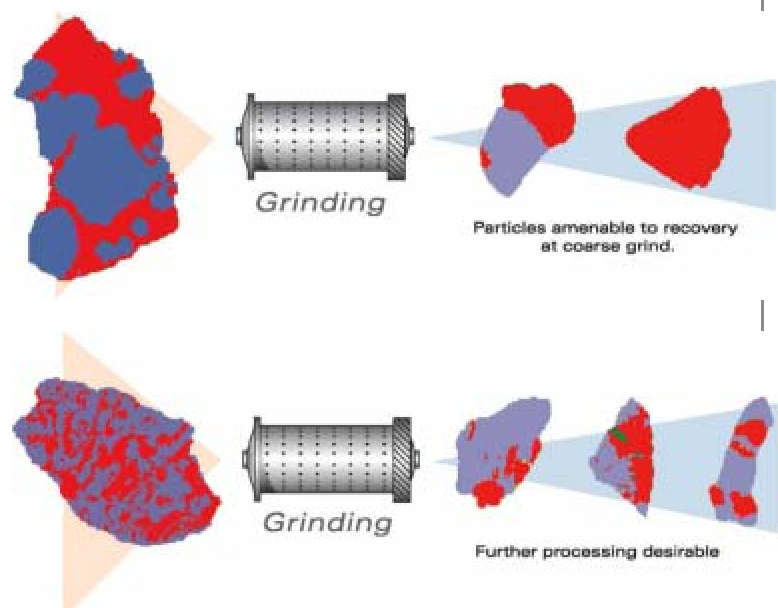
Where's the Value for Metallurgists?

- Metallurgist - GeoMet
  - Linking Mineralogical Data with Metallurgical performance based on
    1. Mineral Abundances
    2. Grain Size
    3. Liberation Characteristics of target minerals
- Ultimately the Deposit type/Minerals within the Deposit will dictate the extraction process
- The characteristics of the minerals will help determine the optimum parameters for mineral concentration.

Where's the Value for Metallurgists?

- Predictive Tool for Grinding
  - The overall mineral assemblage and textural association will be a key factor for predicting how much energy will necessary to grind a sample within a block.
  - Predict Grind Targets based on mineral liberation vs. particle size can be used to determine potential primary and secondary grind targets.





Predictive Tool

- For Flotation
  - Determine the distribution of Recoverable vs. Non-Recoverable elements
    1. Ni-Sulphides (Pentlandite, Millerite) vs. Ni in Silicates (Serpentine, Talc)
    2. This will help determine the Grade vs. Recovery
- For Hydromet
  - Determine the Elemental Deportment of desired Element(s)
    1. Ni-Laterites -- Leaching parameter can be determined by different Ni mineral hosts (serpentine, talc, chlorite)

Common Sample Type - Mineral Processing

- **Feeds/Comps** – to determine the bulk mineral assemblage which will aid in flowsheet development
- **Tailing Products** – what is the loss to tailing and should a particular element been recovered? E.g. Cu loss to tailing during flotation – was it a Cu-sulphide that is finely disseminated or was different copper mineral that would not float
- **Concentrates** – why did this sample not achieve a concentrate grade? Liberation problem of the target mineral? Entrainment of other minerals diluting the con?
- **Ore Variability Samples** – Based on previous work (in conjunction with the metallurgy), predictions on metallurgical performance can be made based on the mineral distributions and exposure.

QEMSCAN Data Outputs

- **Data is processed using the iExplorer Software**
  - **Data Outputs include:**
    - **Modal**: mineral abundance
    - **Grain size**: liberation size
    - **Mineral occurrence** – how? (texture / habit)
    - **Mineral liberation** – free, liberated, middling or locked
    - **Mineral associations** – what with?
    - **Mineral distribution** by size fraction
    - **Distribution** based on bulk chemistry or physical properties
    - **Elemental deportment**: In which minerals do the elements of interest occur?
    - **Grain Size Distribution**
    - **Mineral Simulation based on:** specific gravity
    - **Grade Recovery**
    - **Mineral Release Curves**

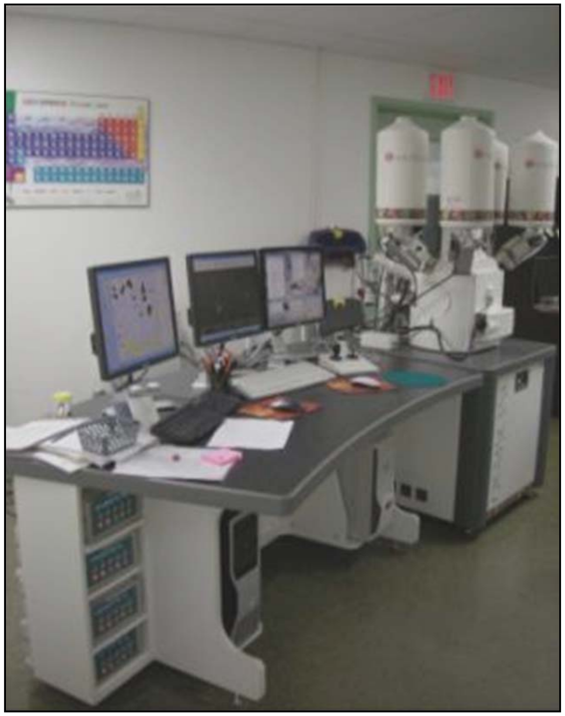
What do we use at SGS?

- High Definition Mineralogical Instrumentation
  - **QEMSCAN**
    - Quantitative Evaluation of Minerals (Flagship Tool) using Scanning Electron Microscopy (SEM) – an automated SEM.
  - **X-Ray Diffraction**
    - Characterizes a sample based on crystallographic structure of minerals
  - **Scanning Electron Microscope**
    - Used for mineral characterization, high magnification imaging, semi-quant analysis by energy dispersive x-ray analysis
    - Provides micro textural information, back scattered images, semi-quantitative analyses; etc.
    - Useful for sulphides and carbonates
  - **Optical Image Analysis**
    - Characterizes minerals on reflective properties (good for simple ores)
  - **Petrographic and Stereoscopic Microscopes**
    - Traditional Mineralogical Analysis using Optical Microscopy

Other Techniques

- **Electron Microprobe**
  - Precision Quantitative Analysis of individual minerals (e.g. low levels of Co in pyrite)
  - Defines the chemistry of sulphides or carbonates, e.g., Ni in pyrrhotite, Co in pentlandite, As in pyrite, Cd in sphalerite etc.
  - Detection limit depends on the matrix (0.01 to 0.1 wt%)
- **Laser Ablation ICP-MS**
  - Defines well the concentration of trace amounts of elements that cannot be determined with the EMPA due to the detection limit restrictions. For example, Hg, Se in sulphides.
  - Detection limit is ppm level.
- **Time of Flight – SIMS and X-ray Photoelectron Spectroscopy**
  - Surface analysis; e..g., Fe speciation on sulphides or Ag on Au-Ag alloys.
- **Dynamic Secondary Ion Mass Spectroscopy (D-SIMS)**
  - Elemental analysis of elements (e.g. Au) within minerals at depth, if colloidal or solid solution.
- **Raman Spectroscopy**
  - Distinction between oxides and oxyhydroxides

QEMSCAN Background



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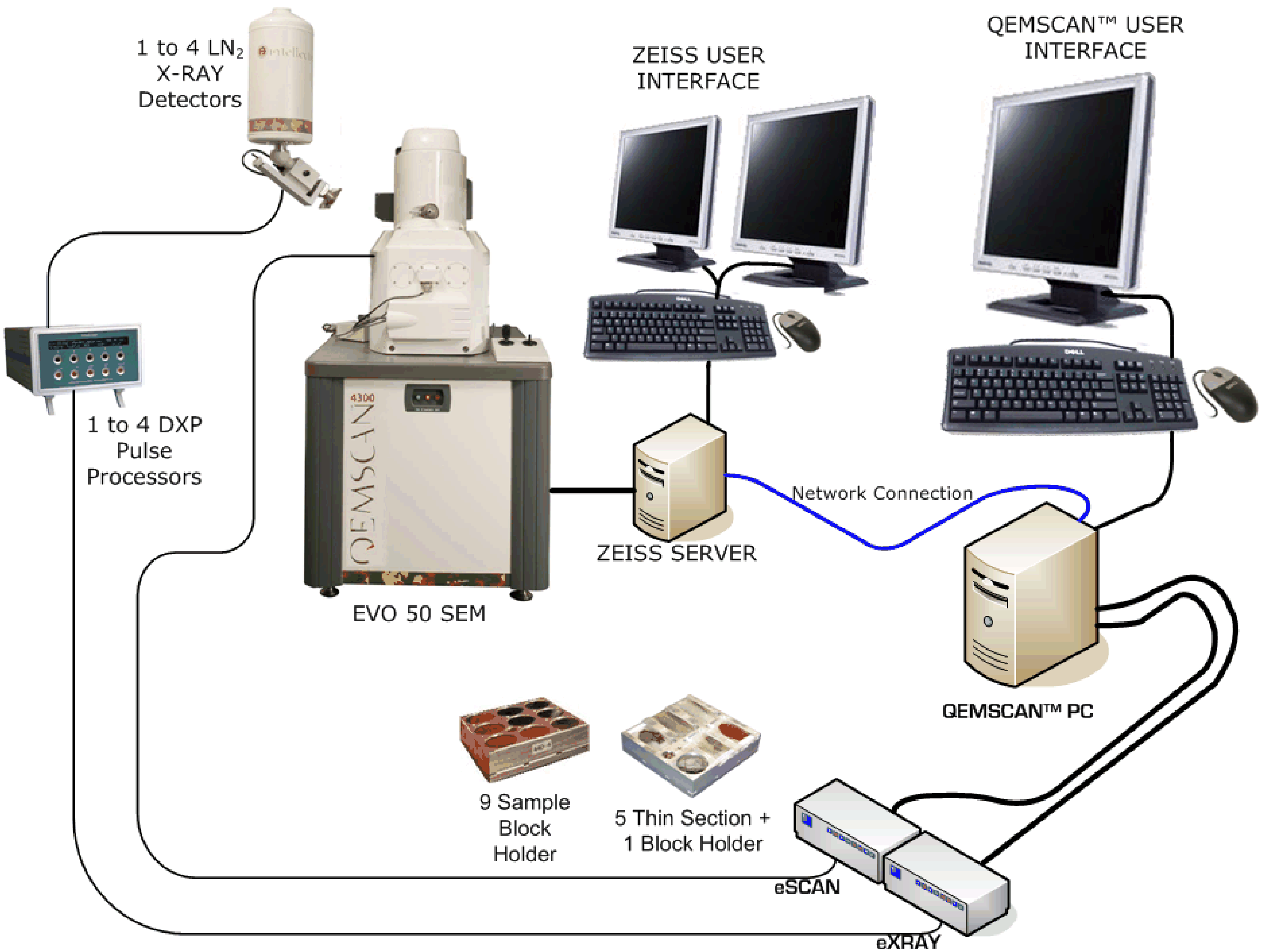
The QEMSCAN System



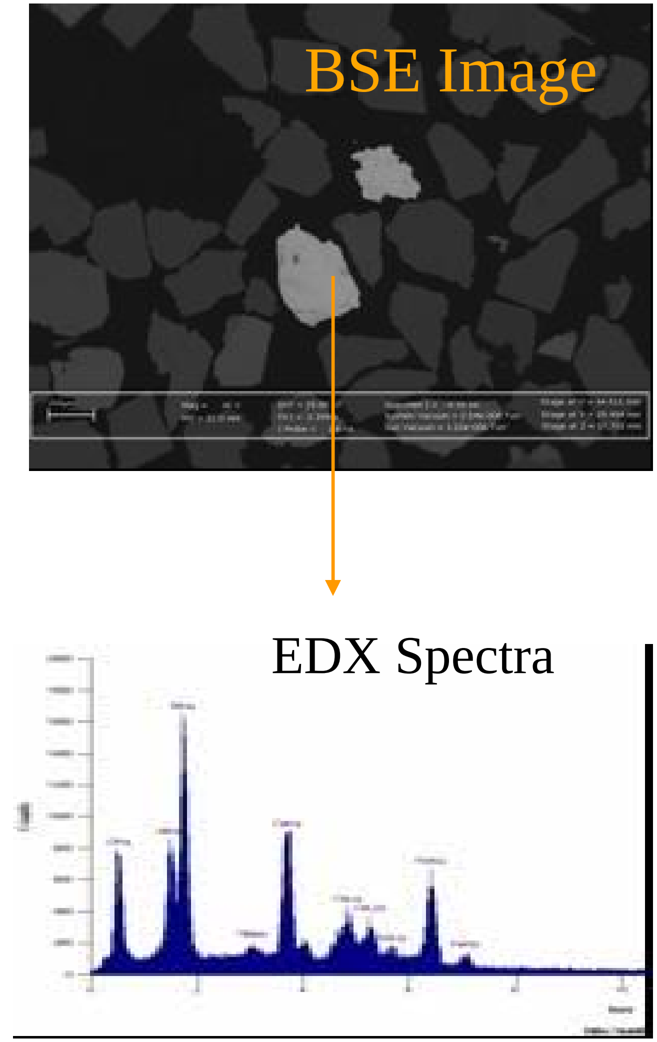
Sample Preparation for QEMSCAN Analysis

- Micro-riffled in order to a representative sample of 1-2 g
- Graphite added (size dependant upon particle size) at a user dependant ratio
  - To provide a supporting matrix for the particles.
  - To ensure dispersion and random orientation of particles.
  - To minimize segregation of particles resulting from density separation.
- Sample “potted” in resin
  - Placed in a pressure vessel to cure to minimize the formation of bubbles during curing.

- Sample block is then ground and polished
  - To ensure a flat well polished surface.
  - Minimal particle relief
  - Limited particle plucking
  - No scratches
- Block then carbon coated ready for QEMSCAN analysis

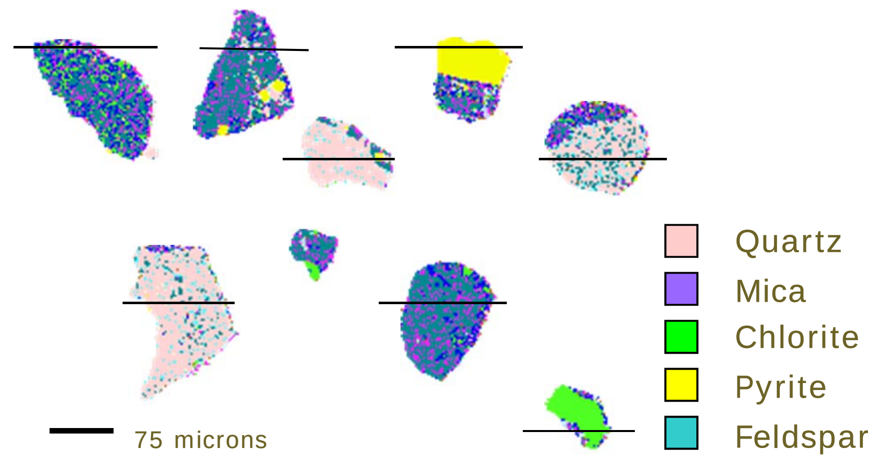
QEMSCAN Hardware

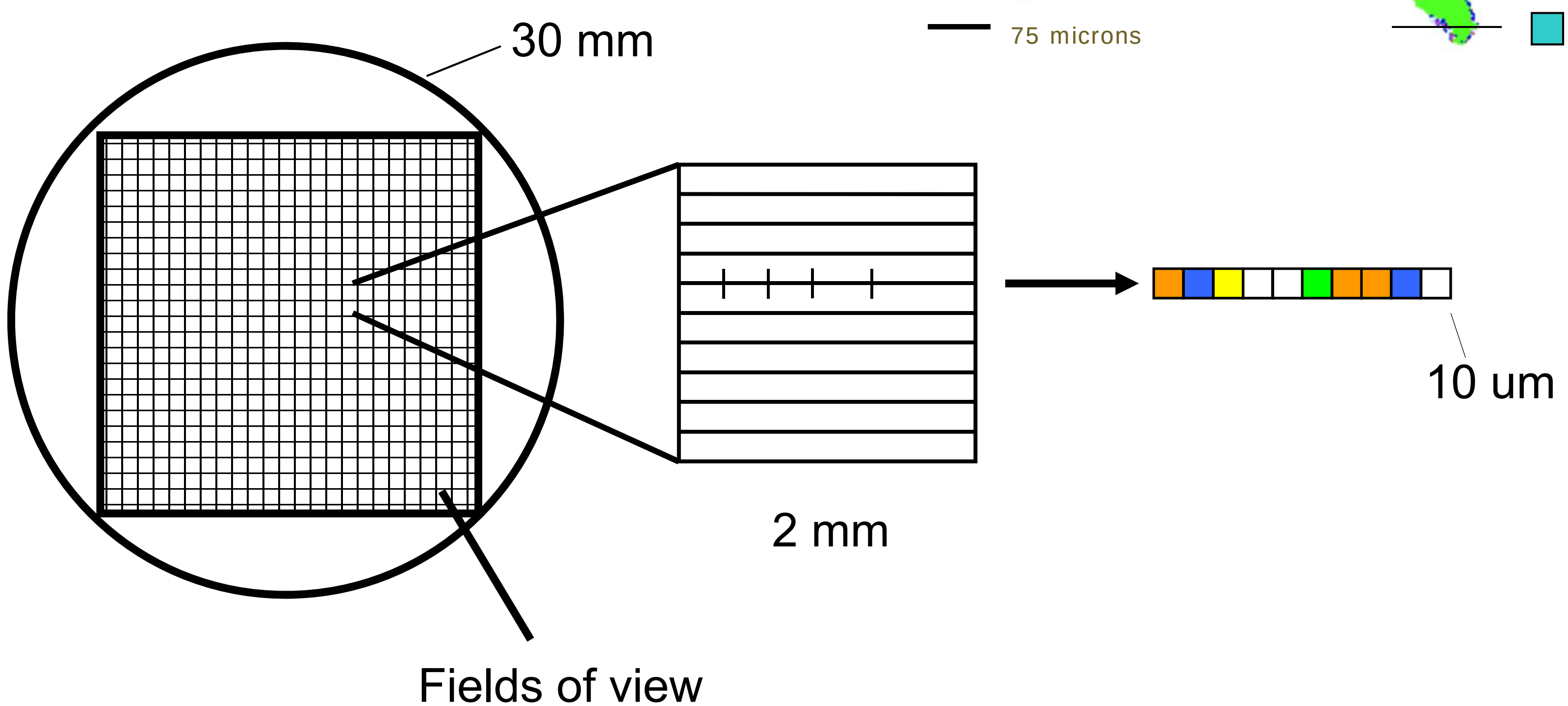
- QEMSCAN combines the technology of a Scanning Electron Microscope (SEM) equipped with Energy Dispersive Spectrometers (EDX) with a hardware/software package known as iDiscover. iDiscover controls the automation of the instrument and the processing of the data.
- The SEM produces an electron beam that excites the electrons in minerals and a chemical X-Ray spectrum and Backscatter Electron Image (BSE) is produced. From the X-Ray counts collected, a mineral definition to distinguish this spectrum can be assigned and input into the mineral library known as a Species Identification Program (SIP).
- Generally, an X-ray spectrum is collected at every 2 to10 µm (Dependent on Application)



MODAL ANALYSIS

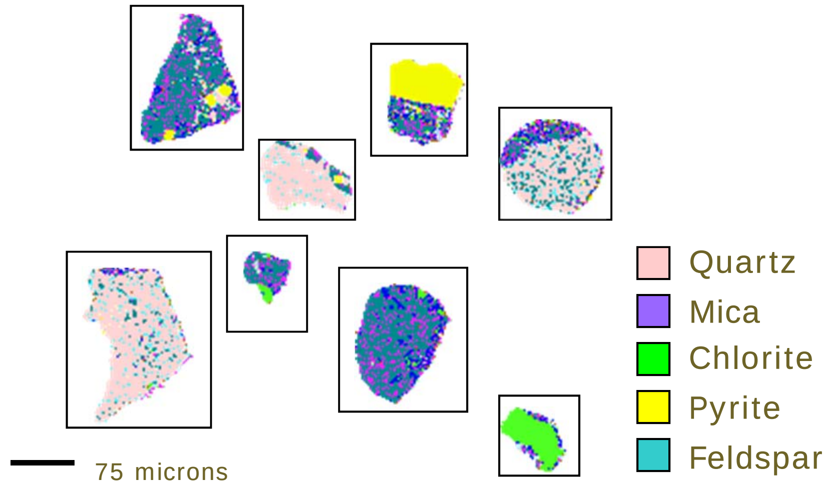
- Numerical Data
- High intercept statistics
- **Deliverables**
  - Modal and grain size data

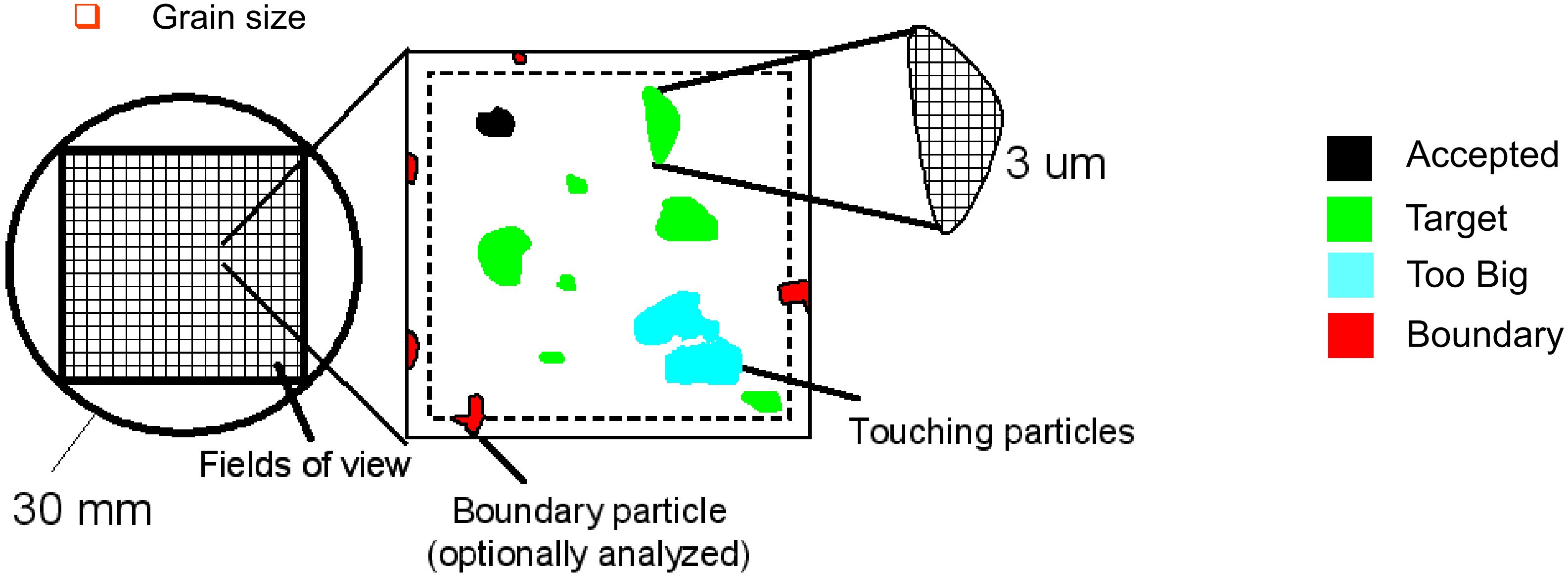




PARTICULATE ANALYSIS

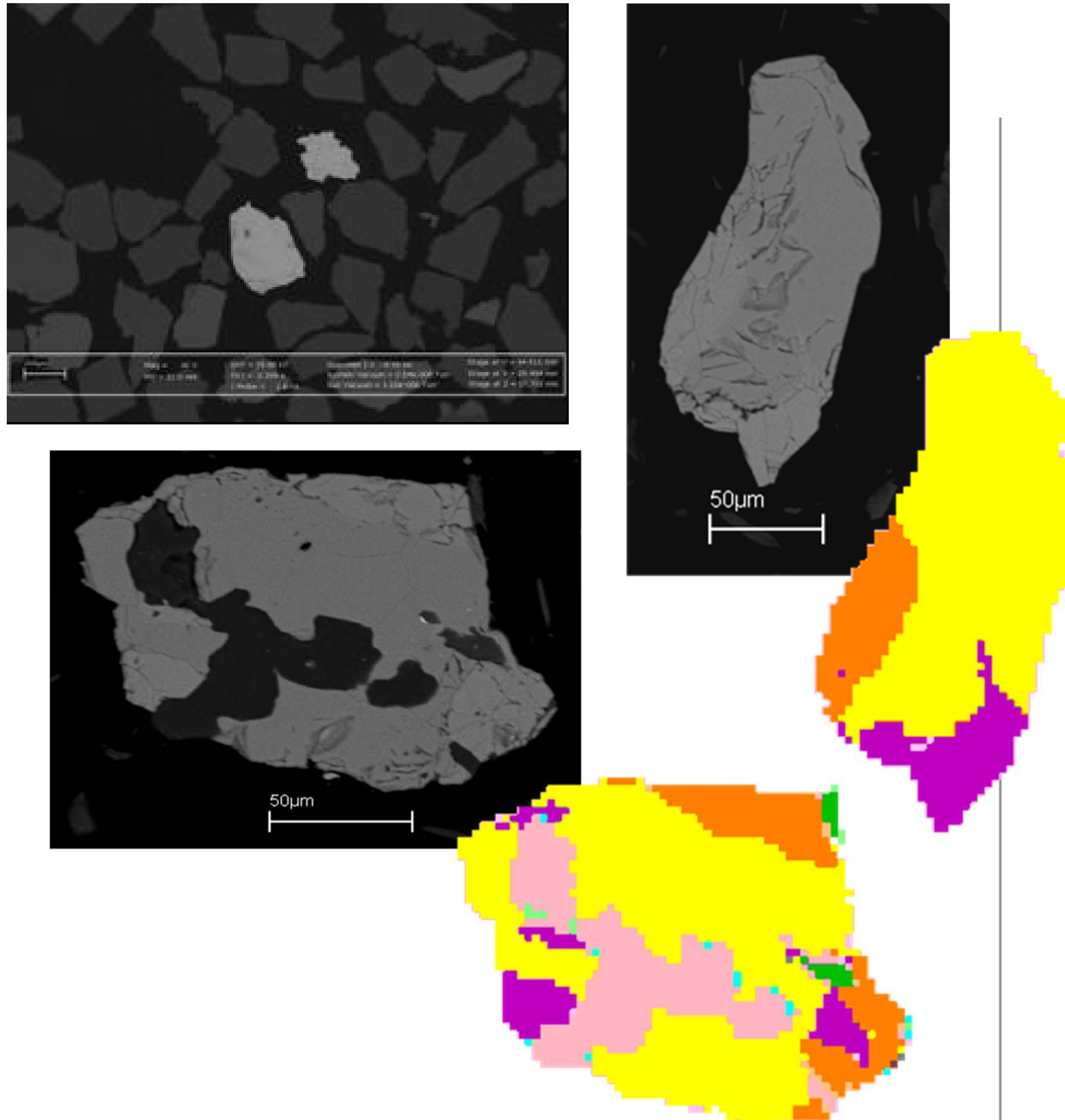
- **Fully maps the particles at set resolution**
  - BSE: grey scale image analysis of field (particle vs. resin)
  - BSE image of particle
  - X-ray analyses (each particle is subdivided into pixels, with every pixel being analyzed separately)
- **Deliverables**
  - Modal mineralogy
  - Exposure
  - Grain size





So what does the QEMSCAN do?

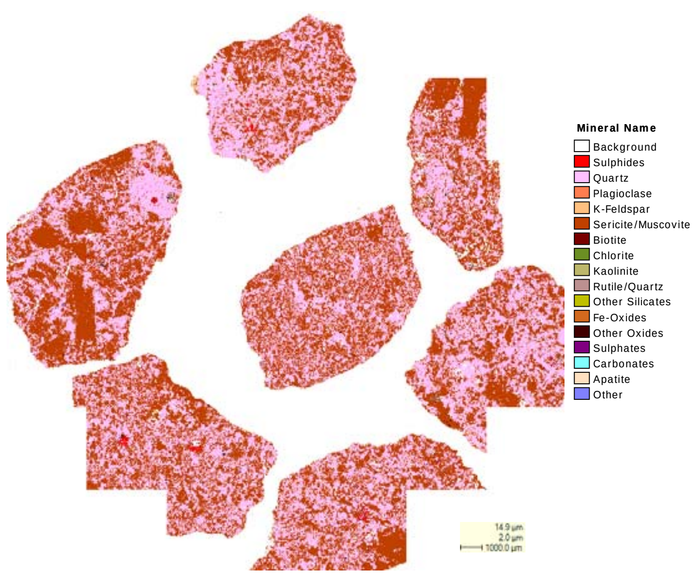
- Maps particles
- using X-ray spectra and BSE Intensity
  - Measures particles at a given resolution (2–15 µm)
  - Creates pseudo images
    - From these images, the locking-liberation and exposure characteristics can be extrapolated
  - *Pyrite (yellow), Silicate (pink), Pentlandite (purple), Chalcopyrite (orange)*

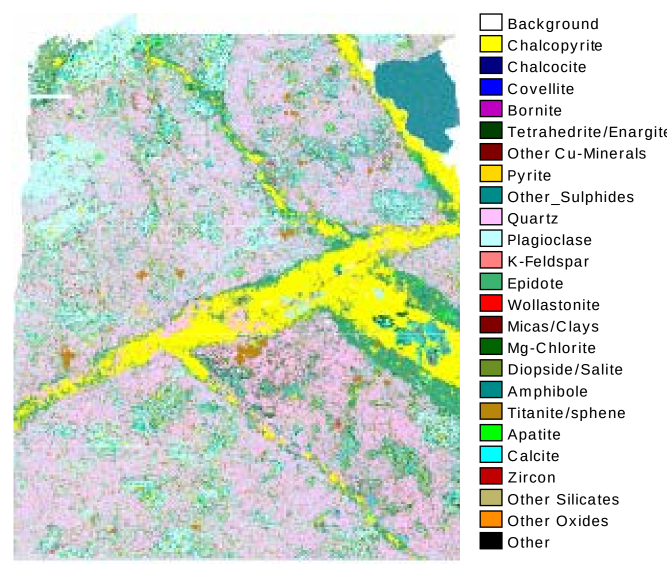


TEXTURAL ANALYSIS

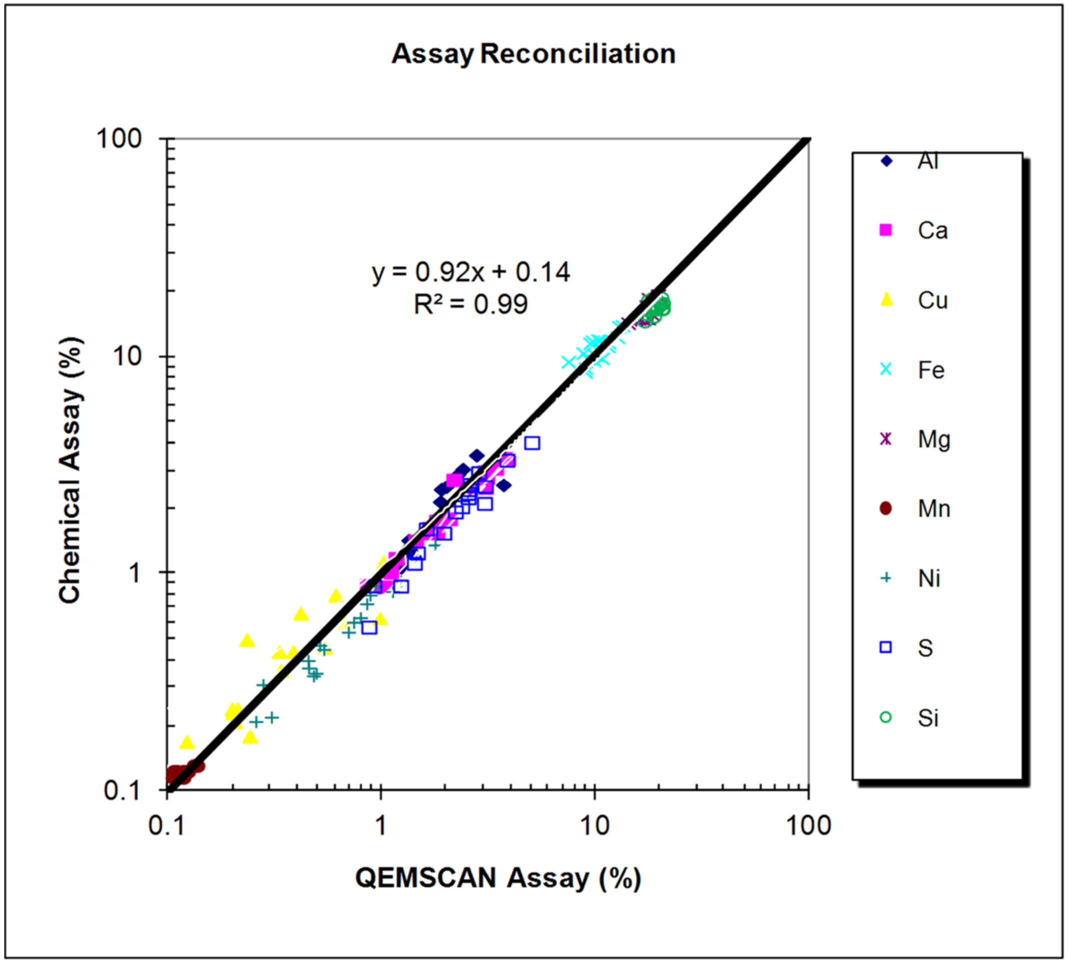
- Maps particles

- A mode of measurement that maps a section of rock (or rock chips) which has been mounted into a polished section or polished thin section.
- It collects a chemical spectrum at a set interval within the field of view. Each field of view is then processed offline and a pseudo image of the core sample is produced.
- Can be used for waste rock samples
- **Deliverables:**
  - Modal mineral abundance for the whole area analyzed
  - Shows the in-situ location of the sulphides/carbonates as a QEMSCAN pseudo coloured image
  - Comparable to the typical optical outputs, but quantitative numbers





QEMSCAN QA/QC



Explomin Modals - Pb-Zn Ore

Sample		**A**	**B**	**C**
Fraction		**-600/+3um**	**-600/+3um**	**-600/+3um**
Mass Size Distribution (%)		100.0	100.0	100.0
Particle Size		13282	19473	22204
		Sample	**Sample**	**Sample**
Mineral Mass (%)	Pyrite	38.9	15.1	32.1
	Cu Sulphides	0.6	0.0	0.0
	Sphalerite	4.1	12.4	61.2
	Galena	44.8	5.1	6.1
	Arsenopyrite	0.1	53.7	0.6
	Enargite	0.4	0.0	0.0
	Other_Sulphides	0.1	0.0	0.0
	Quartz	0.2	0.0	0.0
	Feldspar	0.0	0.0	0.0
	Micas	9.8	0.0	0.0
	Clays	0.1	0.0	0.0
	Other Silicates	0.1	0.0	0.0
	Oxides	0.0	0.0	0.0
	Calcite	0.3	13.2	0.0
	Dolomite	0.2	0.1	0.0
	Other	0.1	0.1	0.0
	Total	100.0	100.0	100.0

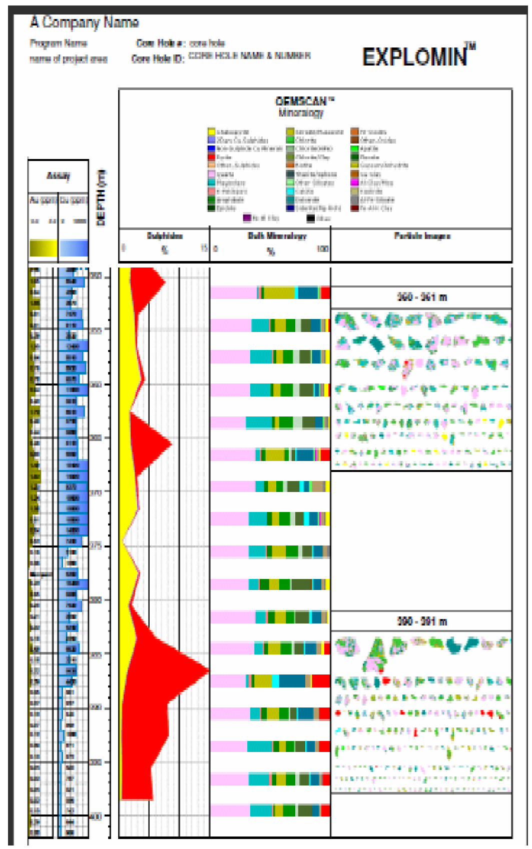
EXPLOMIN Imaging

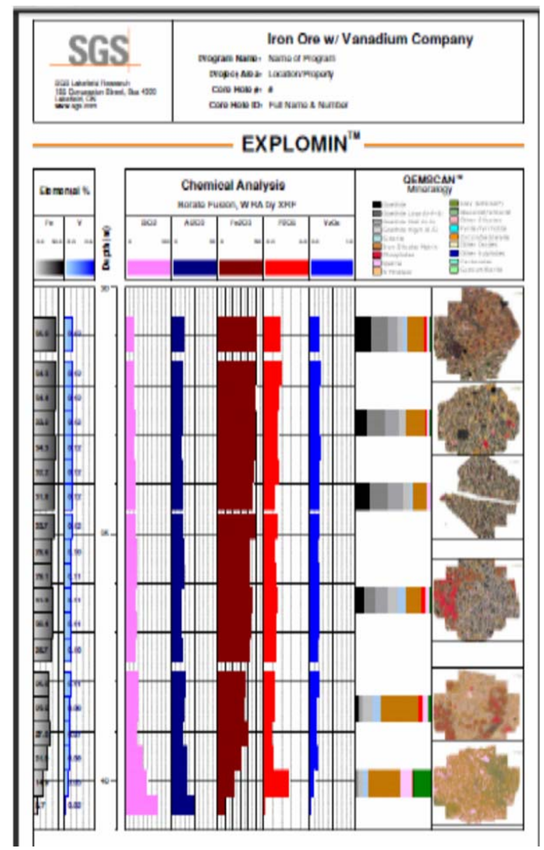
- **Technical deliverables of EXPLOMIN Imaging:**
  - ❑ Addition of particle or

Core false-colour images to the

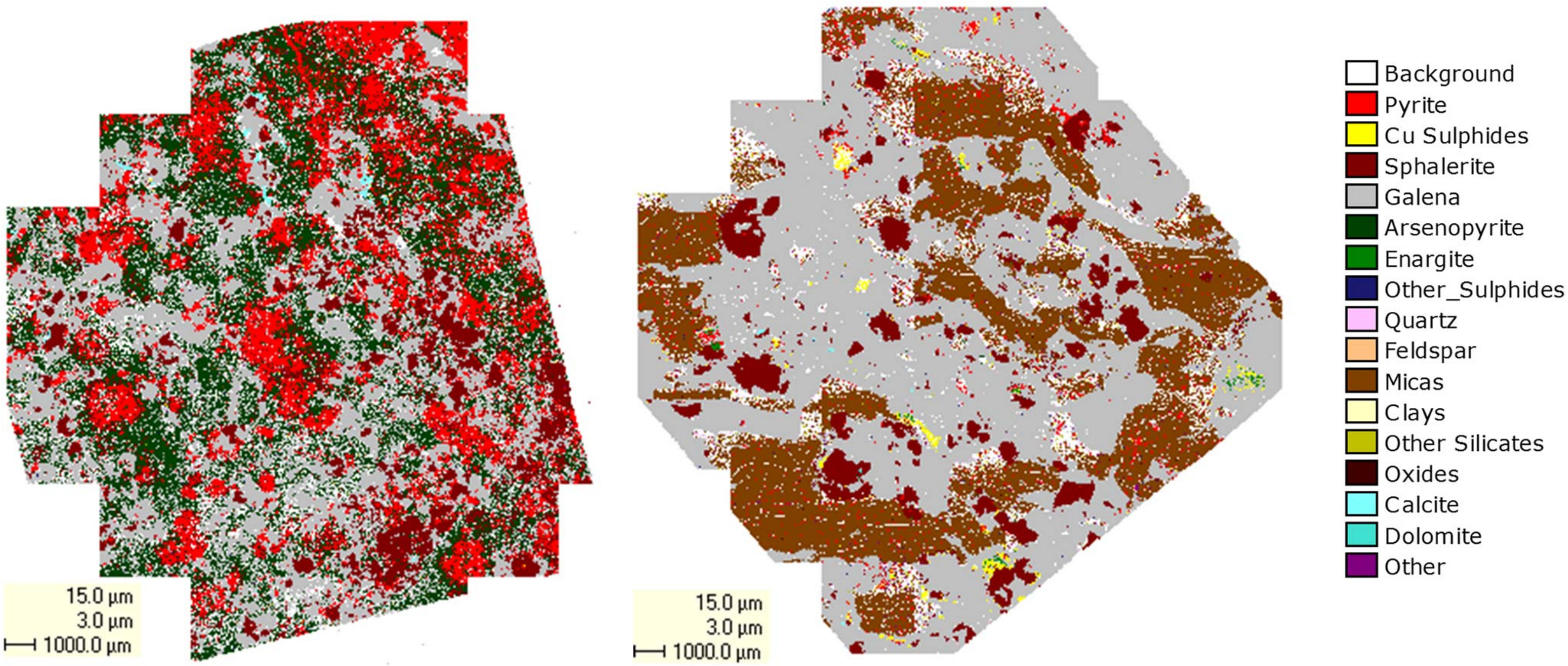
EXPLOMIN™ report

- **Standard output format:**
  - ❑ Modal mineralogy for area
  - ❑ imaged
  - ❑ Tabulated data for area
  - ❑ imaged

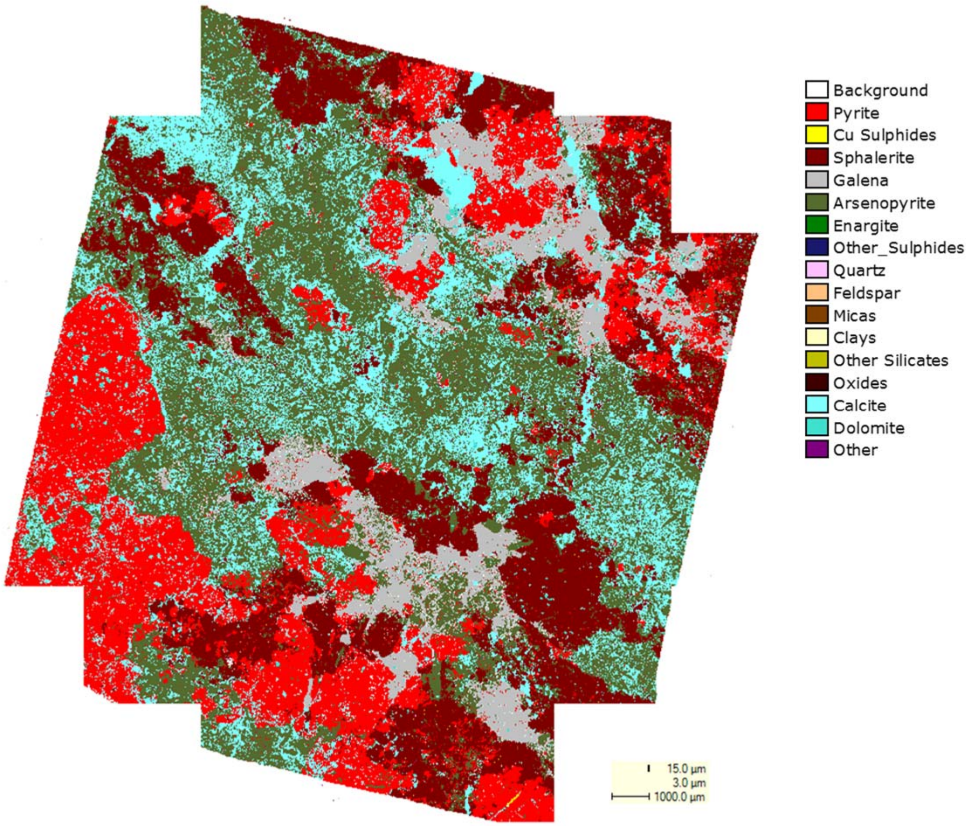


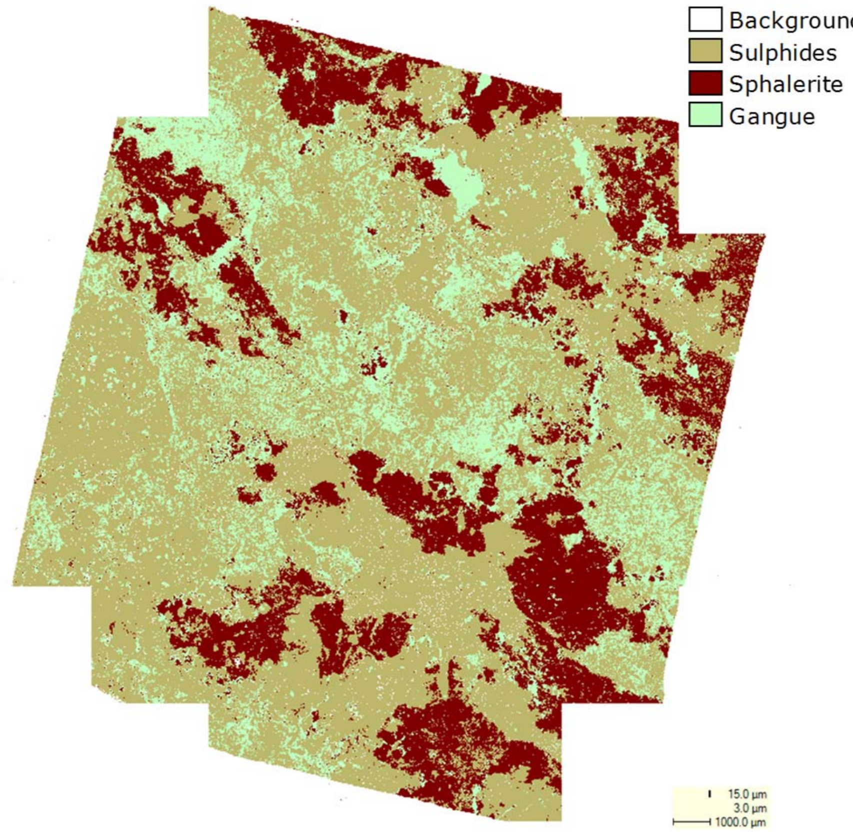


Explomin One Image – 1000 words



Explomin Original List & Short List



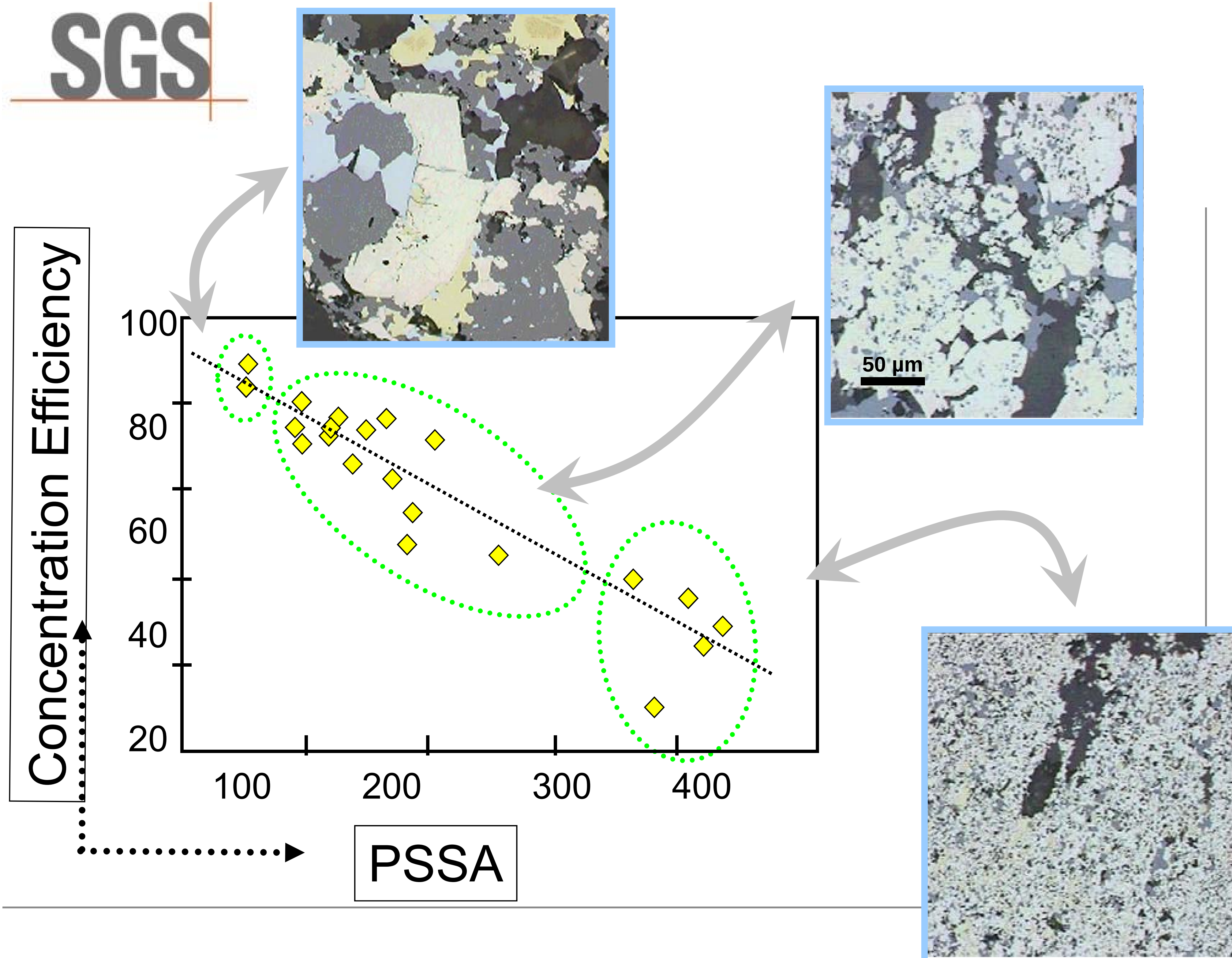


Correlations of Textures

- PSSA: phase specific surface area
  - the surface area per unit volume of a mineral

- **CEI=(C-F)*R/(100-F)**
  - **C: mineral % in a concentrate**
  - **F: mineral % in the feed**
  - **R: recovery**

SGS



Concentration Efficiency
PSSA
100
80
60
40
20
100
200
300
400
50 µm

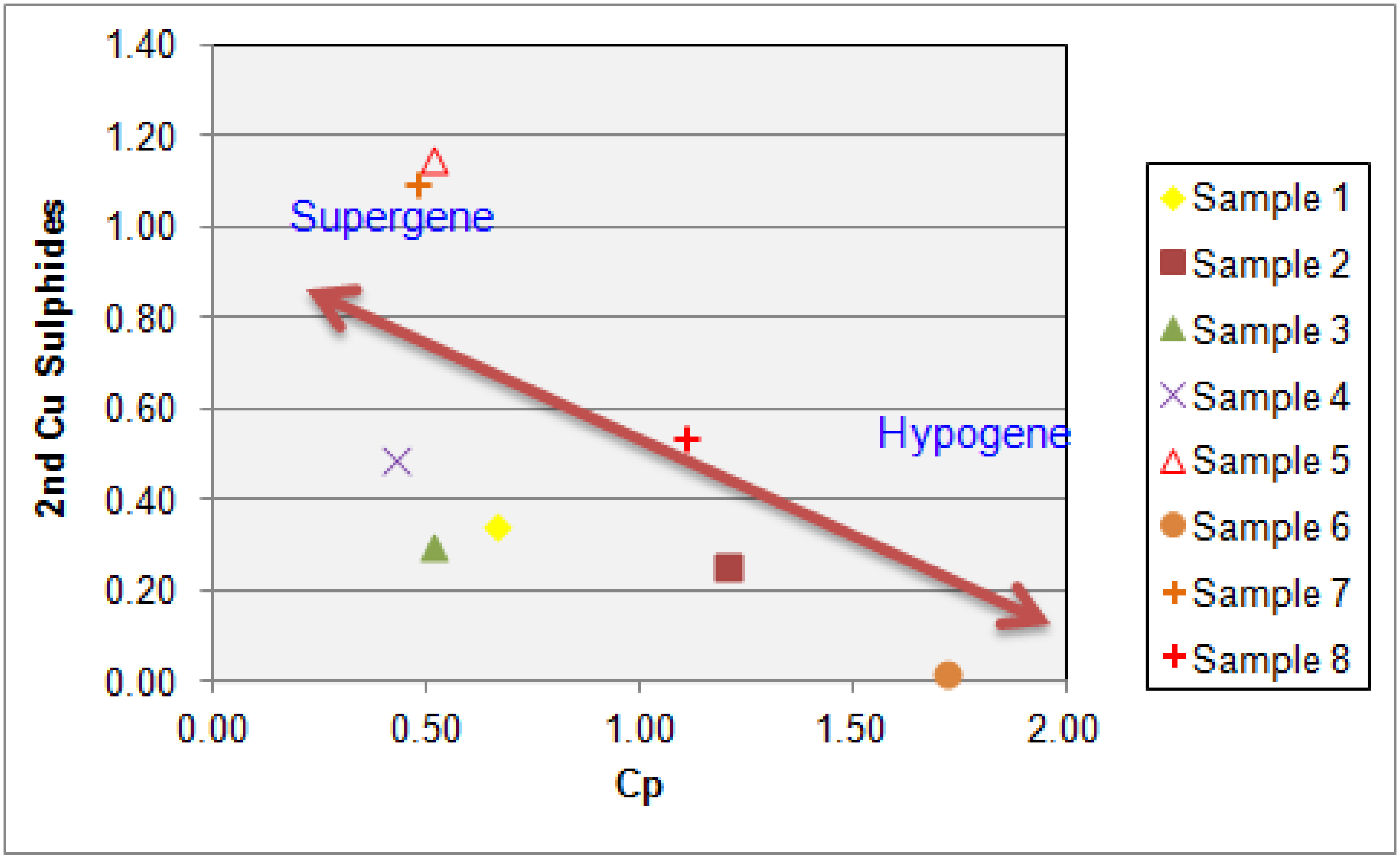
Cu Deposits

- Copper is mined from a variety of different mineral deposit types.
- Nevertheless, deposits with the greatest amounts of contained copper, and thus the most significant exploration targets, are:
    - porphyry,
    - iron oxide-copper-gold (IOCG)
    - sedimentary rock-hosted copper deposits.
    - Cu-Ni magmatic deposits
- Porphyry Cu deposits account for approximately 70% of world copper resources, are the principal source, and as a consequence, are a major exploration objective worldwide.
- Although relatively few IOCG deposits are currently in production, they form an intriguing, but difficult exploration target. The largest examples of this deposit type, Olympic Dam and Salobo, copper systems.
- Sedimentary rock-hosted stratiform copper deposits currently account for approximately 23% percent of the world's copper production and known reserves, in addition to being significant sources of cobalt and silver. These deposits are extremely common, although economically significant deposits are rare.

Cu Minerals

Economically Important Copper Minerals	
bornite	Cu_5FeS_4
chalcopyrite	$CuFeS_2$
chalcocite	Cu_2S
covellite	CuS
cubanite	$CuFe_2S_3$
digenite	$Cu_{1.95-x}S$
stannite	Cu_2FeSnS_4
tennantite	$(Cu,Fe)_{12}As_4S_{13}$
tetrahedrite	$(Cu,Fe)_{12}Sb_4S_{13}$
stannite	Cu_2FeSnS_4
chrysocolla	$CuSiO_3.H_2O$
neoticite	$(Cu,Fe,Mn)SiO_3.H_2O$
tenorite	CuO
pitch limonite	$(Fe,Cu)O_2$
delafossite	$FeCuO_2$
native copper	Cu
cuprite	Cu_2O
atacamite	$Cu_2(OH)_3Cl$
chalcanthite	$CuSO_4{\cdot}5H_2O$
antlerite	$Cu_3SO_4{\cdot}(OH)_4$
brochantite	$Cu_4SO_4{\cdot}(OH)_6$
malachite	$Cu_2CO_3{\cdot}(OH)_2$
azurite	$Cu_3(CO_3)_2{\cdot}(OH)_2$
djurleite	$Cu_{1.95-x}S$

Cu-Porphyry – Composite Samples

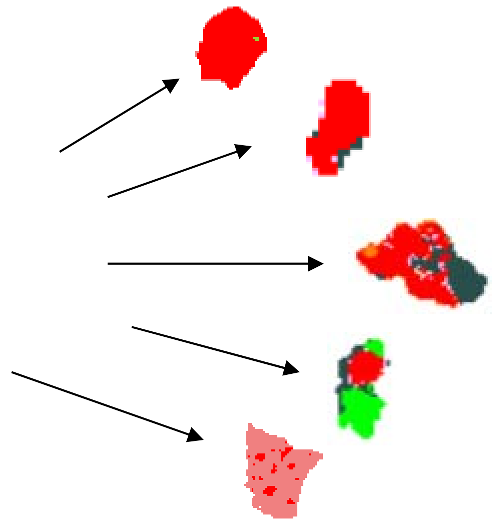


Cu-Porphyry - Modal Mineralogy

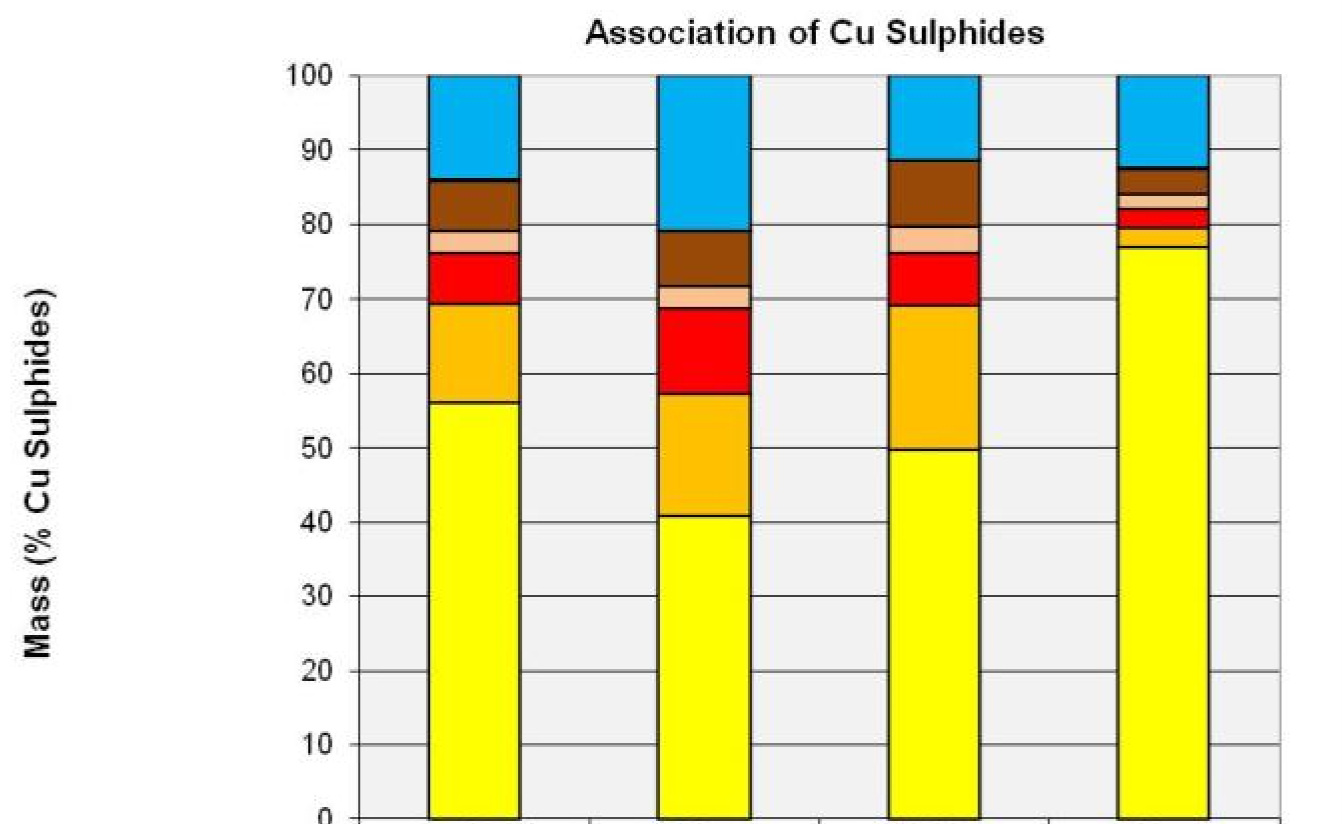
Sample	Combined	+75um		-75/+20um		-20um	
Mass Size Distribution (%)		20.9		36.2		42.8	
	Sample	Sample	Fraction	Sample	Fraction	Sample	Fraction
Pyrite	3.83	1.29	6.17	1.78	4.92	0.75	1.76
Chalcopyrite	0.48	0.14	0.66	0.20	0.54	0.14	0.33
Covellite	0.57	0.10	0.49	0.21	0.59	0.26	0.60
Chalcocite	0.52	0.15	0.74	0.31	0.85	0.06	0.14
Other Cu Sulphides	0.08	0.02	0.11	0.02	0.05	0.04	0.10
Molybdenite	0.02	0.00	0.01	0.01	0.04	0.01	0.01
Other Sulphides	0.03	0.00	0.02	0.02	0.04	0.01	0.03
Quartz	48.61	13.14	62.76	20.90	57.69	14.56	34.01
K-Feldspar	2.92	0.46	2.21	0.99	2.73	1.47	3.42
Albite	1.14	0.13	0.62	0.39	1.08	0.62	1.45
Sericite/Muscovite	37.25	4.95	23.63	9.82	27.11	22.48	52.49
Biotite	0.61	0.09	0.41	0.21	0.59	0.31	0.73
Chlorite	0.69	0.08	0.37	0.24	0.67	0.37	0.86
Clays	1.69	0.22	1.04	0.64	1.75	0.84	1.95
Other Silicates	0.87	0.08	0.39	0.25	0.69	0.54	1.26
Carbonates	0.10	0.00	0.01	0.04	0.11	0.05	0.13
Oxides	0.47	0.06	0.28	0.14	0.40	0.27	0.62
Other	0.12	0.02	0.07	0.06	0.15	0.05	0.12
Total	100.0	20.9	100.0	36.2	100.0	42.8	100.0

QEMSCAN Outputs: Liberation

Liberation classes were defined as the following;
Free: A mineral with ≥95% surface area
Liberated: A mineral with ≥80% but <95% surface area
Midds: A mineral with ≥50% but <80% surface area
Sub-Midds: A mineral with ≥20% but <50% surface area
Locked: A mineral with <20% surface area



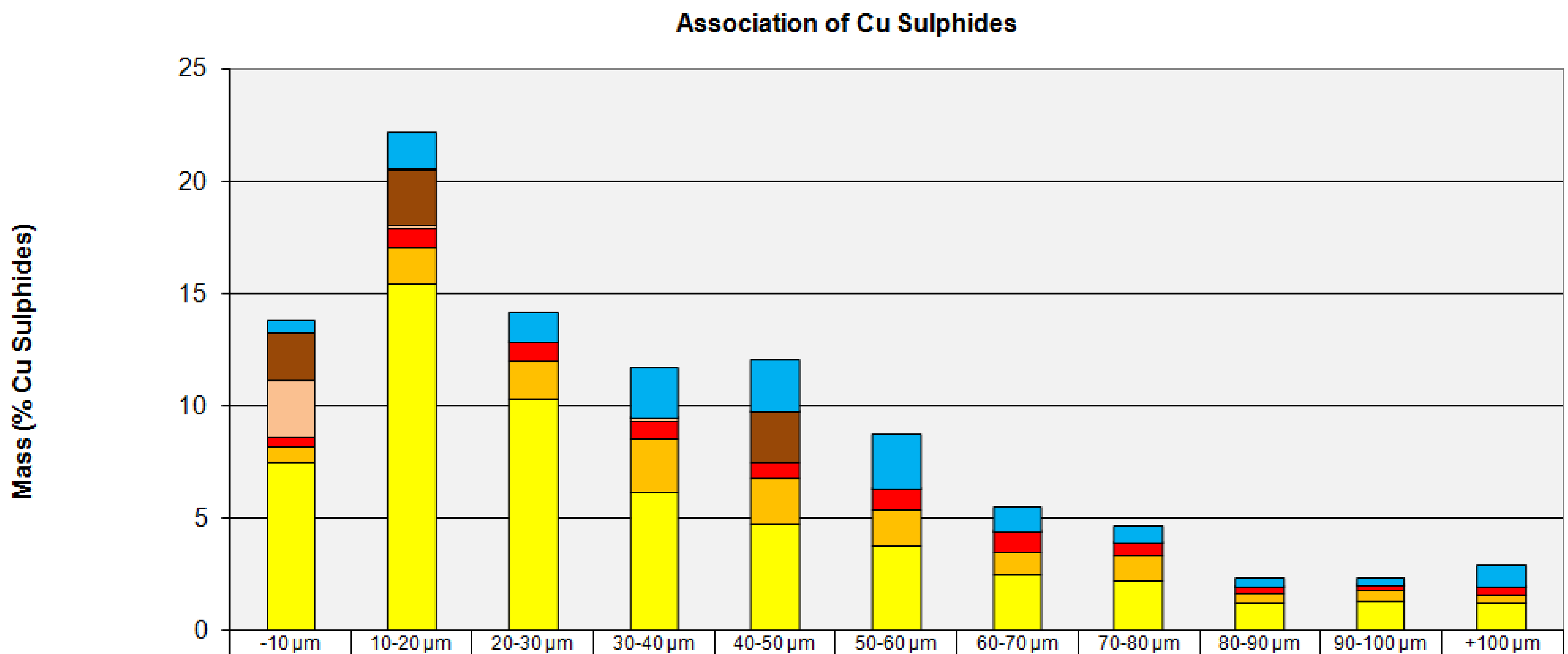
Cu-Porphyry - Liberation by Size



	Combined	+75 µm	-75/+20 µm	-20 µm
Complex CuS	14.2	21.0	11.4	12.4
CuS:Other	0.1	0.0	0.1	0.2
CuS:Micas/Clays	6.8	7.3	8.9	3.5
CuS:Quartz/Feldspar	2.8	2.9	3.4	1.9
CuS:Pyrite	6.8	11.6	7.1	2.7
Liberated Cu Sulphides	13.3	16.4	19.3	2.5
Free Cu Sulphides	55.9	40.8	49.7	76.8

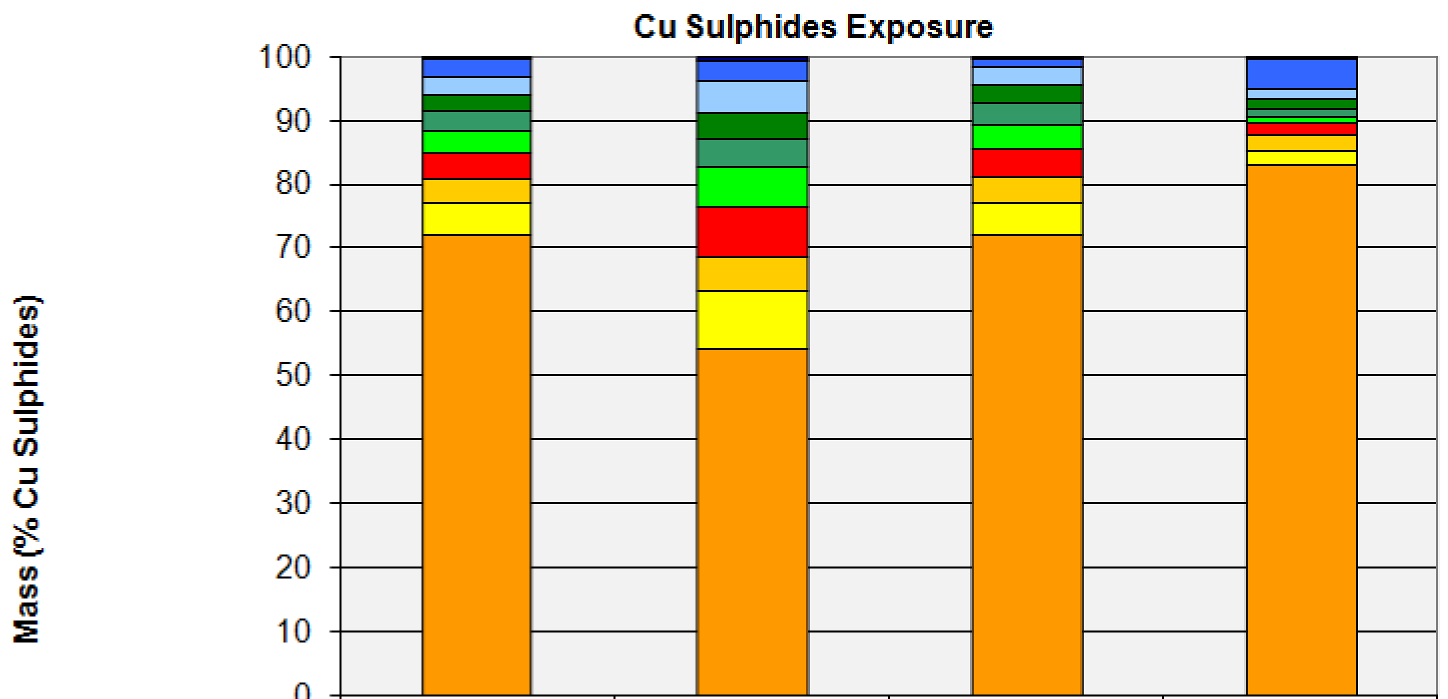
Free: CuS >= 95% surface area, Binary and complex groups have >= 95% combined area of CuS plus another minerals

QEMSCAN Outputs: Liberation by Size



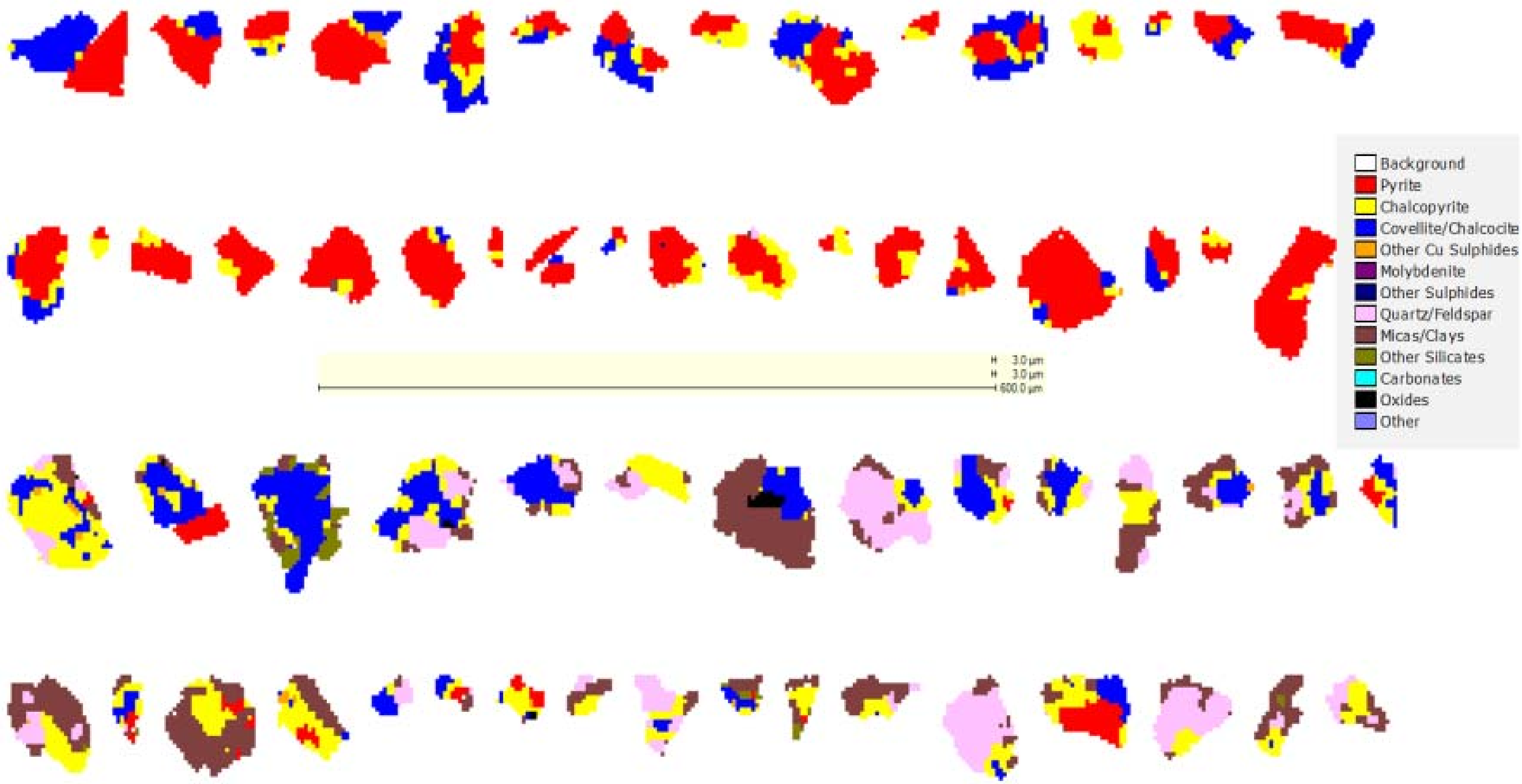
	-10 µm	10-20 µm	20-30 µm	30-40 µm	40-50 µm	50-60 µm	60-70 µm	70-80 µm	80-90 µm	90-100 µm	+100 µm
Complex CuS	0.6	1.6	1.3	2.2	2.3	2.4	1.1	0.8	0.4	0.4	1.0
CuS:Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CuS:Micas/Clays	2.1	2.5	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0
CuS:Quartz/Feldspar	2.5	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CuS:Pyrite	0.4	0.8	0.8	0.8	0.7	0.9	0.9	0.6	0.3	0.2	0.4
Liberated Cu Sulphides	0.7	1.6	1.7	2.4	2.1	1.6	1.0	1.1	0.4	0.5	0.3
Free Cu Sulphides	7.5	15.4	10.3	6.1	4.7	3.7	2.4	2.2	1.2	1.3	1.2

QEMSCAN Outputs: Exposure

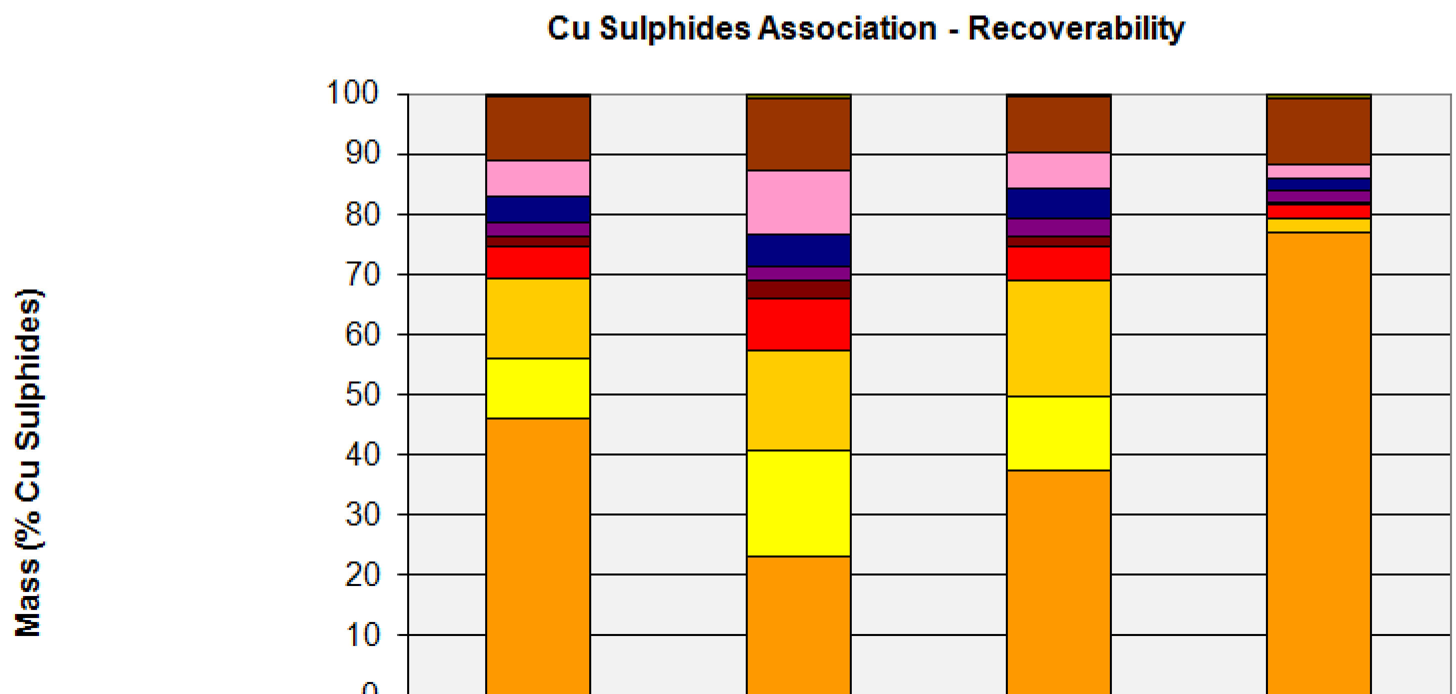


	Combined	+75 µm	-75/+20 µm	-20 µm
Locked CuS	0.3	0.6	0.2	0.2
>0-10% Exposed CuS	3.1	3.4	1.6	5.1
10-20% Exposed CuS	2.7	4.9	2.7	1.3
20-30% Exposed CuS	2.8	4.2	2.9	1.7
30-40% Exposed CuS	2.9	4.5	3.4	1.1
40-50% Exposed CuS	3.4	6.2	3.8	1.2
50-60% Exposed CuS	4.2	7.7	4.3	1.9
60-70% Exposed CuS	3.9	5.3	4.2	2.5
70-80% Exposed CuS	4.8	9.2	4.9	2.2
>80% Exposed CuS	72.1	54.0	72.1	82.8

Cu-Porphyry - QEMSCAN Particle Maps

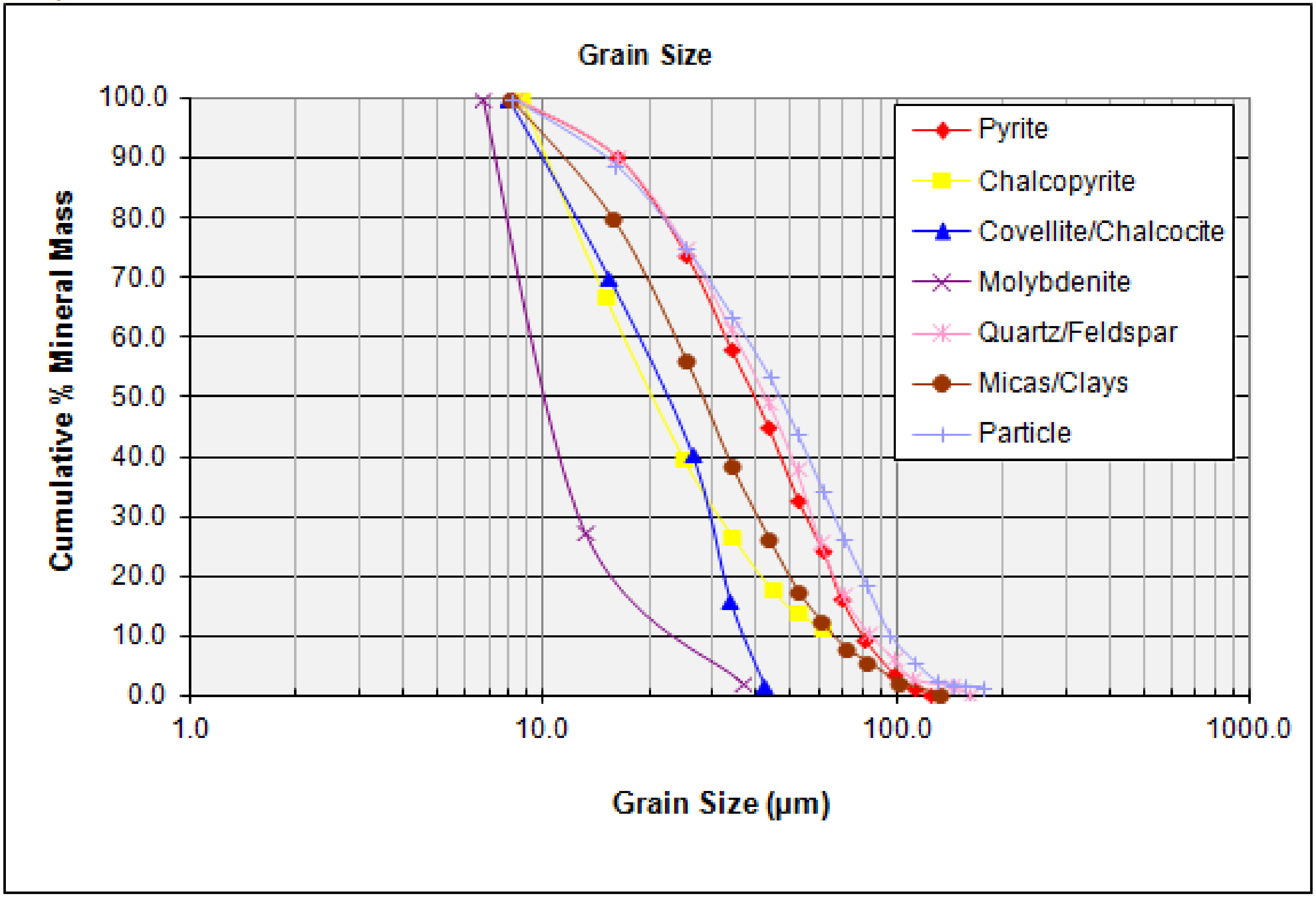


Cu-Porphyry- Recoverable CuS



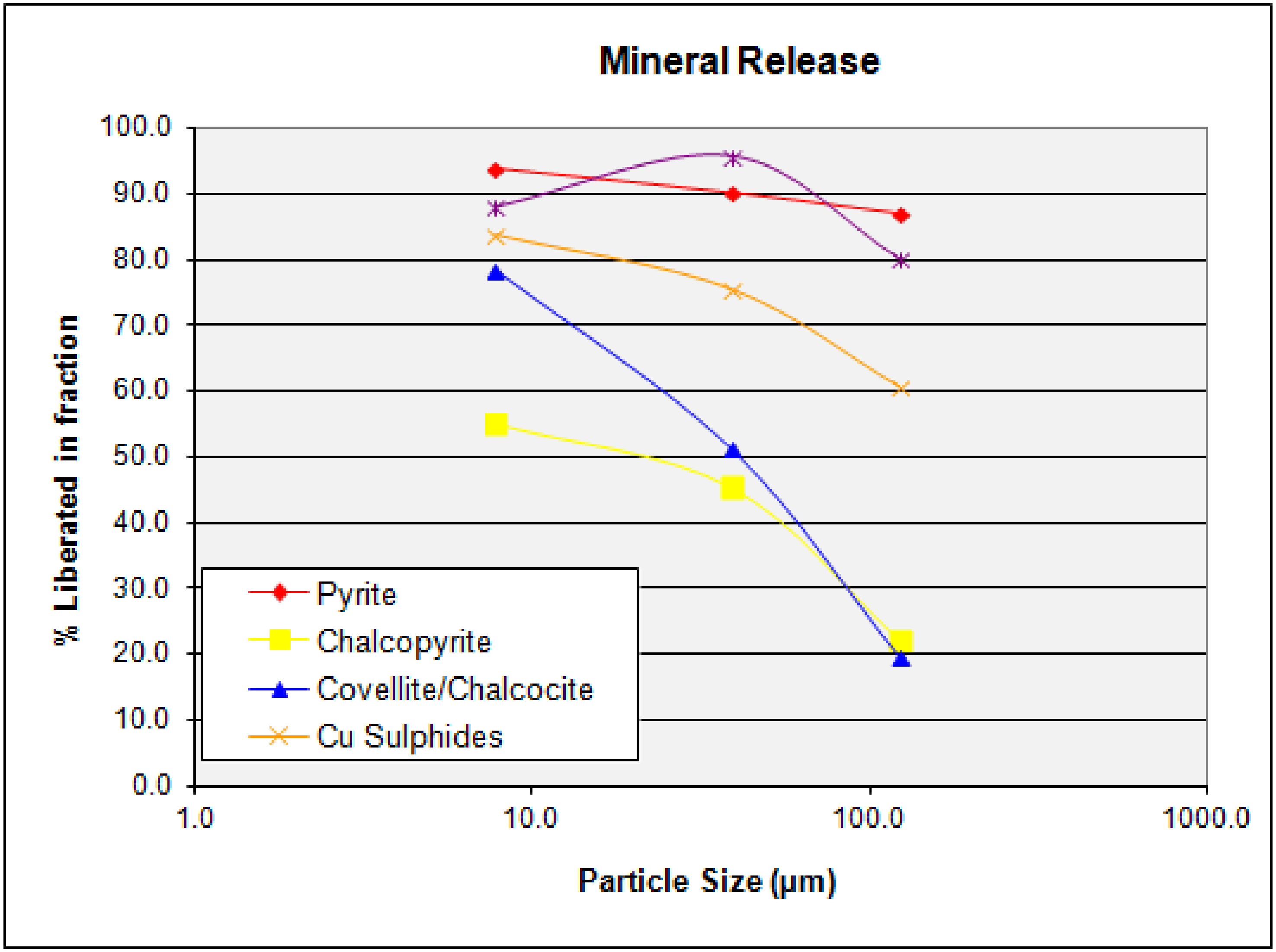
	Combined	+75 µm	-75/+20 µm	-20 µm
Non Recoverable - Locked	0.6	0.7	0.4	0.9
Non Recoverable - Exposed	10.6	12.0	9.5	11.0
Recoverable	5.9	10.9	5.8	2.1
CuS:Mica/Clays (Rec)	4.1	5.1	5.0	2.2
CuS:Qtz/Feld (Rec)	2.6	2.6	3.2	1.8
CuS:Pyrite	1.6	3.0	1.6	0.5
CuS:Pyrite >20% Exp	5.2	8.6	5.4	2.1
Lib CuS	13.3	16.4	19.3	2.5
Free Cu Sulphides	9.9	17.7	12.5	0.0
Pure Cu Sulphides	46.0	23.1	37.2	76.8

Cu-Porphyry - Grain Size Distribution

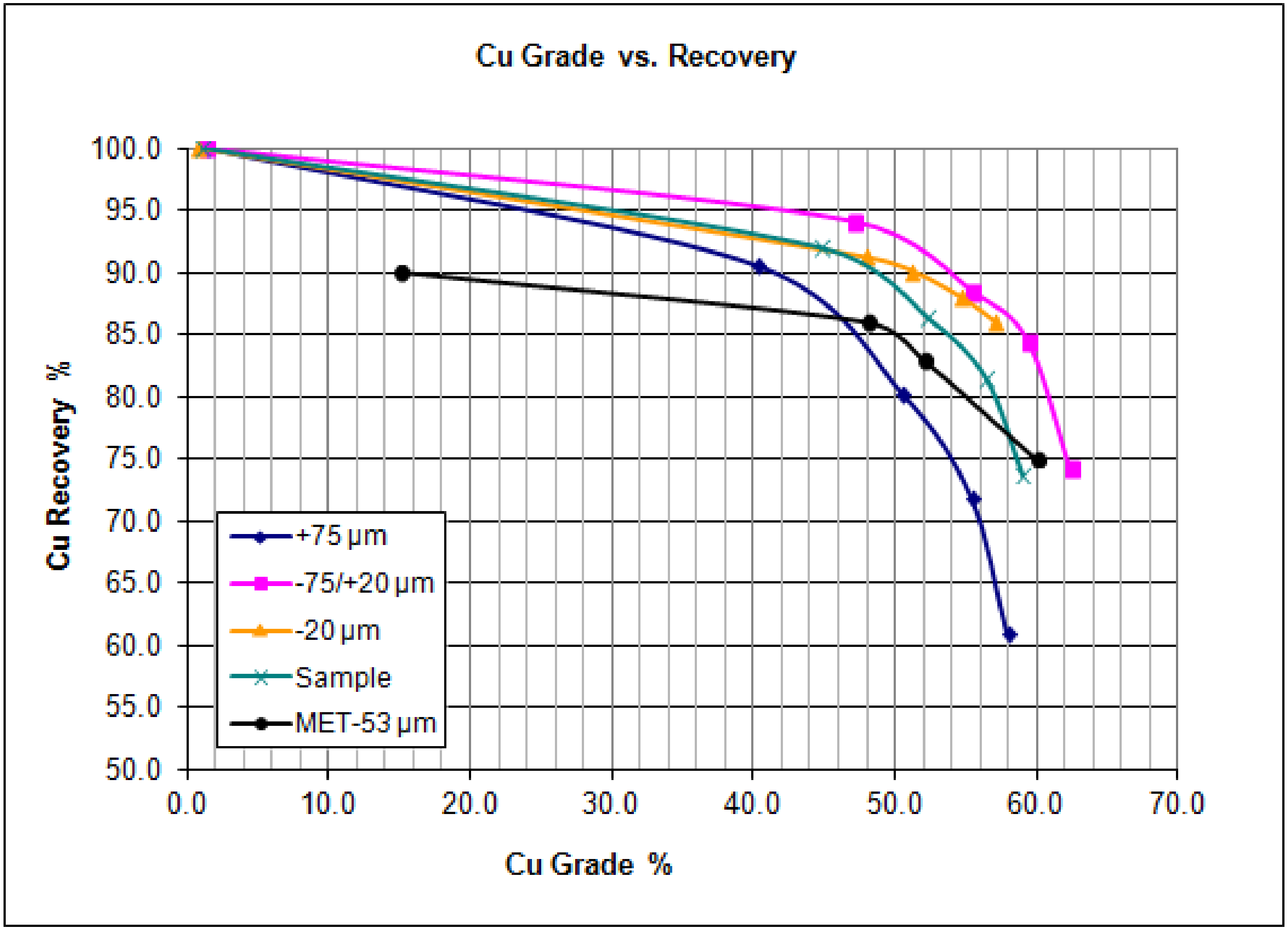


1. Reports the cumulative grain size of groups of minerals within the sample
2. D50 or D80 etc. can be calculated from the data

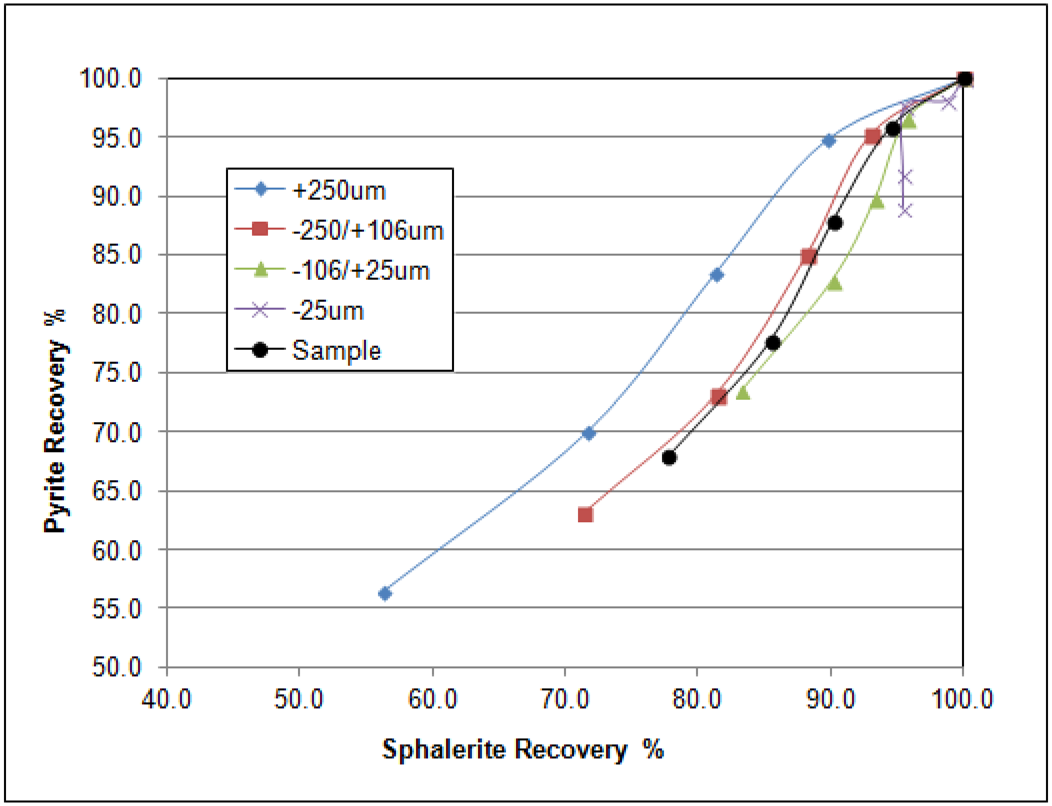
Cu-Porphyry - Mineral Release Curves



Cu-Porphyry - Grade Recovery



Cu-Porphyry - Grade Recovery

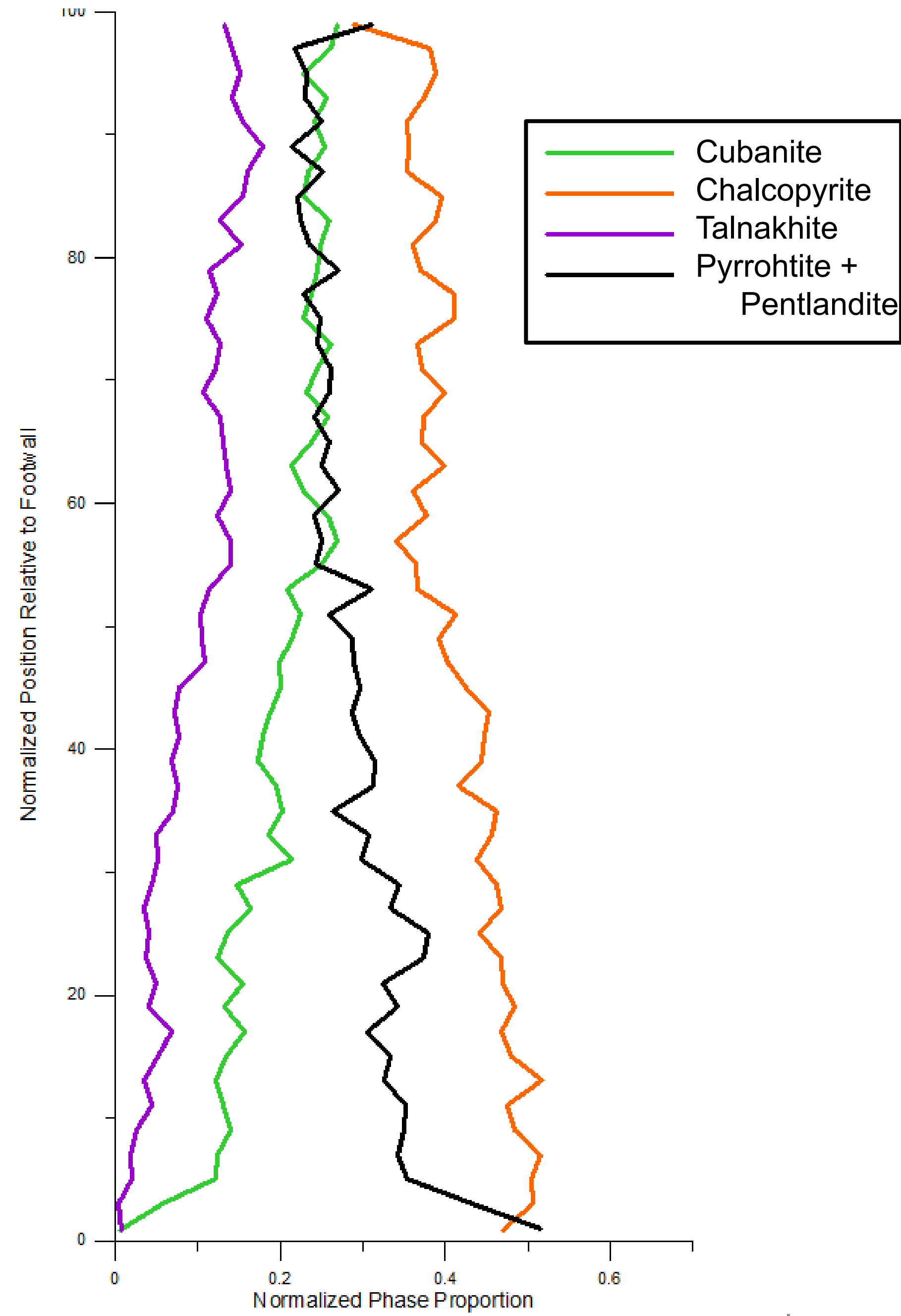


Ni-Cu Project

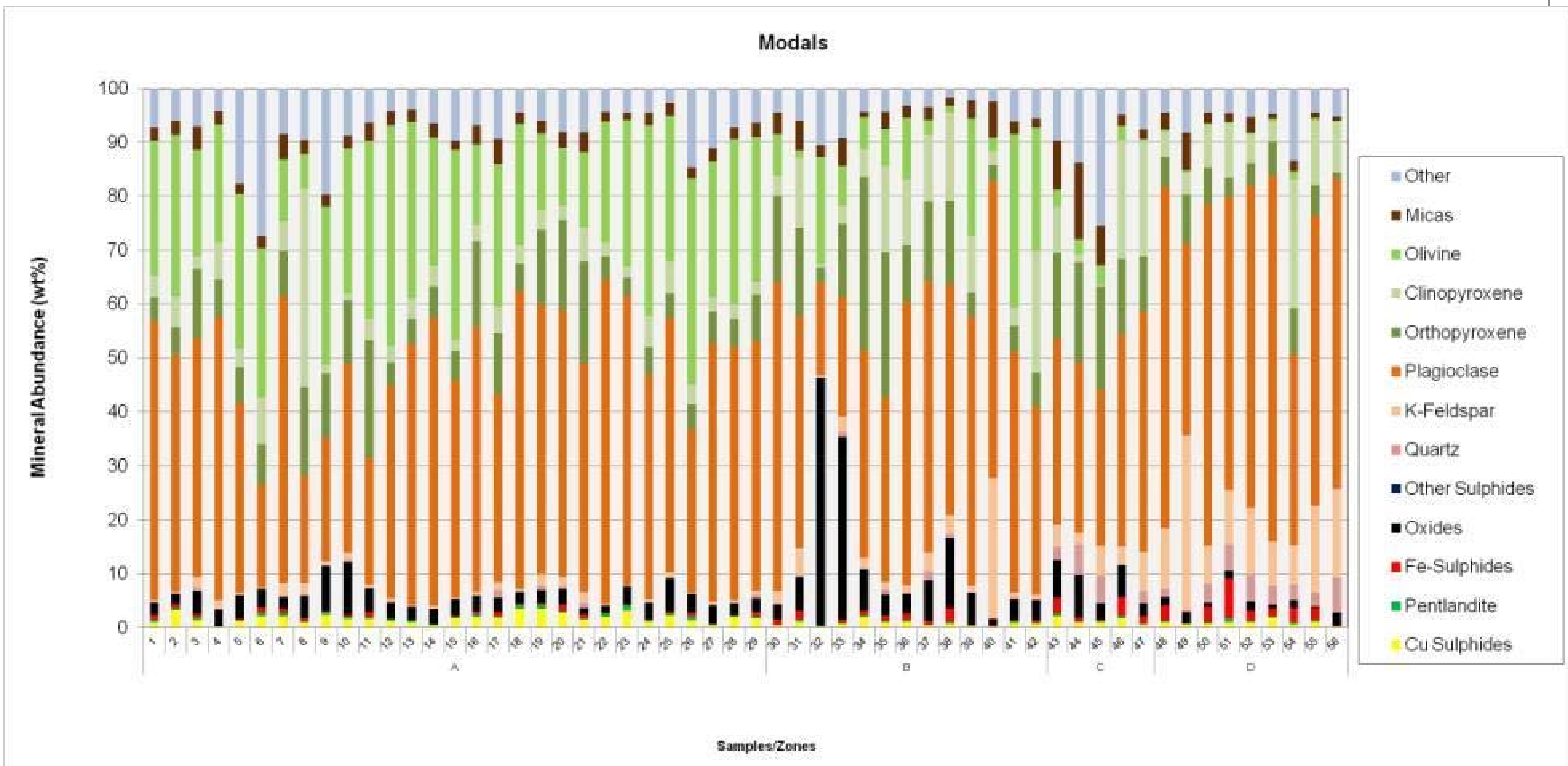
- Determine the Cu, Fe and Ni Sulphides
- Cross-sections
- Drill holes
- Composite samples from assay coarse reject based on:
    - Geologic unit
    - Logged rock type
    - Sulfide mineralogy and estimated amounts
    - Copper, Nickel, and/or PGM grade

Mineralogy

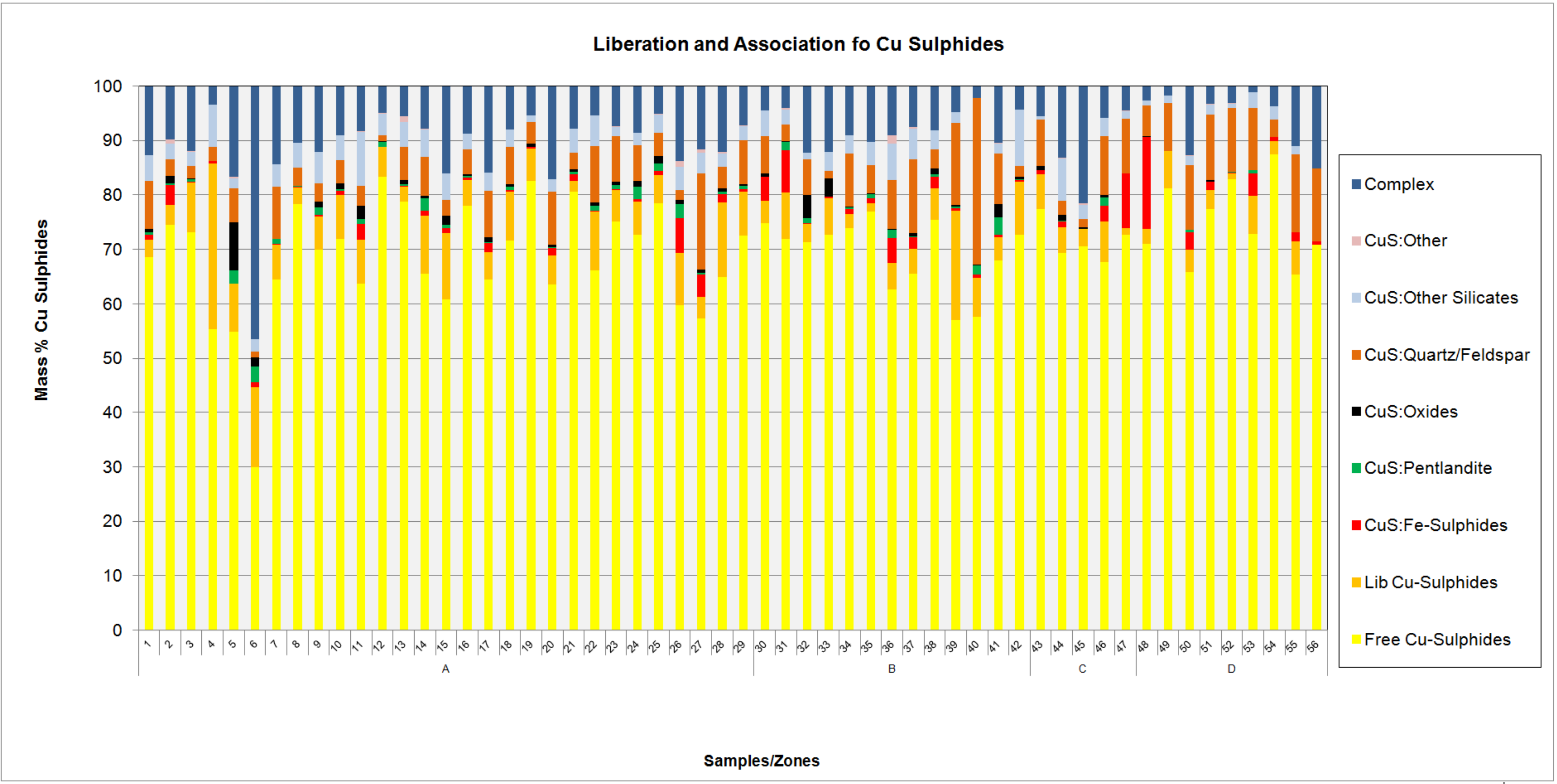
- The current geologic model is based primarily upon the lithogeochemistry from the assay database.
- Sulfide mineralogy
  - Visual estimation
  - Proportions normalized to 100%
- Silicate mineralogy
  - Homogeneity in the heterogeneity within the ore zone
- Sulfide Zonation Study



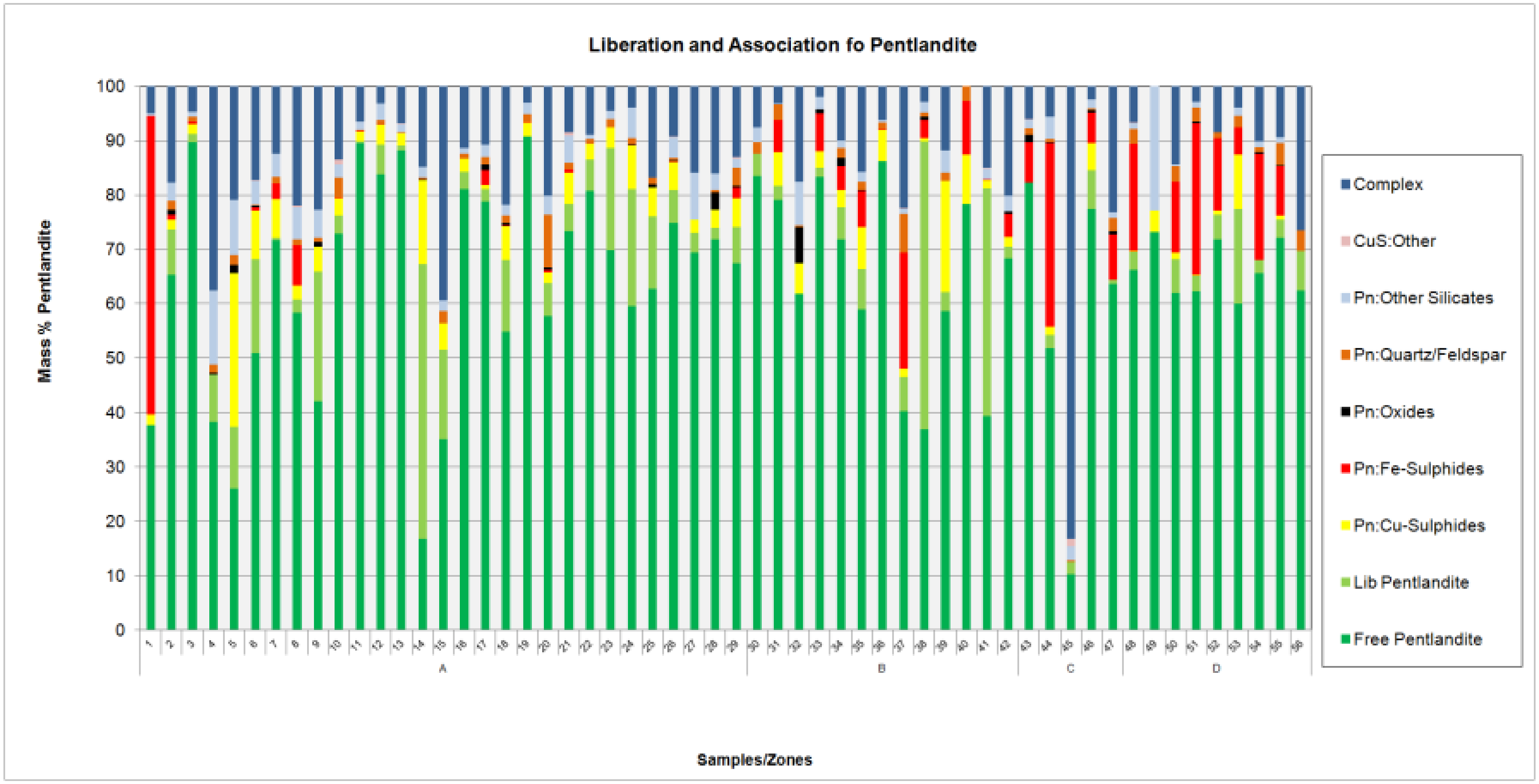
QEMSCAN – Cu-Ni



Cu-Sulphides-Liberation

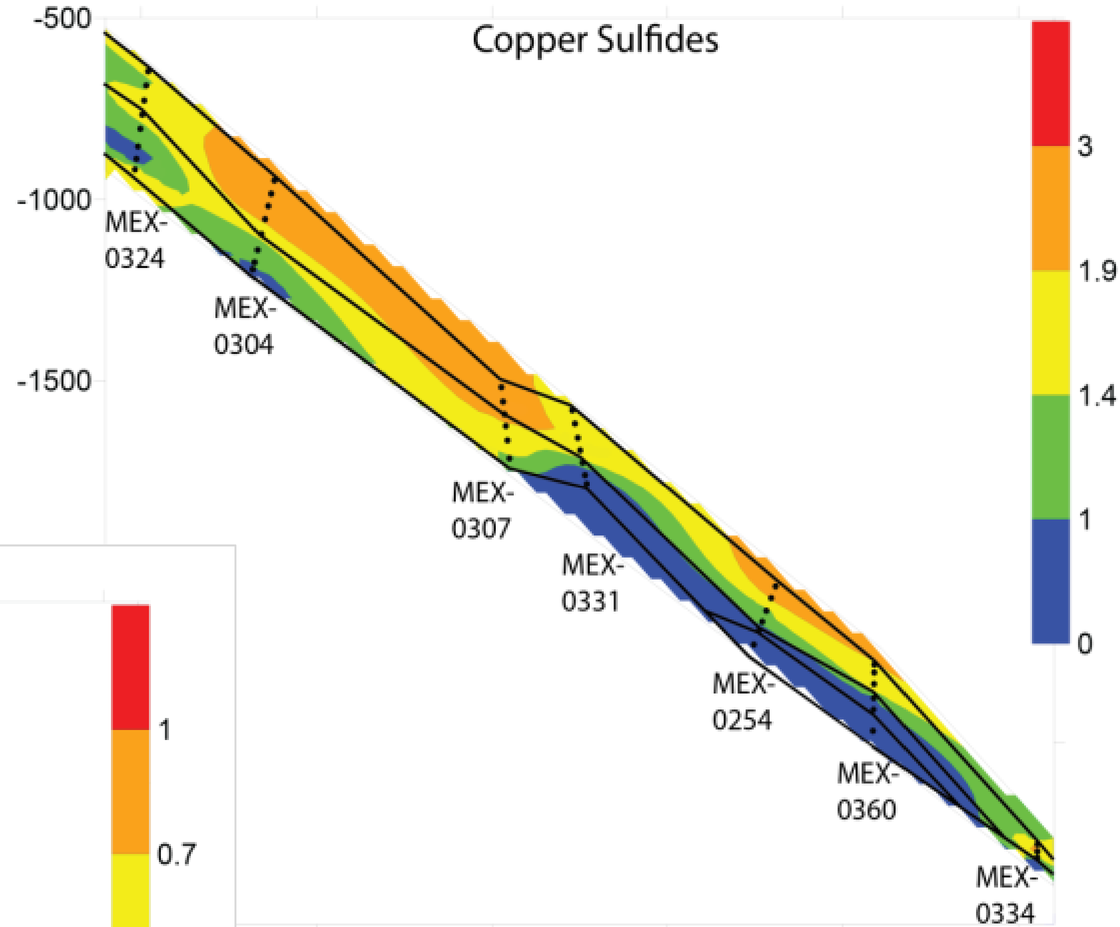


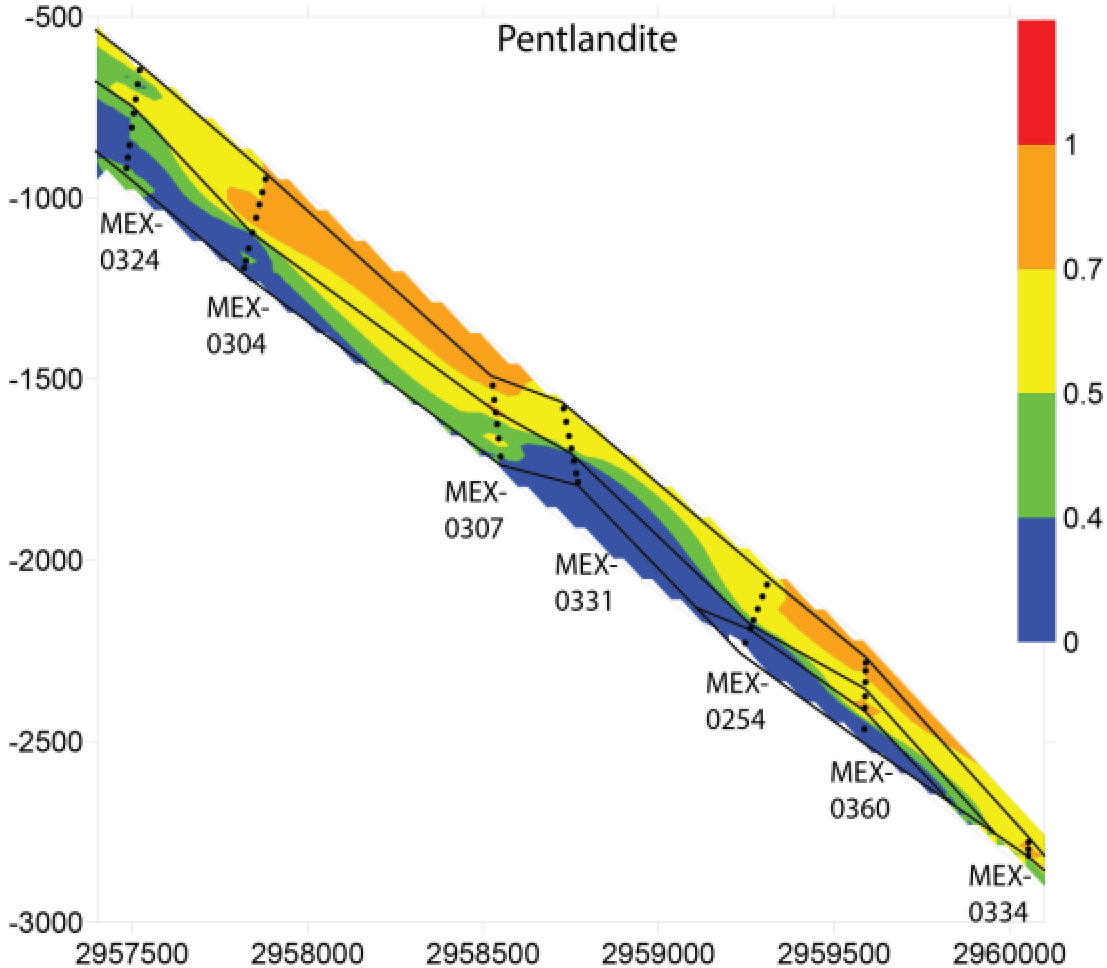
Pentlandite-Liberation



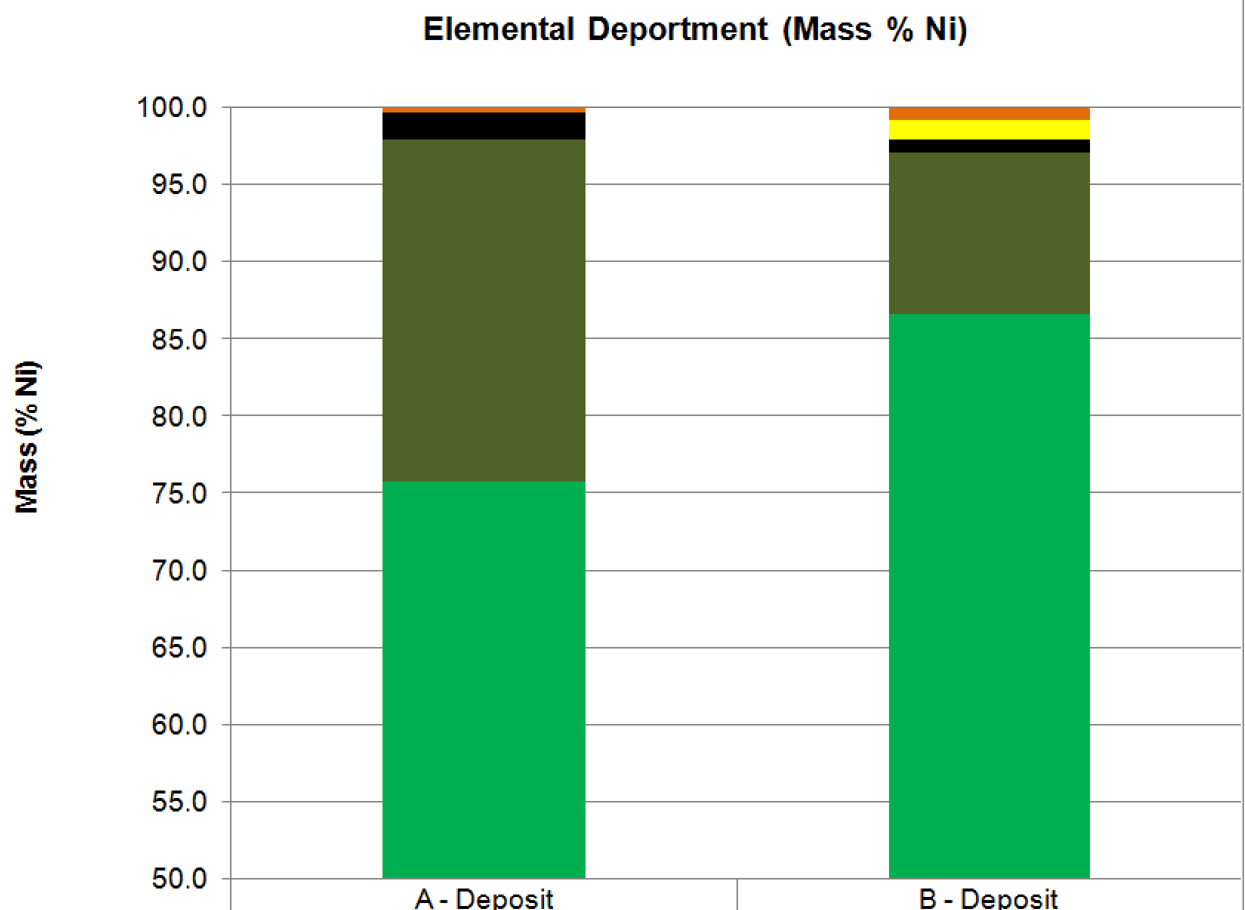
Contour plots - sulfides

Cross sections looking NE
Projected on a line trending 145°



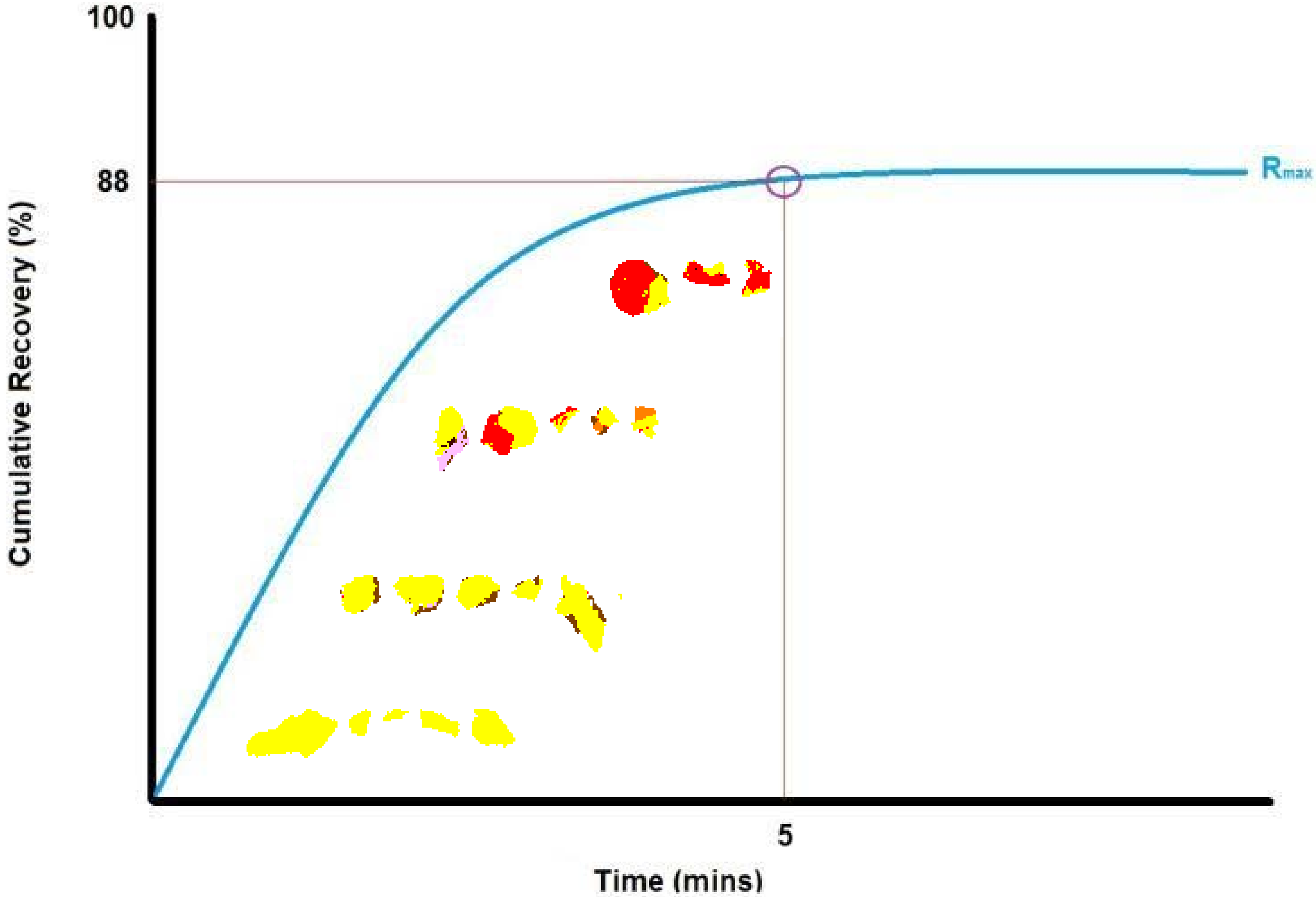


Ni Deportment

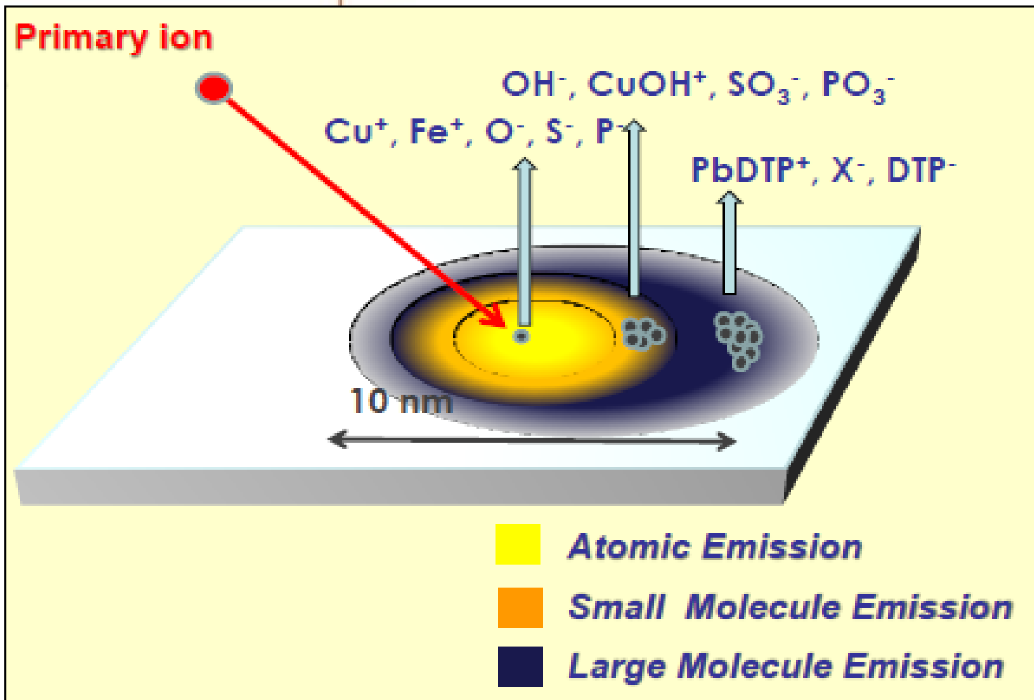


	A - Deposit	B - Deposit
Pyrrhotite	0.3	0.8
Chalcopyrite	0.0	1.3
Fe-Oxides	1.7	0.8
Fe-Mg Silicates	22.2	10.4
Pentlandite	75.7	86.7

FLOWSHEET PREDICTIVE KINETICS

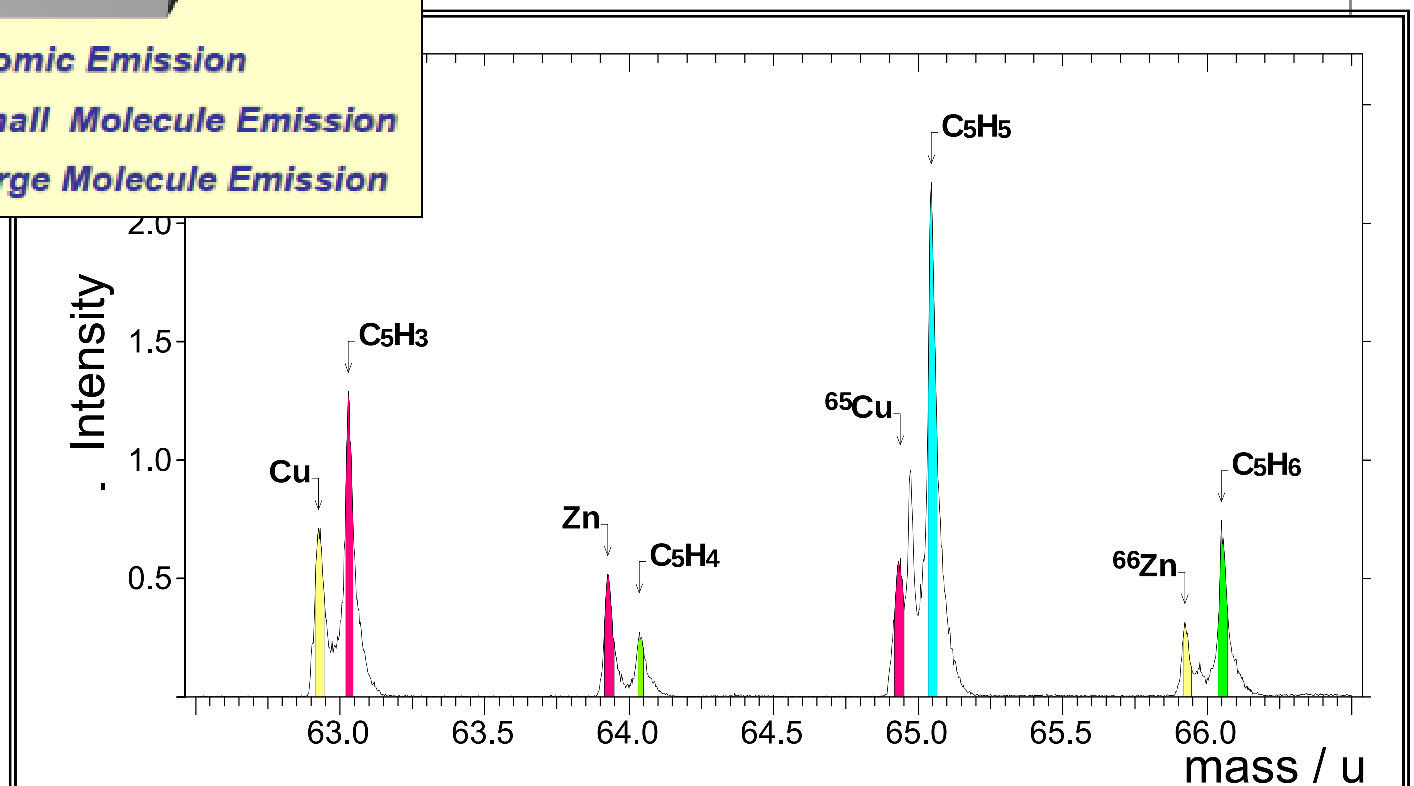


TOF-SIMS, Sputtering and Spectra



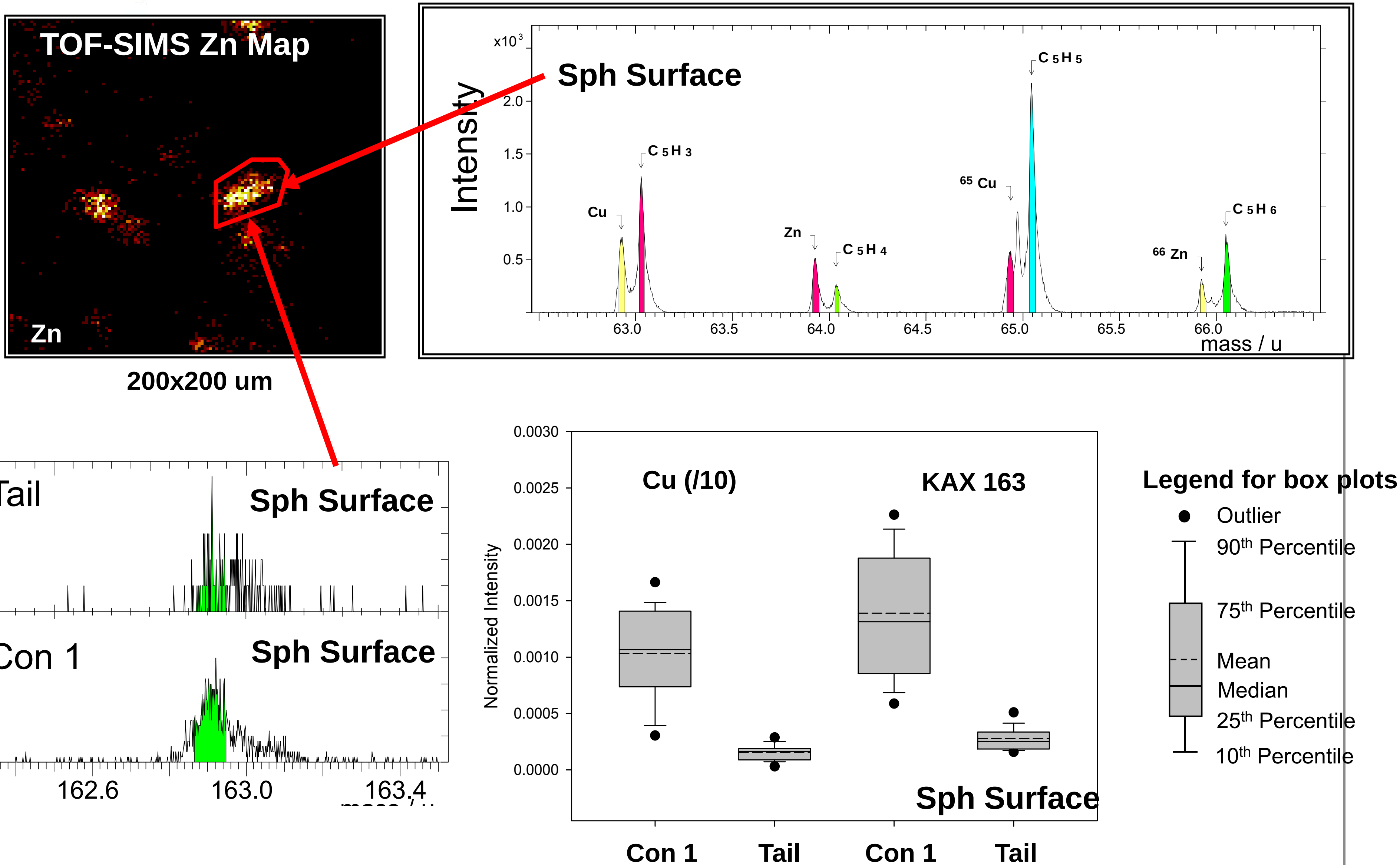
***Primary ion beam (Bi_3+) produces secondary monatomic and polyatomic negative, positive ions and neutral species*; function of energy distribution**

Mass spectra from mixed mineral feed sample in the region of 62 to 66.5 amu; masses relevant to the study (Cu, Zn).



Courtesy of Surface Science Western and B. Hart

Data Collection/Presentation

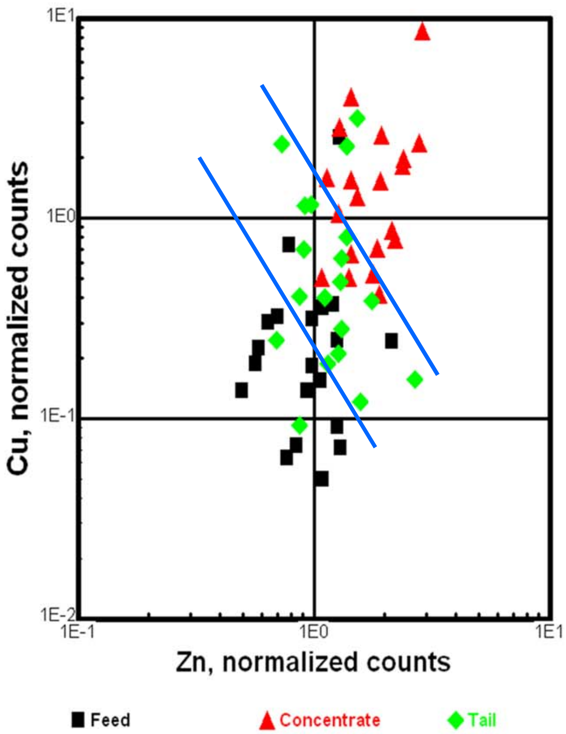


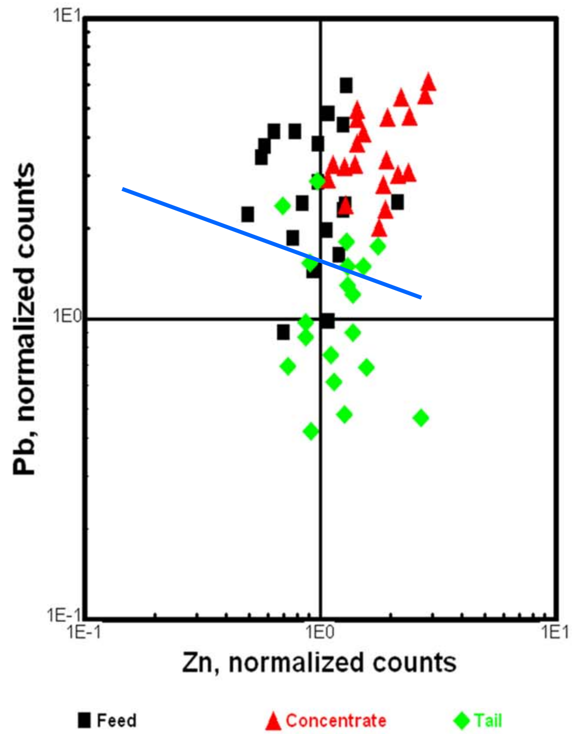
Box plots showing relative difference in measured species between samples

Courtesy of Surface Science Western and B. Hart

Case Study #1: Batch Flotation Study

Met tests on Cu\Pb\Zn ore show significant sphalerite in Cu/Pb con





Scatter plots showing the distribution for Pb and Cu versus Zn on sphalerite surfaces in the feed, concentrate and tail.

CONCLUSIONS: MAJOR FINDINGS

- **Activation of sphalerite by Pb occurs during grinding.**
- **Activation by Cu likely occurs during conditioning and flotation.**
- **No significant role of common depressants observed.**

Courtesy of Surface Science Western and B. Hart

Rare Earth Deposits

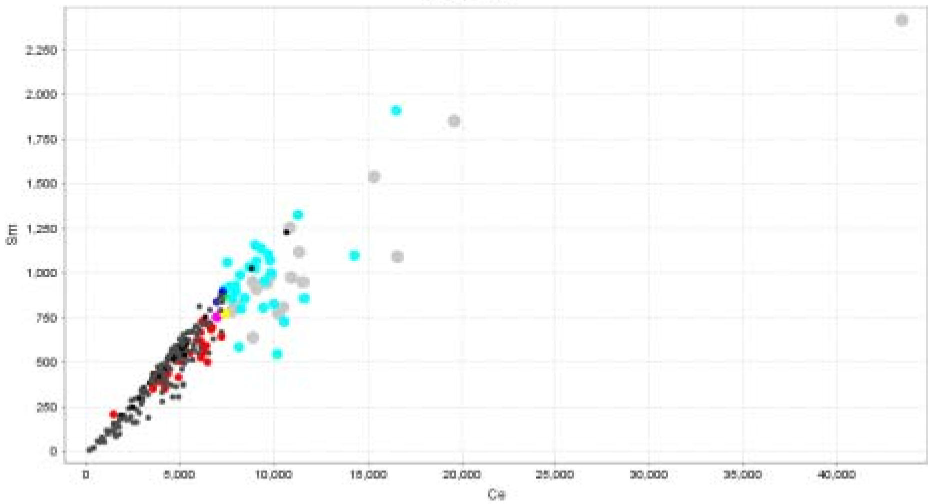
- REE deposits form two main groups.
- The first is a commonly occurring “light rare earth element” (LREE) rich group of deposits (La, Ce, Pr, Nd, Sm).
- The second is a less commonly occurring “heavy rare earth element” (HREE) rich group (Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu and Y).
- The LREE are hosted primarily by carbonatites and the HREE by highly alkaline to peralkaline (Na + K > Al) silicate igneous rocks.
- The LREE are produced mainly from bastnaesite, monazite, while HREE are produced almost exclusively from low-grade secondary ion adsorption clay deposits in which the REE are adsorbed onto surfaces of kaolinite and halloysite, the products of weathering of granites and sediments.
- Most of REE deposits display a high degree of geological and mineralogical complexity that can have serious consequences for metallurgical processing if not well understood.

Selected Rare Earth Minerals

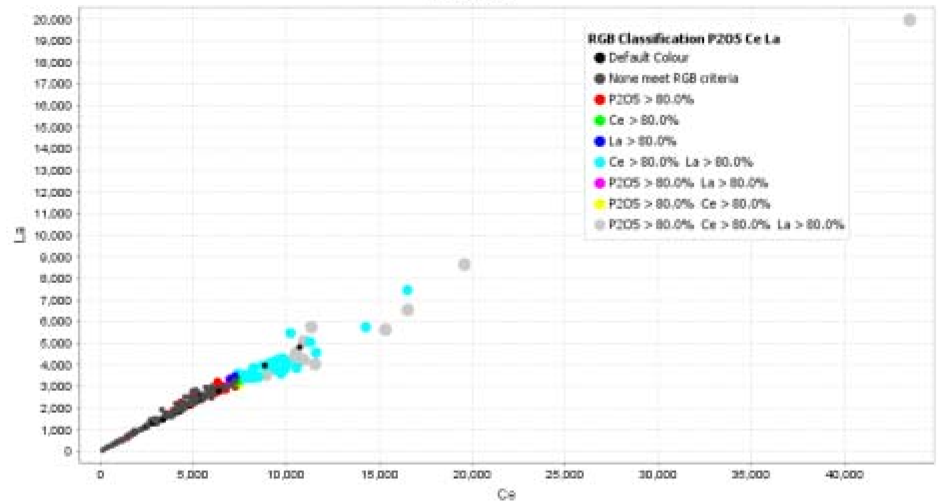
Mineral	Formula
Y-allanite	$(Ca,Y)_2(Al,Fe,REE)_3Si_3O_{12}(OH)$
Monazite	$(LREE,Y,Th)PO_4$
Bastnaesite	$REE(CO_3)F$
Synchysite	$Ca(Ce,REE)(CO_3)_2F$
Fergusonite	$(REE,Y)NbO_4$
Eudialyte	$Na_4Ca_{1.5}Ce_{0.5}Fe^{2+}_{0.6}Mn^{2+}_{0.3}Y_{0.1}ZrSi_8O_{22}(OH)_{1.5}Cl_{0.5}$
Xenotime	$(Y,Yb,HREE)(PO_4)$
Mosandrite	$Na_2Ca_3Ce_{1.5}Y_{0.5}Ti_{0.6}Nb_{0.3}Zr_{0.1}(Si_2O_7)_2O_{1.5}F_{3.5}$
Chevkinite	$Ce_{1.7}La_{1.4}Ca_{0.8}Th_{0.1}Fe^{2+}_{1.8}Mg_{0.2}Ti_{2.5}Fe^{3+}_{0.5}Si_4O_{22}$
Zircon	$Zr_{0.9}Hf_{0.05}REE_{0.05}SiO_4$
Columbite	$(Fe,Mn,Mg)(Nb,Ta)_2O_6$
Apatite	$(Ca, REE,Sr)_5(PO_4)_3(OH,F,Cl)$
Titanite	$Ca_{0.95}REE_{0.05}Ti_{0.75}Al_{0.2}Fe^{3+}_{0.05}SiO_{4.9}F_{0.1}$

Geochemistry

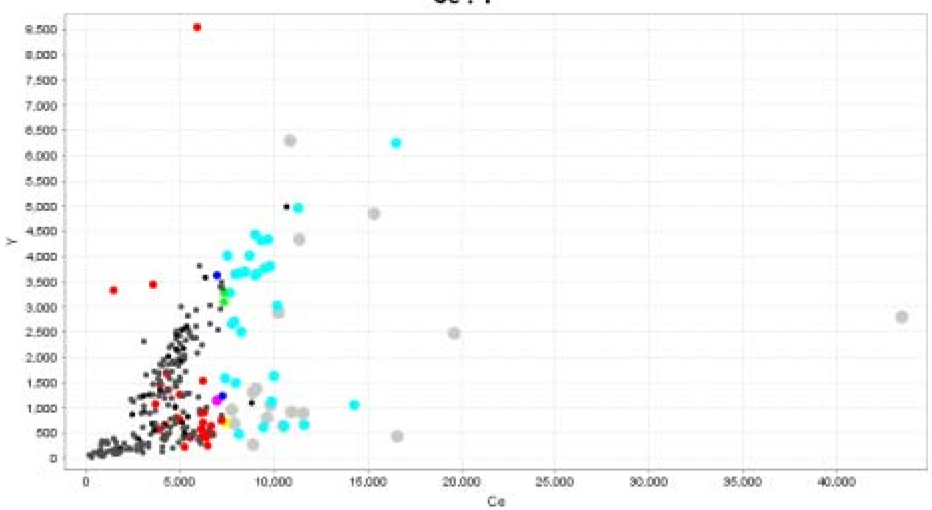
Ce : Sm



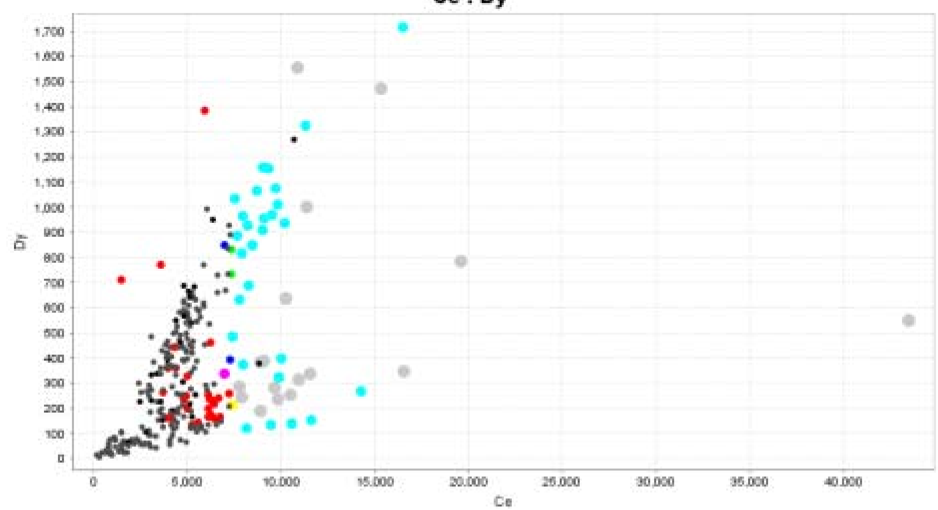
Ce : La



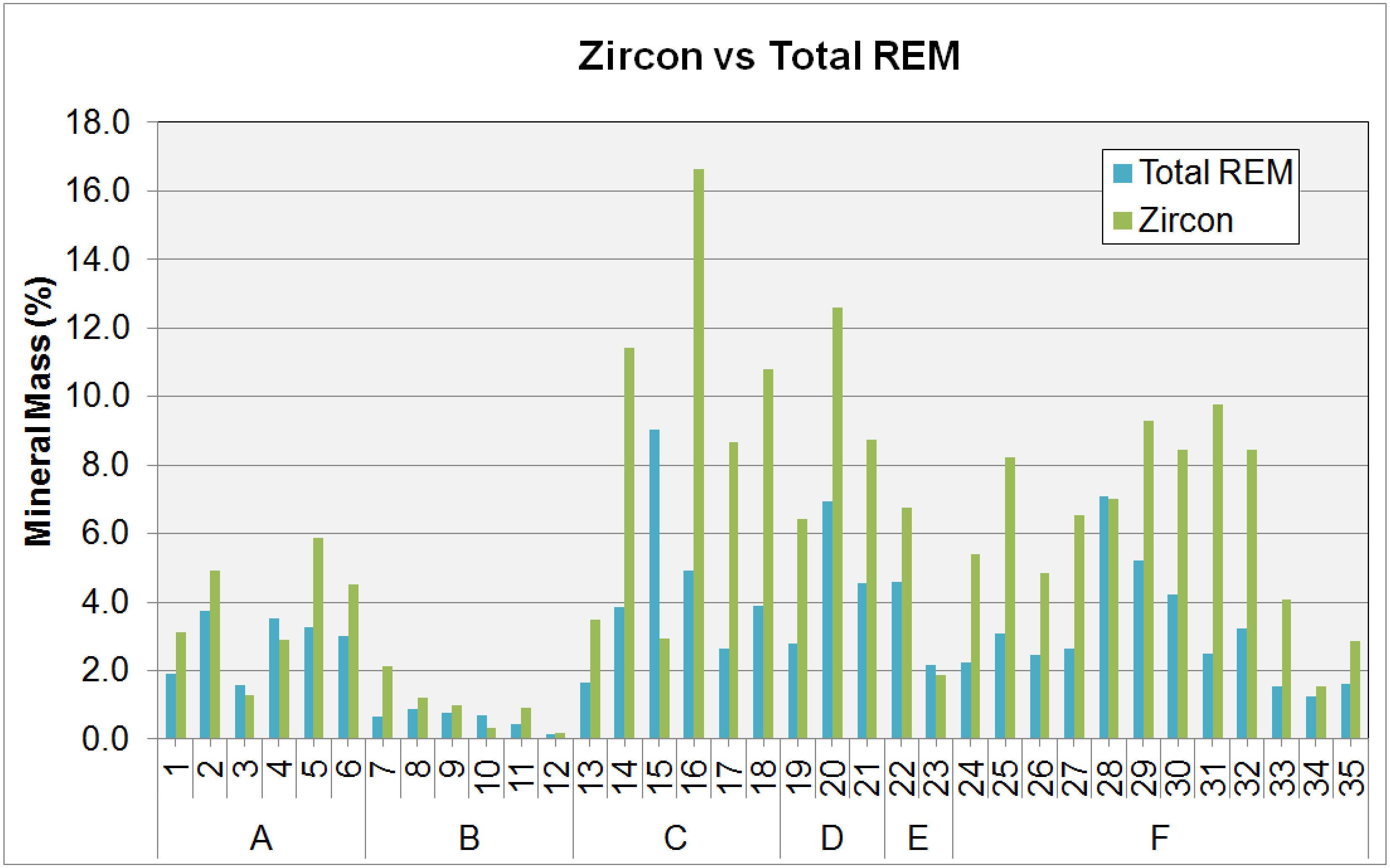
Ce : Y



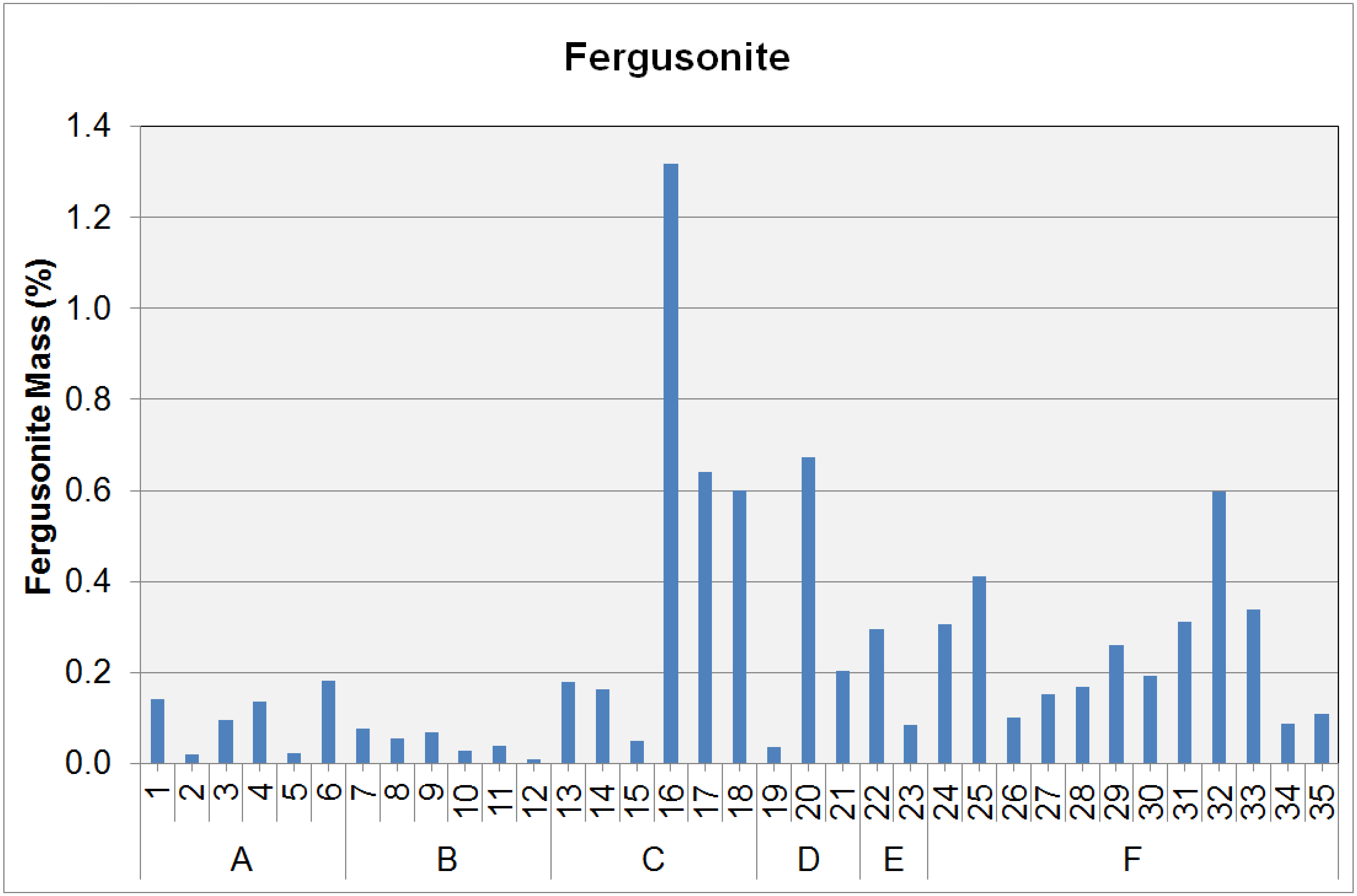
Ce : Dy



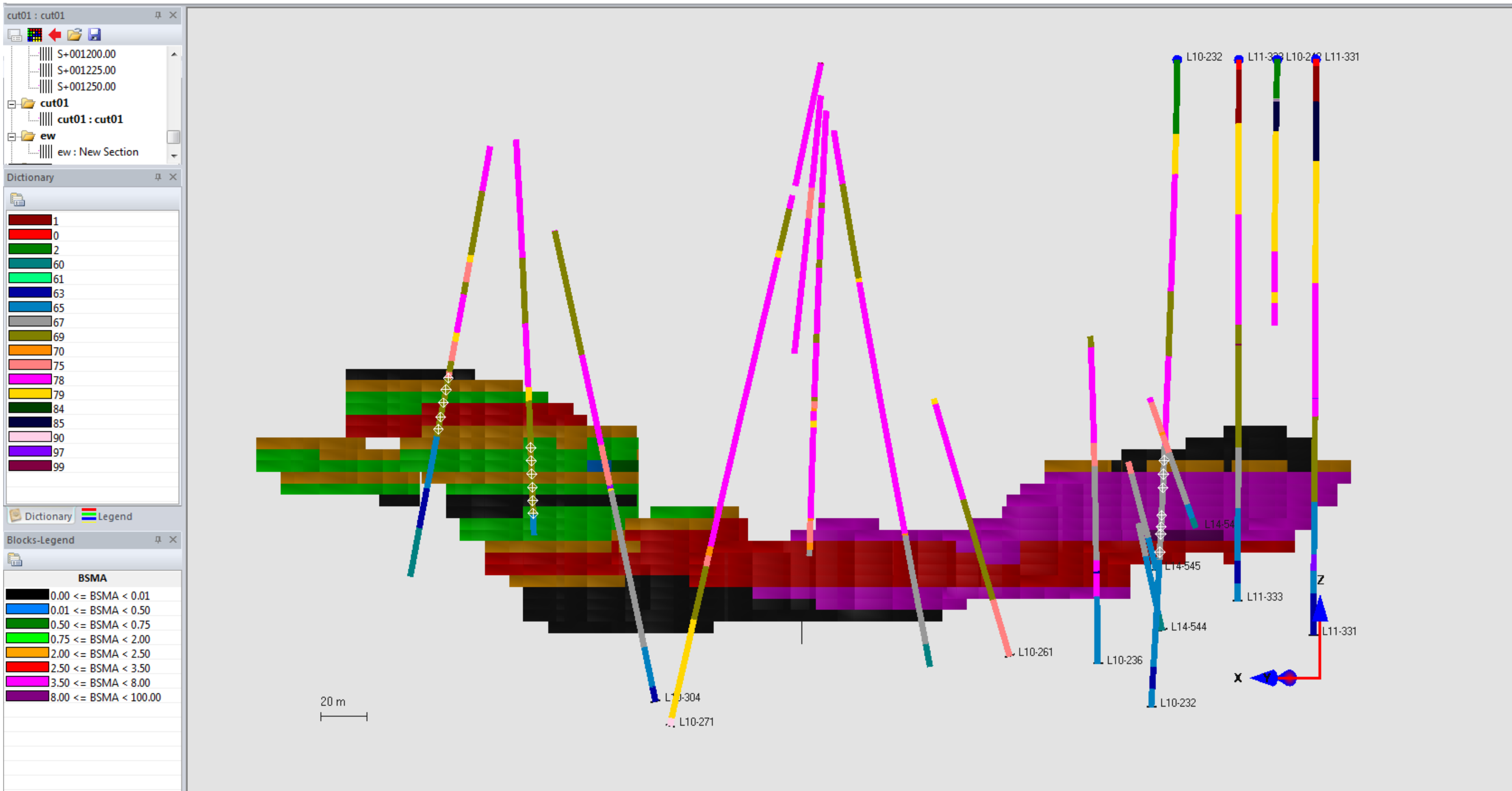
Mineral Variability



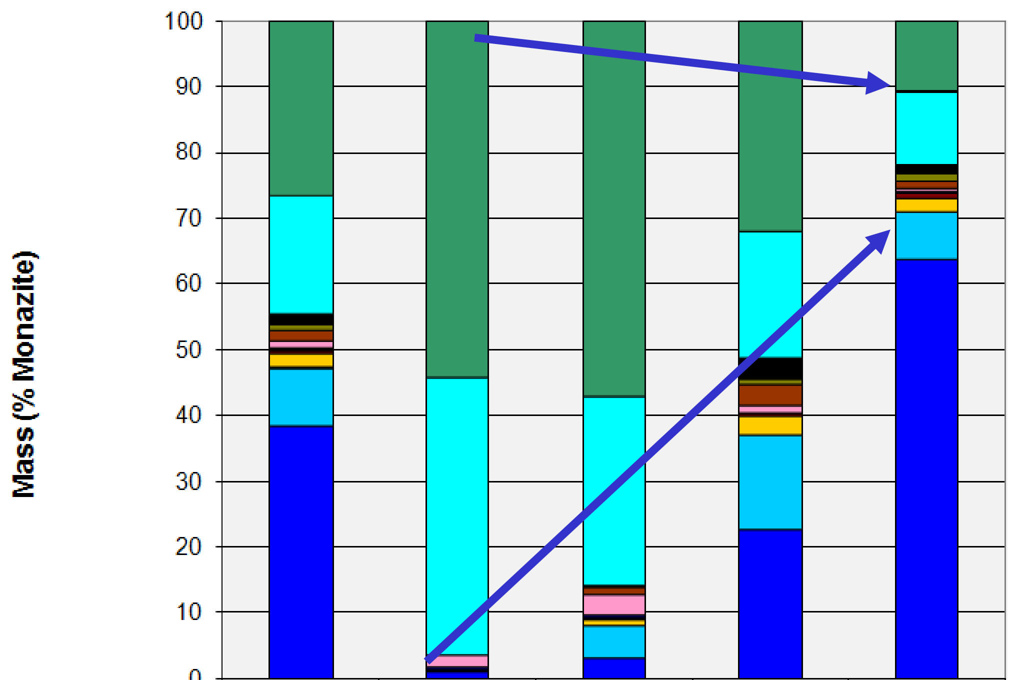
Mineral Variability



LREM Distribution

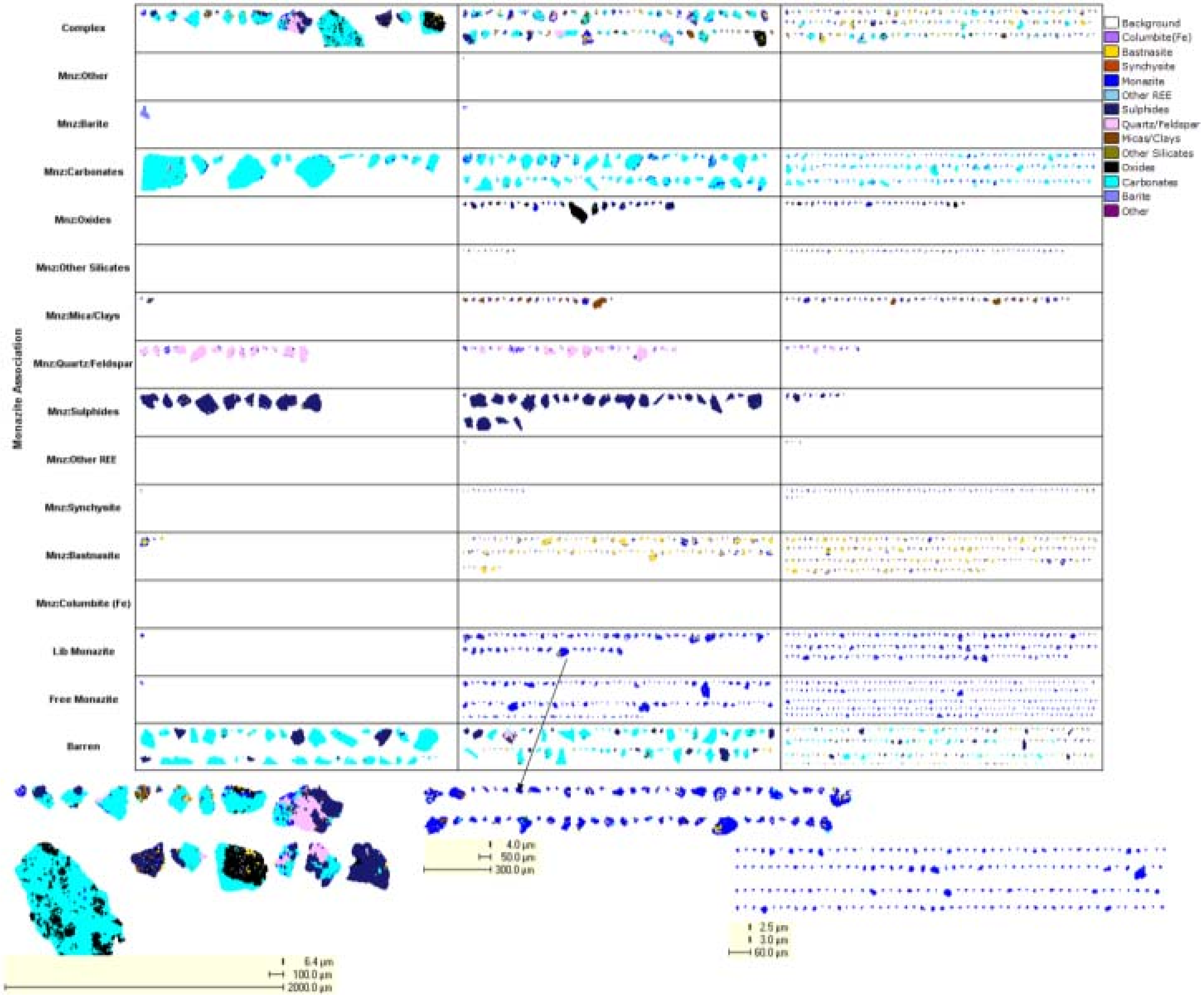


QEMSCAN– Liberation Association

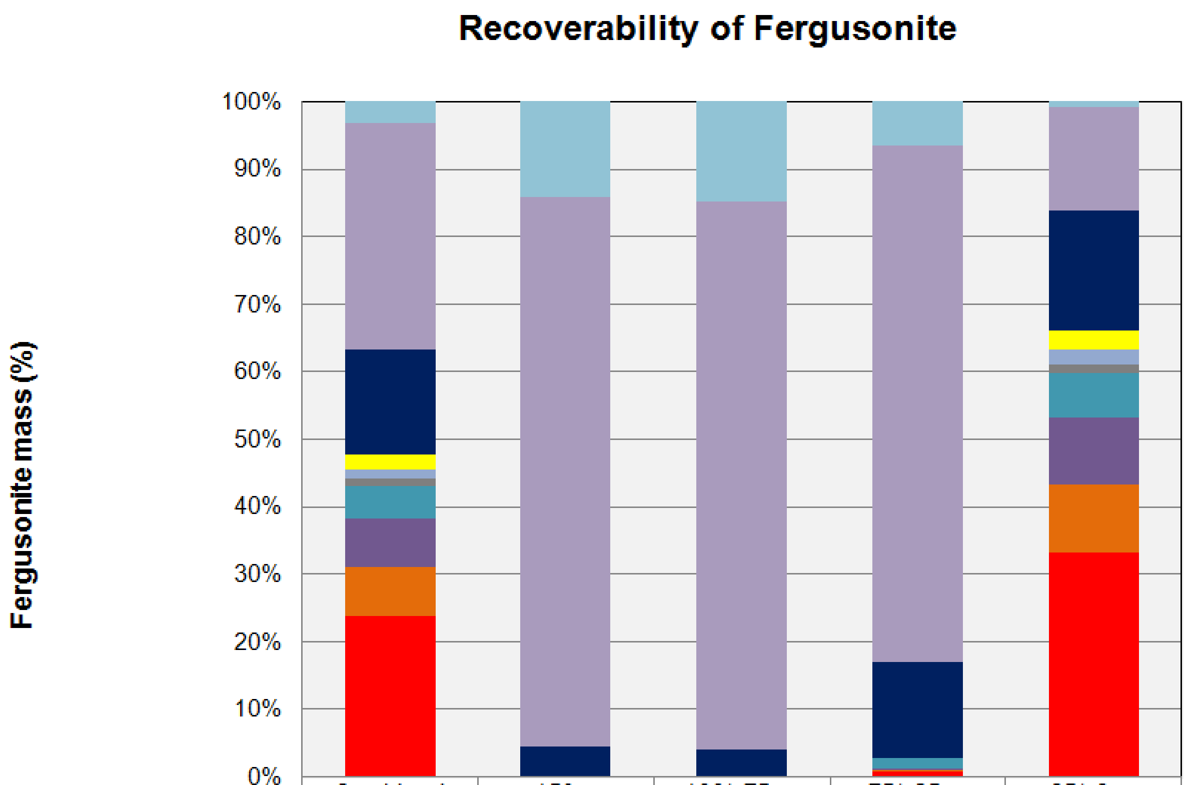


	Combined	+212um	-212/+106um	-106/+25um	-25um
Complex	26.7	54.4	57.4	32.0	10.8
Mnz:Other	0.1	0.0	0.0	0.0	0.1
Mnz:Barite	0.0	0.0	0.0	0.0	0.0
Mnz:Carbonates	17.8	42.4	28.8	19.4	11.2
Mnz:Oxides	1.7	0.0	0.2	3.1	1.3
Mnz:Other Silicates	0.8	0.0	0.1	0.9	1.0
Mnz:Mica/Clays	1.8	0.0	1.0	3.2	1.1
Mnz:Quartz/Feldspar	1.1	1.9	3.2	1.0	0.4
Mnz:Sulphides	0.3	0.3	0.5	0.1	0.3
Mnz:Other REE	0.0	0.0	0.0	0.0	0.0
Mnz:Synchysite	0.6	0.0	0.2	0.3	0.9
Mnz:Bastnasite	2.1	0.2	1.0	3.0	2.0
Mnz:Columbite (Fe)	0.0	0.0	0.0	0.0	0.1
Lib Monazite	9.0	0.3	5.0	14.3	7.2
Free Monazite	38.1	0.7	2.8	22.5	63.6

QEMSCAN – Image Grid *(f)* Association

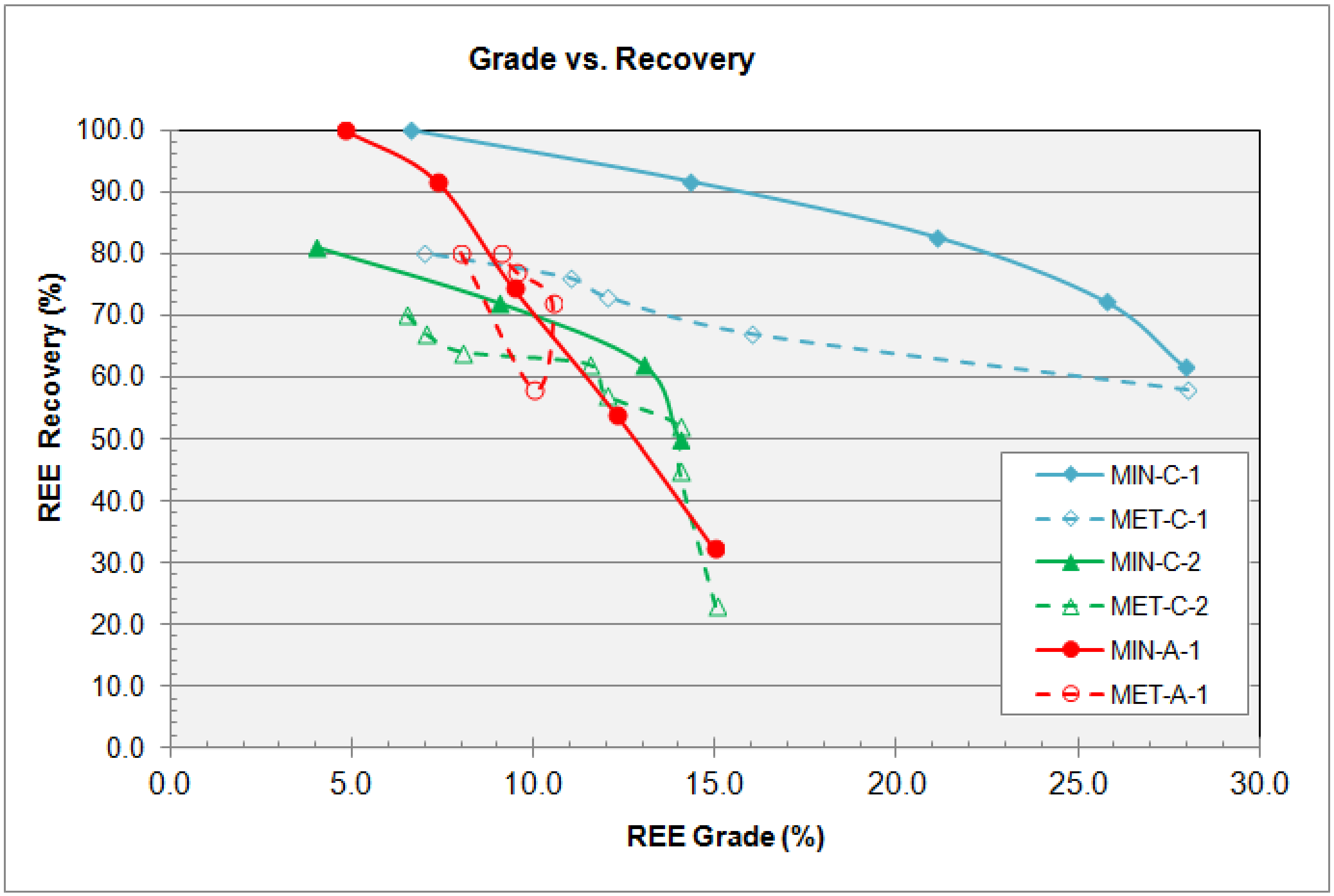


QEMSCAN – Recoverability



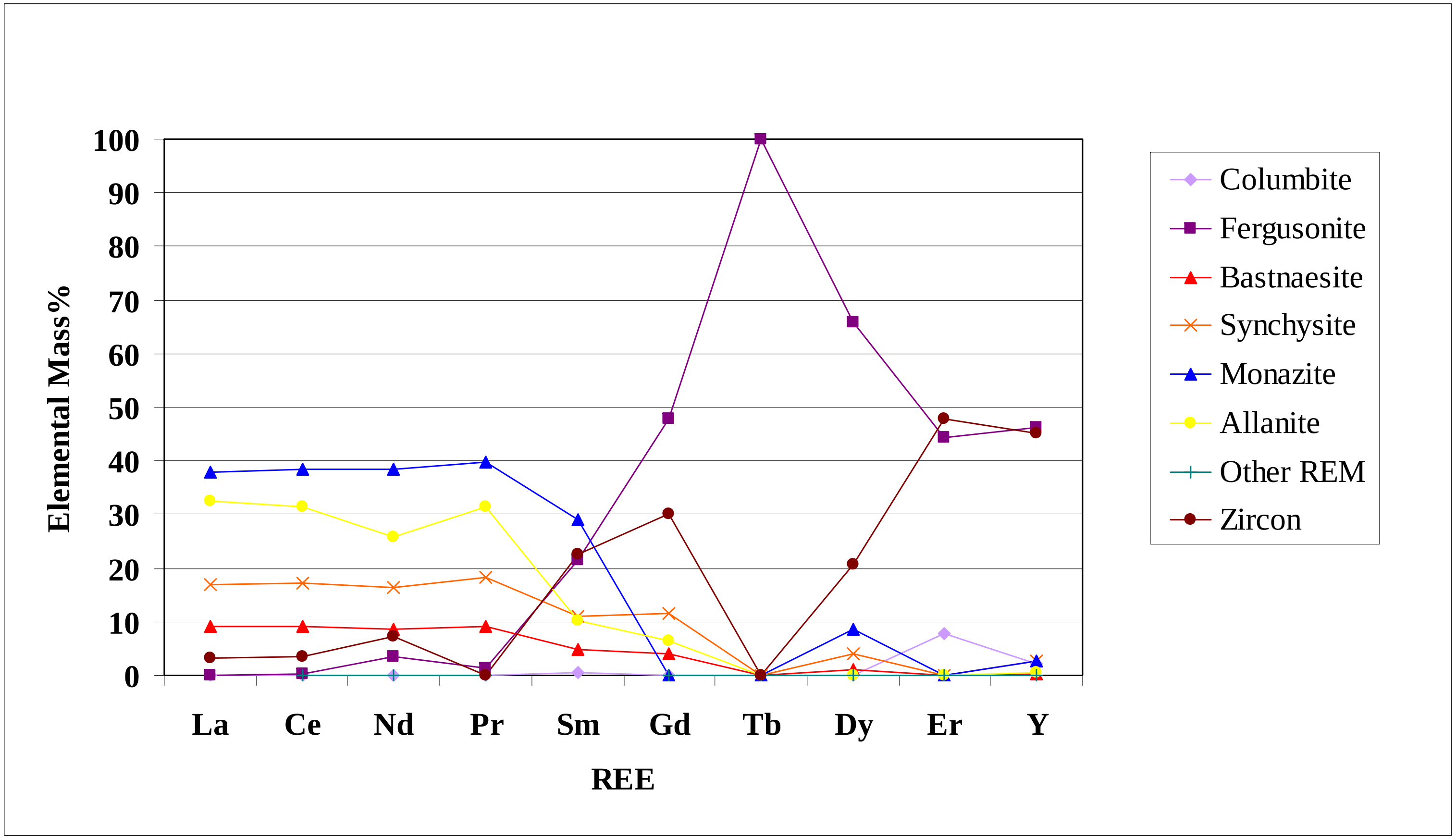
	Combined	+150um	-106/+75um	-75/+25um	-25/+3um
Non Recoverable - Locked	3.3	14.2	14.9	6.4	0.7
Non Recoverable - Exposed	33.5	81.2	81.0	76.6	15.5
Recoverable	15.5	4.5	3.9	14.2	17.7
Fergusonite:Other (Rec)	2.1	0.0	0.0	0.0	3.0
Fergusonite:Mafic Silicates (Rec)	1.5	0.0	0.0	0.0	2.0
Fergusonite:Alkaline Silicates (Rec)	1.1	0.0	0.0	0.0	1.5
Fergusonite:REE	4.9	0.0	0.0	1.5	6.5
Fergusonite:Zircon	7.2	0.0	0.0	0.1	10.0
Lib Fergusonite	7.1	0.0	0.2	0.3	9.9
Free Fergusonite	0.0	0.0	0.0	0.0	0.0
Pure Fergusonite	23.9	0.0	0.0	0.7	33.3

QEMSCAN – REE G-R

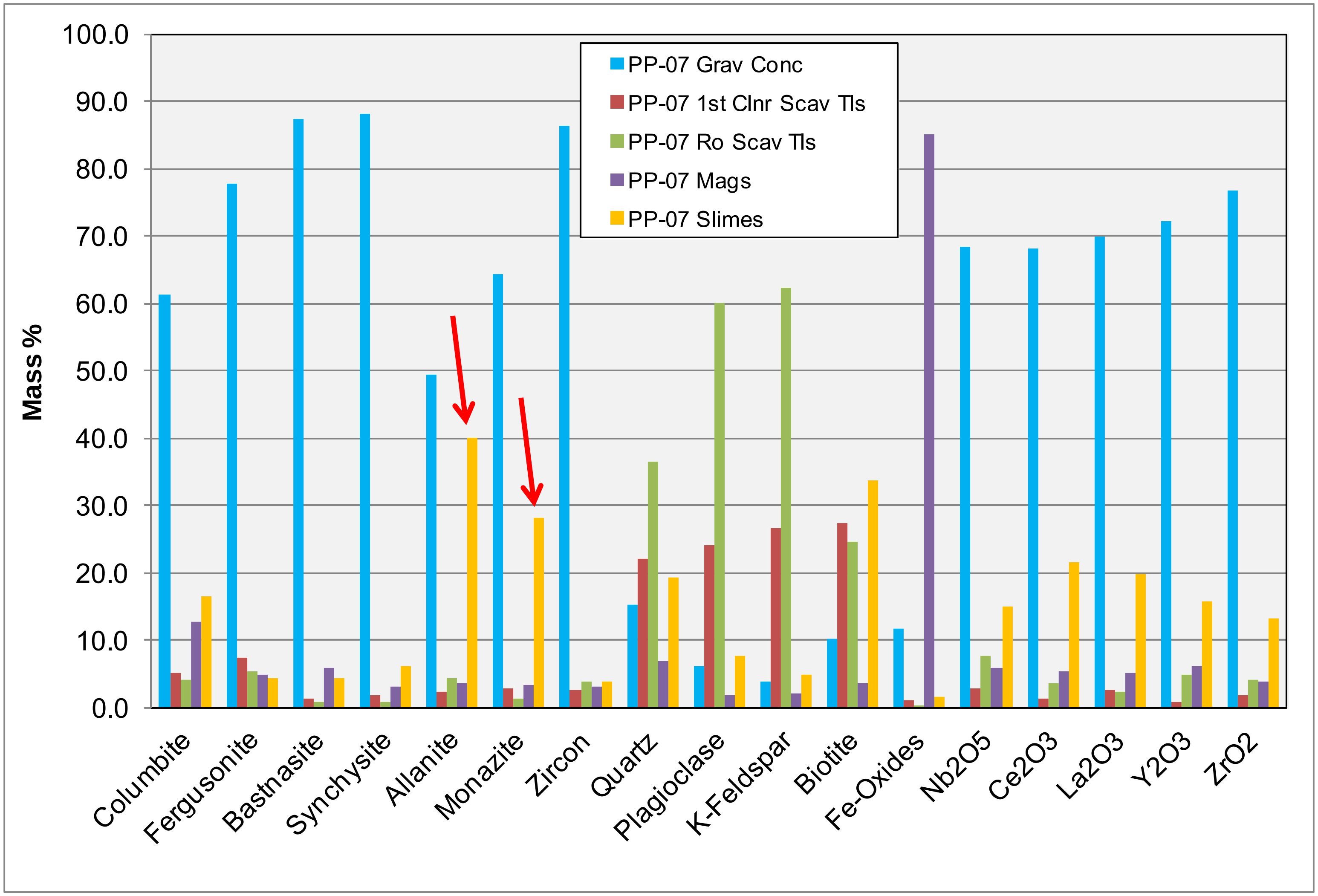


LREE & HREE Distribution

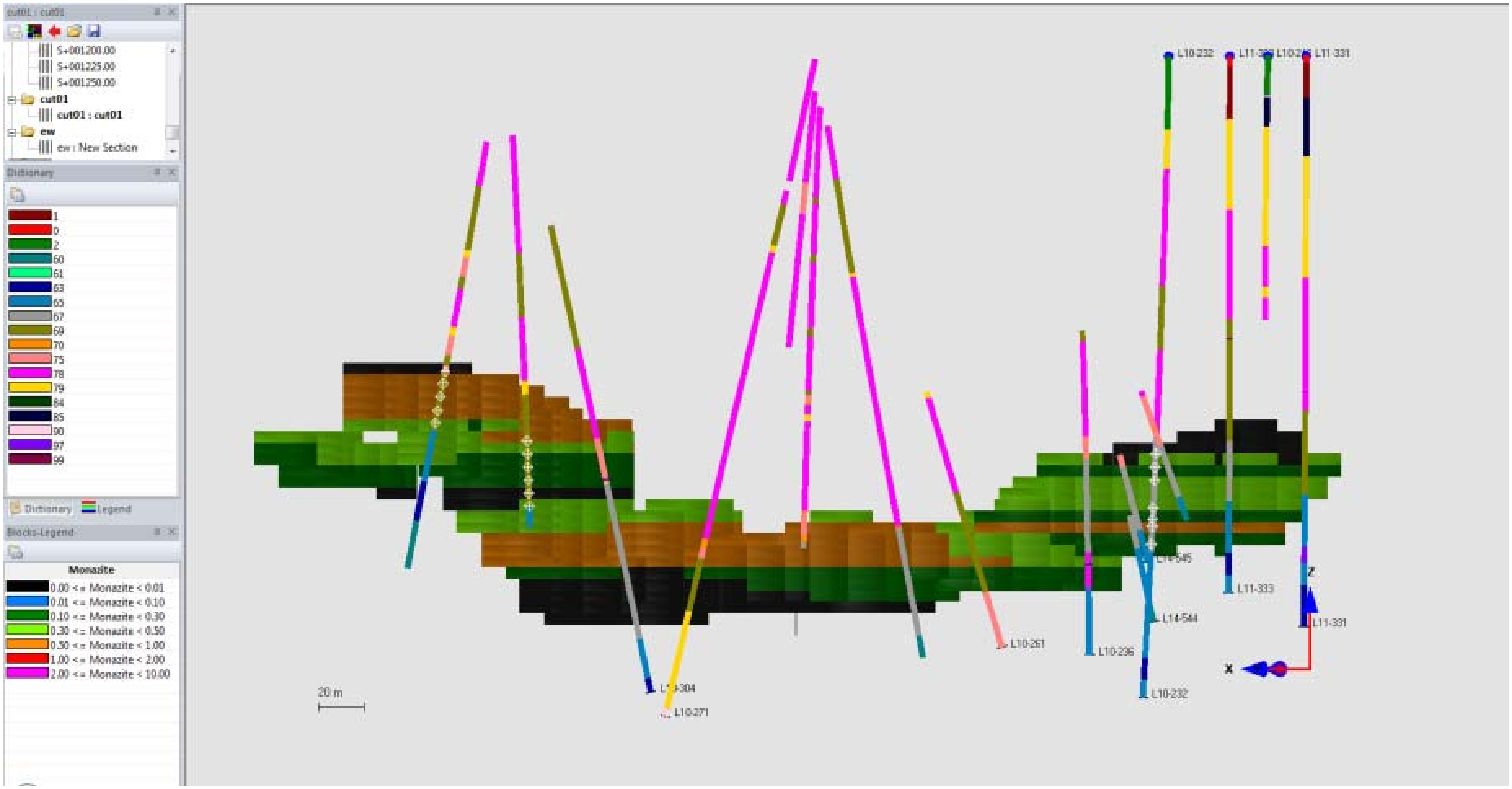
- Distribution of LREE and HREE (& Y)
- Fergusonite and zircon account for most of the HREE
- Monazite, allanite, synchysite and bastnaesite (in decreasing order) for the LREE



Mineral and Oxide Mass Balance



Allanite/Zircon Distribution



Conclusions

- **QEMSCAN is an extremely important tool in assessing the mineralogy of an ore body, supporting metallurgical test work, solving problem, and forecasting the recoveries and grade, and finally assist in the calculation of reserves of the deposit.**
- ***Quantitative and statistically robust data***
- ***Provides textural information for the mineralization***
- ***Variability data of the ore***
- ***Define mineralized and barren domains***
- ***Detailed Modal Data***
- ***Liberation & Association***
- ***Size Distribution***
- ***Elemental Distribution***
- ***Geometallurgy***
- ***QEMSCAN™ is not biased compared to other methods***
- ***Mineralogy essentially dictates the metallurgical process(es)***