# Mineralogical characterisation of gold ores: collaboration is the best technique!

Dorrit de Nooy (Senior Mineralogist, Metallurgy Services)

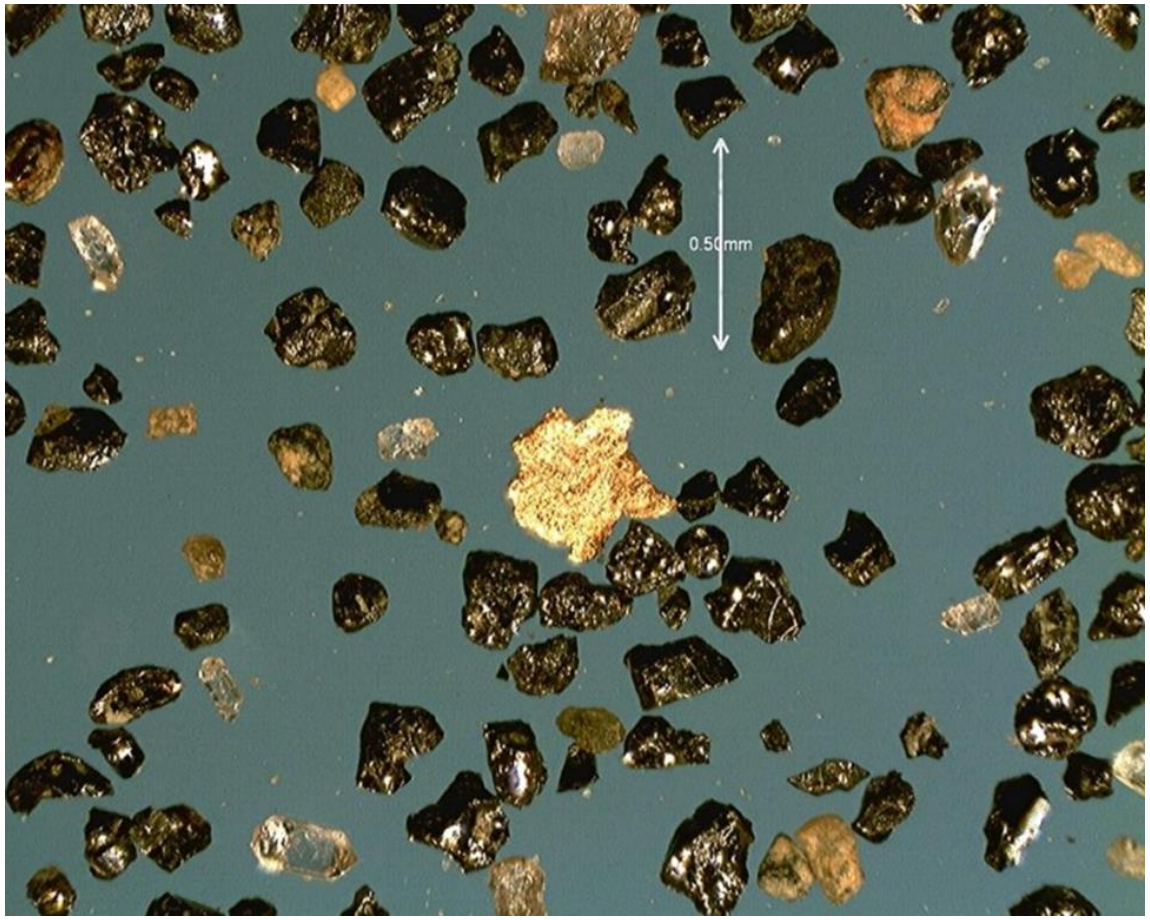
Kalgoorlie Metallurgical Symposium (MetFest)
Friday 20th October 2017

# Outline

1. Relationship between metallurgical testwork and mineralogical characterisation.

2. Overview of the methods currently used by ALS Metallurgy (Balcatta in Perth) for mineralogical characterisation of gold ores.

3. Examples of mineralogical data:
   - host rock (or bulk) mineralogy
   - gold deportment



# Metallurgical testwork and/or mineralogical ore characterisation?

‘Gold deportment studies’ or, more broadly, ‘mineralogical characterisation studies’ are often requested as part of metallurgical testwork programmes on gold ores.

Most commonly the samples submitted for testing would be:

- Composite plant feed samples
- Tailings samples
- Flotation concentrates
- Routine monthly composites

Metallurgical testing can be done on a much larger sample than mineralogical tests and generally provides more quantitative and/or representative data especially on the gold.

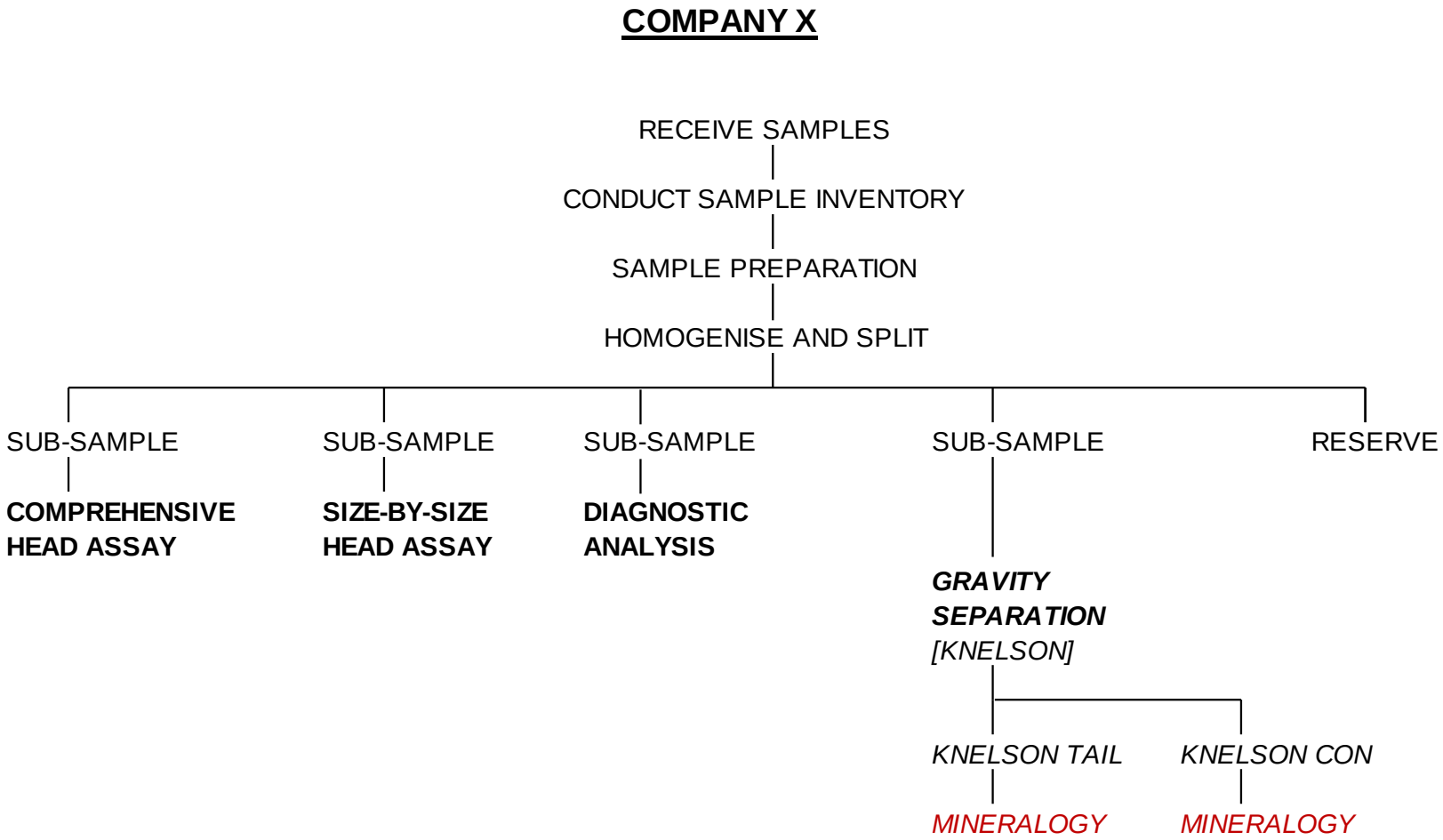
Some of the characteristics of gold ores that might affect efficient gold recovery can be best established using mineralogical methods.

- Information on the host rock minerals and textures
- Information on the sulphide minerals
- Information on the gold minerals

**Mineralogical analyses should be done in conjunction with metallurgical testing and the two sets of data should be reconciled.**

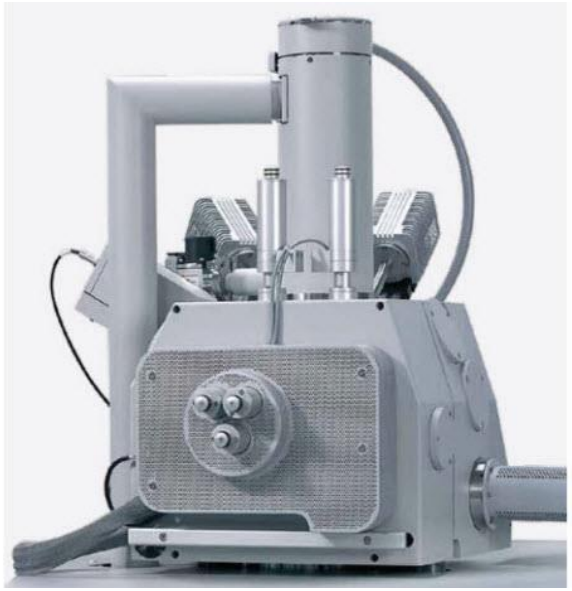
# Mineralogy as part of metallurgical testwork programme

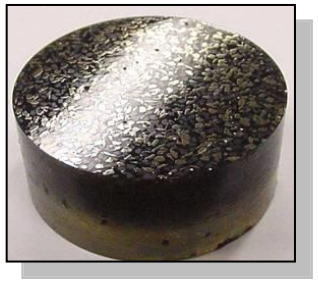
**FIGURE 1: METALLURGICAL TESTWORK PROGRAM - GOLD DEPORTMENT**

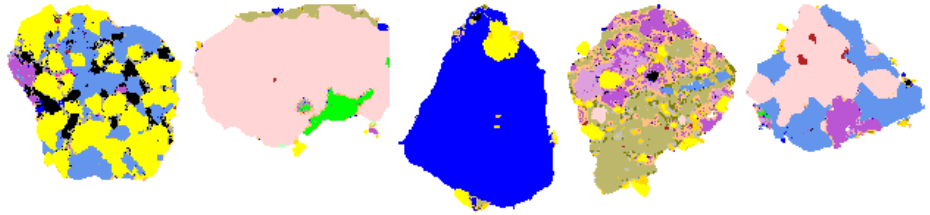


# Main techniques

## Automated scanning electron microscopy – QEMSCAN/MLA





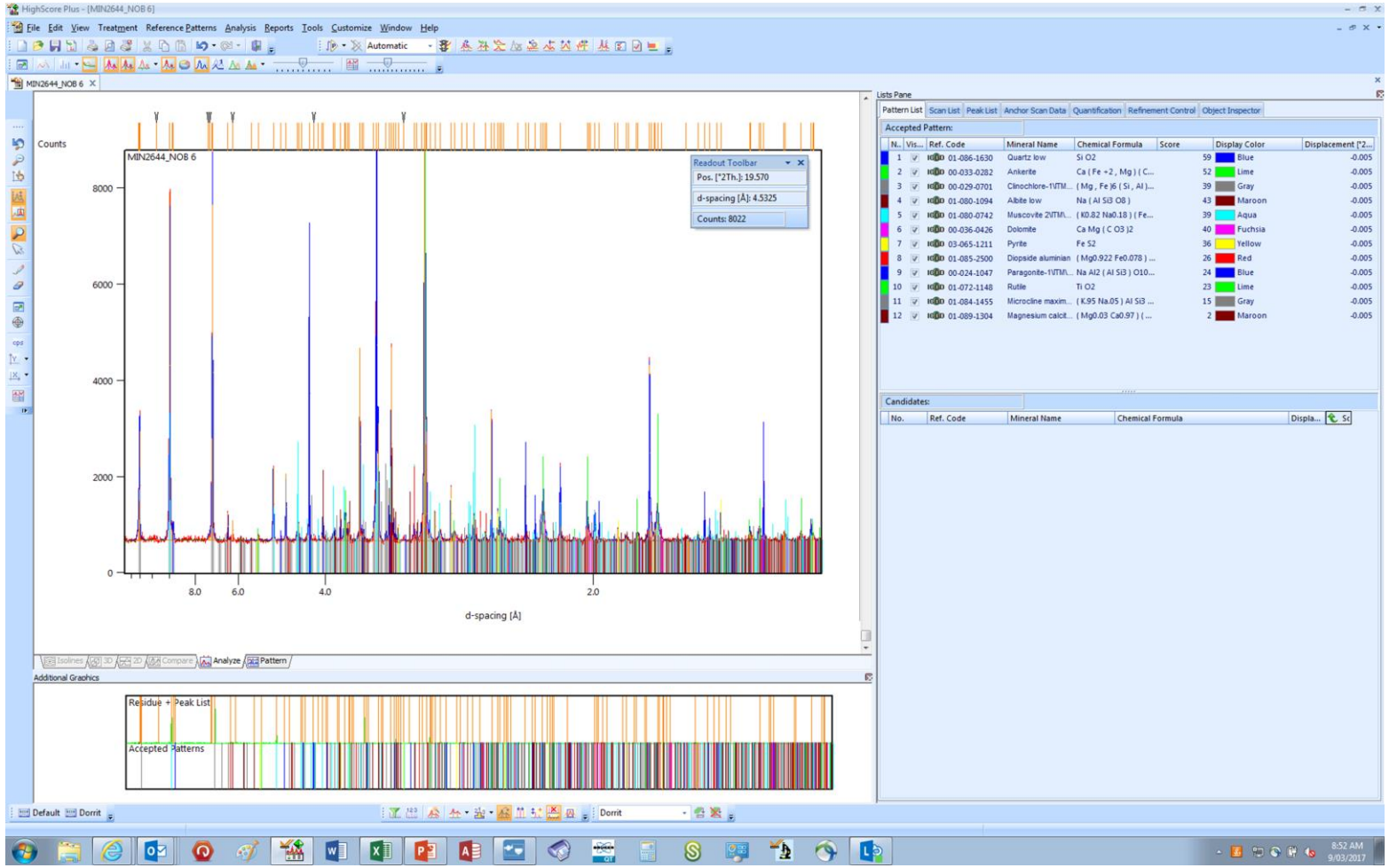


## X-ray diffraction analysis

## Optical microscopy

## LA-ICP-MS

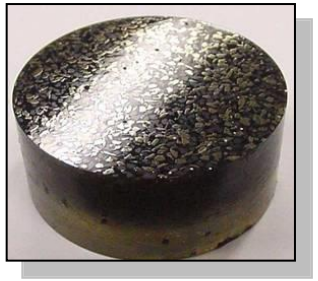
# X-ray diffraction analysis



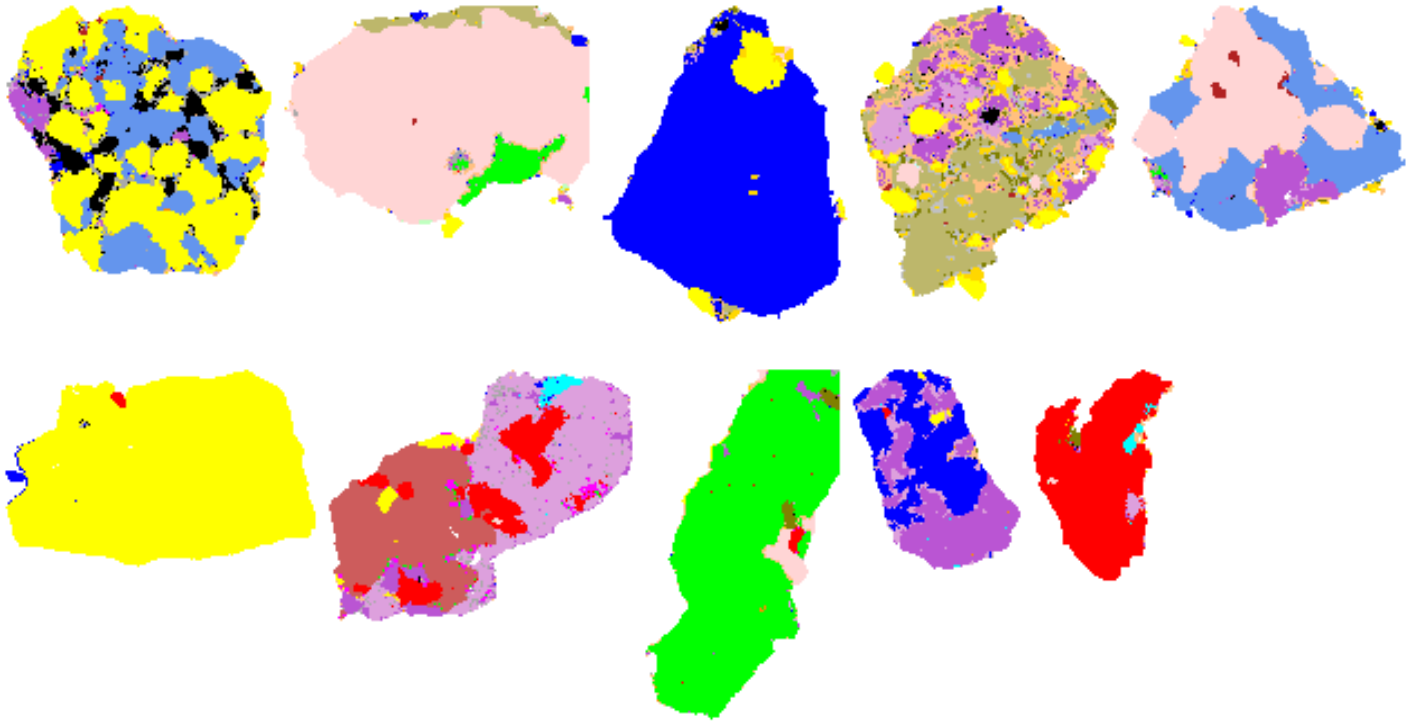

| Mineral group | Sample A |
|---|---|
| | Gravity Tail |
| | Mass% |
| **Pyrite** | <1 |
| **Alpha quartz** | 41 |
| **Calcic and/or sodic plagioclase** | 6 |
| **Microcline - rutile - titanite** | 1 |
| **Muscovite** | 9 |
| **Biotite - phlogopite** | 14 |
| **Calcic amphibole** | 8 |
| **Clinochlore** | 12 |
| **Serpentine** | 1 |
| **Talc** | < 1 |
| **Tourmaline** | 1 |
| **Clay mineral** | 1 |
| **Calcite** | 4 |
| **Dolomite - ankerite** | 2 |
| **Siderite** | < 1 |
| **Magnetite** | 1 |

Mineral abundances on gravity tailings samples

# QEMSCAN analysis: particle maps



Particles are about 150 µm, mapped on 1 µm analysis point spacing



- Background
- Sphalerite
- Galena
- Pb-(Cu)-(Bi)-(Sb)-S phases
- Cu-As-S (enargite)
- Cu-As-Sb-S (tennantite-tetrahedrite)
- Chalcopyrite
- Bornite
- Covellite and similar Cu-sulphides
- Cu-Te-S (goldfieldite)
- Cu-sulphide intergrowths
- Ag-(Cu)-(Bi)-S phases
- Ag-Te phases
- Au-(Ag)-(Te) phases
- Te-(Bi) phases
- Pyrite
- Pyrite-silicate intergrowths
- Other sulphides
- Quartz
- Feldspars
- Micas
- Kaolinite and other clay minerals
- Other silicates
- Alunite
- Barite
- Carbonates/limonite/goethite
- Rutile and other Ti minerals
- Other minerals

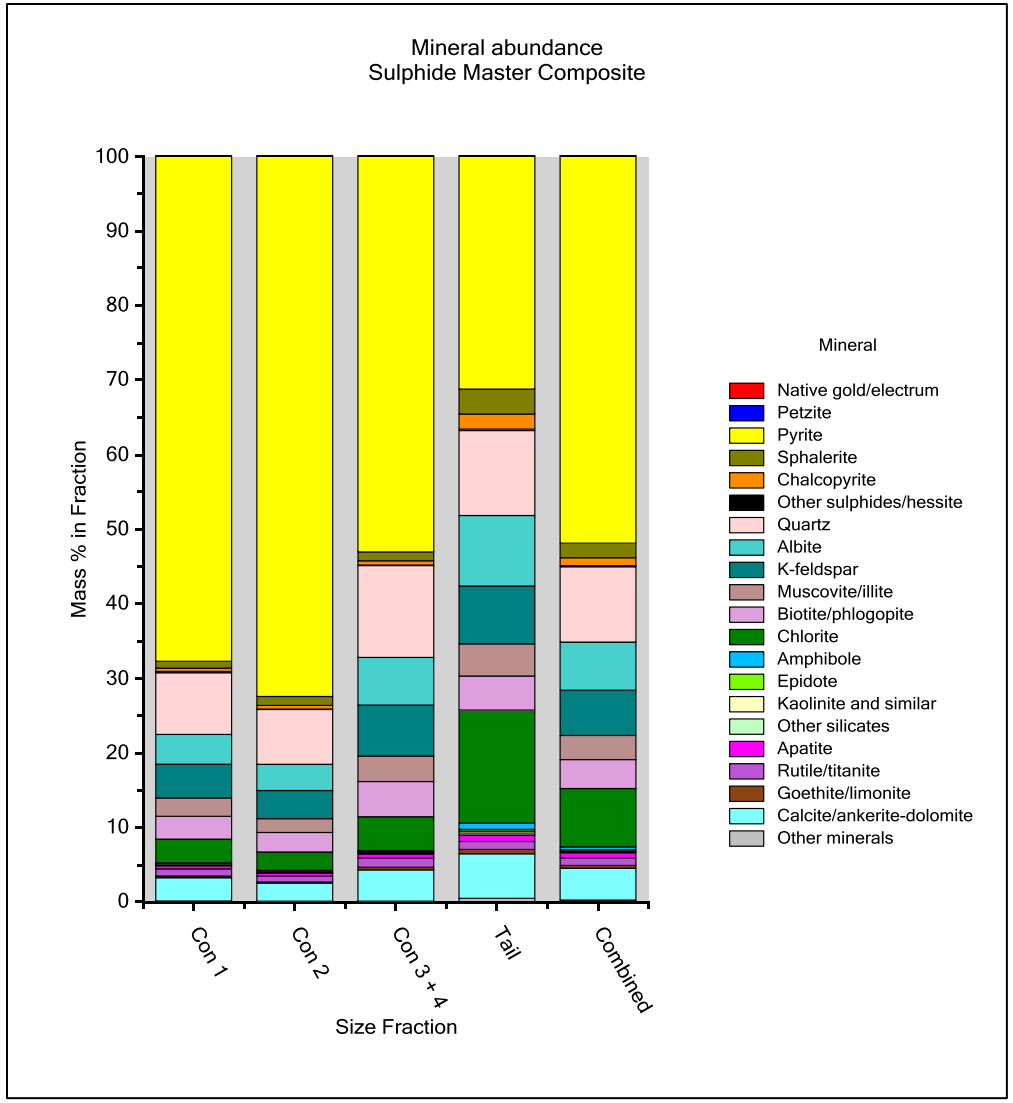
# What mineralogical information can we provide?

Host rock minerals with emphasis on sulphides and gold:

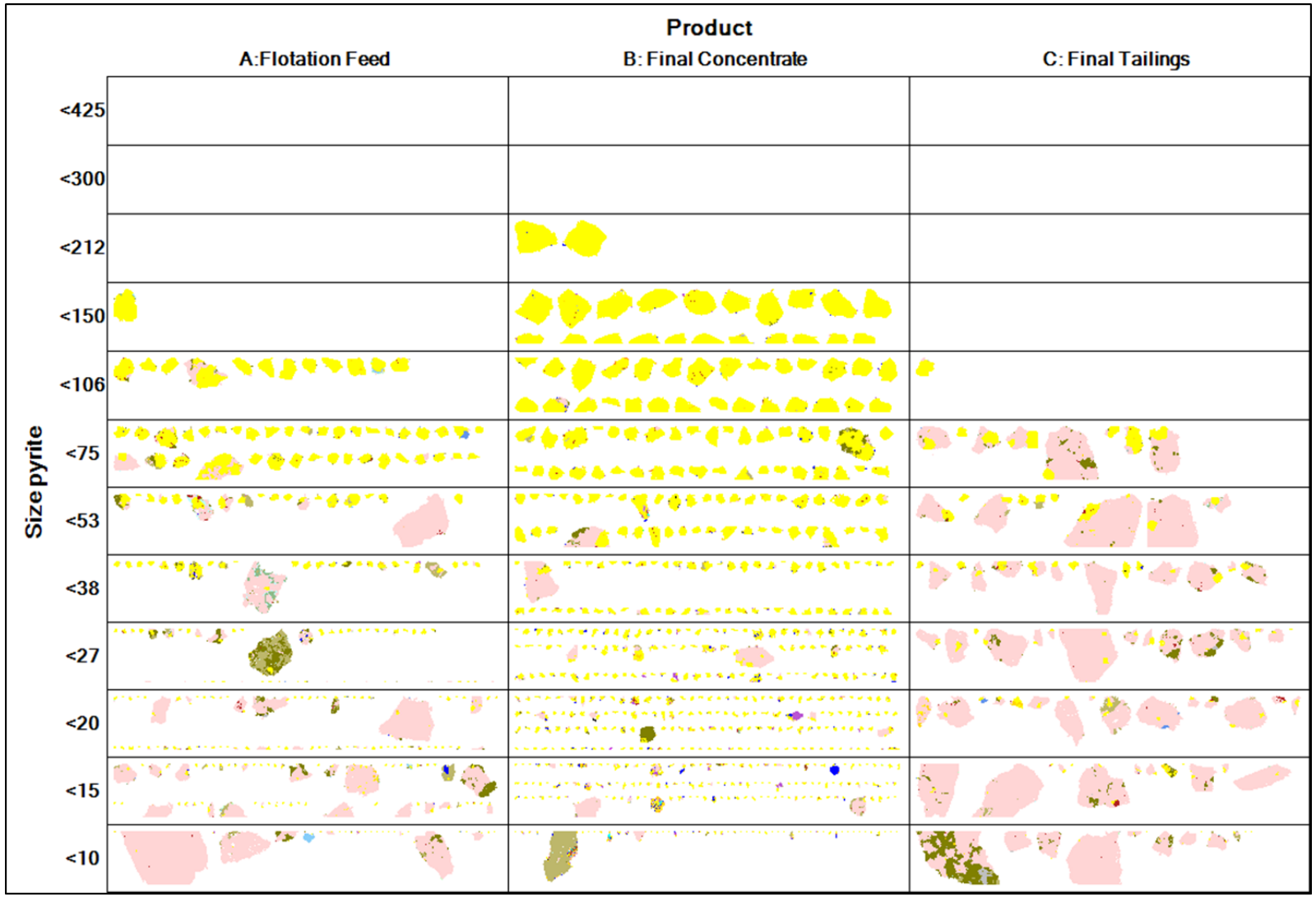
- identity
- abundance
- grain size distribution
- elemental deportment
- liberation
- locking
- false colour particle images
- detailed data on gold

Other information that we obtain from the mineralogical investigation:

- cyanide consumers (secondary copper minerals)
- oxygen consumers (pyrrhotite, marcasite)
- carbonates (tailings disposal)
- clay minerals (especially settling)



# Example of grain size image grid

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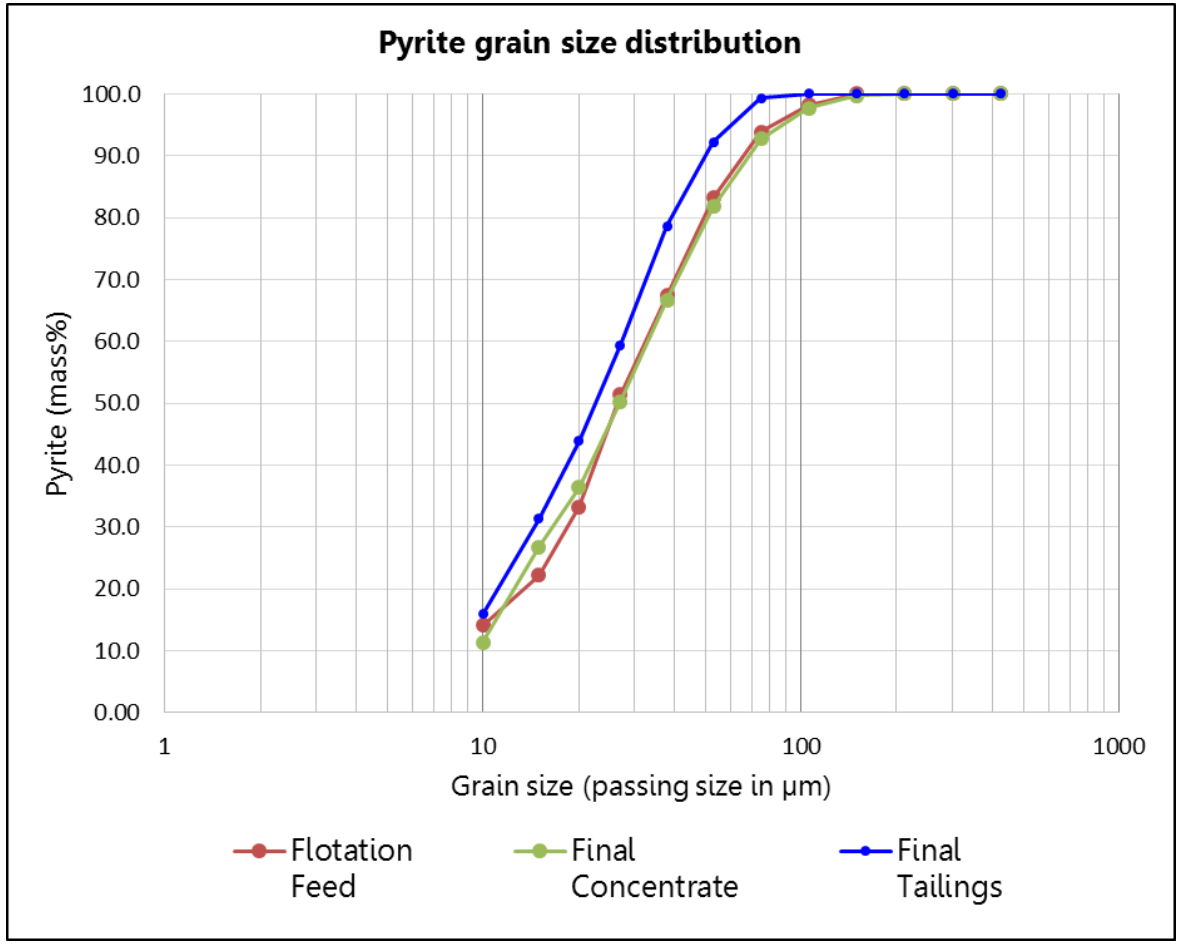
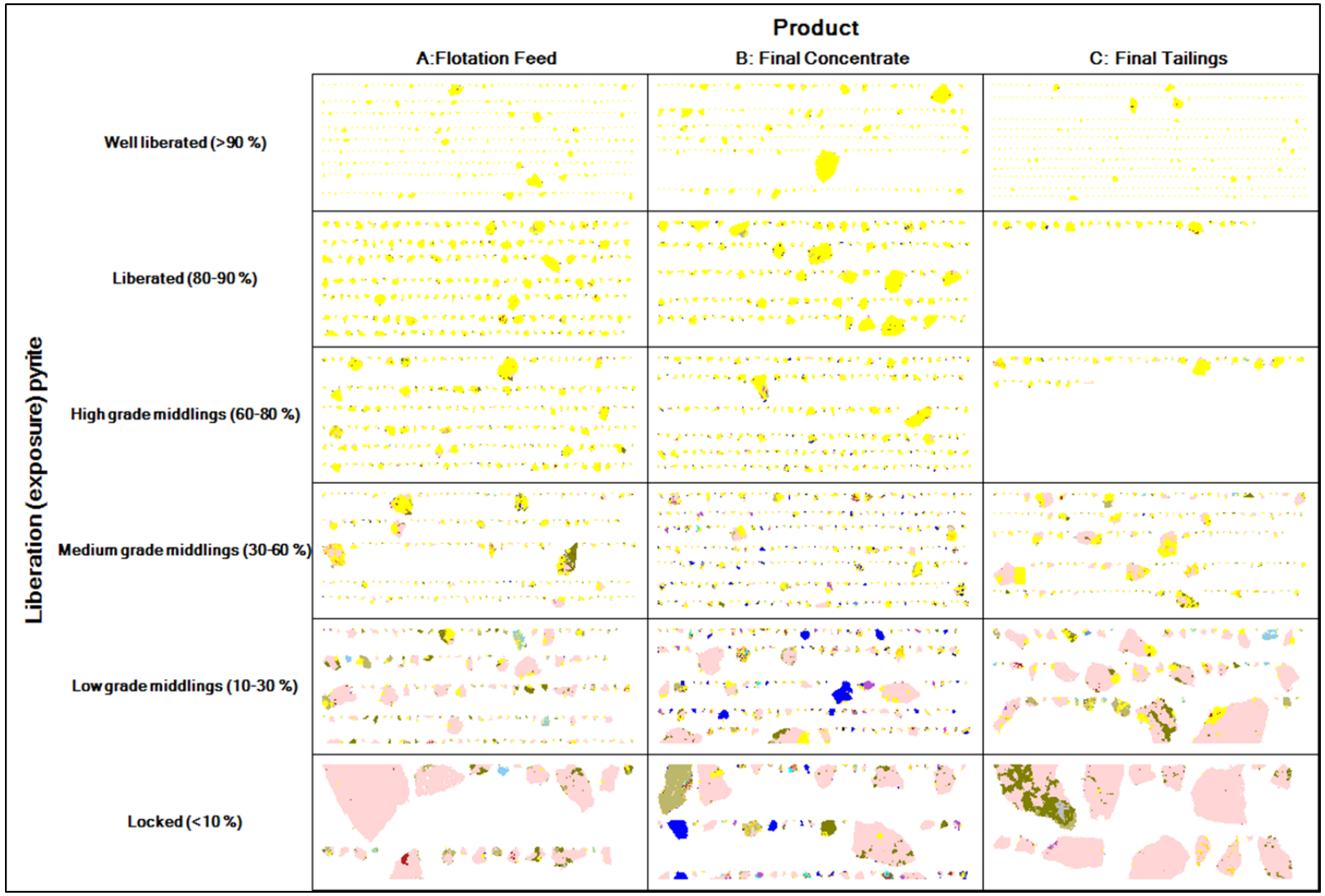
# Example of grain size data

| Pyrite passing size (µm) | | January 2017 Monthly Composites | | |
|---|---|---|---|---|
| | | Flotation Feed | Final Concentrate | Final Tailings |
| | | Pyrite (cumulative mass%) | | |
| < 425 | 425 | 100.0 | 100.0 | 100.0 |
| < 300 | 300 | 100.0 | 100.0 | 100.0 |
| < 212 | 212 | 100.0 | 100.0 | 100.0 |
| < 150 | 150 | 100.0 | 99.7 | 100.0 |
| < 106 | 106 | 98.2 | 97.7 | 100.0 |
| < 75 | 75 | 93.8 | 92.7 | 99.3 |
| < 53 | 53 | 83.2 | 81.8 | 92.2 |
| < 38 | 38 | 67.4 | 66.7 | 78.7 |
| < 27 | 27 | 51.4 | 50.3 | 59.4 |
| < 20 | 20 | 33.3 | 36.4 | 43.9 |
| < 15 | 15 | 22.2 | 26.8 | 31.3 |
| < 10 | 10 | 14.1 | 11.3 | 15.9 |
| **$P_{80}$** | **µm** | **50** | **51** | **39** |
| **$P_{50}$** | **µm** | **26** | **27** | **23** |
| **$P_{20}$** | **µm** | **14** | **13** | **11** |
| **Pyrite (mass%)** | | **3.99** | **51.8** | **1.01** |



# Example of liberation image grid

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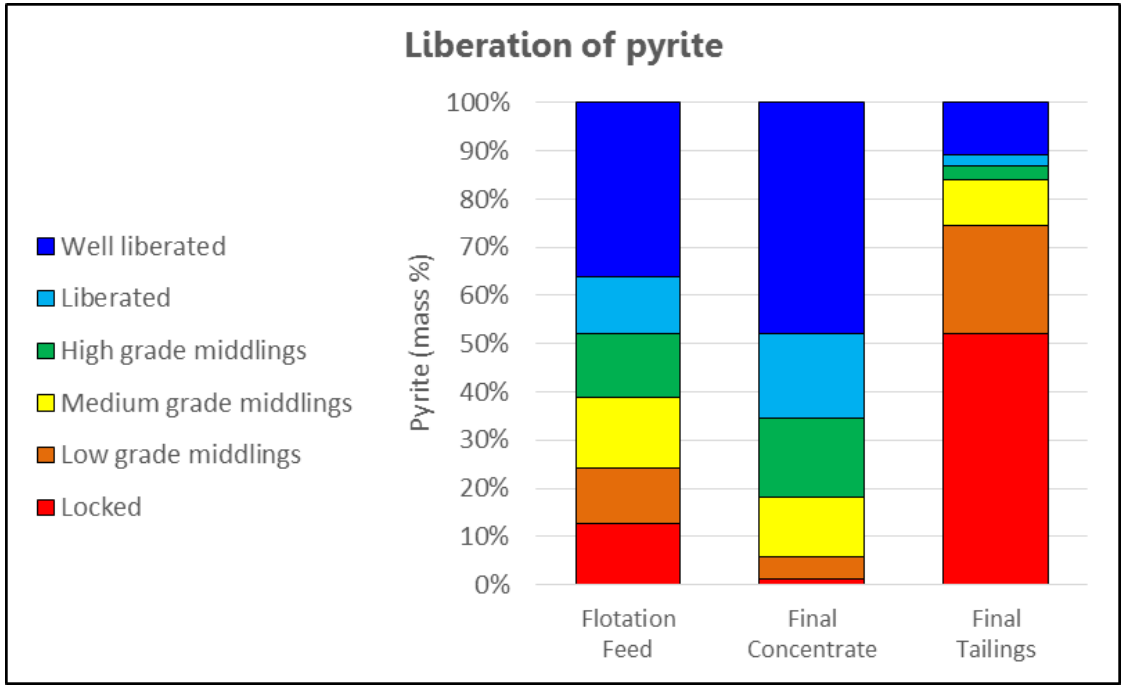
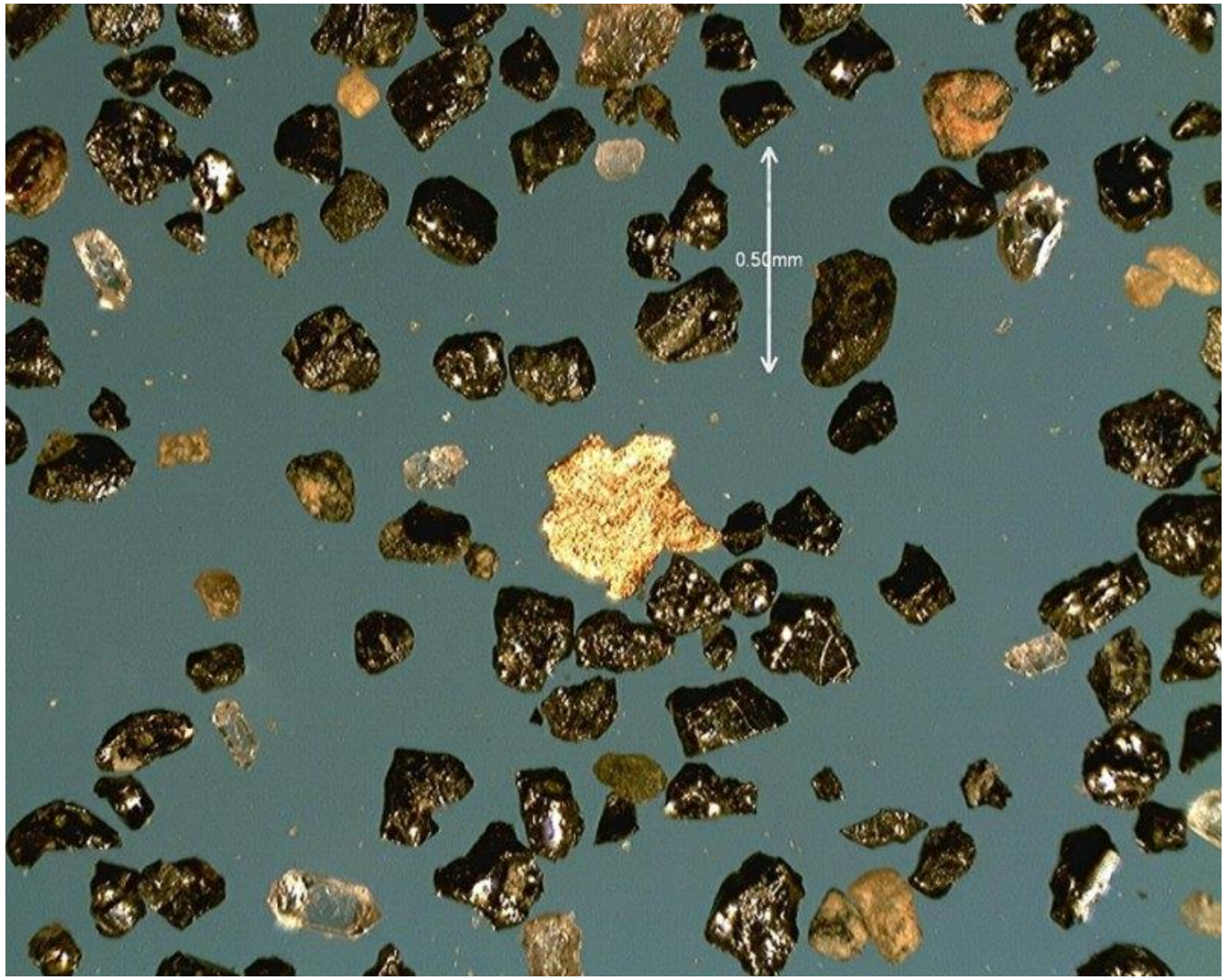
- Alunite
- Barite
- Carbonates/limonite/goethite
- Rutile and other Ti minerals
- Other minerals

# Example of liberation data

| Liberation (exposure) class | Surface area % of mineral | January 2017 Monthly Composites | | |
|---|---|---|---|---|
| | | Flotation Feed | Final Concentrate | Final Tailings |
| | | Pyrite (mass %) | | |
| Well liberated | > 90 % | 36.2 | 48.0 | 10.7 |
| Liberated | 80-90 % | 11.7 | 17.5 | 2.34 |
| High grade middlings | 60-80 % | 13.4 | 16.4 | 2.95 |
| Medium grade middlings | 30-60 % | 14.5 | 12.4 | 9.64 |
| Low grade middlings | 10-30 % | 11.6 | 4.66 | 22.3 |
| Locked | < 10 % | 12.6 | 1.05 | 52.1 |
| **Total** | | **100.0** | **100.0** | **100.0** |
| **Pyrite (mass%)** | | **3.99** | **51.8** | **1.01** |



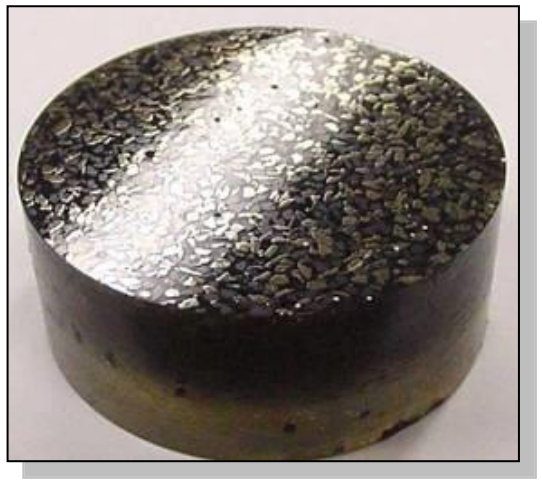
# Searching for gold: coarse gold



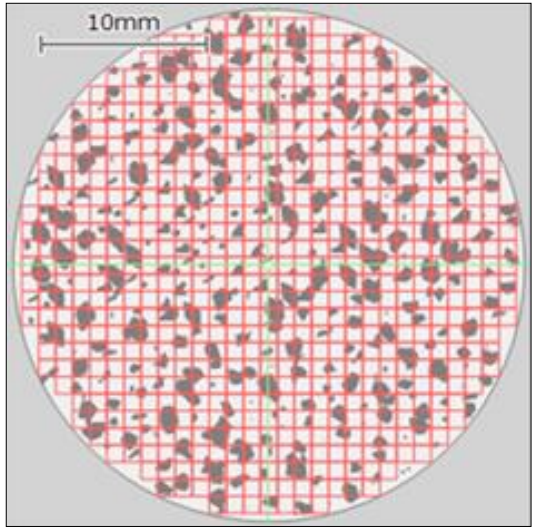

Search gravity concentrate using stereomicroscope methods and then determine:

- size and shape
- composition
- coatings (consider other methods)

# Searching for gold: QEMSCAN analysis

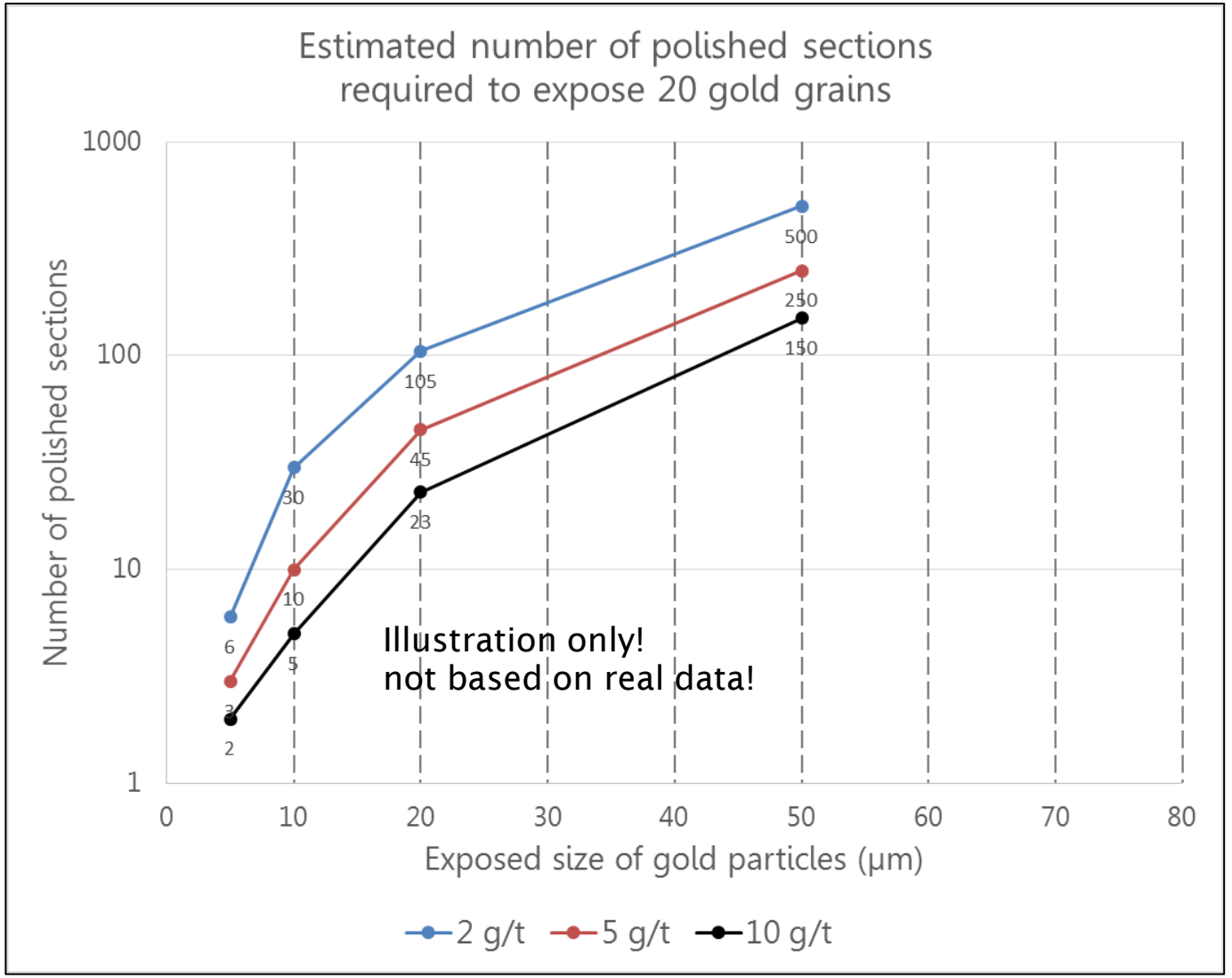


1 g of sample




Challenges: low grade and extreme range in size.

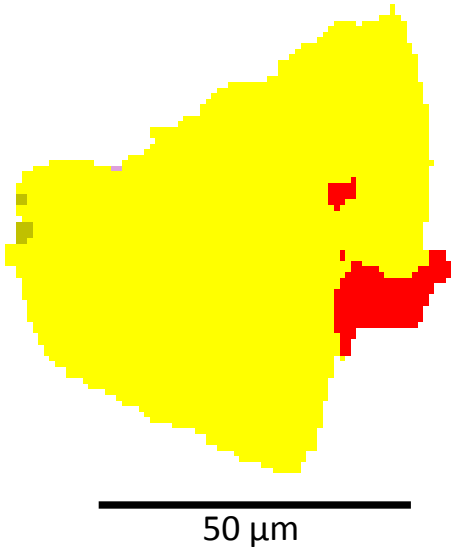
How many gold grains can we expect to find in one polished block?

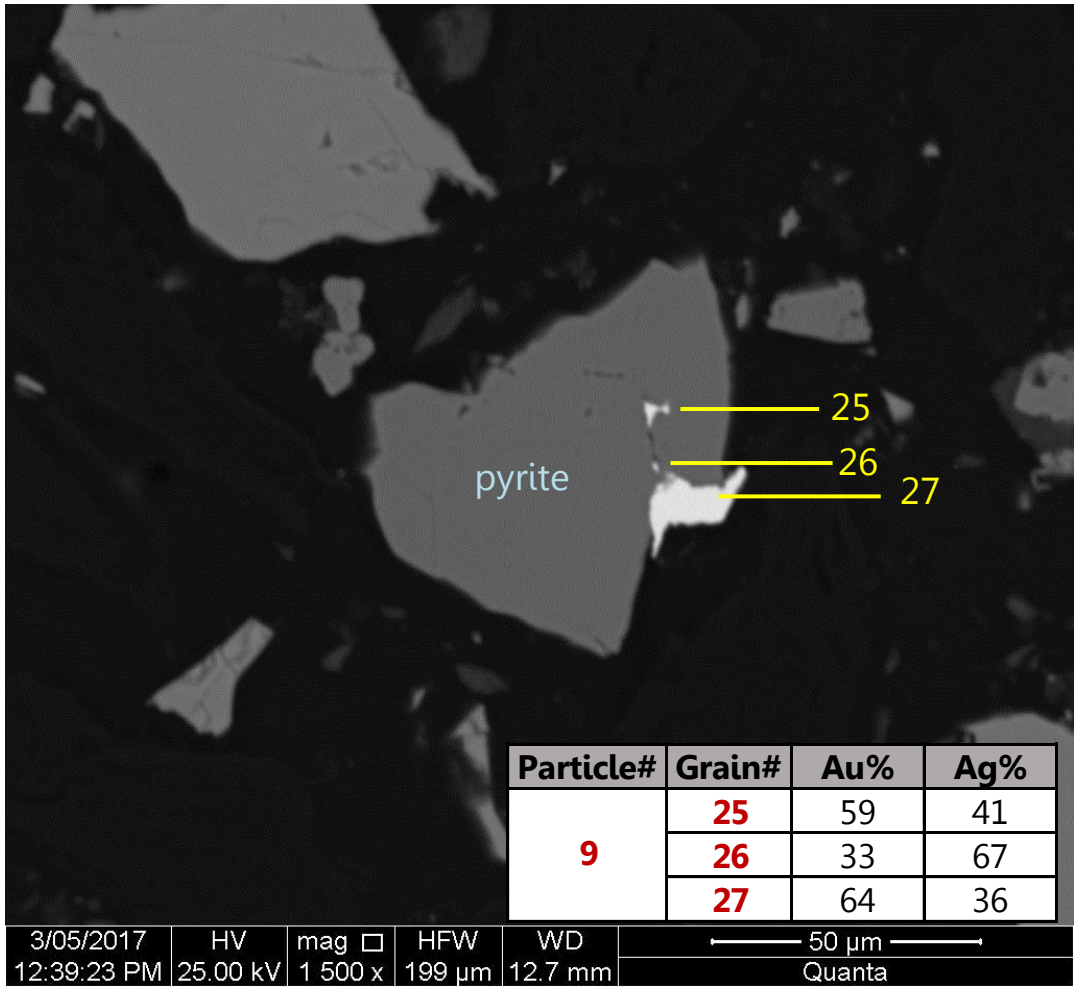


# Gold composition

**Mineral Name**

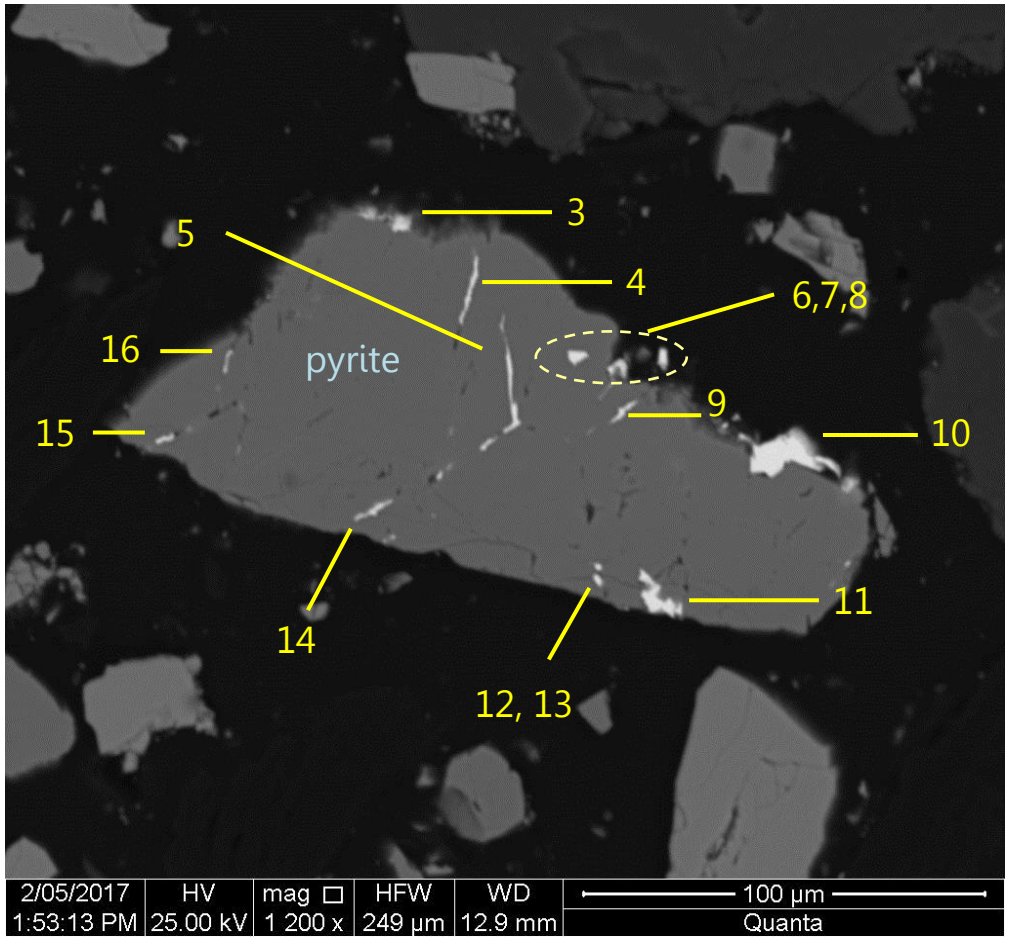
- Background
- Gold
- Pyrite
- Arsenopyrite
- Galena
- Sphalerite
- Chalcopyrite
- Other S/As/Te/Sb phases
- Quartz
- Albite
- Micas
- Kaolinite
- Chlorite
- Other silicates/boundaries
- Carbonates
- Fe-oxides/oxyhydroxides/siderite
- Rutile
- Apatite
- Other minerals

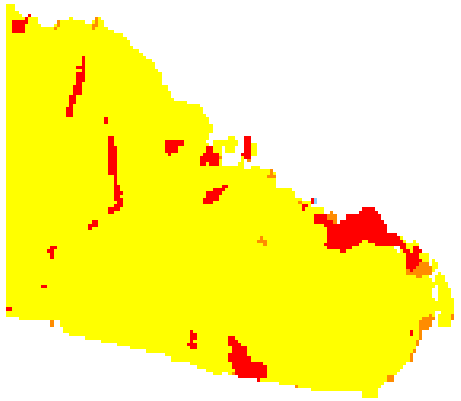


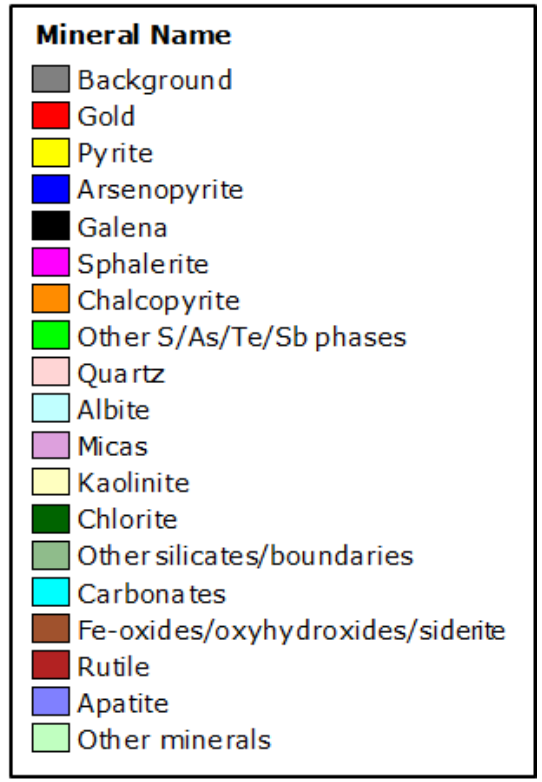

| Particle# | Grain# | Au% | Ag% |
|---|---|---|---|
| 9 | 25 | 59 | 41 |
| | 26 | 33 | 67 |
| | 27 | 64 | 36 |

# Gold locked in sulphides

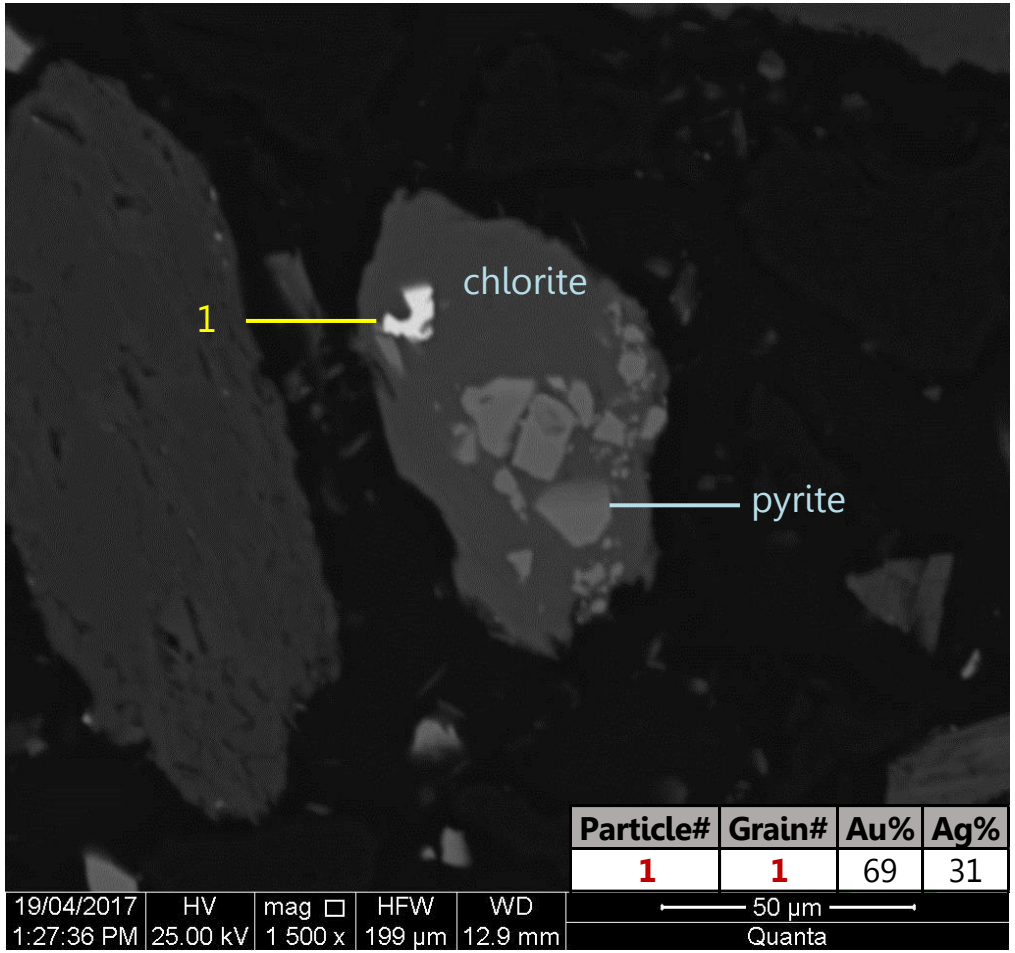


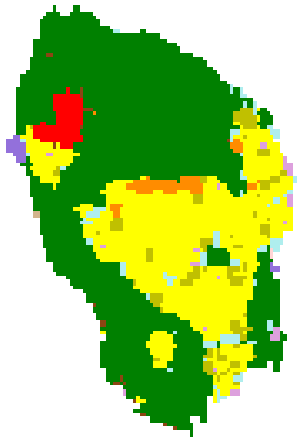



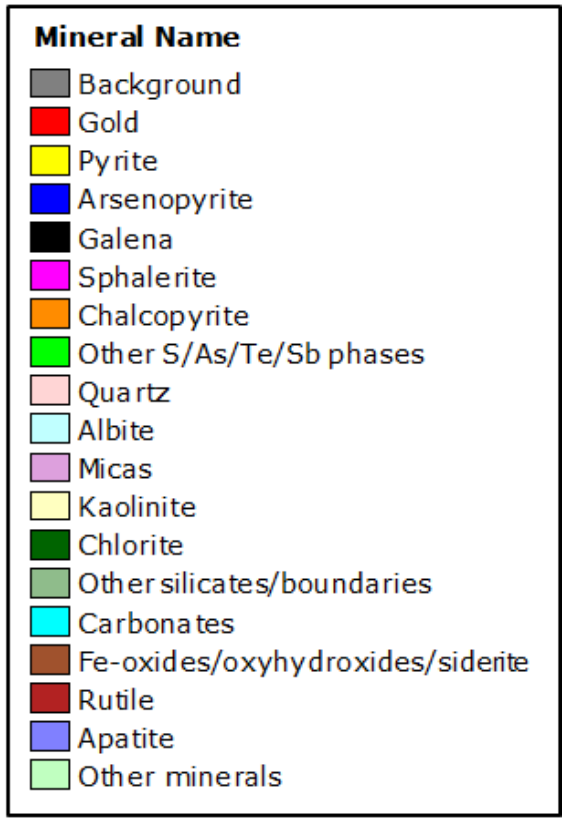
| Particle# | Grain# | Au% | Ag% |
|---|---|---|---|
| 3 | 3 | 50 | 50 |
| | 4 | 52 | 48 |
| | 5 | 60 | 40 |
| | 6 | 63 | 37 |
| | 7 | 59 | 41 |
| | 8 | 61 | 39 |
| | 9 | 62 | 38 |
| | 10 | 65 | 35 |
| | 11 | 63 | 37 |
| | 12 | 57 | 43 |
| | 13 | 57 | 43 |
| | 14 | 51 | 49 |
| | 15 | 61 | 39 |
| | 16 | 52 | 48 |



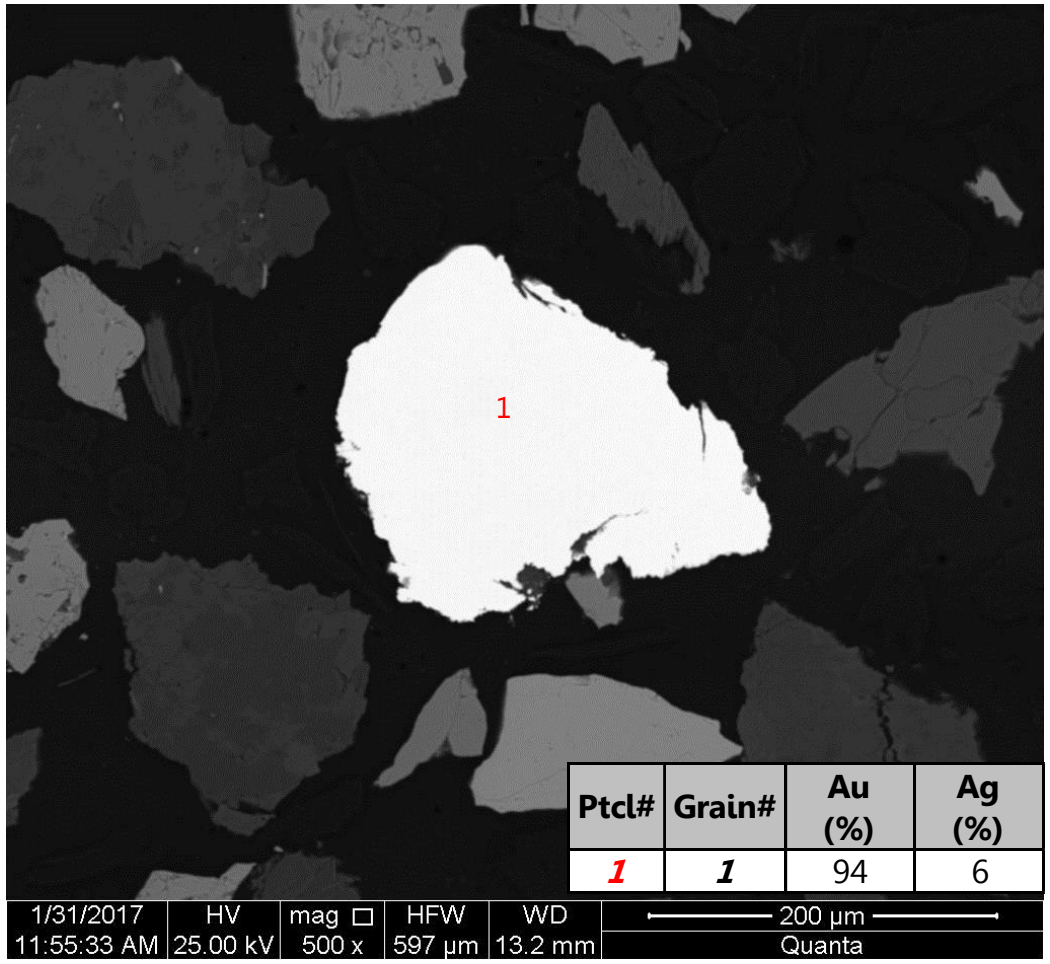
# Gold locked in silicates

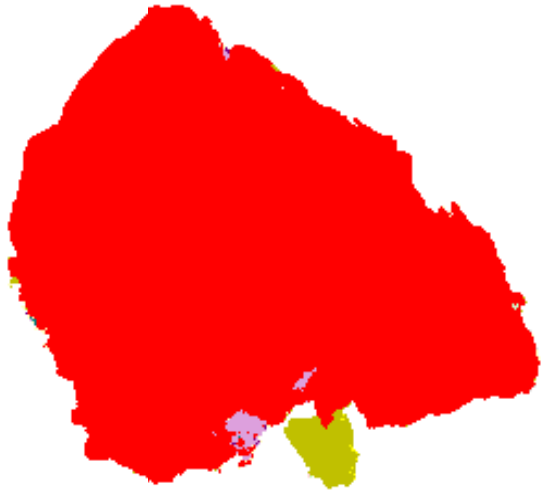




# Coarse gold



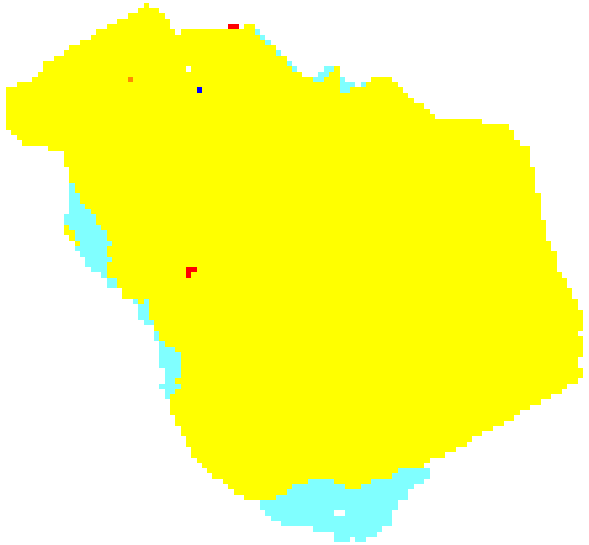
**Mineral Name**

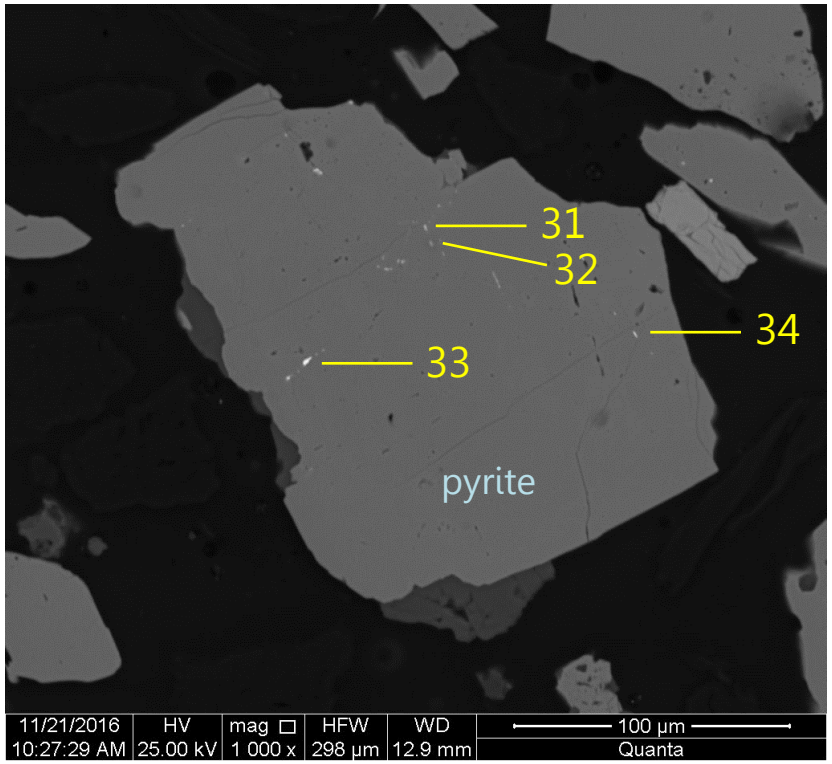
- Background
- Gold
- Pyrite
- Pyrrhotite
- Arsenopyrite
- Galena
- Sphalerite
- Other sulphides
- Quartz
- Feldspars
- Micas
- Amphiboles
- Epidote/zoisite
- Chlorite and similar
- Kaolinite and other clays
- Other silicates
- Apatite
- Titanite/ilmenite
- Goethite/limonite
- Carbonates
- Scheelite
- Steel
- Other minerals

# Fine-grained gold

**Mineral Name**

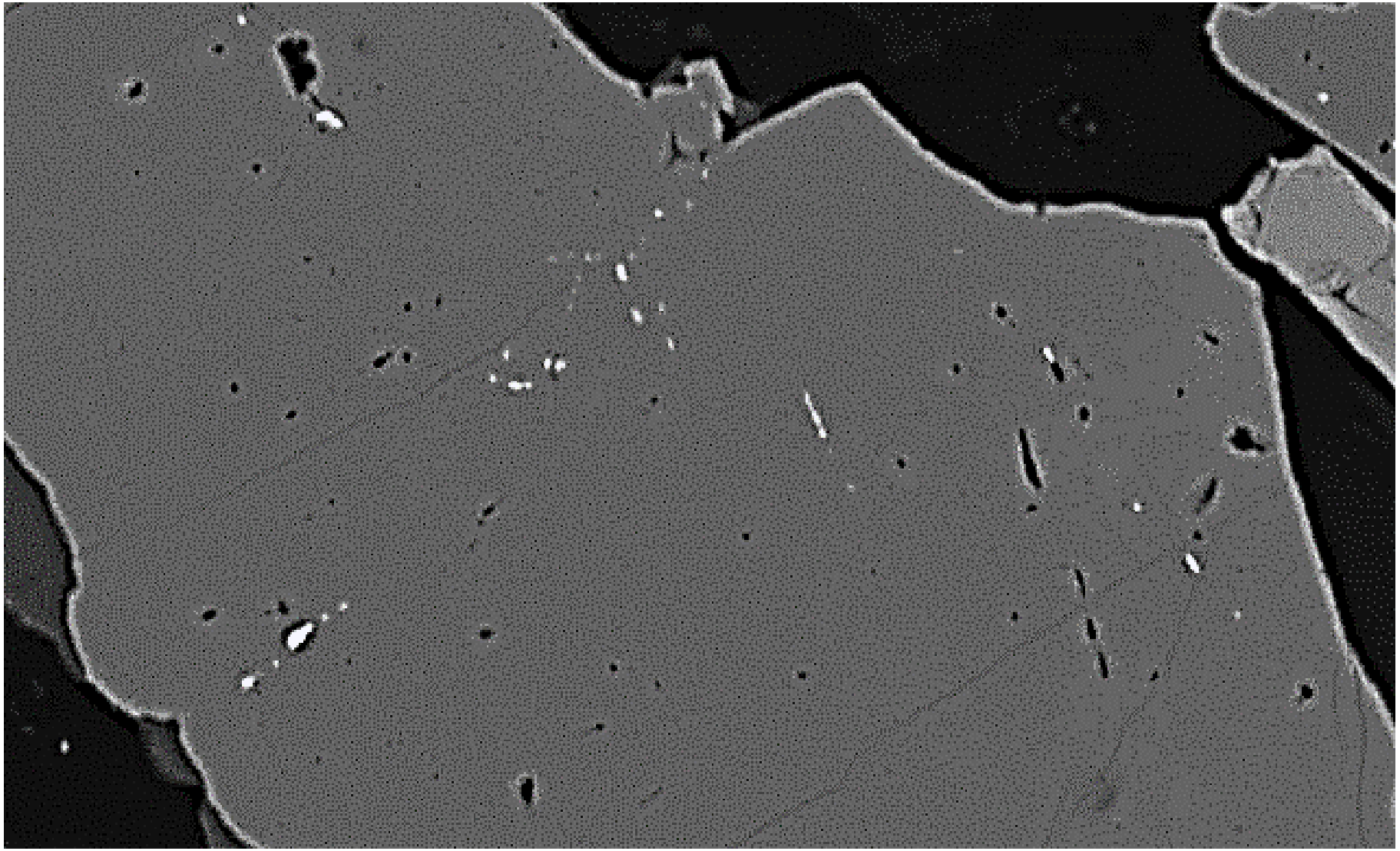
- Background
- Native gold/electrum
- Petzite
- Pyrite
- Sphalerite
- Chalcopyrite
- Other sulphides/hessite
- Quartz
- Albite
- K-feldspar
- Muscovite/illite
- Biotite/phlogopite
- Chlorite
- Amphibole
- Epidote
- Kaolinite and similar
- Other silicates
- Apatite
- Rutile/titanite
- Goethite/limonite
- Calcite/ankerite-dolomite
- Other minerals



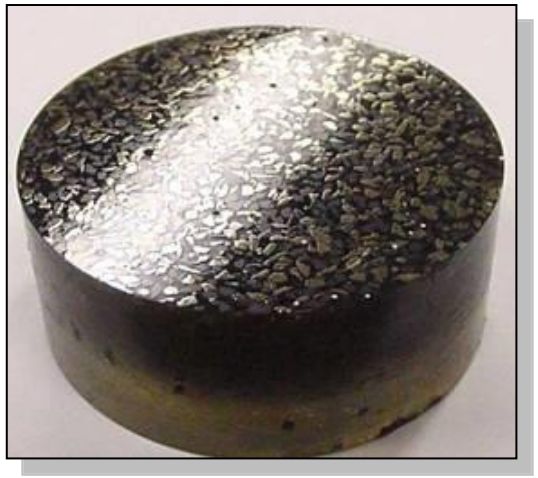



| Ptcl# | Grain# | Au (%) | Ag (%) | Te (%) |
|---|---|---|---|---|
| *10* | ***31*** | 20 | 42 | 38 |
| | ***32*** | 19 | 39 | 42 |
| | ***33*** | 97 | 3 | 0 |
| | ***34*** | 19 | 44 | 37 |

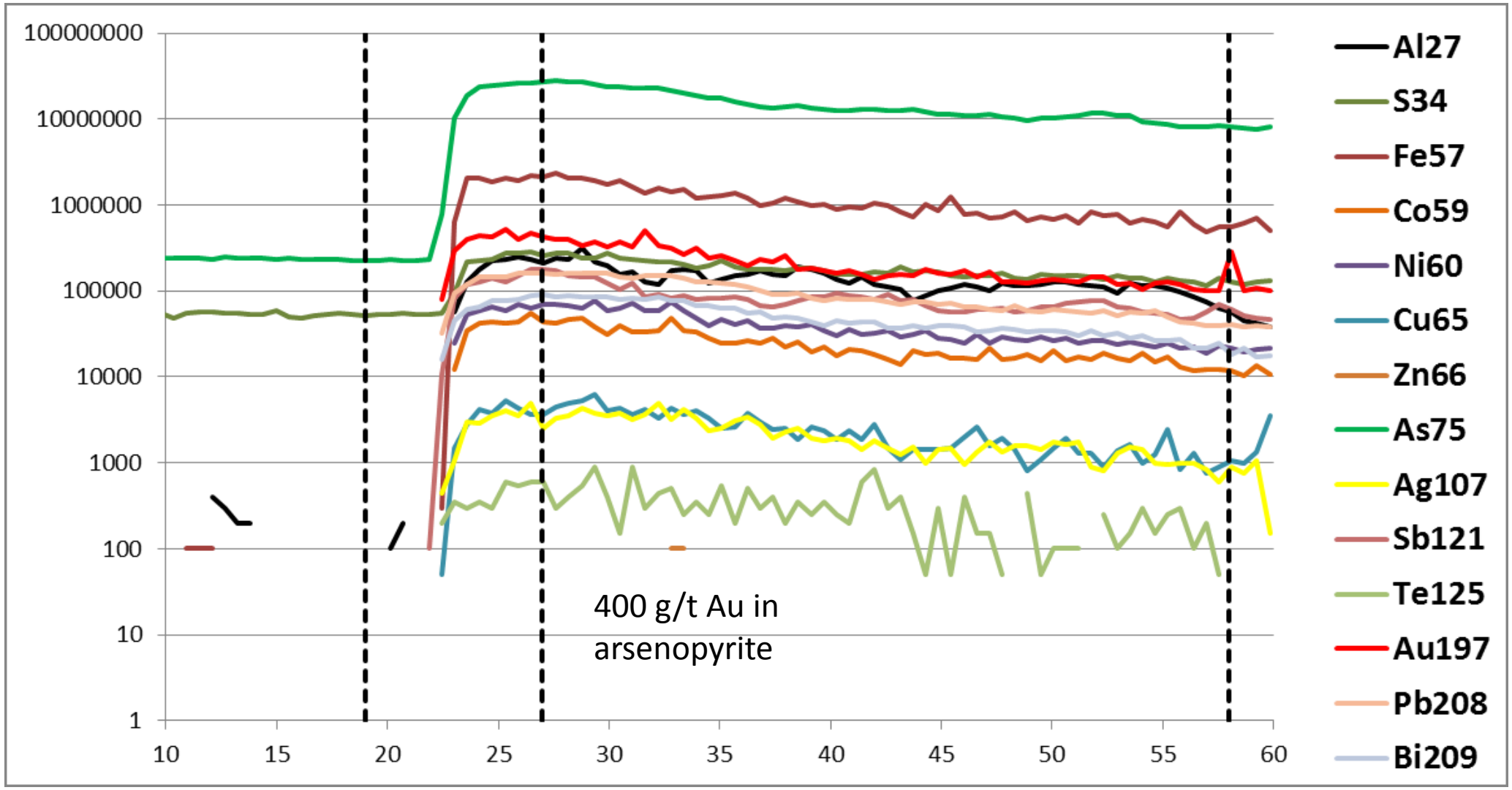
# Gold grains smaller than 1 µm



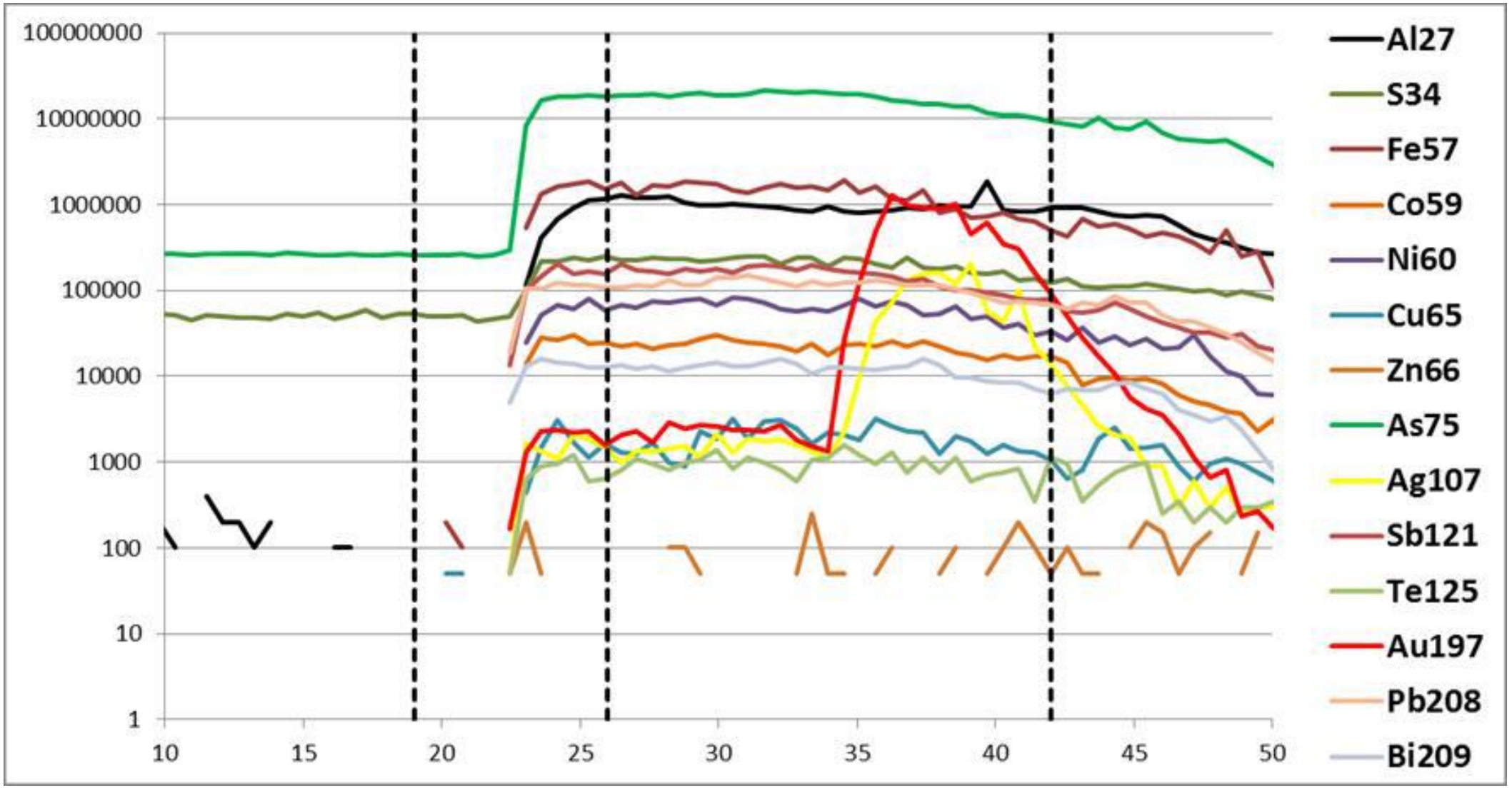
# LA-ICPMS
## (laser ablation inductively coupled plasma mass spectrometry)




# LA-ICPMS example: gold in arsenopyrite



# LA-ICPMS example: gold in arsenopyrite



# Mineralogy studies: aspects for consideration and conclusion

**Scope of work is customised for each testwork programme.**

**Examples of factors for consideration:**

- Gold grade
- Starting mass and method for gravity pre-concentration step?
- Is an upfront optical search for coarse gold required?
- Should we analyse multiple size fractions?
- Number of polished blocks to be prepared?
- Are other techniques such as LA-ICPMS required?

This mineralogical scope of work is then merged into the metallurgical flowsheet so that, by the end of the programme, we have a very useful set of data!

# Contact details

**Dorrit de Nooy**
Senior Mineralogist, Metallurgy Services
Australia

**T** +61 8 9344 2416 **M** +61 459 995 011
**F** +61 8 9345 4688
dorrit.denooy@alsglobal.com
6 Macadam Place
Balcatta WA 6021

Right Solutions • Right Partner
**www.alsglobal.com**