Hydrothermal alteration, ore fluid characteristics and depositions for Au deposition mechanisms at the Wallaby Au Deposit, Laverton, W.A.

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Supervised by Dr. John Mavrogenes

Presentation for the SMEDG – AIG Student Night

Location of Study

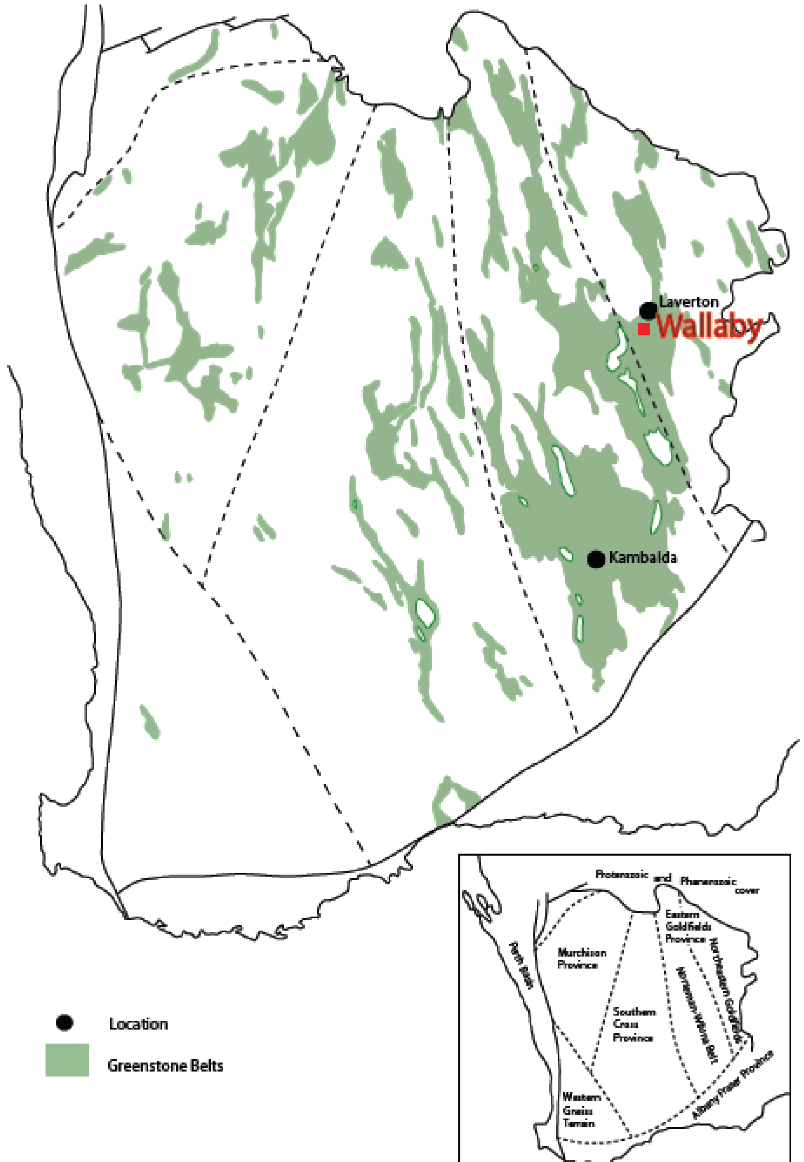


Image from Stoltze (2006)

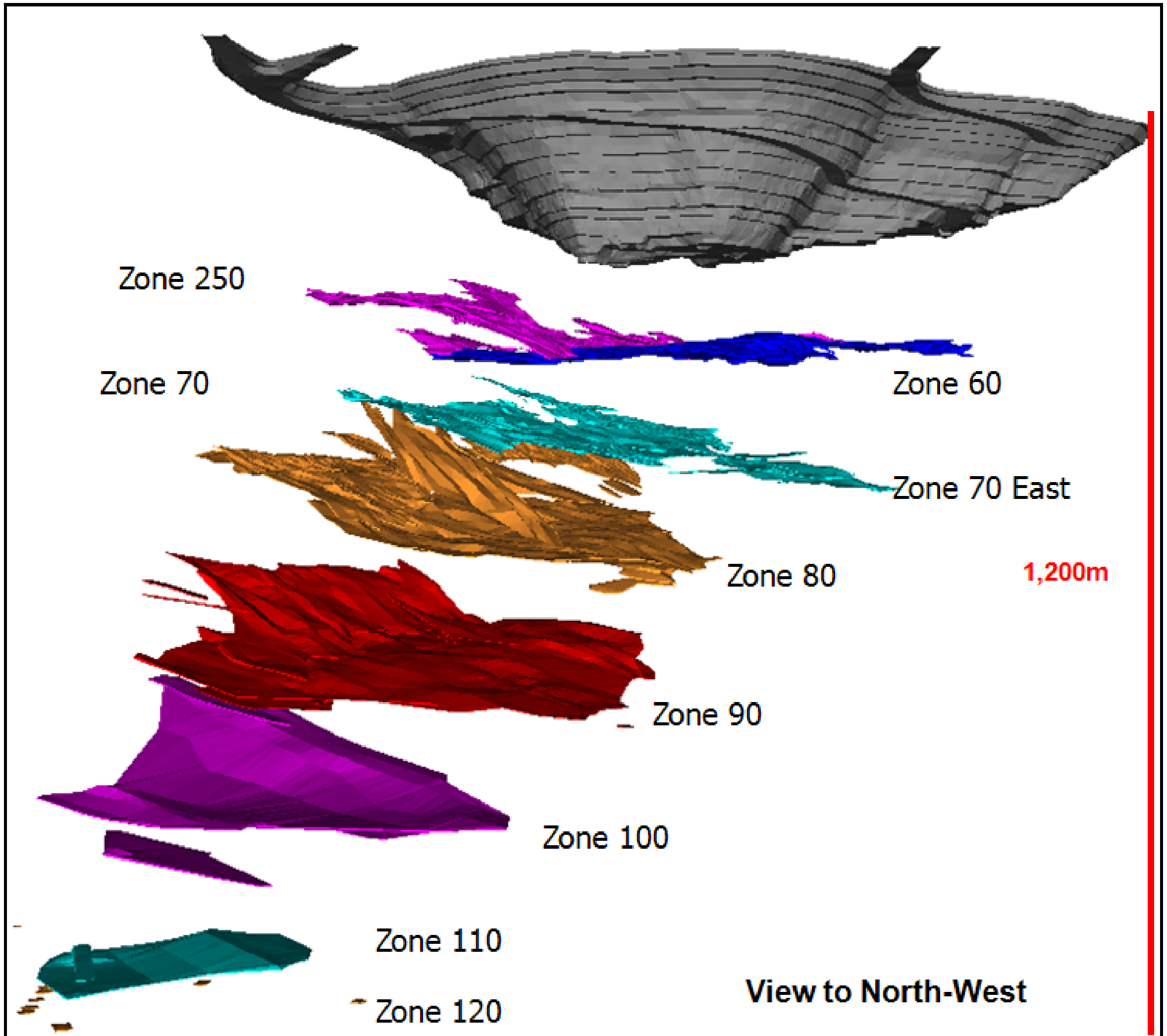
Aims and Purpose of this Study

AIM To document ore fluid characteristics through pyrite analysis and fluid inclusions, and hydrothermal alteration using hyperspectral techniques.

1. *To document characteristics of pyrite within the alteration types at Wallaby.*
2. *Measure fluid inclusion compositions at Wallaby.*
3. *Establish likely fluid pathways and redox indicators using hyperspectral logging.*

GOAL To define the source(s) of gold mineralisation and deposition mechanisms for gold.

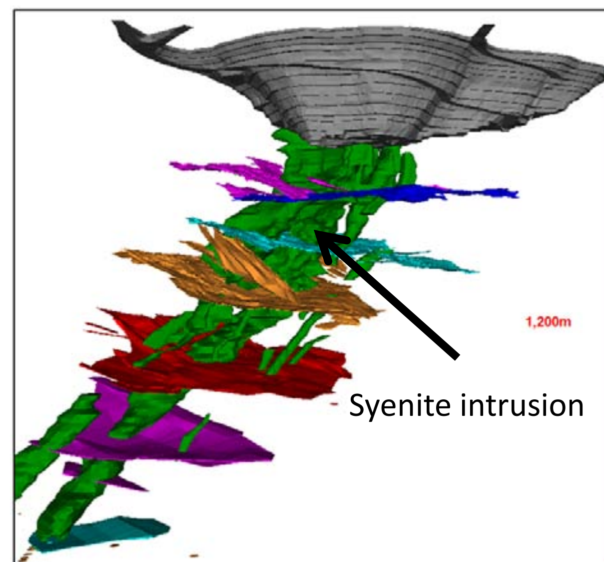
Wallaby Geology



Hosted in a 1500m thick mafic conglomerate.

Intruded by an alkaline suite of igneous rocks .

Sub-horizontal shear zone gold lodes.



Images courtesy of Richard Tully, Barrick Gold Exploration 2011

Previous Model - Wallaby Geology

Regional Greenschist Metamorphism

↓

Emplacement of Syenite Intrusion

↓

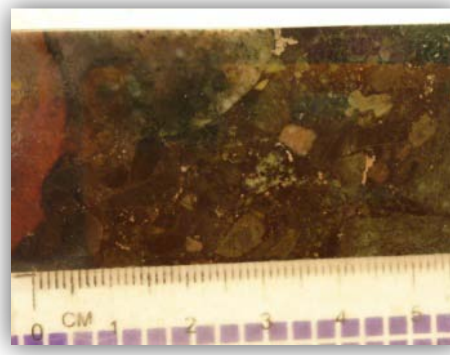
Metasomatism of surrounding wallrock: magnetite – actinolite alteration (mag + act + ab + epi + bio + cal)

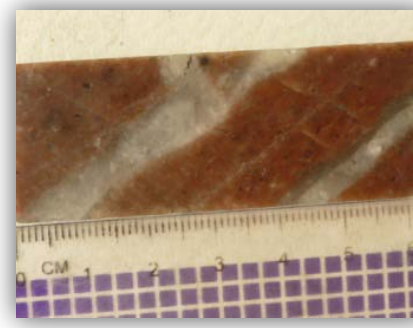
↓

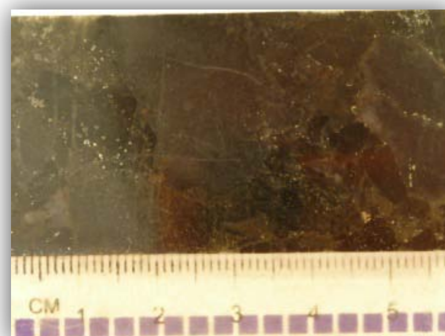
Low grade hematite associated gold grade event (py + hem + ser + dol + ab)

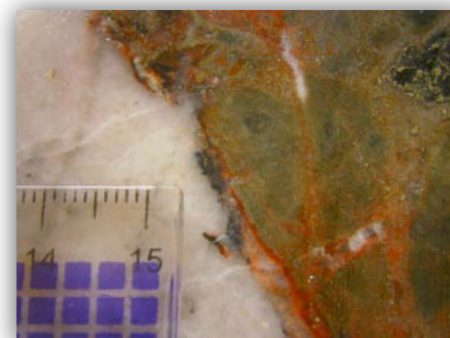
↓

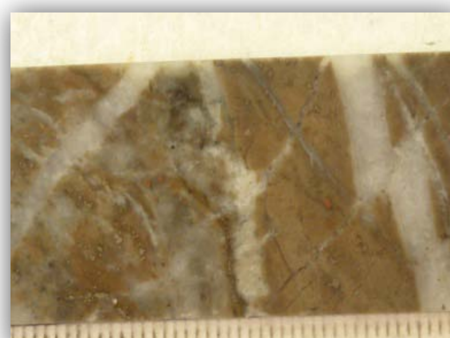
High grade shear zone gold event (py + ser + dol + ab + fuch ± qtz)











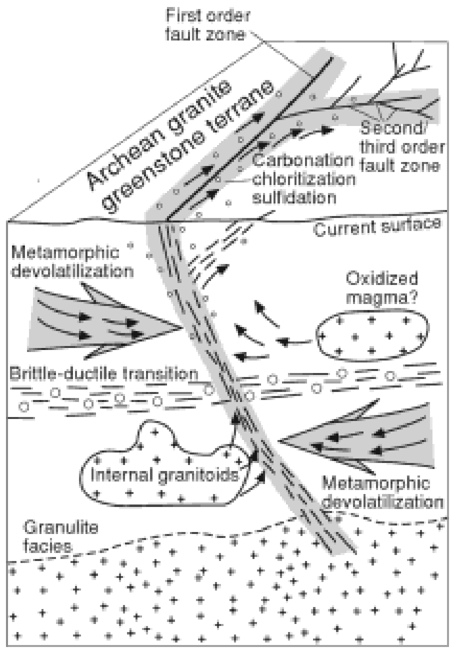
The BIG Questions...

Where did the gold come from and why did it precipitate?

Orogenic lode Au

Crustal continuum model of Phillips and Groves (1983)

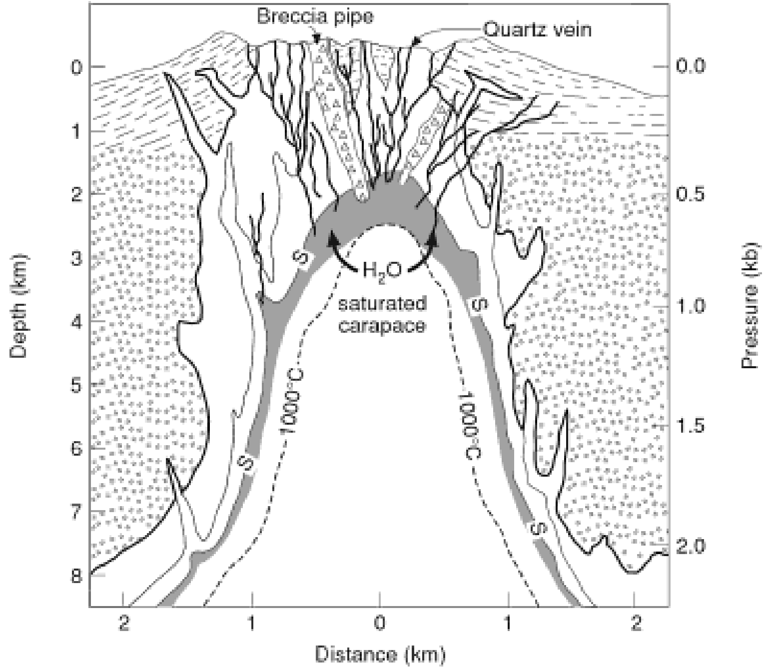
- Metamorphic devolatilisation.
- Magmatic devolatilisation of lower crustal granitoids.



Intrusion Related Au

Proximal-magmatic models favoured by Hall et al. (2001)

- Crystallising mid- to upper-crustal granitoids.



(Robb, L 2009)

Method

Pyrite Studies

↓

1. Reflected Light Microscopy
2. SEM (backscatter and EBSD)
3. Electron Microprobe
4. SHRIMP
5. LA ICP-MS

Fluid Inclusions

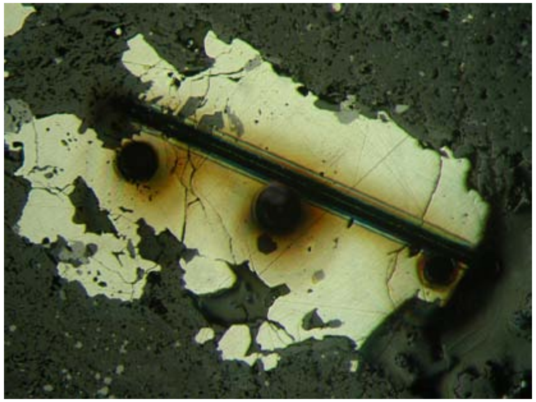
↓

1. Transmitted Light Microscopy
2. Heating / Freezing stage

Hyperspectral Logging

↓

1. The Spectral Geologist (TSG)



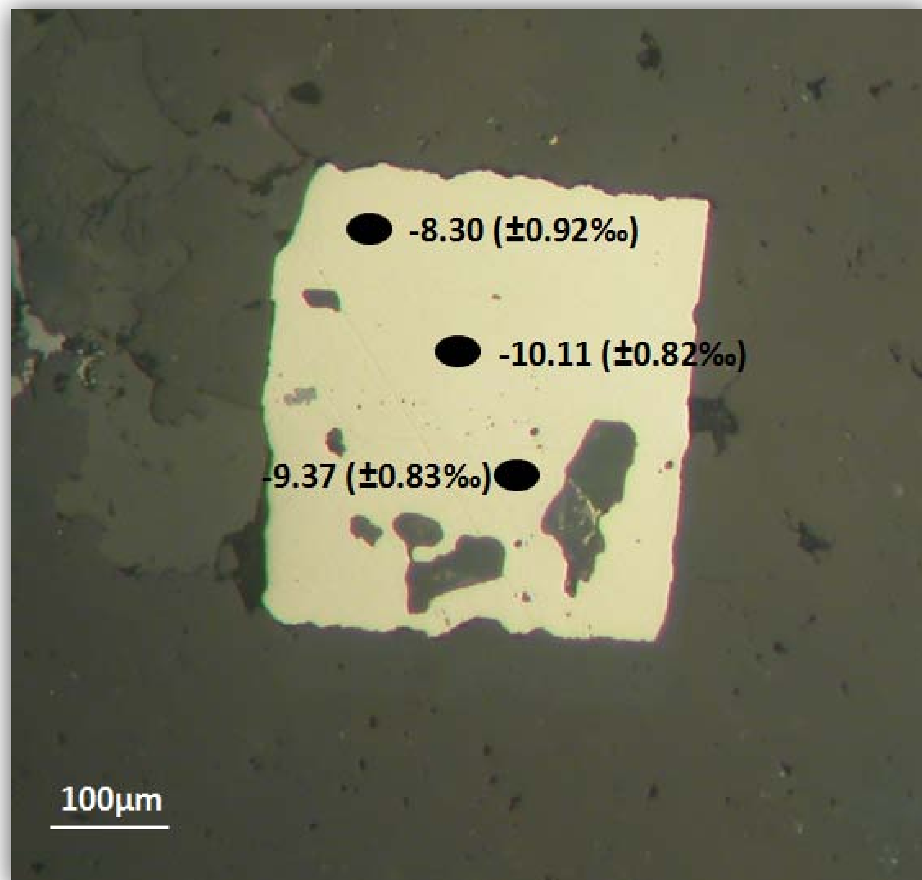
Laser traverse and spots on a pyrite

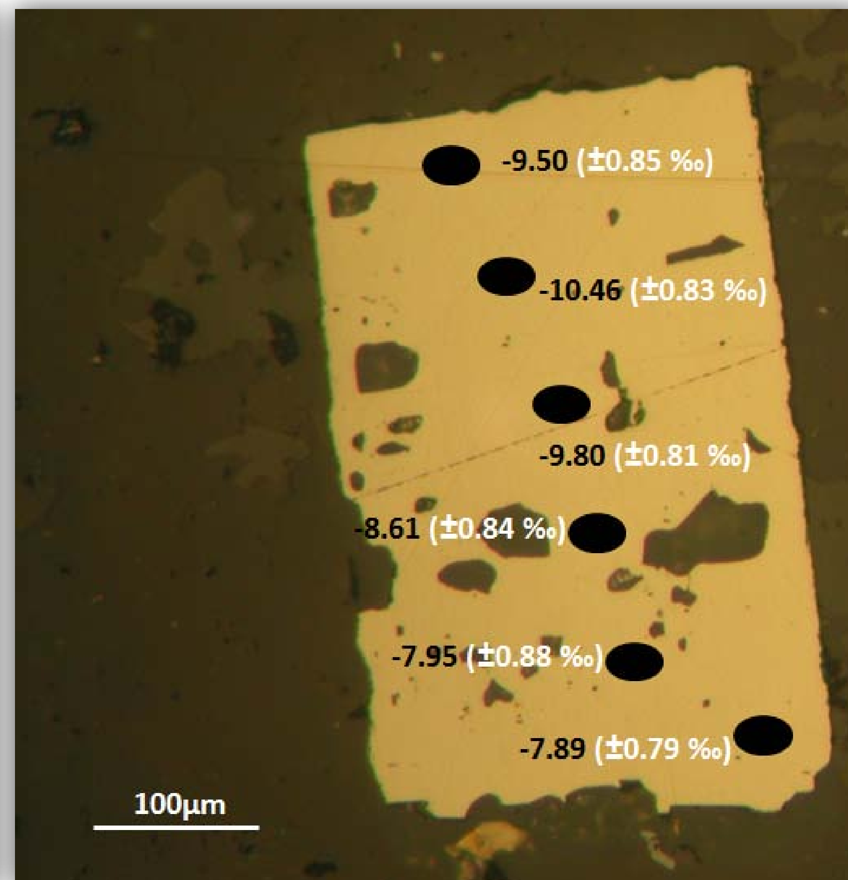
Results

Sulfur Isotopes of pyrite

Group 1

Porous euhedral – subhedral hematite altered low grade gold related pyrite

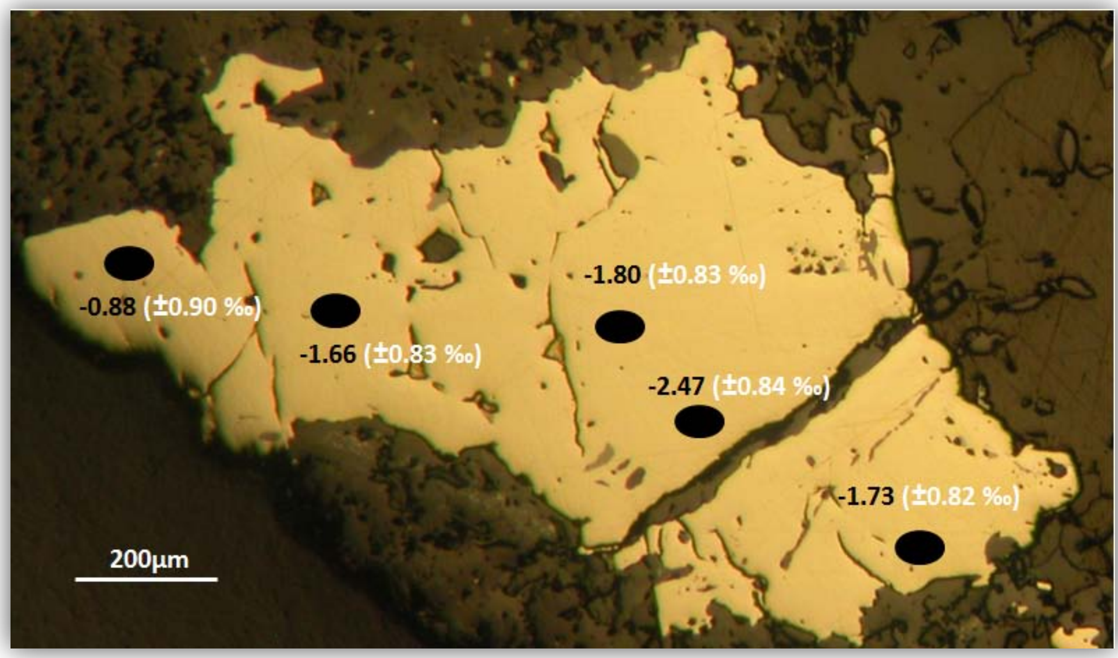


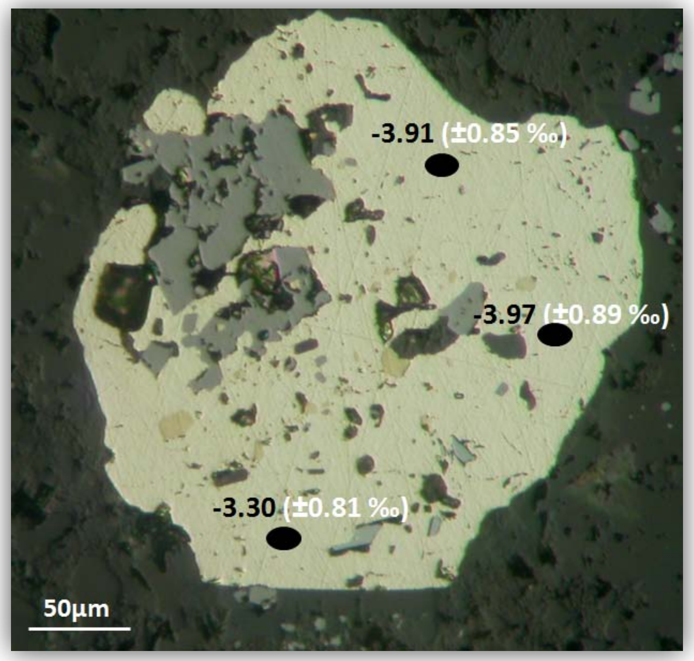


Range $\delta^{34}S$: -10.5‰ to -7.9‰

Group 2

Porous, anhedral inclusion-rich pyrite

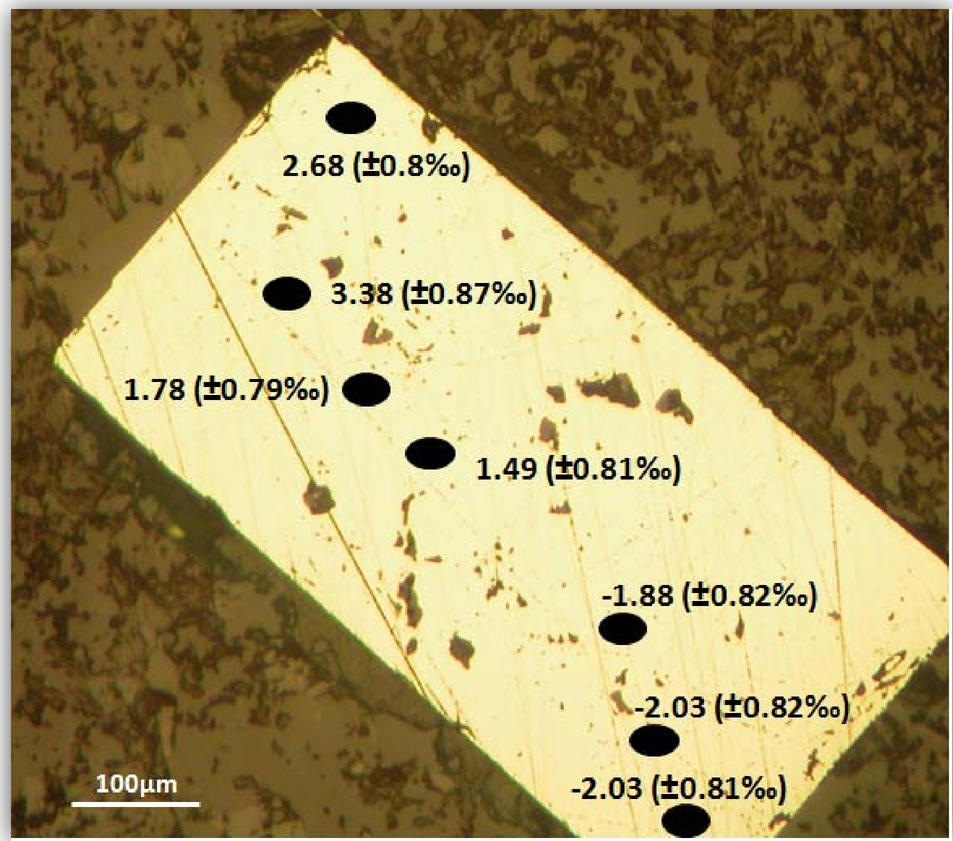




Range $\delta^{34}S$: +0.3‰ to -5.6‰

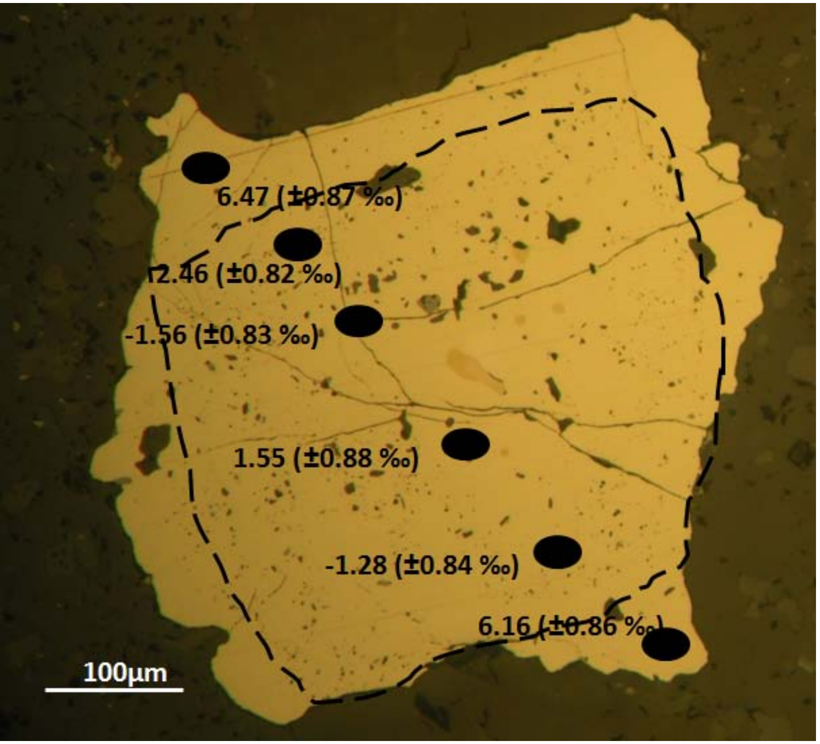
Group 3

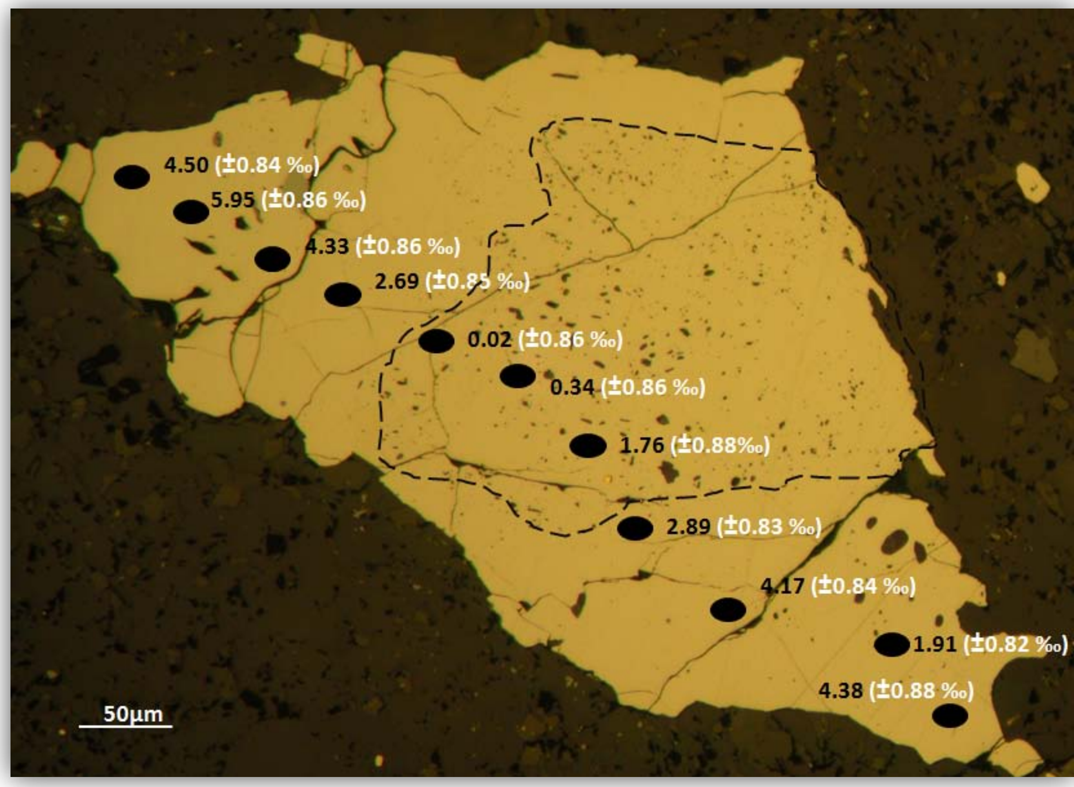
Euhedral – subhedral syenite-related pyrites



Range $\delta^{34}S$: -2‰ to + 3.8‰

Group 4
Zoned euhedral pyrites in
high grade gold shear zones



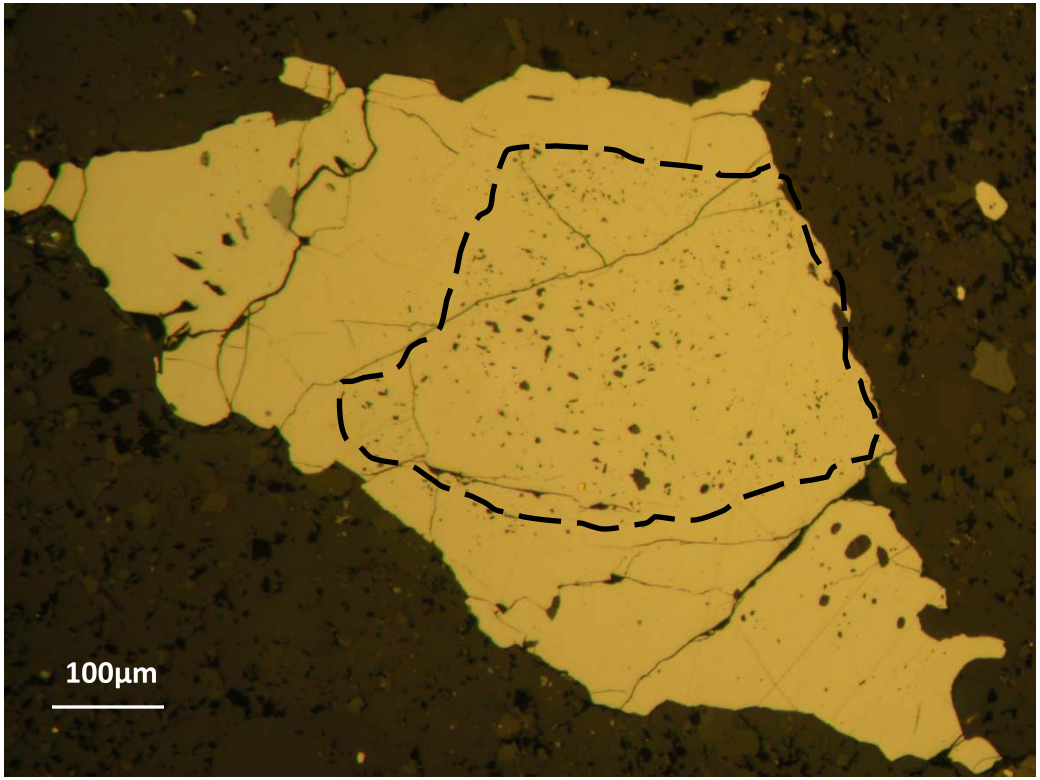


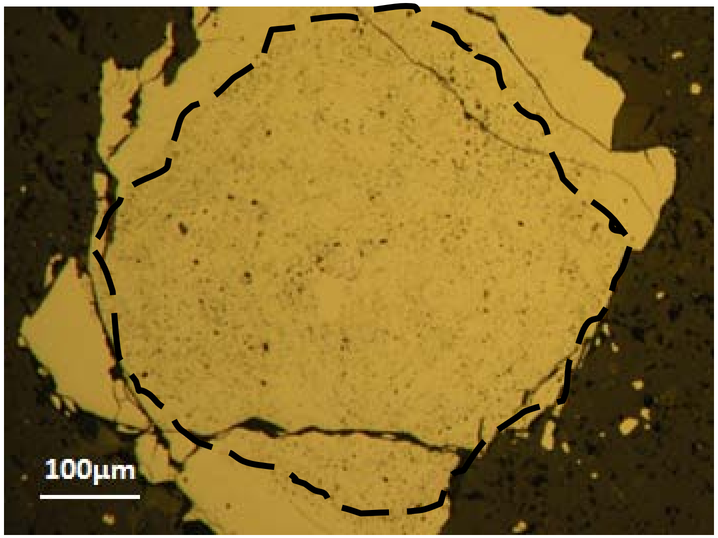
Core $\delta^{34}S$
-2.8‰ to +4.5‰

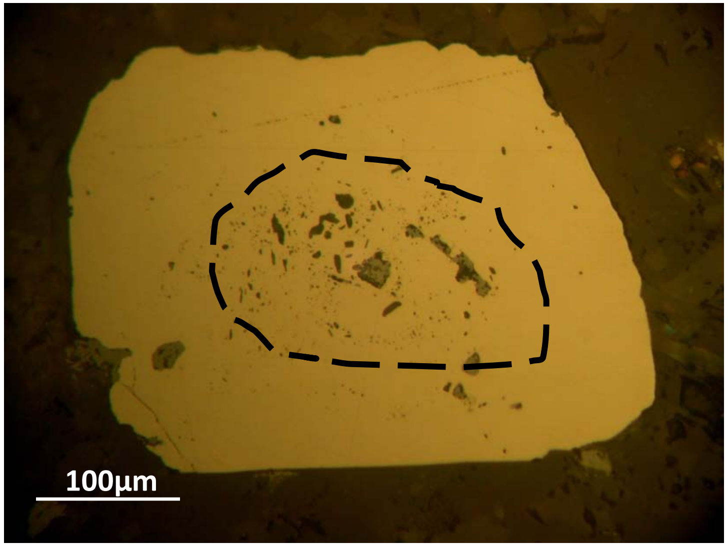
Rim $\delta^{34}S$
+4.5‰ to +6.9‰

Group 4

Zoned euhedral pyrites in high grade gold shear zones

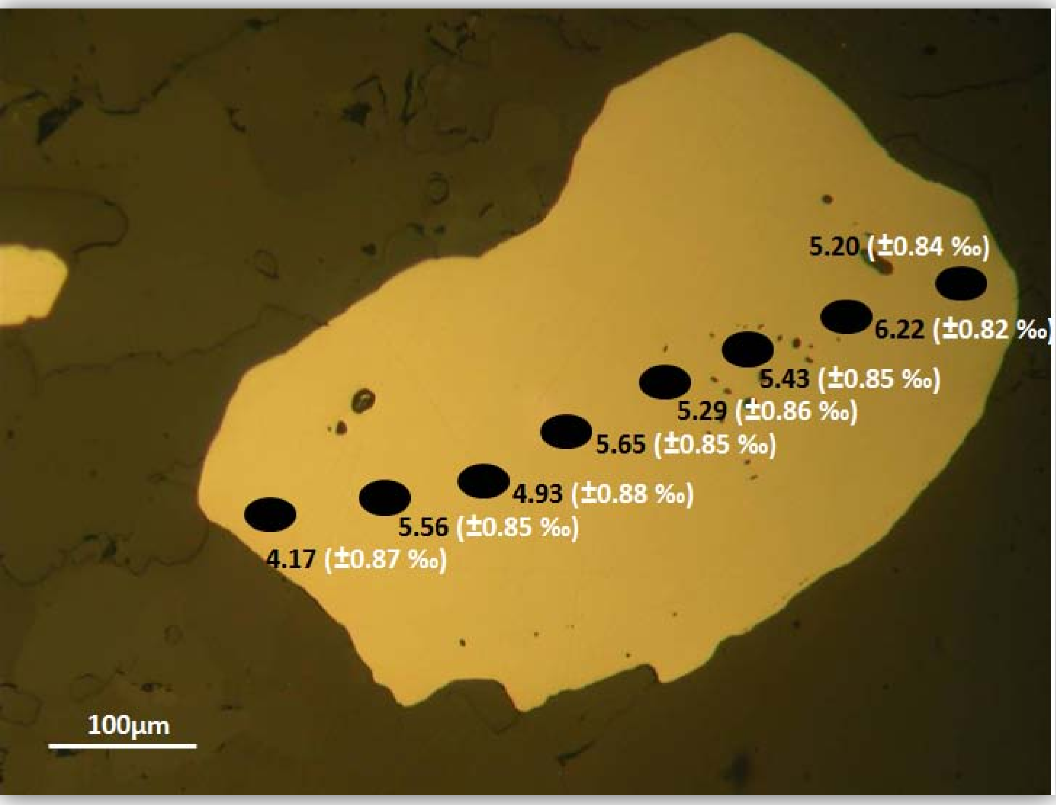


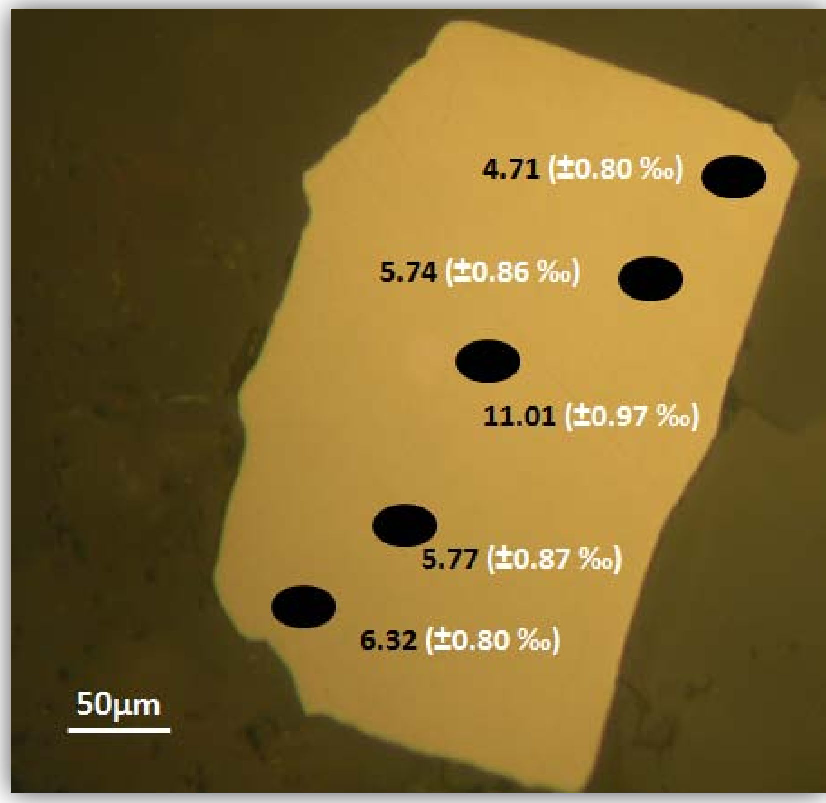




Group 5

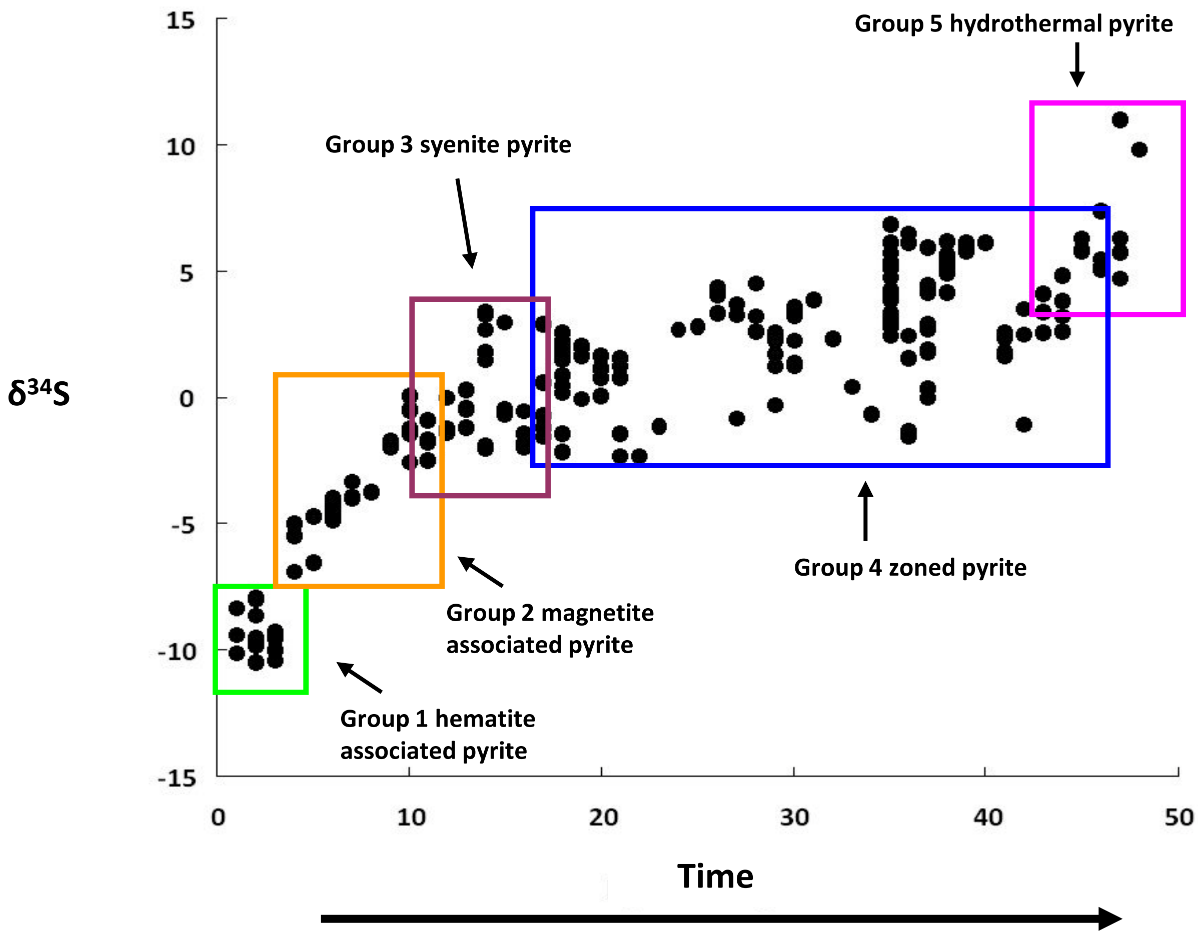
Euhedral vein related hydrothermal pyrite

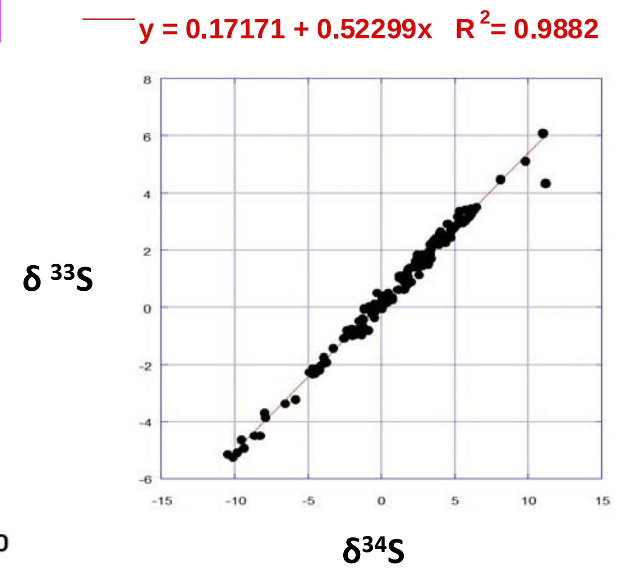




Range: +4.2‰ to +11‰

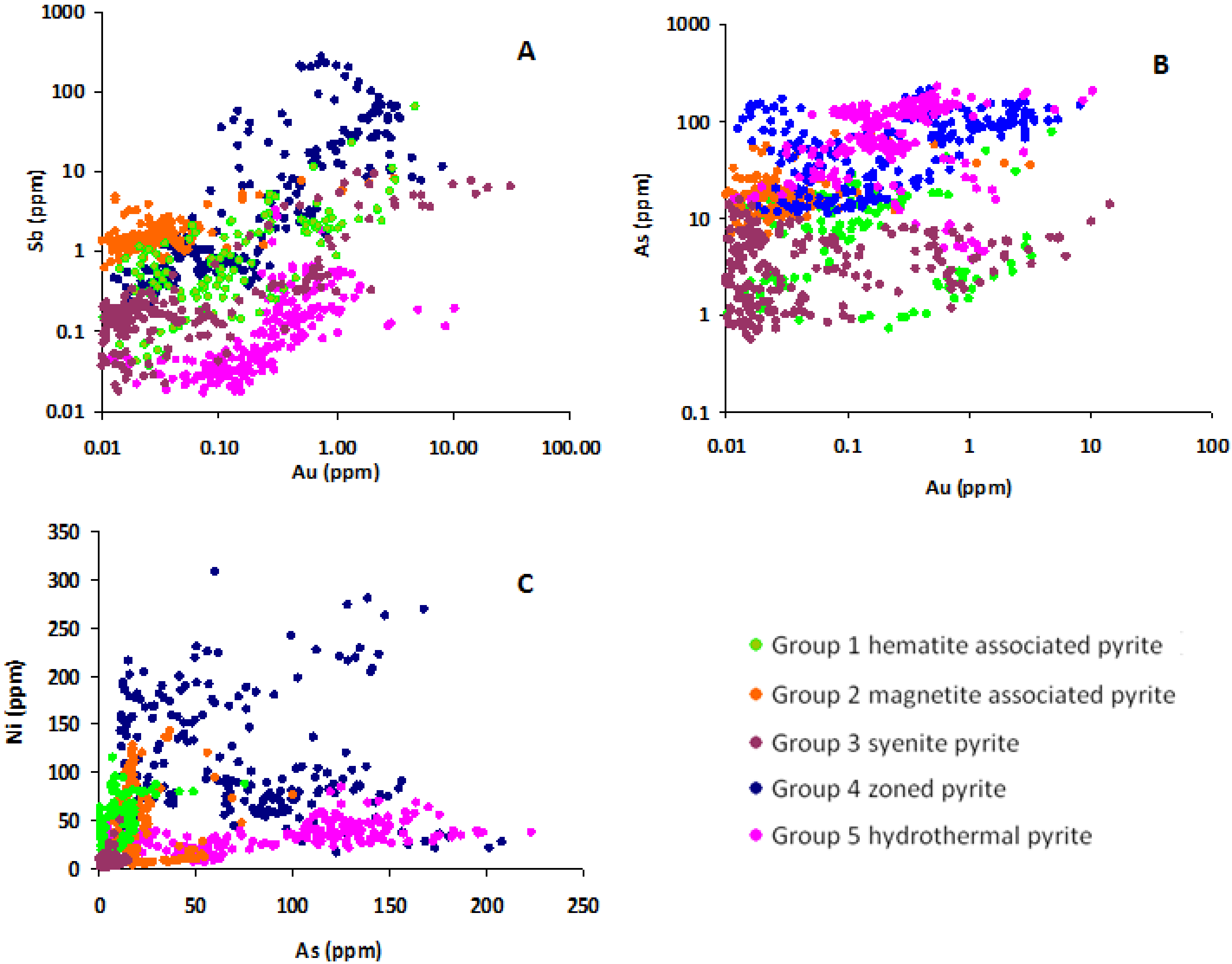
So what does this sulfur isotope data mean?

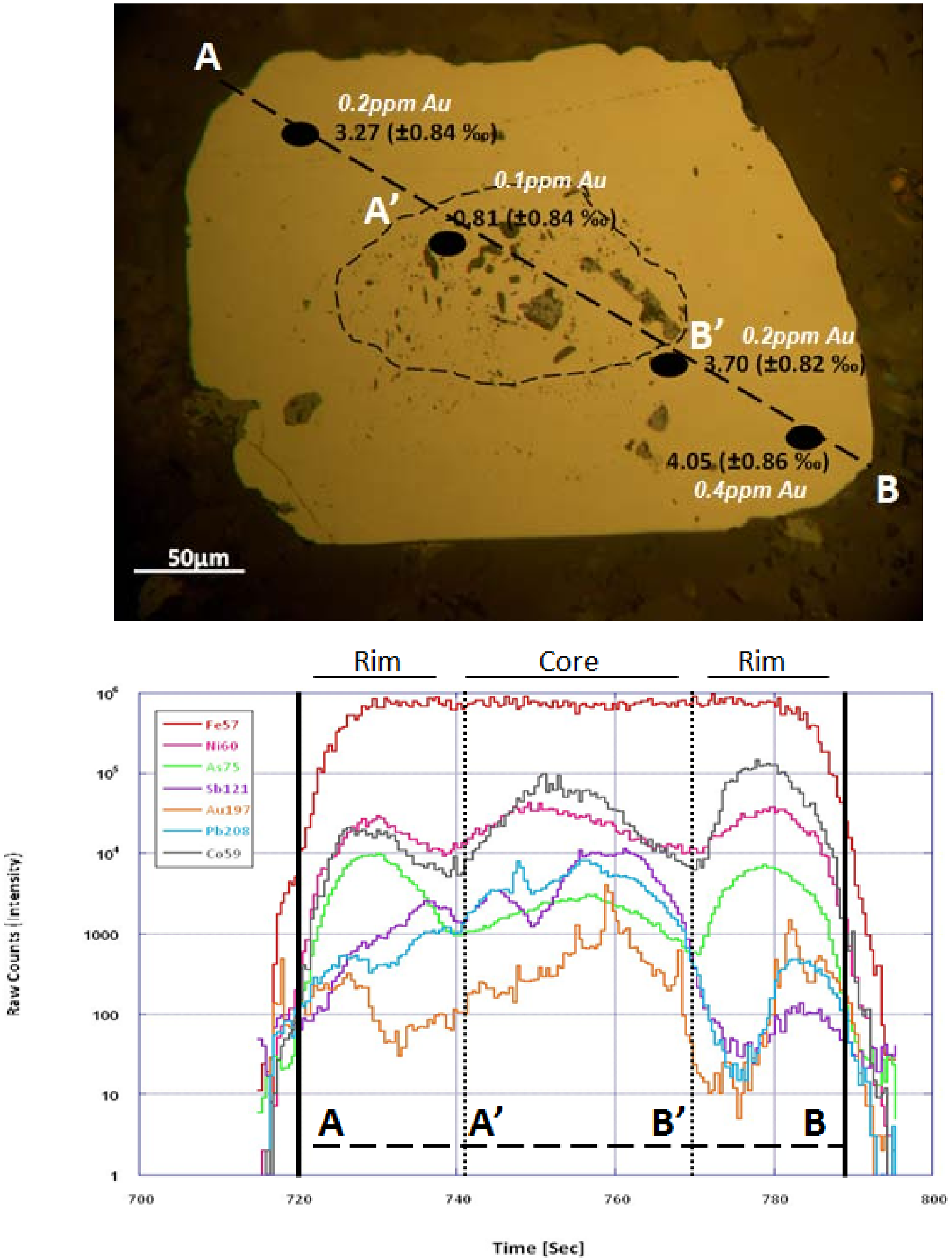




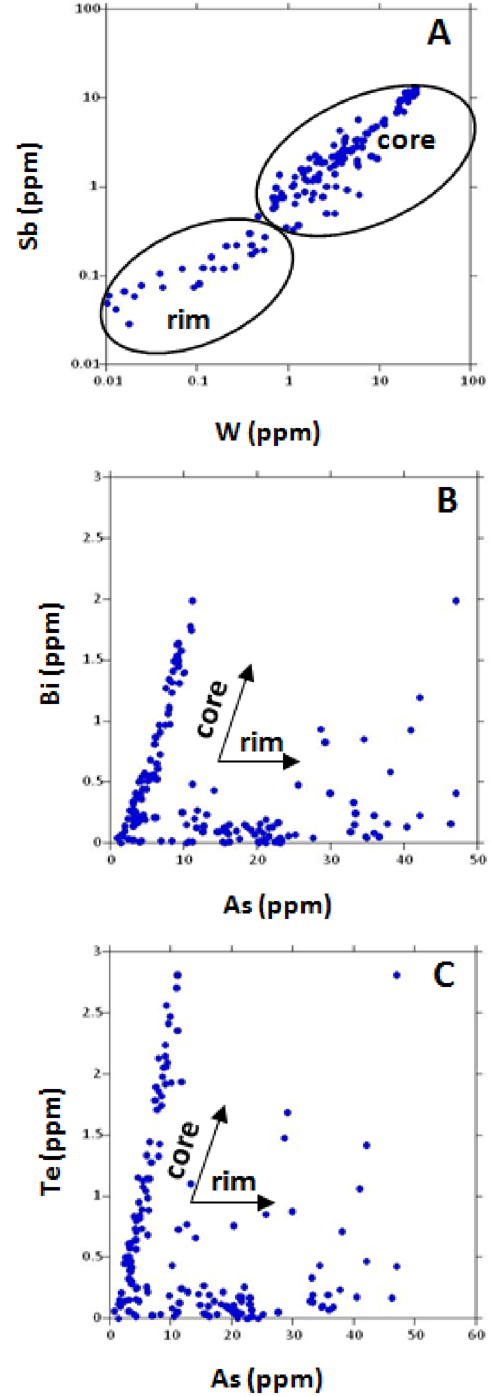
Results

Trace element zoning and x-ray mapping of pyrite


A
Sb (ppm)
1000
100
10
1
0.1
0.01
0.01
0.10
1.00
10.00
100.00
Au (ppm)
B
As (ppm)
1000
100
10
1
0.1
0.01
0.1
1
10
100
Au (ppm)
C
Ni (ppm)
350
300
250
200
150
100
50
0
0
50
100
150
200
250
As (ppm)
Group 1 hematite associated pyrite
Group 2 magnetite associated pyrite
Group 3 syenite pyrite
Group 4 zoned pyrite
Group 5 hydrothermal pyrite



A
0.2ppm Au
3.27 (±0.84 ‰)
0.1ppm Au
A'
0.81 (±0.84 ‰)
B'
0.2ppm Au
3.70 (±0.82 ‰)
4.05 (±0.86 ‰)
0.4ppm Au
B
50µm
Rim
Core
Rim
Fe57
Ni60
As75
Sb121
Au197
Pb208
Co59
Raw Counts (intensity)
Time [Sec]
A
A'
B'
B

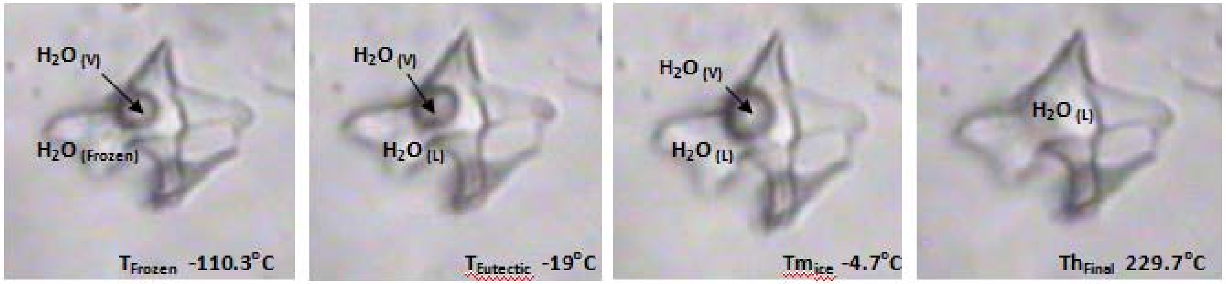


A
core
rim
Sb (ppm)
W (ppm)
B
core
rim
Bi (ppm)
As (ppm)
C
core
rim
Te (ppm)
As (ppm)

Results

Fluid Inclusions

Aqueous H_2O-rich fluid inclusion

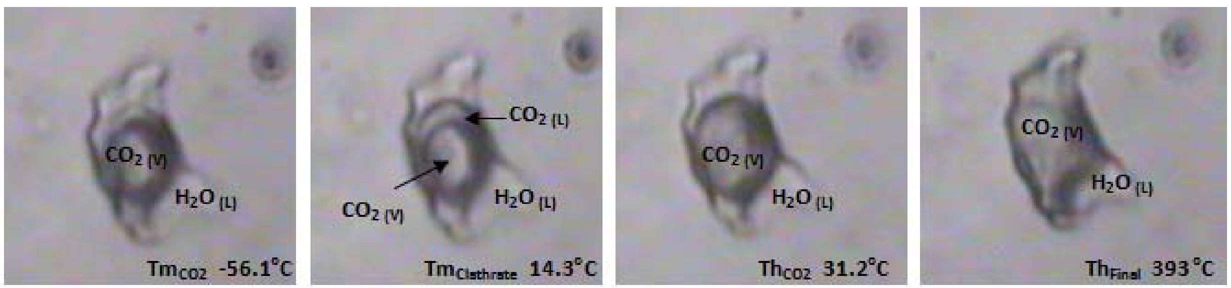


HEATING

H_2O-rich inclusion

- derived from the intrusion
- moderate salinity, hot fluid

CO_2 + L fluid inclusion

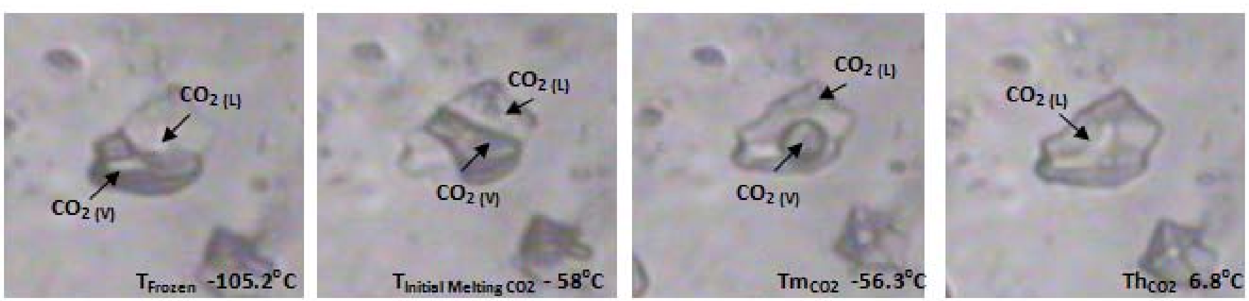


HEATING

CO_2 + L inclusion

- typical shear zone fluid
- low CO_2, low salinity fluid

CO_2 fluid inclusion



HEATING

CO_2 inclusions

- post entrapment modification
- unmixing of a single fluid of different densities

Information overload!

____

Discussion

The story goes something like this…

LOW Mo, Sb, Zn, Sn

HIGH As, Ni, Cu, Pb, Co

Au content (pyrite) = 0-0.2 ppm

LOW As, Cu, Co, Sb, Sn

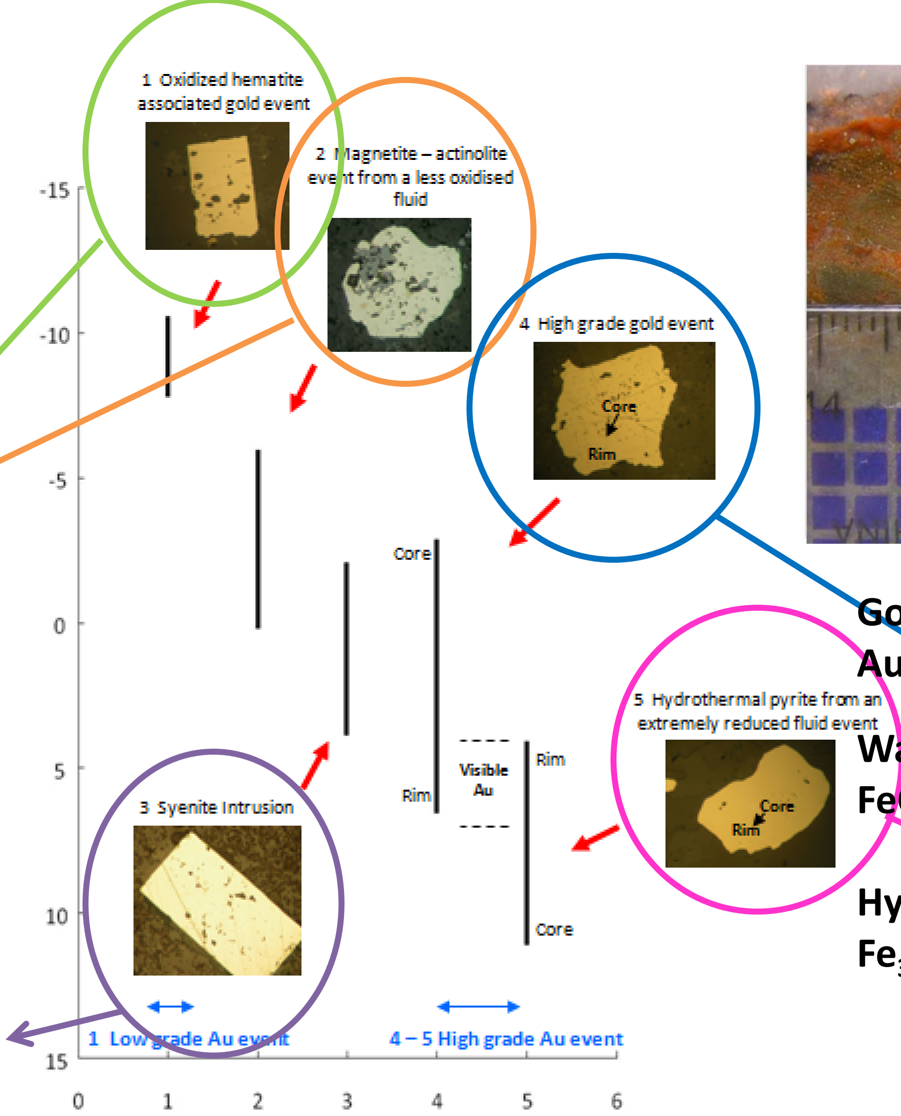
HIGH Bi, Mo, Ni, Pb, W

Au content (pyrite) = 0.4-0.7 ppm

LOW As, Ni

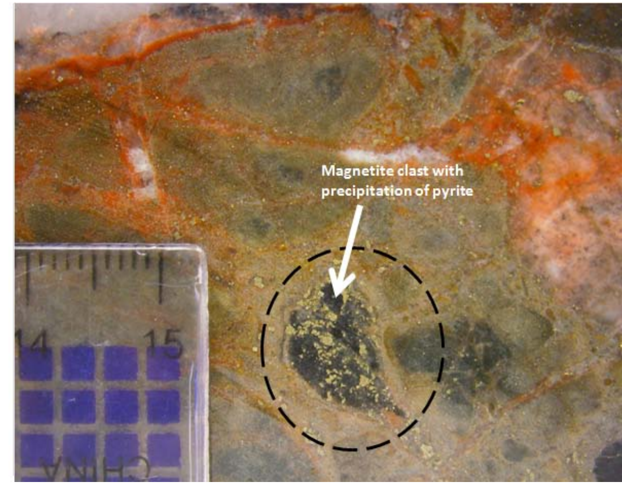
HIGH Co, Cu, Pb, Zn

Au content (pyrite) = 0-0.6 ppm



SO_4^{2-} **Oxidised** ⟶ H_2S **Reduced**

High Ni/As ⟶ Low Ni/As



Gold deposition

$AuHS_2^- + Fe^{2+} = Au + FeS_2 + ½O_2$

Wallrock – fluid interaction

$FeO + 2H_2S + ½O_2 = FeS_2 + 2H_2O$

Hydrothermal alteration

$Fe_3O_4 + 3CO_2 = 3FeCO_3 + ½O_2$

Core

LOW Mo, Pb, Zn, Sn

HIGH Au, Ni, Cu, Sb, W

Au content (pyrite) = 0.5 – 1.5ppm

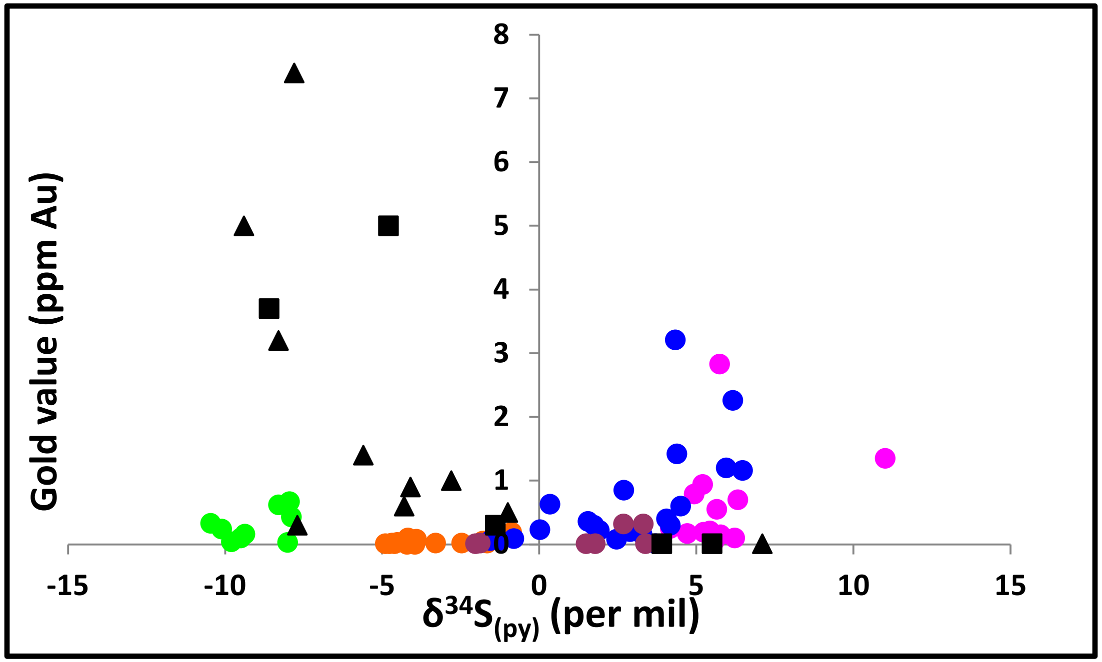
Rim

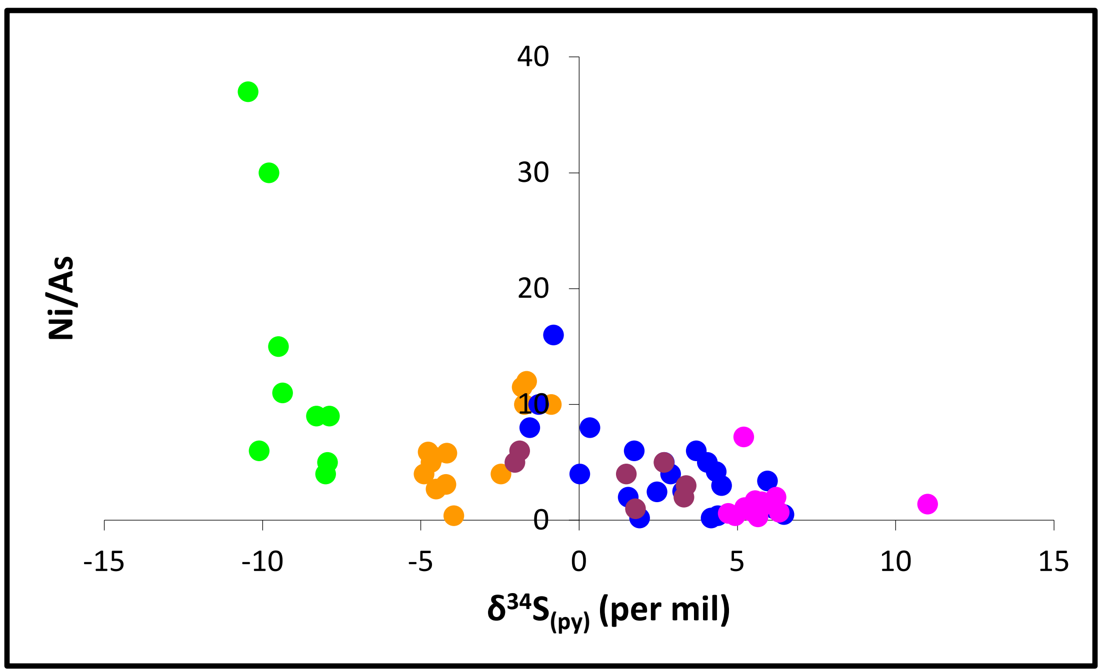
LOW Ni, Cu, Pb, Zn, Cu

HIGH As, Au, Sb

Au content (pyrite) = 0.3 – 0.9 ppm

Overall trends...



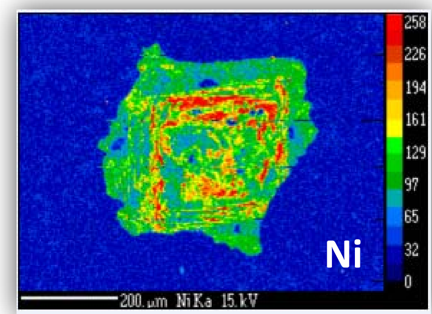


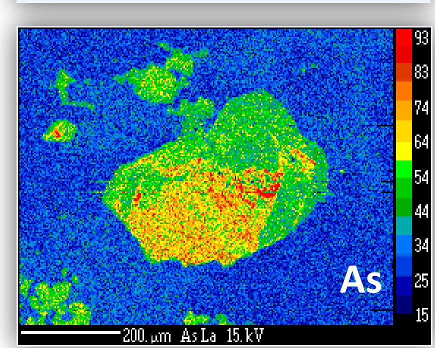
My Study

- Group 1 hematite associated pyrite
- Group 2 magnetite associated pyrite
- Group 3 syenite pyrite
- Group 4 zoned pyrite
- Group 5 hydrothermal pyrite

Hodkiewicz et al. (2008)

- ■ New Celebration
- ▲ Porphyry





Conclusions...

Four events

(1) oxidised pervasive hematite alteration event;
(2) widespread magnetite – actinolite alteration of the conglomerate;
(3) emplacement of the syenite intrusion
(4) high grade gold event associated with an As-rich reduced fluid.

One evolving fluid

- sulfur isotopes vary but overlap (-10.5‰ to +11 ‰)
- trace elements vary
- H_2O rich FLINCs (intrusion) and CO_2 rich FLINCs (shear zone)

Main deposition for gold is sulfidation (and minor redox).
Combination of intrusion – related and orogenic!

A HUGE thank you to the AIG and the SMEDG for supporting me through the 2011 bursary, and giving me the opportunity to present this evening.

☺

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Supplementary Slides

Recommendations...

Larger sample collection and more time ☺

Structural setting.

Noble gas studies to better constrain the source of gold-bearing fluids.

Selenium analysis on pyrites to determine if the element is a useful redox indicator.

Comparison between other Yilgarn deposits and obtain a larger database on ore deposits that exhibit both orogenic and intrusion related characteristics.

Thorough fluid inclusion studies.

A metamorphic study.

Acknowledgements...

A HUGE thank you to Mav – an awesome supervisor who is super keen about ore deposit research, and saved me from having stress breakdowns. Your insights and suggestions towards my thesis were much appreciated! ☺

To all those who helped me with data collection, reduction etc..
Charlotte Allen (for teaching me a PhD in Microsoft excel and use of the LA ICP-MS).
Pete Holden and Richard Armstrong (teaching me the SHRIMP (the coolest machine I used this year!) and reducing my data).
Bob Rapp (for his awesome skills at producing some gorgeous x-ray maps).
Frank Brink (for his assistance on the SEM).
Terry Mernagh (for his amazing insight on fluid inclusions).
Rob Hough (for his thoughtful insights at Wallaby during my field work).
John Vickers (for his company and help in the thin section lab for many weeks)!

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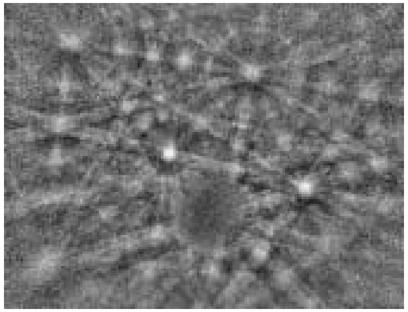
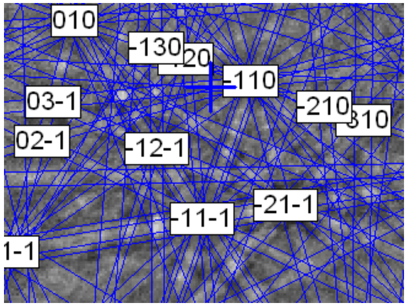
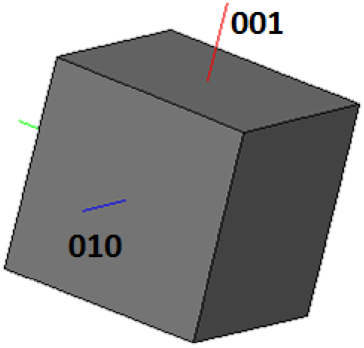
The honours cohort – in particular, Kelly Mills, Kate Holland, Elle Peterson, and Jen Deng Lee for fuelling my alcohol and tim tam addiction with wine o'clock Fridays, slumber parties, tea time and endless laughs.

My amazing family – mum, dad, Amanda, Alex and Alana, and boyfriend Grant Reynolds for all your love and support. Getting out of house chores because my thesis was more important is much appreciated! ☺ I'm sure I'll be making up for it now.

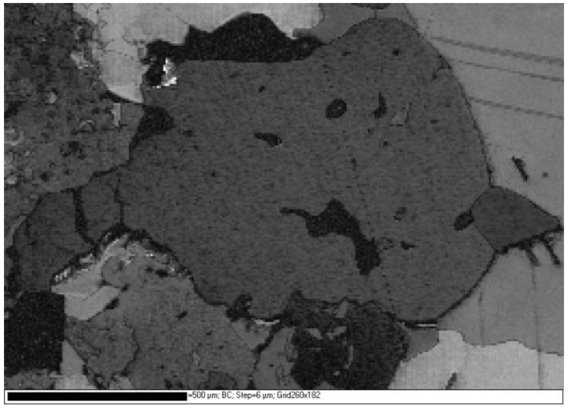
Electron Backscatter Diffraction (EBSD)

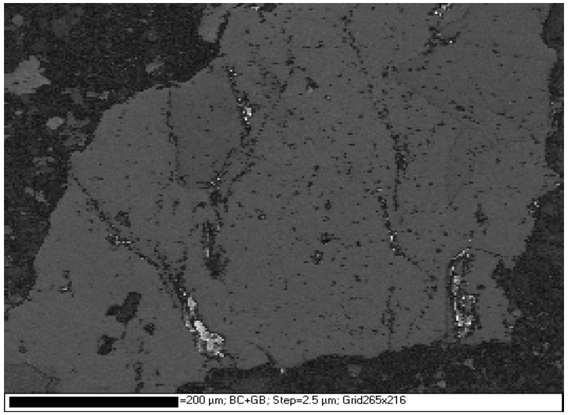


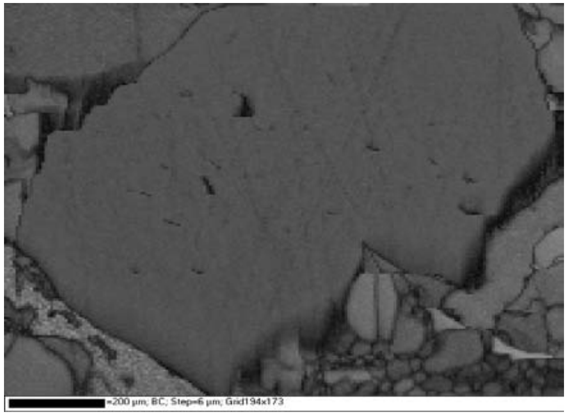




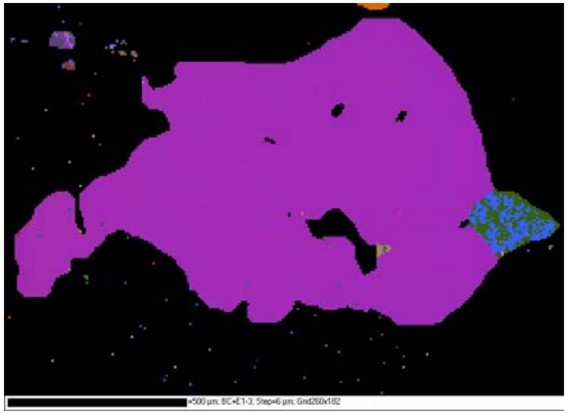
Band Contrast Maps

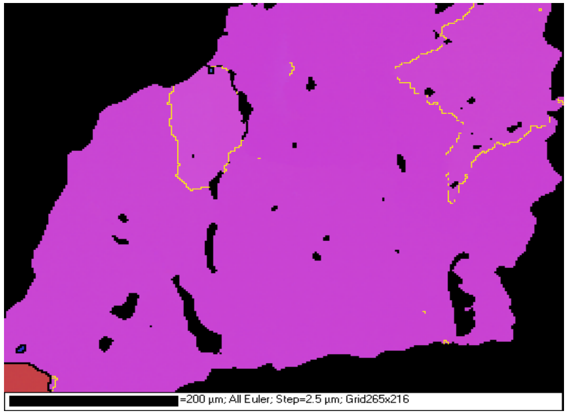


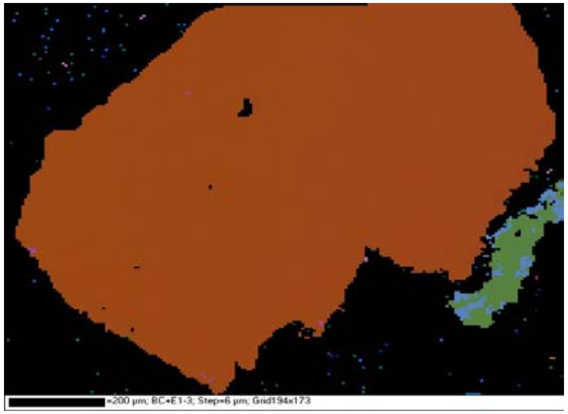




All Euler Maps

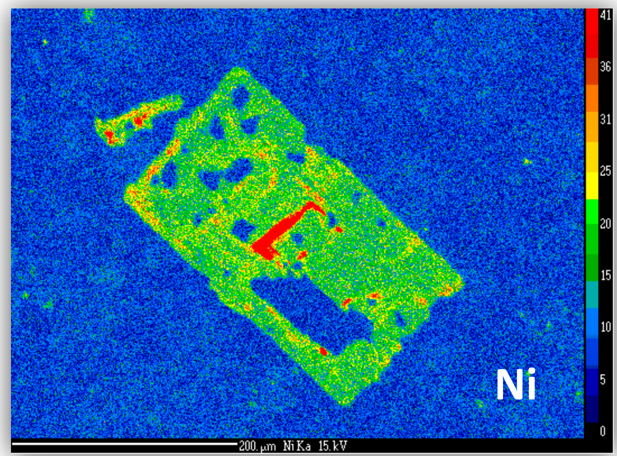


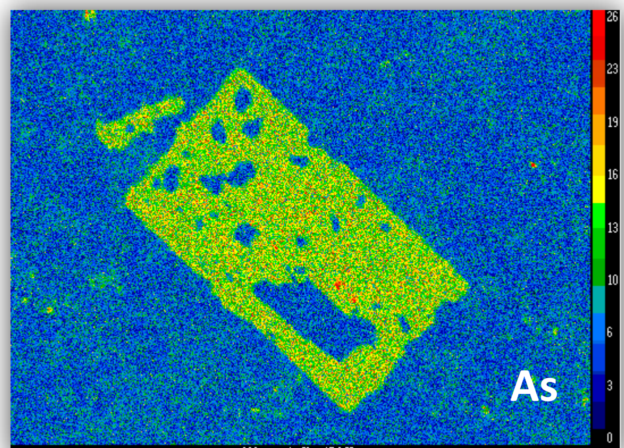




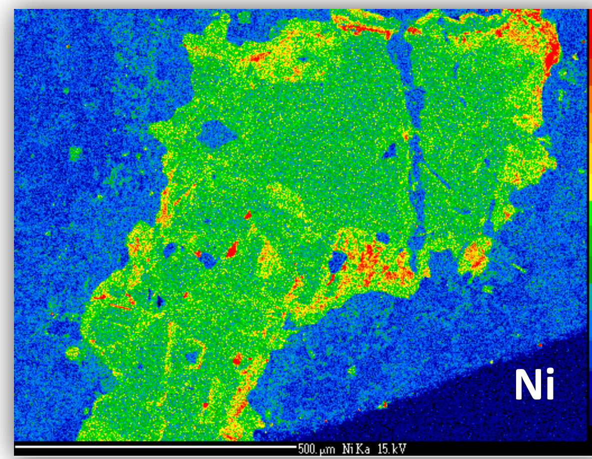
As and Ni zoning in pyrites

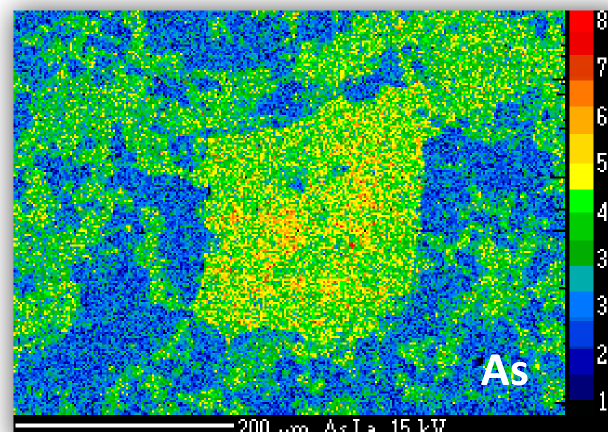
Group 1
Porous euhedral – subhedral hematite altered low grade gold related pyrite





Group 2
Porous, anhedral inclusion-rich pyrite

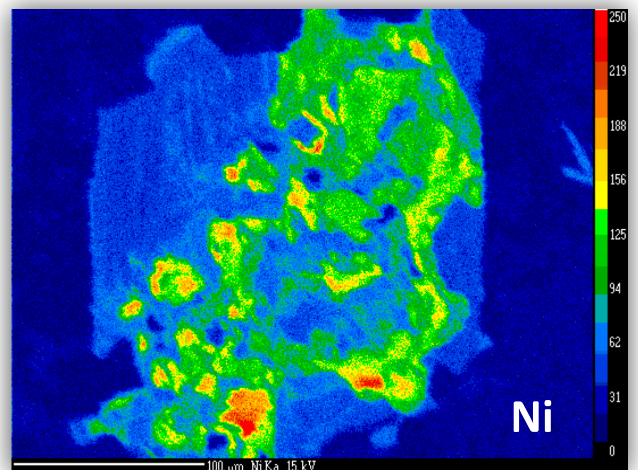


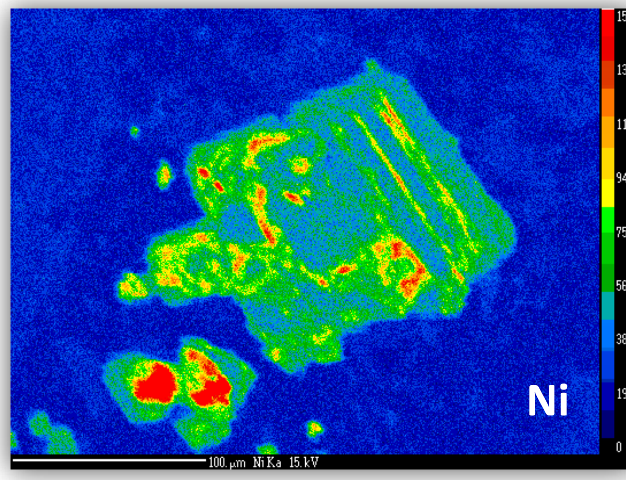


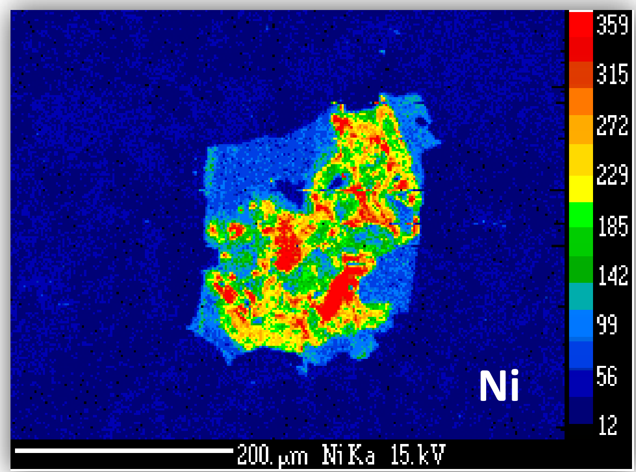
As and Ni zoning in pyrites

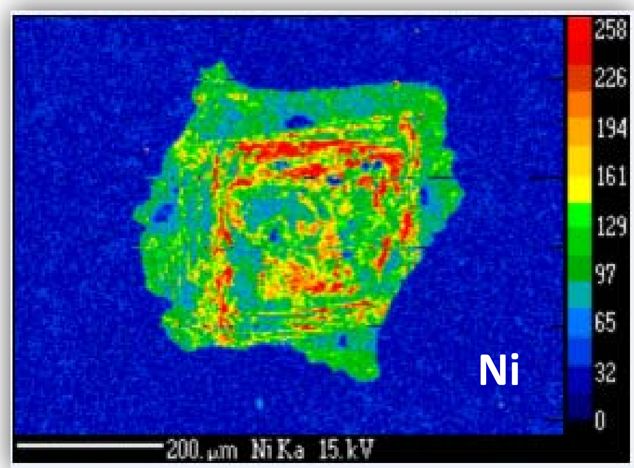
Group 4

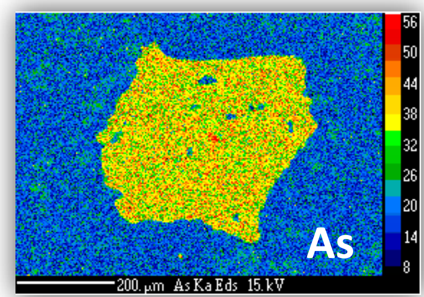
Zoned euhedral pyrites in high grade gold shear zones







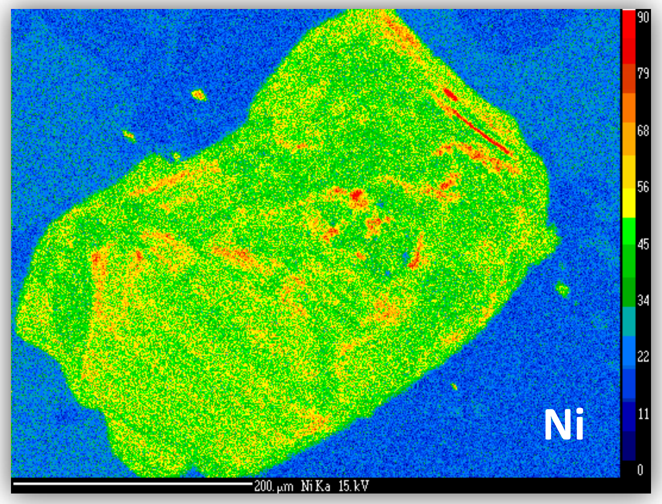


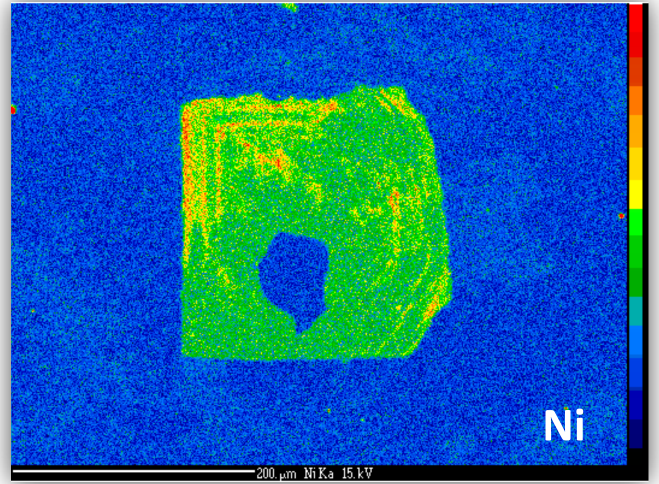


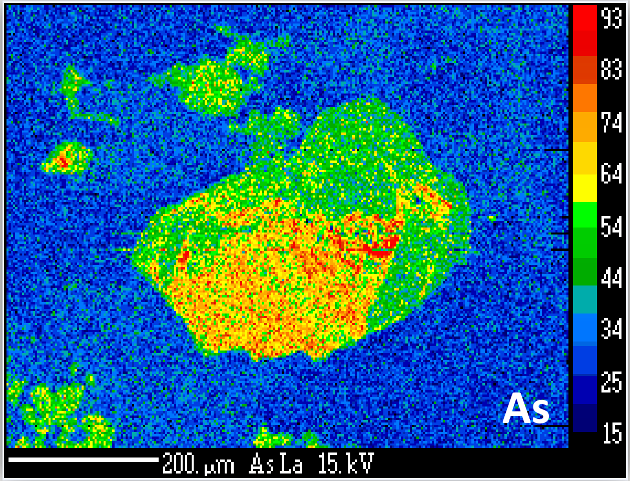
As and Ni zoning in pyrites

Group 5

Euhedral vein related hydrothermal pyrite



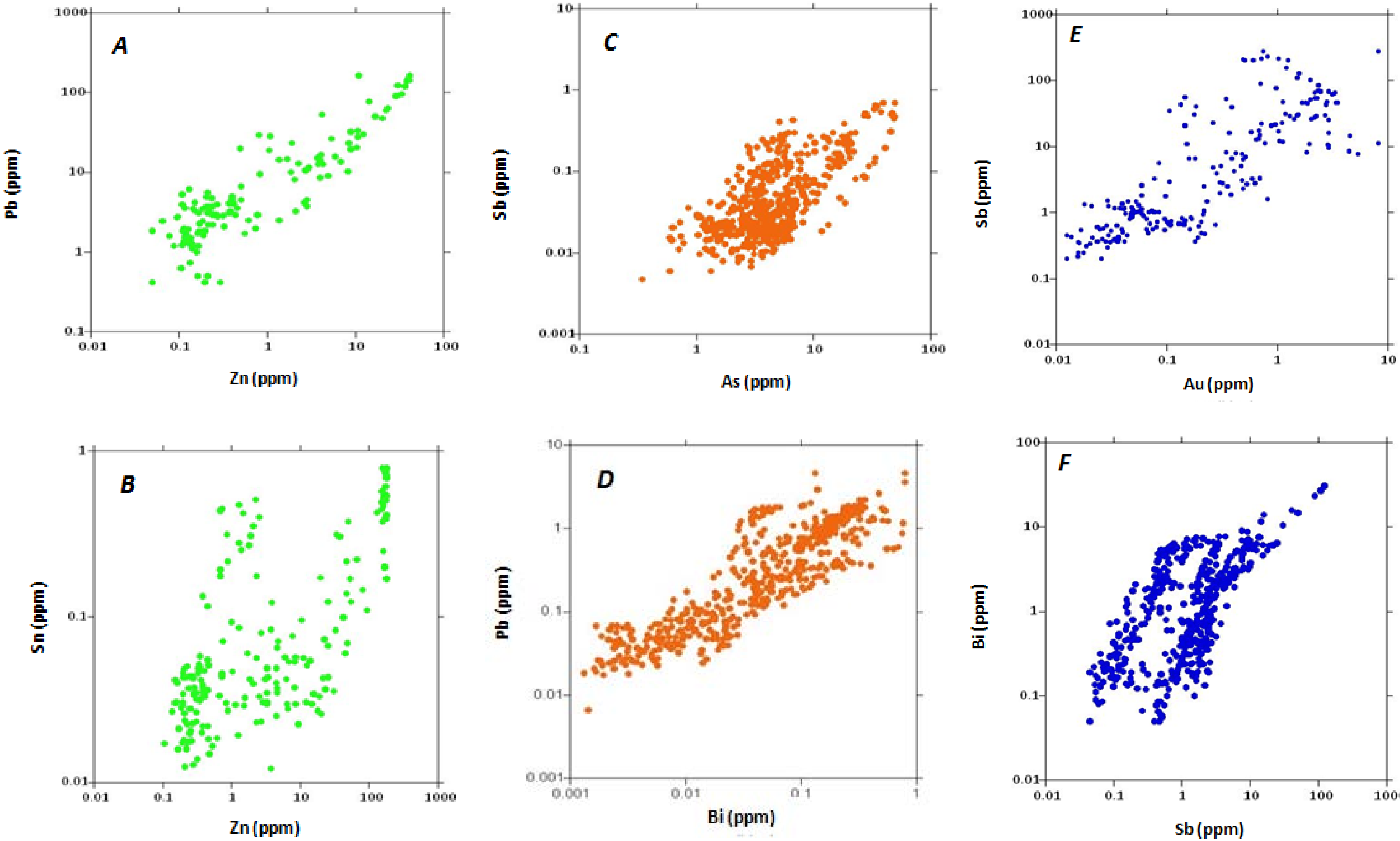


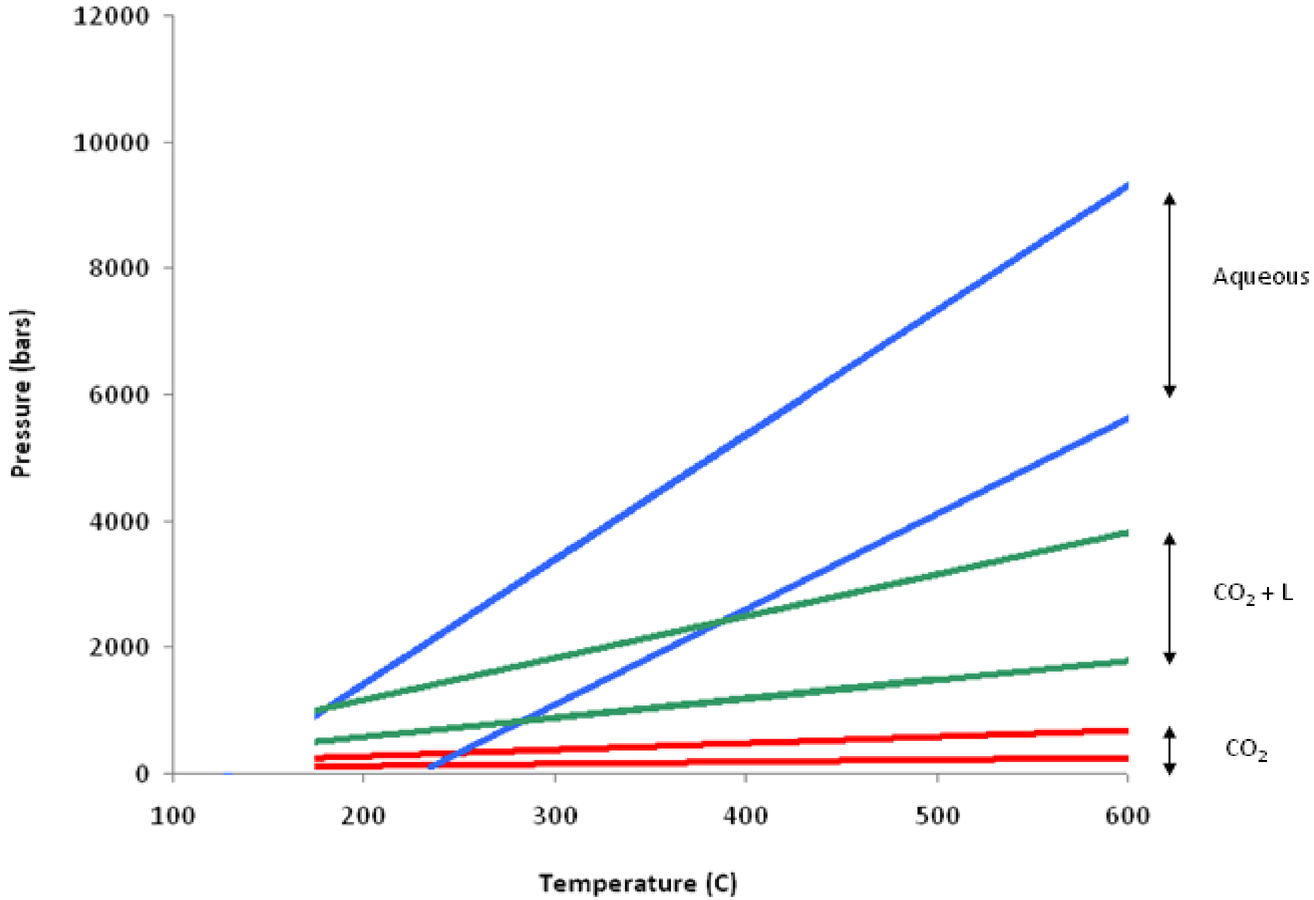


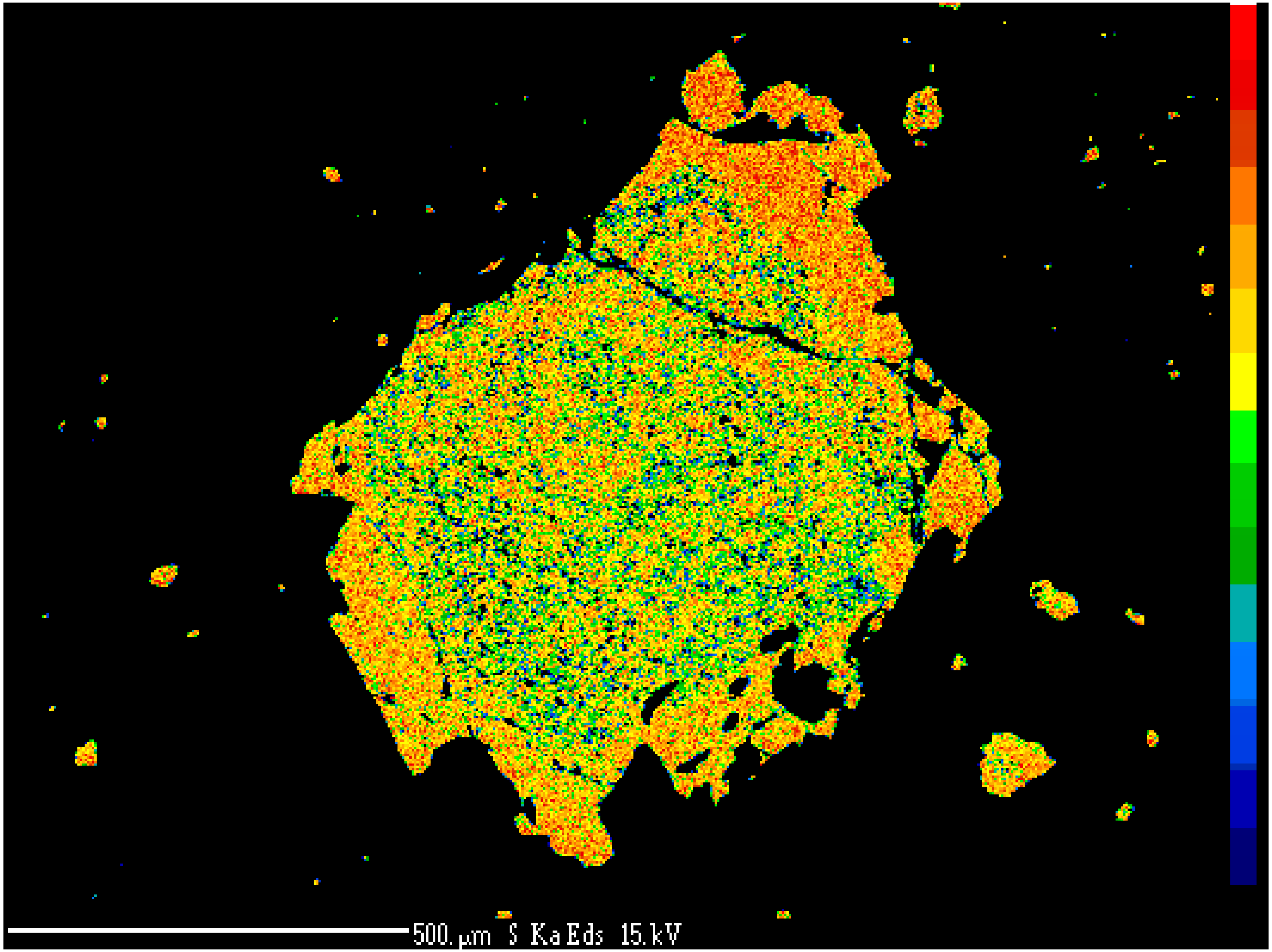
Group 1
Porous euhedral – subhedral hematite altered low grade gold related pyrite

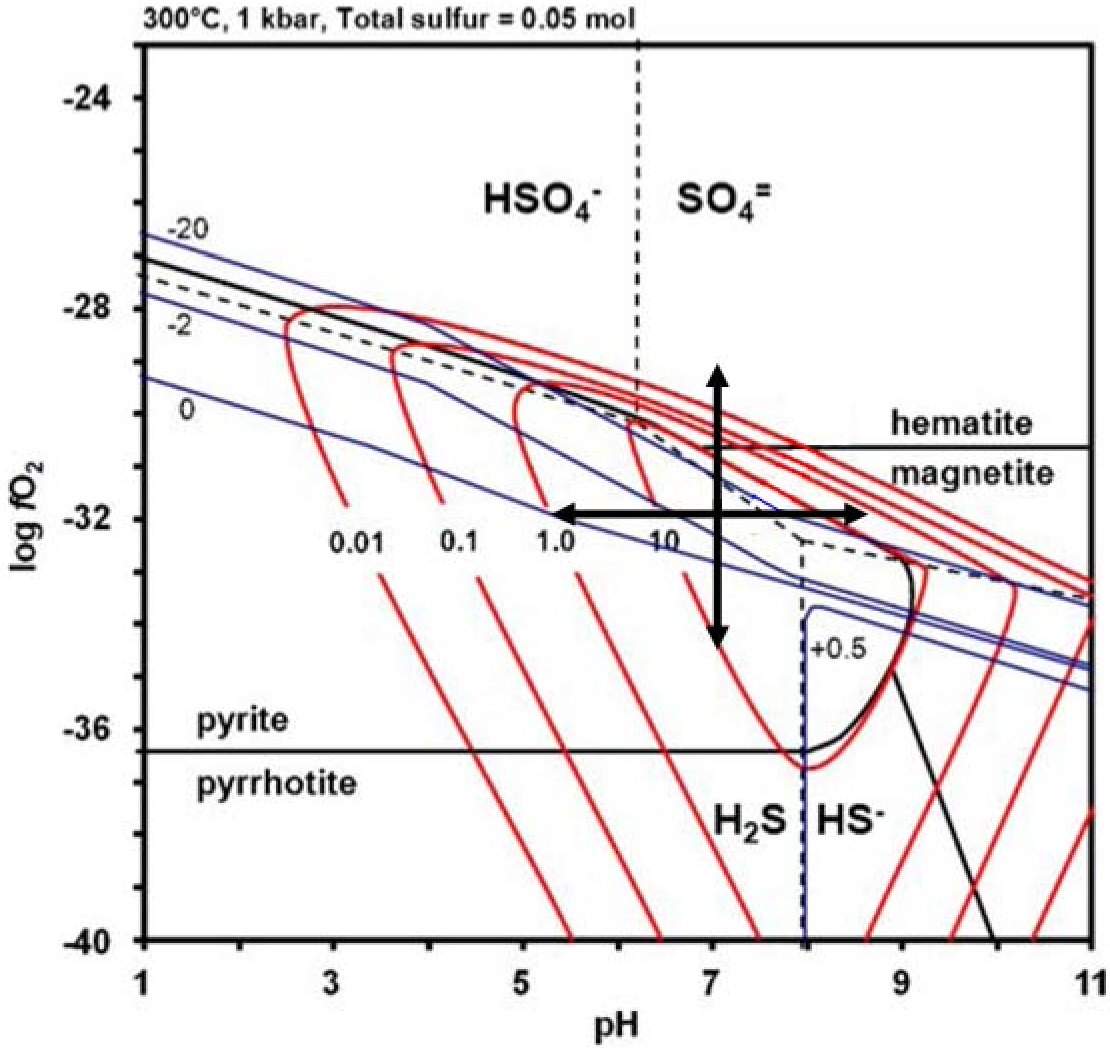
Group 2
Porous, anhedral inclusion-rich pyrite

Group 4
Zoned euhedral pyrites in high grade gold shear zones

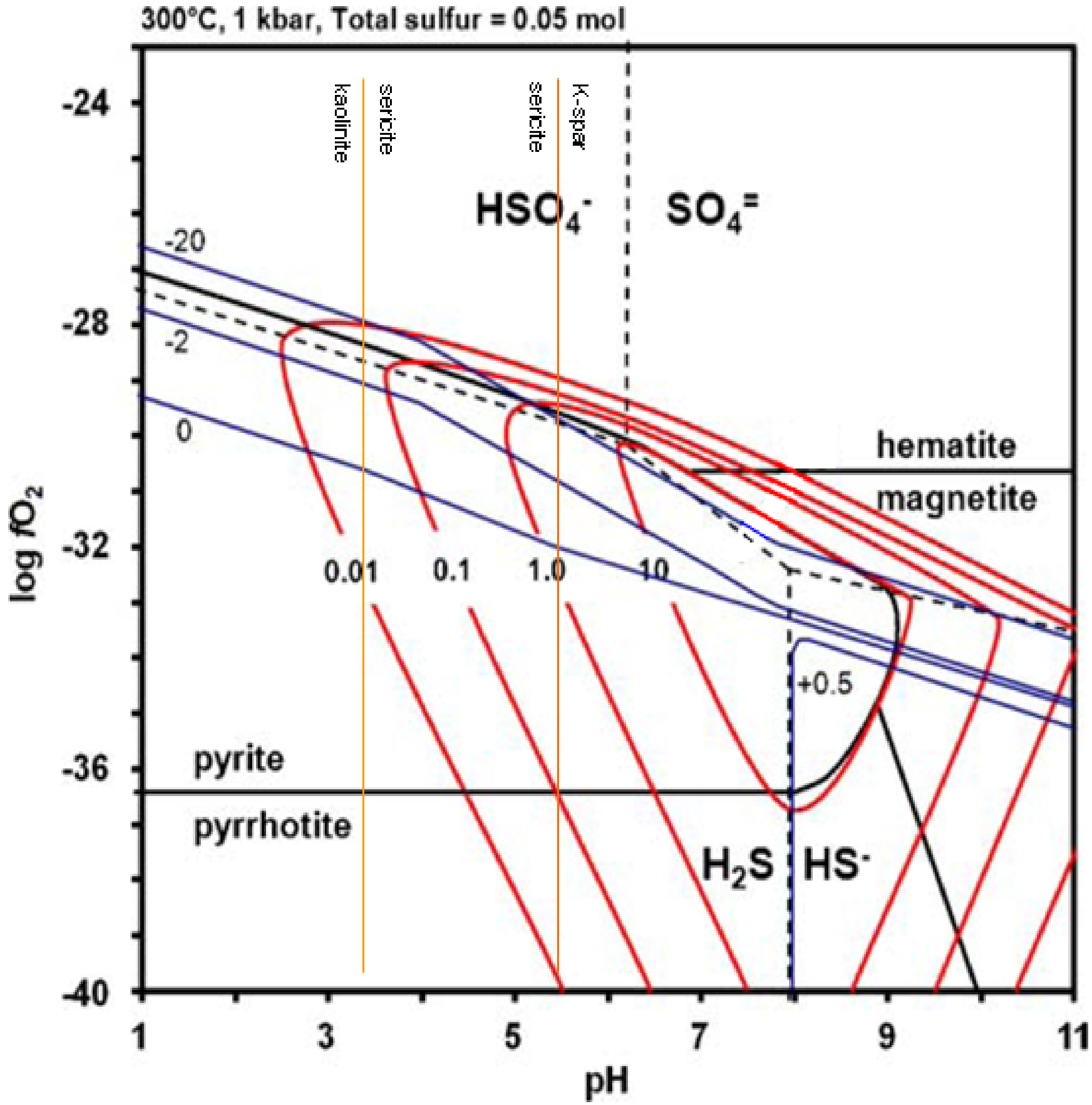



12000
10000
8000
6000
4000
2000
0
Pressure (bars)
100
200
300
400
500
600
Temperature (C)
Aqueous
CO_2 + L
CO_2


500. µm S Ka Eds 15. kV



300°C, 1 kbar, Total sulfur = 0.05 mol
-24
-28
-32
-36
-40
log fO2
HSO4-
SO4=
-20
-2
0
hematite
magnetite
0.01
0.1
1.0
10
+0.5
pyrite
pyrrhotite
H2S
HS-
1
3
5
7
9
11
pH


300°C, 1 kbar, Total sulfur = 0.05 mol
kaolinite
sericite
sericite
K-spar
HSO4-
SO4=
-20
-2
0
hematite
magnetite
0.01
0.1
1.0
10
+0.5
pyrite
pyrrhotite
H2S
HS-
log fO2
pH
-24
-28
-32
-36
-40
1
3
5
7
9
11

What are sulfur isotopes?

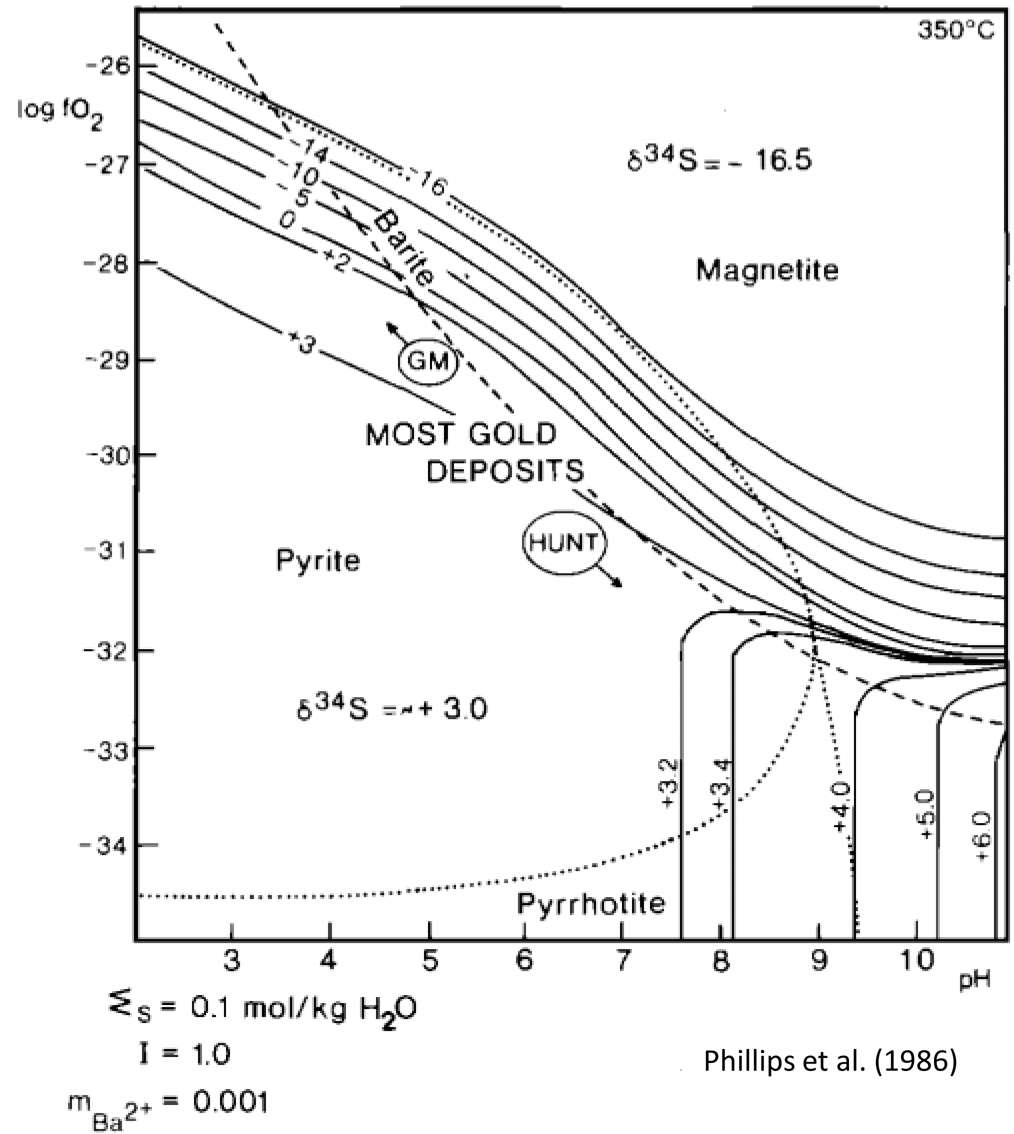
^{32}S (95.02%)
^{33}S (0.75%)
^{34}S (4.21%)
^{36}S (0.02%)

Expressed as $\delta^{34}S$ (‰) of the $^{34}S/^{32}S$ ratio
(Ohmoto and Rye 1979)

Vary in nature

Yilgarn gold deposits:
-4‰ to +4‰ $\delta^{34}S$
(McCuaig and Kerrich 1998)

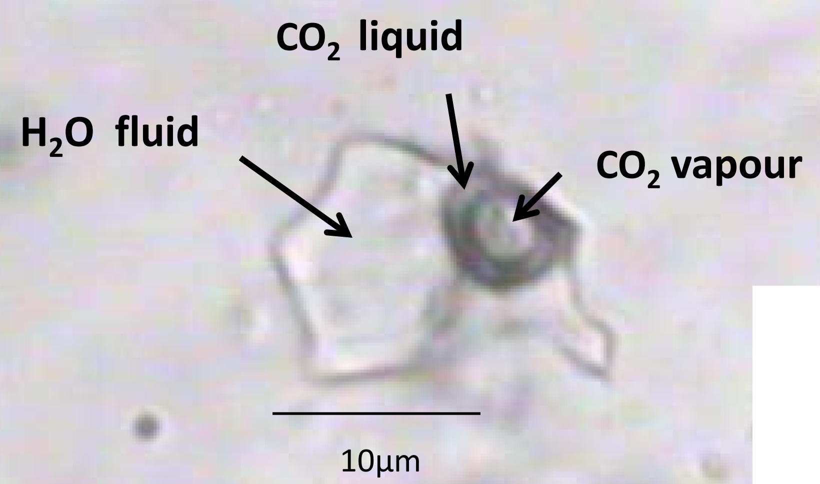
Mechanisms responsible for variations:
(1) Redox
(2) Sulfidation
(3) Wallrock – fluid interaction
(4) Phase separation
(Ohmoto 1972; Rye and Ohmoto 1974)



Phillips et al. (1986)

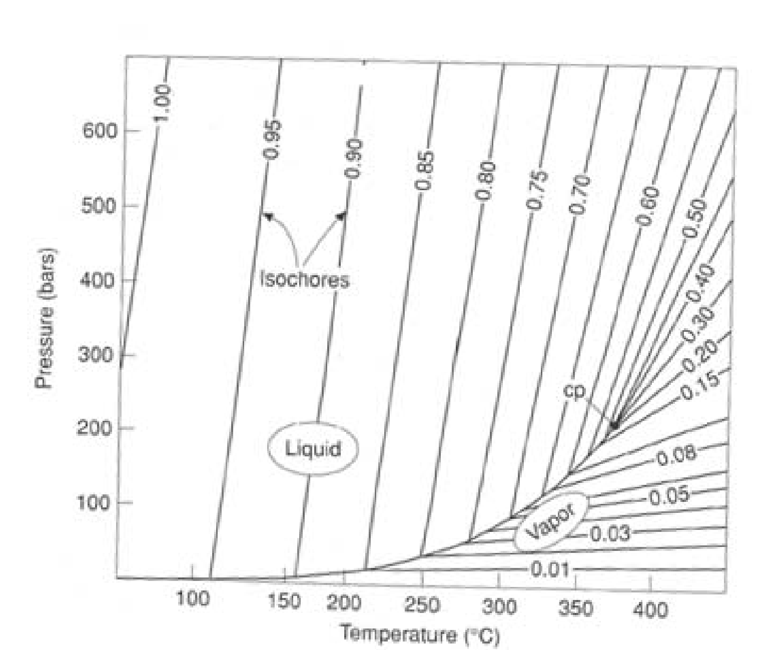
What are fluid inclusions (FLINCs)

Fluid Inclusions are bubbles of liquid, gas and solids trapped inside a crystal (Roedder 1984).



Primary, pseudosecondary and secondary inclusions.

Temperature
Composition
Deformation
Pressure



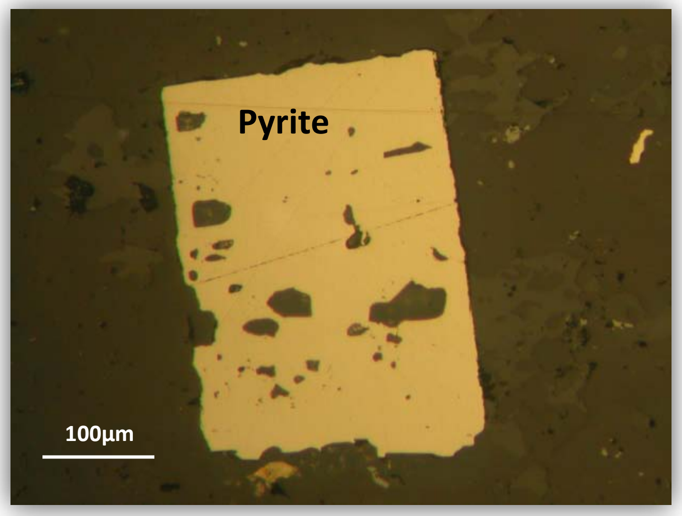
(Robb 2009)

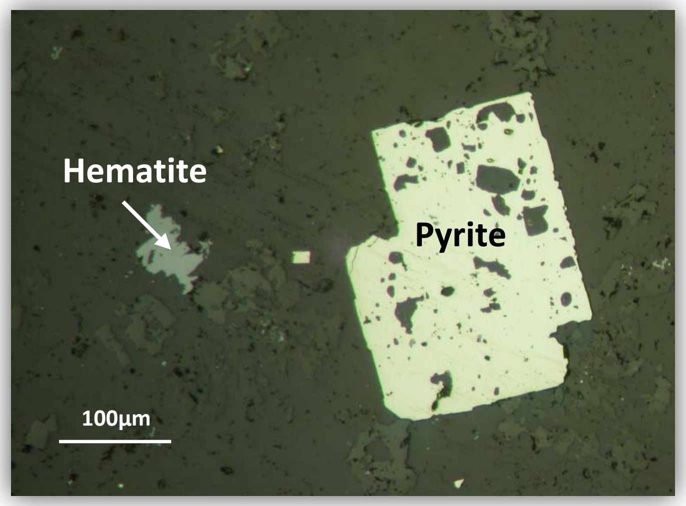
Results

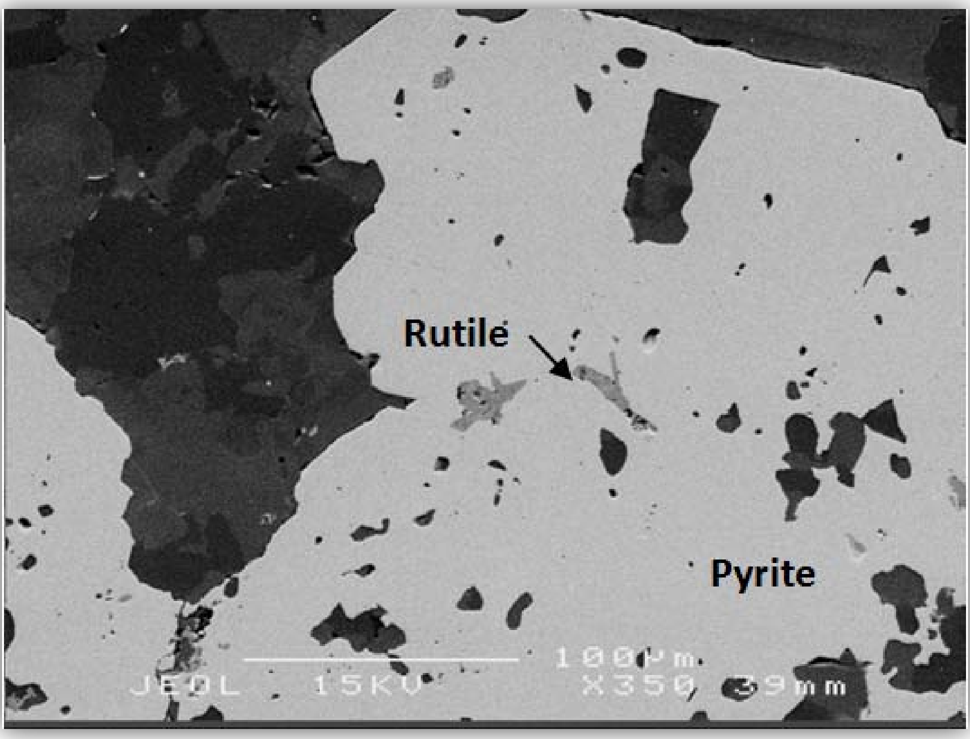
Textural analysis of pyrite

Group 1

Porous euhedral – subhedral hematite altered low grade gold related pyrite

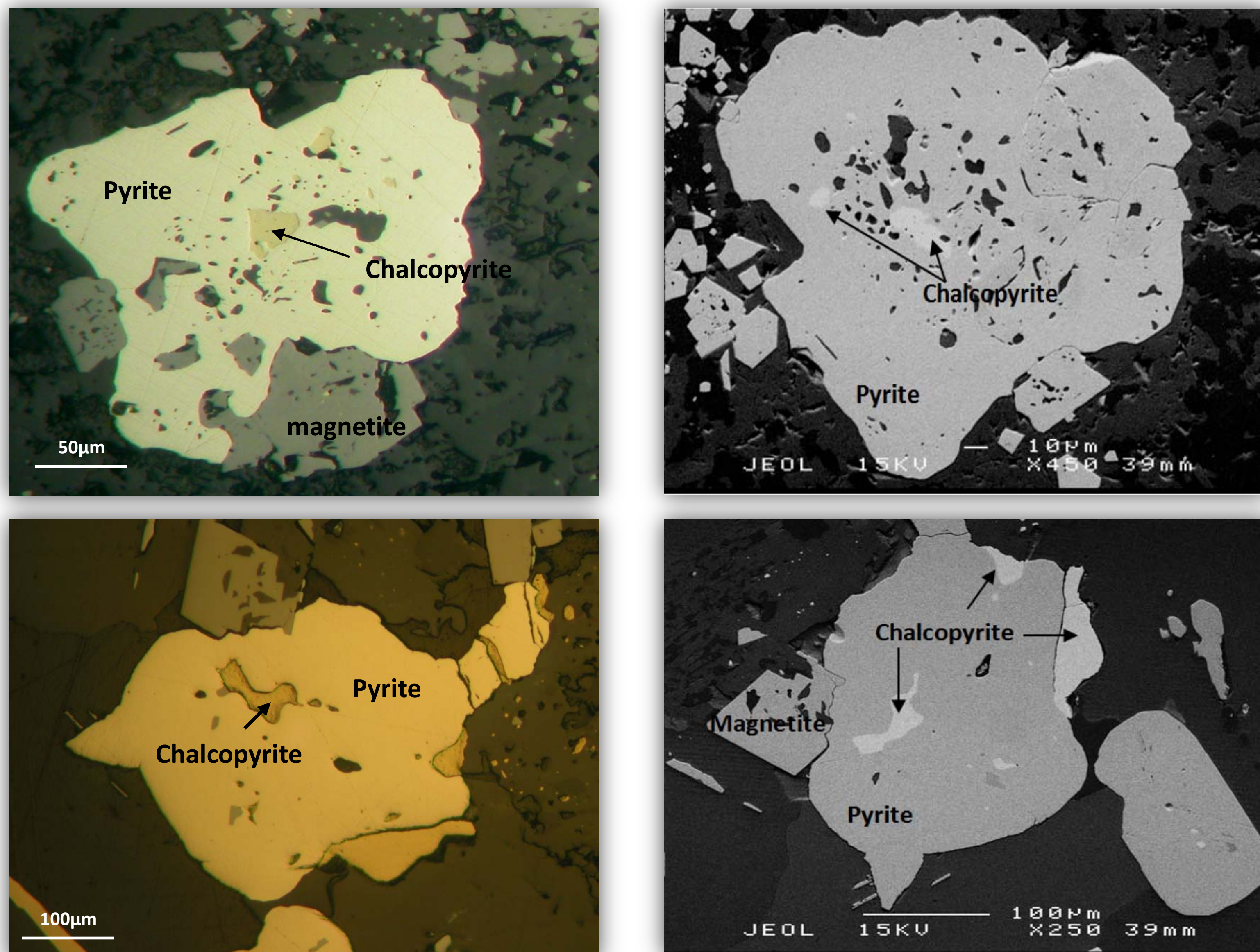


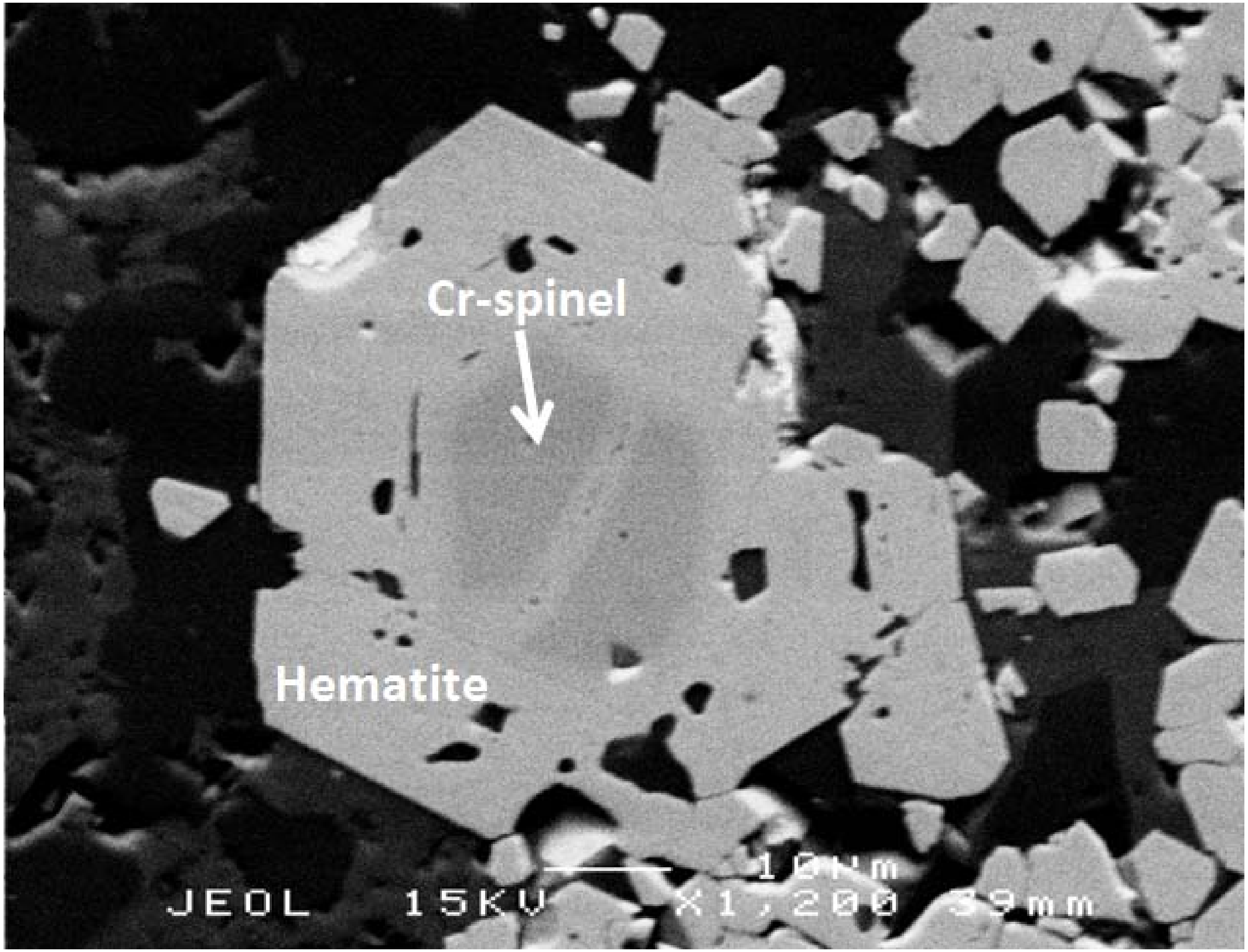




Group 2

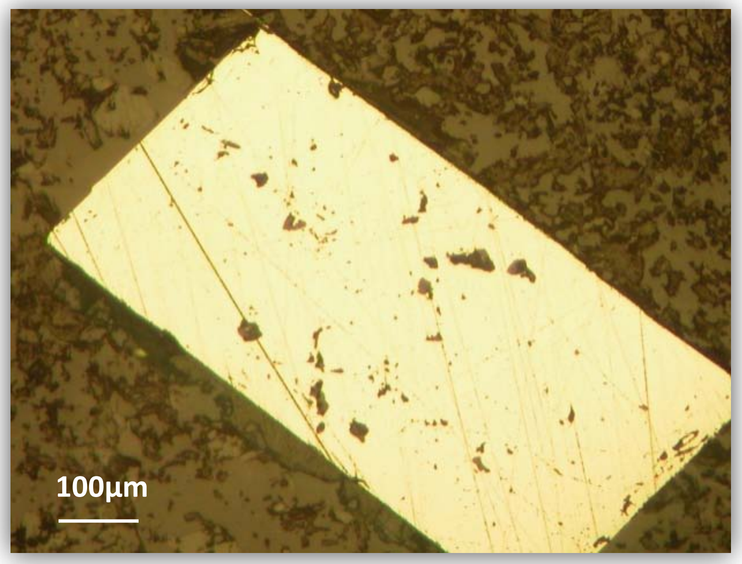
Porous, anhedral inclusion-rich pyrite

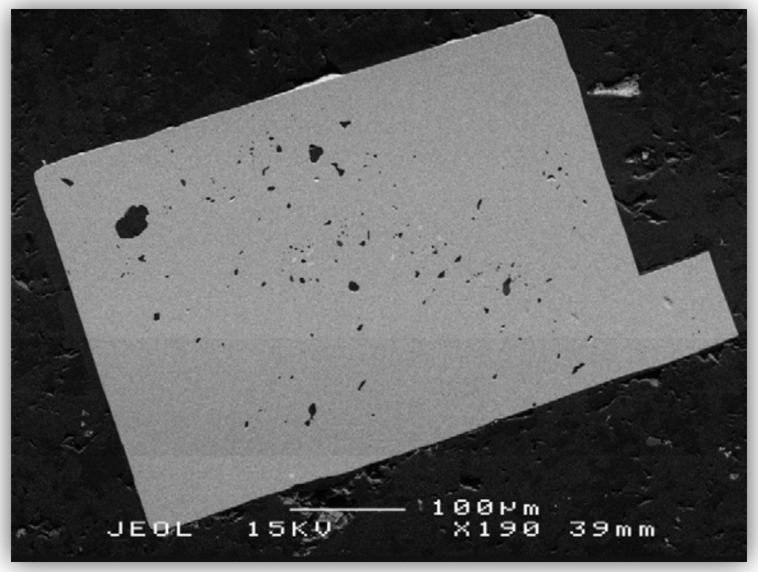


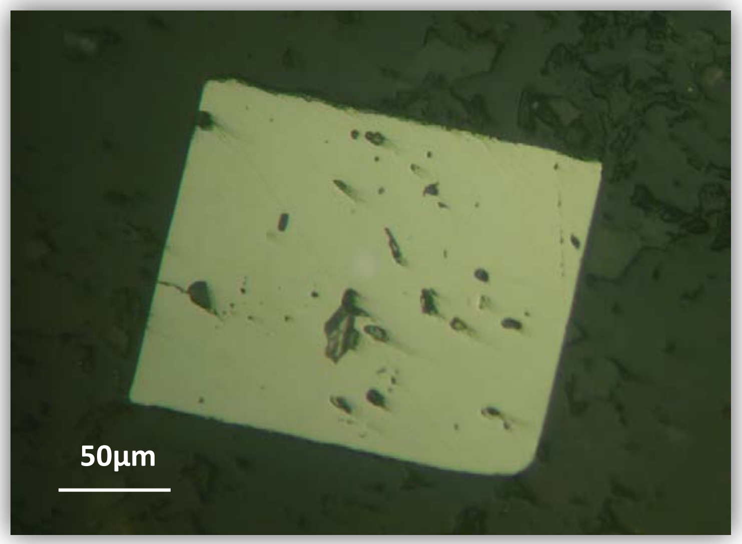

Cr-spinel
Hematite
10μm
JEOL 15KV X1,200 39mm

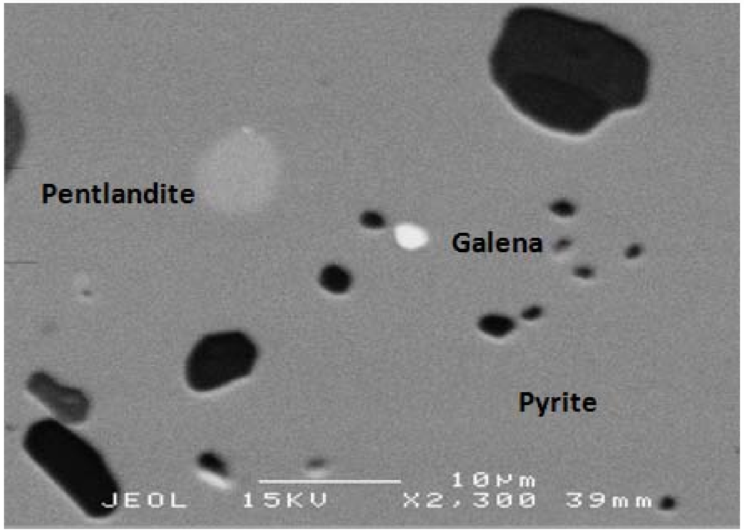
Group 3

Euhedral – subhedral syenite-related pyrites



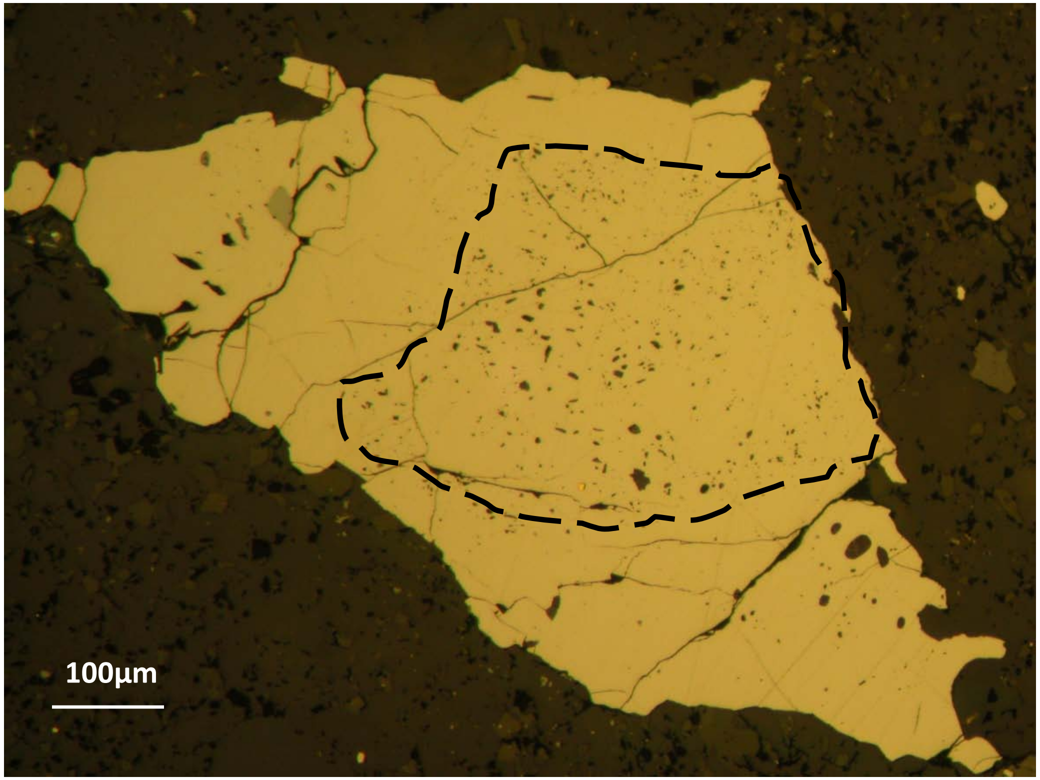


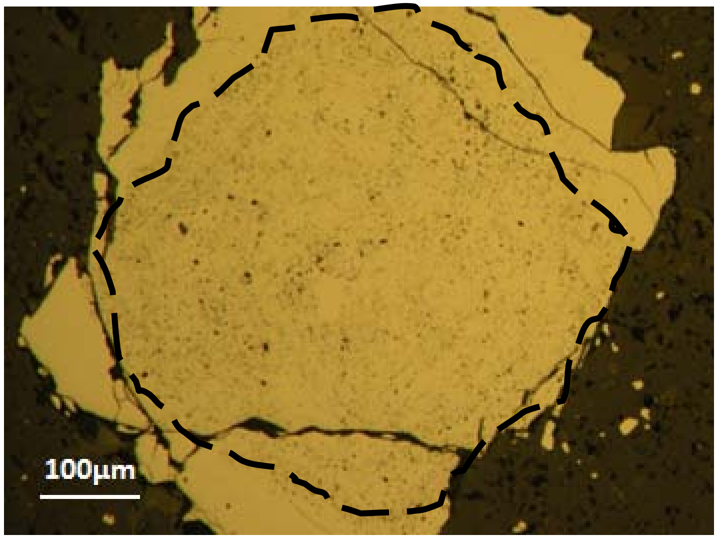


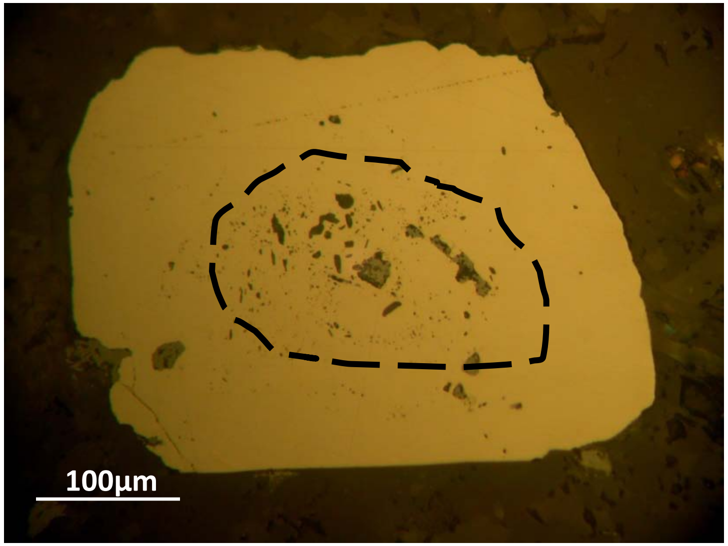


Group 4

Zoned euhedral pyrites in high grade gold shear zones







Group 5

Euhedral vein related hydrothermal pyrite