

# New discoveries of rare Au and Ag minerals in some Montana ore deposits

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Geological Engineering, Montana Tech

- Butte
- McDonald Meadows
- Virginia City District
- Elkhorn (Boulder) District



# Butte

- Produced over 600 million oz of silver
  - 2<sup>nd</sup> in U.S. to Couer d'Alene district ID
- Produced roughly 3 million oz of gold
  - 2<sup>nd</sup> in Montana to Golden Sunlight Mine

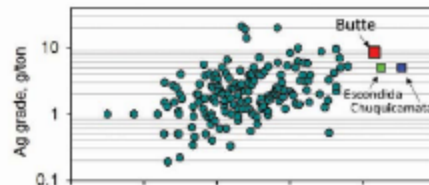
## Web Exclusive

### New investigations of the mineralogy of silver in the world-class porphyry-lode deposits of Butte, MT

by O.H. Gammons, J. Szarkowski and R. Stevenson

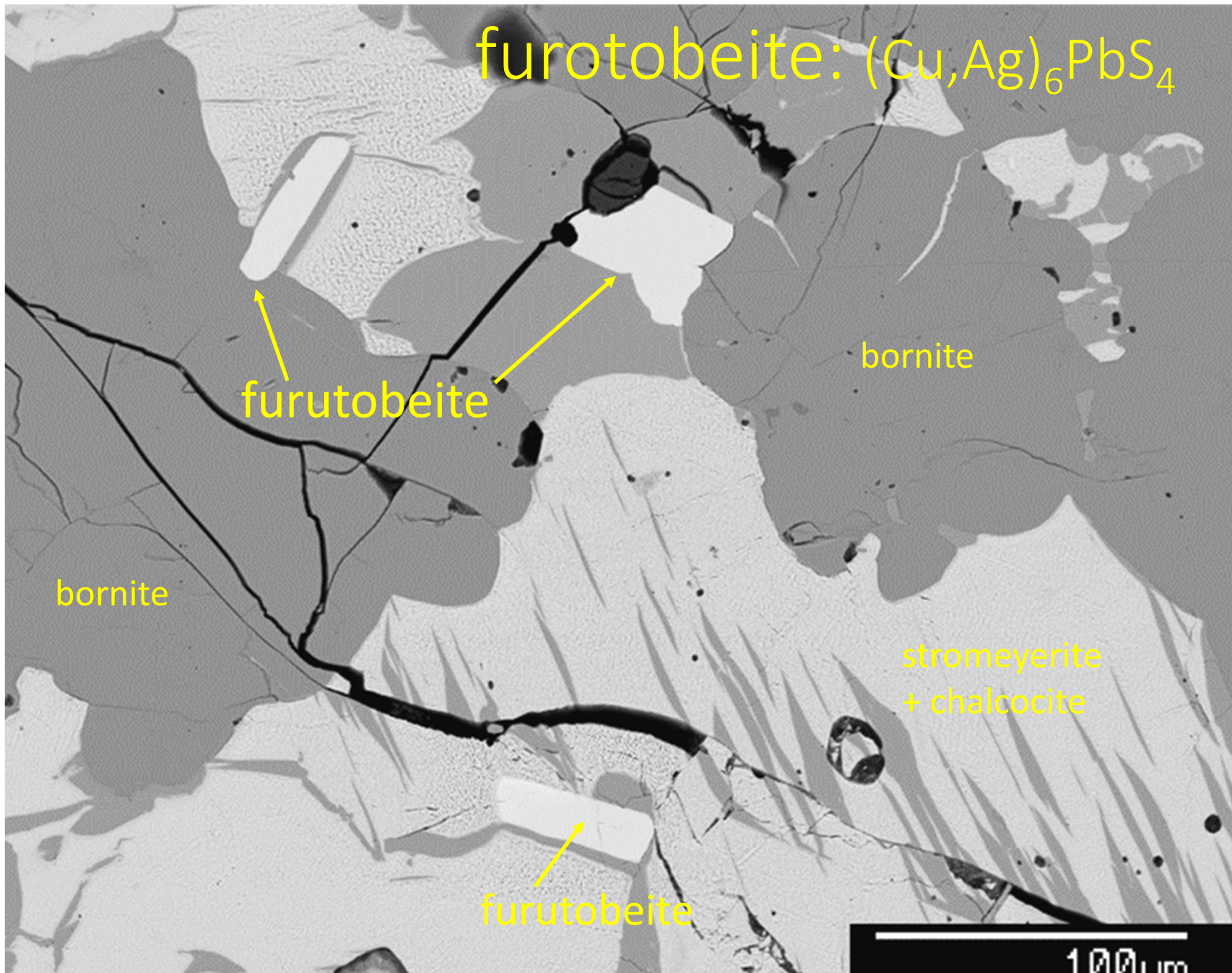
The Butte district of Montana is well-known as one of the biggest historic producers of copper in the world. It is also a classic example of a porphyry copper-molybdenum (Cu-Mo) system that has been overprinted by zoned, polymetallic copper-zinc-lead-silver (Cu-Zn-Pb-Ag) lode mineralization. After copper, silver was the next most important metal mined from Butte, with

**Figure 1**  
Average silver grade, Ag/Cu mass ratio, and total Ag production + reserves for the global database of porphyry copper deposits (Singer et al., 2008).

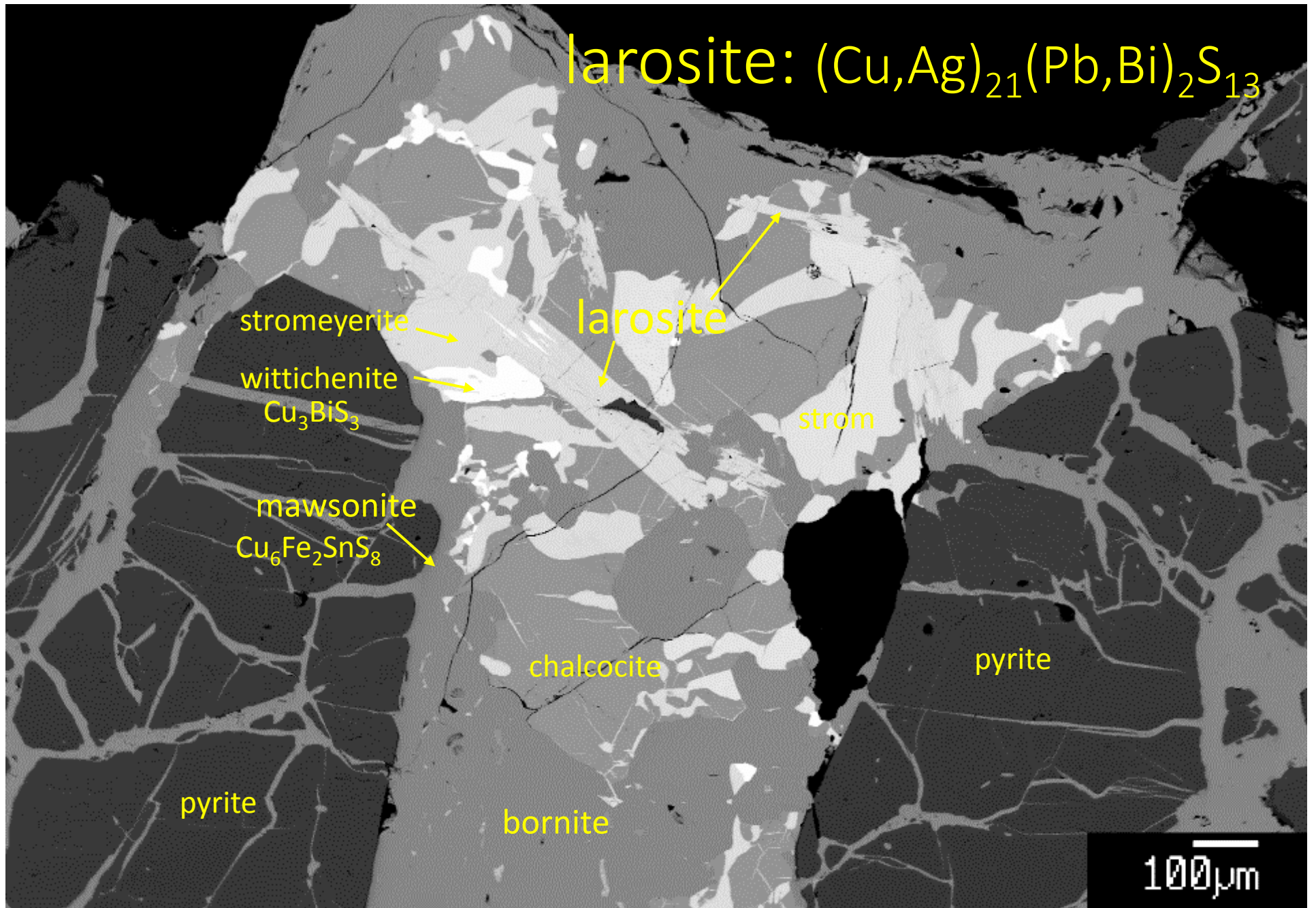


*Mining Engineering, Web Exclusive  
2016*

Mineral (group)	Formula	Guilbert & Ziehn, 1964	This study
<b>HYPOGENE</b>			
Argentite	$\text{Ag}_2\text{S}$	X	X
Pearceite-polybasite	$(\text{Ag,Cu})_{16}(\text{As,Sb})_2\text{S}_{11}$	X	X
Proustite-pyrargyrite	$\text{Ag}_3(\text{As,Sb})\text{S}_3$	X	X
Stephanite	$\text{Ag}_5\text{SbS}_4$	X	
Andorite	$\text{PbAgSb}_3\text{S}_6$	X	
Stromeyerite	$\text{AgCuS}$	X	X
Ag-tetrahedrite	$(\text{Ag,Cu})_{12}\text{Sb}_4\text{S}_{13}$	X	X
Furutobeite	$(\text{Cu,Ag})_6\text{PbS}_4$		X
Larosite	$(\text{Cu,Ag})_{21}(\text{Pb,Bi})_2\text{S}_{13}$		X
Matildite	$\text{AgBiS}_2$		X
Jalpaite	$\text{Ag}_3\text{CuS}_2$		X
Electrum	$\text{AgAu}$		X
Petzite	$\text{Ag}_3\text{AuTe}_2$		X
Hessite	$\text{Ag}_2\text{Te}$		X
Empressite (?)	$\text{AgTe}$		X
<b>SUPERGENE</b>			
Acanthite	$\text{Ag}_2\text{S}$	X	X
Silver	$\text{Ag}$	X	X
Cerargyrite	$\text{AgCl}$	X	



Mt. Con mine (AMC # 591)



MT. Con 5933

# Occurrences of furutobeite and larosite:

## **Furutobeite**

- None in U.S.
- < 5 locations world-wide
- Type locality = Furutobe mine, Japan

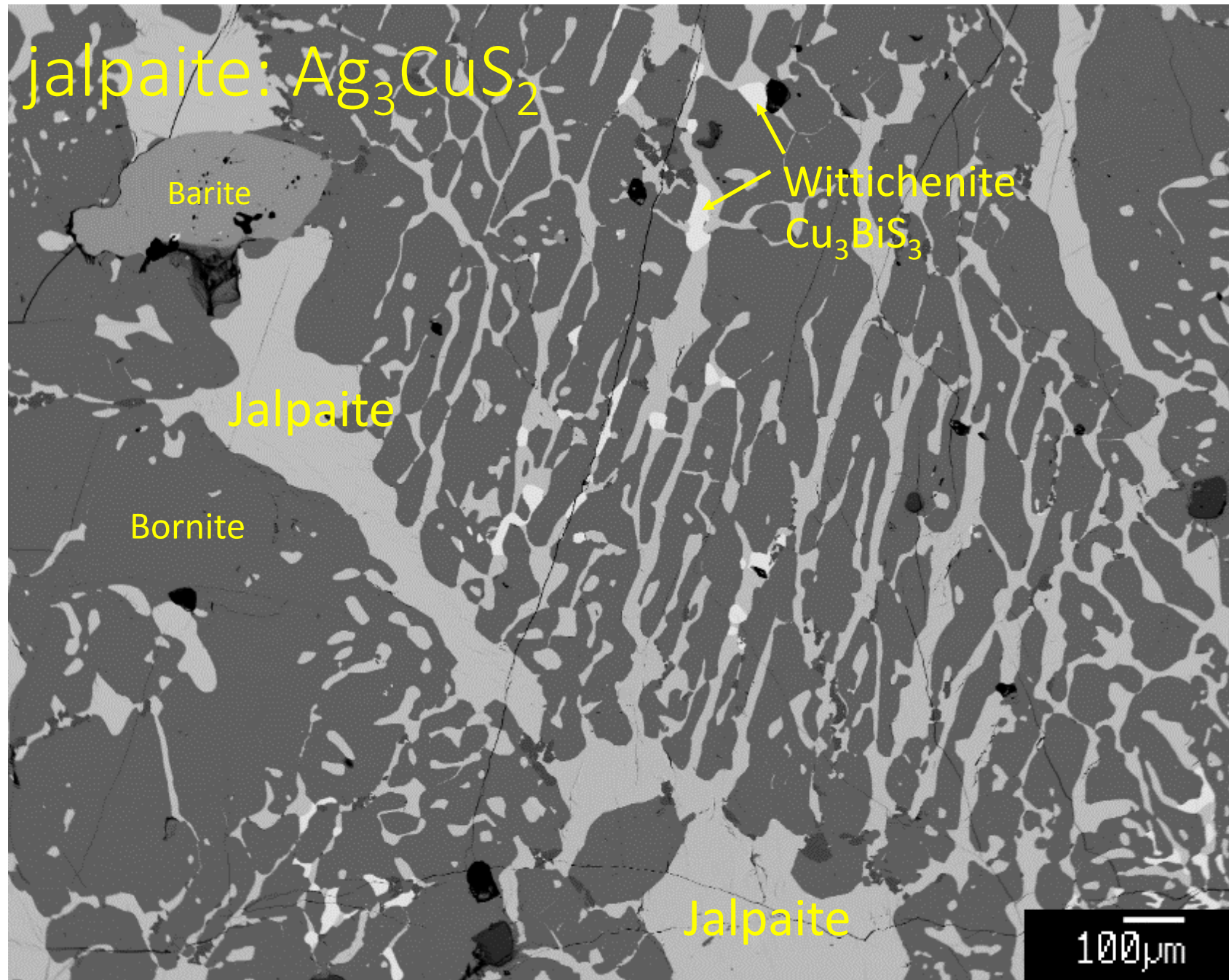
(Kuroko-type VMS)

## **Larosite**

- None in U.S.
- Butte = 3<sup>rd</sup> (?) locality world-wide

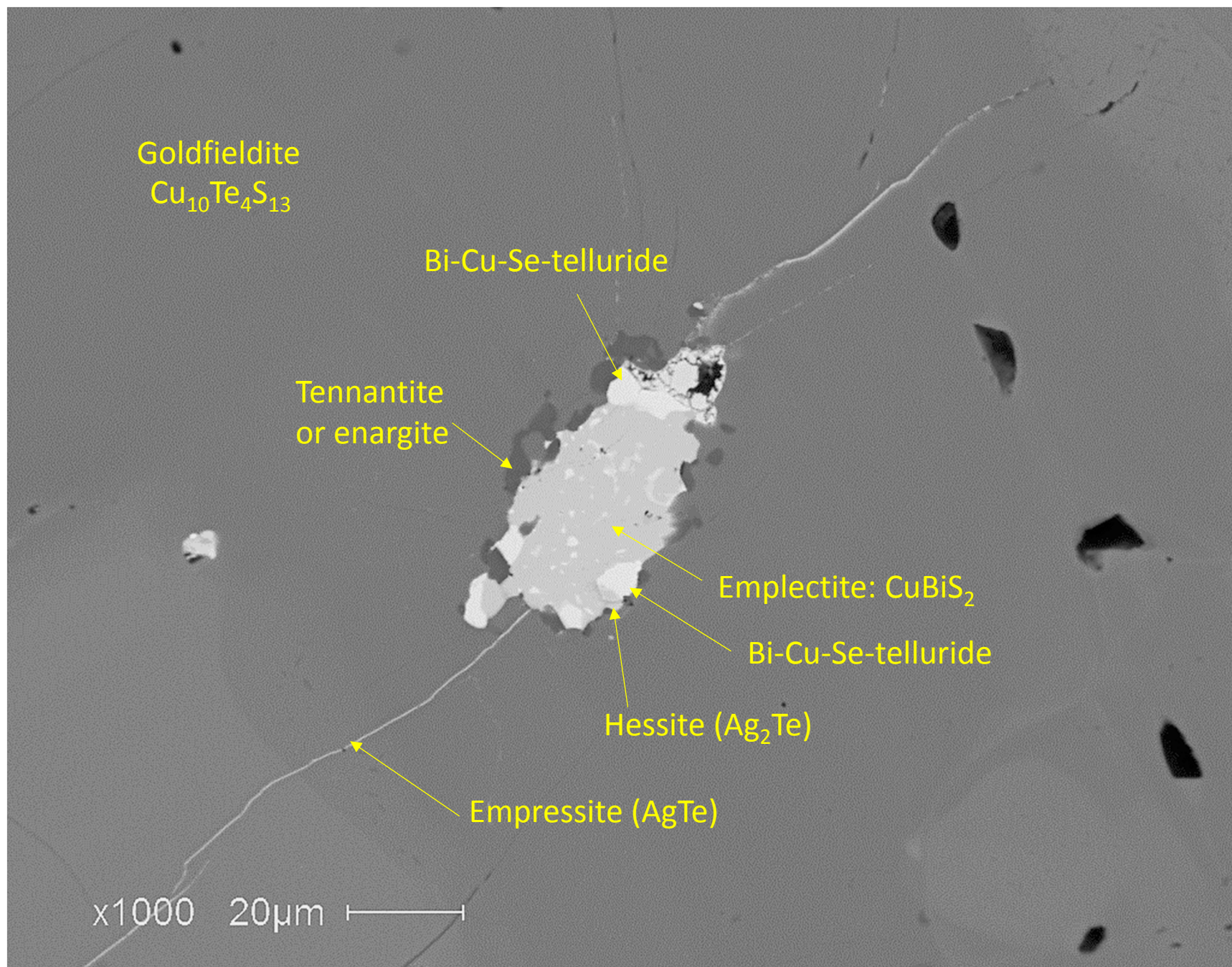


Fred Larose  
Early prospector  
in Cobalt silver  
camp, Ontario



AMC 4756 Anselmo Mine

EPMA-BSE image

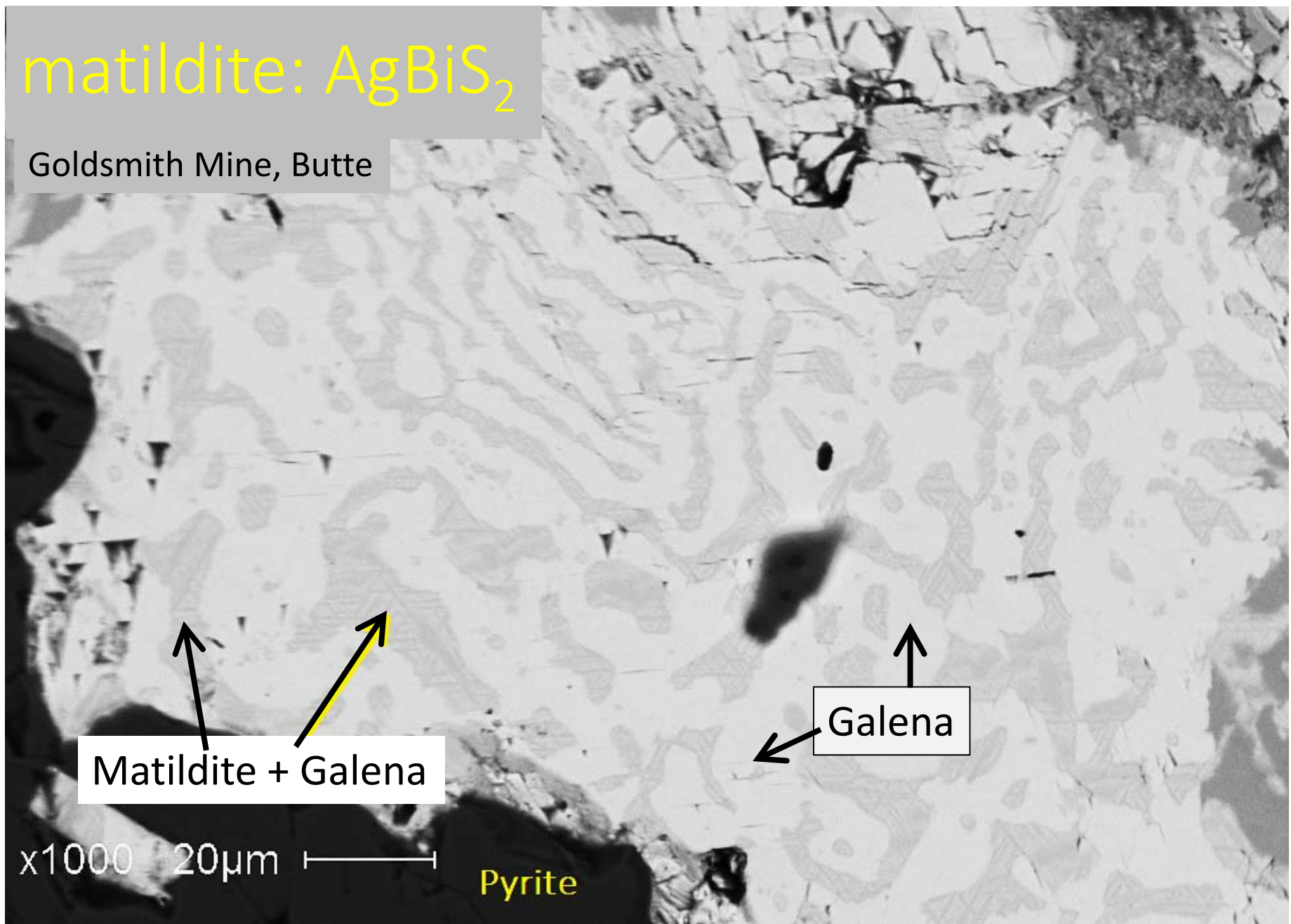


St. Lawrence Mine



matildite:  $\text{AgBiS}_2$

Goldsmith Mine, Butte



Matildite + Galena

Galena

x1000 20 $\mu\text{m}$

Pyrite

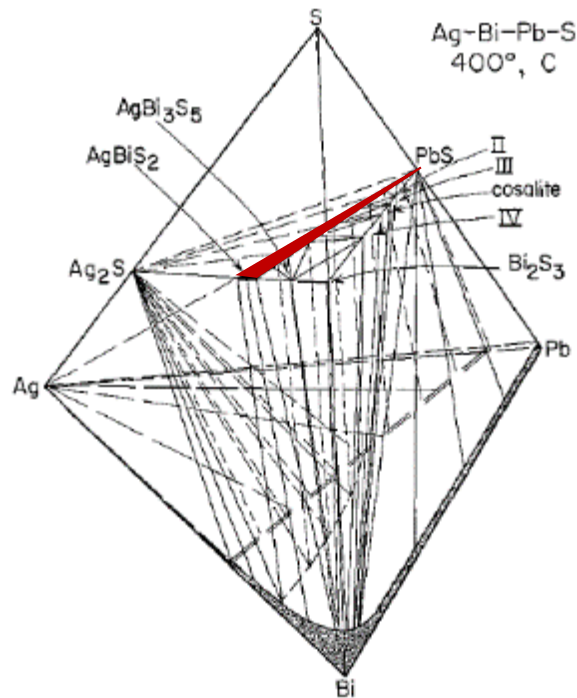


Fig. 23. Schematic phase relations of the Ag-Bi-Pb-S system at 400°C. (Mol-% diagram.)

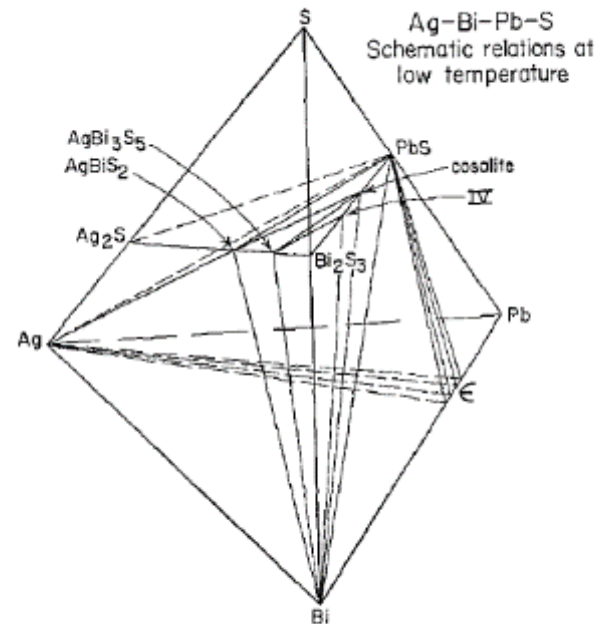
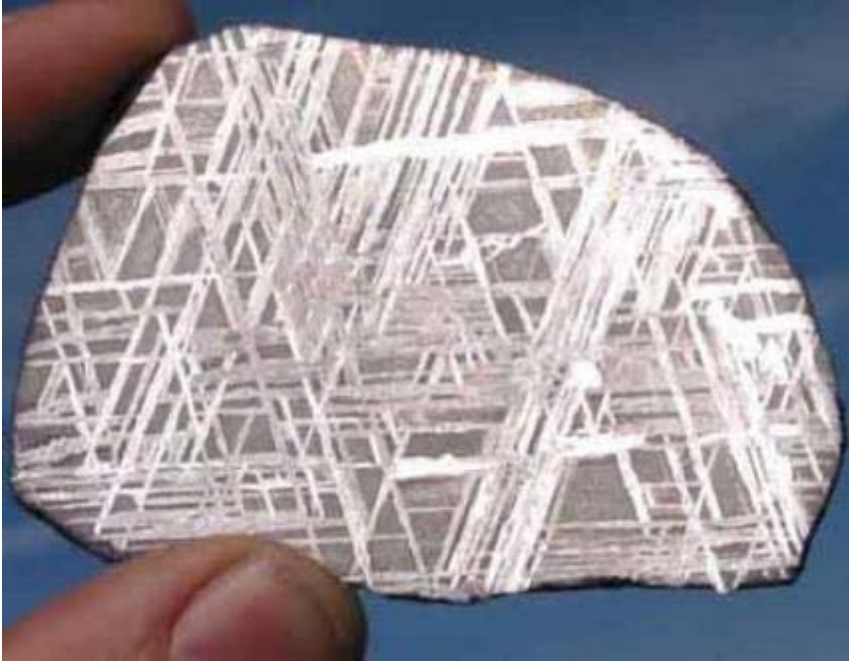


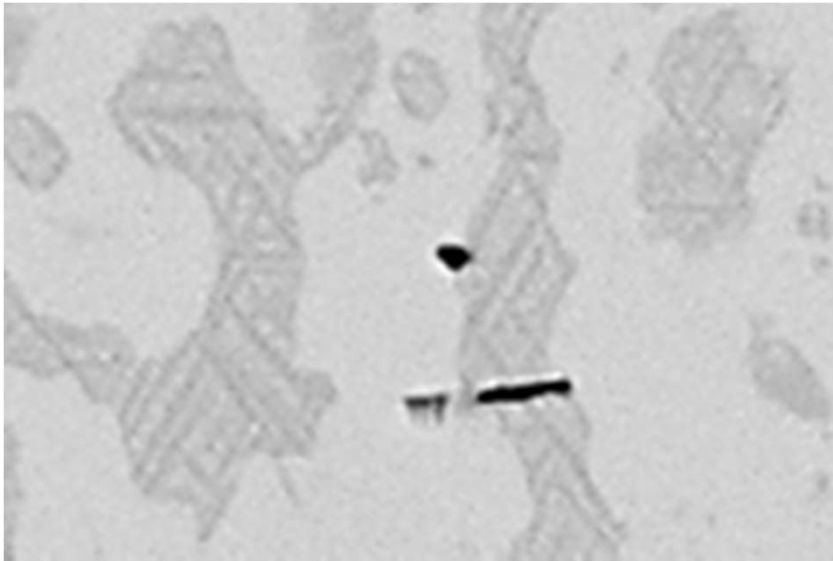
Fig. 24. Schematic relations of the Ag-Bi-Pb-S system at low temperature. (Mol-% diagram.)

The texture shown on previous page is due to exsolution of pure  $\text{PbS} + \text{AgBiS}_2$  from a  $\text{PbS-AgBiS}_2$  solid solution. According to Craig (1967), the solvus for this reaction crests at a temperature of  $215 \pm 15^\circ\text{C}$ .

Craig J.R. (1967) Phase relations and mineral assemblages in the Ag-Bi-Pb-S system. *Mineralium Deposita* 1, 278-306.

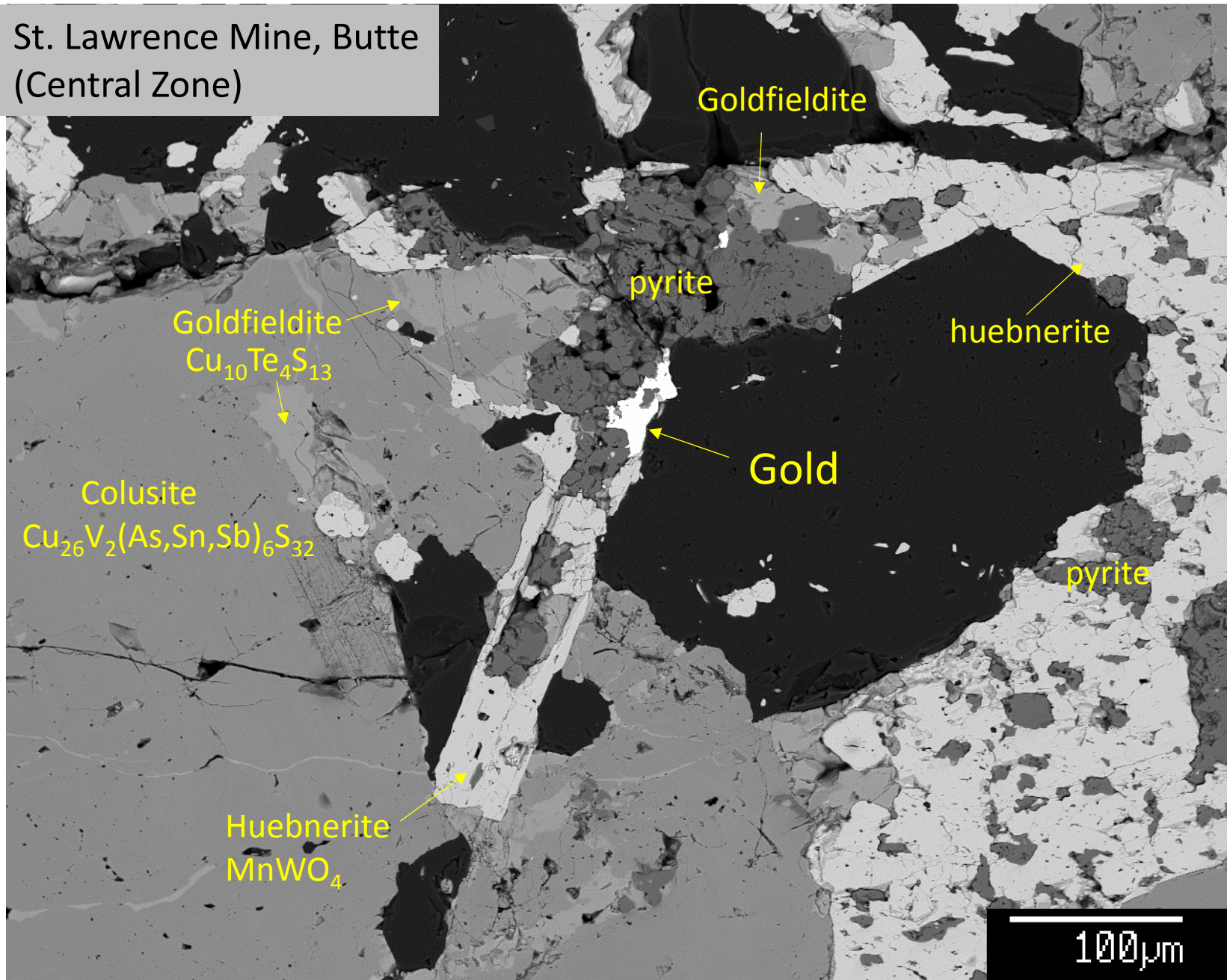


This is an example of  
Widmanstätten Structure from a  
meteorite  
Exsolution of Fe-Ni alloys

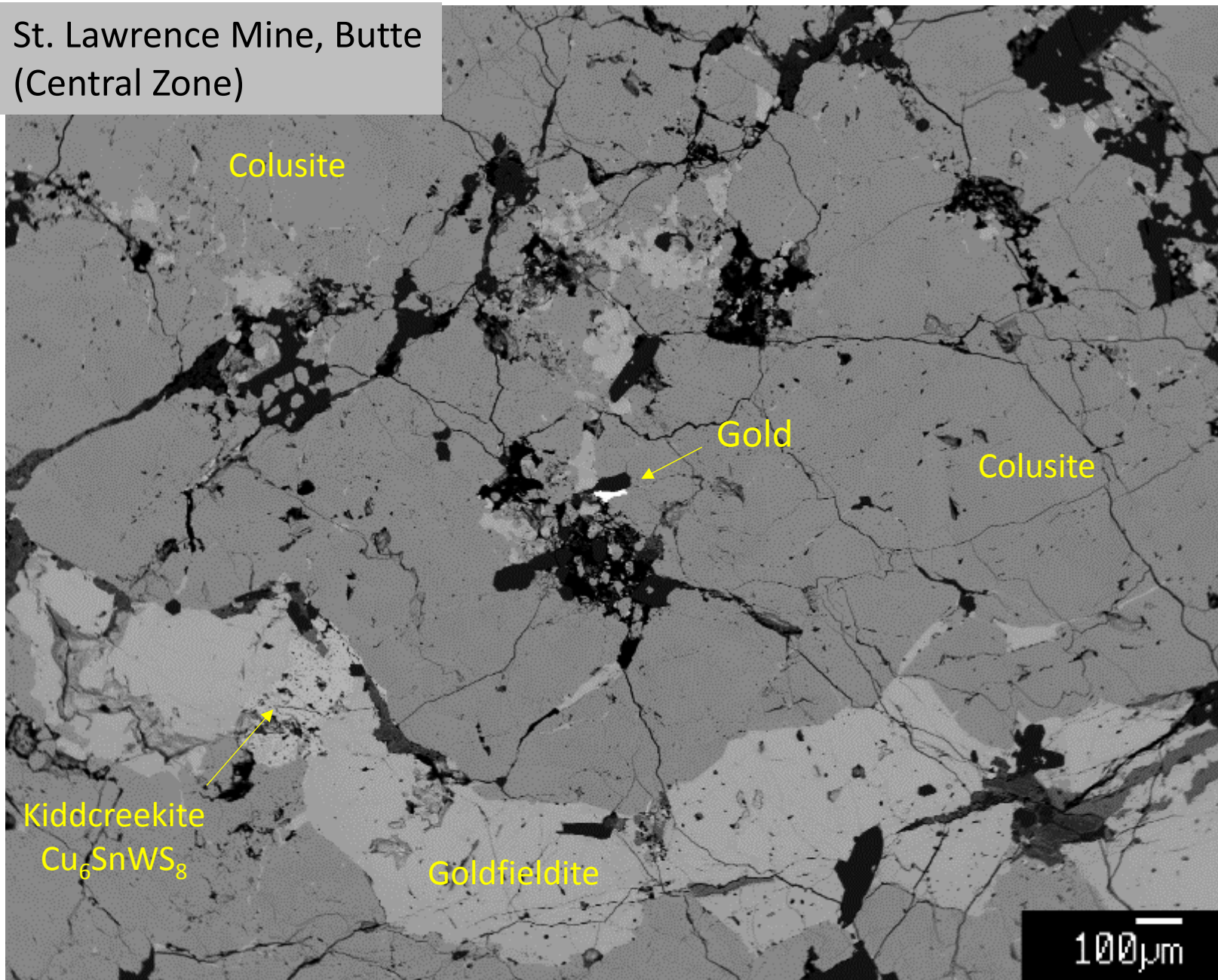


In this blowup of the Goldsmith  
sample, you can see the darker  
patches are actually intergrowths  
of galena and matildite almost  
identical to the meteorite texture

St. Lawrence Mine, Butte  
(Central Zone)



St. Lawrence Mine, Butte  
(Central Zone)



# Butte: summary thoughts

- Uniquely complex metal endowment
  - Cu-Pb-Zn-Mn-Mo-Ag-Au-As-Sb-Bi-W-Sn-Cd-Te
- Many more discoveries will be made using modern methods of ore microscopy
- Thanks to Lester Zeihen and MBMG for preserving the Anaconda Research Collection

# McDonald Meadows gold deposit

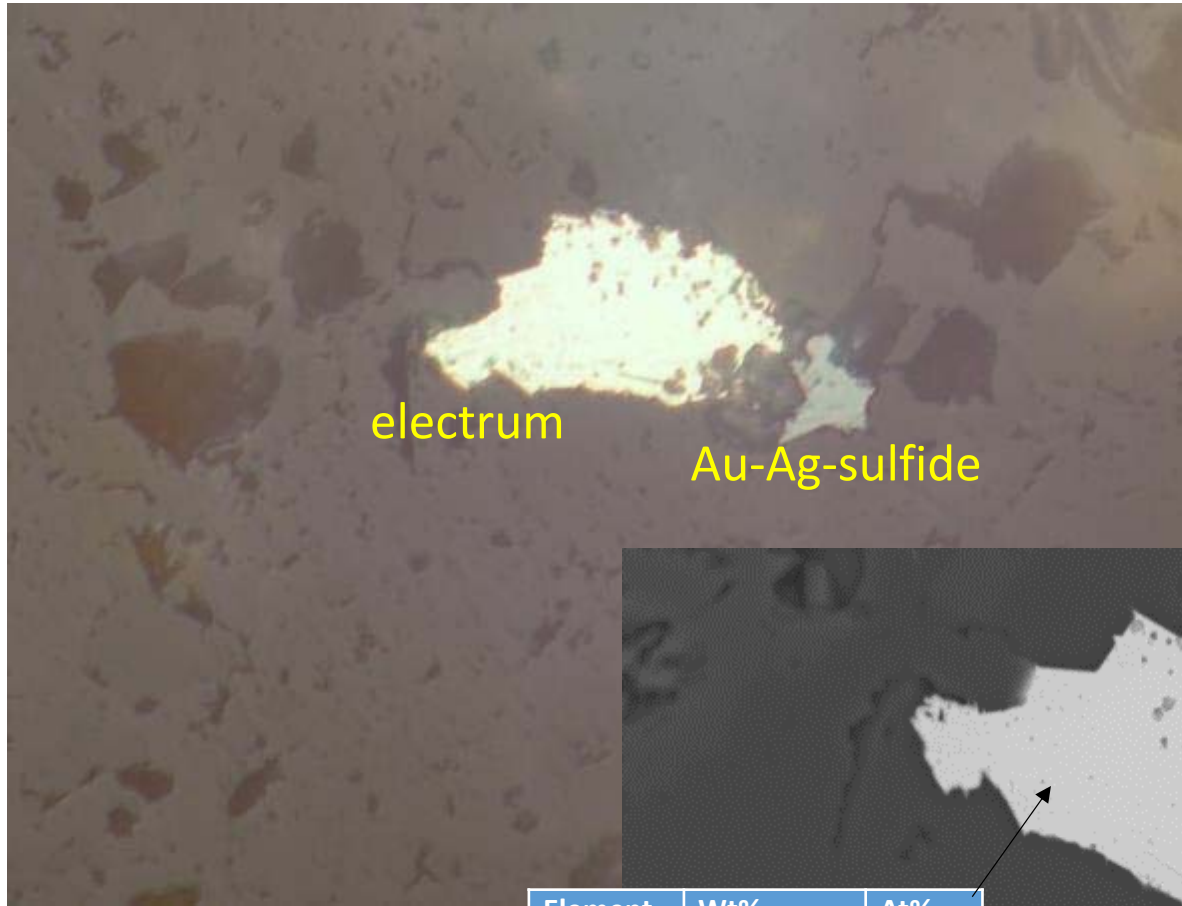
- Largest gold deposit in Montana (> 7 M oz.)
- Near Lincoln, upper Blackfoot River
- Shallow, volcanic-hosted epithermal Au-Ag deposit
- Unmined

- Sample donated by Bill Fuchs

From: William A. Fuchs

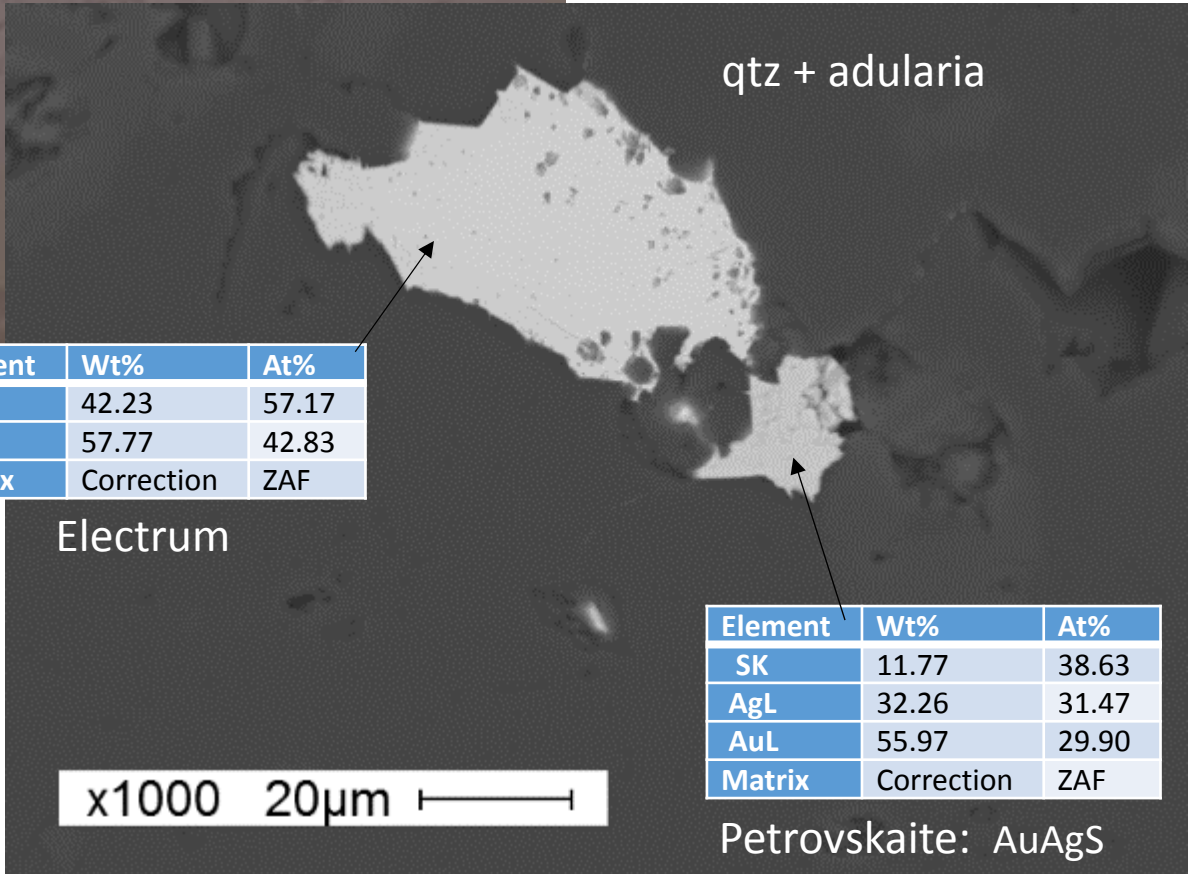
Subject: Proposal to Establish the Gold-Silver Sulfide  
 $\text{Ag}_5\text{Au}_2\text{S}_2$  from the McDonald Deposit as a New Mineral  
to be called "Phelpsdodgeite"

1992 internal memo



electrum

Au-Ag-sulfide



qtz + adularia

Element	Wt%	At%
AgL	42.23	57.17
AuL	57.77	42.83
Matrix	Correction	ZAF

Electrum

x1000 20µm

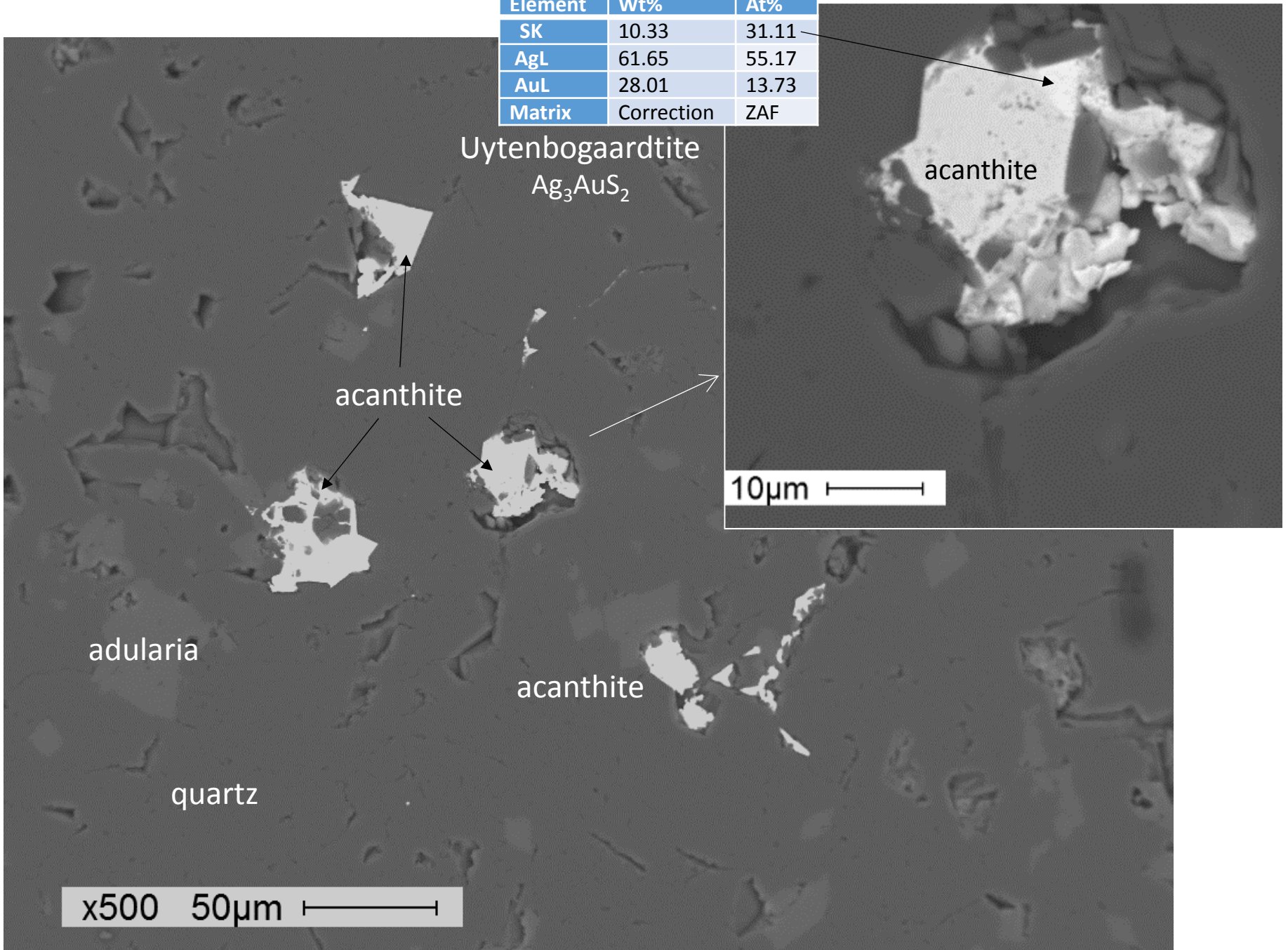
Element	Wt%	At%
SK	11.77	38.63
AgL	32.26	31.47
AuL	55.97	29.90
Matrix	Correction	ZAF

Petrovskaitite: AuAgS



Element	Wt%	At%
SK	10.33	31.11
AgL	61.65	55.17
AuL	28.01	13.73
Matrix	Correction	ZAF

Uytenbogaardtite  
 $\text{Ag}_3\text{AuS}_2$



acanthite

acanthite

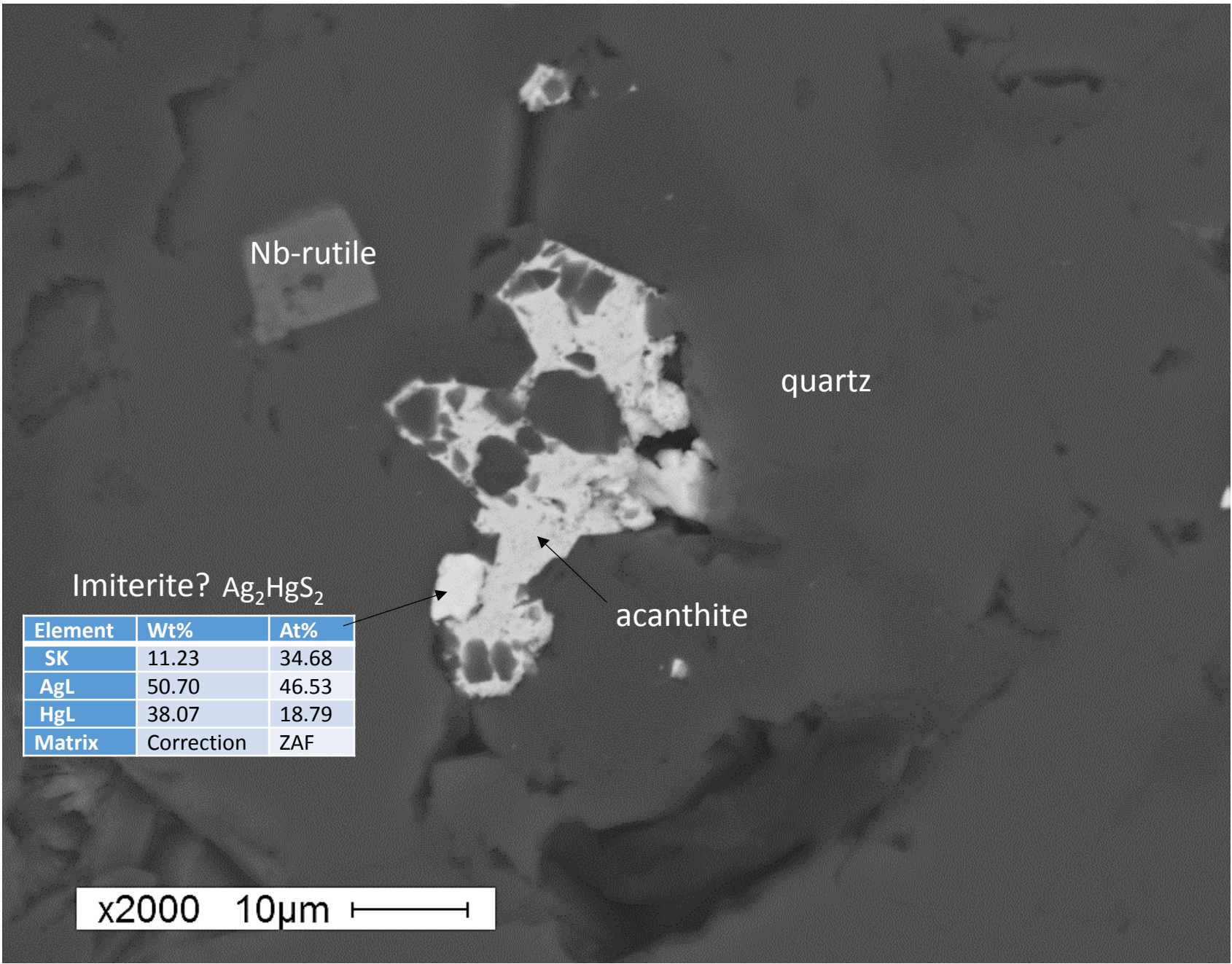
adularia

acanthite

quartz

x500 50µm

10µm



Nb-rutile

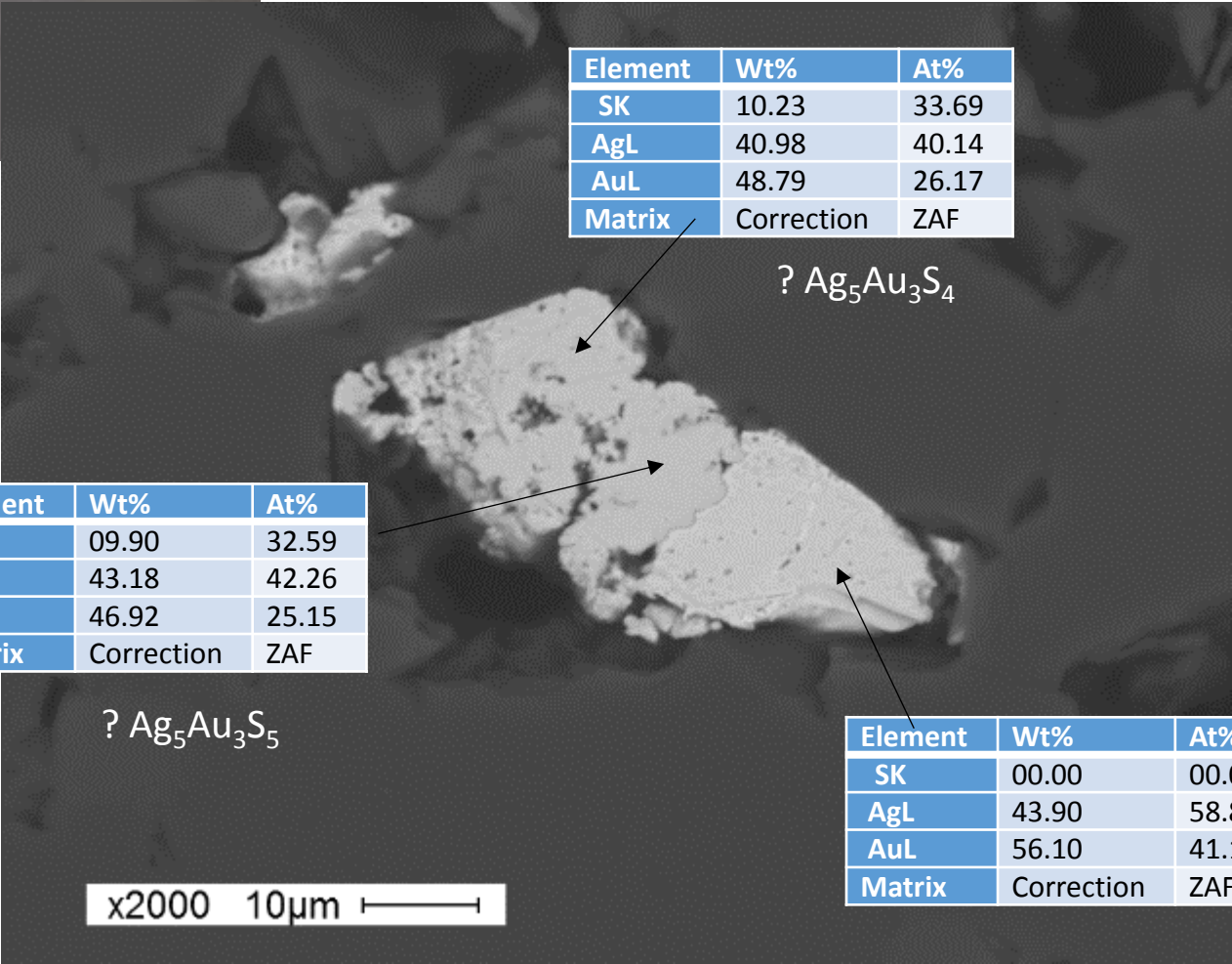
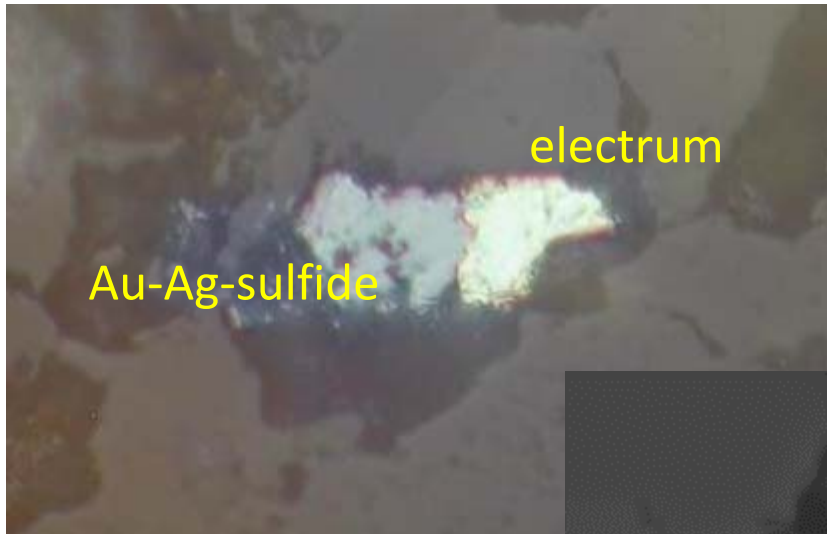
quartz

Imiterite?  $Ag_2HgS_2$

acanthite

Element	Wt%	At%
SK	11.23	34.68
AgL	50.70	46.53
HgL	38.07	18.79
Matrix	Correction	ZAF

x2000 10µm



Element	Wt%	At%
SK	10.23	33.69
AgL	40.98	40.14
AuL	48.79	26.17
Matrix	Correction	ZAF

Element	Wt%	At%
SK	09.90	32.59
AgL	43.18	42.26
AuL	46.92	25.15
Matrix	Correction	ZAF

Element	Wt%	At%
SK	00.00	00.00
AgL	43.90	58.83
AuL	56.10	41.17
Matrix	Correction	ZAF

# Other U.S. occurrences of uytenbogaardtite

## Arizona

- Comstock Mine, Dos Cabezas district

## California

- Morning Star, Ivanpah district

## Colorado

- Creede district

## Nevada

- Dean Mine
- Bullfrog District
- Life Preserver Mine
- Comstock Lode



The late Willem Uytenbogaardt  
Delft Univ., Holland

# Other U.S. occurrences of petrovskaitite

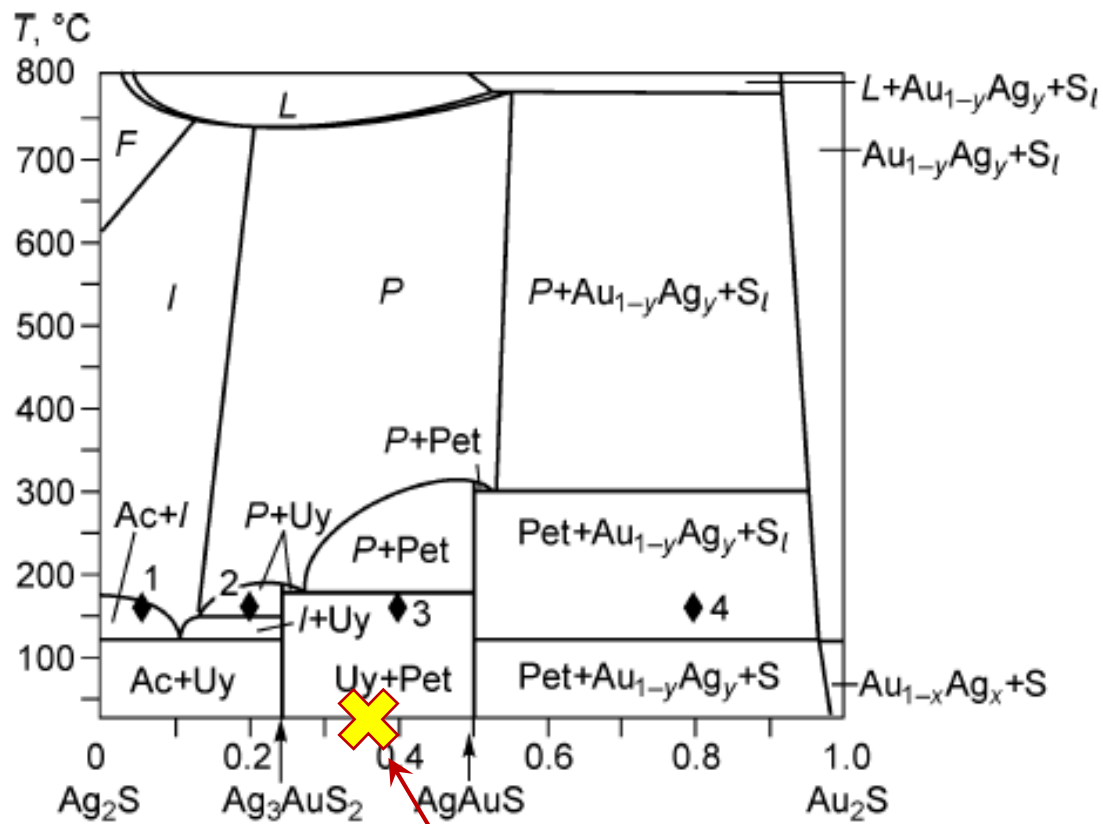
Washington

- Cannon mine, Wenatchee district

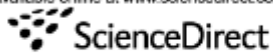
## Unknown phase?

Might be a new mineral (probably not)

- Need EMPA analysis!



Available online at [www.sciencedirect.com](http://www.sciencedirect.com)



Russian Geology and Geophysics 52 (2011) 443–449

RUSSIAN GEOLOGY  
AND GEOPHYSICS

[www.elsevier.com/locate/rgg](http://www.elsevier.com/locate/rgg)

Unknown phase

### Formation of gold and silver sulfides in the system Ag–Au–S

G.A. Pal'yanova<sup>a,\*</sup>, K.A. Kokh<sup>a</sup>, Yu.V. Seryotkin<sup>a,b</sup>

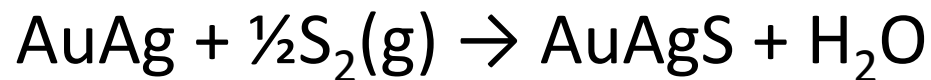
# Origin of Au-Ag sulfides?

## 1. Primary hydrothermal minerals

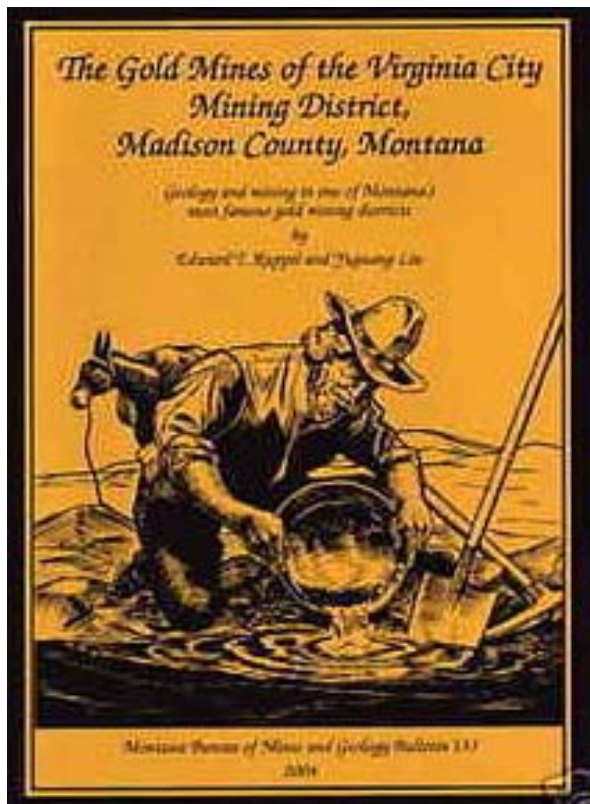
Uytenbogaardtite stable at  $T < 180^{\circ}\text{C}$

Petrovskaitite stable at  $T < 300^{\circ}\text{C}$

## 2. Low temperature sulfidation (tarnishing) of electrum



# Pacific Mine, Virginia City district

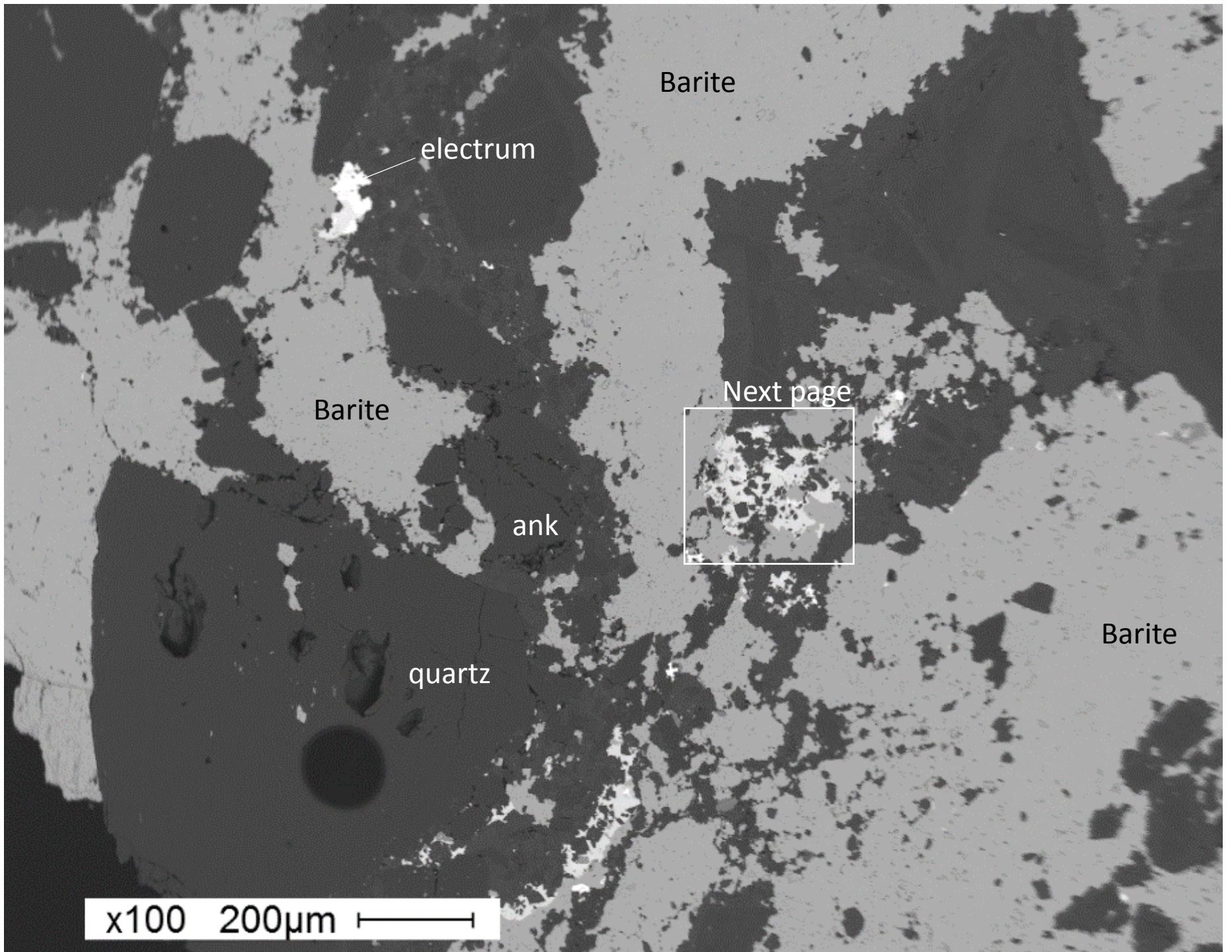


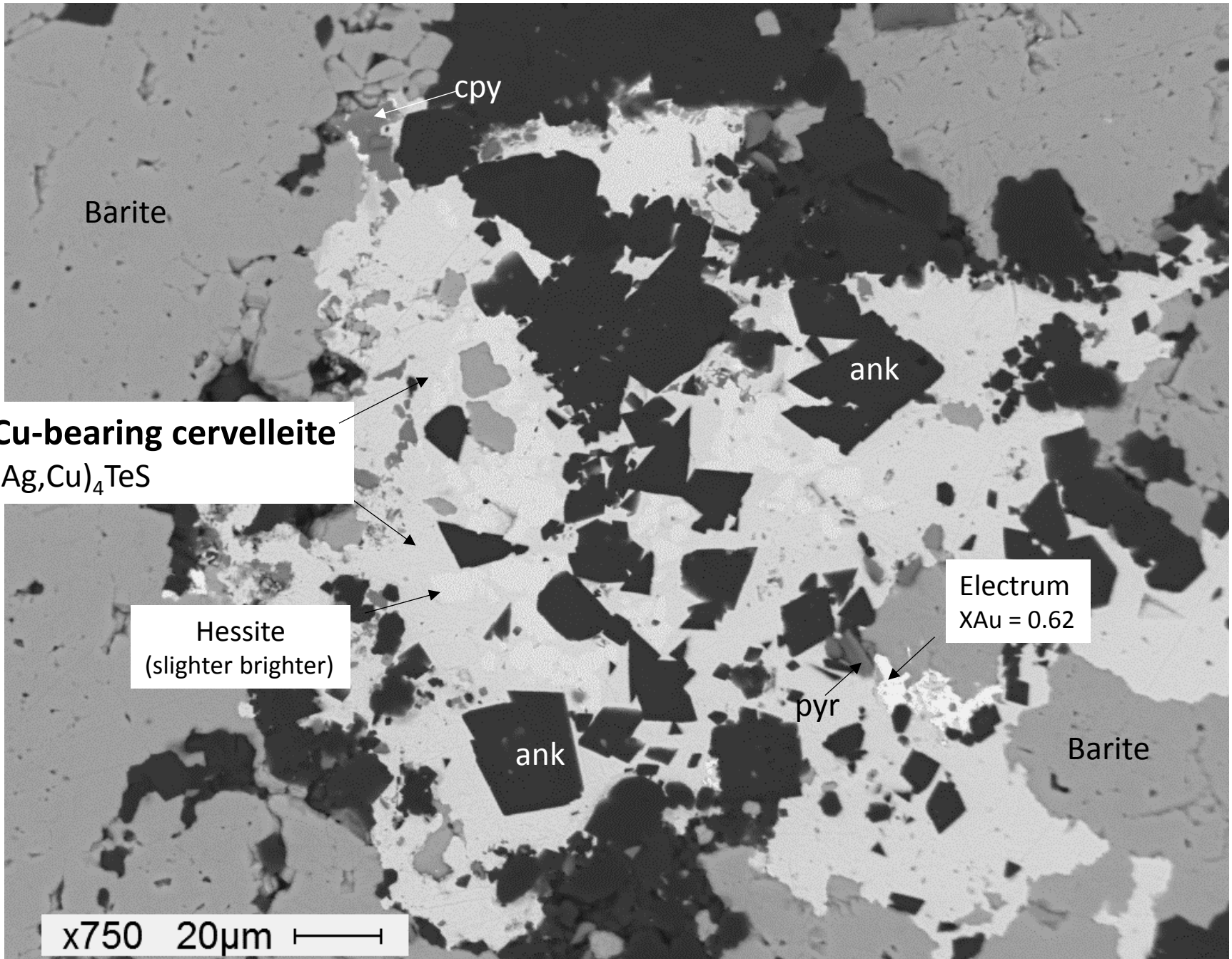


# Pacific Mine, Virginia City district



June, 2017  
Field trip with  
Matt Moen





Barite

cpy

ank

**Cu-bearing cervelleite**  
 $(Ag,Cu)_4TeS$

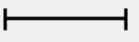
Hessite  
(slightly brighter)

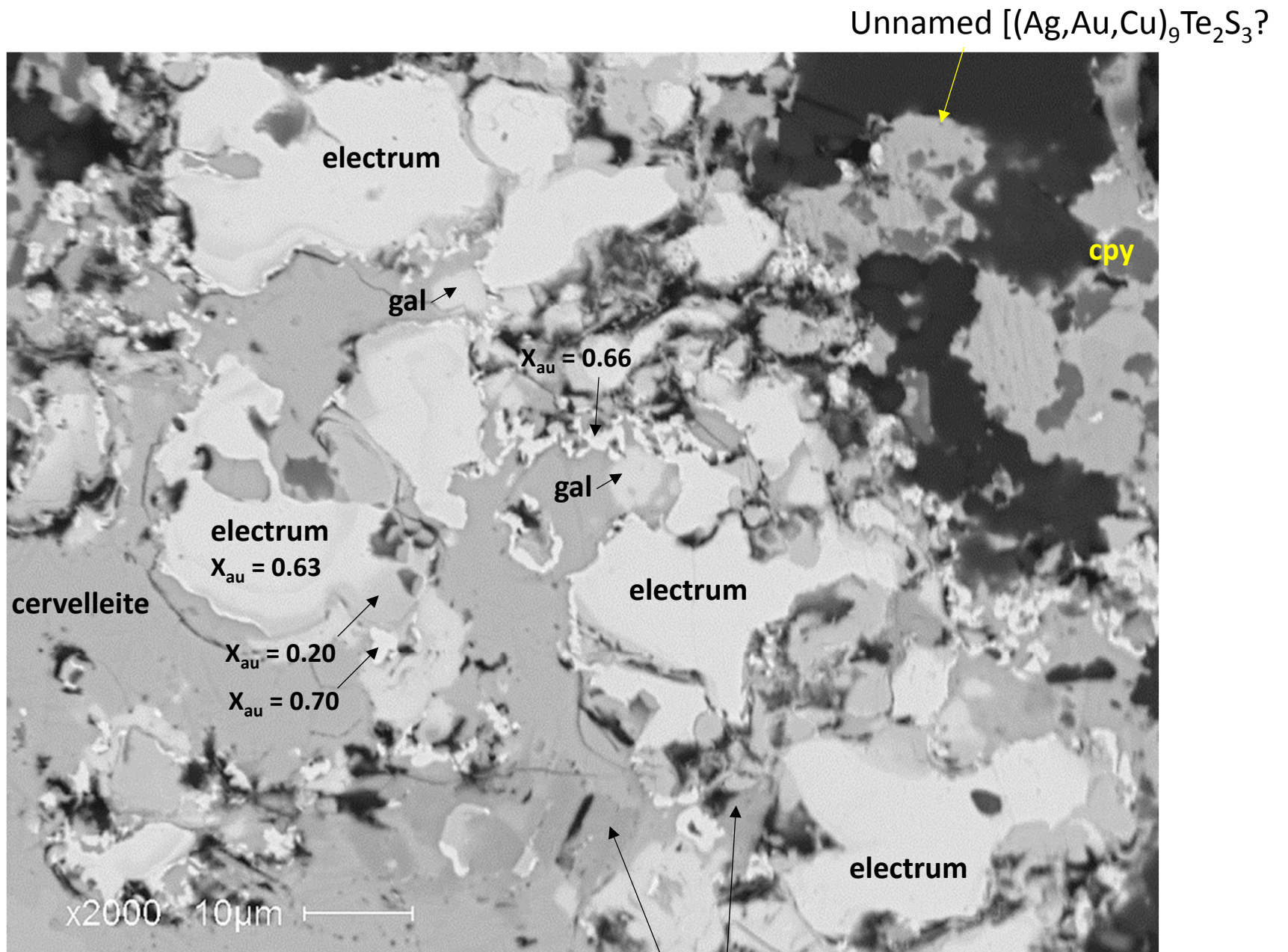
Electrum  
 $X_{Au} = 0.62$

pyr

ank

Barite

$\times 750$   $20\mu m$  



**Benleonardite (Te-rich pearceite)**  
 $[Ag_6(Sb,As)_2S_6Te]$   $[Ag_9Cu(S,Te)_2Te_2]$

# Other U.S. occurrences of benleonardite

## Montana

- Zies Mine (Judith Mtns)
- Mayflower Mine (Cardwell)

## Utah

- Tintic district



The late Ben Leonard  
of USGS

# Other U.S. occurrences of cervelleite

Montana

- Mayflower Mine (Cardwell)

Arizona

- Empire Mine, Tombstone

California

- Otto Mountain mine, Silver Lake district

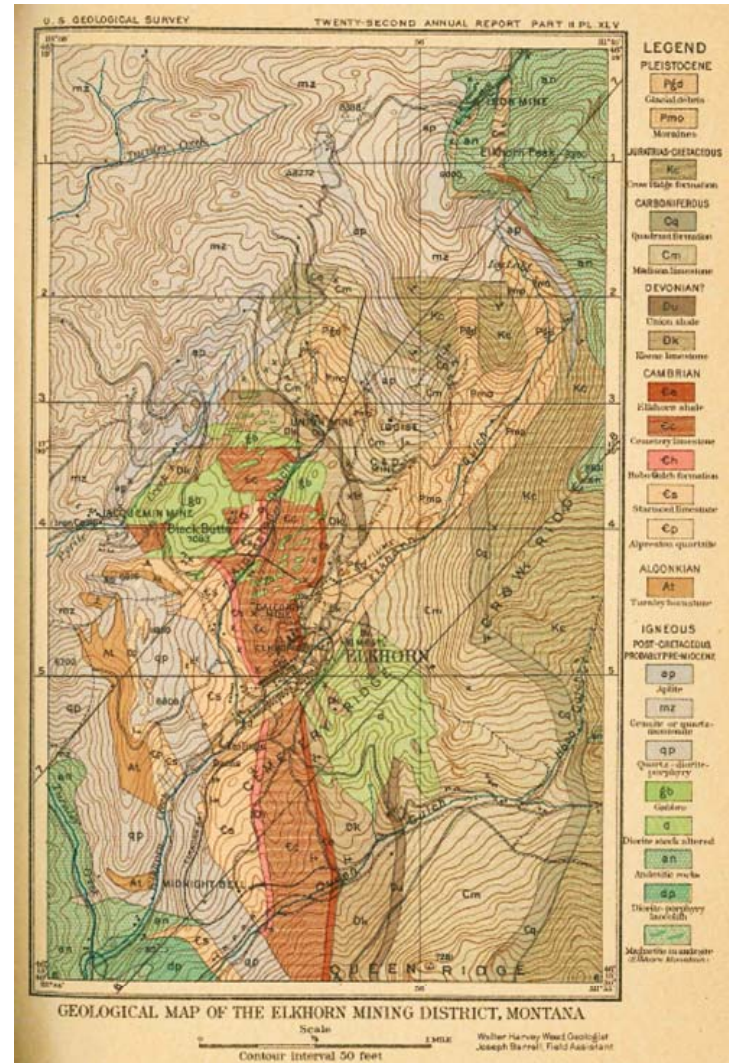
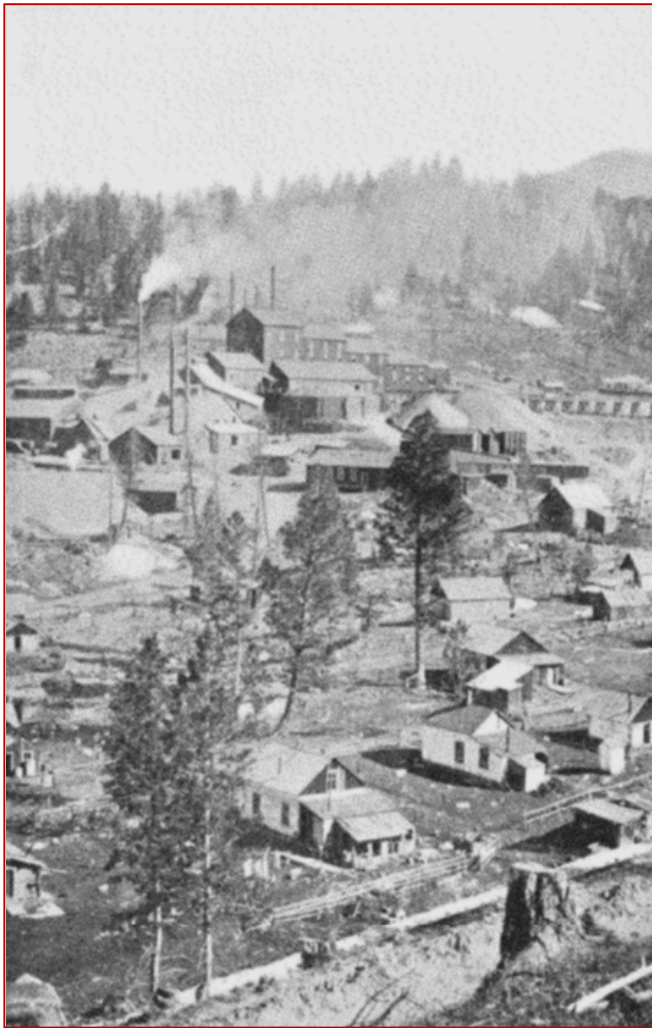
Colorado

- Grey Eagle mine, Ward district



Bernard Cervelle  
Univ. of Paris

# Elkhorn (Boulder) district



Weed, 1902



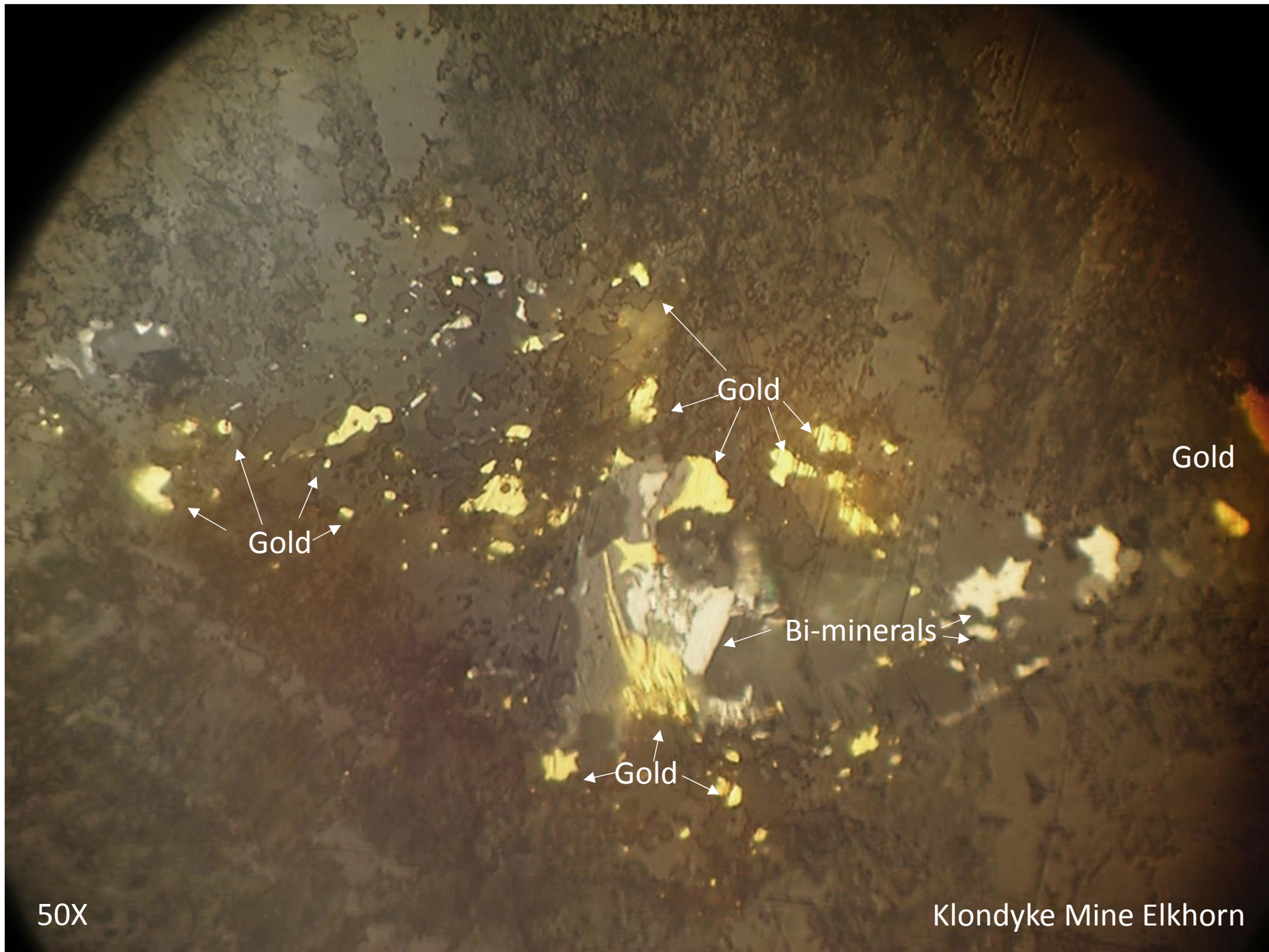
Tetradymite ( $\text{Bi}_2\text{Te}_2\text{S}$ ) with calcite + andradite





# Gold with bismuth minerals!





Gold

Gold

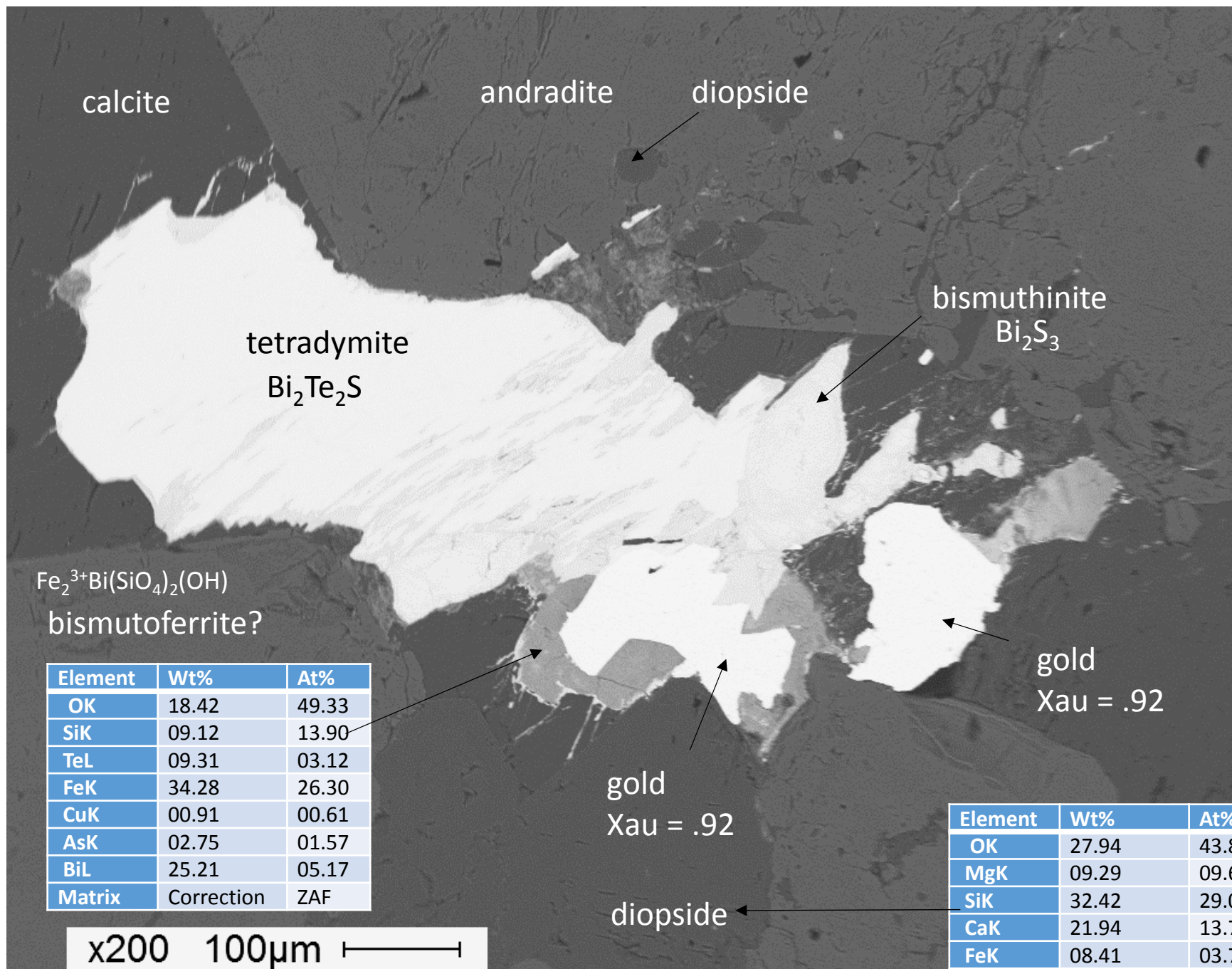
Gold

Bi-minerals

Gold

50X

Klondyke Mine Elkhorn



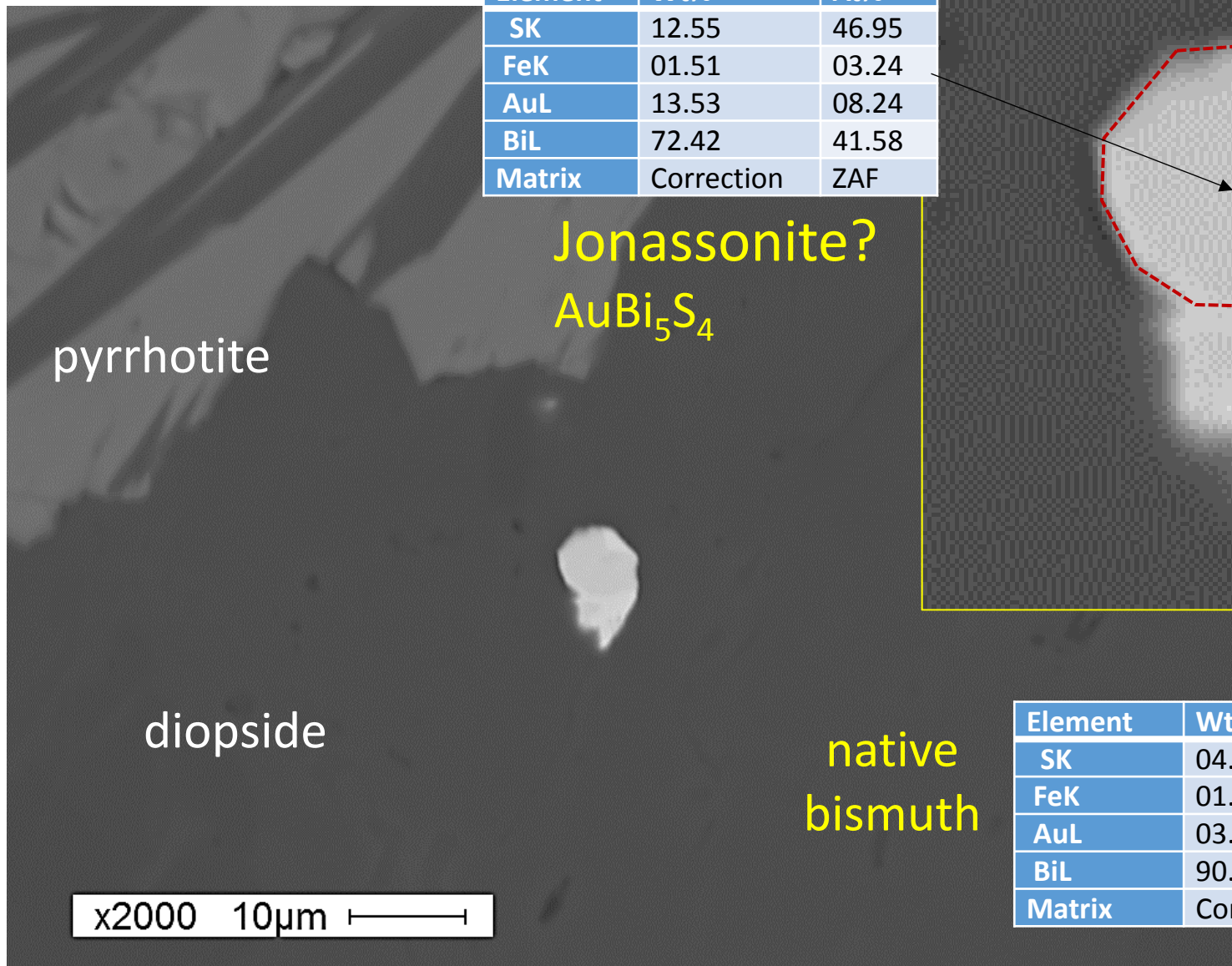
$Fe_2^{3+}Bi(SiO_4)_2(OH)$   
bismutoferrite?

Element	Wt%	At%
OK	18.42	49.33
SiK	09.12	13.90
TeL	09.31	03.12
FeK	34.28	26.30
CuK	00.91	00.61
AsK	02.75	01.57
BiL	25.21	05.17
Matrix	Correction	ZAF

Element	Wt%	At%
OK	27.94	43.87
MgK	09.29	09.60
SiK	32.42	29.00
CaK	21.94	13.75
FeK	08.41	03.78
Matrix	Correction	ZAF

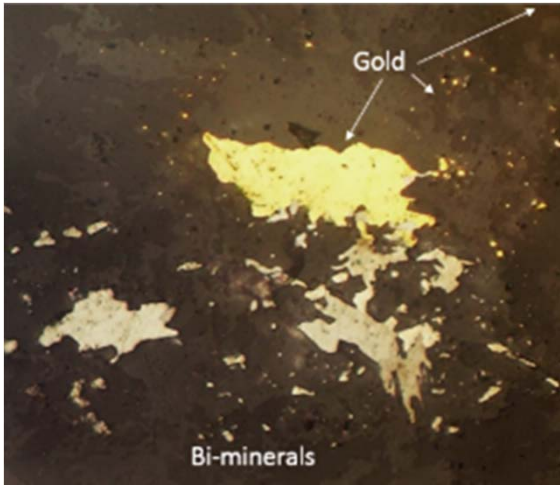
x200 100µm

Dalcoath-1



Element	Wt%	At%
SK	12.55	46.95
FeK	01.51	03.24
AuL	13.53	08.24
BiL	72.42	41.58
Matrix	Correction	ZAF

Element	Wt%	At%
SK	04.88	24.04
FeK	01.86	05.28
AuL	03.19	02.56
BiL	90.07	68.12
Matrix	Correction	ZAF



Elkhorn

Zone of stability of gold-rich bismuth melt

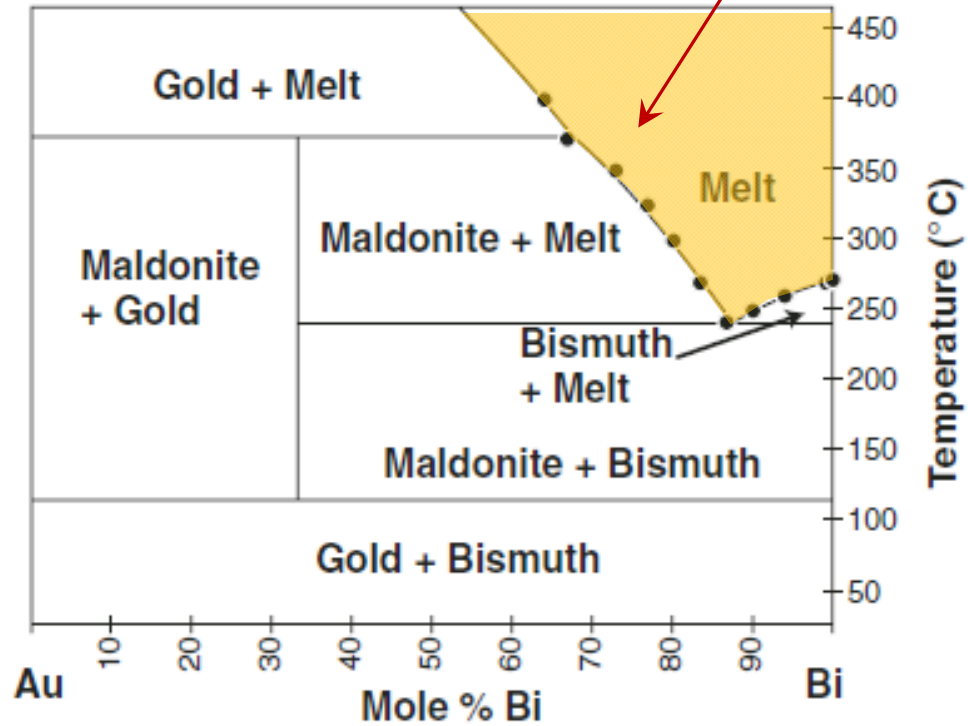
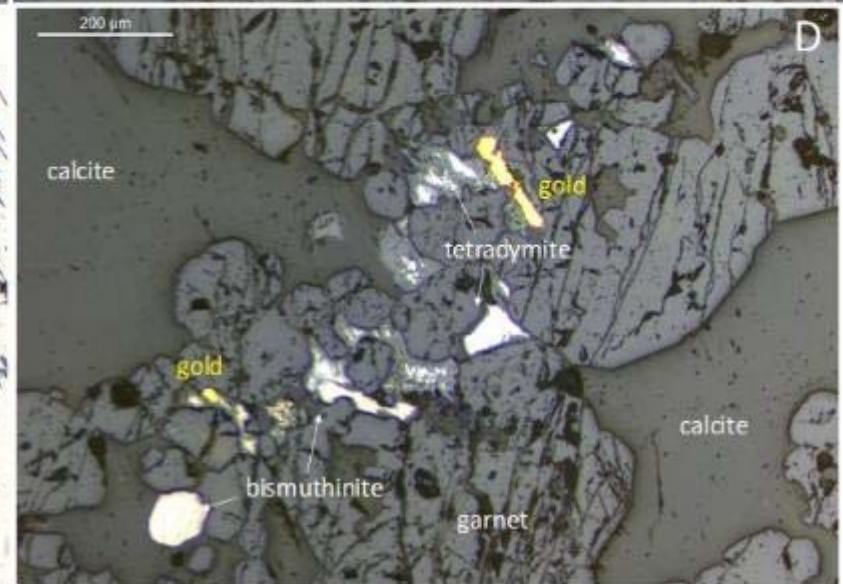
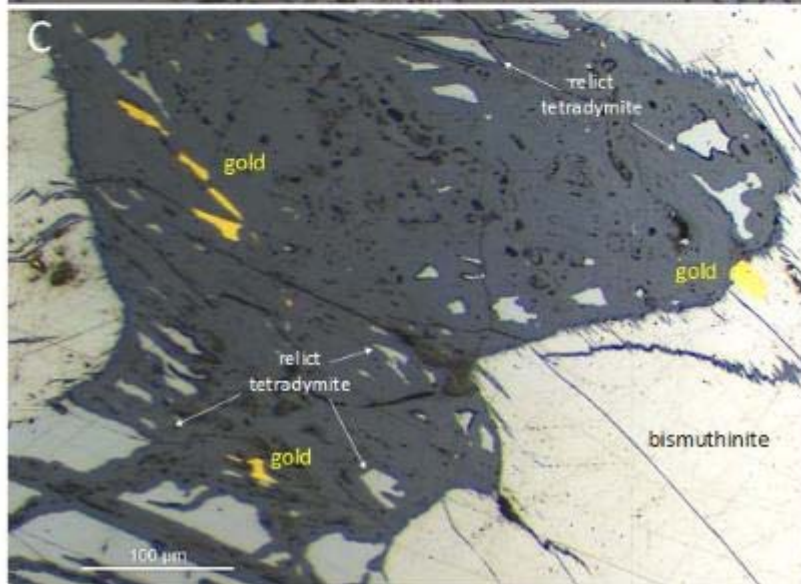
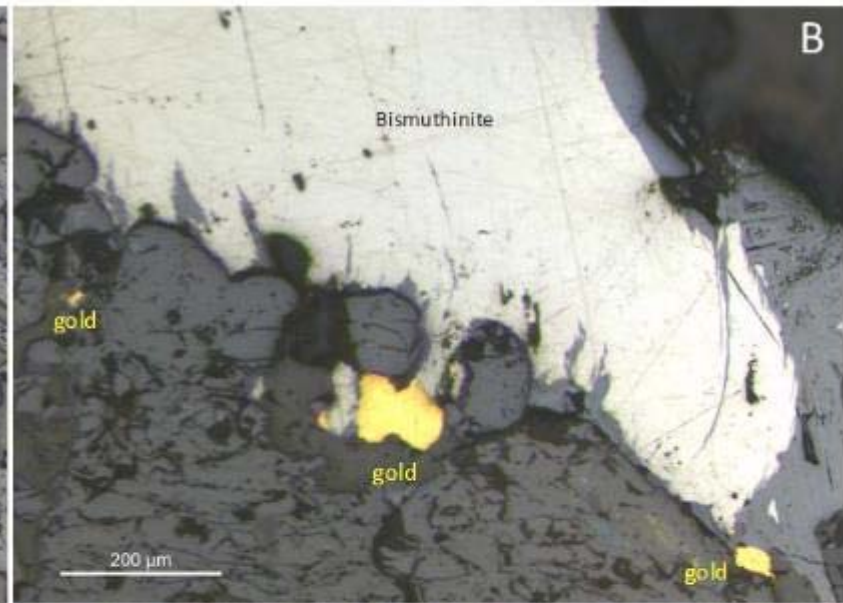
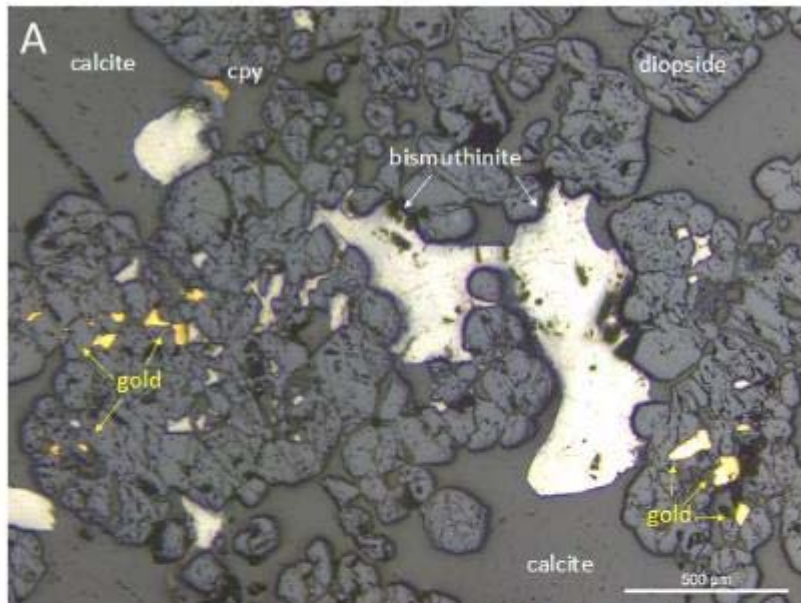


Figure 1. Phase diagram for Au-Bi system at 1 bar, calculated using HCh thermodynamic model developed in this study (see Data Repository [see footnote 1]). Experimental data points on liquidus composition by Nathans and Leider (1962) are shown as solid circles.

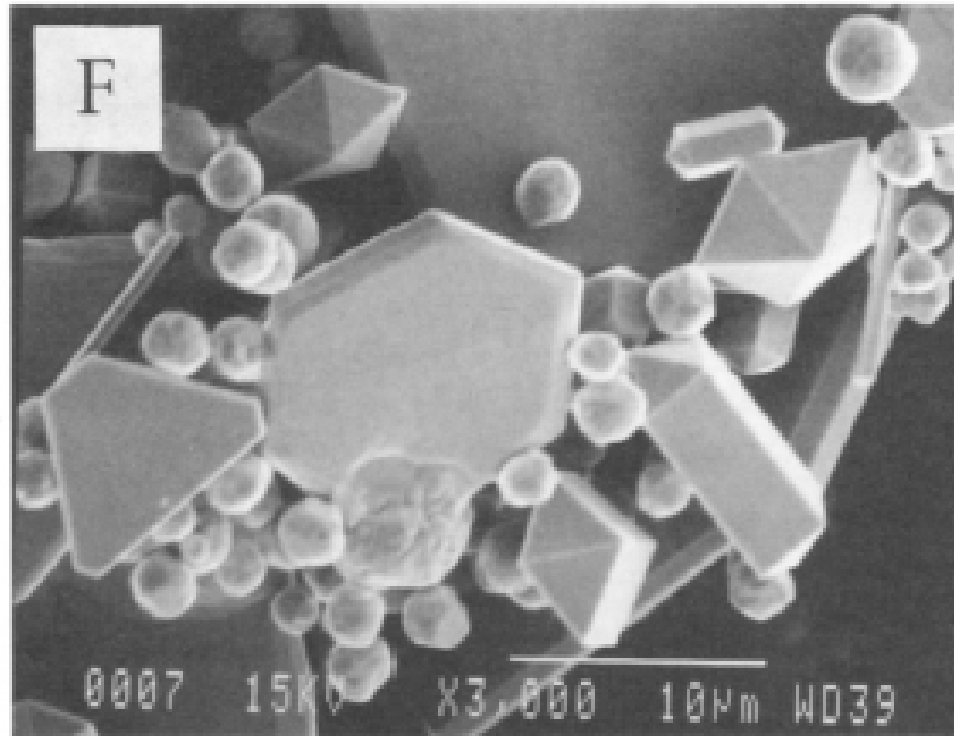
Modeling of gold scavenging by bismuth melts coexisting with hydrothermal fluids

Blake Tooth<sup>1</sup>, Joël Brugger<sup>1,2</sup>, Cristiana Ciobanu<sup>1,2</sup>, Weihua Liu<sup>3</sup>



Gold and bismuth minerals: Dalcoath mine, Elkhorn

Thanks for your attention  
Questions??



*Gold crystals grown hydrothermally  
Gammons et al., 1997, GCA*