Dendritic ore minerals in the Buckskin National and Fire Creek bonanza-style low-sulfidation epithermal deposits, Nevada

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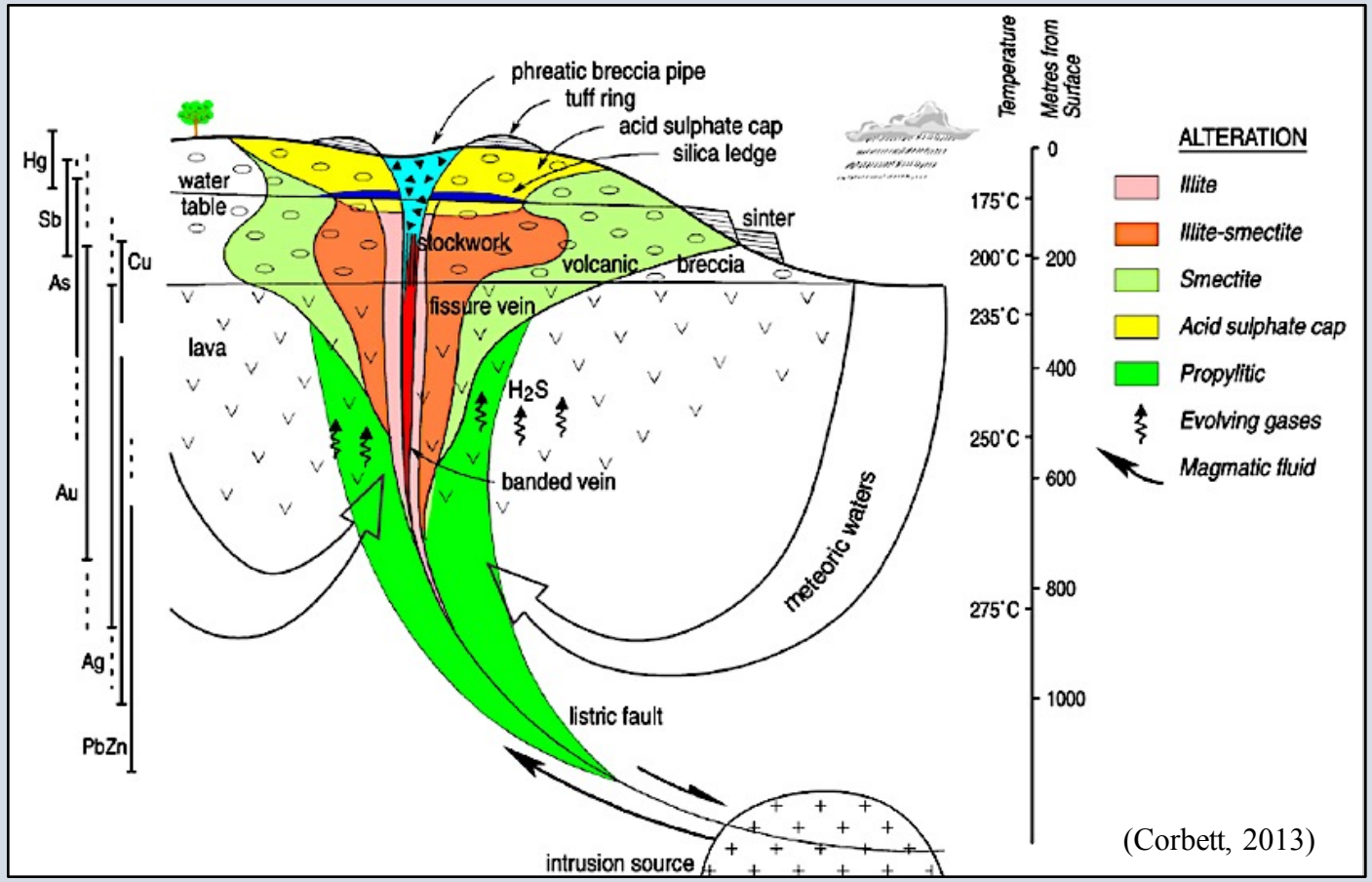
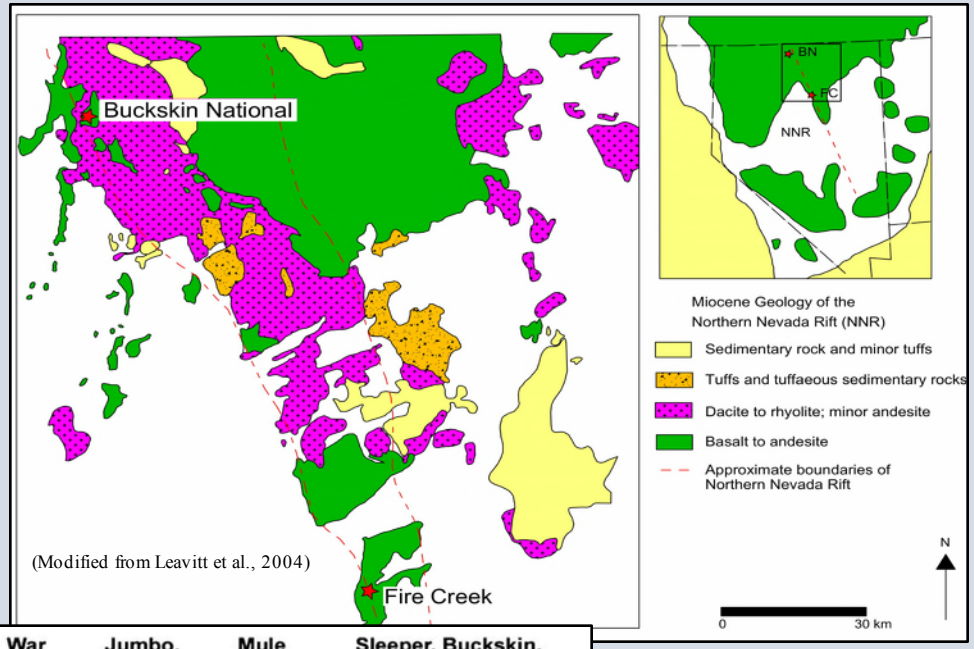
Background

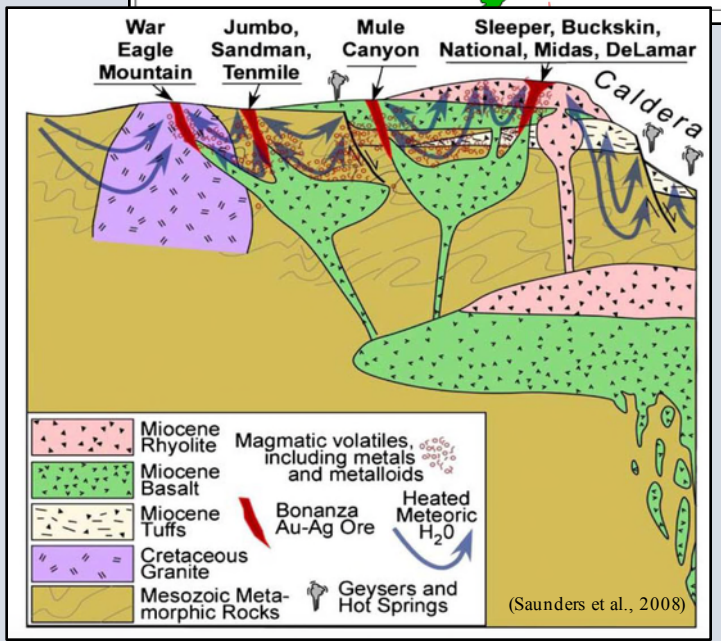


(Corbett, 2013)

- Low-sulfidation epithermal deposits form within hundreds of meters of the surface to less than 2 km at temperatures below 300 °C.
- The deposits are dominated by meteoric water with only minor amounts of magmatic fluid.
- Ore-forming fluids are near neutral-pH and principally composed of NaCl, H_2S, and CO_2
- Ore-forming processes are significantly related to adiabatic boiling of hydrothermal fluids.
- Ore deposits formed in low-sulfidation system usually exhibit open-space or cavity-filling veins and stockworks as well as breccias.
- Precious metals (Au and Ag) can occur in banded silica veins at bonanza grades (e.g. >10's g/t).
- Due to the associated alteration, they are also called "Adularia-Sericite Epithermal Gold-Silver" deposits.

Background

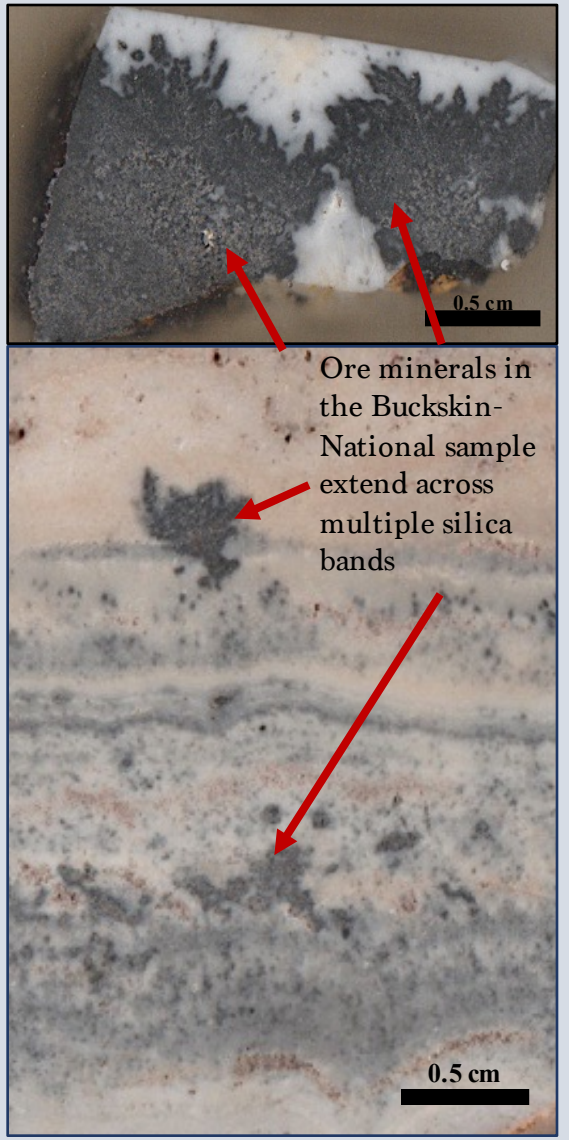


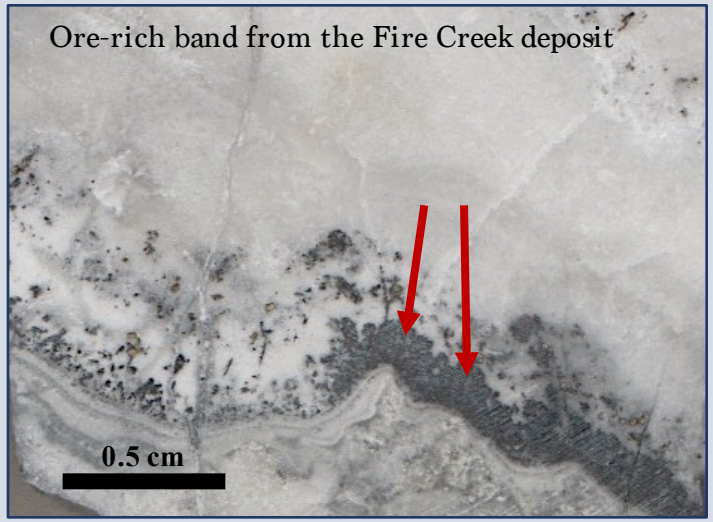


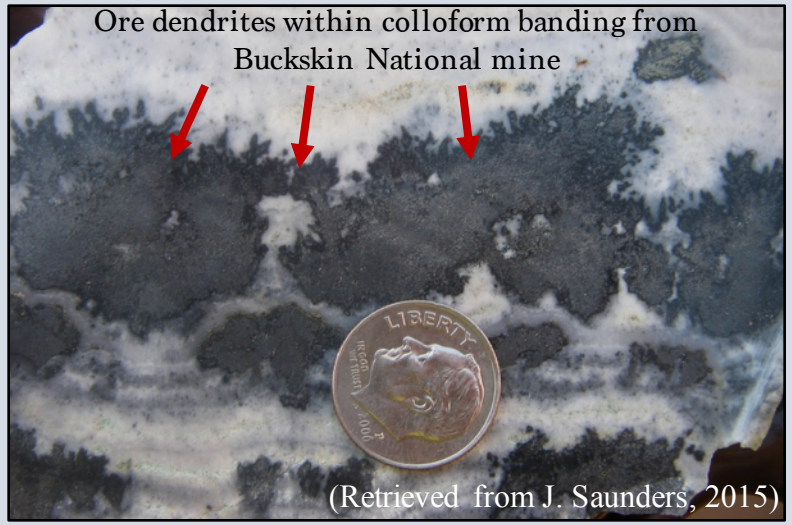
- The Buckskin National and Fire Creek deposits are typical bonanza-style low-sulfidation epithermal precious metal deposits located in the northern Great Basin, northern Nevada.
- Both deposits formed in middle Miocene related with bimodal rhyolitic-basaltic magmatism derived by the Northern Nevada Rifting.
- Saunders et al. (2008) and Hames et al. (2009) suggested that precious metals were initially derived from partial melting of fertile mantle to produce basalts enriched in Au.
- The Bell vein in the Buckskin National deposit produced around 24,000 ounces of gold and 300,000 ounces of silver from 34,000 tons of ore between 1906 and 1941.
- The recent total ore reserves at Fire Creek are currently around 228,000 tons averaging 20.13 g/t of Au and 19.56 g/t of Ag. The inferred resources are 1,142,000 tons with grades of 12.96 g/t of Au and 13.13 g/t of Ag.

Background

- Epithermal veins exhibit crustiform-colloform banded textures along with recrystallization textures, and pseudobladed quartz after calcite.
- Gangue minerals include quartz, calcite, chalcedony, adularia, and clay minerals.
- Ore minerals are typically composed of Ag-Se-S phase minerals and electrum in specific colloform banded quartz veins as well as minor amounts of Hg in associated sinters formed at the paleosurfaces overlying these veins.
- Previous studies (*Saunders, 1994; Hedenquist et al., 2000; Simmons et al., 2005*) suggested that the ore-depositing processes within banded silica veins are influenced by either boiling or flashing of the hydrothermal fluid within the conduit.





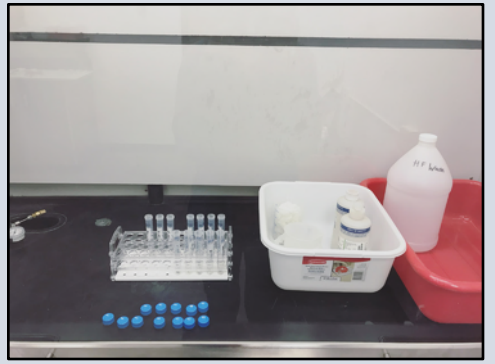
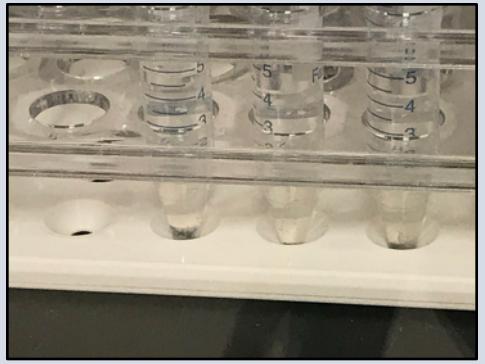


Objectives

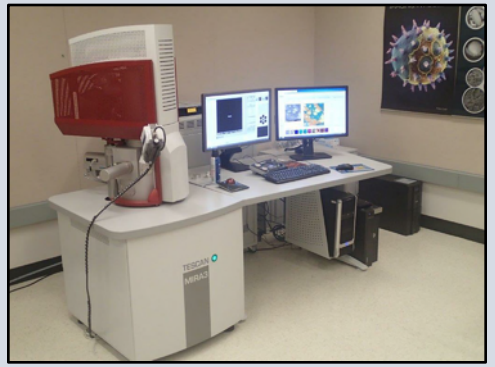
- **To observe textural characteristics and elemental information of ore minerals found in the bonanza-style epithermal veins**
- **To better understand the textural relationship between ore minerals and quartz in low-sulfidation epithermal veins**
- **To be able to establish an ore-forming process, which effectively produces bonanza-style epithermal deposits**

Methodology

- Petrographic study (two dimensions)
  - Polished thin sections
  - Transmitted light microscope
- Topography of ore minerals (three dimensions)
  - Hydrofluoric acid (HF) experiment
  - Gold coated samples on the aluminum stub
  - TESCAN MIRA3 LMH FE-SEM
- Elemental Information
  - Bruker XFlash®6130 silicon drift detector
  - Energy-dispersive x-ray spectrometry (EDS)
  - 2D Micro X-ray Fluorescent by M4 TORNADO

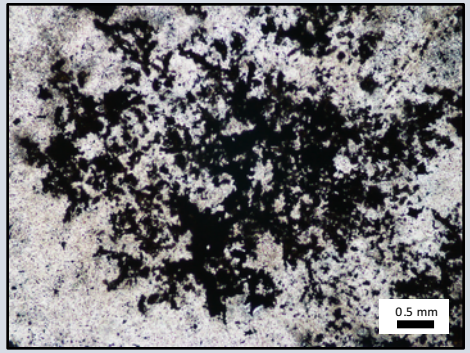


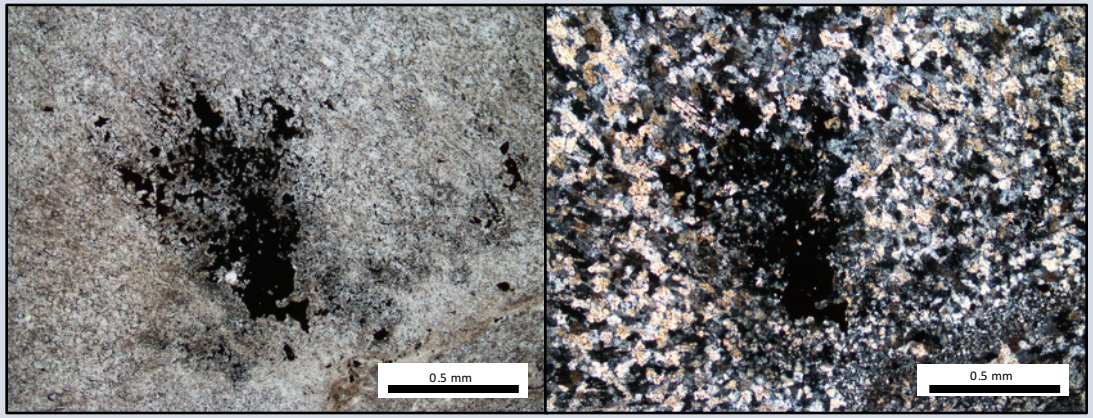


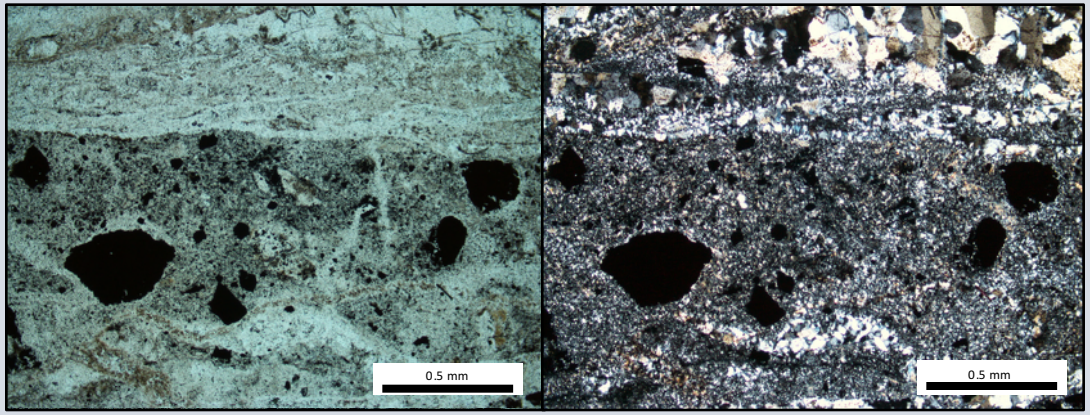

Buckskin National

Ore-bearing

- Mosaic-colloform quartz
- Breccia-like bands

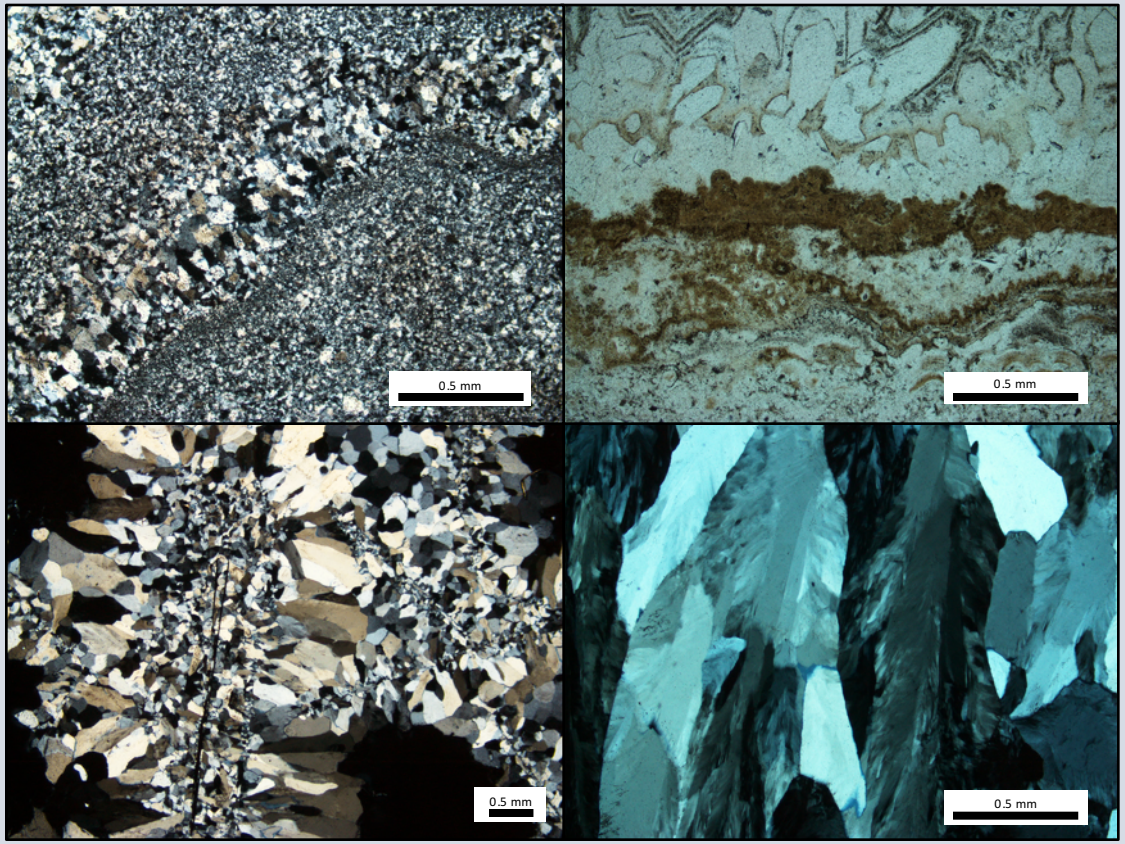






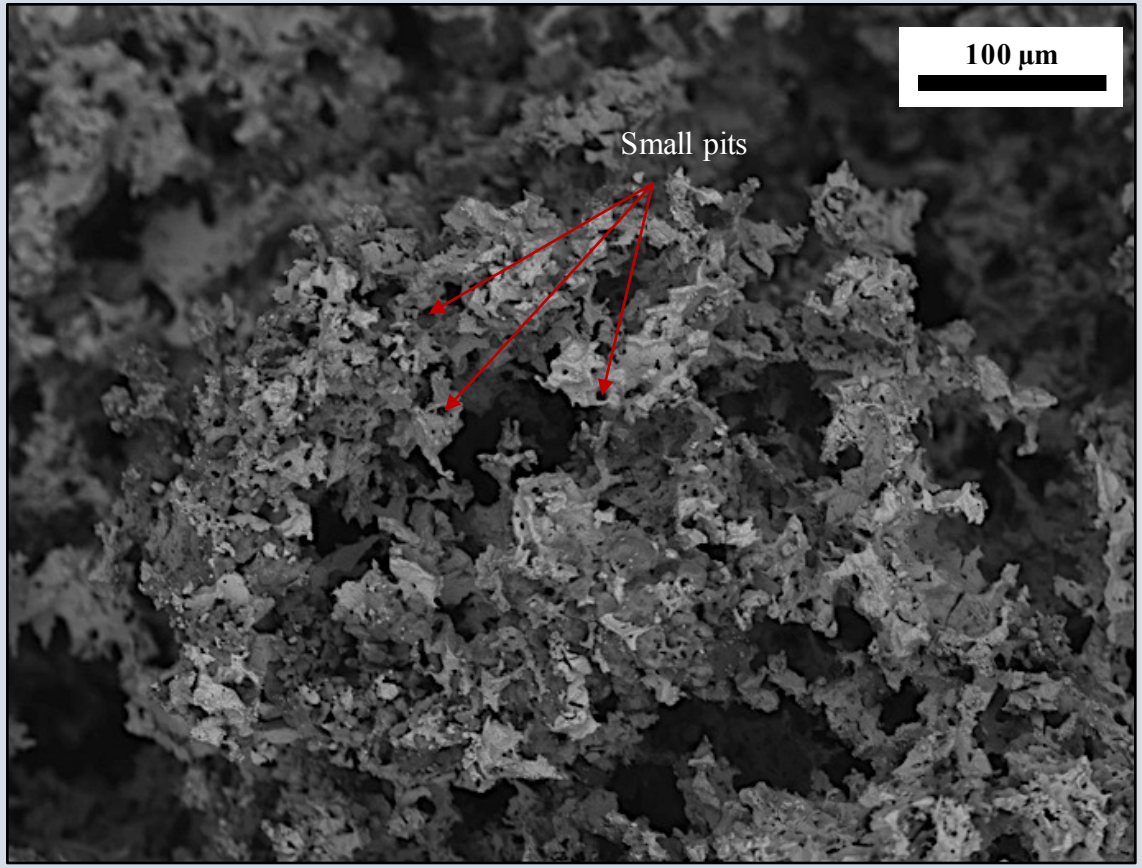
Barren

- Plumose quartz
- Euhedral comb quartz
- Pseudobladed quartz
- Chalcedonic quartz
- Coarse-grained mosaic quartz



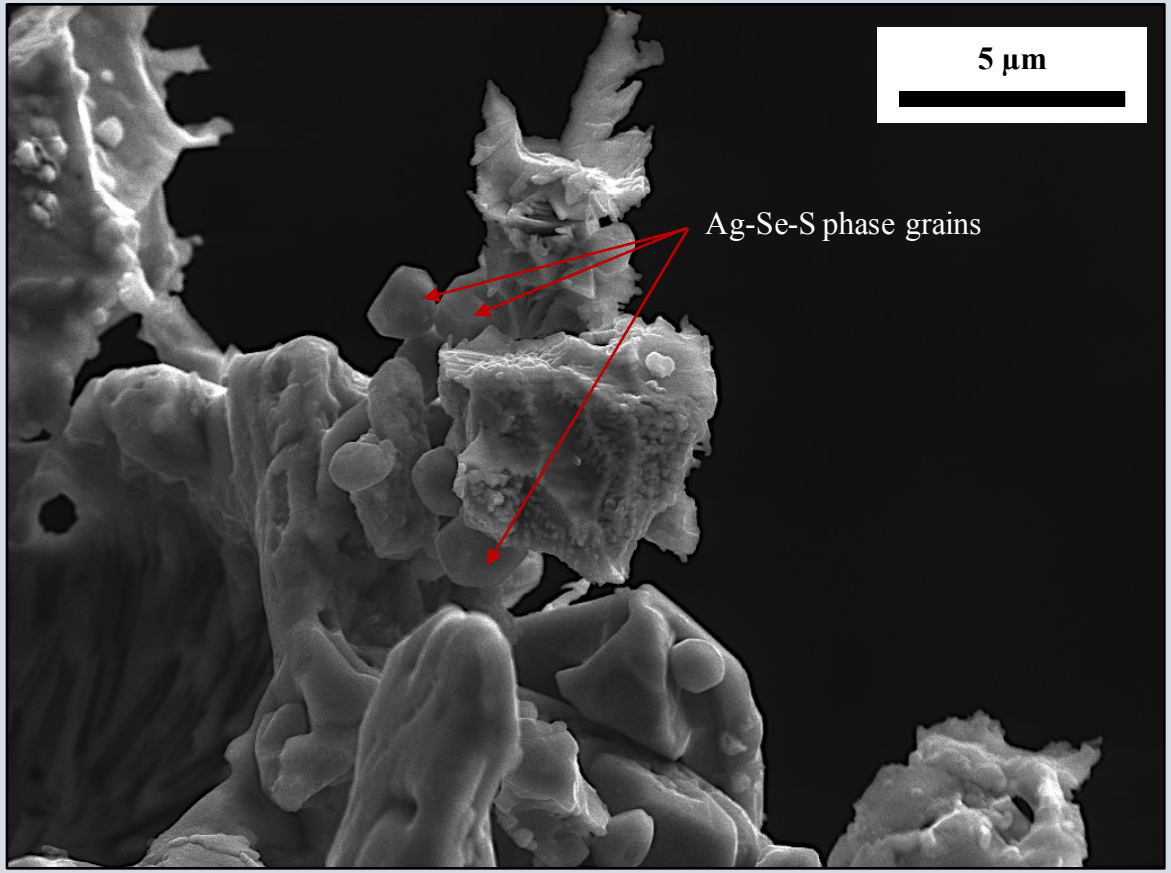
Buckskin National

Ore minerals have small pits showing a fractal pattern



[SE image at magnification of 500x, 20.0 kV, and WD of 9.8 mm]

Multi-branching tree-like forms

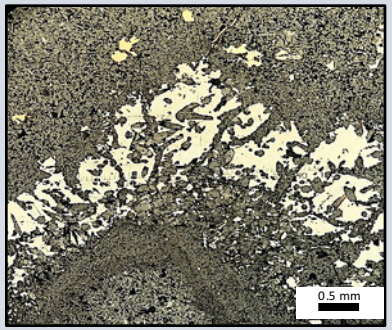


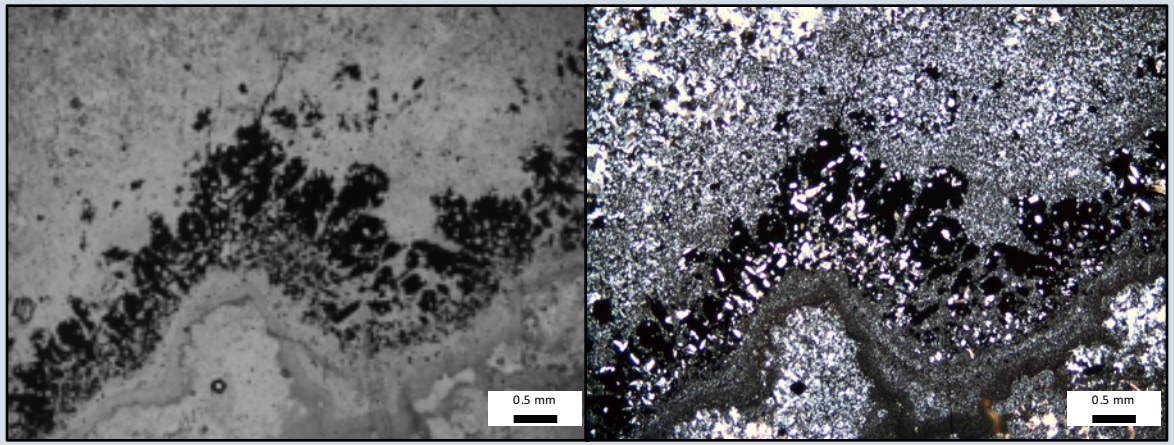
[SE image at magnification of 11.5 kx, 15 kV, and WD of 10.59 mm]

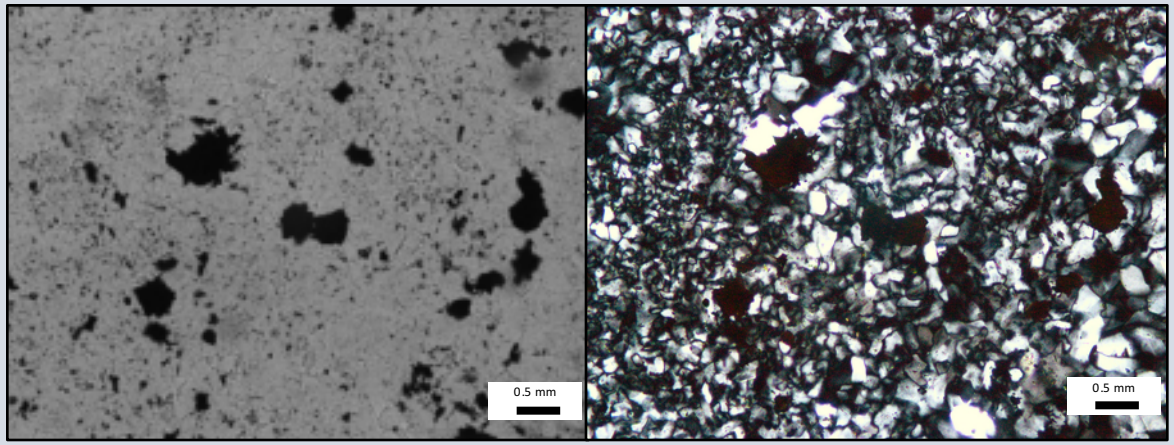
Fire Creek

Ore-bearing

- Microcrystalline-colloform quartz
- Rhombic adularia bands

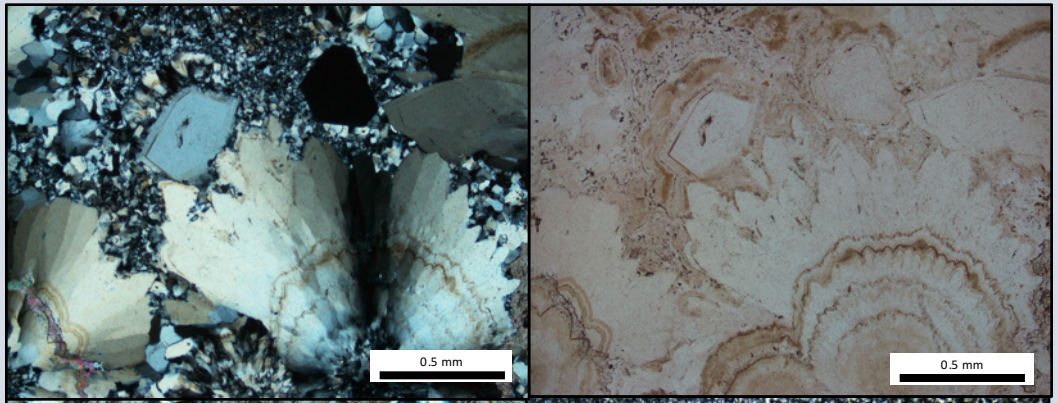


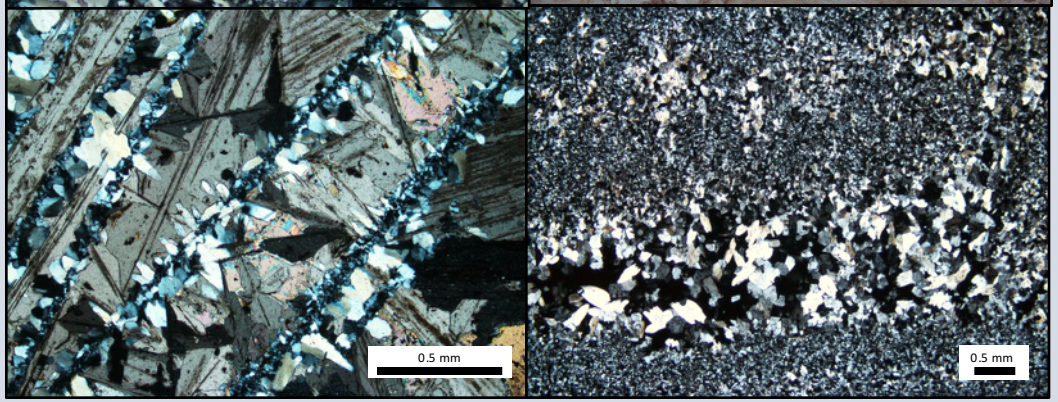




Barren

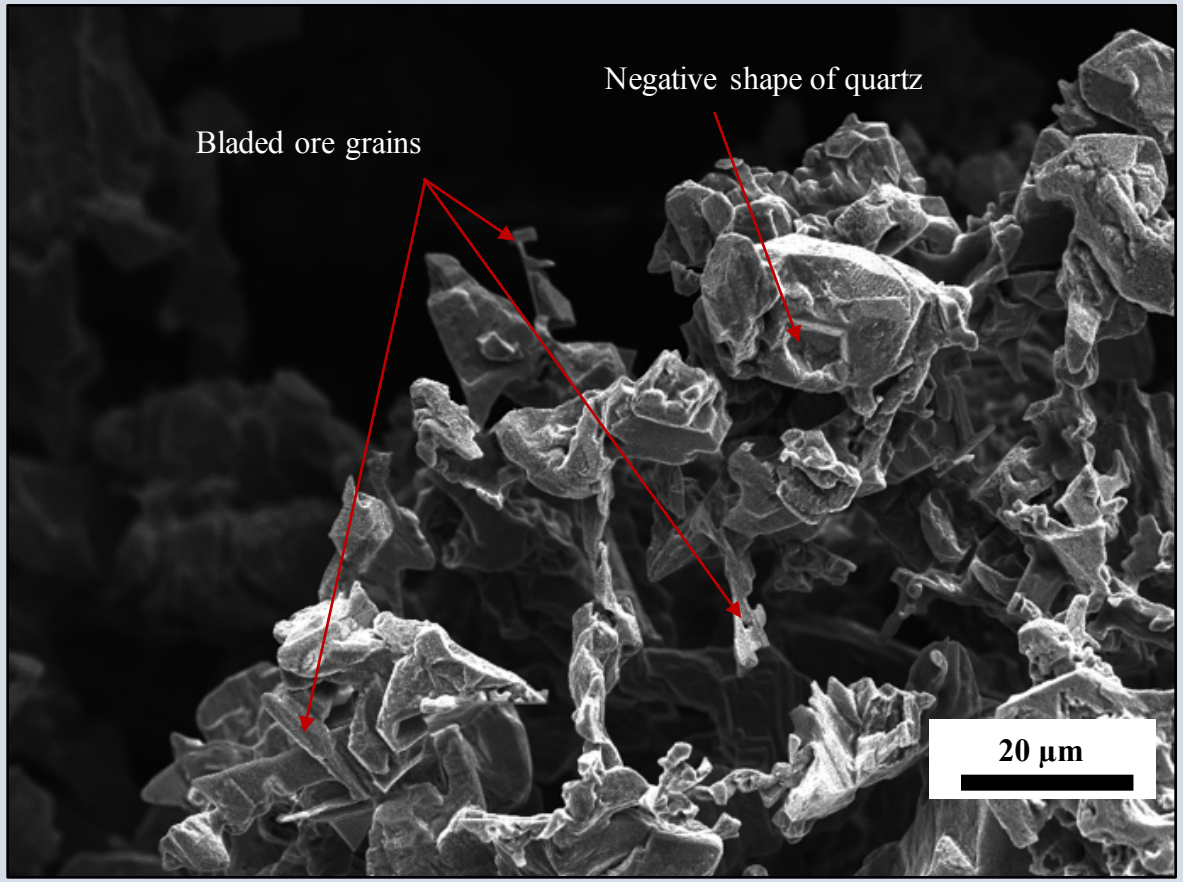
- Plumose quartz
- Comb quartz
- Zonal quartz
- Chalcedonic quartz
- Late platy calcite





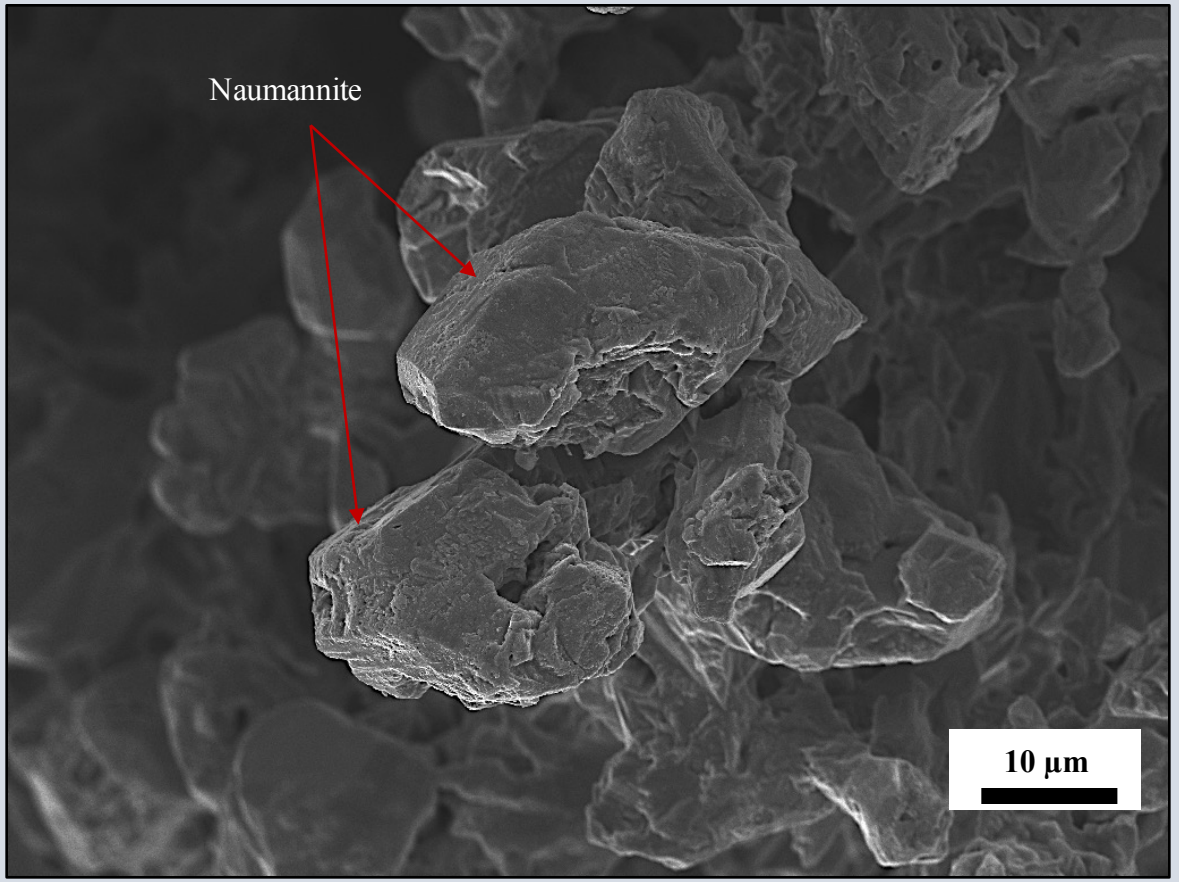
Fire Creek

Negative crystal shape cutting through the dendrites



[SE image at magnification of 2.08 kx, 15 kV, and WD of 7.62 mm]

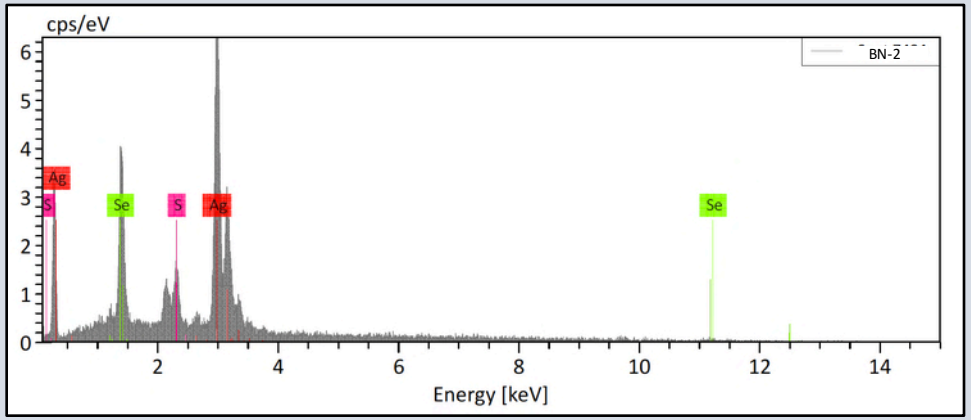
Naumannite grains

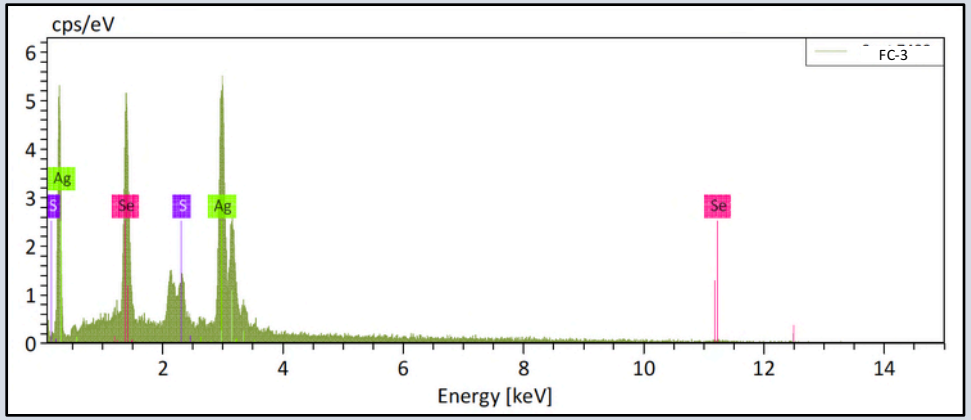


[SE image at magnification of 3.14 kx, 15 kV, and WD of 7.30 mm]

Elemental Information

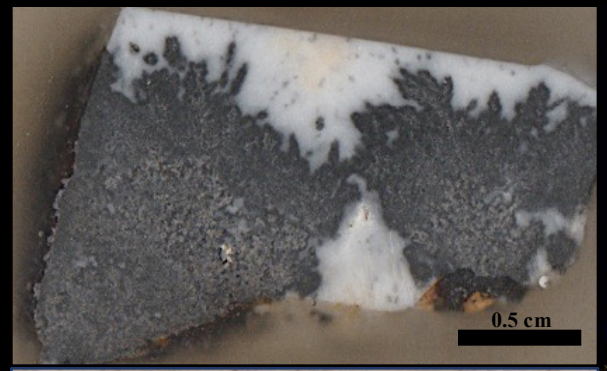
Sample ID	wt% Ag	wt% Se	wt% S	Mineral Name
BN-1	63.94	20.36	15.7	*S-rich naumannite*
BN-2	63.78	21.95	14.27	*S-rich naumannite*
FC-1	66.46	20.53	13.01	*S-rich naumannite*
FC-2	72.24	27.44	0.32	*Naumannite*
FC-3	58.55	23.31	18.14	*S-rich naumannite*
FC-4	78.09	21.91	0	*Naumannite*

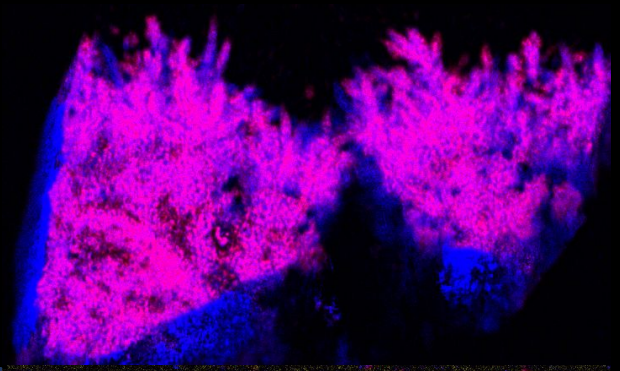


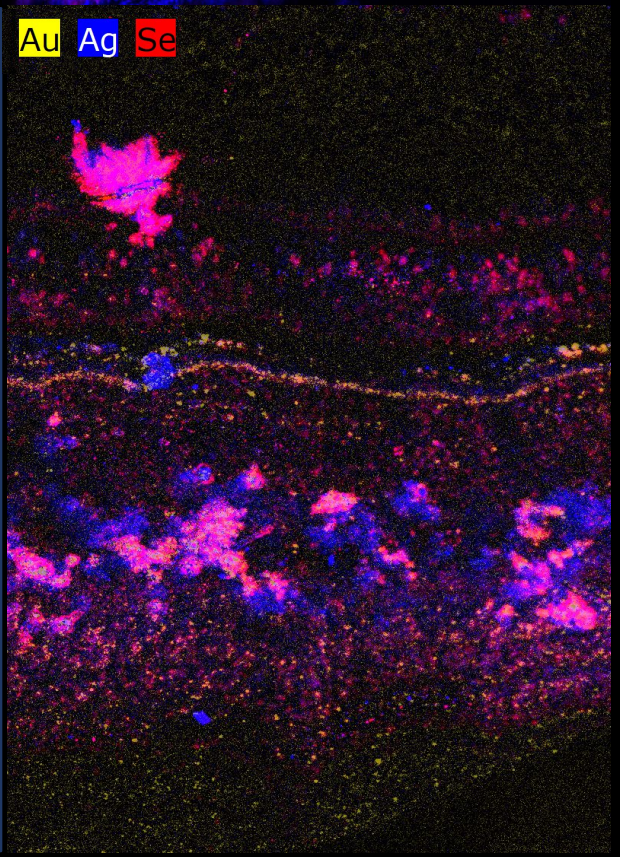


M4 maps

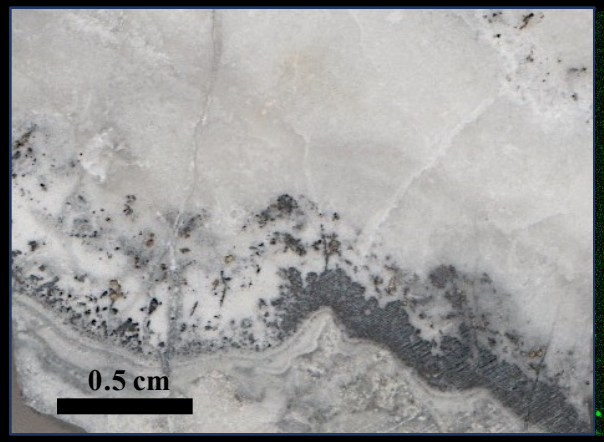
Buckskin National

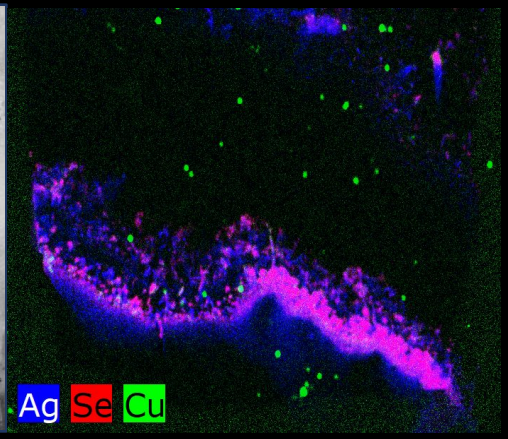


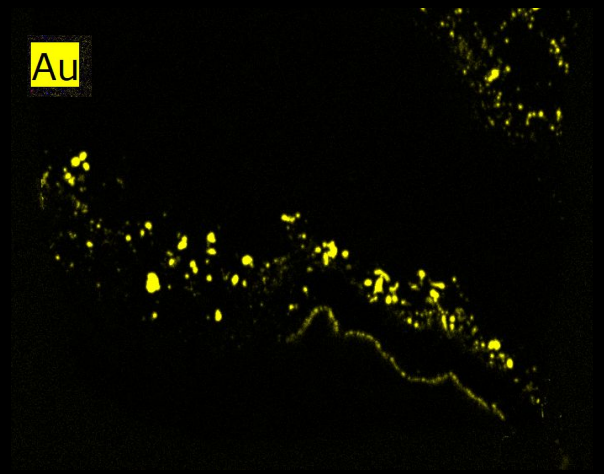




Fire Creek





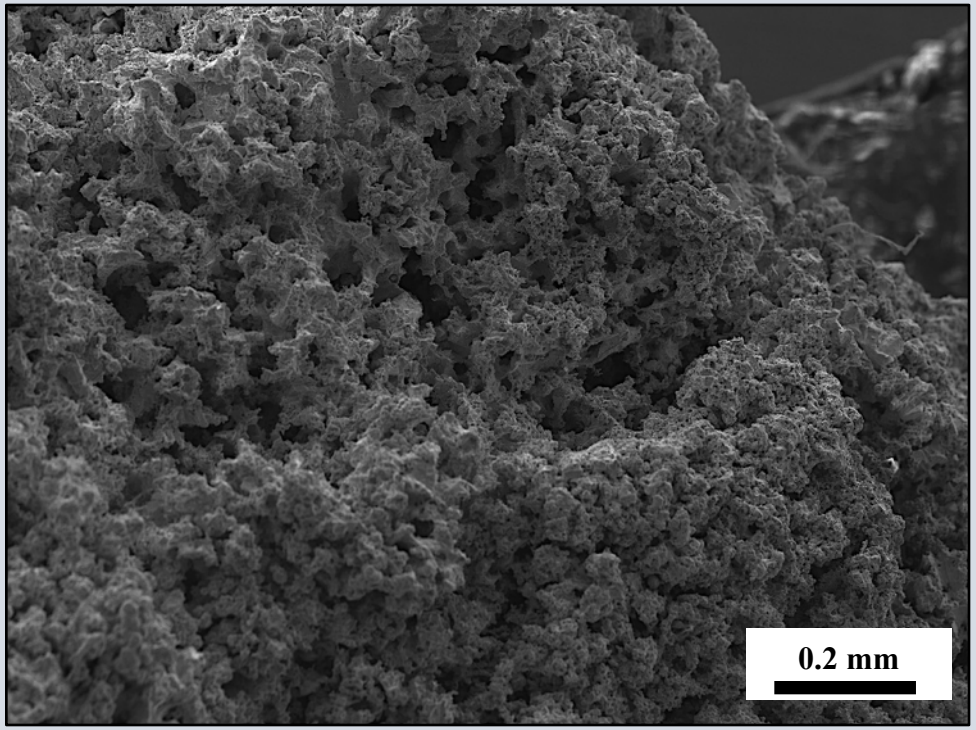


Discussions

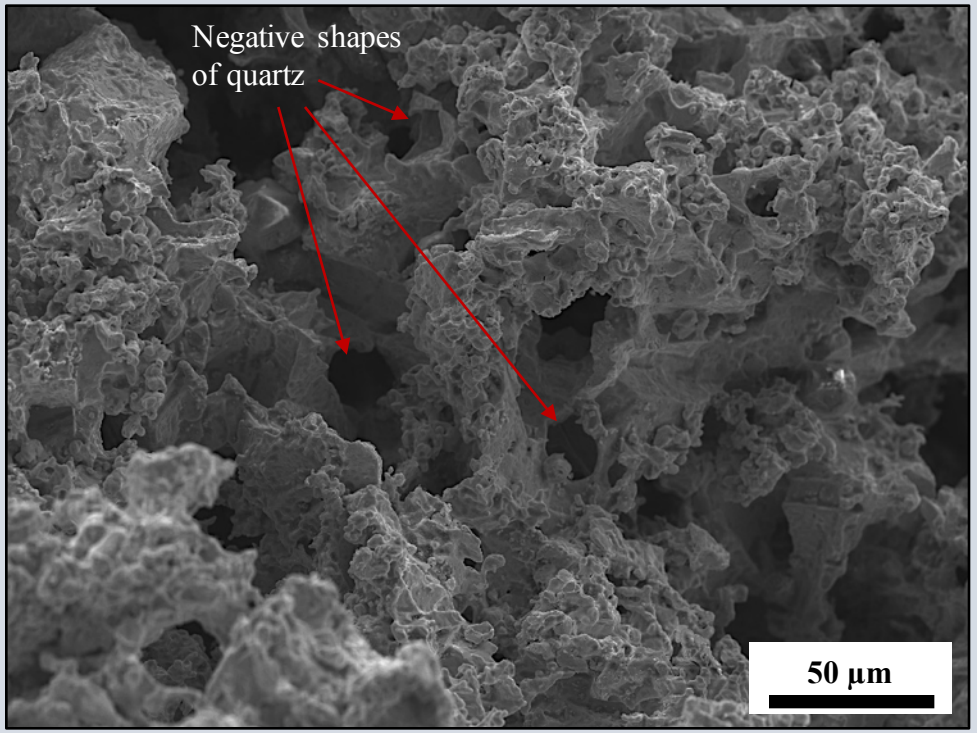
- **Comparison with electrum dendrites from the Sleeper deposit**
- **Relict microsphere in colloform banded epithermal veins**
- **Relationship to textural characteristics of silica sinters in modern geothermal system**

Electrum Dendrites

- The naumannite dendrites from BN and FC deposits are similar to electrum dendrites in a matrix of very fine-grained silica found in the Sleeper deposit (*Saunders, 1994*)
- The formation of ore dendrites are probably results of coagulation and aggregation of colloidal particles within the boiled hydrothermal fluids (*Saunders, 1990&1994*)
- Mosaic quartz within ore dendrites are result of (re)crystallization of noncrystalline silica precursor (*Lovering, 1972; Oehler, 1976; Saunders, 1990; Moncada et al., 2012*)

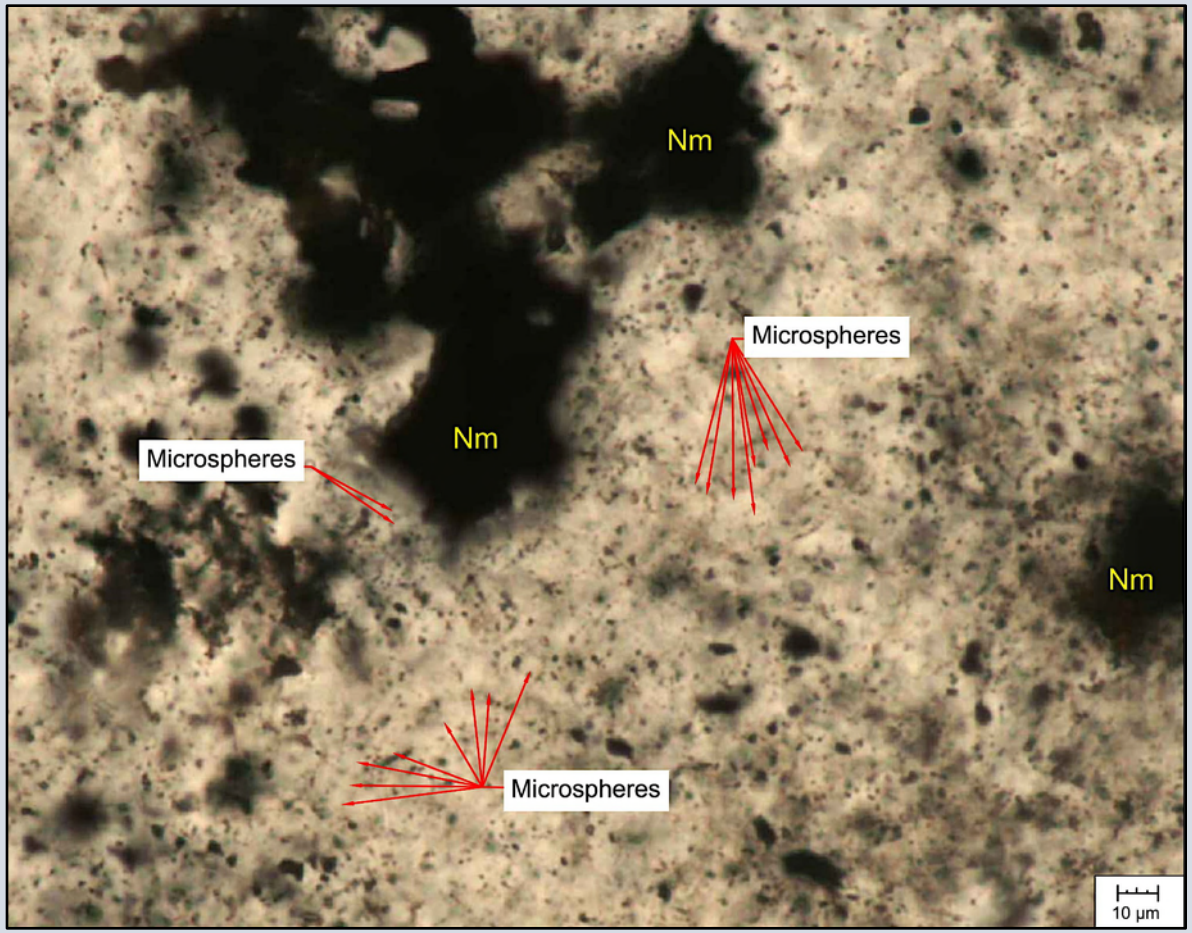


[SE image at magnification of 204 x, 15 kV, and WD of 11.98 mm]

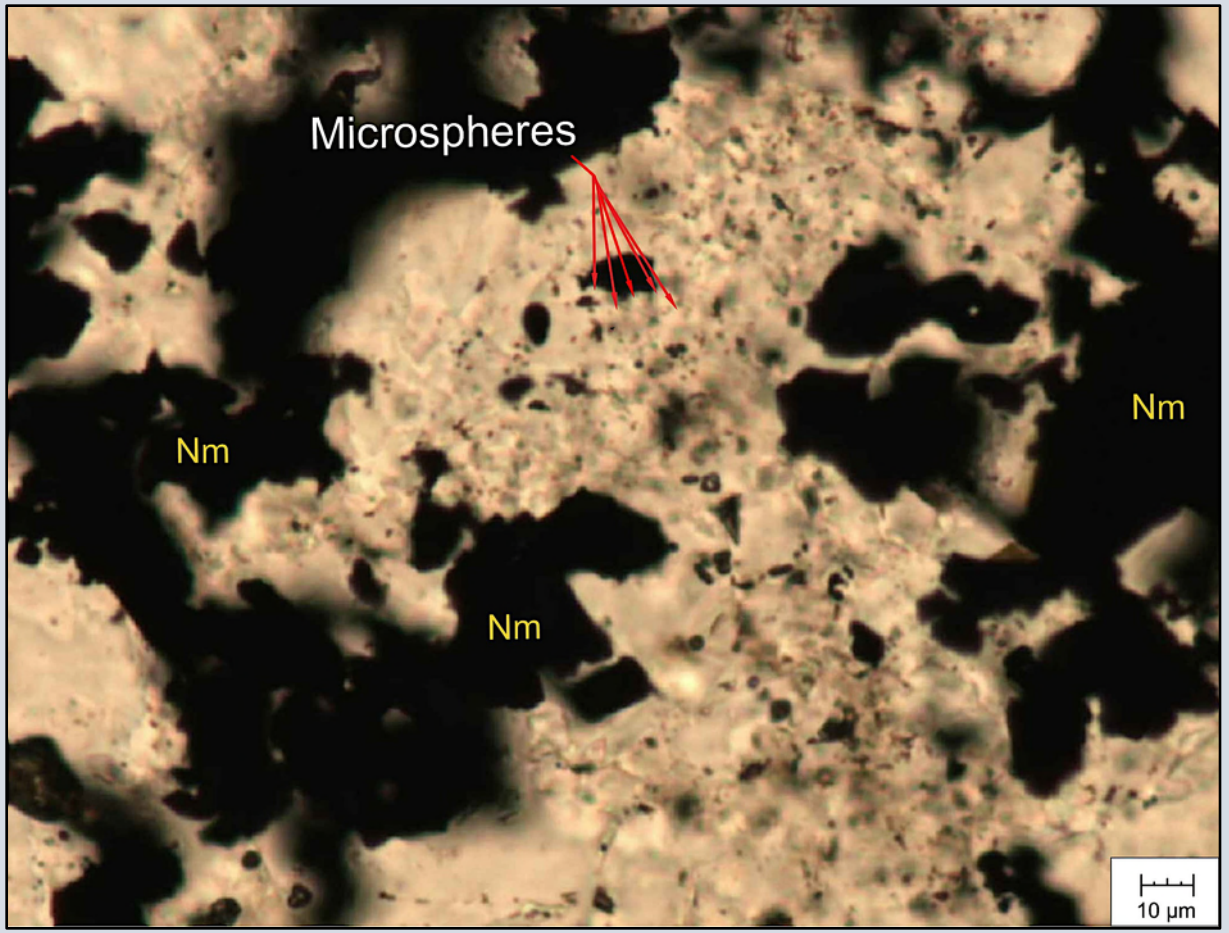


[SE image at magnification of 944 x, 15 kV, and WD of 11.83 mm]

Relict Microspheres in Epithermal Veins

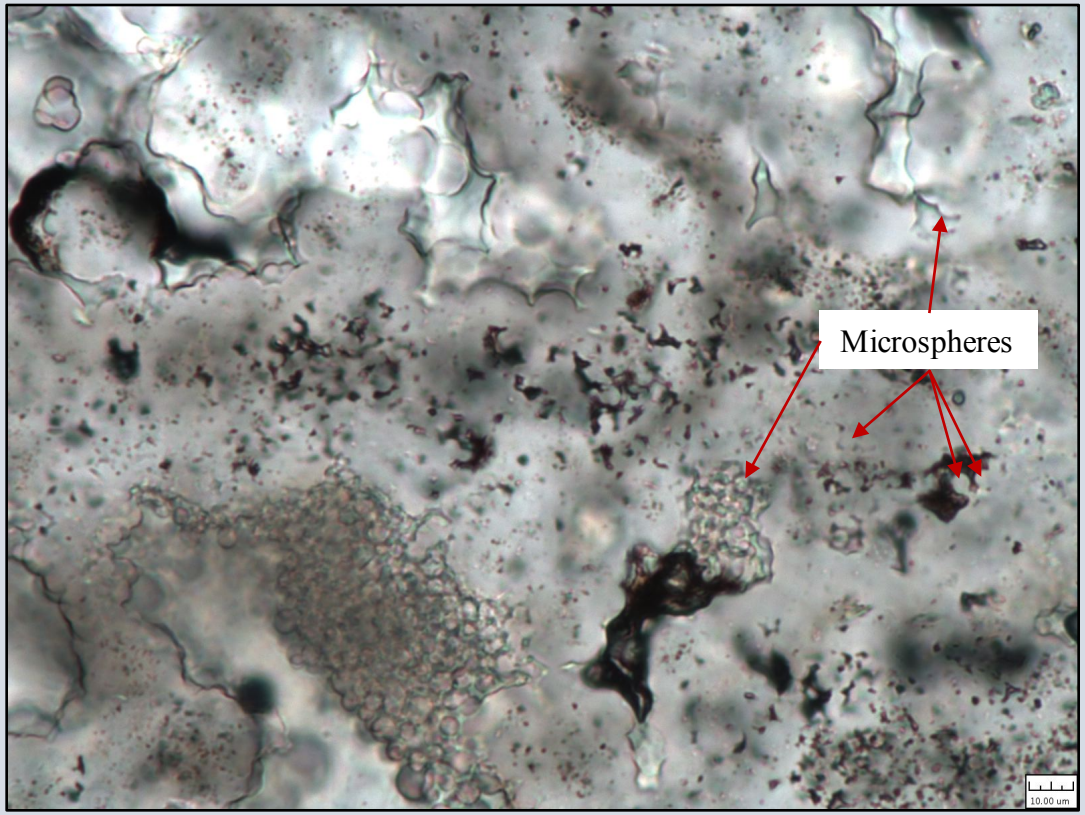


10-micron-sized relict microspheres found in ore-bearing vein sample of the Buckskin National deposit.



Relict microspheres are associated with naumannite occurring in ore-rich bands in the Fire Creek deposit.

Textural Relationship to Silica Sinters

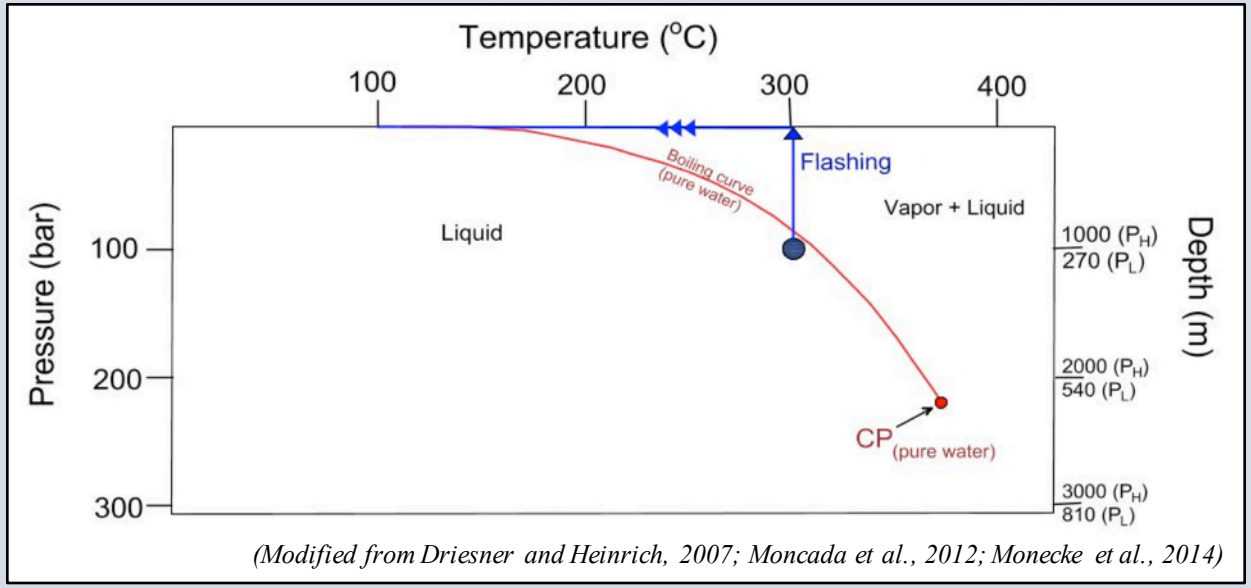


5-µm-sized microspheres of opal-A forming globular aggregates in the silica sinter at the Wairakei geothermal power plant

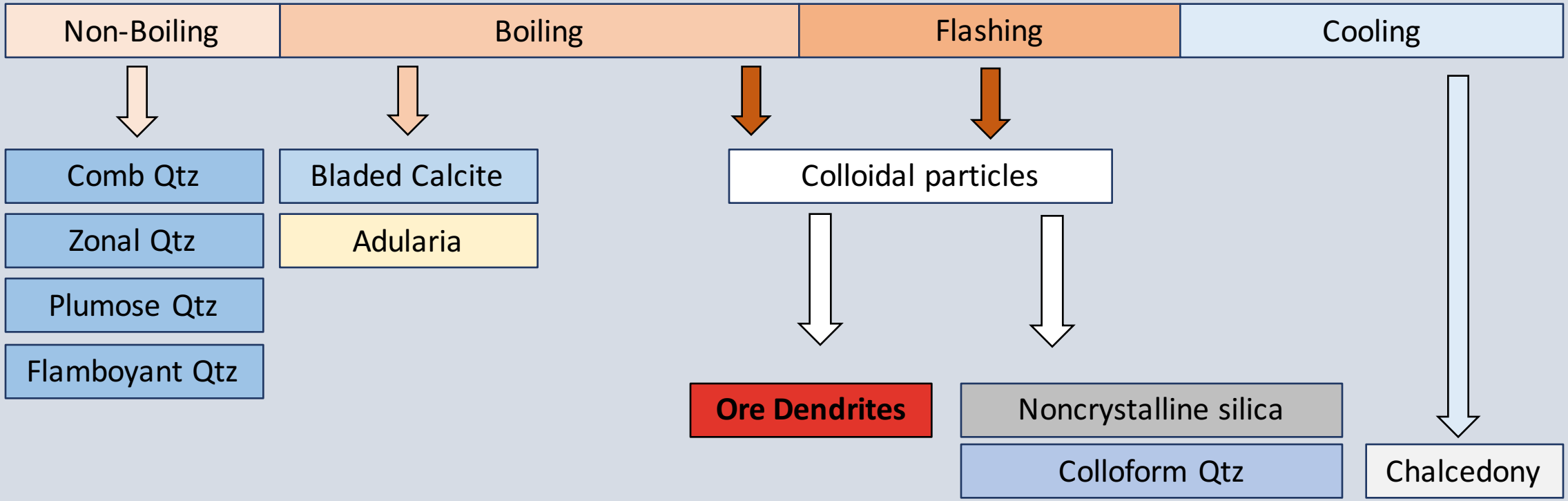
- Taksavasu et al. (2018) compared the textures of banded silica epithermal veins with those of modern silica sinters.
- Silica sinters at the Wairakei geothermal power plant, New Zealand, are composed of opal-A, which rapidly deposited from cooling geothermal liquids flashed to atmosphere.
- Textural characteristics of the sinters commonly show silicified filamentous microbes encrusted by fused silica microspheres, which are similar to the relict microspheres observed in the colloform bands of epithermal veins.
- Relict microspheres observed in the ore-bearing quartz in banded epithermal veins are interpreted to result from intense boiling of the hydrothermal fluids creating silica supersaturation and the deposition of amorphous silica.

Conclusions

- **Highest grade ores in this study generally contain sulfur-rich naumannite dendrites in the Buckskin National, and naumannite dendrites in the Fire Creek, which are found in colloform quartz.**
- **Dendritic pattern of ore minerals in colloform bands should be a result of the coagulation and aggregation of gold/silver and silica colloids during phase separation of hydrothermal fluids.**
- **Small negative shapes of euhedral quartz in the dendrites are likely formed by recrystallization of noncrystalline silica precursor.**
- **Relict microspheres preserved in the ore-rich bands in combination with fractal pattern of ore dendrites could be key evidences for the occurrence of intense boiling (flashing) of hydrothermal fluids, allowing the formation of bonanza-style ore deposits.**



(Modified from Driesner and Heinrich, 2007; Moncada et al., 2012; Monecke et al., 2014)


Non-Boiling
Boiling
Flashing
Cooling
Comb Qtz
Zonal Qtz
Plumose Qtz
Flamboyant Qtz
Bladed Calcite
Adularia
Colloidal particles
Ore Dendrites
Noncrystalline silica
Colloform Qtz
Chalcedony

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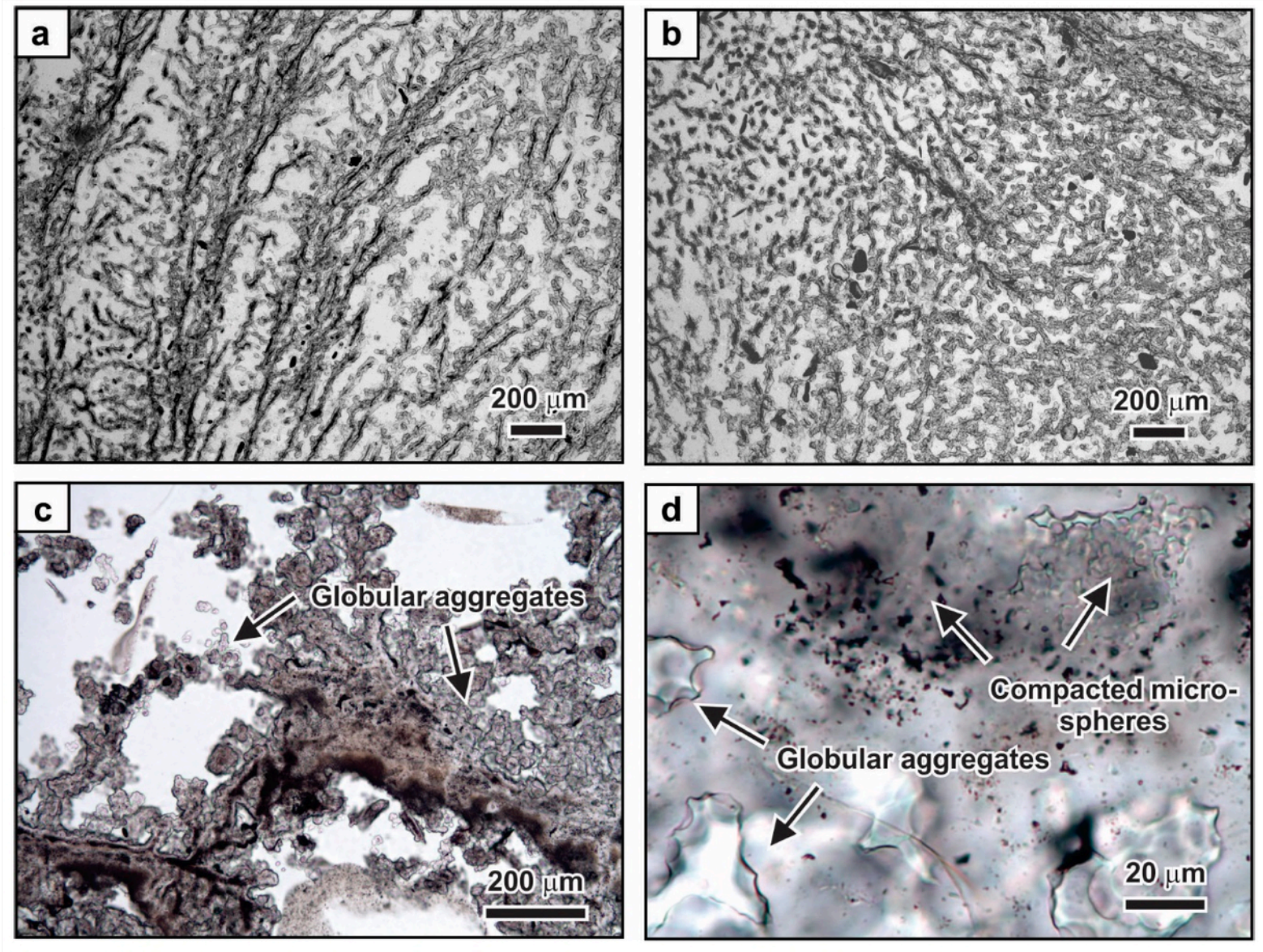
Thank you

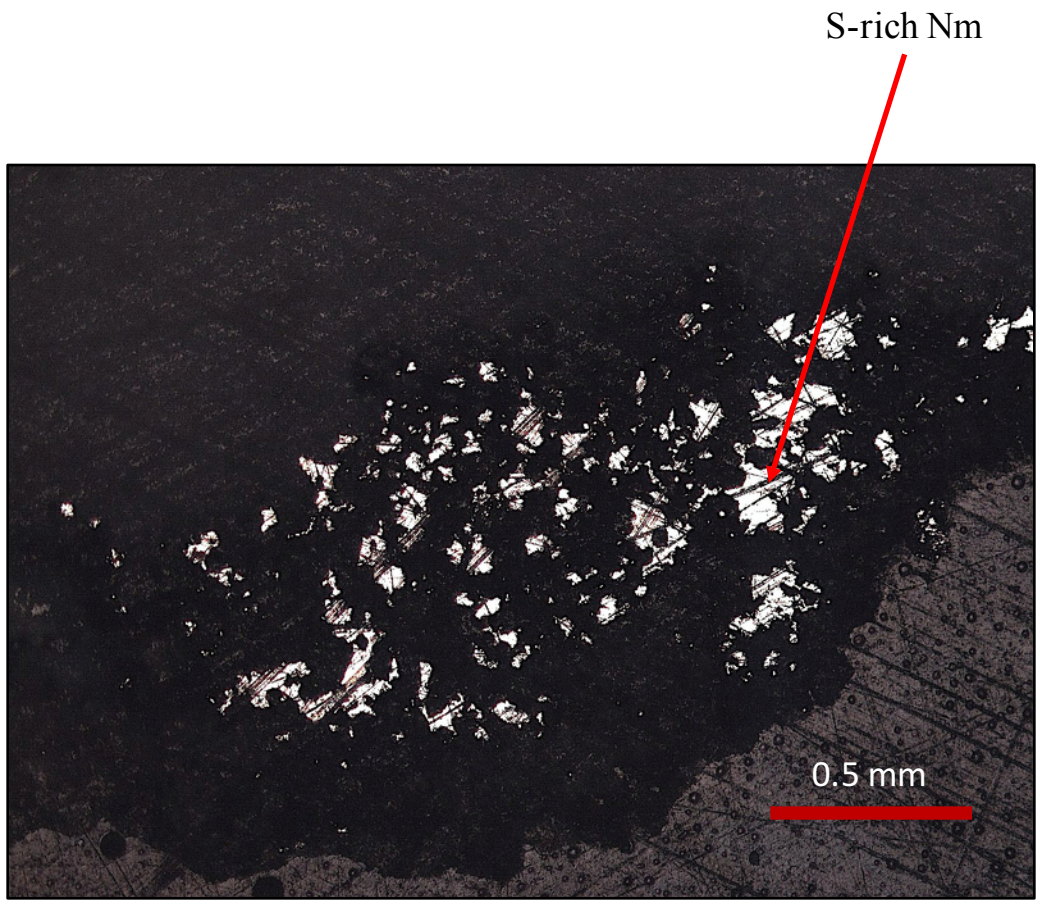
Question Time!

Silica scaling from the Wairakei Geothermal Power plant, NZ

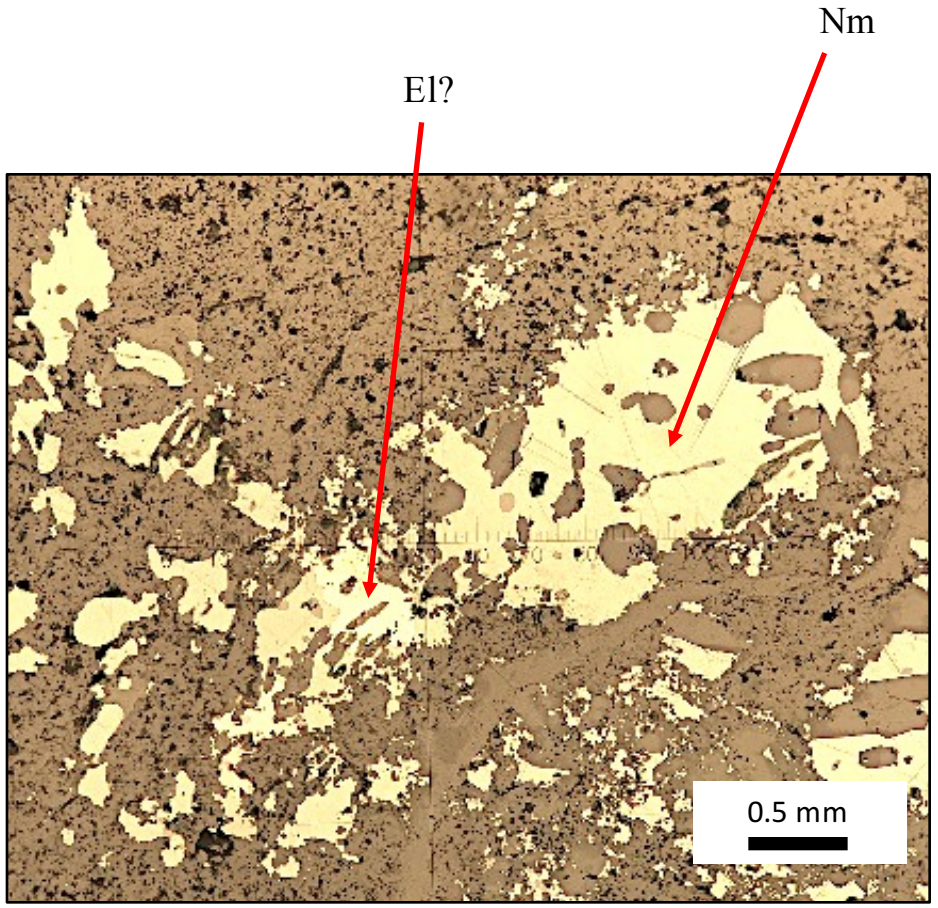


(Taksavasu et al., 2018)

Buckskin National



Fire Creek



Ag-Se-S phase minerals

- Acanthite (Ag_2S)
- Naumannite (Ag_2Se)
- Aguilarite (Ag_4SSe)