The Mineralogy, Origin, and Economic Potential of Arsenide Five-Element Vein Deposits: Examples from the Black Hawk District, New Mexico and Worldwide

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The annual New Mexico Mineral Symposium provides a forum for both professionals and amateurs interested in mineralogy. The meeting allows all to share their cumulative knowledge of mineral occurrences and provides stimulus for mineralogical studies and new mineral discoveries. In addition, the informal atmosphere encourages intimate discussions among all interested in mineralogy and associated fields.

The symposium is organized each year by the Mineral Museum at the New Mexico Bureau of Geology & Mineral Resources.

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The Mineralogy, Origin, and Economic Potential of Arsenide Five-Element Vein Deposits: Examples from the Black Hawk District, New Mexico and Worldwide

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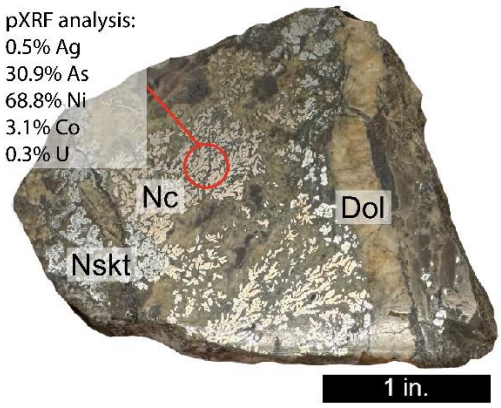
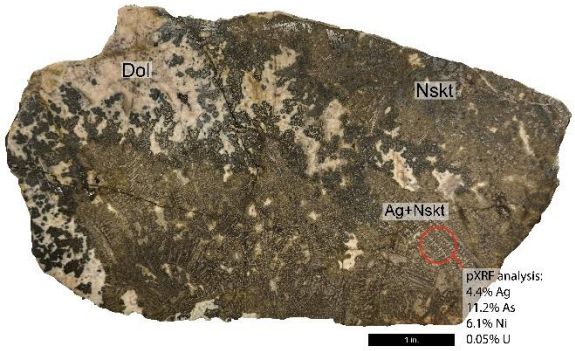
Arsenide five-element vein deposits are mineralogically and texturally complex, low- to moderate-temperature, hydrothermal, structurally-controlled Ag-Co-Ni-Bi-As bearing carbonate vein systems with local minor to trace elements such as U, Cu, Pb, Zn, Sb, Hg and others. There are many subtypes or variations of this deposit type, since some elements do not occur at all localities. They also have been called five element association, Ni-Co-native Ag ore type, Bi-Co-Ni-As-U-Ag-formation, Ag-Co-Ni-As-Bi type, and polymetallic veins. They contain high-grade silver (1000s g/t Ag), but are low tonnage (<1 Mt) and low in Au and Cu. Ag, Bi, and As are commonly found as native elements, whereas Co and Ni are found as arsenides and/or sulfides.



Polished slab of dendritic nickelskutterudite & nickeline, in carbonate vein, Alhambra mine, Black Hawk District.

The five-element veins possibly represent segments of potentially larger mineral systems, the end members of which may be significantly different in composition and mineralogy. Nonetheless, five-element districts are being re-evaluated in many districts worldwide due to the significant quantities of critical minerals that these deposits host, especially Co and Ni, which are important components in batteries.

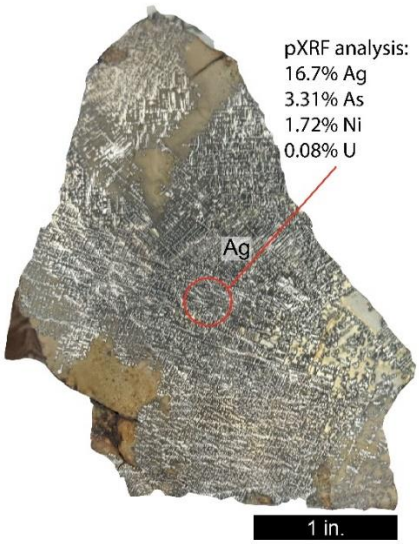


Polished slab of silver & nickelskutterudite in carbonate vein, Alhambra mine, Black Hawk District.

The elements (i.e., Ag, Co, Ni, Bi, As) forming most five-element vein systems have different chemical properties and are not normally found together in other deposit types, which highlights the need for specific hydrothermal processes leading to the formation of this particular element association. In other deposit types, such as epithermal Au-Ag deposits or polymetallic vein deposits; Ag is typically found with Cu and Au in sulfide- and sulfosalt-rich assemblages, both of which are rare in the five-element vein deposits. Bi is rare in low- to moderate-temperature vein deposits and is typically found in very high-temperature veins, skarns, and VMS deposits, however, the association with major Ni and Co mineralization is absent in these deposits. Common gangue (non-economic) minerals in five-element veins comprise of carbonates, such as calcite, siderite,

ankerite, and dolomite with minor locally present barite, quartz, and fluorite.

Textures of five-element veins are not usual for open-space filling veins and include thin wires, fern-shaped dendrites of native metals (Ag, As, and Bi), herringbone Ag, and botryoidal masses. The dendritic textures common to most five-element veins are thought to have formed very quickly. Other minerals grow slowly and form euhedral crystals or massive aggregates. Many five-element vein deposits have erratic shapes and grades of ore bodies, but most are open-space fillings with little replacement of wall rock. Typically, these deposits are small, narrow (<2 m) and discontinuous, making exploration for new ore shoots challenging. Host rock composition, high-salinity fluids, rheology of veins and host rock, and intersections with former hydrothermal systems seem to play a critical role in the formation of five-element veins. Host rocks may act as sources of elements. Shale is locally attributed as a source of elements, but other five-element vein systems, such as the Black Hawk district (New Mexico) are hosted by Proterozoic rocks with no shale. World-wide examples include: Schneeberg (Germany), Jachymov (Czech Republic), Cobalt, (Ontario, Canada), Port Radium/Great Bear Lake (Northwest Territories, Canada), and Bou Azzer (Morocco).



Polished slab of silver in carbonate vein, Alhambra mine, Black Hawk District.

The Black Hawk district is east of Bullard Peak in the Burro Mountains in southwestern New Mexico and is one of the few localities of five-element veins in the U.S. In 1881, Cherokee Jim Bowman discovered rich silver float in a wash. John Black and his partner, Sloan, located the source of the float, near the Alhambra (formerly Blue Bell) mine. By 1881, claims were staked and a town developed. Although production records are lost, it is estimated that over $1,000,000 was produced from the district from1883 to 1893, when silver prices dropped due to the silver panic of 1893. Solid Silver Mining Co. produced $600,000 from the Black Hawk mine; one car load contained $28,000 worth of silver! An estimated $400,000 of high-grade silver was produced from the Alhambra, $100,000 from the Rose, $40,000 from the Hobson, and $10,000 from the Good Hope mines. From 1880 to 1890 the price of silver dropped from $1.15/oz to $0.95/oz, and by 1898 was $0.565/oz. The mines operated sporadically because of lack of capital, water issues, difficulty in finding ore shoots, and theft. The district is a favorite for mineral collectors and even during early production in 1883-1893, theft of high-grade silver samples was a problem. Guards had to be hired to make sure some ore actually made it to the mill!

Recent mapping, geochemistry, and petrography in the Black Hawk district have shown epithermal textures such as bladed quartz after calcite (indicative of boiling) and brecciation are common in the higher levels of the system. General paragenesis includes 1) early barren hydrothermal calcite-quartz stage with minor sulfides (pyrite, sphalerite), 2) Ni-Co-As-Ag arsenides and sulfarsenides hosted by carbonates with native Ag, 3) uraninite stage, 4) sulfide stage, 5) late calcite-dolomite-quartz veins, and 6) late dissolution and reprecipitation (supergene). Brecciation occurs throughout the middle to later stages. Mineralized samples contain up to 9970 ppm Ag, 8540 ppm As, 5690 ppm Co, 72,400 ppm Ni, 57 ppm Bi, 165 ppm Sb, and 32,600 ppm U.

Minerals in the Black Hawk district

Mineral Name	Mineral Formula	Mineral Name	Mineral Formula
Acanthite	Ag_2S	Nickeline	NiAs
Anglesite	$PbSO_4$	Nickelskutterudite	$(Ni,Co,Fe)As_3$
Ankerite	$Ca(Fe^{2+},Mg)(CO_3)_2$	Nimite	$(Ni,Mg,Al)_6((Si,Al)_4O_{10})(OH)_8$
Annabergite	$Ni_3(AsO_4)_2 \cdot 8H_2O$	Pearceite	$[Ag_6As_2S_7][Ag_9CuS_4]$
Aurichalcite	$(Zn,Cu)_5(CO_3)_2(OH)_6$	Polybasite	$[Ag_6Sb_2S_7][Ag_9CuS_4]$
Azurite	$Cu_3(CO_3)_2(OH)_2$	Proustite	Ag_3AsS_3
Barite	$BaSO_4$	Pyrargyrite	Ag_3SbS_3
Bismuthinite	Bi_2S_3	Pyrite	FeS_2
Bismutite	$(BiO)_2CO_3$	Pyrostilpnite	Ag_3SbS_3
Bornite	Cu_5FeS_4	Pyrrhotite	$Fe_{1-x}S$ x = 0 to 0.17
Chalcopyrite	$CuFeS_2$	Rammelsbergite	$NiAs_2$
Chlorargyrite	AgCl	Rhodochrosite	$MnCO_3$
Covellite	$Cu^{+}{}_4Cu^{2+}{}_2(S_2)_2S_2$	Safflorite	$(Co,Ni,Fe)As_2$
Cubanite	$CuFe_2S_3$	Scheelite	$Ca(WO_4)$
Digenite	Cu_9S_5	Siderite	$FeCO_3$
Erythrite	$Co_3(AsO_4)_2 \cdot 8H_2O$	Siegenite	$CoNi_2S_4$
Galena	PbS	Silver	Ag
Gersdorffite	NiAsS	Skutterudite	$CoAs_3$
Gold	Au	Sphalerite	ZnS
Hematite	Fe_2O_3	Stannite	Cu_2FeSnS_4
Jalpaite	Ag_3CuS_2	Stromeyerite	AgCuS
Manganite	$Mn^{3+}O(OH)$	Tennantite subgroup	$Cu_6(Cu_4\mathbf{C}^{2+}{}_2)As_4S_{12}S$
Marcasite	FeS_2	Tetrahedrite subgroup	$Cu_6(Cu_4\mathbf{C}^{2+}{}_2)Sb_4S_{12}S$
Mckinstreyite	$Ag_{5-x}Cu_{3+x}S_4$ x ≈ 0-0.28	Uraninite	UO_2
Millerite	NiS	Zircon	$Zr(SiO_4)$
Molybdenite	MoS_2		