Northwest
Micro Mineral
Study Group

MICRO PROBE

Spring, 2013 VOLUME XI, Number 7

SPRING MEETING . . . . .VANCOUVER, WASHINGTON

May 4, 2013 9:00 am to 5:00 pm

Clark County P. U. D. Building
1200 Fort Vancouver Way
Vancouver, Washington

Schedule for the day;

9:00 am Doors open at the PUD building for table set up. Helpers needed.

9:30 am Meeting starts: (trading, selling, free tables, viewing specimens, and visiting). Come ready to visit and see what others have come up with since our last meeting. Be sure to bring something to share on the free table.

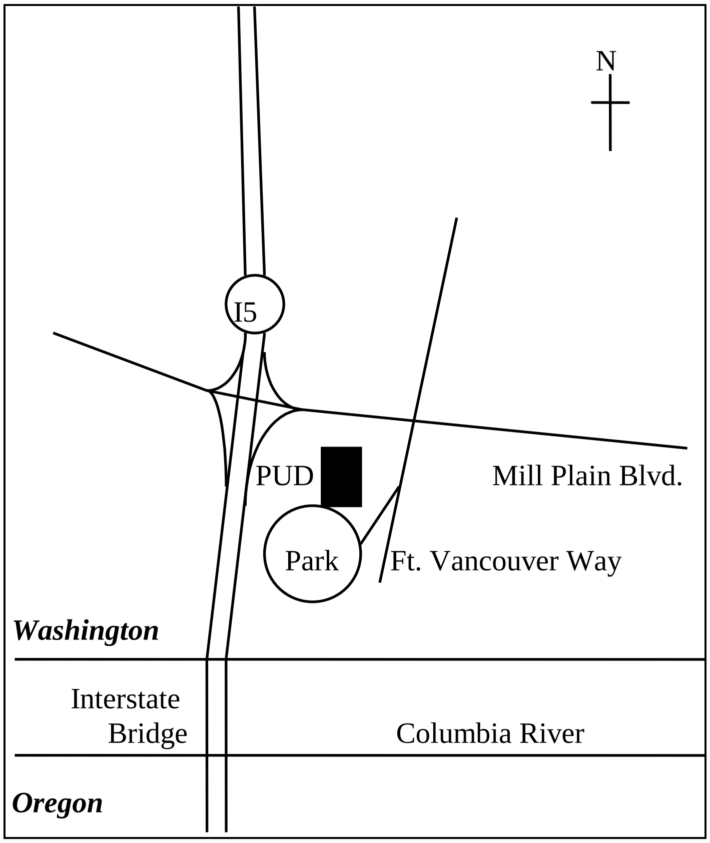
10:30 am Bob Meyer will show pictures of the minerals from Tiger, Arizona, and also of his travels to the Second International Mindat Conference in Morocco.

12:00 noon Lunch potluck: Club provides sandwich makings (bread, meat, lettuce, cheese, dressings, and coffee, tea, cocoa). Please bring salads, chips, pop, nuts, chili, cookies, pie, or cake to add to the lunch.

1:30 pm Business meeting, including field trip reports and an update of research on the minerals from the Golden Horn by Rudy Tschernich

4:00 pm End of meeting and clean up. Please stay to put away tables and help clean up.

5:00 pm Dinner will be at the Country Buffet in Vancouver. Please join us if you can.



Presidents Page

by Rudy Tschernich

Winter is now behind us and it is time to share our mineral studies with each other. A lot of work has been done on the minerals from the Golden Horn Batholith, some of which is found in the papers in this newsletter, but the important research is still on-going and is not ready for publication. This material will be presented in one of our programs at this meeting**: Research on the Golden Horn Batholith by Rudy Tschernich.** Be sure to come to find out about the new research. A tray of specimens under study will be passed around the group at the meeting to be studied under your own microscope.

Bob Meyer has written a paper on the **Minerals of Tiger, Arizona** for this newsletter which includes information on the new mineral **bobmeyerite** named in his honor. Bob will present a program on these minerals at this meeting. He will also present a program on the **Second International Mindat Conference in Morocco** showing a travelogue of the trip and some of the collecting sites he visited.

Come to the meeting early, bring specimens for the free tables or for selling or trading. Bring something for the pot luck lunch and enjoy the minerals, friends, and programs.

IN MEMORY OF MARGARETTE JOHNSON

In the May, 2010 issue of the Microprobe, we sadly reported on the passing of Stan Johnson. Now we have the equally sad news that his wife, Marg, has gone to join him on February 25, 2011. Stan and Marg attended meetings regularly for many years, but were forced to stop in recent years because the drive down from Salmon Arm, British Columbia had become just too difficult. We have missed their cheery faces and encouraging words. Marg had been in declining health since the loss of her husband, battling with macular degeneration and congestive heart failure.

Living in Salmon Arm for many years, Marg and Stan were in the middle of some great zeolite collecting areas. They were eager to explore the countryside around their area, and kept us abreast of the status of collecting areas in the upper Okanogan Valley and south-central British Columbia. We were sad to not see them regularly any more, and even sadder to learn of the loss, first of one and then of the other of our friends in British Columbia.

Our condolences go out to their children still living in Salmon Arm.

Don Howard

Lead Minerals from Golden Horn Batholith, Okanogan County, Washington

Randy Becker --- huntbecker @aol .com

Most mineral collectors do not think of lead minerals occurring in the miarolitic cavities found in the Gold Horn Batholith. Yet very sparse amounts of the lead minerals galena, cerussite, linarite, wulfenite, and mimetite have been found in the batholith. Plumbopyrochlore and lead-rich catapleiite have been reported by Boggs (1984) as occurring in the Golden Horn Batholith but are not included in this paper. The occurrence of lead minerals does not appear to be related to the three basic types of granite in the batholith (one-feldspar annite granite, two-feldspar annite granite and the arfvedsonite granite) but is a reflection of lead being a trace element randomly scattered within the batholith. Although Stull (1969) indicated that the trace element lead was below the atomic absorption detection limits in the Golden Horn Batholith, the following lead minerals are occasionally found by collectors.

Galena PbS

Galena has been found as small, corroded masses to sharp crystals up to several mm across in all the granite types of the Golden Horn Batholith. The physical characteristics, color, cleavage and isometric crystals, usually cubic, make for fairly reliable physical identification. Rounded masses to sharp cubic crystals with a slightly altered surface have been found in the more alkaline one-feldspar annite granite (border granite) on Liberty Bell Talus. Several specimens were found in Bob Boggs' Blue Calciohilairite Boulder (CCB#2) associated with malachite, zircon, calciohilairite, fergusonite-beta-(Y), fluorite, plus other species. Galena rarely has been found in the one-feldspar annite granite at the MP 164 collecting site. Recently found at MP 164.4 was a small rock composed of miarolitic two-feldspar annite granite which contained several microscopic masses of galena in cavities associated with sphalerite, hematite, albite, quartz and an unidentified REE carbonate similar to synchysite–(Ce).

Associated secondary lead minerals occasionally occur with the galena. A fist-sized mass of partially altered galena was found in a rusty arfvedsonite granite boulder at MP 166 in about 1990. Within this galena mass were small cavities which contained small cerussite crystals, with some showing "v" twining (fig. 5). Other smaller masses of galena, found in the arfvedsonite and the one-feldspar annite granites, have massive secondary lead and copper minerals (cerussite, chrysocolla and linarite) surrounding unaltered galena. Boggs (1984) reports agardite associated with galena. Anglesite could also occur with these secondary lead minerals but its presence has not been confirmed.

Figure 1. Cubic galena with octahedral faces with brown chamosite from Liberty Bell talus. Collected by Randy Becker in the early 1980's. Photo RB157a by Rudy Tschernich.

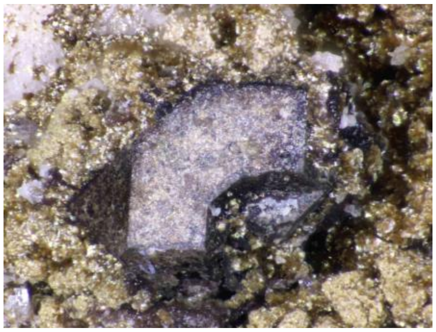


Figure 2. Cubic galena with "bend" and brown chamosite from Liberty Bell talus. Collected by Randy Becker in the early 1980's. Photo RB157b by Rudy Tschernich.

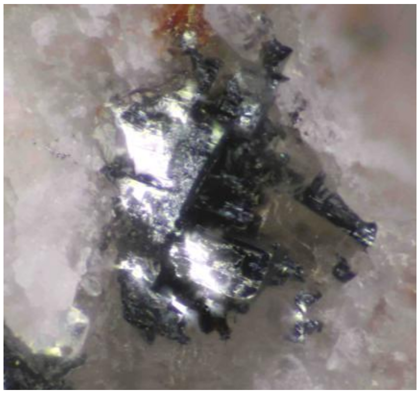


Figure 3. Silver gray cleavages of galena on colorless albite from 9-10-12B rock at MP 164.4. Collected by Randy Becker September 10, 2012. Photo RB 562 by Rudy Tschernich.

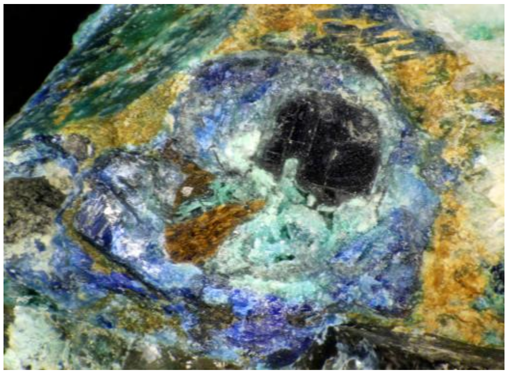


Figure 4. Blue linarite with green chrysocolla surrounding black galena from the Liberty Bell talus. Collected by Randy Becker mid 1980’s. Photo RB 212 by Rudy Tschernich.

Cerussite $PbCO_3$

Cerussite rarely occurs as a secondary mineral formed from the alteration of galena in the arfvedsonite and one-feldspar annite granites. Most of the cerussite is found as massive white to colorless material surrounding small masses of galena. Very small cavities in this massive material sometimes contain sharp, well-defined colorless to white elongated prisms of cerussite. Cerussite can be identified by the association with altered galena, crystal morphology, and the very common presence of twining. Species sometimes found associated with cerussite include linarite, agardite and several unknown minerals.

Boggs (1984) reported cerussite crystals occurring as a primary mineral formed from hydrothermal fluids, with some cerussite found included in quartz crystals. This type of occurrence of cerussite has not been seen by the author.

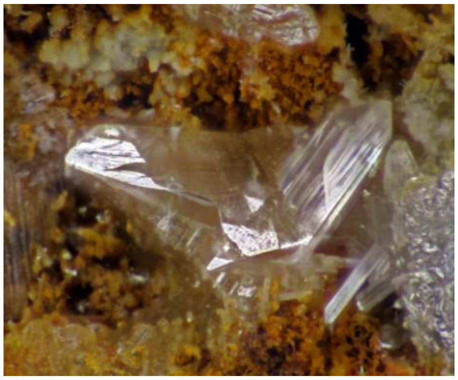


Figure 5. Colorless “V” twin of cerussite on limonite in galena pod from MP166 talus. Size of the twin is less that 1 mm. Collected by Randy Becker on August 4, 1990. Photo RB530 by Rudy Tschernich.

Figure 6. Colorless prisms of cerussite showing twinning, with green clay? from MP 166 talus. Collected by Randy Becker. Photo RB531b by Rudy Tschernich.

Linarite $PbCu^{2+}(SO_4)(OH)_2$

The occurrence of linarite in the Golden Horn Batholith was suggested by Bob Boggs in 1981 (unpublished notes), but has only recently been confirmed by analysis and reported by Friis (2012).

Linarite is found as a massive azure-blue mineral usually associated with green secondary copper minerals (chrysocolla and/or malachite?) and cerussite. It seems to occur mainly in the arfvedsonite granites and the one-feldspar annite granite in the vicinity of Liberty Bell. Very small voids in the massive material sometimes show evidence of small, crude crystals overgrowing the massive material. Well-formed crystals are not known to occur.

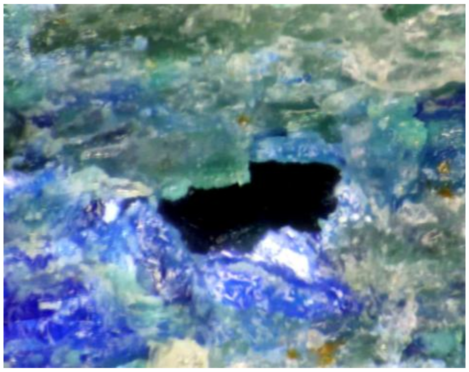


Figure 7. Crude linarite crystal at the mouth of a cavity associated with green chrysocolla from the Liberty Bell Talus. Cavity is less than 1 mm across. Collected by Randy Becker mid 1980s. Photo RB211 by Rudy Tschernich.

Figure 8. Light brown bundle of wulfenite crystals on colorless to white zektzerite from Boggs 1500 lb Boulder at MP166.5. Collected by Randy Becker. Photo RB532 by Rudy Tschernich.

Wulfenite $PbMoO_4$

Wulfenite occurs very rarely in the arfvedsonite granite. Its occurrence is unusual and the wulfenite was recognized only with analytical work. The first occurrence was discovered by the author in the early 1980s, in the “1500 lb Boulder”. This boulder (found and named by Bob Boggs) was about one-half mile north of MP166 in the talus below the highway. On one side of this boulder was a medium grained arfvedsonite-bearing pegmatite. Zektzerite, ceriopyrochlore, astrophyllite, microcline and quartz also occurred in this pegmatite. While collecting this pegmatite with Bob Boggs, the author noticed a few small specimens of brownish-white, elongated stick-like crystals, usually growing wall to wall in small angular cavities in the pegmatite. Analysis by Boggs (1984) indicated that these crystals are wulfenite. Boggs (1984) also noted that sulphide minerals were not present in this pegmatite and this wulfenite is probably a primary mineral formed from hydrothermal fluids rather than alteration of galena or other lead-bearing sulphides.

A second verified occurrence of wulfenite has recently been found in the Golden Horn Batholith. In October of 2009 the author discovered a basket ball sized rock (10-10-09 Rock) on the upper edge of the talus slope on the west side of Kangaroo Ridge. This rock consisted of a fine to medium-grained, annite rich arfvedsonite granite that contained numerous miarolitic cavities. The minerals found in these cavities included zoned annite, zircon, pyrochlore, okanoganite, and several unknowns. One of these unknowns, WP-62, look like very small yellow “blobs”. These yellow “blobs” appeared to be masses of very small crystals. These masses were very scarce in tiny cavities and were only found due to their bright yellow color. The largest mass was about 0.25 mm across with most samples less than 0.1 mm. WDS and RAMAN analysis by Dr. Markus Raschke, University of Colorado, January 2013(unpublished), has shown that these masses are wulfenite. As with the original

1500 Pound Boulder wulfenite, there is no evidence of sulphides in the 10-10-09 Rock, so these are probably primary wulfenite.

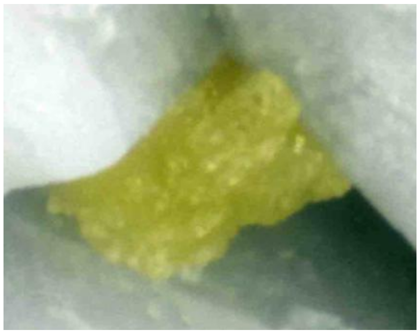


Figure 9. Yellow wulfenite on white albite/microcline and colorless quartz from 10-10-09 Rock on Kangaroo Ridge. Collected by Randy Becker October 10, 2009. Photo RB275 by Rudy Tschernich.

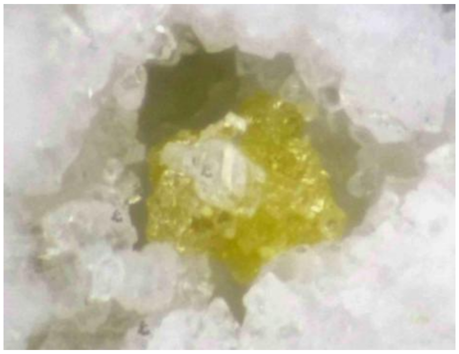


Figure 10. Colorless albite on yellow wulfenite with white albite/microcline from 10-10-09 Rock on Kangaroo Ridge. Collected by Randy Becker October 10, 2009. Photo RB276 by Rudy Tschernich.

Mimetite $Pb_5(AsO_4)_3Cl$

A single specimen of white, elongated, chalky-appearing, hexagonal prisms (WP-91) was found in the MP 166 road cut talus in an arfvedsonite granite boulder which contained loellingite. The material appeared to be somewhat altered. EDX analysis of this material by Dr Markus Raschke, (January 2010, unpublished) indicated the presence of lead and arsenic. Although no other analysis has been done on this material, it is reasonable to identify it as mimetite due to the morphology, EDX results, and known presence of lead and arsenic (loellingite) minerals in the arfvedsonite granite.

Figure 11. Colorless to white hexagonal prisms of mimetite on colorless quartz from a loellingite-bearing rock in the MP166 road cut. Collected by Randy Becker October 10, 1993. Photo RB309 by Rudy Tschernich.

References

1) Stull, Robert J. (1969) The Geochemistry Of The Southeastern Portion of the Golden Horn Batholith, Northern Cascades, Washington, p 95.

2) Boggs, Russell C. (1984) Mineralogy and Geochemistry of the Golden Horn Batholith, North Cascades Washington PhD Dissertation University of California, Santa Barbara California pp 23, 36, 47, 59, 91.

3) Friis, Henrik (2012) Linarite from the Golden Horn Batholith, Okanogan County, Washington, Micro Probe Vol. XI Number 6, p 24.

Titanium-bearing Hematite from the Golden Horn Batholith, Okanogan County, Washington

by
Rudy W. Tschernich, 300 Alps Road Unit 1007, Moxee, Washington 98936
Randy Becker, 13005 Wide Hollow Road, Yakima, Washington 98908

Hematite Fe_2O_3 and ilmenite $FeTiO_3$ are both found in the Golden Horn Batholith. Ilmenite was reported forming thin to thick silver-gray hexagonal crystals by Tschernich (2012). Hematite usually forms red coatings on various minerals but now has been found to form thin to thick hexagonal prisms that appear just like ilmenite. The crystals are too small to be distinguished by x-ray diffraction, which leaves EDX or Raman spectra for identification. Titanium commonly forms as an impurity in hematite and in some cases forms a complete solid solution series with hematite.

Figure 1 *Hematite on colorless albite from a rock near MP 164.4. Randy Becker specimen RB552. Photography by Rudy Tschernich. Crystal 2.3 mm across*

Figure 2 *Hematite with red hematite stain on colorless albite from near MP 164.4. Randy Becker Specimen RB564. Photography by Rudy Tschernich. FOV 1.8 mm across*

Figure 3 *Thin titanium hematite plates from the "Parasite Boulder" on colorless albite. Randy Becker No. 12. Photography by Rudy Tschernich. FOV 1.4 mm*

Figure 4 *Thick titanium hematite plates from the "Parasite Boulder" on colorless albite. Randy Becker specimen No. 13. Photography by Rudy Tschernich. FOV 2.2 mm*

Figure 5 *Ilmenite from the Cirque near MP167. Randy Becker specimen RB318. Photography by Rudy Tschernich. Crystal 1.5 mm across.*

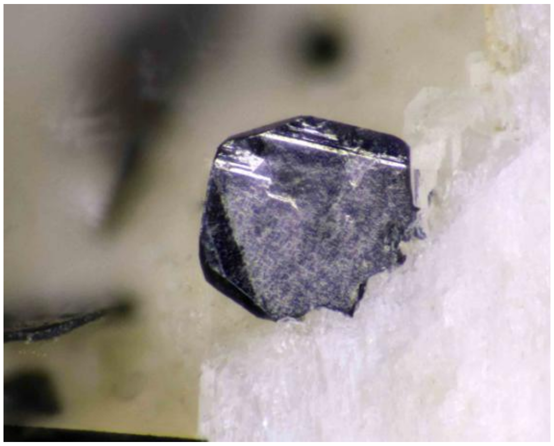


Figure 6 *Ilmenite from the Cirque near MP167. Randy Becker specimen RB318. Photography by Rudy Tschernich. Crystal 0.49 mm across.*

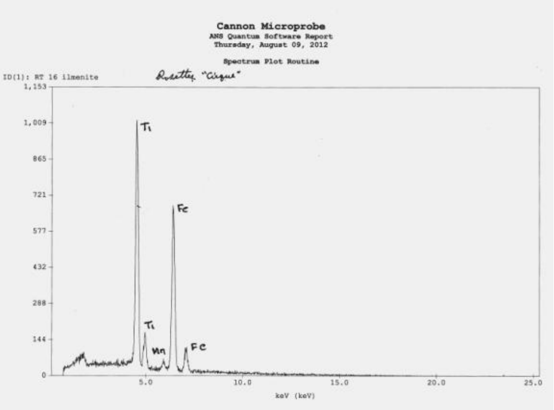


Figure 7 *EDX Ilmenite from the Cirque near MP 167.*

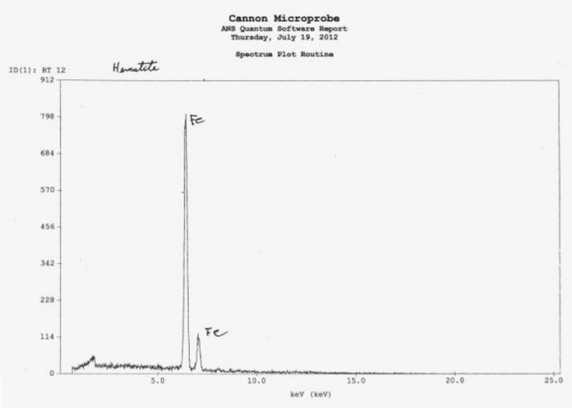


Figure 8 *EDX of Hematite from the Liberty Bell talus.*

EDX of ilmenite (Fig. 7) from GHB shows four peaks. Ti is shown by one set of high and smaller peaks, and another set for Fe is represented by a pair of medium and smaller peaks. EDX of pure hematite (Fig. 8) from the GHB shows only the two Fe peaks.

In this study, tiny thick to thin silver-gray to black hexagonal platelets from feldspar-rich phase of the so called "Parasite Boulder" found on the Liberty Bell talus and in tiny miarolitic cavities from a small two-feldspar annite granite boulder found in debris along the road near MP 164.4 were studied with EDX (Fig. 9). The results show major and minor Fe peaks typical of hematite along with a small and tiny pair of peaks of Ti. Since hematite commonly contains Ti as an impurity, this material is considered simply to be a titanium-rich hematite.

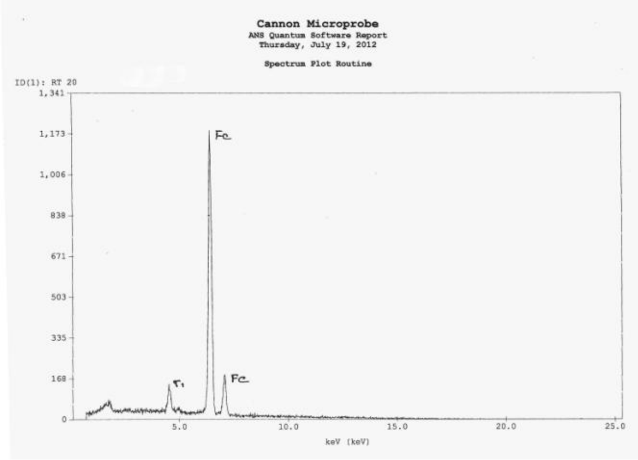


Figure 9 *EDX of hematite containing titanium from the "Parasite Boulder" on Liberty Bell talus.*

Simple streak tests on the samples yielded a black powder, although some thin broken crystal surfaces on the MP164.4 samples did reveal an occasional red reflection. A test for the degree of magnetism was conducted with a strong magnet on the samples from the two sites under study as well as magnetite from Idaho, hematite from Denny Mountain, King County, Washington, and ilmenite from the Golden Horn Batholith. The magnetite was strongly magnetic, hematite was medium strength, while the two titanium-rich hematite samples and ilmenite were weaker in strength. This leads to the conclusion that neither streak nor magnetic tests are useful in determining hematite, titanium hematite, or ilmenite from crystals that look identical in the Golden Horn Batholith. EDX analysis is the best method for such determination.

References:

Tschernich, R.W. (2012) Ilmenite from the Golden Horn Batholith, Washington Pass, Okanogan County, Washington, Micro Probe V-11, No. 6, pp. 19-23.

THE MICROPROBE

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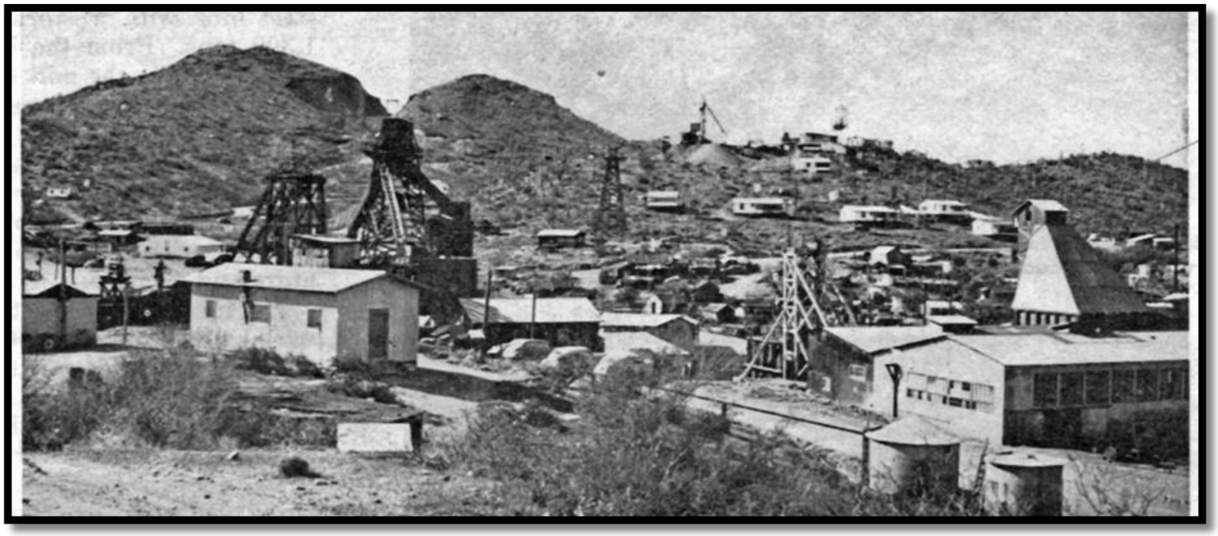
Donald G. Howard, editor
356 SE 44th Avenue
Portland, Oregon, 97215
e-mail: pogodh@hei.net

DUES: $15 per year per mailing address, payable at the Spring meeting or by mail to the Secretary/Treasurer:
Patrick "Kelly" Starnes
1276 SE Goodnight Avenue
Corvallis, Oregon, 97333
e-mail: bikeklein@yahoo.com

Minerals of the Pinalite Assemblage, Mammoth-Saint Anthony Mine, Tiger, Pinal County, Arizona

By Bob Meyer



Panoramic View of the Mammoth-St. Anthony Mine complex—1941, (Huttl, 1943)

Abstract

A highly complex mineral paragenesis occurring in one rock type at the Mammoth Saint-Anthony Mine of Tiger, Pinal County, Arizona has produced three type minerals, pinalite (1989), georgerobinsonite (2011), and bobmeyerite (2013). In addition, the mine has seven other type locality species, bringing the total to ten with the addition of bobmeyerite in 2013. Specimens of this paragenesis, referred to here as the pinalite assemblage, are characterized by a matrix of compact vuggy quartz with sparse pockets of diaboleite, and will typically host a complex array of numerous individual species in habits that tend to be distinctive to the paragenesis.

The Mammoth-Saint Anthony Mine is well known for its suites of rare anomalous oxidized sequence minerals, which occurred there in unsurpassed richness and quality. Students of this material, starting with Sidney Williams in 1980 (Bideaux, 1980), have postulated that the anomalous group minerals formed in closed geochemical systems. Subsequent study of specimens from Tiger, and study of related deposits *in situ* have added credence to the closed system theory at Tiger. The Mammoth Saint-Anthony mine hosts, in addition, several suites of normal oxidized species that also occur in very distinctive associations. Historical accounts of the mine workings reported that lenses of the anomalous group minerals would sometimes occur in the same areas of the mine as the normal group minerals (Bideaux, 1980), but specimens that exhibit the traits of both groups are exceedingly rare. This strengthens arguments for the closed system theory in that there was little to no admixing of types despite the minerals occurring in close proximity. There are examples, though, of specimens that do exhibit traits of both sequences. Specimens from the pinalite assemblage are one example, as is the assemblage that hosts the species yedlinite. After careful study of a number of specimens from the pinalite assemblage, the author postulates that this material represents a third sequence at Tiger, resulting from a partially closed geochemical system.

Introduction

The Mammoth-Saint Anthony Mine at Tiger, Arizona, which was operated for gold starting in 1879, and later for gold, silver, lead, molybdenum, and vanadium until its closing in 1953, is renowned among mineral collectors for its superb suites of mineral specimens. The fine quality and quantity of the display specimens it produced would have earned the deposit fame on their own. For example, Tiger is well-known for its abundant specimens of world-class vanadinite and wulfenite; its high-quality suites of oxidized minerals such as cerussite, dioptase, azurite, malachite, leadhillite, caledonite, smithsonite, and linarite; and its “trademark” associations, such as wulfenite with dioptase, willemite, fluorite, and fornacite on pale blue allophane. In addition, the unusual variety of associations and the quality of the mineralization make Tiger material particularly suited to study with the stereomicroscope.

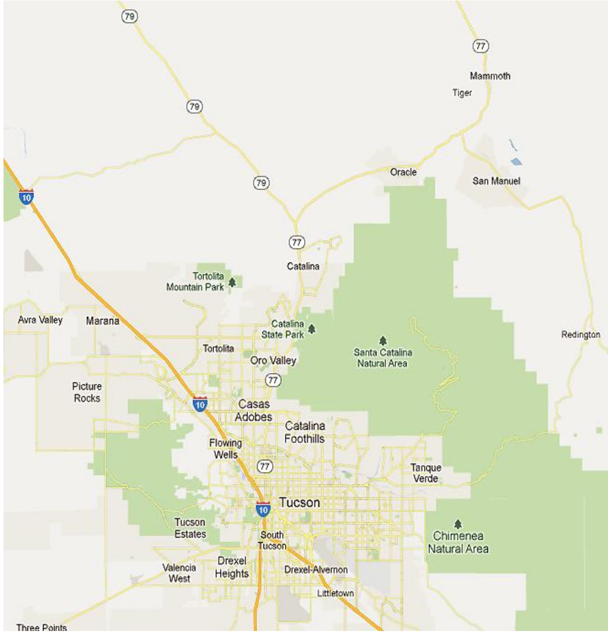
However, what makes Tiger truly unique as a mineral locality is an additional group of very unusual species, often containing copper and lead, which occurred in richness and quality unsurpassed by any other locality. This group of species, referred to as the anomalous oxidized sequence by Richard A. Bideaux in his 1980 *Mineralogical Record* article on the deposit (Bideaux, 1980), often contain volatile halogen elements such as chlorine and fluorine. Some of these species do occur at other localities, but typically in very sparse amounts. The highly reactive environments that form such species would not allow them to persist, except in cases where boundary rock was relatively impermeable and fully enclosed. Rich specimens of rare species such as diaboleite from Tiger are commonly bounded by layers of dense, fine grained rock, which lends strength to the idea that such specimens were formed as wholly enclosed lenses in isolated geochemical systems.

The subject paragenesis, referred to here as the pinalite assemblage, exhibits traits of both the anomalous and normal oxidized sequence minerals at Tiger. The author suggests that specimens from the pinalite assemblage formed in an environment that was partially closed and that the material bounding the open zones was itself fairly impermeable, but that allowed some interaction between the anomalous and normal group geochemistry so that elements of both persisted.

As a whole, the Mammoth Saint-Anthony Mine is an outstanding locality on many levels. However, to fully fathom the depth and complexity of the mineralogy at Tiger one must study the material with a microscope.

Location

The town and workings at Tiger were located about 80 km Northeast of Tucson, Arizona, and about 5 km west of the town of Mammoth. The workings are closed, fenced, and access is prohibited.



Location map of Tiger (Google, 2013)

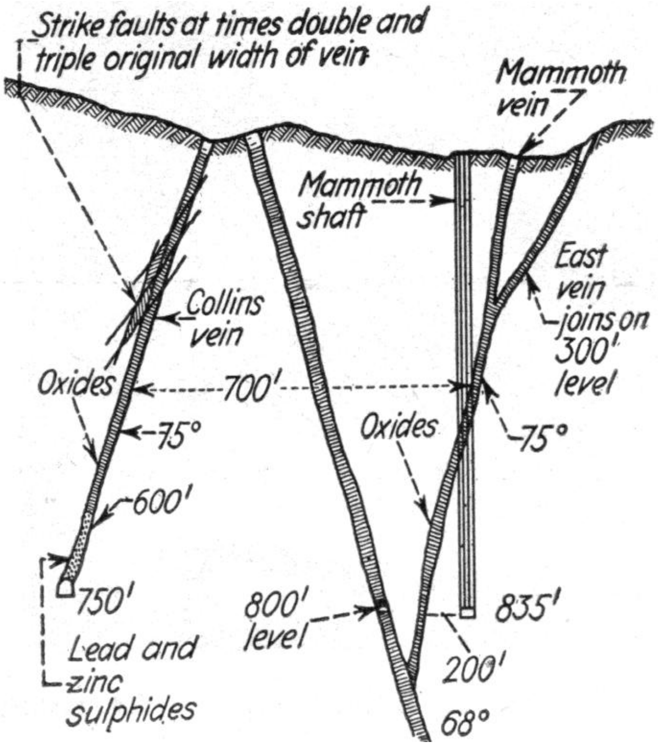
A computer-rendered three dimensional image of the topography around the mines. The distinctive saddle where the Collins vein was can be seen in the left. The red "A" is the site of the Mohawk mine headframe. The Mammoth Mine workings were on the rise that is on about a direct line between the Collins workings on the left and the Mohawk/New Year's workings on the lower right. (Google, 2013).

A Brief Chronological History

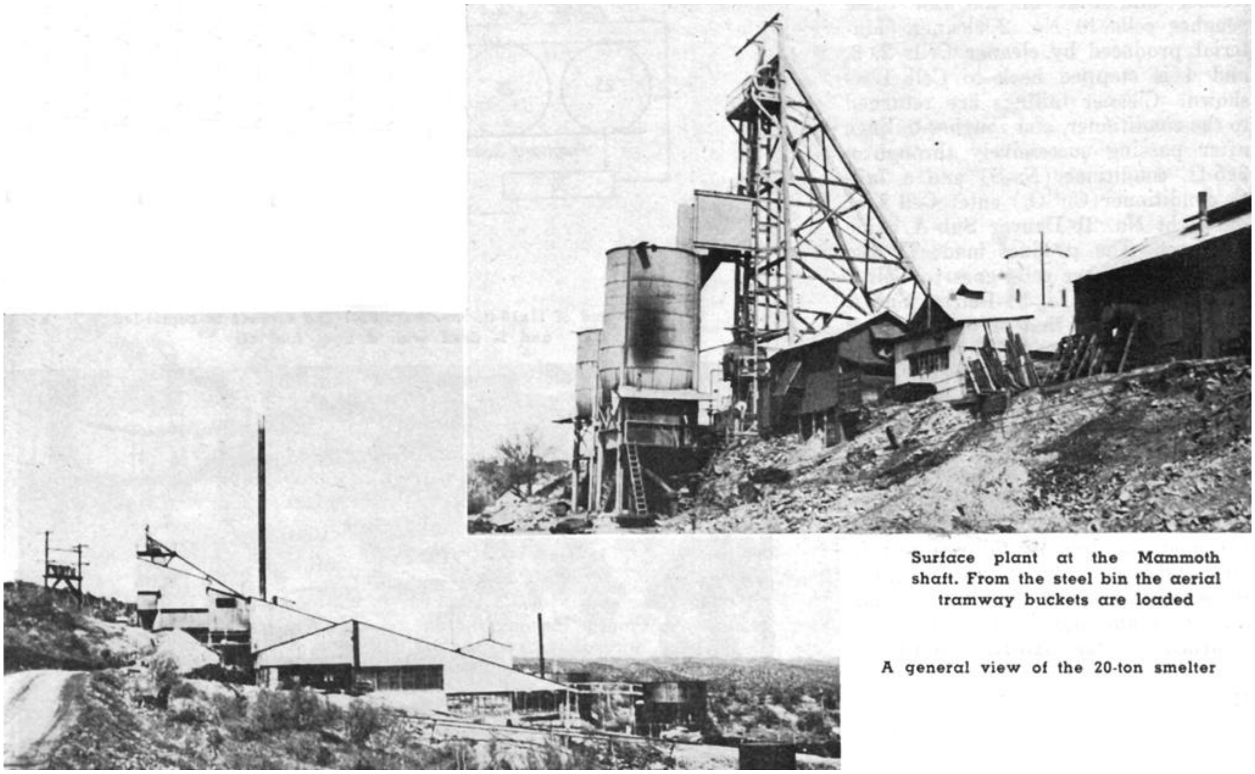
1879—Frank Schultz located the Hackney and Aaven claims on the Collins Vein (Huttl, 1943).
1881 & 1882—Location of the Mohawk, Mammoth, and Mars claims (Huttl, 1943).
1883—Mammoth Camp (Later Mammoth, AZ) established as mill site (Huttl, 1943).
1896—Town of Schultz, Arizona Territory established on the mine site (Huttl, 1943).
1879-1901—Mammoth Mine worked for gold.
1901—Workings caved from 750' level to surface. Mining ceased (Bideaux, 1980).
1902—May 1—Schultz, Arizona Territory post office closed (Wikipedia, 2013).
1913—Mine reopened by Great Western Copper Company (Huttl, 1943).
1915—Acquired by the Mammoth Development Company (Huttl, 1943).
1916-1919—Wulfenite reserves worked due to demand for molybdenum during WWI.
1919—Mines closed (Huttl, 1943).
1934—Mammoth, Collins, and Mohawk-New Years mines consolidated by the St. Anthony Mining and Development Company (Huttl, 1943).
1939—March 15—Town of Tiger, Arizona established. Named for the Princeton Tigers (one of the owner's alma mater) (Wikipedia, 2013). Maximum population at about 1800 (Wikipedia, 2013).
1934-1953—Mammoth St. Anthony Mine worked for gold, silver, lead, molybdenum, and vanadium.
1953—Mine properties and Tiger, Arizona sold to Magma Copper. Mining ceased (Bideaux, 1980).
1954—November 26—Tiger, Arizona post office closed, all structures eventually demolished (Wikipedia, 2013). Output of gold, silver, lead, molybdenum, and vanadium is estimated at $950 Million (Calculated 2012 dollars).

Tiger, Arizona—Geology at a Glance

The major regional geological unit is the Tertiary Cloudburst Formation, consisting of conglomerates and arkose originating from the underlying Precambrian Oracle granodiorite, interbedded with basalt and tuff (Bideaux, 1980). More locally, a younger porphyritic intrusive rhyolite is dominant, and is sometimes brecciated (Huttl, 1943). Faulting events established the initial vein structures, which were later filled with gangue and ore minerals. There is a potential relationship with the nearby and older San Manuel copper / molybdenum porphyry deposit (Bideaux, 1980), and probably contributed these elements to Tiger (Turner, 2006). Supergene weathering oxidized the veins to great depth. Finally, a second cross faulting event offset the main vein forming the lower Collins vein (oxidized to 600 ft) and the upper Mammoth vein (oxidized to about 900 ft) (Huttl, 1943).



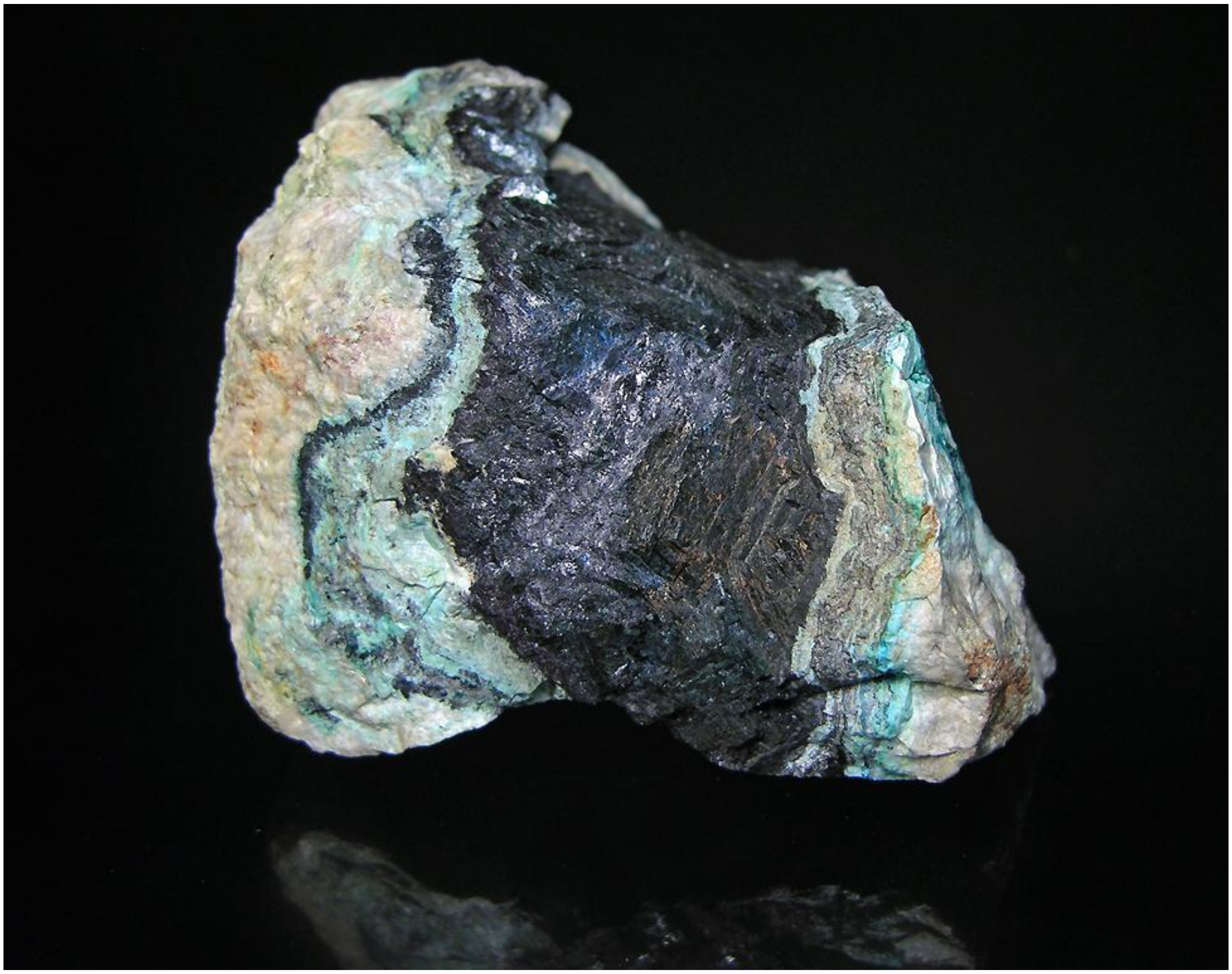
Vertical projection of the vein systems and the Mammoth fault (Huttl, 1943)



Surface plant at the Mammoth shaft. From the steel bin the aerial tramway buckets are loaded

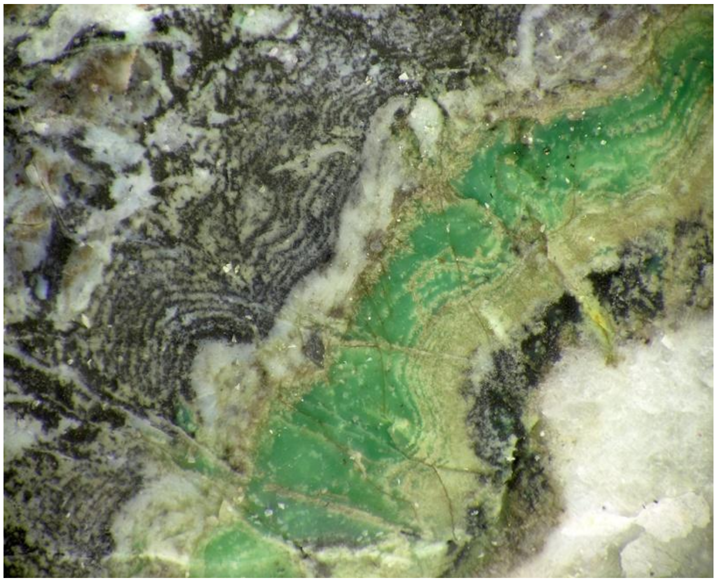
A general view of the 20-ton smelter

Mammoth-St. Anthony Mine surface plant and smelter—1941, (Huttl, 1943)



Galena pod in Chysocolla, Mammoth Saint-Anthony Mine—7.5 cm wide

Closed System Mineralogy



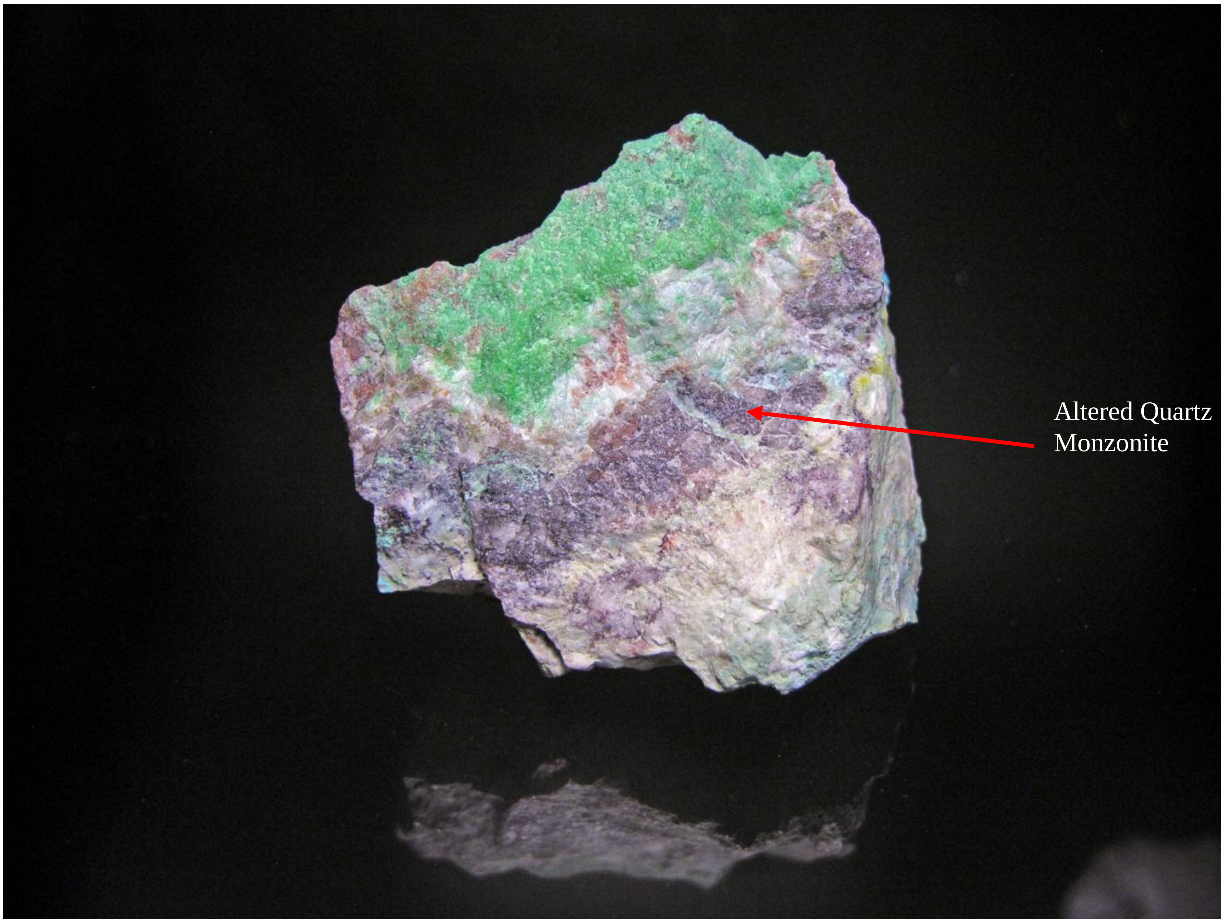
Intricate ore structure surrounding galena pod—1.6mm wide

The anomalous group minerals at Tiger very often contain halogen elements, notably chlorine, but also fluorine, bromine, and iodine, along with various metallic elements, predominantly lead and copper. The richness of specimens of many of these species far exceeds examples from any other locality. This unusual trait led to the theory, originally postulated by Sid Williams, that these minerals formed in closed systems (Bideaux, 1980). Such minerals typically could not persist unless they were constrained to react together, and would disperse. The image above shows a relict galena pod, surrounded by a complex and highly siliceous alteration rim. Galena played an important role as a starting point at Tiger. Many specimens bear witness to the presence of the original galena crystals, showing up as boxworks and other shapes.

A typical hydrothermal enrichment and oxidation sequence might start with the replacement of the original galena by copper sulfides. Oxidation would alter the galena to anglesite and the copper sulfides to chrysocolla. The anglesite would then alter towards cerrusite (Fahey, 1950). This is a normal oxidation sequence. Later, though, chlorine ions and possibly other halogen elements would become available, presumably from groundwater (Bideaux, 1980) associated with channels derived from fault movement (Fahey, 1950). The deposit is highly faulted, and includes the major cross-faulting event that broke off the upper portion, forming the Mammoth vein, from the lower, the Collins vein (Huttl, 1943). This allowed oxidation to great depths. Local conditions, which would presumably include the altered quartz monzonite wall rock and impervious chrysocolla, allowed the minerals that formed from the reactions between the halogen ions and the existing normal oxidized minerals to persist within closed lenses and to not be subject to further incursions of water.

Later work at other related deposits, such as the Mendip quarries near Somerset, England, showed clear evidence of mineralization in closed systems, and other phases where the pods were not completely enclosed and the volatile element mineralization did not persist (Turner, 2006). Although mining ceased at Tiger before this theory was postulated, evidence from existing specimens and the historical record strongly support the closed system theory.

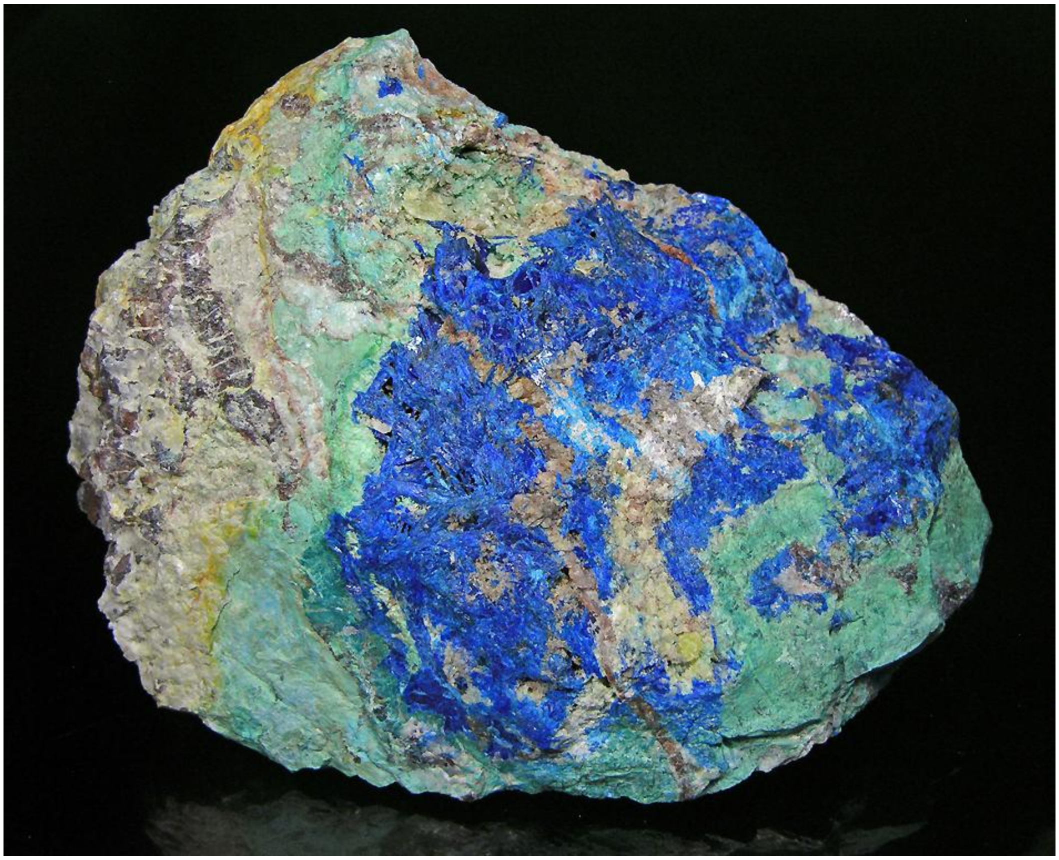
Descriptions of actual occurences at Tiger that support the idea of formation within closed systems are uncommon. One example of such a find was reported by Fahey, Daggett, and Gordon as a



Massive/Compact Fibrous Apple-Green Wherryite bordered by impermiable wall rock—5.5 cm wide

part of the original description of the species wherryite in 1950. "In May of 1943 one of the authors, E.B. Daggett, then mining engineer at the Mammoth Mine, discovered a small vug of leadhillite crystals associated with cerussite, anglesite, phosgenite, paralaurionite, hydrocerussite, diaboleite, boleite, matlockite, and quartz. Within the cavity was some friable chalcocite with a relict structure of the galena which it has replaced. The massive wall of the vug consisted of a light green fine granular mineral enclosing some bluish chrysocolla, and at the cavity some blue diaboleite and greenish paralaurionite. This green matrix was up to 5 cm in thickness and extended to the silicified wall of the vein-an altered quartz monzonite" (Fahey, 1950).

A letter from Daggett to Gordon dated March 11, 1949, says, "It [the vug] was a lens about a foot thick and three feet across. The outside shell of the vug was composed of massive minerals with chrysocolla on the outside grading to the apple green mineral [wherryite] toward the inside, and the chrystalline (sic) minerals making up the inside core'" (Bideaux, 1980).



A large, (14.5 cm across), specimen that depicts the closed system formation. The outer wall of the specimen (on the left) is an incredibly tough altered quartz monzonite. Inside of this is a layer of dense chrysocolla zoning to greenish, fine grained wherryite towards the inside. In the middle of the piece is a very rich pod of crystallized minerals, including blue diaboleite along with minor matlockite and paralaurionite. The specimen was once in the collection of Richard and Helen Rice, and was purchased by them in February 1960 in Tucson from George Bideaux (Richard's father).

The Pinalite Assemblage

The sealed nature of the lenses and pods that hosted the anomalous oxidized sequence minerals at Tiger presumably prevented subsequent egress of water that could have reacted with, replaced, and dispersed the contents of the pockets. There are instances that call into question whether this was universally the case at Tiger. In isolated cases, normal oxidized sequence minerals such as wulfenite have been found in association with some of the minerals attributed to the anomalous oxidized sequence.

While wulfenite was very common at Tiger, with 7500 tons of pure wulfenite concentrates being produced during its history (Bideaux, 1980), the mineral is not thermodynamically stable with lead chlorides, sulfates, and carbonates, and would tend to replace them (Turner, 2006).

Specimens from the Pinalite Assemblage differ from other specimens from the anomalous oxidized sequence. The typical anomalous oxidized sequence specimen is extremely rich. The large specimen of diaboleite shown above exhibits this trait very well. Such specimens frequently have borders of the very compact chrysocolla/wherryite, which are in turn bordered by the altered quartz monzonite wall rock. The mineralization that is present on these pieces is typically complex, but not as complex as specimens from the Pinalite Assemblage.

In contrast, wherryite, chrysocolla, and wall rock are not present in Pinalite Assemblage specimens. The matrix for Pinalite Assemblage specimens is a dense buff, tan, or slightly reddish quartz, which tends to be quite vuggy. Diaboleite is almost always present, but only as isolated pockets—a stark contrast with the typical anomalous sequence specimen. The mineralization in Pinalite Assemblage specimens is quite complex, with the typical small specimen hosting in the range of six to ten individual species.

Leadhillite and Caledonite are typically present in specimens from the Pinalite Assemblage. These are cross-over species at Tiger, because they occur in both the normal oxidized sequence and anomalous sequence environments. In the Pinalite Assemblage, both species tend to be etched. The leadhillite from the Pinalite Assemblage is typically yellow, and is commonly thought to be chromian. The caledonite from the Pinalite Assemblage is typically greener that is usual for the mineral, ranging to a bright apple-green. A WDS analysis performed for the author at Cannon Microprobe on this material confirmed that trace amounts of chromium were present and could be responsible for the green coloration.

The presence of chromium is significant. It is not present in the typical anomalous oxidized sequence specimen, but the element is relatively abundant in minerals of the normal oxidized sequence, for example in the minerals fornacite and macquartite. These species are members of a “trademark” Tiger association that consists predominantly of wulfenite, dioptase, and willemite, often on sky-blue clay (allophane) and on compact vuggy quartz. Thousands of such specimens were preserved. Other associated minerals in this assemblage include quartz, fluorite, cerussite, mimetite, and the aforementioned fornacite and macquartite.

The mineral species yedlinite, an extremely rare lead chromium oxy-chloride, is of interest in this discussion. Until recent finds of the yedlinite in Pinalite Assemblage specimens, specimens of yedlinite occurred in an association at Tiger that is a combination of anomalous and normal oxidized sequence minerals. Yedlinite occurs with wulfenite, dioptase, cerussite, willemite, and fluorite as per the “trademark” Tiger association described above. In addition, however, the yedlinite association includes diaboleite and phosgenite, which are anomalous group minerals. The yedlinite appears to be within a border phase, similar to the Pinalite assemblage and argues for a partially closed system. The highly siliceous compact quartz matrix would be fairly impervious, but possibly not so impervious as the chrysocolla / wherryite and altered quartz monzonite in the more typical anomalous sequence specimens.

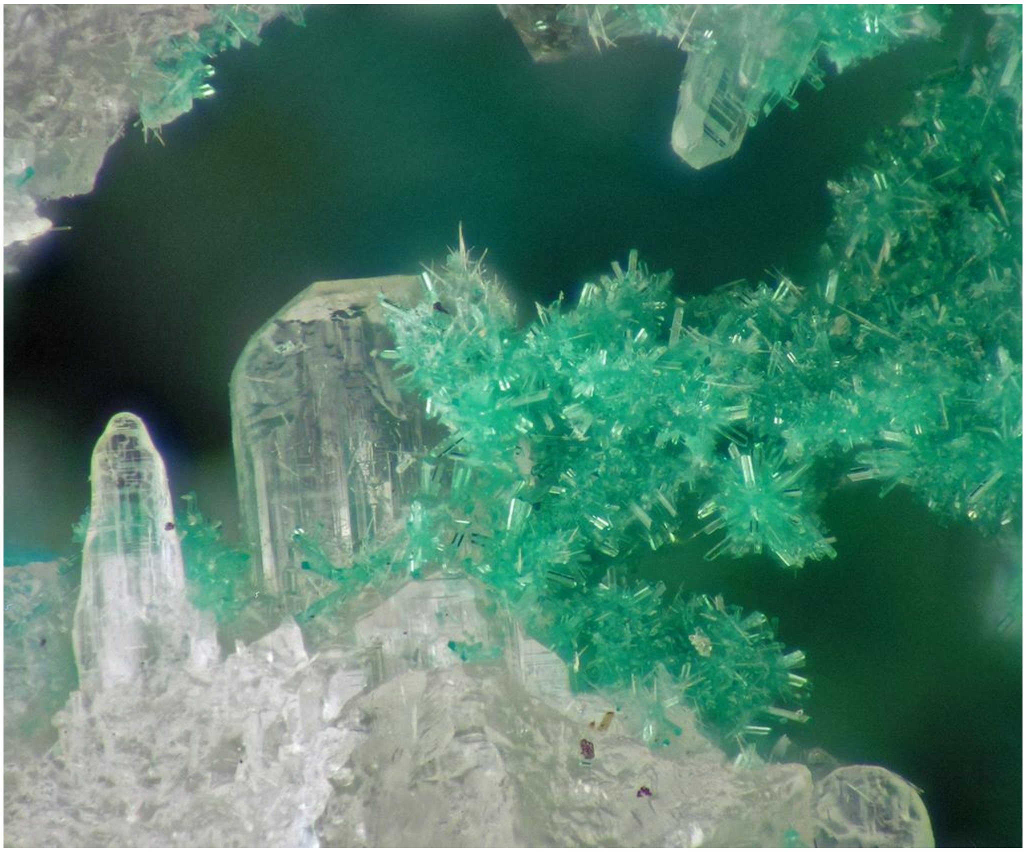
The Pinalite Assemblage argues similarly for a partially closed system. The lack of wherryite, chrysocolla, and wall rock; the more dilute amounts of diaboleite in contrast with the typical extremely rich example from the anomalous oxidized sequence; the presence of chromium in the leadhillite, caledonite, and in the species georgerobinsonite and bobmeyerite, and the generally etched condition of the minerals from the normal oxidized sequence, leadhillite and caledonite, are arguments for the Pinalite Assemblage representing another border phase at Tiger.

There is one historical account that appears to describe the occurrence of the Pinalite Assemblage at the Mammoth-Saint Anthony Mine. The account is in an unpublished Harvard term project written circa 1947-1948 by Ira Dubins, Dan E. Mayers, and Henry E. Wenden (Bideaux, 1980). "The . . . locality, on the east wall of the main haulage tunnel of the Collins vein, 500 level, is characterized by the occurrence of small crystals of diaboleite in occasional vugs in an exceptionally tough siliceous matrix. The diaboleite crystals are either alone or accompanied by small crystals of caledonite; these latter tend to be more green than that from other localities. These specimens are readily distinguished by their hard matrix and small, scattered diaboleite crystals (Bideaux, 1980).

Minerals of the Pinalite Assemblage

The following list of species has been identified from the pinalite assemblage. In most cases, specimens from the assemblage will have quite a number of these species present. Ten different species is not an unusual total. Some of the species occur quite sparingly, or are very rare in the assemblage. Those that are not will typically be present on each piece. All are typically micro-sized, with most crystals ranging between 0.1 to 1.0 mm.

Atacamite, $Cu_2(OH)_3Cl$ occurs very sparingly in the assemblage as tiny green to blue-green prismatic crystals. The attribution of atacamite is via sight ID only; none of the material has been analyzed to the knowledge of the author, but the form is very consistent with that mineral. The mineral will sometimes occur in isolated vugs. Specimens are known with atacamite in association with bobmeyerite and caledonite.

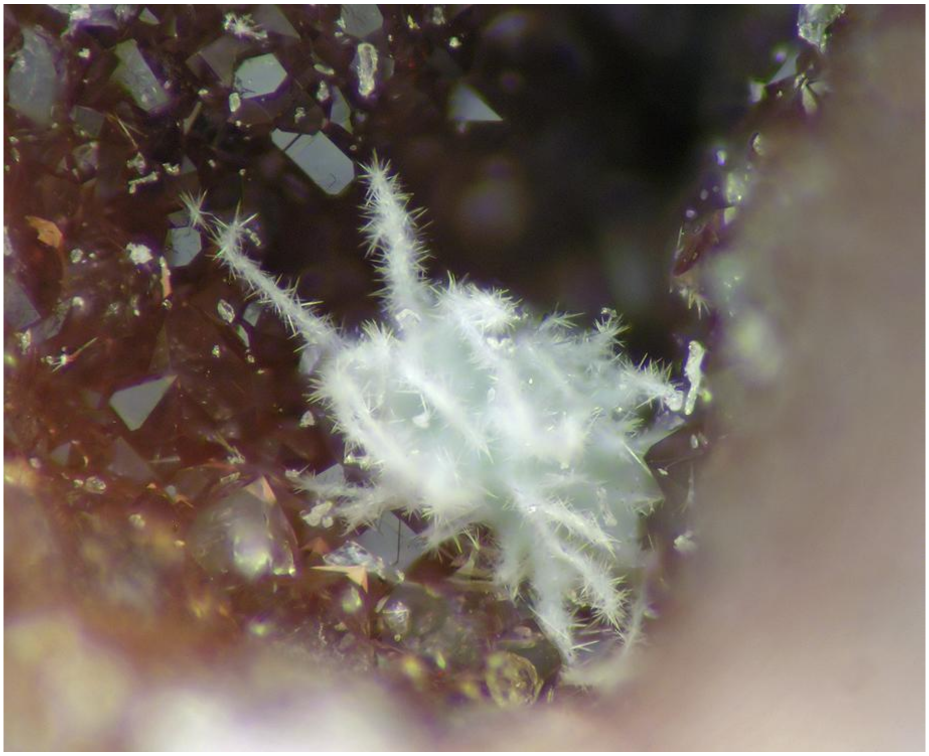


Atacamite—green prismatic crystals associated with white acicular bobmeyerite and white to colorless cerussite crystals. The identity of atacamite has not been confirmed via analysis, but the form and color are consistent with that mineral. The field of view is 0.9 mm. Tom Loomis specimen.

Bobmeyerite, $Pb_4(Al_3Cu)(Si_4O_{12})(S_{0.5}Si_{0.5}O_4)(OH)_7Cl(H_2O)_3$ occurs in the assemblage as colorless, white, cream-colored, pale blue, pale green, or pale yellow needle-like crystals, up to 300 μ in length, tapering to sharp points (Kampf, 2013), and often aggregating into groups that exhibit larger morphology or form in odd twisting groups that can resemble fuzzy caterpillars. Small percentages of chromium and copper were detected in the analyses, but were not considered essential (Kampf, 2013). The mineral is common and widespread among Pinalite Assemblage specimens, although it should be noted that specimens from the assemblage are quite rare themselves. The description of the mineral was published in the February 2013 issue of *Mineralogical Magazine*. The mineral was approved by the IMA in 2012 (IMA 2012-019).

The mineral has been known for some time. Richard A. Bideaux described an unknown lead silicate that undoubtedly was bobmeyerite in his 1980 *Mineralogical Record* article on Tiger. The author obtained his first specimen from Tiger in 1977, and later noted the mineral on that piece. Analyses were undertaken at Cannon Microprobe facilities in Seattle on the material in the late 1980s, and showed it to be a likely new species, but the fine acicular nature of the mineral and lack of any scientist willing to undertake the description efforts resulted in no work being done on the material. The EDS and WDS analysis showed the mineral to be a lead aluminum silicate with minor copper.

In 2008, photographs of the species were posted on Mindat.org and identified as being the species mattheddleite, a lead silicate sulfate chloride hydroxide. The photographs and the identity of mattheddleite were discussed on the Mindat message board along with the contradictory earlier analysis results obtained by the author. Further off-line discussion of this, especially among a group of Tiger mineral enthusiasts including Joe A. Ruiz, Brent Thorne, Bruce Murphy, and the author, furthered the idea that the ID of mattheddleite was questionable. The group contacted Dr. Anthony Kampf of the Mineral Sciences Department at the Natural History Museum of Los Angeles County who agreed to analyze samples to help solve the controversy.



Bobmeyerite—branching aggregates of fine acicular crystals on quartz. The field of view is 1.5 mm.

Bobmeyerite—acicular crystals forming elongated acicular aggregates. The field of view is 1.6 mm.

Dr. Kampf determined that the mineral was related structurally to ashburtonite and cerchiaraite, but that the mineral would be very difficult to describe due to the acicular nature of the crystals. The fineness of the crystals would complicate both elemental analysis and the x-ray work needed to solve the structure. Ultimately, however, the authors persevered and single crystal work was accomplished by the authors at the Advanced Photon Source at the Argonne National Laboratories, and an acceptable elemental analysis was obtained by another author at the Division of Geological and Planetary Sciences, California Institute of Technology.

Bobmeyerite was found to have the same general structure as cerchiaraite and ashburtonite (Kampf, 2013). The mineral is orthorhombic and the structure features large channels, which run parallel to [001] (Kampf, 2013). It is a cyclosilicate with four-membered silicate rings (Kampf, 2013).

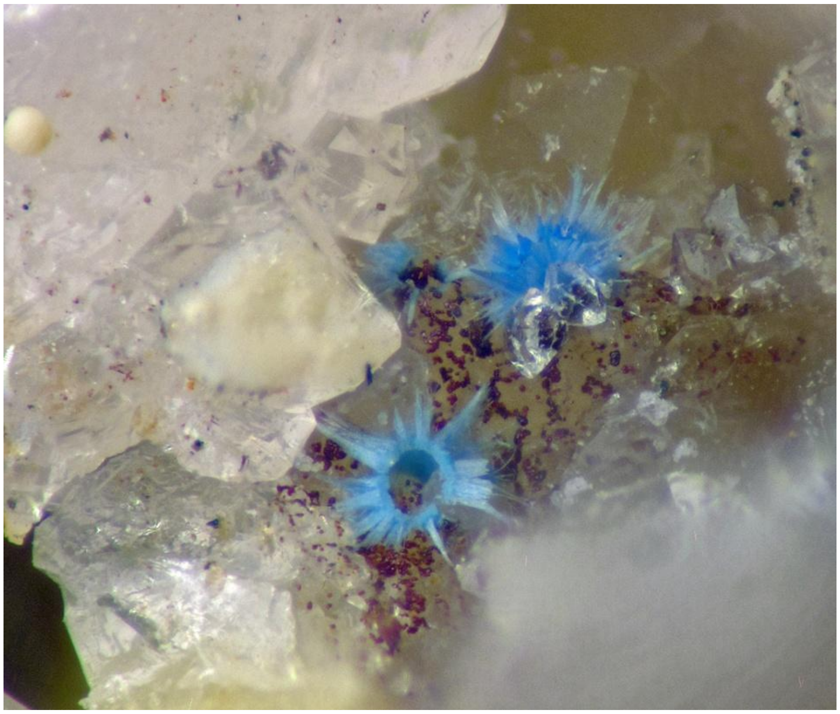
Caledonite, a crystal that exhibits the green coloration that is typical of the Pinalite Assemblage. The crystal is on diaboleite, and a small colorless crystal of matlockite is perched on the diaboleite. Associated with quartz. The field of view is 5.5 mm.

Caledonite, $Pb_5Cu_2(SO_4)_3(CO_3)(OH)_6$ occurs on most specimens from the assemblage in etched masses to well formed crystals, most often of a color that is greener than is typical for caledonite. The color ranges to a bright apple green. Caledonite seems most often to be associated in the assemblage with leadhillite. A WDS analysis performed at Cannon Microprobe facilities in Seattle confirmed the presence of trace amounts of chromium, which is possibly responsible for the green coloration.

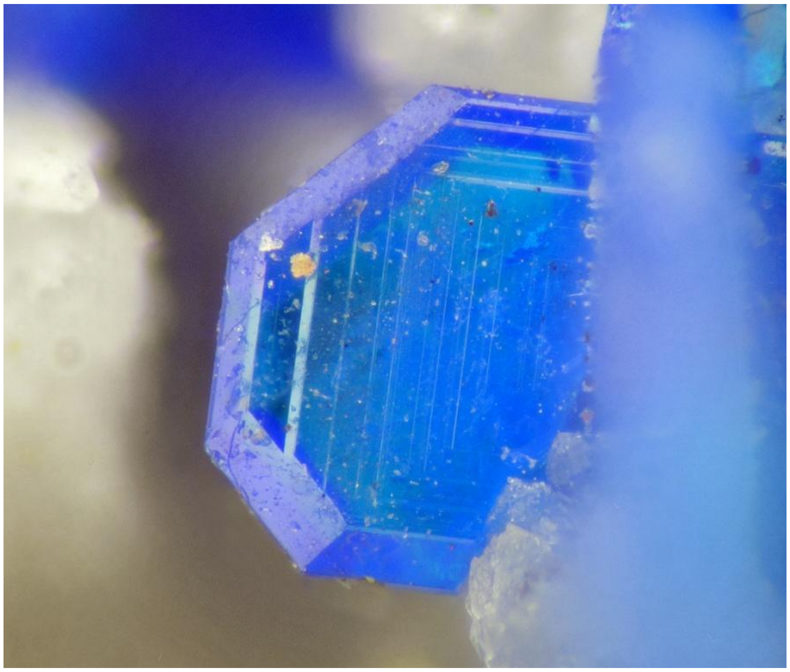
Caledonite—etched crystals with white acicular bobmeyerite on quartz. These crystals are bluer than is typical for Pinalite Assemblage caledonite. The field of view is 2.1 mm. Tom Loomis specimen.

Cerussite, $PbCO_3$ is common in the assemblage as well-formed crystals and reticulated groups. Bobmeyerite is sometimes associated with cerussite and is sometimes included in cerussite.

Connellite, $Cu_{19}(SO_4)(OH)_{32}Cl_4 \cdot 3H_2O$ is very rare in the assemblage as tiny blue divergent radiating sprays of crystals.



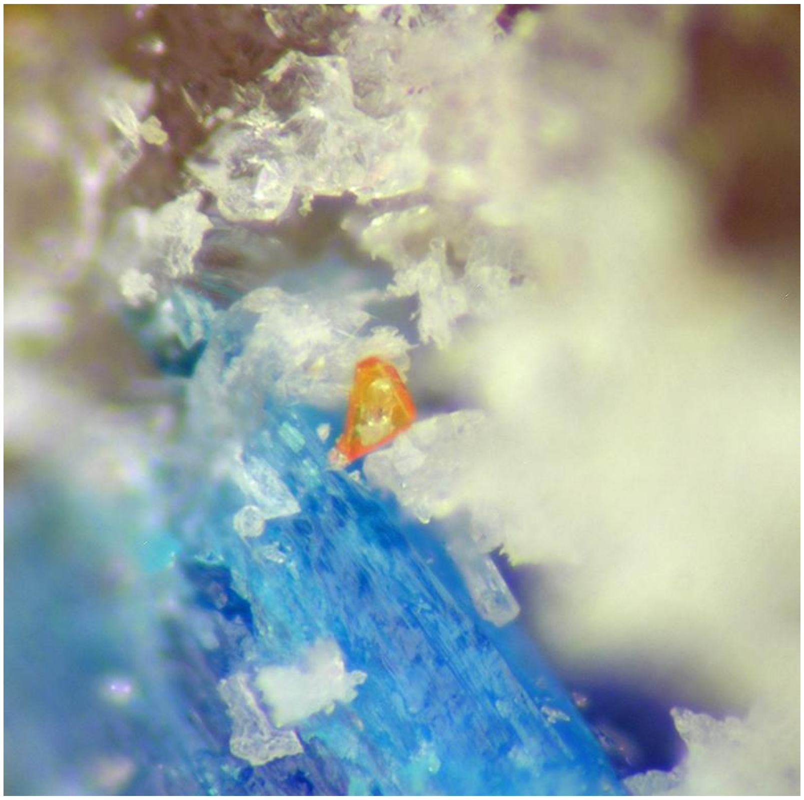
Connellite—divergent radiating sprays of silky blue acicular crystals on quartz with red hematite balls. The field of view is 0.8 mm.
Tom Loomis specimen.



Diaboleite—a sharp transparent deep blue striated crystal. The field of view is 0.8 mm.

Diaboleite, $Pb_2CuCl_2(OH)_4$ is present on almost all pinalite assemblage specimens as isolated pockets of deep blue crystals, sometimes well-formed, and associated at times with matlockite.

Georgerobinsonite, $Pb_4(CrO_4)_2(OH)_2FCl$ rarely occurs in the assemblage as tiny, less than 0.1 mm, orange red tabular crystals and aggregates of crystals (Cooper, 2011). Georgerobinsonite is usually associated with bobmeyerite, and occurs with some of the other species in the assemblage, such as diaboleite, cerussite, quartz, and leadhillite. The mineral was described in 2011. Specimens have been known for some time. One photograph of the mineral was on Mindat for some years, but identified as iranite.



Georgerobinsonite—a partial orange tabular crystal on blue diaboleite. The field of view is 0.6 mm.

Georgerobinsonite—orange tabular crystal on yellow leadhillite with quartz and minor white acicular bobmeyerite. The FOV is 0.7 mm.

Hematite, FeO_2 occurs in the assemblage as small black to sub-metallic bladed crystals and as reddish staining and inclusions in quartz.

Leadhillite, $Pb_4(CO_3)_2(SO_4)(OH)_2$ occurs on most specimens from the assemblage as small lemon yellow etched crystals and masses. The leadhillite from the pinalite assemblage is reported to be chromian. It is often associated with caledonite and bobmeyerite, but is also associated with other species.

Leadhillite, a lemon-yellow crystal on quartz. The field of view is 1.5 mm.

Matlockite, PbFCl rarely occurs in the assemblage as colorless to white thin tabular crystals. The shape of the crystals tends to be fairly square, with the corners cut off and angled. Matlockite most commonly occurs with or on diaboleite.

Matlockite, white to colorless tabular crystal on diaboleite. The field of view is 5.5 mm.

Murdochite, $PbCu_6O_{8-x}(Cl,Br)_{2x}$ where $x<=0.5$ has been reported from the assemblage as tiny black octahedral crystals. No subject specimen examined by the author has murdochite present. The Mammoth Saint Anthony Mine is the type locale for murdochite. It is typically found at Tiger in association with species from the normal oxidized sequence, such as mimetite and creaseyite.

Phosgenite, $Pb_2(CO_3)Cl_2$ was reported to be present in the association by the authors of the papers on bobmeyerite (Kampf, 2013).

Pinalite, $Pb_3WO_5Cl_2$ rarely occurs in the assemblage as tiny acicular bladed yellow crystals, often twinned at 90 degrees, and possessing sword-shaped terminations. The mineral is flexible, exhibiting bends when crystal growth has continued despite being constrained in length by pocket walls. The maximum length of the crystals is 0.2 mm (Dunn, 1989). Pinalite, the namesake species of this paragenesis, was the first of the new species in the assemblage, having been described in 1989.

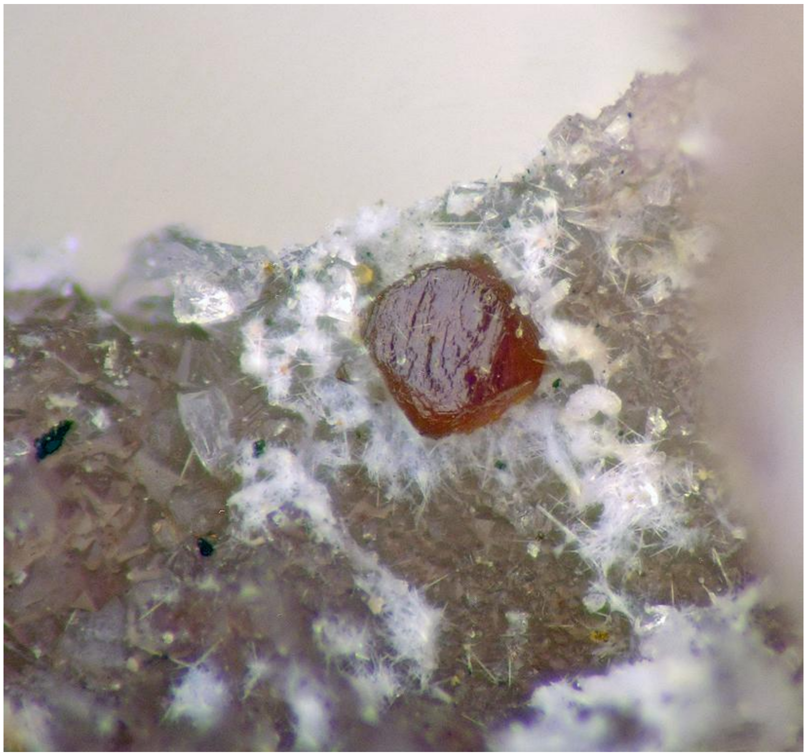
Quartz, SiO_2 is the major constituent of the matrix rock for the pinalite assemblage. The matrix is vuggy, and the vugs are usually lined with druzes of quartz crystals.

Yedlinite, $Pb_6Cr^{3+}Cl_6(O,OH,H_2O)_8$ occurs very rarely in the assemblage as tiny magenta to lilac etched crystals. No subject specimen examined from the pinalite assemblage by the author has yedlinite present. The Mammoth Saint Anthony Mine is the type locale for yedlinite, but the typical association that it occurs in is not the Pinalite Assemblage. The typical paragenesis of yedlinite represents another border phase at Tiger.

Pinalite—twinned lemon-yellow crystals on quartz with acicular bobmeyerite. The field of view is 1.1 mm. Richard Thomssen specimen.

Pinalite crystals with hematite and quartz. The crystals exhibit the flexible nature of the mineral and its twinning at 90 degrees. The field of view is 0.6 mm.

Unidentified Minerals. There are quite a number of as-yet unidentified minerals present in the assemblage. These minerals often exist in only a few crystals.



Unidentified red-brown crystal with bobmeyerite on quartz. The field of view is 1.0 mm.

Unidentified lemon-yellow mineral on quartz. The field of view is 1.2 mm.

Conclusion

The Mammoth Saint Anthony Mine, Tiger, Pinal County, Arizona is fascinating to mineral collectors on a number of levels. For one, the deposit produced large numbers of very fine display quality specimens in a variety of species. The mine ceased operating in 1953, so specimens have become very scare and very highly prized among collectors.

To really appreciate Tiger, however, it is necessary to study the material with a microscope. Tiger is one of the most interesting micro mineral localities in the world, particularly when it comes to rare species, many of which belong to an anomalous oxidized sequence. This sequence produced specimens of species, such as diaboleite and paralaurionite, which are far richer than at any other deposit. There is good evidence that formation within closed systems was responsible for the persistence of such rich specimens of these species.

Another paragenesis at Tiger, referred to here as the Pinalite Assemblage, calls into question whether all such specimens at Tiger formed within completely sealed environments. The rare halogen containing species, such as diaboleite, that occur in the assemblage are much more dilute than in the typical anomalous group specimen. There is no evidence of wall rock, chrysocolla, or wherryite, which typically act as sealing agents in the anomalous group specimens. Despite this, the rock matrix of the Pinalite Assemblage itself is highly siliceous, and is relatively impermeable. Some of the species present contain chromium, which is not usually present in the anomalous group minerals, but is in the normal sequence minerals. Taken together, the Pinalite Assemblage argues for a partially closed system, where enough constraint existed to not allow all of the halogen containing species to disperse, but that would also allow them to react with elements that were present from the normal oxidized sequence chemistries.

The Pinalite Assemblage has produced three new minerals, pinalite (1989), georgerobinsonite (2011), and bobmeyerite (2013).

Acknowledgements

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On an organizational level, Mindat.org was invaluable in this process, first for providing the forum whereby the initial discussions regarding Tiger unknowns took place, and directly in helping with this article by providing general mineralogical knowledge, such as the chemical compositions of minerals.

Finally, the author would like to thank the miners and mineral dealers who helped to preserve specimens from this historically significant locality.

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