THE PICKING TABLE

JOURNAL OF THE FRANKLIN-OGDENSBURG MINERALOGICAL SOCIETY

VOL. 61, NO. 2 – FALL 2020

$10.00 U.S.

IN THIS ISSUE

- **Minerals of the Apatite Supergroup at Franklin and Sterling Hill, With Historical Notes**
- **The Sparta Flood of August 2000 and the Partial Collapse of the "Backwards Tunnel" in Ogdensburg, N.J.**

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The Franklin-Ogdensburg Mineralogical Society, Inc.

OFFICERS AND STAFF

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GARY KERSTANSKI
P.O. Box 703
Goshen, NY 10924
C: 845-978-4141
glowrocks703@gmail.com

VICE PRESIDENT

RALPH BONARD
P. O. Box 282
Ogdensburg, NJ 07439
C: 973-222-9968
rbonard@yahoo.com

SECOND VICE PRESIDENT

STEPHANIE KOLES
C: 973-370-2898
stephanie.koles@gmail.com

SECRETARY

TEMA J. HECHT
600 West 111th Street, Apt. 11B
New York, NY 10025
H: 212-749-5817
C: 917-903-4687
thecht@att.net

TREASURER

DENISE KROTH
85 Beaver Run Road
Lafayette, NJ 07848
W: 973-209-7212
Denise.Kroth@shmmuseum.org

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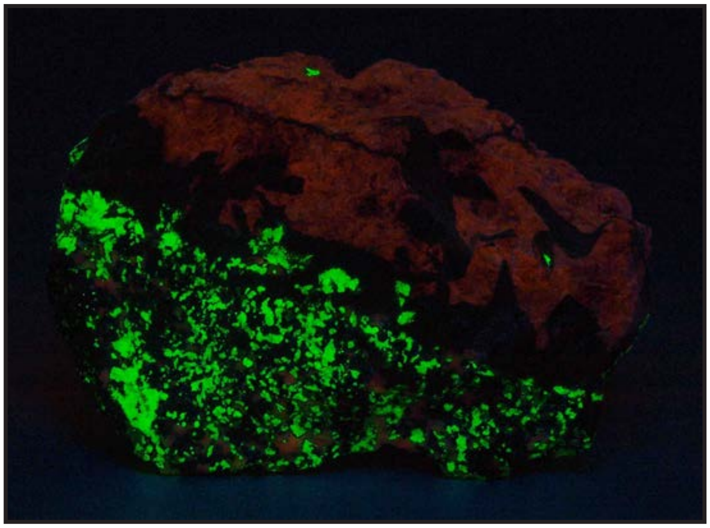

THE PICKING TABLE

VOL. 61, NO. 2 – FALL 2020

ABOUT THE FRONT COVER

This issue of *The Picking Table* features a landmark article on apatite from the Franklin-Sterling Hill mining district, by Earl Verbeek and Richard Bostwick. Literally years in the making, it is the product of extensive laboratory work, careful analysis, and their combined experience collecting and studying our local apatite species. Cover photo: Hedyphane with rhodonite, from Franklin, N.J. Facing page: The same specimen under midwave UV light. Read their article for more details.

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PUBLISHER
THE FRANKLIN-OGDENSBURG MINERALOGICAL SOCIETY, INC.

MANAGING EDITOR
JAMES VAN FLEET

EDITORS
RICHARD C. BOSTWICK
MARK A. BOYER
TEMA J. HECHT
ALEX KERSTANSKI

ART DIRECTOR
CAITLIN WHITTINGTON

PRINTING
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Denise Kroth, Treasurer, FOMS
85 Beaver Run Road
Lafayette, NJ 07848
treasurer@fomsnj.org

The Picking Table is the official publication of the Franklin-Ogdensburg Mineralogical Society, Inc. (FOMS), a nonprofit organization, and is sent to all members. *The Picking Table* is published twice each year and features articles of interest to the mineralogical community that pertain to the Franklin-Ogdensburg, New Jersey, area.

Members are encouraged to submit articles for publication. Articles should be submitted as Microsoft Word documents to James Van Fleet at javanfleet8@gmail.com.

The views and opinions expressed in *The Picking Table* do not necessarily reflect those of FOMS or the editors.

FOMS is a member of the Eastern Federation of Mineralogical and Lapidary Societies, Inc. (EFMLS).

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FRANKLIN-OGDENSBURG MINERALOGICAL SOCIETY
FALL AND WINTER 2020 ACTIVITY SCHEDULE

WWW.FOMSNJ.ORG **COMPILED BY TEMA J. HECHT**

Due To The Covid-19 Pandemic, Check Online Media For Confirmation Of All Events.
Proper Wearing Of Masks And Social Distancing Required For All Activities.
!!!FOMS MEETINGS AND SPEAKERS TBD!!!

SATURDAY, SEPTEMBER 19, 2020

9:00 AM – NOON
FOMS Field Trip
Collecting at the Hamburg Mine/Lang Shaft (private property)
Meet at the Franklin Mineral Museum at 8:30 AM *sharp*, where participants will be escorted to the location.

SATURDAY AND SUNDAY SEPTEMBER 26-27, 2020

****64TH ANNUAL FRANKLIN-STERLING GEM & MINERAL SHOW**
THIS WILL BE AN OUTDOOR EVENT ONLY
Sponsored by the Franklin Mineral Museum and the Franklin-Ogdensburg Mineralogical Society (FOMS).
Outdoor vendor setup time: 7:00 AM

!!!NEW LOCATION!!!
FIREMEN’S MEMORIAL PARK
Parker Street and Buckwheat Road
(across from the Franklin firehouse),
Franklin, New Jersey.
9:00 AM – 5:00 PM Saturday
10:00 AM – 4:00 PM Sunday
$7.00 per day for adults, $4.00 per day for children (6-16).
Food can be purchased in the pavilion, courtesy of the Franklin Fire Department.

THERE WILL BE NO FOMS BANQUET ON SATURDAY, SEPTEMBER 26.

**FRIDAY AND SATURDAY SEPTEMBER 25-26, 2020

10:00 AM – 4:00 PM
Mineral sale at the Franklin Mineral Museum

**SATURDAY AND SUNDAY SEPTEMBER 26-27, 2020

Garage sale and mineral collecting at the Sterling Hill Mining Museum.
For more information, please call: **(973) 209-7212**.
Or visit the website at **www. sterlinghillminingmuseum.org**

WEDNESDAY-SUNDAY, SEPTEMBER 30-OCTOBER 4, 2020

****NY/NJ Mineral, Fossil, Gem & Jewelry Show**
New Jersey Convention & Expo Center, Raritan Center
97 Sunfield Ave., Edison, N.J.
For more information, please go to: **www.ny-nj-gemshow.com**.

SATURDAY, OCTOBER 3

****Collecting on the Buckwheat Dump at the Franklin Mineral Museum**
Noon – 5:00 PM daytime collecting
6:00 PM –10:00 PM night collecting.
Fee charged.

SATURDAY AND SUNDAY OCTOBER 10-11, 2020

9:00 AM – 5:00 PM
****NORTH JERSEY MINERALOGICAL SOCIETY SWAP**
Sterling Hill Mining Museum.

SATURDAY, OCTOBER 17, 2020

9:00 AM – NOON
FOMS Field Trip
Sterling Hill Mining Museum.
Collecting permitted on the Mine Run Dump and in the Fill Quarry, Passaic Pit, and “saddle” area.
Admission fee waived. $2.00 for each pound of material taken.
For more information, call 973-209-7212.

SATURDAY, NOVEMBER 7

11 AM – NOON
FOMS Meeting
Franklin Mineral Museum Pavilion.

****Collecting on the Buckwheat Dump at the Franklin Mineral Museum.**
Noon – 5:00 PM daytime collecting
6:00 PM – 10:00 PM night collecting
Fee charged.

⚒ ⚒ ⚒ ⚒ ⚒ ⚒ ⚒ ⚒ ⚒ ⚒ ⚒

Scheduled activities of the FOMS include meetings, field trips, and other events. Regular meetings are held on the third Saturdays of March, April, May, June, September, October, and November, and generally comprise a business session followed by a lecture. FOMS meetings are open to the public, and are held at 1:30 PM, usually in Kraissl Hall at the Franklin Mineral Museum, 30 Evans St., Franklin, N.J. (check listings for exceptions). Most FOMS field trips are open only to FOMS members aged 13 or older. Proper field trip gear required: hard hat, protective eyewear, gloves, sturdy shoes.

**Activities so marked are not FOMS functions but may be of interest to its members. Fees, and membership in other organizations, may be required.

Schedule information, including fees, is subject to change without notice.

President's Message

GARY KERSTANSKI
P.O. BOX 703
GOSHEN, NY 10924
glowrocks703@gmail.com

Well, it certainly has been an unprecedented year thus far. First we had to feverishly work to put the pieces of the Spring show back together. Then Covid-19 arrived and changed everything in our lives. Unfortunately, this forced the cancellation of the Spring show. Our spring activities also fell victim to the pandemic. Some of the new changes I was hoping to institute have been put on hold indefinitely.

On the brighter side, the Franklin Mineral Museum had a very successful volunteer day July 11th, with the intention of doing some light maintenance and cleanup for reopening soon. Many FOMS members volunteered their time and we wish to thank them all. Although the museum has not resumed its normal schedule, they did open the Buckwheat Dump a few days. This allowed everyone to get outside and dig some rock.

Our Fall schedule will be a little bit different than our past experiences. We are hoping to have some in-person activities and possibly some virtual meetings. Hopefully science will catch up to the virus and we may return to our more normal lives and activities. The fall show will have a new venue. For this year there will be no indoor show, but we will have the outdoor "Pond" swap at the Firemen's Memorial Park in Franklin. We invite everyone to volunteer some time for our show and activities wherever you can lend a hand.

The Picking Table is well-renowned as a top-notch, award-winning publication. Jim Van Fleet and his editorial staff are working hard to keep it that way, but we need your help. So pull out one of your favorite specimens and consider writing an article. If not, at least you can use this time to enjoy your specimens and bring your catalog up to date.

Please look at our website and Facebook page, expertly handled by Bill Pazik and Tema Hecht, respectively, for current up-to-date information regarding all of our activities.

Stay safe. ⚒

From the Editor's Desk

JAMES VAN FLEET
222 MARKET STREET
MIFFLINBURG, PA 17844
javanfleet8@gmail.com

Why is being an editor like being an nineteenth century dentist?

Well, if we believe author Patrick O'Brien, dentistry aboard an English man-of-war in 1812 involved beating a drum loudly in the patient's ear, to stun him into insensibility. The offending tooth was then invariably pulled (no other treatment was possible), using crude instruments or even just by hand!

On land, you could expect your local barber to do the job, after giving you a close shave. At least the instruments were clean.

Yes, being an editor is like beating the drum to promote participation in *The Picking Table*, and pulling teeth to get content! I find that producing every issue of the *PT* is a close shave (drumroll please).

I'm not complaining; I knew the job was dangerous when I took it. Above and beyond the "usual suspects" who can be relied on for content, we are seeing participation from new authors, photographers, researchers, and storytellers. This issue features a really important article on the apatite minerals from Franklin-Sterling Hill, courtesy of regular contributors Dr. Earl Verbeek and Richard Bostwick. Please, FOMS members, know that you are invited! In fact, we would like to put together a special issue, as we have in the past, of stories and tales from our members, including former Franklin or Sterling Hill miners, mineral collectors, researchers, curators, and dealers.

If you have a yarn to share, whether it is about work or play, the "best thing in your collection" or the one that got away, please consider sending it to us. A picture is worth a thousand words, but does not take up as much printing space.

Here's hoping we can continue to give our FOMS readers something they can sink their teeth into, and to offer just a bit of business-as-usual in what are being politely called "difficult times." ⚒

Happenings at Sterling Hill

BILL KROTH
PRESIDENT, STERLING HILL MINING MUSEUM
30 PLANT STREET, OGDENSBURG, NJ 07439

Due to the coronavirus, Sterling Hill Mining Museum closed to the public on March 16. Some of our staff maintained the property during this shutdown, and key folks, including Denise and I, returned in Mid-June. We are in a good situation regarding cash reserves, so we can weather the pandemic regardless of its duration, but we do not anticipate school field trips returning in full for at least a year.

As of August 2020, we are gradually easing back into opening and have given family, birthday party, and special guest tour events following all guidelines set by the CDC and State of New Jersey. I am also taking reservations with colleges for the Fall semester. We hope that in several months we can accommodate the general walk-in public.

During this hiatus, I have adopted the viewpoint that we will all get through this, and it is best to have some nice accomplishments to show for the downtime. Sterling Hill has completed its pavilion and replaced its old vinyl panels with a new glass and aluminum storefront. A new roof has been installed on the pavilion along with a new ceiling fan to keep things cool. As of this writing, we have ordered a new rubber tile floor to cover the existing concrete slab. It really looks "finished" now.

Our gift shop received a new roof and the interior was completely detailed.

Alex Kerstanski and Ken Daubert completed priming and painting our 1942 caboose. It came out much better than I ever expected. By the time you read this, all of the numbering and lettering should be completed. Sue Conklin and Carol Dunn gave the interior a final perfect cleaning.

Doug Francisco worked on various site projects including the motorized manlift / ore skip at the shaft station, and extracting "last day" ore from the day bin on the upper property. Doug has moved to California but has promised that he will spend several months at Sterling Hill every year, helping us.

During July, we rented a man-lift for a week, and Alex Kerstanski completed the roof on our new ten-stamp mill, applied preservative and stain to both of our stamp mills, repaired the soffits on our office building, and repaired various items that could only be reached with a lift.

Tour guide Andy Marancik was able to obtain two important telescopes from the Delmhorst Memorial Observatory of the Montclair University School of Conservation, near Stokes State Forest, Sussex County, N.J. Both are refractor (all-lens) telescopes made in the 1930s and 1940s. That facility closed, and we are now in the process of restoring both telescopes for our astronomy program. Parts were missing and the mounts were seized and broken, but we have nicely solved all of the mechanical and optical issues. We hope to have "first light" for Labor Day when both Jupiter and Saturn are well placed for viewing.

I read that one out of three museums in the U.S.A. will not reopen due to the effects of the coronavirus. Thankfully, Sterling Hill will not be one of them! ⚒

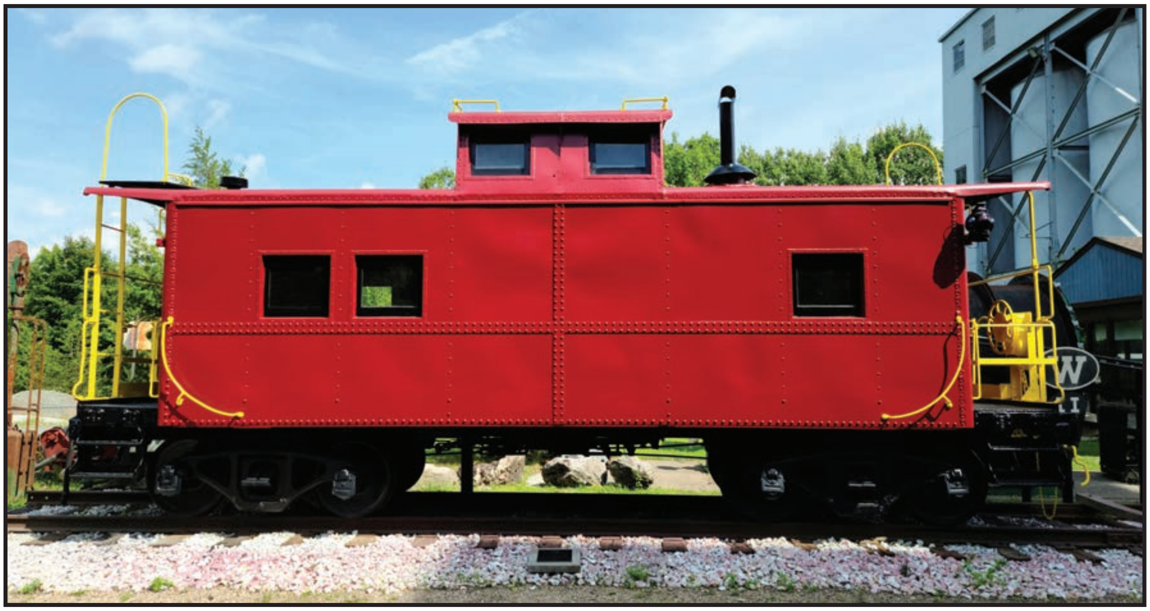

Figure 1. 1942 caboose with its final coat of paint. *Photo by Alex Kerstanski.*

The Sparta Flood of August 2000 and the Partial Collapse of the "Backwards Tunnel" in Ogdensburg, N.J.

MARK BOYER
25 CORK HILL ROAD
OGDENSBURG, NJ 07439
markaboyer@earthlink.net

It has been 20 years since the great flood of August 11 – 14, 2000, that created major havoc throughout southeastern Sussex County, western Morris County, and parts of Warren and Hunterdon Counties. The localized thunderstorms stalled over Sparta Mountain on Saturday, August 12, and dumped as much as 18 inches of rain in 24 hours. The greatest intensity was 15 inches of rainfall between 9 a.m. and 3 p.m., considered to be a once-per-1,000-year event. As the old-timers used to say, "We ain't had rain like that since Hector was a pup." Remarkably, just 10 miles to the east, rainfall that day was less than an inch, and in Wayne, N.J., the sun was shining and the skies were clear.

The resulting flooding of streams and rivers caused massive devastation to homes, roads, bridges, and dams. About 2,700 homes and businesses were flooded, and 2,600 people were evacuated to shelters on higher ground. Twenty-six dams sustained damage, and an additional four dams were washed out completely, draining the impounded waters behind them. Entire hillsides collapsed, turning the rivers and streams into raging torrents of mud and debris. Three bridges were destroyed and many others were rendered impassible. Portions of three roads were washed away and two dozen other roads were significantly damaged. The region suffered nearly $180 million in damage and was declared a federal disaster area.

Among the casualties was Ogdensburg's famed Double Arch Tunnel, popularly albeit erroneously known as the "Backwards Tunnel." The dual tunnel was built in 1871, part of a viaduct to carry the New Jersey Midland Railroad over the Wallkill River valley; its larger tunnel spans the Wallkill River and the parallel smaller tunnel contains a one-lane-wide section of Cork Hill Road. The length of both tunnels is 176 feet, 6 inches. During the late afternoon of August 12, the flood-swollen Wallkill River poured through the Cork Hill Road tunnel (Figs. 1 and 2) and started ripping up chunks of the road surface. The floodwater crested during the night at about where the base of the arch meets the vertical wall, a height of about four feet. (The anecdotal report in the book *The Backwards Tunnel* of the water reaching to within a foot from the top of the roof of the tunnel is a wild exaggeration.)

The force of the raging floodwaters ripped up the asphalt at the northern (i.e., downstream) portal of the tunnel and undermined the road's base. As the roadbed inside the tunnel washed away, the ground supporting the tunnel's western abutment gave way and an approximately 36-foot-long section of the stonework at the base of the tunnel collapsed. Several of the stones, some weighing nearly a half ton or more, washed into the Wallkill River. As the floodwaters receded, the damage to this revered old landmark was painfully evident (Figs. 3-5). Consideration was given to tearing down the tunnel completely, but as it had been designated a local historic landmark in 1991, the decision was made to get federal funding for its repair. In the meantime, before the construction equipment arrived on the scene, the washed-out roadbed immediately downstream of the tunnel provided a rare opportunity for mineral collecting (Figs. 6 and 7).

My property abuts the railroad right-of-way a few yards north of the tunnel portal. The ground here is mostly glacially deposited till, once known as a portion of the Ogdensburg-Culvers Gap recessional moraine. Boulders and cobbles of so-called "glacial ore" scraped from the Franklin zinc orebody were deposited here and were once found in abundance. One would have expected glacially deposited Franklin material to lie beneath the road surface in this area, but surprisingly, the roadbed base immediately north of the tunnel contained a large amount of lean Sterling ore! Many pieces of fluorescent calcite with stout crystals of troostite-variety willemite were exposed (Fig. 8). One small boulder weighing 50 pounds even contained semi-gemmy, doubly terminated willemite crystals (Fig. 9), along with a band of franklinite crystals. Large pieces of the washed-away asphalt had red- and green-fluorescing gravel and mill tailings coating their undersides. One lucky rockhound found in the rubble a nice specimen of calcite with veins of sphalerite, which he quickly turned into cash (but not from me!).

During the three-month closure of the tunnel, the neighborhood along Cork Hill Road was blissfully quiet, with no through traffic and the ever-annoying horn-blowing of inconsiderate joyriders. The rebuilding of the collapsed section of the tunnel commenced in October. The repairs involved recovering the washed-out cut stones, recutting them as needed, and using them as part of the repair instead of merely filling the gap with concrete. (This method of architectural restoration by using original materials is known as anastylosis.) The stonework repairs were completed by the end of October, but the road itself remained closed until November when a new roadstone base and asphalt were installed. For a couple of weeks, the scene resembled a vintage postcard view of a quaint and rustic time before pavement and road signs (Fig. 10). For the sneaky local resident, it was a forbidden treat to move aside the barricade and traverse the dirt floor of the tunnel.

At nearly 150 years old, the tunnel today is a picturesque and oft-photographed historic relic, as well as a perpetual hazard to vehicular and pedestrian traffic and an attractive nuisance that appeals to the disrespectful disturbers of residential peace and quiet. The tunnel was added to the National Register of Historic Places on December 28, 2005, and a historical plaque that commemorates the tunnel's significance is mounted on a two-ton boulder of white Franklin Marble near the south end of the tunnel.

ACKNOWLEDGEMENTS

Thanks to Earl Verbeek for scanning and color-adjusting the flood photos and for photographing the specimens.

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Hadowanetz, Wasco (2008). *The "Backwards" Tunnel*. Privately published. 66 pp.

Reisner, Robert G., and Schopp, Robert D. (2002), *Sparta, New Jersey, Flood of August 11-14, 2000*. Water-Resources Investigations Report 02-4099. U.S. Geological Survey, West Trenton, N.J. 88 pp. ⚒

Figure 1. Floodwaters of the Wallkill River flowing through both tunnels on the afternoon of August 12, 2000. Goodbye fence! *Mark Boyer photo.*

Figure 2. Floodwaters as of Sunday, August 13, 2000. Note the chunks of ripped up asphalt. Photo has been color-adjusted to enhance the water-current flow pattern; the actual water color was "caffe latte." *Mark Boyer photo.*

Figure 3. Collapse of stonework at northwest corner of tunnel. The water level is at about the same level as the former road surface. The exposed pipe is a water main. *Mark Boyer photo.*

Figure 4. View from inside the tunnel showing the extent of collapsed stonework. The water is more than a foot deep. *Mark Boyer photo.*

Figure 5. View to the north showing the extent of the washed-out road. The author's property is the wedge of wooded land between the road and the river. *Mark Boyer photo.*

Figure 6. Washed-out roadbed, August 14, 2000. *Mark Boyer photo.*

Figure 7. Road rubble ready for pickin'! The exposed rock was a mix of glacial cobbles and lean Sterling ore. Note the two loads of stone dumped by the road department as a traffic safety barrier. *Mark Boyer photo.*

Figure 8. Euhedral, terminated troostite crystal found in the exposed road base north of the tunnel as shown in Figure 7. Longest crystal edge measures 7/8″ (22 mm). Boyer specimen no. 1668. *Earl R. Verbeek photo.*

Figure 9. Glossy, doubly terminated willemite crystal at upper left of photo is >1″ (2.5 cm) in length. Rock is as found and uncleaned other than a rinse with water. Uncataloged Boyer specimen, 16.5″ × 8.5″ × 7″ (42 × 21.5 × 18 cm). *Earl R. Verbeek photo.*

Figure 10. Repaired "Backwards Tunnel" before repaving of Cork Hill Road, late October 2000. *Mark Boyer photo.*

Remembering Barb Wagner

SARAH LAINE PETERSON
CHESTERFIELD, VA
S.Laine.Peterson@gmail.com

It was with great sadness that we learned of the passing of Barb Wagner, who you will remember after reading the tribute below, prepared by her daughters, Sarah and Maggie, and her husband, Kent.

Barb Wagner, of Meriden, Conn., cashed in her earthly chips* early on Sunday, April 5, 2020. She enjoyed a rich life of 68 years, and passed away quickly and unexpectedly of natural causes (unrelated to the COVID-19 pandemic). She did not suffer or linger, which is just as she always said she wanted.

Born in Takoma Park, Md. on May 23, 1951, Barb was the third child and second of four daughters born to Bob and Dot (Holder) Wagner. She graduated from Ayer High School in Ayer, Mass., and went on to receive a degree in occupational therapy from the University of Puget Sound in Tacoma, Wash. She was an occupational therapist, an old-school OT, for decades and worked with children in the Meriden school system for almost 20 years.

Barb's talents, hobbies, and knowledge were extensive. She loved antiques and rocks, Andrew Lloyd Webber and Billy Joel, Downton Abbey, and Doctor Who. She loved exploring, close to home and in the maritime provinces of Canada, taking scenic drives, camping, canoeing, and tromping through the woods with a rock hammer in hand. She was a longstanding member of the Lapidary & Mineral Society of Central Connecticut, and enjoyed shaping and polishing stones in the lapidary shop as much as she enjoyed participating in monthly meetings and helping to organize the annual Jewelry, Gem & Mineral Show. She co-authored an article in the Fall 2019 issue of *The Picking Table*, "Bringing the Roy Epting Collection to Light," about an extensive rock collection that she, Kent, and her sisters unearthed while cleaning out their aunt's house.

Barb was endlessly crafty, and could create anything she put her mind to. She made jewelry, she sewed, she knitted and crocheted. She could wield a paintbrush, had beautiful handwriting, and loved standing behind the camera for any occasion. She baked the best cupcakes and topped them with the most delicious frosting. She decorated the fanciest and most whimsical cakes. She had beautiful flower gardens all throughout her yard, and was generous in sharing cuttings of her garden and house plants with those she loved. She loved trout fishing, down and dirty with a nightcrawler, not that snooty fly fishing. One of her special skills was the ability to pack, as they say, "10 pounds of stuff into a 5-pound bag."

Barb had a kind and generous nature, was thoughtful in her words and actions and gestures, and gave the best advice. She was serious when she needed to be, but she also had a great sense of humor, and appreciated and even envied a quick wit in others. She was proud and supportive of her family and friends through all their endeavors. She had a keen intellect, loved learning, asking questions, and reading ALL the signs at museums. She never met anyone she couldn't talk to like a friend. She dreamed of fixing up a cool old house on Prince Edward Island, but always made the blue house on Converse Avenue a home for anyone who came to visit. She loved her family and her friends, and was happiest when all of her "chickens" were home.

Those who knew her best had this to say… "She was a classy girl, she truly was." "I knew her for 36 years and she never pi$$ed me off. Not even once!" "She could do anything! She really could!" "Bet your life, your sweet wife is gonna catch more fish than you." "I did enjoy whatever drummer she marched to." "She was a wonderful person and friend." And finally, simply, perfectly, "She was the *best* person I ever met."

Barb was predeceased by her parents and a brother, and is survived by her husband of 38 years, Kent Peterson; two daughters – Sarah Peterson and her husband, Justin Carpenter, of Chesterfield, Va., and Maggie Peterson of Hartford, Conn.; three sisters – Elaine Bissell of Worcester, Mass., Betty Siegenthaler and her husband, John, of Millbrook, N.Y., and Terry Wagner of Thomaston, M.E.; sister-in-law Joan Emerson and her husband, Mark, of Norfolk, Mass.; brother-in-law Jack and his wife, Debbie, of East Berlin, Conn.; many nieces, nephews, great-nieces, and great-nephews; and countless friends.

Given the general concerns about the pandemic situation, a small, private ceremony was held in April at John J. Ferry & Sons Funeral Home in Meriden, Conn.. This will be followed by a more inclusive celebration, at a date and location yet to be determined. In lieu of flowers, please consider honoring Barb by helping to make the world a better place through a donation to the charity of your choice.

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*Barb also enjoyed walking around the casino with a big bucket of quarters; she was not happy when they switched over to vouchers.

Field Trip Report

August 1, 2020

JAMES VAN FLEET
222 MARKET STREET
MIFFLINBURG, PA 17844

Not surprisingly, many of the members of the Franklin Mineral Museum board of directors are also members of the Franklin-Ogdensburg Mineralogical Society (FOMS). The board has been meeting to plan for the reopening of the Museum in some form, and the current plan is to host special events for the rest of this year. The first such event was a dig on the Buckwheat Dump on Saturday, August 1. Let's call it a field trip for our rock-starved FOMS members, and give a brief report.

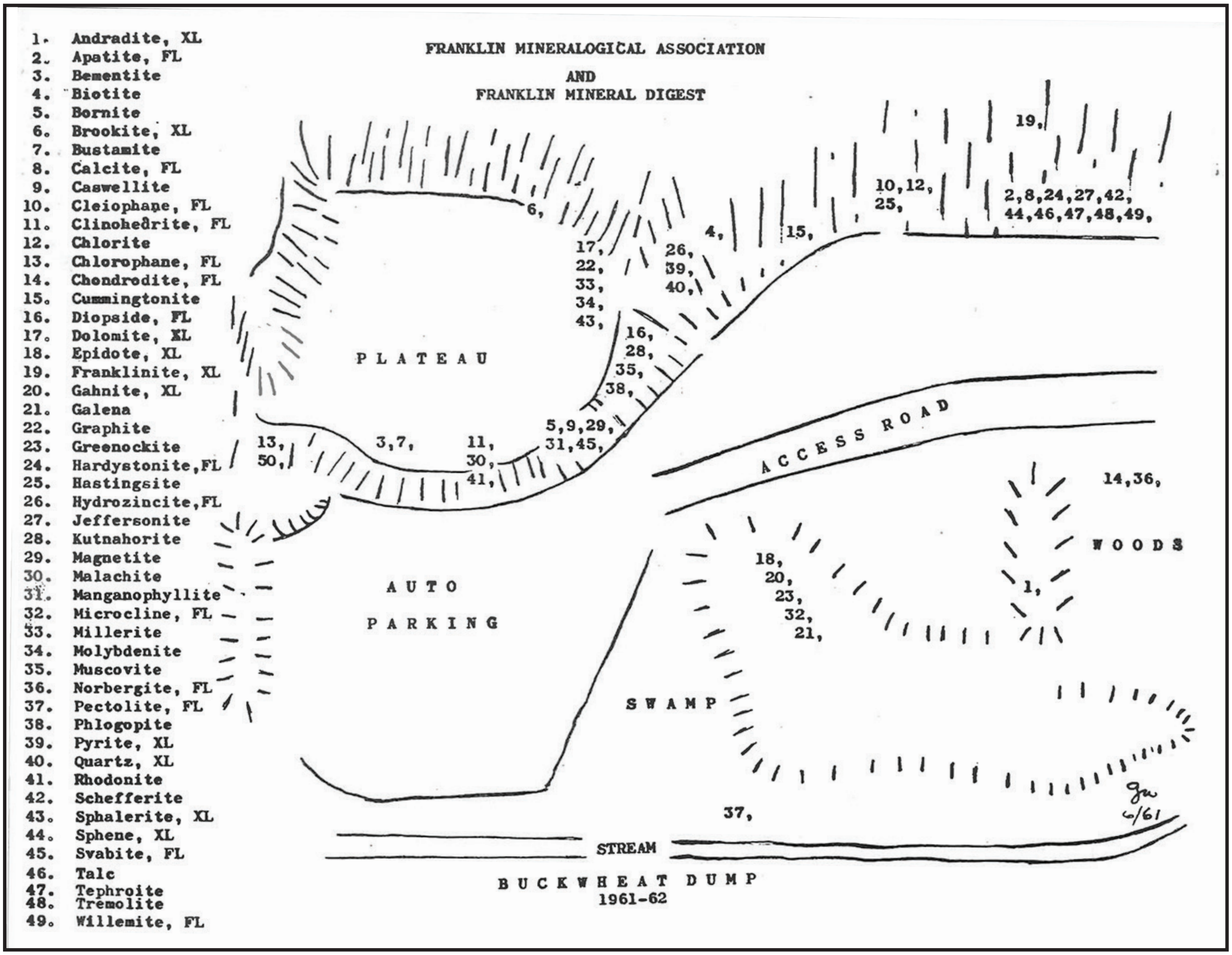
First, thanks must go to the Museum staff members who volunteered many unpaid hours of work to make this event safe and successful. Carol and Jessica LeBrie, Andy Richter, Jean Castimore, Chrisann Lucciola, Deb Rohde, John Christiano, Fred Fox, and Steven Misiur all worked hard to prepare the Museum to host collectors while maintaining social distancing and safety guidelines, and staffed the Museum check-in and check-out for long hours on Saturday. Mandatory mask-wearing was enforced, and diggers registered singly or as family groups. We were greeted at the front of the Museum by president Mark Boyer. Forty diggers signed in for the daytime dig, which ran from noon to 5 p.m.

August 1 turned out to be another in a long string of brutally hot summer days, and most of the diggers, yours truly included, could only manage an hour or two on the rock pile. Tents and tarps sprang up on the dump, including one ingenious rig with a battery-operated electric fan!

The Buckwheat Dump from street level. *Photo by James Van Fleet.*

Diggers lining up in a socially responsible manner, thanks to the preparations made by Museum staff. *Photo by James Van Fleet.*

Bill Pazik and his sons James and John won the award for most effective darkroom / shelter from the sun AND heat. That's an electric fan at the lower left of the photo! *Photo by James Van Fleet.*

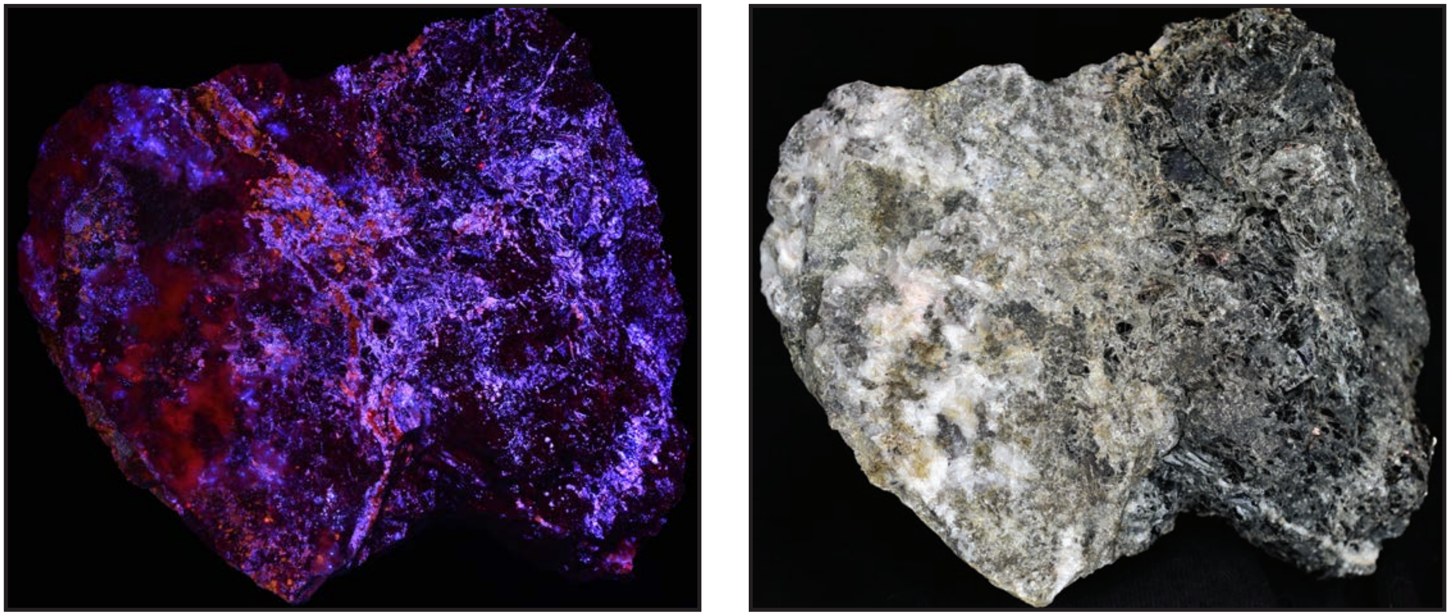


Just for comparison, here's a map drawn by Gerry Navratil, showing the layout of the Buckwheat Dump in 1961. The "plateau" is still the main dig site.

Despite decades of collecting, there is still a wide variety of mineral specimens to be found on the Buckwheat Dump, including calcite, of course, with willemite and franklinite grains. I saw one specimen with tiny fine green willemite crystals. I found massive, gneissic willemite ore that shows some nice green color on freshly broken surfaces. There is always plenty of microcline feldspar, including the green "amazonite" variety. Much of this was associated with quartz and allanite. Sphalerite has become easier to find and identify with the popular longwave UV LED flashlights. Interesting mineral finds included gray sphalerite in veins, silvery sphalerite, and an unusual association of sphalerite in hendricksite mica.

The chlorophane variety of fluorite proved to be abundant on the dump. The dark pyroxene matrix stands out, and the longwave UV flashlight reveals a dark blue fluorescence on weathered surfaces. Many specimens were cracked open to reveal the beautiful (and fleeting) teal-green fluorescence of freshly exposed fluorite.

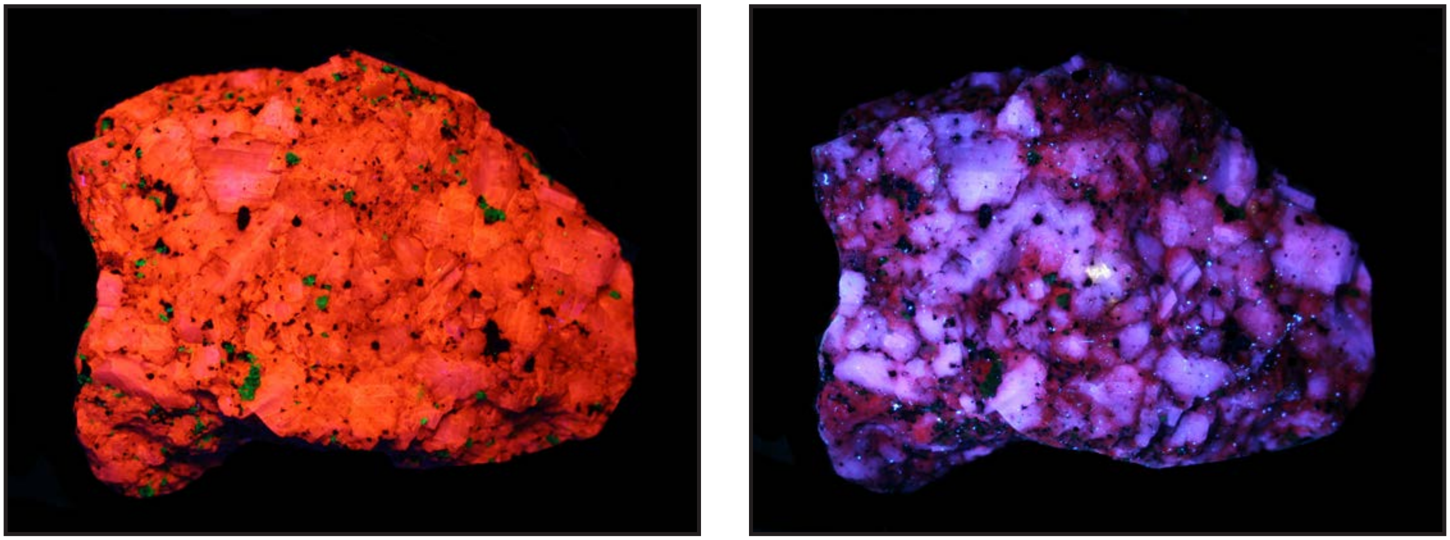
The daytime dig was wrapped up at 5 p.m., and collectors were encouraged to return for a night dig from 7 – 11 p.m. An additional 30 attendees were registered. We braved the usual night dig hazards; stumbling over rocks, and swarmed by insects when we used our UV lights. My own collecting preference is to use a 12-pound sledgehammer, and a number of interesting specimens went flying off into the night. However, I was lucky enough to find a boulder of the "multi-wavelength" calcite, fluorescing red in shortwave UV, red and purple in longwave. One collector found a big boulder of rich orange-fluorescing sphalerite, and opted to take it home in one piece. Blue-fluorescing hydrozincite, and also aragonite, were widely found on the dump rocks.



Sphalerite var. cleiophane fluorescing blue and orange in longwave UV light, in an unusual assemblage with hendricksite mica. *Photos by Bill Pazik.*

One of the most heartening aspects of our mineral digs is the sharing that occurs, especially the consideration shown to new rock collectors. Diggers practically lined up to share specimens of fluorite, var. chlorophane, sphalerite, and other finds with folks who were new to the Buckwheat Dump. Families with children received extra attention and advice, help with identification, and sample rocks. One of our FOMS members brought extra UV flashlights for sale, and after folks saw what they could reveal, they bought up all of them.

As diggers labored up the ramp from the Buckwheat Dump at the end of the evening, under heavy burdens, it was clear the event was a success for collectors and for the Museum. Look for announcements of the next event on the Museum website, on our own FOMSNJ.org web pages, and on Facebook.



Calcite fluorescing the usual orange-red under shortwave UV, and purple and deep red under a longwave UV LED flashlight. *Photos by James Van Fleet.*

Minerals of the Apatite Supergroup at Franklin and Sterling Hill, With Historical Notes

EARL R. VERBEEK
CURATOR, FRANKLIN MINERAL MUSEUM
32 EVANS ST., FRANKLIN, NJ 07416
earlrverbeek@gmail.com

RICHARD C. BOSTWICK
600 W. 111TH ST., APT. 11B
NEW YORK, NY 10025
rbostwick@att.net

INTRODUCTION

The mineral name *apatite* is derived from the Greek word for "to deceive," as apatite was (and is) often mistaken for other minerals, including beryl and corundum. When Abraham Gottlob Werner (for whom wernerite is named) christened apatite in 1788, he had no way of predicting how complex and deceitful apatite would become as the science of mineralogy progressed. Today, 232 years later, we have the apatite supergroup, which includes five named groups of minerals (the apatite, hedyphane, belovite, britholite, and ellestadite groups) comprising 47 different mineral species. Of these, the Franklin Mining District (which includes the Franklin and Sterling Hill orebodies, several iron orebodies, and the enclosing Franklin Marble) has a mere six proven apatite species: from the apatite group, fluorapatite, johnbaumite, svabite, turneaureite, and mimetite; and from the hedyphane group, hedyphane. Hydroxylapatite and pyromorphite have also been reported, but the evidence to date is inconclusive, and these species have not yet been added to the list of local minerals.

In this paper we summarize the history of the apatite supergroup in the Franklin-Sterling Hill area and then discuss, with photographs, the results of recent chemical analyses of more than two dozen apatite specimens. The results are at once enlightening and discouraging: Despite common claims to the contrary, attempts at sight identification of most of the local apatites, especially those within or associated with the zinc ores, are ill-advised, the few exceptions being specimens from known, analyzed finds.

HISTORICAL NOTES

Apatite from the Franklin - Sterling Hill area was first reported (as "phosphate of lime") in 1822 by Thomas Nuttall. A century later, as more and more chemical data on the local minerals became available, svabite and hedyphane had been added to the list. Charles Palache, in his 1935 monograph on the local minerals, noted that among those apatite crystals that had been subjected to optical or chemical analysis, all crystals from the Franklin Marble were free of arsenic and contained little or no chlorine. An analysis of one such crystal showed an appreciable content (3.37 wt.%) of fluorine and negligible OH (expressed as H_2O), thus corresponding to the species fluorapatite. In contrast, all apatite specimens associated with the Franklin ores were found to contain arsenic, often in appreciable amounts. For these, Palache stated that "Those in which As_2O_5 is molecularly in excess of P_2O_5, which include about two-fifths of the crystals examined, have been classed as svabite." He added that there is nothing in the general appearance of svabite to differentiate it from [fluor]apatite, and concluded that without optical data or chemical analysis, "There is no other way…to distinguish the two species as they are found at Franklin." Only decades later would Palache's "svabite" be redescribed as three separate species—johnbaumite, turneaureite, and svabite—thereby further complicating the matter of sight identification of these minerals.

The third member of the apatite supergroup mentioned in Palache's monograph is hedyphane, one of 11 species in the hedyphane group. It was first described from Franklin by Foshag and Gage (1925) and from another find shortly thereafter by Palache and Berman (1927). Palache's description in his 1935 monograph is accurate and worth reading. It's also worth noting that hedyphane is the only one of the apatites he mentions as fluorescing (Palache, 1928). However, in a further complication, Palache used an iron-arc spark as his source of ultraviolet light, and results from such observations can differ, sometimes markedly, from those using modern mercury vapor lamps.

Fast forward from 1935 to the fall of 1960, when one of us (RCB) began collecting at Franklin. The Franklin-Ogdensburg Mineralogical Society, Inc. (FOMS) had been founded in 1959, and the annual Franklin-Sterling Mineral Exhibit, sponsored by the Kiwanis Club of Franklin, was in its fourth year. Palache's 1935 monograph was still "the Franklin Bible," and in 1972, when his successor at Harvard, Clifford Frondel, published *The Minerals of Franklin and Sterling Hill–A Check List*, the only addition to the list of locally occurring apatites was pyromorphite – tiny yellow crystals and crusts on weathered augite, from the Noble Pit at Sterling Hill. Frondel's addition of pyromorphite was based on an unpublished 1971 report by C.S. Hurlbut, which showed the mineral contained appreciable arsenic and thus had a composition intermediate between that of pyromorphite, $Pb_5(PO_4)_3Cl$, and mimetite, $Pb_5(AsO_4)_3Cl$. Upon later analysis (Dunn, 1995) it was found to be mimetite, thereby temporarily striking pyromorphite from the list of locally occurring apatite species.

As far as most collectors could tell from Palache's monograph, svabite and fluorapatite from the Franklin Mine and dumps all had some arsenic in them, and looked like each other. There were a few analyzed Franklin svabites in local collections, so there was a bias toward believing that if your specimen looked like one of them, it was svabite. That bias persists to this day. The most reputable examples of svabite had been identified by Lawson Bauer, the New Jersey Zinc Company chemist who collaborated with Professor Palache, but both had died in 1954 and couldn't be asked, "Is this still svabite?" They *were* svabite according to the nomenclatural conventions of their time, but later studies of apatites worldwide resulted in the recognition of new apatite species and the redefinition of others, thereby complicating things for the casual collector, but also adding more richness and context to the apatite supergroup as a whole.

The postwar boom fueled the growth of mineral-related hobbies, so Franklin attracted rockhounds and micromounters, high-end collectors and species collectors, and anyone who owned an ultraviolet lamp. Much fresh material had come out of the Franklin Mine in its last years, more was coming out of Sterling Hill as miners learned there was money in it, and the Franklin dumps were relatively untouched. This was an exciting time for collectors, but a confusing one if you wanted to know what you had collected. Book learning and sight-identification went only so far, and experts differed. We relied on many knowledgeable people, including Ewald Gerstmann, an aggressive collector who had his own mineral museum; John Baum, a Harvard man who had been a geologist for the New Jersey Zinc Company; mineral dealers such as John Albanese; and miners like Mike Petro, Stan Hocking, and Nick Zipco. We never got enough answers because they didn't yet exist. During this time, the only serious reference work for a beginning collector was Palache's 1935 monograph, which proved so popular that it was reprinted in 1960. While Palache was the first academic to describe the fluorescence of Franklin minerals (in 1928, under the iron arc), his 1935 monograph was printed in black-and-white and required multiple leaps of faith to link the text with the photo plates, which for neophytes worked best for franklinite, magnetite, and hematite, all of which are black. This is why Sterling Gleason's *Ultraviolet Guide to Minerals* (1960) and Bob Jones's *Nature's Hidden Rainbows* (1964), both of which had color plates, were so important to our generation. In those books, collectors were finally able to view color photographs of various Franklin-Sterling Hill minerals fluorescing. Of the apatite minerals, however, only one photograph appeared in each book, and they were of the same specimen. It was labeled svabite then, but today we know it's turneaureite.

Then, in the late 1970s, Dr. Pete Dunn, from his cubbyhole at the National Museum of Natural History, launched his crusade to investigate the minerals of Franklin and Sterling Hill and publish his findings in a welcome flood of papers. Before long, he described the new apatite minerals johnbaumite (Dunn et al., 1980) and turneaureite (Dunn et al., 1985). He dropped svabite from the Franklin-Sterling Hill species list because he hadn't found any there that conformed to the modern definition of that species: an arsenic apatite with F>OH,Cl. Dr. Dunn's observations on minerals of the apatite supergroup were later summarized on p. 649-653 of his monograph, released in 1995: a work that comprises five volumes, with two supplements added later. This work quickly became the new "Franklin Bible" for collectors—but it, like Palache's 1935 monograph, featured only black-and-white plates, so it was still difficult for collectors to visually match their specimens with the analyzed ones.

More recent work, since the time of Dunn's 1995 monograph, resulted in restoration of svabite to The List (Crimmins, 2012) and, in work not yet published, possibly of pyromorphite and hydroxylapatite as well. Table 1 shows the (ideal) chemical formulas for local members of the apatite supergroup:

Table 1. Ideal compositions of selected apatite species. **Bold** = species known to occur in the Franklin-Sterling Hill area.

Ca phosphate apatites		Ca arsenate apatites		Lead apatites	
Fluorapatite	$Ca_5(PO_4)_3F$	**Svabite**	$Ca_5(AsO_4)_3F$	**Hedyphane**	$Ca_2Pb_3(AsO_4)_3Cl$
Hydroxylapatite	$Ca_5(PO_4)_3OH$*	**Johnbaumite**	$Ca_5(AsO_4)_3OH$	**Mimetite**	$Pb_5(AsO_4)_3Cl$
Chlorapatite	$Ca_5(PO_4)_3Cl$	**Turneaureite**	$Ca_5(AsO_4)_3Cl$	Pyromorphite	$Pb_5(PO_4)_3Cl$*

* Local occurrence uncertain.

Today, as in the past, most Franklin-area specimens are sight-identified, particularly the rare (and fluorescent) arsenic apatites: johnbaumite, turneaureite, and svabite. All are exponentially more valuable than similarly appearing (and fluorescing) fluorapatites, but few have analytical credentials. Examples of those rare species are on display in the Franklin Mineral Museum, but as we are also learning, looks aren't everything, and it remains a frustrating exercise to attempt identifying these species by visual means alone. That hasn't stopped collectors from trying.

DAYLIGHT COLOR OF APATITE

Palache (1935) described the color of "svabite" (later divided into johnbaumite, turneaureite, and svabite) as being "gray to grayish green" and of (fluor)apatite as being "commonly green or bluish-green, ranging to gray and brown." Though Palache stressed that these species could not be told apart by sight, his color descriptions probably led to an early tendency to assume that any gray apatite from the Franklin orebody was more likely svabite than fluorapatite. That early impression persisted through ensuing decades and was probably strengthened by published announcements of the new species johnbaumite (Dunn et al., 1980) and turneaureite (Dunn et al., 1985), both of which, from their type assemblages at Franklin, are gray or white. Meanwhile, in May and June, 1982, authentic johnbaumite had been found by John Kolic in the 1570E stope, 1200 level of the Sterling Mine, and it, too, is gray. Thus arose a bias that any gray orebody apatite from either Franklin or Sterling Hill was probably one of the arsenic apatites, and any green, blue-green, blue, or brown apatite was fluorapatite. Prices were set accordingly.

Though it is understandable how this simple guideline to apatite species identification arose, its use nevertheless ignored strong cautionary evidence and statements against it. Recall that Palache (1935) mentioned gray as a known color of fluorapatite as well as of svabite and stated pointedly that "in its [svabite's] general appearance there is nothing to distinguish it from [fluor]apatite." Decades later, as more analyses accumulated, Dunn (1995, p. 650) likewise said of fluorapatite that "color is not a useful discriminant." Indeed, though John Kolic's find of johnbaumite in the Sterling Mine is demonstrably that species, much of the gray apatite from the next cut above was fluorapatite instead, and the gray apatite found by RCB from the 1680 stope of the Sterling Mine is also fluorapatite. As knowledge of the local apatites gradually grew through increasing numbers of analyses, color as a species indicator became more and more suspect.

To mineralogists this was no surprise. The calcium phosphate and arsenate apatites, if synthesized as pure compounds in a laboratory, would all be colorless or white because they contain none of the chromophore elements (e.g., Fe, Co, V, Mn, Cr) widely responsible for coloration in natural minerals. The color of apatite as it occurs in nature is due to several causes, most often to impurity elements present in minor to trace quantities, but also, at some localities, to crystal defects caused by natural radioactive decay, or to minute inclusions of other minerals that impart their color to the apatite. For example, Rakovan and Waychunas (2013), in a highly readable summary of some known and potential mechanisms of color in apatites, point out that pentavalent manganese (Mn^{5+}) substituting for phosphorus results in blue coloration. Because manganese is a nearly ubiquitous impurity element in the local apatites, often in amounts of 0.2-1.0 wt.%, it is perhaps the cause of color in some of the deep blue, nonfluorescent apatites from Franklin, but this is conjecture only. Potential causes of the more common pale green, green, and bluish-green colors in the local apatites are likewise uncertain, in part because there are several known and suspected mechanisms of producing those colors (see, again, Rakovan and Waychunas, 2013), but as one possibility, Deer et al. (1992) noted that impurities of ferrous and ferric iron together in both natural and synthetic apatites produce a green color. They also noted that manganese can result in pink and violet colors in apatite, as well as blue, depending on its oxidation state, and that the rare-earth elements (REEs) may produce yet other colors. Regardless of cause, the point remains that none of these colors are intrinsic to any given apatite species, but are possible in all of them. Though specific causes of coloration among the local apatites have not been much investigated, and offer opportunities for further research, it has been firmly established that the color of the local apatites is not a useful guide to species identity.

COLOR OF FLUORESCENCE

The fluorescence of some of the local apatite species is part of their appeal to collectors and plays a large role in setting the price for individual specimens. As noted before, Charles Palache (1928) described the fluorescence of Franklin hedyphane under the iron-arc spark but did not mention the response of any other local apatite species then known. Later, with the advent of readily available shortwave ultraviolet lamps, in part due to the "scheelite boom" of the 1940s (when tungsten was needed for the war effort), and again during the "uranium boom" of the 1950s and 1960s, the hobby of collecting fluorescent minerals took root and grew quickly. Observations on the fluorescence of Franklin-Sterling Hill mineral species were eventually codified into a series of documents published in *The Picking Table* (Bostwick, 1977, 1992, 2016, 2017) and, because they were based on authenticated specimens, served as a guide to collectors wishing to use fluorescence as an aid to mineral identification.

So, what of the apatites? Can their colors of fluorescence be used as diagnostic of certain species? The greenish-blue (Bostwick, 2016) to grayish-blue SW fluorescence of fluorapatite from the Franklin Marble certainly sets it apart from the orebody apatites, and the identity of some of the apatite crystals in the Franklin Marble as fluorapatite had already been long established. Although the great preponderance of apatite in the Franklin Marble is probably fluorapatite, Dunn (1995) excluded Franklin Marble apatite specimens from study, and more remains to be learned (is it *all* fluorapatite?). The fluorescence of presumed fluorapatite from the area iron mines, meanwhile, is variable: some of it (e.g., from the Edison mines east of Ogdensburg) fluoresces orange SW, but in the Franklin Mineral Museum is a specimen (FMM-7923) of a pale greenish gray apatite showing pink to lavender fluorescence SW. This apatite occurs with a dark green pyroxene and magnetite, but unfortunately we do not know from which iron mine it was collected. Some apatite from the Balls Hill iron mines in Franklin seems not to fluoresce at all.

Within the Franklin and Ogdensburg Zn-Fe-Mn orebodies, the four known Ca-apatite species—fluorapatite, johnbaumite, turneaureite, and svabite—all fluoresce similarly, and for the same reasons. Most common is an orange fluorescence SW, but specimens showing pinkish-orange, pink, and blue fluorescence SW are also known. Worldwide, orange SW fluorescence in these minerals, all of which contain calcium as an essential constituent (Table 1), is caused by divalent manganese (Mn^{2+}) substituting for calcium. Rakovan and Waychunas (2013) have confirmed Mn^{2+} as the dominant activator in those Franklin-Sterling Hill samples studied by fluorescence spectroscopy. The same authors note that blue to violet SW fluorescence, a response seen in apatite from numerous localities, is often caused by rare-earth elements, notably Ce^{3+} and, in some apatites, Eu^{2+}, also substituting for calcium. Combinations of the two responses in apatite specimens give rise to pinkish-orange and pink fluorescences under SW UV light, and additional rare-earth elements can produce additional color variations. Numerous other activators of fluorescence in apatite have been identified, and still others, observed to date only in synthetic apatites, may have counterparts in nature. In addition, crystal defects are a known cause of apatite fluorescence, as they are in many other mineral species. Thus, the color of fluorescence of apatite is not an intrinsic property (Waychunas, 2002; Rakovan and Waychunas, 2013) and is not a valid guide to species identity.

The local lead apatites, meanwhile, have their own problems. Among these, the burnt-orange fluorescence of some Franklin hedyphane (the massive, honey-colored material with brown rhodonite in veins), combined with its daylight appearance, usually suffice to identify it, particularly because its fluorescence is brightest MW rather than SW. However, this is not a constant for the species. Franklin hedyphane occurs in a wide variety of assemblages, and from one of them shows a rather astonishingly bright SW orange fluorescence (Bostwick, 2016). In other assemblages it fluoresces a weak cream color LW (Bostwick, 1977) or weak orange SW (Bostwick, 2016). Moreover, Franklin hedyphane is indistinguishable from mimetite in daylight (Dunn, 1995), and Dunn did not state whether Franklin mimetite fluoresces, so questions remain. However, Dunn noted that mimetite is much the rarer of the two species at Franklin.

Both mimetite and pyromorphite have also been reported from Sterling Hill. These two minerals form a complete solid-solution series between the arsenate (mimetite) and phosphate (pyromorphite) end members. Pyromorphite from Sterling Hill was reported by Frondel (1972), citing an unpublished 1971 report by C.S. Hurlbut, and was said to contain "much arsenic, intermediate to mimetite." This is the material that forms tiny yellow botryoids on limonitic matrix and was found along the north wall of the Noble Pit at Sterling Hill. This material fluoresces dim orange MW but was stated by Dunn (1995) to be mimetite, not pyromorphite. This is the problem with intermediate members of a solid-solution series; the difference between an arsenic-rich pyromorphite as originally reported and phosphate-rich mimetite as maintained by Dunn can be sufficiently minor that careful, quantitative chemical analysis is needed for accurate determination. Meanwhile, it appears that true pyromorphite may also be present at Sterling Hill; King et al. (in prep.) show a druse of tiny, yellow, steeply pyramidal crystals on altered ore. No fluorescence is mentioned, but much pale-colored pyromorphite worldwide shows a dim to moderate yellow to orange fluorescence, so this would probably be of little use in distinguishing mimetite from pyromorphite locally.

BRIGHTNESS OF FLUORESCENCE

But what about brightness of fluorescence? Among the orange-fluorescing apatites from the local zinc mines, there has until recently been a tendency among collectors to identify any brightly fluorescing apatite as turneaureite. This was based mostly on the exceptionally bright fluorescence of turneaureite from the type assemblage at Franklin, where it occurs as gray masses in orange calcite, often accompanied by brown garnet. Moreover, it was known that turneaureite fluoresces significantly more brightly than johnbaumite from the best-known assemblage at Sterling Hill, where crystal sections of johnbaumite occur with barite in a matrix of red-fluorescent calcite on the 1200 level, and also more brightly than many specimens of *purported* fluorapatite. Recent work, however, has largely discredited any correlation between brightness of fluorescence vs. species in the local apatites, as has already been mentioned for hedyphane. There is, instead, a strong correlation between daylight color and brightness of fluorescence, regardless of species: The most brightly orange-fluorescing orebody apatites tend to be of pale gray color (or white in the case of two known finds of hedyphane), and those that fluoresce most dimly or not at all are medium to dark blue. However, pale gray apatites with dim fluorescence are hardly rare, and the dim to absent fluorescence of blue apatites has little to do with species and more to do with the nature and oxidation states of impurity elements within them. In addition, the range in brightness of fluorescence among apatites of green and brown daylight color is quite large (and again, of little help in identifying which species of apatite is at hand). Overall, then, both the color of fluorescence and its brightness are of little aid in species identification among local members of the apatite group, and in most cases are probably more misleading than helpful.

So far we've seen that the local apatites generally cannot be differentiated on the basis of their daylight appearance, or on the color or brightness of their fluorescence, unless it is in reference to analyzed specimens from the same find. Some collectors over the past few decades, then, in desperation have resorted to having some of their specimens chemically analyzed, but even here, complications abound.

ANALYTICAL LIMITATIONS

The splitting of Palache's svabite into three separate mineral species—johnbaumite, turneaureite, and svabite *sensu stricto*—created new hurdles for collectors. These, together with fluorapatite, which occurs in similar orebody mineral assemblages, are still not readily distinguishable from one another without careful chemical analyses. The first thing to realize is that few apatite specimens conform closely to the ideal formulas given in Table 1. Instead, most are impure, some markedly so, and contain variable ratios of phosphate to arsenate, and variable ratios in their contents of fluorine, chlorine, and hydroxyl. The local apatites offer splendid examples of multiple solid-solution series, which is to say that specimens having a wide spectrum of compositions between two or more of the end-members listed in Table 1 are not only present, but common. What this means in turn is that an accurate chemical analysis is usually necessary to identify a given apatite specimen to the species level. Given what is known so far of the local apatites, only those from the Franklin Marble can be assumed, with any confidence, to be fluorapatite. Apatites associated with the ores at Franklin and Sterling Hill could be any of the species listed in bold type in Table 1, with, again, intermediate compositions between the end members being the norm.

In practice, determination of arsenate or phosphate dominance in any given apatite specimen is a fairly simple procedure and can be done by several methods: X-ray fluorescence (XRF), X-ray diffraction (XRD), scanning electron microscopy/energy dispersive spectrometry (SEM/EDS), and Raman spectroscopy, to name a few, plus by optical means, as mentioned by Palache (1935). Thus it is generally possible to distinguish fluorapatite from any of the arsenate apatites except for examples with As:P ratios near the 50:50 mark, in which case analytical accuracy comes into play.

The determination of F:Cl:OH ratios, in contrast, is hardly a straightforward exercise but is necessary to the distinction between johnbaumite, svabite, and turneaureite. Part of the difficulty is that fluorine, chlorine, and hydroxyl constitute such a small part of these mineral species that highly accurate chemical analyses are necessary to produce believable numbers. Pure johnbaumite contains only 1.34% (OH) by weight, pure svabite contains 2.99% F, and pure turneaureite contains 5.43% Cl. In practice this means that one is attempting to determine the contents of three different chemical components that *together* often constitute only 1/20th or less of the mineral by weight. Moreover, determination of the (OH) content cannot be done directly because elements of such light atomic weight cannot be "seen" by any of the analytical techniques mentioned. Fluorine, too, is problematic because of its low atomic weight. Without getting into further details, XRF and SEM/EDS analyses commonly are not up to the task, and it requires careful analyses by electron microprobe, using polished samples and done with reference to known and carefully selected standards, to obtain the necessary data.

As an aside, we should mention here that the "affordable" analyses often sought by mineral collectors are either XRF or SEM/EDS analyses done on rough, unpolished, and uncoated mineral fragments and are standardless, which means the raw data are subjected to preset rather than customized correction factors and then autosummed to 100%. The adjusted data are then run through an internal search-match library to identify the mineral that most closely conforms to the results obtained. Such analyses are useful, to be sure, and generally are worth the money charged for them, but they should not be overinterpreted as rigorously accurate. For specimens where species identity depends on accurate determination of minor components, the mineral ID suggested by the "black box" is often off the mark. On multiple occasions, both authors of this paper have had collectors approach them with chemical reports in hand while announcing "Look, I have an analyzed specimen of svabite!" In nearly every instance we have had the sad duty to state that yes, the specimen has been analyzed, but no, that does not make it svabite. All too often, these collectors did not believe what we had to say, and felt we were simpy "raining on their parades." It gets lonely out there…

For the other three lead apatite species – hedyphane, mimetite, and pyromorphite – the limitations of analytical procedures are in general less severe. All three minerals are chlorides, and the other elements in them (lead, arsenic, and phosphorus) generally present no special analytical hurdles. The problems inherent in solid-solution series, however, still apply, so for specimens with compositions near the dividing line between end members, it can still be difficult to assign a species name. In those cases, though, it matters little whether a specimen is a phosphate-rich mimetite or an arsenic-rich pyromorphite; near the 50:50 divide they are much the same thing.

APATITE SPECIMENS ANALYZED BY ELECTRON MICROPROBE

We turn now to apatite specimens whose compositions have been established by electron probe microanalysis (EPMA). Some years back, Dr. John Rakovan of Miami University (Oxford, Ohio) requested that the authors submit to him fragments of apatite specimens from the Franklin-Sterling Hill area. Of the 30 specimens sampled for this study, 29 were analyzed by EPMA. The results were reported in a 2012 M.S. thesis by Laura Crimmins, then one of Dr. Rakovan's students. A summary of her analyses is given here in Table 2.

Table 2. Chemical analyses of 29 apatite specimens; data from Crimmins (2012).

Crimmins no.	Spec. no.	CaO	MnO	SrO	PbO	P_2O_5	As_2O_3	SiO_2	Na_2O	F	Cl	Total	Calculated As:P ratio	Species ID
EV293	ERV-293	49.7	1.5	0.21	0.07	24.86	16.74	0.21	0.03	1.72	0.13	95.18	28:72	Fluorapatite
EV441	ERV-441	47.45	0.76	0.22	0.36	13.81	26.97	1.31	0.19	1.17	1.21	93.45	53:47	Johnbaumite
EV506	ERV-506	42.02	0.52	0.38	6.12	5.57	42.15	0.12	0.09	0.95	0.21	98.15	81:19	Johnbaumite
EV1368	ERV-1368	43.66	0.54	0.42	1.04	9.16	33.12	0.52	0.2	1.31	0.01	89.97	68:32	Johnbaumite
EV1369	ERV-1369	51.88	0.3	0.56	0.19	31.89	12.08	0.07	0.08	4.15	0.09	101.28	18:82	Fluorapatite
EV1371	ERV-1371	42.81	0.52	0.28	2.33	1.79	46.32	0.04	0.04	1.07	0.07	95.26	94:6	Johnbaumite
EV1383	ERV-1383	45.71	2.74	0.28	0.38	15.98	27.59	0.24	0.15	1.8	0.62	95.48	50:50	Svabite/Fluorapatite
EV1384	ERV-1384	42.95	0.21	0.5	3.92	8.82	35.54	0.06	0.18	0.95	0.02	92.92	70:30	Johnbaumite
EV1385	ERV-1385	46.81	0.52	0.34	1.03	19.14	25.16	0.19	0.07	1.78	0.01	95.06	43:57	Fluorapatite
FL783	ERV-2213	47.84	0.43	0.33	1.25	19.56	26.99	0.23	0.07	2.64	0.01	99.34	44:56	Fluorapatite
RB1	RCB-210	47.01	0.24	0.97	0.56	12.43	32.83	0.2	0.03	0.94	0.01	95.22	60:40	Johnbaumite
RB2	RCB-354	46.32	1.48	0.22	0.91	14.08	31.51	0.09	0.12	1.02	0.5	96.24	56:44	Johnbaumite
RB3	RCB-351	44.25	0.47	0.23	1.51	7.71	40.51	0.13	0.08	0.59	2.12	97.6	75:25	Turneaureite
RB4		53.63	0.3	0.65	0.18	39.51	0.14	0.54	0.06	3.56	0.01	98.58	0.2:99.8	Fluorapatite
RB5	RCB-352	48.2	0.48	0.21	0.14	13.72	30.33	0.37	0.06	1.19	0.01	94.7	56:44	Johnbaumite
RB7	RCB-360	41.74	0.78	0.2	3.74	1.88	47.79	0.07	0.04	1.51	0.16	97.91	94:6	Svabite/Johnbaumite
RB8	RCB-361	9.83	0.02	2.77	54.36	0.02	28.7	0.08	0.02	0.04	3.26	99.09	100:0	Hedyphane
RB9	RCB-353	8.94	0.06	0.81	59.17	0.1	27.48	0.1	0.03	0.06	3.18	99.93	99:1	Hedyphane
RB10	RCB-358	55.79	0	0.02	0.02	41.42	0.04	0.13	0.06	2.4	0.1	100	0.1:99.9	Fluorapatite
RB11	RCB-356	47.42	0.46	0.95	0.13	13.97	31.21	0.32	0.09	1.23	0.13	95.78	56:44	Johnbaumite
RB12	RCB-355	42.65	0.23	0.23	2.07	1.95	45.61	0.51	0.06	0.89	0.19	94.4	93:7	Johnbaumite
RB13		50.21	0.07	2.27	0.65	24.12	21.1	0.09	0.04	1.84	0.01	100.4	34:66	Fluorapatite
RB14	RCB-214	48.51	0.82	0.44	0.38	20.69	24.44	0.15	0.18	1.49	0.07	97.17	40:60	Hydroxylapatite
RB15	RCB-211	49.43	0.68	0.35	0.12	27.37	15.33	0.16	0.15	2.11	0.06	95.75	24:76	Fluorapatite
RB16		50.58	0.68	0.49	0.14	25.1	19.02	0.23	0.13	2.21	0.15	98.72	30:70	Fluorapatite
RB17	RCB-217	55.79	0.72	0.6	0.05	40.91	0.04	0.15	0.04	4.04	0.003	102.34	0.1 :99.9	Fluorapatite
RB18	RCB-212	53.01	0.18	0.64	0.14	33.43	9.59	0.02	0.06	2.84	0.05	99.97	14:86	Fluorapatite
RB19	RCB-216	51.62	0.55	0.3	0.15	27.28	15.7	0.32	0.13	2.59	0.09	98.72	25:75	Fluorapatite
RB20	RCB-213	46.94	1.07	0.64	0.33	13.21	32.14	0.12	0.06	1.97	0.43	96.91	58:42	Svabite

EPMA analyses, when done carefully and in reference to known standards, generally supply high-quality quantitative data on the major and minor element contents of minerals. Even here, however, there are limitations that can trip up the unwary. For example, as with the analytical methods previously mentioned, the (OH) content of an apatite cannot be measured directly by EPMA. The usual procedure for apatites is to calculate the atomic proportions of F and Cl and determine the (OH) content by difference, but the results depend on the accuracy of both the F and Cl measurements and so cannot be independently verified. Until fairly recently, accurate determination of fluorine or chlorine contents via EPMA was problematical because results for the same sample varied widely, depending on operating conditions such as accelerating voltage, beam current, spot size, and sample orientation (Goldoff et al., 2012). Problems of fluorine migration under the electron beam had been reported previously (Stormer et al., 1993), which meant that results sometimes differed as a function of how long a given spot on a sample had been under the electron beam. Nevertheless, highly accurate results can be obtained with the proper operating conditions, as specified in the Goldoff et al. (2012) paper.

With these limiting factors in mind, for each apatite specimen analyzed by Crimmins (2012) we calculated the atomic proportion of arsenic to phosphorus (herein designated the As:P ratio) and the relative atomic proportions of fluorine, chlorine, and hydroxyl (F:Cl:OH). These calculations were performed using the method of Ketcham (2015), which was designed specifically for use with microprobe data for apatites with mixed F, Cl, and OH in the monovalent anion site, but for which no information is available on H_2O (OH) contents (the usual case, per discussion above). We added arsenic to the Ketcham (2015) spreadsheet to enable calculations for apatites of any As:P ratio. As general results for the 29 specimens analyzed we note that (a) all of the samples but one yielded totals reasonably close to 100%; (b) the calculated contents of the M sites (nominally Ca, but also including minor Mn, Sr, and Na as substituents) and of the T site (nominally As and P, but also including minor Si) all come close to the theoretical 10:6 ratio; (c) the F:Cl:OH ratios are all quite close to those we'd calculated before from a different method; and (d) our calculations of As:P for each specimen are nearly identical to those given by Crimmins (2012). Together these results lend confidence both to the original analyses and to the atomic ratios calculated from them.

We now show photographs of some of the specimens analyzed by Crimmins (2012) so their daylight appearance, fluorescence, and compositions can be compared.

Fluorapatite: Figures 1-6 show six specimens of orebody fluorapatite, four from Sterling Hill and two from Franklin. In daylight the color of the fluorapatite is variable, from gray through greenish gray to pale green, blue, and also pale tan through orange-tan, locally with a reddish tinge. Color mottling is common. All fluoresce orange SW, of weak to moderate brightness (but brightly fluorescing fluorapatite specimens are known). Their arsenic contents range widely, from nearly pure fluorapatite (Figure 4) to apatite with an As:P ratio of 44:56 (Figure 3). Twelve of the 29 specimens analyzed by Crimmins (2012) are fluorapatite, suggesting this species is among the most common of the orebody apatites at Franklin and Sterling Hill.

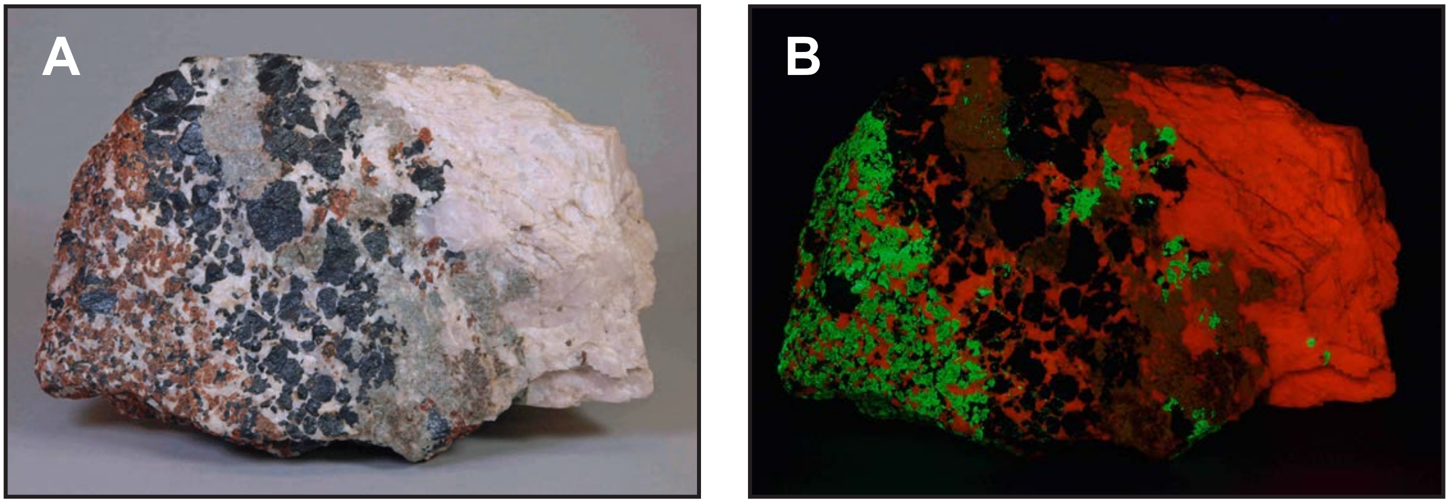


Figure 1. Fluorapatite, Sterling Mine. A, daylight view; B, same specimen under SW UV. Pale grayish-green fluorapatite along the contact between white calcite marble on right and granular willemite-franklinite-calcite ore on left. This is an arsenian fluorapatite with $As_{28}P_{72}$, 1.72 wt.% F, and 0.13 wt.% Cl. The fluorapatite shows a dull orange-brown to ruddy orange fluorescence SW. Earl R. Verbeek specimen ERV-293, 7.5 × 4.5 × 2.0 inches (19 × 11.5 × 5 cm).

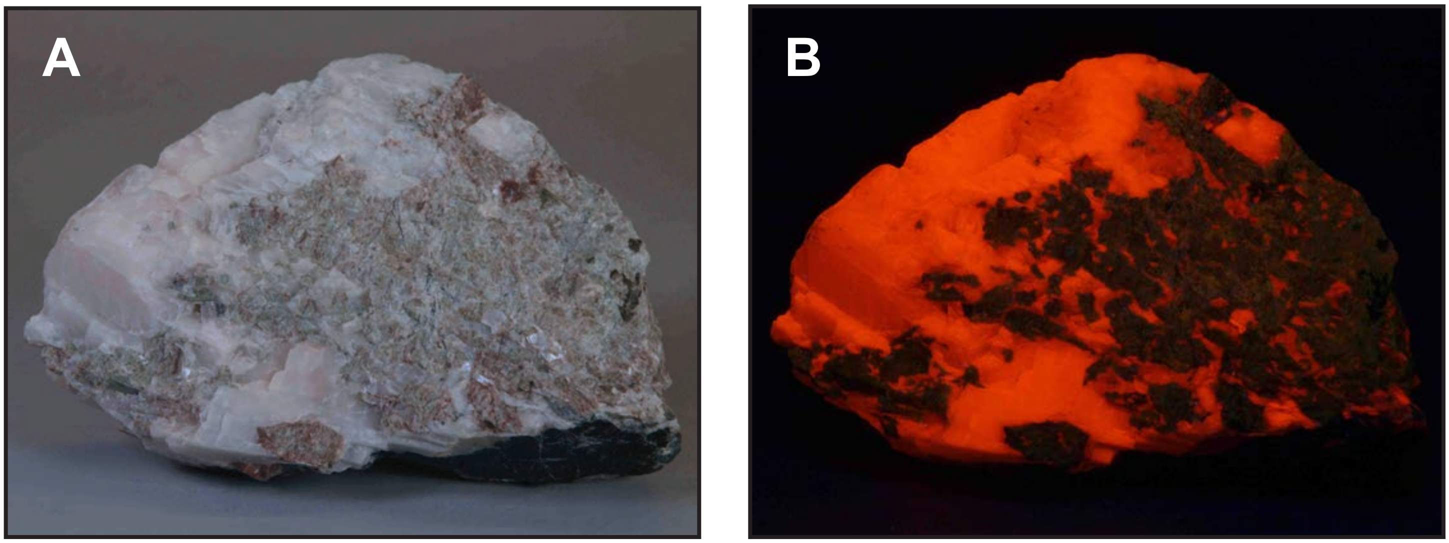


Figure 2. Fluorapatite, Sterling Mine. A, daylight view; B, same specimen under SW UV. Color-mottled, pale grayish green to pale tan fluorapatite in coarse-grained calcite marble (fl. red), with minor black mica. This is an arsenian fluorapatite with $As_{18}P_{82}$, 4.15 wt.% F, and 0.09 wt.% Cl. The fluorapatite shows a dull to moderate orange fluorescence SW. Earl R. Verbeek specimen ERV-1369, 3.7 × 2.6 × 1.2 inches (9.5 × 6.5 × 3 cm).

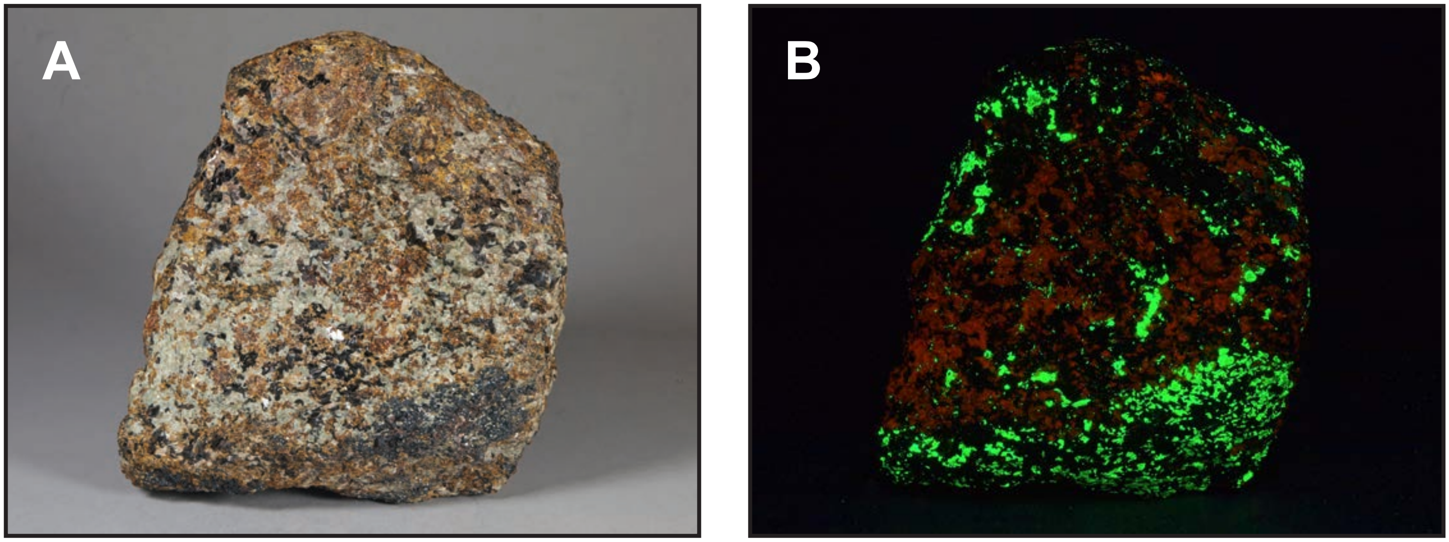


Figure 3. Fluorapatite, Franklin. A, daylight view; B, same specimen under SW UV. Abundant, pale green fluorapatite with ochre-brown andradite and dark brown (black in aggregate) hendricksite in contact with finer-grained franklinite-willemite ore at base. This is an arsenic-rich fluorapatite of composition $As_{44}P_{56}$ and with 2.64 wt.% F and only 0.01 wt.% Cl. Earl R. Verbeek specimen ERV-2213, 4.7 × 4.1 × 2.6 inches (12 × 10.5 × 6.5 cm).

Figure 4. Fluorapatite, Franklin. Slightly color-mottled, orange-tan to rosy tan fluorapatite in anhedral masses intergrown with coarse masses of hendricksite mica, with minor grayish-green actinolite and sparse epidote. This is nearly pure fluorapatite with composition $As_{0.1}P_{99.9}$ and with 2.4 wt.% F. Richard C. Bostwick specimen RCB-358, 4.7 × 3.0 × 2.0 inches (12 × 7.5 × 5 cm).

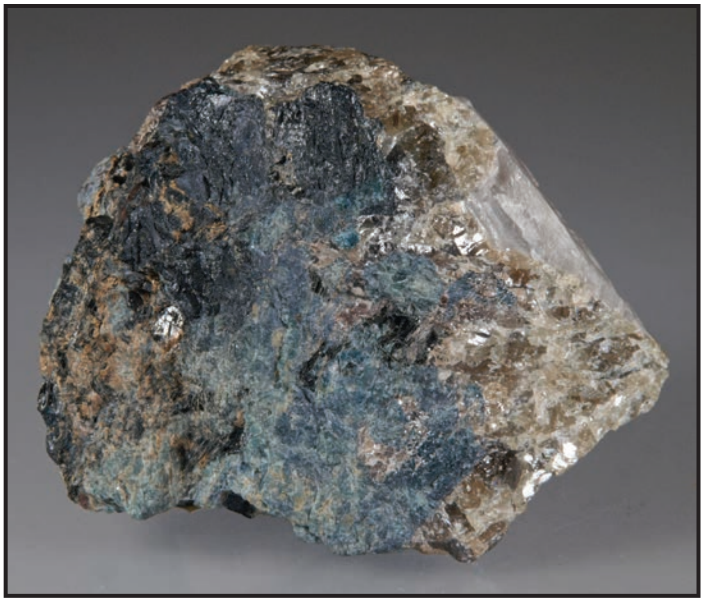


Figure 5. Fluorapatite, Sterling Mine. Massive, pale to medium blue apatite with coarse-grained magnetite or magnetic franklinite, pale yellow sphalerite, pale gray calcite, small grains of a tawny brown garnet, and a few grains of a greenish-brown mica. Under SW ultraviolet light, the apatite and sphalerite fluorescence a similar weak orange color. The fluorescence of the apatite is dimmest in the zones of deeper blue color. Richard C. Bostwick specimen RCB-211, 3.0 × 2.2 × 1.6 inches (7.5 × 5.5 × 4.5 cm).

Figure 6. Fluorapatite, Sterling Mine. Elongated crystals of fluorapatite in a matrix of pale gray, coarse-grained calcite. The main apatite crystal is prismatic, with hexagonal cross section, and is 3.7 cm long. The apatite is pale gray to slightly greenish-gray where fresh but is locally stained brown on exterior surfaces. The crystals fluoresce dim orange SW, but somewhat more brightly where they have been broken open. Richard C. Bostwick specimen RCB-212, 2.8 × 1.6 × 0.8 inches (7 × 4 × 2 cm).

Johnbaumite: Figures 7-16 show ten specimens of johnbaumite. All are from Franklin, but Dunn (1995) described an occurrence of johnbaumite from Sterling Hill, and Jenkins (1994) described another. As shown, johnbaumite occurs in a wide range of mineral assemblages at Franklin, and in a wide range of daylight colors as well, including pale gray, pale through medium green, greenish-blue to blue, and tan through orange-tan to brown. The fluorescence is variable, from almost nonexistent (dim orange-brown) to bright orange SW. Their compositions range from fairly pure johnbaumite with As:P of 93:7 (Figure 13) to decidedly impure examples such as that of Figure 9, with As:P of 53:47. One specimen (ERV-1383, not shown) has As:P of 49.9:50.1, within analytical error of the 50:50 join between the arsenate and phosphate apatites. Ten of the 29 specimens analyzed by Crimmins (2012) are johnbaumite, suggesting that johnbaumite is fairly common among the orebody apatites, at least at Franklin. Dunn (1995) suggested it may have been locally abundant at Sterling Hill as well.

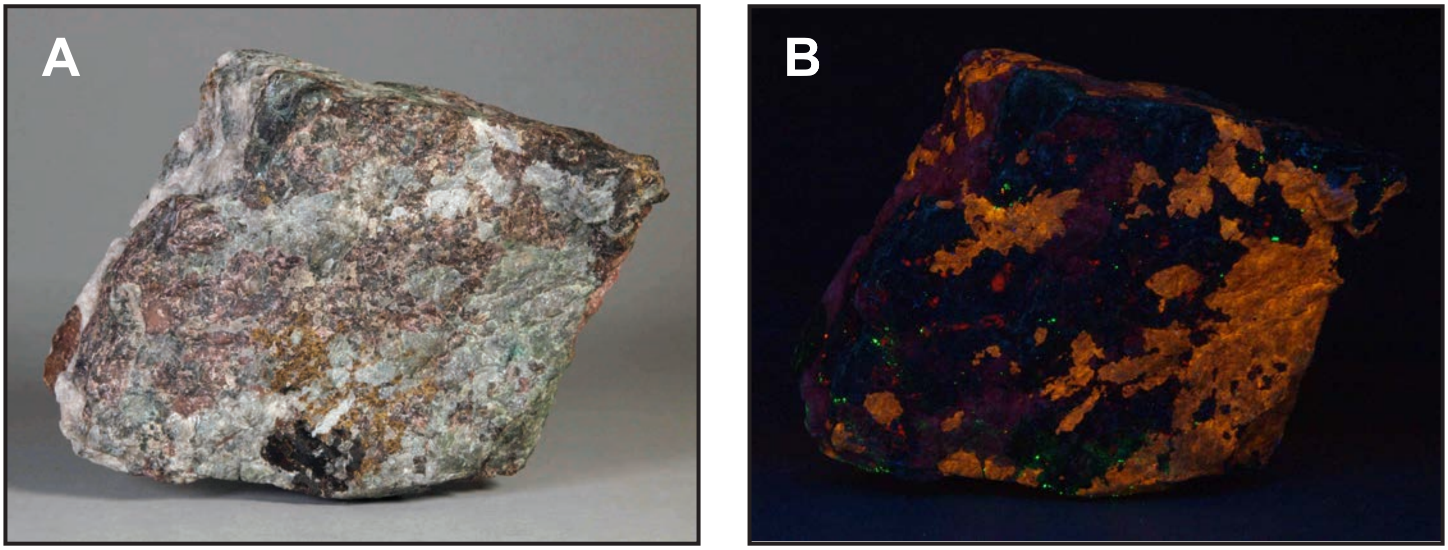


Figure 7. Johnbaumite, Franklin. A, daylight view; B, same specimen under SW UV. A coarse-grained assemblage consisting of grayish-green johnbaumite and pinkish-brown rhodonite, with minor white feldspar, orange-brown garnet, dark brown diopside, willemite, and calcite. The johnbaumite shows a mottled, dull to moderate orange fluorescence SW; the accompanying feldspar fluoresces dull deep red. The composition is As$_{68}$P$_{32}$ with an appreciable svabite component (1.31 wt.% F) and negligible turneaureite component (0.01 wt.% Cl). Earl R. Verbeek specimen ERV-1368, 3.1 × 2.8 × 1.8 inches (8 × 7 × 4.5 cm).

Figure 8. Johnbaumite, Franklin. Euhedral crystal sections of leek green johnbaumite and a single grain of orange-brown garnet embedded in a matrix of fine-grained calcite suffused with tiny grains of willemite. The bright green fluorescence of the matrix effectively masks that of the johnbaumite, but upon close inspection the johnbaumite is seen to fluoresce dim ruddy orange SW. The composition is As$_{56}$P$_{44}$, with 1.19 wt.% F. Richard C. Bostwick specimen RCB-352, 4.0 × 2.6 × 2.4 inches (10 × 6.5 × 6 cm).

Figure 9. Johnbaumite, Franklin. Massive, dark blue johnbaumite with a dark brown pyroxene, minor orange-brown garnet, and small grains of white calcite. The johnbaumite is nearly nonfluorescent but upon close inspection shows a dim orange-brown fluorescence SW. Its composition of As$_{53}$P$_{47}$ puts it close to the dividing line between hydroxylapatite and johnbaumite, just barely within the compositional range of an arsenic apatite. Moreover, this specimen contains appreciable components of both svabite and turneaureite, with 1.17 wt.% F and 1.21 wt.% Cl. Earl R. Verbeek specimen ERV-441, 4.1 × 3.1 × 2.4 inches (10.5 × 8 × 6 cm).

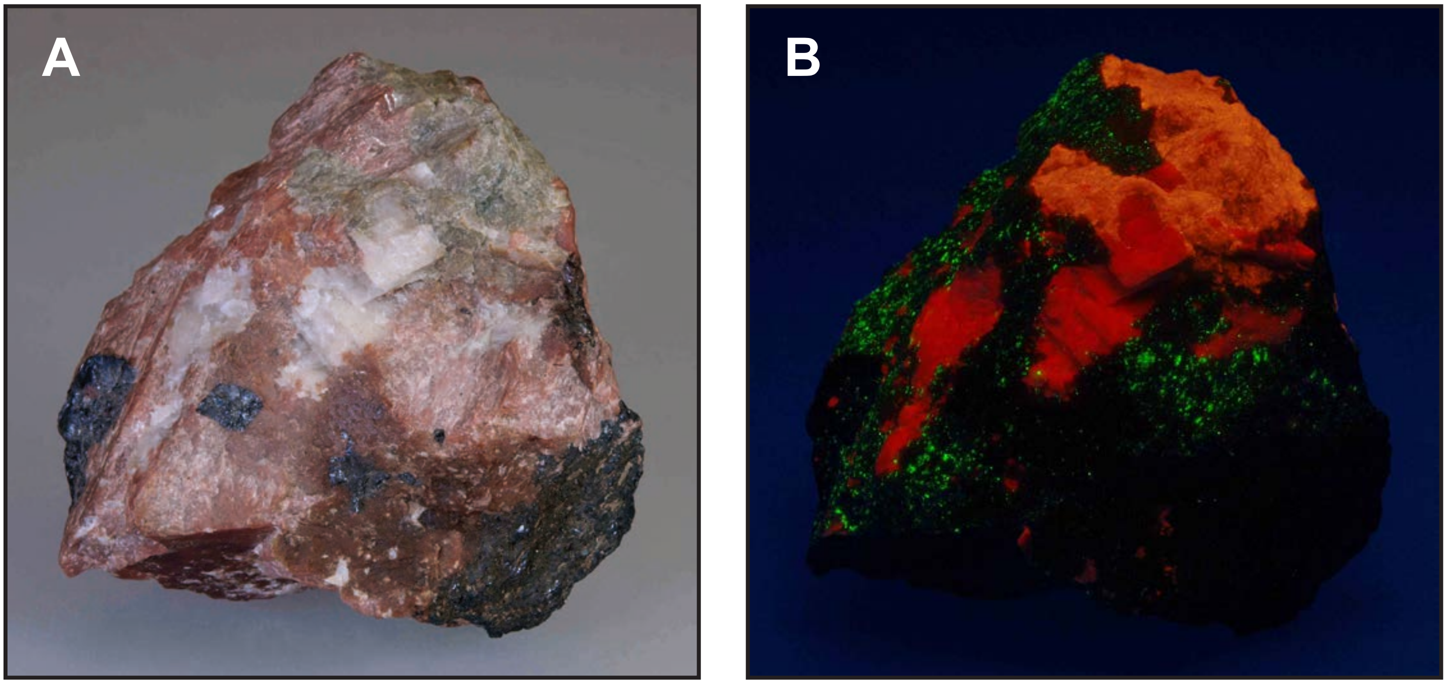


Figure 10. Johnbaumite, Franklin. A, daylight view; B, same specimen under SW UV. Pale grayish-green johnbaumite in a coarse-grained assemblage with brownish-pink rhodonite, white calcite, and black franklinite. The johnbaumite in this specimen shows unusually bright orange fluorescence SW. The composition is $\mathrm{As}_{56}\mathrm{P}_{44}$, with 1.02 wt.% F and 0.50 wt.% Cl. Richard C. Bostwick specimen RCB-354, 2.4 × 2.2 × 1.2 inches (6 × 5.5 × 3 cm).

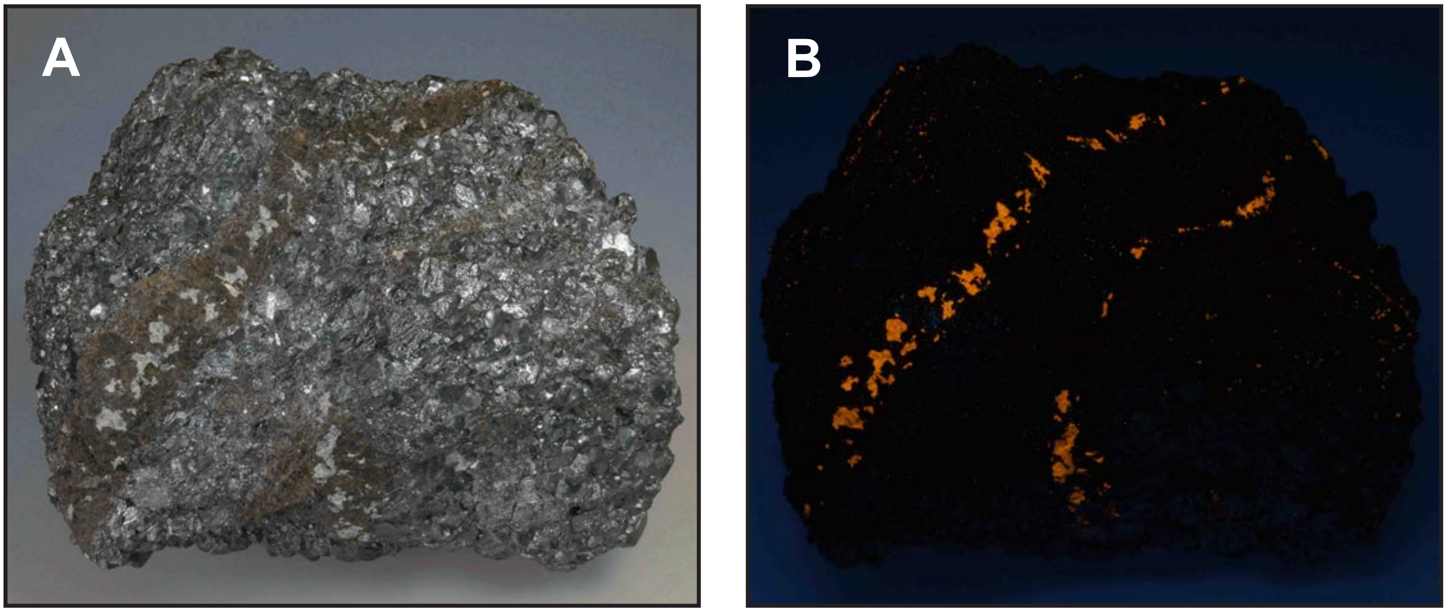


Figure 11. Johnbaumite, Franklin. A, daylight view; B, same specimen under SW UV. Pale grayish-green grains of johnbaumite occupying the central portions of two veins of dark brown pyroxene and orange-brown garnet in a matrix of granular hematite and magnetite. In a direct comparison, the color and brightness of the SW fluorescence of this johnbaumite are identical to those of turneaureite from the type assemblage at Franklin, but this specimen is of much different composition, with 0.95 wt.% F and only 0.21 wt.% Cl (pure turneaureite contains 5.43% Cl). The phosphate content is also fairly low, with $\mathrm{As}_{81}\mathrm{P}_{19}$. Earl R. Verbeek specimen ERV-506, 5.1 × 4.0 × 2.2 inches (13 × 10 × 5.5 cm).

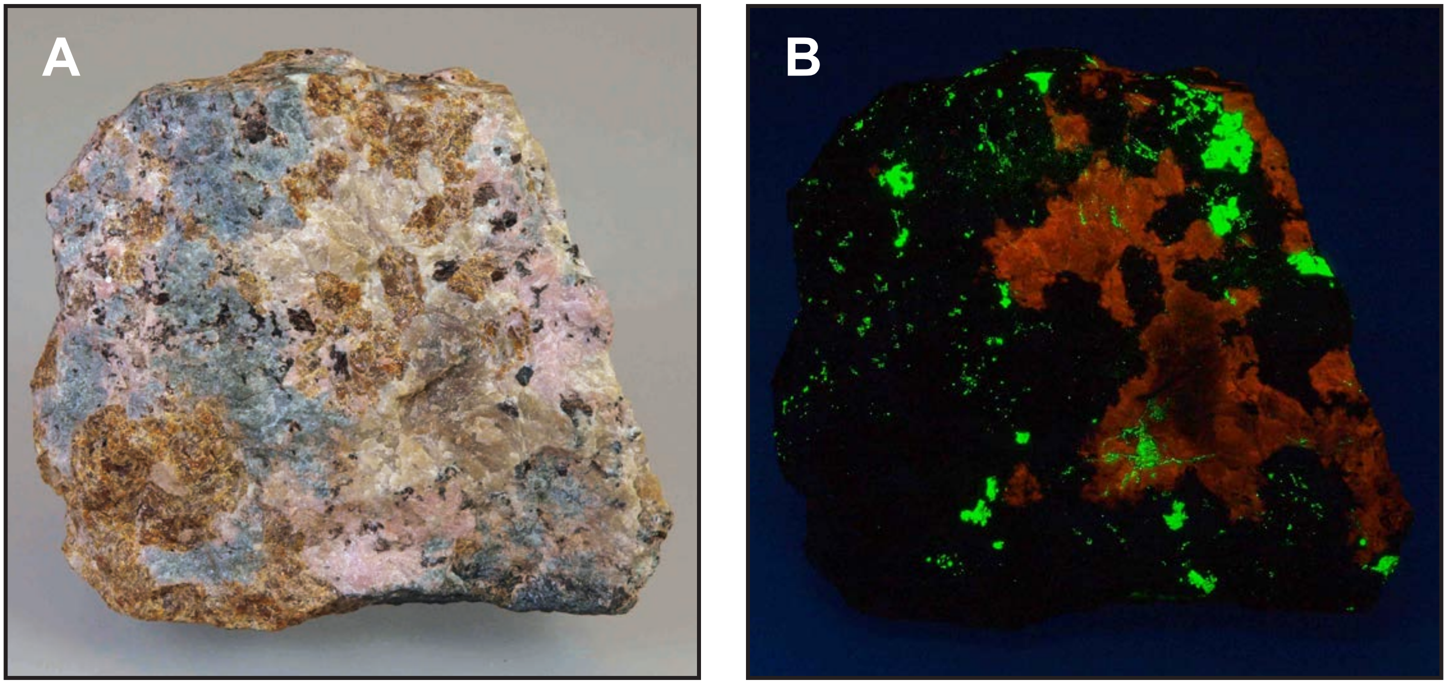


Figure 12. Johnbaumite, Franklin. A, daylight view; B, same specimen under SW UV. Pale yellow johnbaumite in a coarse-grained assemblage with pink bustamite, orange-brown garnet, dark brown hendricksite, and a blue mineral not yet analyzed. The johnbaumite shows a fairly bright orange fluorescence SW. The composition is $As_{70}P_{30}$ with 0.95 wt.% F and only 0.02 wt.% Cl. Earl R. Verbeek specimen ERV-1384, 2.6 × 2.4 × 1.8 inches (6.5 × 6 × 4.5 cm).

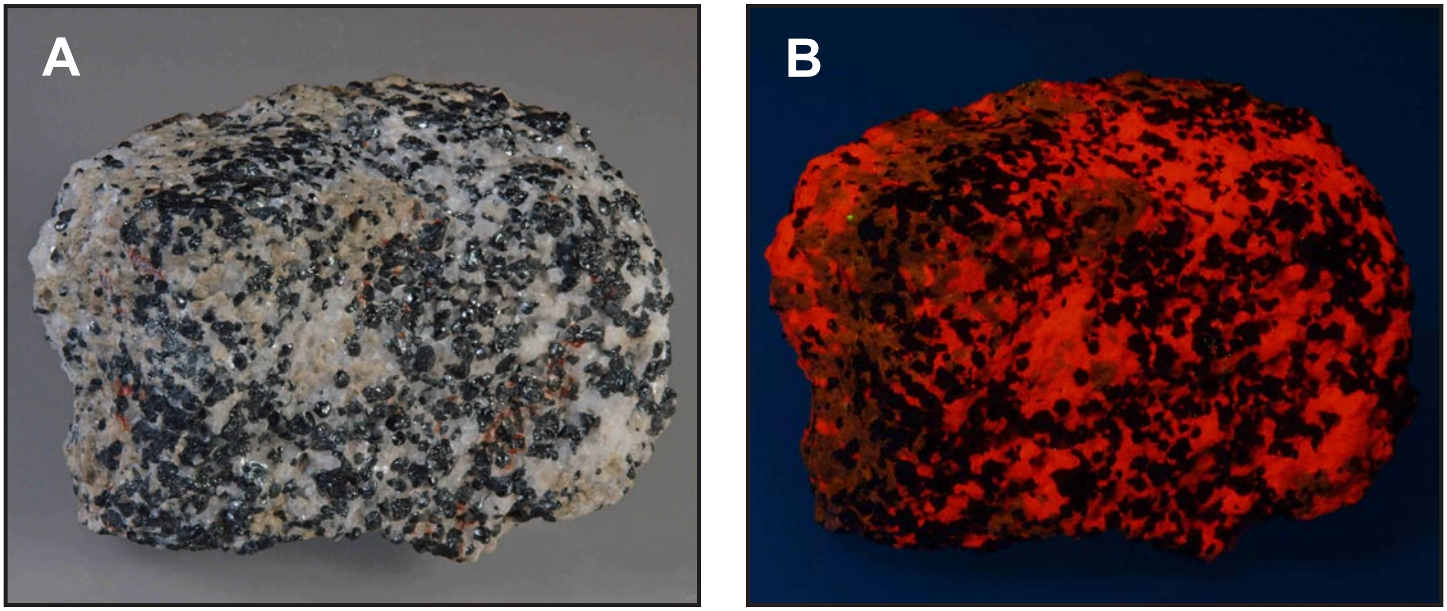


Figure 13. Johnbaumite, Buckwheat Dump, Franklin. A, daylight view; B, same specimen under SW UV. Pale yellowish-green to tannish-green grains of johnbaumite in granular franklinite-calcite ore with minor zincite. The johnbaumite fluoresces dull to moderate orange SW, much dimmer than that of the matrix calcite. The composition is $As_{93}P_{7}$ with 0.89 wt.% F and 0.19 wt.% Cl. Richard C. Bostwick specimen RCB-355, 2.6 × 1.6 × 1.0 inches (6.5 × 4 × 2.5 cm).

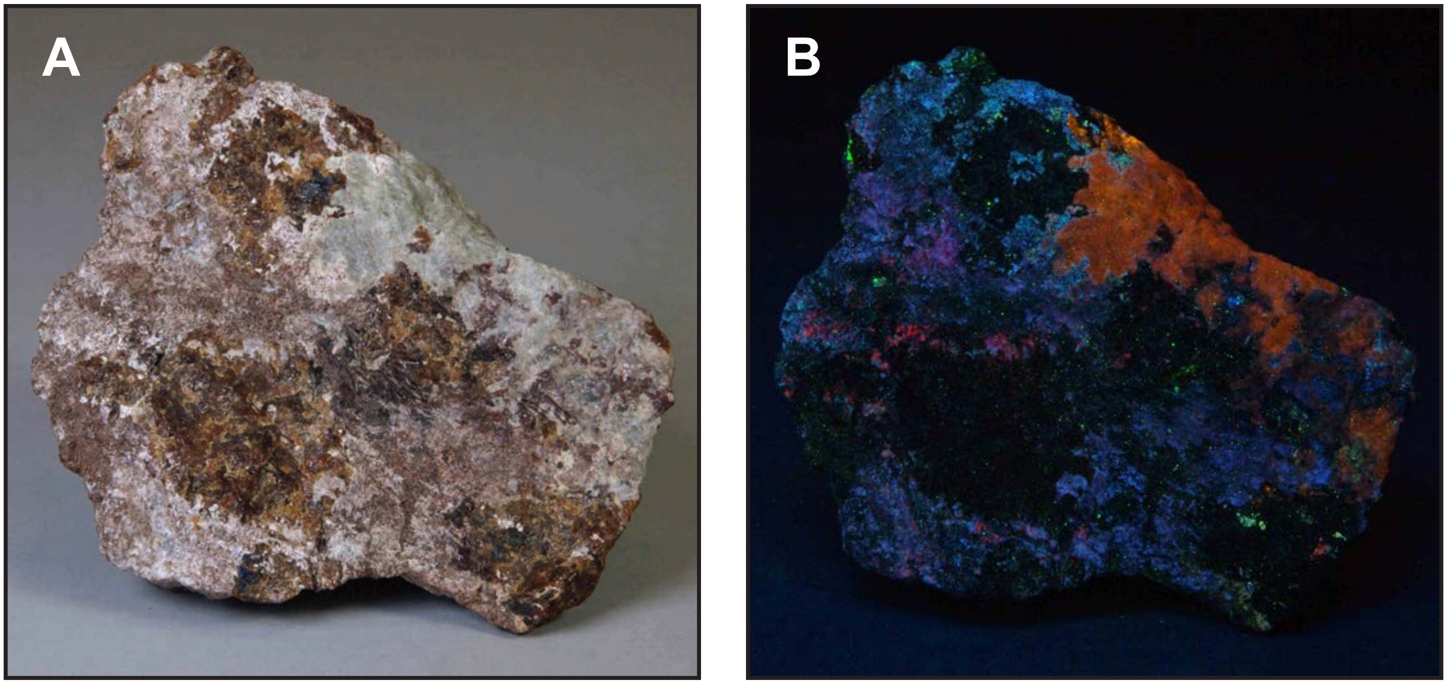


Figure 14. Johnbaumite, Franklin. A, daylight view; B, same specimen under SW UV. Pale green, phosphatian, fluorian johnbaumite in a matrix of altered hancockite with garnet, hendricksite, prehnite, xonotlite, and minor clinohedrite. The johnbaumite fluoresces moderately bright orange SW. The composition is $As_{56}P_{44}$ with 1.23% F and 0.13% Cl. Richard C. Bostwick specimen RCB-356, 2.2 × 1.8 × 0.8 inches (5.5 × 4.5 × 2 cm).

Figure 15. Johnbaumite, Franklin. Anhedral masses of pale brown johnbaumite associated with andradite, brown to black serpentine, and minor willemite and calcite. The johnbaumite fluoresces bright orange SW. The composition is $As_{94}P_6$ with 1.07 wt.% F and 0.07 wt.% Cl, making this johnbaumite with a considerable svabite component. Earl R. Verbeek specimen ERV-1371, 3.5 × 2.4 × 1.8 inches (9 × 6 × 4.5 cm).

Figure 16. Johnbaumite, Franklin. Anhedral masses of nearly white johnbaumite (with slight greenish tinge) in a granular matrix of franklinite, zincite, green willemite, and pink to brown leucophoenicite(?). The johnbaumite fluoresces moderately bright, ruddy orange SW. The composition is $As_{60}P_{40}$ with 0.94 wt.% F and 0.01 wt.% Cl, making this a phosphatian johnbaumite. Richard C. Bostwick specimen RCB-210, 3.3 × 2.2 × 2.2 inches (8.5 × 5.5 × 5.5 cm).

Svabite: Of the 29 specimens analyzed by Crimmins (2012), only one (Figure 17) calculates unequivocally as svabite. A second specimen (Figure 18) is so close to the svabite-fluorapatite join (F-dominant, As:P = 50:50 within analytical error) that its species cannot be definitively stated, and in a third specimen (Figure 19), the atomic proportions of F and OH are so nearly identical ($F_{48}Cl_3OH_{49}$) that the apatite lies squarely on the svabite-johnbaumite join. Their daylight colors—leek green, pale to medium blue, and tan to dark brown—have counterparts among known johnbaumite and fluorapatite specimens from Franklin and Sterling Hill, and their orange fluorescence SW ranges from bright to fairly dim, which in the specimens of Figures 17 and 19 is directly related to variations in their daylight color, the paler parts showing the brightest fluorescence. One of these specimens (Figure 19) is a nearly pure arsenate apatite, with As:P of 94:6, but the other two have much higher phosphate contents. For reasons later stated, svabite appears to be a rare species locally.

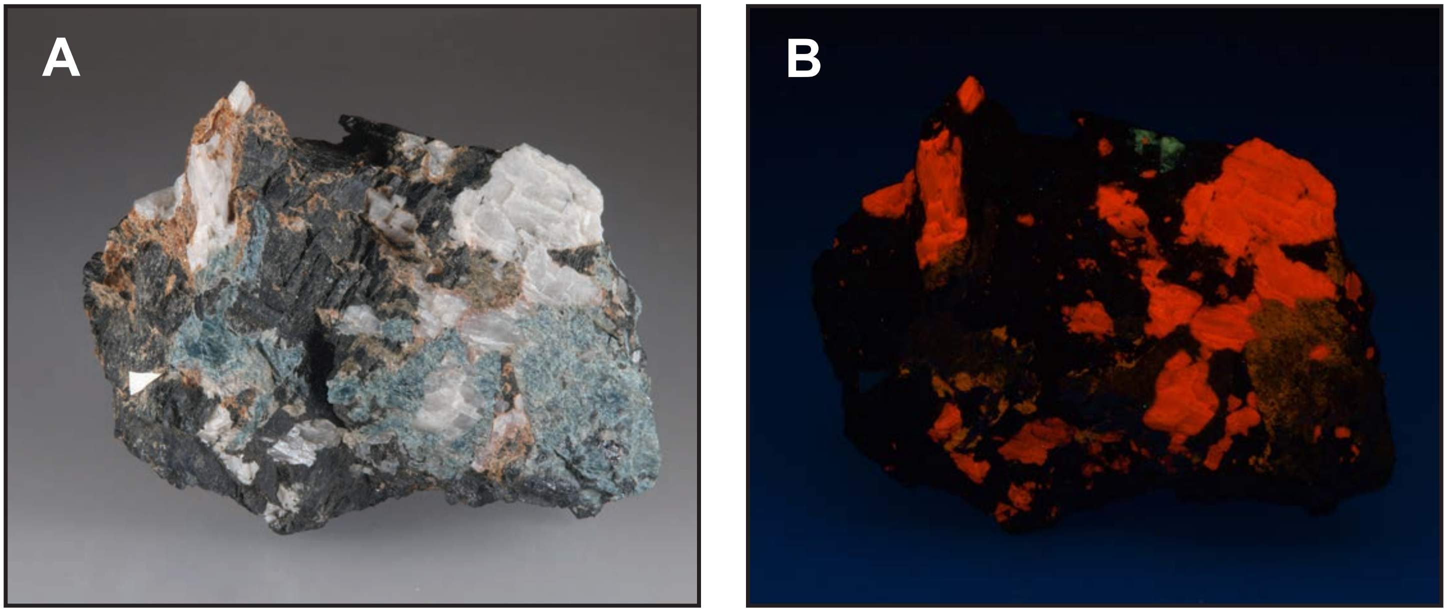


Figure 17. Svabite, 700 crosscut, 600 level, Sterling Hill. A, daylight view; B, same specimen under SW UV. A coarse-grained assemblage including anhedral masses of medium-blue svabite with abundant, very dark green pyroxene, franklinite, calcite, minor brownish-orange garnet, and, in one area, a little white barite. The svabite shows strongly zoned SW fluorescence ranging from bright orange to dull brown. The brightness of fluorescence correlates strongly with daylight color, with the brightest fluorescence occurring in small patches of creamy white svabite, those of moderate brightness in areas of moderate grayish-blue color, and the dull brown response in areas that are a deeper shade of blue. Richard C. Bostwick specimen RCB-213, 4.1 × 2.8 × 1.8 inches (10.5 × 7 × 4.5 cm).

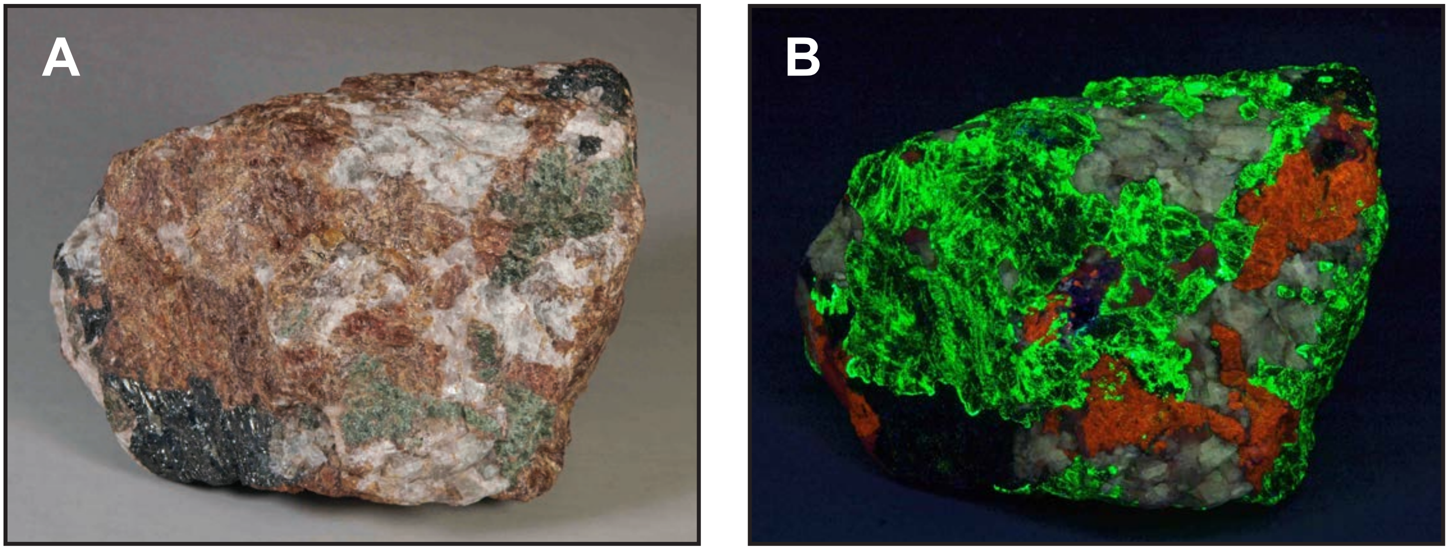


Figure 18. Svabite-fluorapatite, Franklin. A, daylight view; B, same specimen under SW UV. Anhedral masses of svabite-fluorapatite (fluorescent bright orange SW) with coarse-grained barite (white), willemite (green), and minor nonfluorescent franklinite. This apatite has a calculated composition of $As_{50}P_{50}$ and is F dominant, with 1.8% F. It thus sits squarely on the join between svabite and fluorapatite. Earl R. Verbeek specimen ERV-1383; 3.3 × 2.4 × 1.8 inches (8.5 × 6 × 4.5 cm).

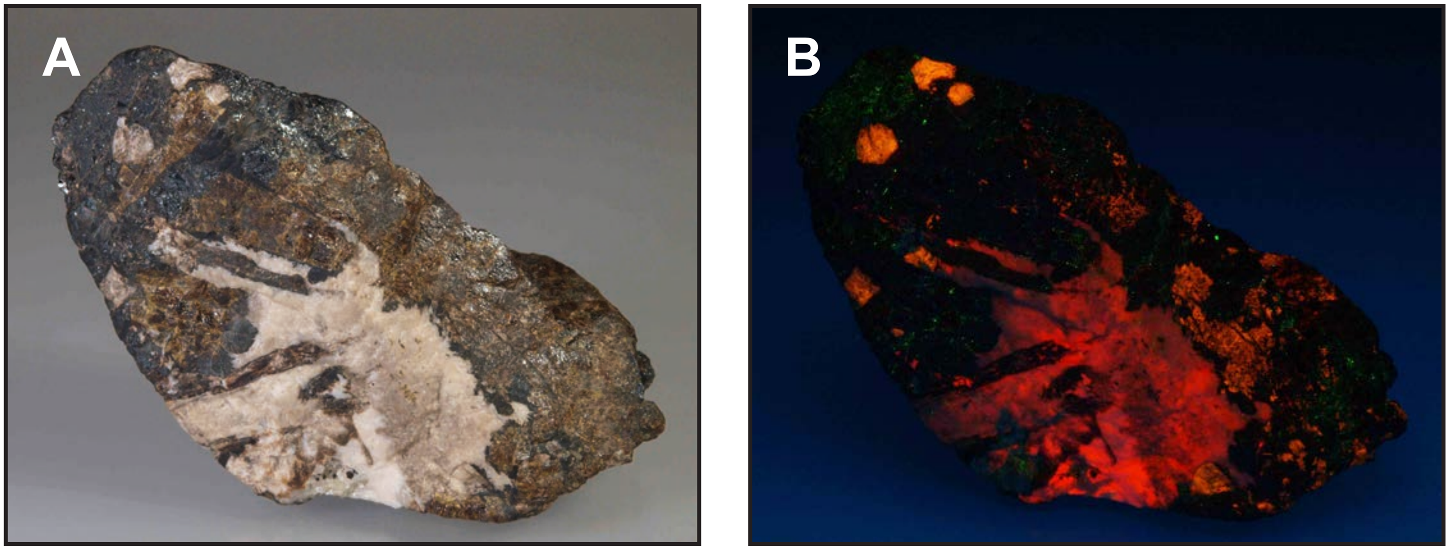


Figure 19. Svabite-johnbaumite, Franklin. A, daylight view; B, same specimen under SW UV. Grains of tan to dark brown svabite-johnbaumite in a coarse-grained matrix of dark orange-brown garnet and franklinite, with minor calcite and serpentine(?). The svabite-johnbaumite fluoresces orange SW, brightest in the grains of palest daylight color and much dimmer in the brown material. The composition is $As_{94}P_6$ with 1.51 wt.% F and 0.16 wt.% Cl. Richard C. Bostwick specimen RCB-360, 3.3 × 1.8 × 1.6 inches (8.5 × 4.5 × 4 cm).

Turneaureite: The specimen shown in Figure 20 is from the type assemblage of this species, well known to collectors of the local fluorescent minerals. In this type assemblage, turneaureite occurs as pale gray masses and crystal sections in salmon-orange, coarse-grained calcite, accompanied in many specimens by abundant brown garnet. The fragment analyzed by Crimmins (2012), however, is somewhat more OH-dominant than Cl-dominant, and thus calculates as johnbaumite, thereby hinting at compositional zoning among the apatites of this assemblage. Excepting hedyphane, all other specimens analyzed contain far too little chlorine to approach the turneaureite compositional field, and the type assemblage from Franklin, described by Dunn (1985), remains the only one known locally. Turneaureite has not yet been found at Sterling Hill.

Hydroxylapatite: Frondel (1972, p. 42), in his checklist of Franklin-Sterling Hill minerals, mentioned a then-recent report of hydroxylapatite from the area, but in the absence of further information, the species was not added to the official list of locally occurring species. One of the phosphate apatites

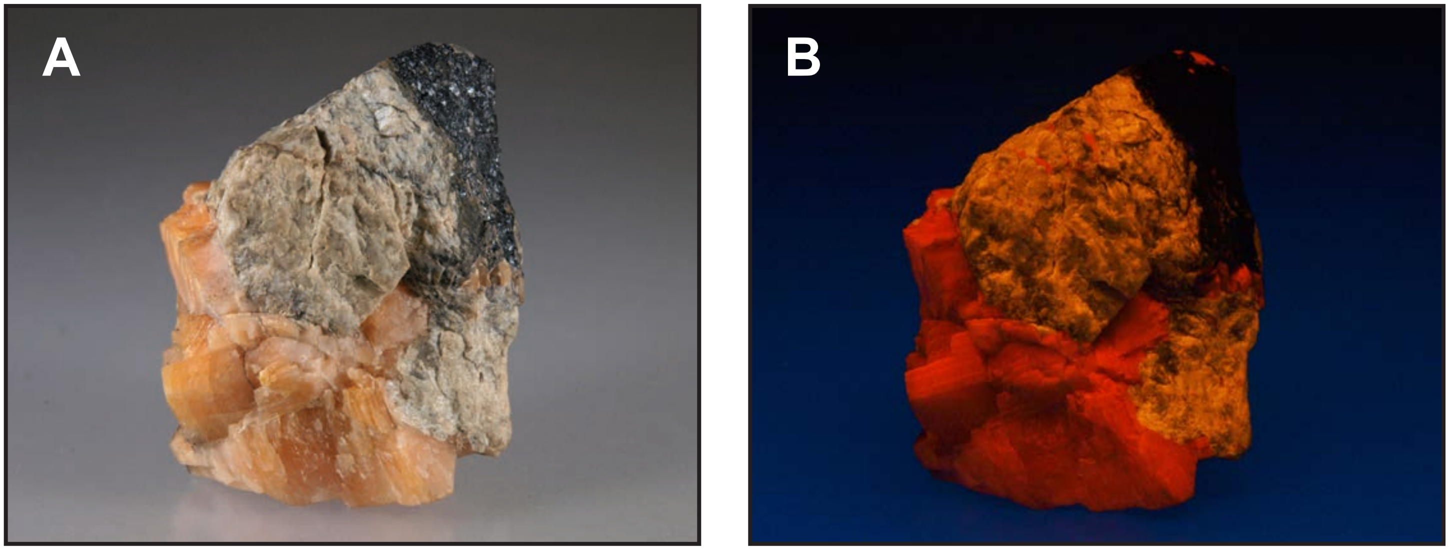


Figure 20. Turneaureite, Franklin. A, daylight view; B, same specimen under SW UV. Pale greenish-gray masses and a hexagonal crystal section of turneaureite in a matrix of salmon-orange calcite. This specimen is from the type assemblage of the species at Franklin and has a composition of $As_{75}P_{25}$ with 2.12% Cl. The chlorine content is far higher than that of any of the johnbaumite, svabite, or fluorapatite specimens analyzed and is exceeded only by that of hedyphane. Richard C. Bostwick specimen RCB-351; 2.0 × 1.6 × 1.4 inches (5 × 4 × 3.5 cm).

Figure 21. Hydroxylapatite, Sterling Mine. An elongated grain several centimeters long of a medium greenish-gray apatite embedded in nearly white calcite, with several small grains of franklinite and, in one small area only, a few tiny grains of bright red zincite. The apatite fluoresces dull ruddy orange SW, rather inconspicuous compared to the bright orange-red fl. of the associated calcite. Richard C. Bostwick specimen RCB-214, 3.7 × 2.4 × 1.4 inches (9.5 × 6 × 3.5 cm).

analyzed by Crimmins (2012), however, contains more OH than either F or Cl and thus calculates as hydroxylapatite. This specimen (Figure 21) is interesting in that it was collected from one cut above the 1200-level occurrence of johnbaumite in the Sterling Mine. Some of the specimens from this higher cut are known to be fluorapatite instead—so now we have three different apatite species reported from the same general area. Note, however, that the specimen of Figure 21 has an As:P content of 40:60 and an F:OH content of 44:55, so is not far from the 50:50 join between both As:P and F:OH. Thus, even modest compositional differences in different apatite grains from this area could result in johnbaumite (As and OH dominant), fluorapatite (P and F dominant), and hydroxylapatite (P and OH dominant). We note, also, that specimen ERV-441 (Figure 9), with As:P = 53:47 and F:OH = 37:42, is close to hydroxylapatite in composition, though it is johnbaumite. Despite these findings, we do not recommend adding hydroxylapatite to the list of local mineral species until a specimen is verified as such by direct determination of OH content.

Hedyphane: Two of the specimens supplied to Crimmins are hedyphane. The one shown in Figure 22 is from the well-known Franklin vein assemblage of massive, honey-colored hedyphane with embedded crystals of brown to pinkish-brown rhodonite. In this assemblage the hedyphane fluoresces a “burnt orange” color, best MW but still of only modest brightness. In the other assemblage (Figure 23) the hedyphane is white in daylight and fluoresces bright orange, best SW. In still other assemblages, only a dim orange SW fluorescence is visible, or none at all. The two specimens analyzed are almost pure arsenate apatites, with only 0.1 wt.% or less of P_2O_5. Their F contents are likewise low, 0.06 wt.% or less. As shown by Rouse et al. (1984), Sr is a significant impurity element in Franklin hedyphane, constituting in some specimens up to 7 wt.% SrO substituting for CaO in the hedyphane structure. Strontium is likewise elevated in the two specimens shown here (Table 2).

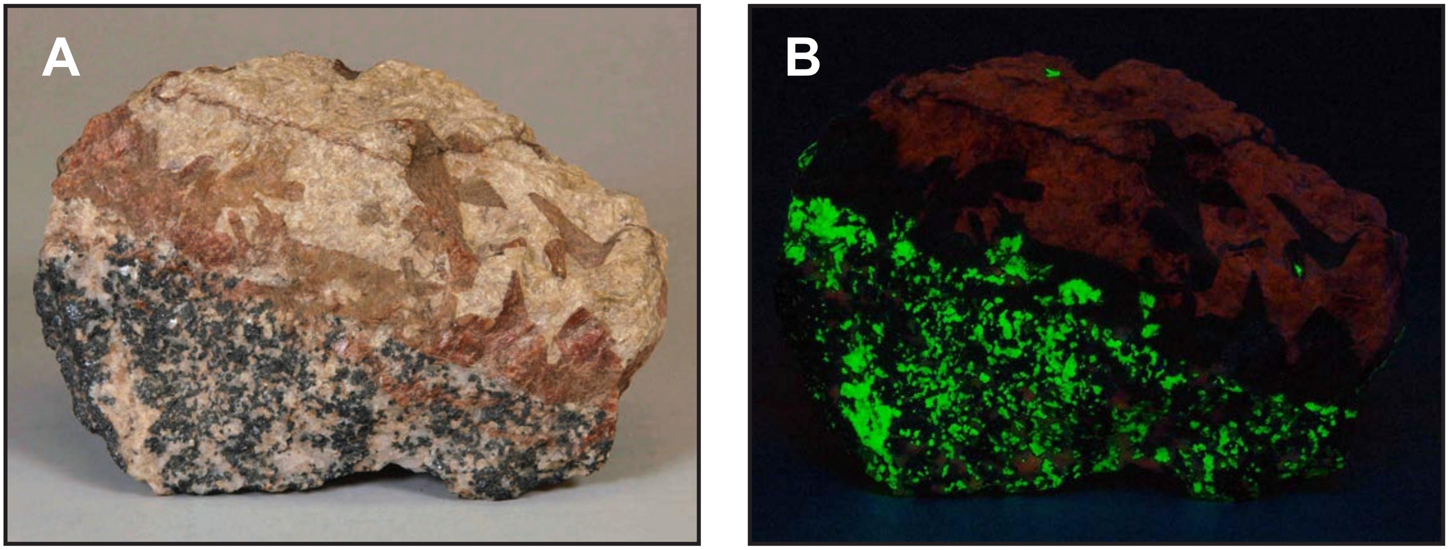


Figure 22. Hedyphane, Franklin. A, daylight view; B, same specimen under MW UV. Massive, pale honey-brown hedyphane with crystals of pinkish-brown rhodonite in a vein cutting granular willemite-franklinite-calcite ore. This specimen is from the most well-known assemblage of hedyphane from Franklin but is unusual in that it broke obliquely through the vein to expose a broad surface of hedyphane and rhodonite. The low F content, only 0.06 wt.%, is in accord with the work of Rouse et al. (1984), who found that fluorine in analyzed specimens of Franklin hedyphane is either absent or present only in traces. Hedyphane from this assemblage fluoresces dim to moderate orange, brightest MW rather than SW. Richard C. Bostwick specimen RCB-353, 4.0 × 2.8 × 1.2 inches (10 × 7 × 3 cm).

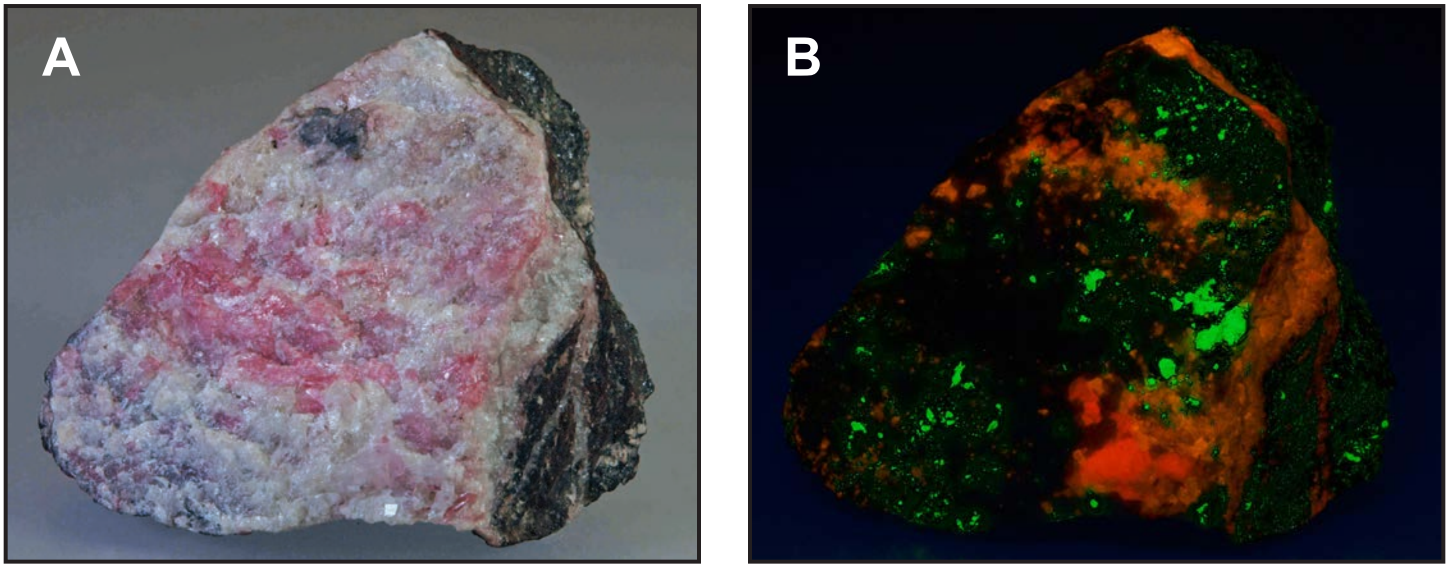


Figure 23. Hedyphane, Franklin. A, daylight view; B, same specimen under SW UV. A vein of fine-grained, white to cream-colored hedyphane with bladed, pink rhodonite crystals atop white calcite, all on a dark matrix of gneissic franklinite-willemite ore. The matrix rock within 1 cm of the vein is dark brown rather than black, the gneissic texture does not exist, and some of the grains are comminuted; this is a fault breccia. The hedyphane in this specimen, in contrast to that of Figure 22, fluoresces bright orange and fluoresces best SW rather than MW. Richard C. Bostwick specimen RCB-361, 2.6 × 2.0 × 1.6 inches (6.5 × 5 × 4 cm).

Mimetite: No specimens of mimetite were submitted for analysis in this study, but Figure 24 shows a specimen of the Sterling Hill (Noble Pit) material that originally was labeled pyromorphite and was later stated by Dunn (1995) to be mimetite. An analysis of this material on p. 650 of Dunn's 1995 monograph shows it to be an arsenic-dominant (thus mimetite) intermediate member of the mimetite-pyromorphite solid-solution series with As:P of 60:40. As shown in the detail photo, a microbotryoidal habit is typical of this material, and its color ranges from tan through orange-tan to bright yellow. A weak orange fluorescence MW is seen in some specimens.

Pyromorphite: Pyromorphite is not yet known with certainty from either Franklin or Sterling Hill. It was provisionally added to the 2015 list of Franklin-Sterling Hill species in the Fall 2015 issue of *The Picking Table*, but the studied material (from Sterling Hill) was subjected only to an EDS scan (Vandall

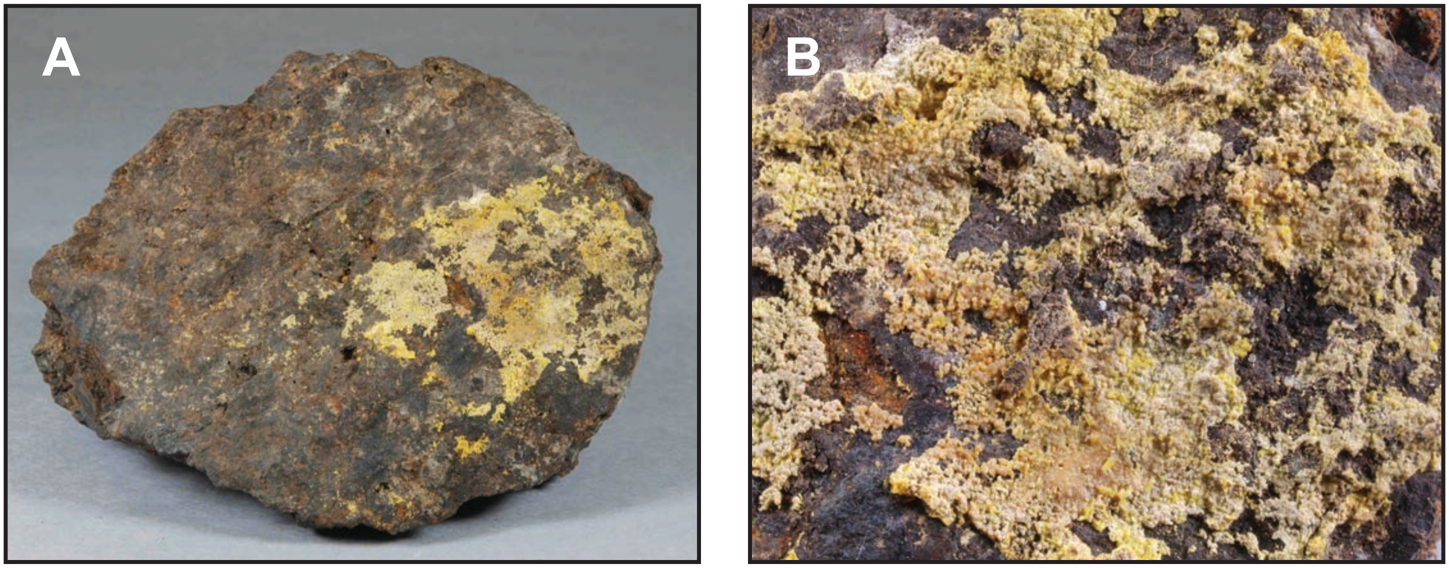


Figure 24. Mimetite, Sterling Hill. A, whole specimen view; B, detail view. A crust of pale tan to yellow, microbotryoidal mimetite from the Noble pit at Sterling Hill. This specimen was not analyzed, but an analysis of another specimen from the same find was presented in Dunn (1995, p. 650) and shows it to be an intermediate member of the mimetite-pyromorphite solid-solution series. Richard C. Bostwick specimen RCB-208, 3.5 × 2.8 × 2.0 inches (9 × 7 × 5 cm).

King, written commun., 2020) and requires more detailed analysis for confident species determination. One specimen of possible pyromorphite occurs as yellow to orange crusts, greatly resembling the mimetite described above in both daylight appearance and its dull fluorescence, but the matrix is "red ore" from Sterling Hill and not the weathered augite from the Noble pit occurrence. Microprobe data for this occurrence are not yet available.

DISCUSSION

All of the specimens submitted for analysis were from the Franklin and Sterling Hill orebodies, as shown by their association with franklinite, willemite, red-fluorescent calcite, zincite, and other species typical of orebody assemblages. The apatites range widely in composition, from almost pure phosphate apatites with As:P ratios of <5% to arsenic apatites with As:P ratios of >95%, and with widely varying F, Cl, and OH contents. Their chlorine contents are in general low, mostly well below 0.5 wt.%, with only five of 29 specimens analyzed having Cl contents above that amount. In contrast, only a few of the samples contain negligible fluorine, 22 of the 29 samples having F contents of 1% or more, in keeping with the abundance of F locally, both in the orebodies and also within the Franklin Marble. Nevertheless, only one of the apatite specimens analyzed contains sufficient F to qualify as svabite. Most of the apatites are either fluorapatite (12 specimens) or johnbaumite (10 specimens), plus two others that are on the dividing line between these species and svabite.

Few of the apatites analyzed fall near end-member compositions. Most instead are mixed phases, some markedly so. Specimen ERV-441, for example, is johnbaumite but contains nearly enough phosphate to be termed hydroxylapatite instead (As:P = 53:47). In terms of its fluorine, chlorine, and hydroxyl ratios, its composition is $F_{37}Cl_{21}OH_{42}$. Thus, this apatite has substantial components of johnbaumite, svabite, turneaureite, fluorapatite, hydroxylapatite, and chlorapatite end members, the last unknown locally as a mineral species. Specimen RCB-360 is overwhelmingly an arsenate apatite ($As_{94}P_6$) but is so close to the dividing line between svabite and johnbaumite that its species designation is equivocal. Specimen ERV-1383, meanwhile, is similar and within analytical accuracy is on the 50:50 join between svabite and fluorapatite. Other specimens are impure in different ways, and to varying degrees, lending added complexity to assigning species designations.

An interesting feature of the Franklin-Sterling Hill apatites is that the phosphate-rich apatites tend to have the highest F contents, whereas the opposite is true for the arsenate-rich members. An inverse correlation between As:P ratio and F content is shown in Figure 25 and graphically illustrates why svabite appears to be so uncommon among the orebody apatites. Only rarely are the fluorine contents for the arsenate apatites sufficiently high to elevate the apatite into the svabite compositional field; most instead are johnbaumite. In similar fashion, the generally high F contents of phosphate apatites from the Franklin-Sterling Hill area correlate with the local rarity of hydroxylapatite, $Ca_5(PO_4)_3(OH)$, only a single example of which was found during this study. In addition, this graph serves to illustrate that a complete compositional series exists between the phosphate and arsenate apatites locally, as foreseen by Frondel (1972, p. 42).

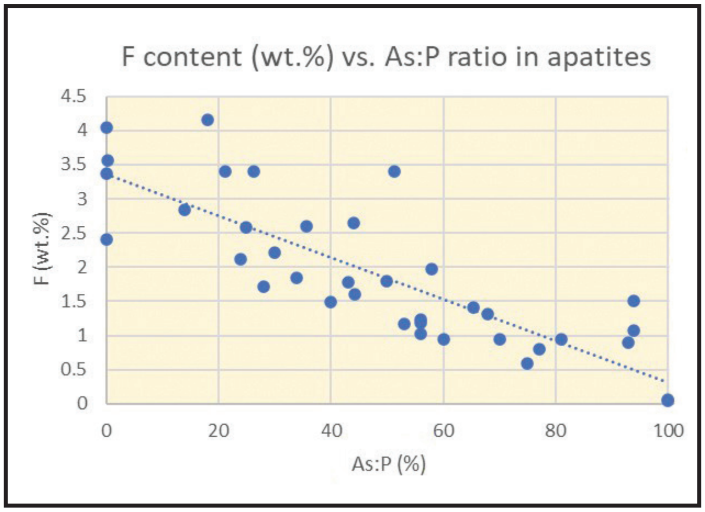


Figure 25. Plot of F content (in wt.%) versus As:P ratio (in %) of analyzed apatite specimens from Franklin and Sterling Hill. Data from Crimmins (2012), with additions from Palache (1935) and Dunn (1995). The data show an inverse correlation between F vs. As contents in the local apatites.

In terms of impurity elements, all of the apatites analyzed contain detectable Pb and Sr. Lead, of course, is a large and essential component of hedyphane (54 wt.% Pb when pure), but it is also present as an impurity element in the calcium arsenate-phosphate apatites, in some to amounts of 2.0 wt.% or more. Similarly, the local apatites commonly host strontium as an impurity element, with most specimens containing 0.3 wt.% Sr or more. Two specimens contain >2 wt.% Sr, and Rouse et al. (1984) reported a hedyphane with 7.0 wt.% Sr. Local alteration of the apatite minerals, which are widespread both at Franklin and Sterling Hill, may thus have liberated Sr to form late-stage, low-temperature hydrothermal minerals such as celestine and strontianite. Small amounts of Mn, too, are nearly ubiquitous in the local apatites and are responsible for their common orange fluorescence SW, as opposed to the greenish-blue to grayish-blue SW fluorescence of fluorapatites in the Mn-poor Franklin Marble external to the orebodies. Rare-earth elements (REEs), not analyzed, are probably responsible for the pink to blue overtones of fluorescence in some specimens of Franklin-Sterling Hill apatites, as they are elsewhere (e.g., Panasqueira, Portugal, specimens of which are common in the mineral trade). All of these impurity elements—Sr, Mn, Pb, and the REEs—are known and common substituents for calcium in apatite-supergroup minerals.

As expected, the analytical results to date of Franklin-Sterling Hill orebody apatites confirm that their daylight colors are not reliable indicators of species identity. Orebody fluorapatite can be gray, greenish-gray, green, greenish-blue, and various shades of tan to brown. Johnbaumite shows a similar range in daylight colors. We have too few examples of turneaureite and svabite to judge color variability in those species, but the known daylight colors for both species have counterparts among johnbaumite and fluorapatite, so again, they cannot be recognized on sight except for specimens from known, analyzed assemblages.

Color mottling is common among the apatites analyzed, not only in terms of depth of color, but also of hue. The fluorapatite of Figure 2, for example, ranges in color from pale green through varying shades of tan to reddish-brown, and the johnbaumite of Figure 7 from pale gray through grayish-green (dominant) to a few tiny areas of bluish-green. The svabite of Figure 17 ranges in color from creamy white to blue, and the svabite-johnbaumite of Figure 19 from tan to dark brown. Regardless of color or species of apatite, those specimens that fluoresce most brightly have pale daylight colors, and increasing depth of color among the color-mottled specimens generally correlates with decreasing brightness of fluorescence. Again this is related to the identity, oxidation states, and concentrations of impurity elements in the apatite structure and has little to do with species identity. Color mottling within individual apatite grains from Franklin and Sterling Hill is suggestive of compositional variation on the millimeter to centimeter scale but has not yet been much studied.

CONCLUSIONS

The analytical data of Crimmins (2012) lead to several principal conclusions:

- The most common orebody apatite species appear to be fluorapatite and johnbaumite. Svabite, turneaureite, and hydroxylapatite are all rare. Among the lead apatites, hedyphane is fairly common and is known from numerous assemblages, but pyromorphite and mimetite only rarely have been reported.
- An inverse correlation exists between the As:P ratio in Franklin-Sterling Hill apatites and their F contents, thereby explaining the rarity of svabite locally and the near-absence of hydroxylapatite.
- The daylight color of Franklin-Sterling Hill apatite minerals is due to various impurity elements and is not specific to any species.
- Likewise, the color of fluorescence, whether orange, pinkish-orange, pink, or blue, is largely due to impurity elements and is of little help in species identification.
- The brightness of fluorescence in individual specimens is related to daylight color, being brightest in the areas of palest color and generally dimming as daylight colors deepen to various hues of green, brown, and blue. Again, however, this does not help with species identification.

We thus end where we began: Attempts to identify the local apatite species on the basis of their visible characteristics (color in daylight, color of fluorescence, brightness of fluorescence) have met with scant success due to the various factors discussed above. Moreover, although numerous means exist of determining or estimating the As:P ratio in the apatite minerals, and thus of separating the arsenic apatites from the phosphate apatites, it requires careful (and expensive!) analytical data to determine their contents of OH, F, and Cl and thus distinguish between johnbaumite, svabite, and turneaureite.

ADDENDUM: RESEARCH POSSIBILITIES

In this paper we have made repeated reference to the colors in daylight, and the colors and brightness of fluorescence of the local apatite minerals, but beyond a few general statements we have said little about the specific causes of these properties, and we have added nothing new to existing knowledge of the apatite supergroup minerals. Among apatites showing differences in color within single grains, for example, how do these variations relate to the minor- and trace-element concentrations of each color variant? What are the specific mechanisms that produce color in the local apatites? Can minor variations in the color of the orange fluorescence be correlated to partitioning of Mn^{2+} between the two different Ca sites in apatite, as is known to be the case elsewhere (Gaft et al., 1997)? Do substitutional impurities such as Sr and Pb, both common in local apatites, and both known to cause slight lattice distortions, result in a shift toward more yellow Mn-activated fluorescence, as mentioned by Rakovan and Waychunas (2013)? Among the various elements that can either promote or inhibit fluorescence in Mn-activated apatites, and thus influence the brightness of fluorescence, which of them are present in the local apatites, at what concentrations, and what is their effect? These and dozens of similar questions have yet to be addressed. As is true of so much concerning Franklin-Sterling Hill mineralogy, far more remains to be learned than is known thus far.

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All photos by Earl R. Verbeek.

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A Most Unusual Specimen of Zincite and Esperite

STEVEN M. KUITEMS, DMD
14 FOX HOLLOW TRAIL
BERNARDSVILLE, NJ 07924
smkuitems@gmail.com

About 20 years ago I purchased a small collection of Franklin, New Jersey, specimens that had an assortment of historic Lawson Bauer and John Kenneth Fisher specimens that appear to have been collected in the 1930s and 1940s. One peculiar pale-colored specimen, measuring 55 mm by 35 mm by 25 mm (see back cover), and had a 3 cm pod of pure esperite surrounded by a rim of willemite mixed with pale blue tephroite, all on top of white hardystonite with just a hint of thin clinohedrite films on its surface. What was immediately noticeable in the center of the esperite pod were numerous red zincite crystals ranging in size from one to four millimeters in length in a loose linear parallel arrangement. That alone was ample reason to study this particular specimen. The four-color response under shortwave ultraviolet light (SW UV) was striking: yellow esperite, green willemite, violet-blue hardystonite, and orange clinohedrite.

Most extraordinary to me were the euhedral zincite crystals, not in an open cavity or fissure but entirely encapsulated in the esperite. These crystals were, to the unaided eye, prismatic in form, not the usual pyramidal hemimorphic morphology. I examined them under low-power (20-40x) magnification and realized they had the classic hexagonal cross-section with a slightly matte surface. There indeed was a taper along the *c*-axis but it was of a very low order of 1 to 4 degrees, not the 55 to 60 degrees found in the open-fissure euhedral crystals from the Franklin Mine, perhaps owing to their growth entirely encapsulated within the esperite, which may have physically limited the normally wide-based pyramidal form.

In Dunn (1995), illustrations 22-4 and 22-14, there are two SEM images of subparallel prismatic crystals with rough oscillatory surface growth features from the Sterling Mine, but I have not found images of nearly prismatic zincite crystals from the Franklin Mine. If they do exist, they must be extraordinarily rare. I have noted highly elongated pyramidal forms from both local mines, with those from the Sterling Mine often growing in tapered needle-like form in cavities and open fissures. These can have a pale color of orange to light yellow and even white in which, according to Dunn, the Mn is markedly reduced or removed from these secondary crystals. When I examined the tiny zincite crystals in the esperite, I noticed thin films of hetaerolite on a parting plane, and on one crystal there was hetaerolite on the exterior surface of the zincite crystal. This would suggest that these zincite crystals had some of the manganese removed during their crystallization process to form the hetaerolite. There was an absence of zincite elsewhere on the specimen and there was also no detectable (eye-visible) response of the zincite under SW, MW, or LW UV.


Close-up view of zincite crystals in esperite. Field of view 3 cm (approx. 1 inch). *Photo by Earl R. Verbeek.*

There appears to have been a small number of zincite crystal specimens available in the specimen base of Palache (1935), as he only referenced euhedral pyramidal hemimorphic crystals from the Franklin Mine, and did not note any zincite crystals from the Sterling Mine. Dunn (1995) remedied the situation by studying examples from both mines and provided several fine SEM illustrations of zincite crystals from the Sterling Mine. With the plethora of shared digital images, more studies on the crystal morphology and associations should be available, and these rare forms and associations of zincite will enhance our study of the local mineralogy.

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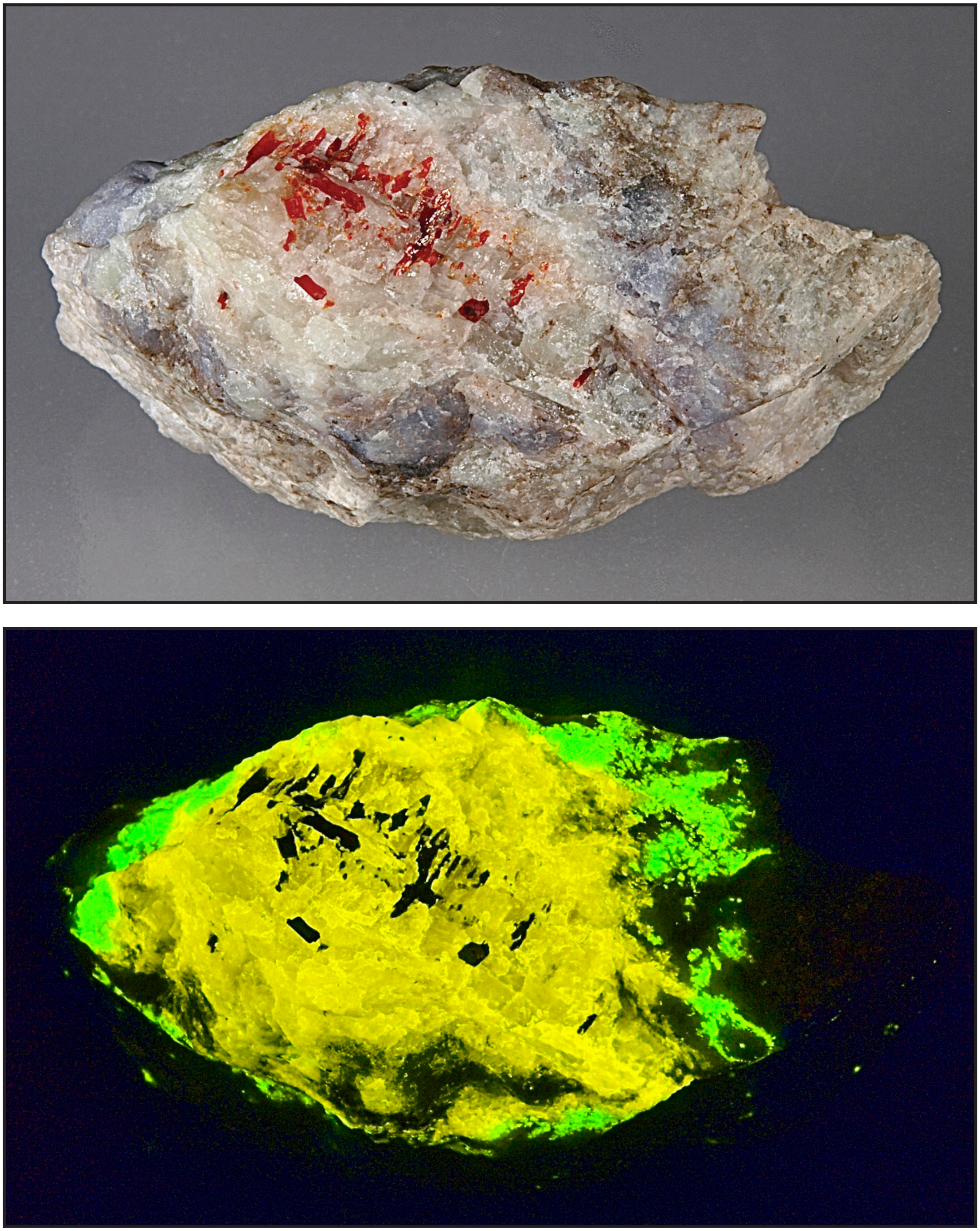

Zincite crystals in esperite, with willemite, tephroite, and hardystonite from the Franklin Mine. Measures 55 mm × 35 mm × 25 mm (approx. 2 inches × 1 ½ × 1 inch). Steven M. Kuitems specimen. *Photos by Earl R. Verbeek.*

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