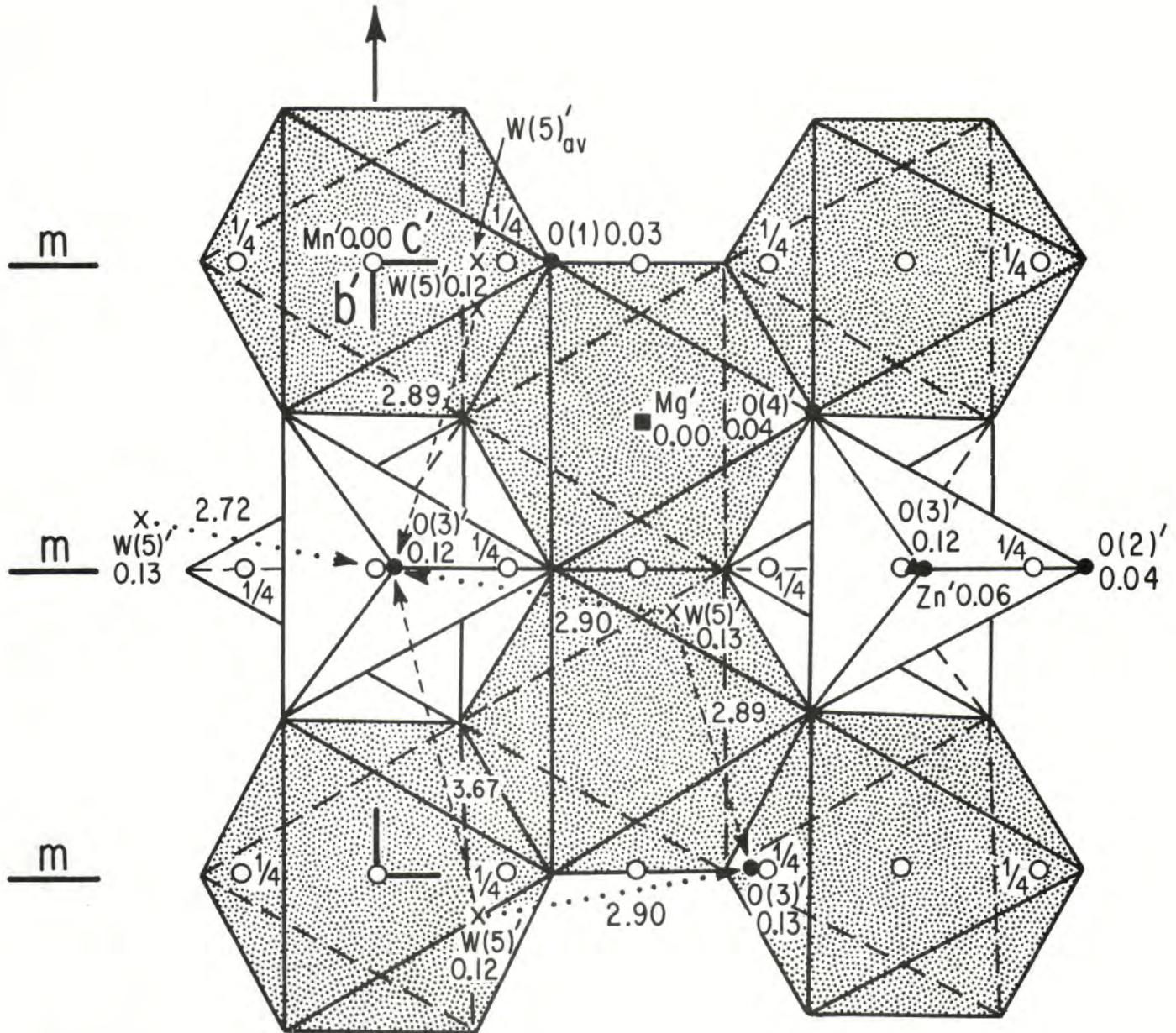


# THE PICKING TABLE

JOURNAL OF THE FRANKLIN-OGDENSBURG MINERALOGICAL SOCIETY, INC.



VOLUME 36 NUMBER 1

SPRING/SUMMER

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*The Picking Table* is the official journal of the FOMS, and publishes articles of interest to the mineralogical community which pertain to the Franklin-Ogdensburg, New Jersey area.

Articles related to the minerals or mines of the district are welcome for publication in *The Picking Table*. Prospective authors should contact the editor at the address listed above for further information.

Subscription to *The Picking Table* is included with membership in the FOMS. For membership, back-issues, and information on available publications, see the opposite page and the inside back cover.

The views and opinions expressed in *The Picking Table* do not necessarily reflect those of the FOMS, the Editors, or the Editorial Board.



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# FROM THE EDITORS' DESK

Richard C. Bostwick  
Tema J. Hecht  
600 West 111th Street  
New York NY 10025

## A CHANGE OF EDITORSHIP

Our readers should not be alarmed at this rather sudden change of editors; The Picking Table has survived more abrupt transitions. It must be said, though, that there is no way to appreciate what's involved in putting out the PT like being there. Do you remember your first ride on a roller coaster? Nothing much happens when the car starts crawling upwards, other than a general sense of foreboding. Then there is that brief shocking pause at the top when you see very clearly where you are, where you are going, and what (in short) you have gotten yourself into. After that you're much too busy to worry, except to hope that when you get to the end of the ride you can still stand up. Your new editors are happy to report that holding on to each other helps.

This change of editorship was not anticipated at the time the Autumn/Winter 1994 *Picking Table* went to press, but was announced at the October 15 F.O.M.S. meeting. Joe Kaiser, having successfully put together Vol. 35, No. 2, resigned for personal reasons. In his own words, his "main goal was to maintain the quality and availability of the *Picking Table*," and this is what he accomplished. He has been extremely cooperative and helpful during the transition, and we have learned much from him, as from the previous editor, Herb Yeates. Here it must be added that although Herb's editorship lasted only two years, the *PT*'s current format and style were established during his tenure. He specified the desktop-publishing system now used to compose *The Picking Table*, and the current type selection, page format, and other features are largely his choice. Herb was also notable for being the only *Picking Table* editor with some formal training in mineralogy, and as readers may remember, the superb SEM photomicrographs which graced the *PT* covers during his editorship were provided by him. There is still some astonishment on the part of its audience that a man with such remarkable qualities could place career, family, and sanity ahead of editing *The Picking Table*.

The new editors wish to remind *PT* readers that this magazine is intended to benefit all F.O.M.S. members. We welcome your comments, suggestions, and articles. A note here for potential contributors: *The Picking Table* is produced on an IBM-clone-based desktop-publishing system. If you submit an article on disc, please make sure it is IBM-compatible

## CHANGES IN THE F.O.M.S. OFFICERS' SLATE

With the turn of the year, this was a time of other transitions for the F.O.M.S. The officers' slate has changed in its bi-yearly fashion, rotating George Elling into perhaps the most difficult officer's job, that of First Vice-President and Program Chairman, and Lee Lowell from a three-year stint in that position into the President's chair. Both have tackled their new responsibilities with vigor, as can be seen from the eloquent President's Message and the completed speaker's program for the spring

1995 season. The new Second Vice-President is Dr. Steve Kuitens, a dentist with an uncommonly sharp eye for minerals. Chet Lemanski, whose vigorous presidential style enlivened F.O.M.S. meetings and was instrumental in the success of the recent Trotter Dump Field Trips and the May Swap-and-Sell sessions at Sterling Hill, is retiring (as is customary) to become a Trustee and the Chairman of the Nominating Committee. All are to be congratulated and encouraged in their new responsibilities.

## DEATHS IN THE FAMILY

On a more sober note, there have been a few notable transitions unconnected with the electoral or editorial processes. Helen Warinsky, Secretary of the F.O.M.S. for many years and the sparkplug of the old Micro Group, died after a long illness on November 4, 1994. With her husband Joe she was a notably positive influence in a group not always known for its saintly personalities. As Dick Hauck has said, "Helen was the personality of the club. Her gracious hospitality and warm nature put new members at ease and attracted many others in the belief, 'If mineral collectors are this nice, it must be a great hobby.'" Letters of sympathy may be sent to Joseph Warinsky, 695 Suffern Road, Teaneck NJ 07826. We ask that memorials and reminiscences of Helen by her fellow collectors be mailed to the *Picking Table* editors for inclusion in a future memorial.

Two months and a day later, Nicholas Trofimuk died at the age of 82. Lee Lowell's comment in sending us the obituary was, "another Franklin legend has fallen." During the latter years of the Franklin mine Nick worked in the shaft pillars near the Palmer Shaft, in that part of the ore where stoping in the 1890s had yielded the rare-mineral assemblage associated thereafter with the Parker shaft. Gifted with a sharp eye and tenacious memory, and encouraged by Lawson Bauer, Nick recovered many superb examples of roebingite, barysilitite, nasonite, margarosanite, and other Franklin rarities, far more than were saved by any other individual. His accumulation of thousands of specimens was bought by John Albanese shortly after the closing of the Franklin mine, and while many of the major pieces and unknowns went to Harvard, others were dispersed to the National Museum of Natural History and to collectors lucky enough to be favored by Mr. Albanese, whose subsequent status and vaunted access to Harvard and the Smithsonian were in large measure due to his handling of the Trofimuk material. The legendary "second Trofimuk collection," a few powder boxes of minerals which Nick had kept, was purchased by Dick Hauck decades later.

Missed in earlier *Picking Tables* was the death in November, 1993, of Alfred Standfast, M.D., a radiologist from Binghamton, N.Y. whose collecting career spanned about sixty years. While his collection was extensive, much of his time was given to the photography of Franklin-Sterling Hill minerals. He

was best known for his slides of microminerals, and much of his best work is now in the hands of the F.O.M.S. Slide Collection Custodian, Ed Wilk, or in the archives of the Franklin Mineral Museum. Also a pioneer in photographing minerals under ultraviolet light, "Doc" experimented with techniques like split-frame photography. As a lapidary he was the creator of a remarkable fireplace, now in ruins, faced with stone panels sawn from fluorescent rarities like margarosane and esperite. When younger he had led a rather adventuresome life, helping to build Trail Ridge Road through Rocky Mountain National Park, and later racing sled dogs in Alaska. The Standfast collection has been dispersed, with part of it going to the Franklin Mineral Museum.

#### THE SPRING 1995 ACTIVITIES SCHEDULE

Looking forward to the 1995 season, we would like to draw your attention to a remarkable speaker program for the spring.. George Elling will lead off in March with a potpourri of historical photographs of the Franklin area, taken when both mines were producing and it was possible to buy a good nickel cigar. In April, we will hear from Bob Svecz. As a geologist for the New Jersey Zinc Co. and its successors, he spent much time underground at Sterling Hill, often with a camera. His slides and narrative constitute a unique record of scenes and activities there. Phil LaPorta, the May speaker, is known to a few F.O.M.S. members as an archaeologist with a comprehensive and definitive collection of local stone artifacts and an unrivaled knowledge of regional Native American quarry sites and trade routes. Of what use was zincite before Columbus? This may be your opportunity to find out. In June Co-Editor Richard Bostwick will attempt to shed some light on his favorite topic, the fluorescent minerals of Franklin and Sterling Hill. He will cover some of the recent (Hauckian period) Sterling Hill finds as well as the Franklin classics; the talk will be lavishly illustrated with slides by Henry Van Lenten, Dr. Alfred Standfast, and others.

The two events in the schedule which are not regular F.O.M.S. functions are nevertheless important to all local collectors: the opening of the Edison Tunnel at Sterling Hill on April 8, and Old Miner's Day at the Franklin Mineral Museum on May 7.

#### EVENTS FOR COLLECTORS

An event not listed in the schedule but for which attendance is urged is the New Jersey Earth Science Association Show on April 22 and 23. It's at a new location this year: the Westfield Armory, 500 Rahway Ave., Westfield, N.J. Hours are as usual, 9 to 6 on Saturday and 10 to 5 on Sunday. For information call the Show chairman, Fred Stohl, at (908) 240-9006, or Mary Guinter at (201) 539-5116.

The F.O.M.S. Spring Swap-and-Sell at Sterling Hill on May 6 and 7 is an important event for vendors and consumers of minerals, attracting nearly as many tailgaters as "The Pond" at the Franklin-Sterling Gem & Mineral Show in the fall. Although the madness nominally begins at 7:30 A.M. on Saturday, dealers have been known to set up earlier. If you are interested in helping the staff, please contact Chet Lemanski at (609) 893-7366.

Chet also assures us that there will be another Trotter Dump field trip in 1995, but the date has not been selected.

#### FRANKLIN-STERLING GEM & MINERAL SHOW FRIDAY, SATURDAY, AND SUNDAY SEPT. 29-30 AND OCT. 1, 1995

Please mark your calendars now; this will be the first three-day Franklin show, and like the 1994 show it is being held a week

before its traditional "first full weekend in October." The location is the Franklin School, across Route 23 from MacDonald's. This show is sponsored by the Franklin Mineral Museum but the adjunct swap-and-sell event known as "The Pond" is managed by the F.O.M.S. Set-up for the show will be Thursday afternoon and evening. As show-time approaches further information will be available from the Franklin Mineral Museum at (201) 827-3481. With this early announcement we hope to forestall some of the show-goers who migrate by instinct and have shown up for the last two years a week late at the Franklin Armory.

The annual F.O.M.S. banquet will take place on Saturday night. The speaker will be William Henderson, whose talk is entitled *Geological and Mineralogical Curiosities*. Dr. Henderson is known to most *Picking Table* readers as the author of a micromount column which appears in *The Mineralogical Record*, but he is also a distinguished organic chemist and a renowned mineral collector. The mineral willhendersonite is named for him. His talk promises to include such unlikely (but fascinating) items as petrified lightning bolts and shock waves, volcanic bombs, and calcite lenses in trilobite eyes. It is deemed to interest both neophytes and advanced collectors.

For those who have not attended the "banquet," it is neither a formal affair nor a drab one. Dinner is buffet style, dress is casual, the price is reasonable, and all are welcome. The dinner is followed by a talk, after which an auction of minerals, memorabilia, and other oddities is held. Advance tickets for this event may be reserved by calling Joe Cilen, (201) 427-4550.

#### TUCSON 1996

Those of you who plan even farther ahead may want to highlight Feb. 8-11, 1996 on your calendars, as this will be the Year of the Fluorescent Mineral at the Tucson Gem & Mineral Show. The Fluorescent Mineral Society will be hosting a display of as many as 60 cases of fluorescent minerals there. We mention this because Franklin-area minerals and collectors will undoubtedly be strongly in evidence there, and because planning has already started. ANYONE within reach of *The Picking Table* who is interested in exhibiting at Tucson one fine fluorescent specimen or a caseful, whether from Franklin or anywhere else, should contact the F.M.S. Show Chairman, Don Newsome, at (206) 228-9988. (Membership in the F.M.S. is a prerequisite, but it is not hard to join.) There will be some local organizing for Tucson '96 through the N. E. Region Vice-President of the F.M.S., *Picking Table* Co-Editor Richard Bostwick, who may be reached at (212) 749-5817.



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Assuming he lives long enough, there is some possibility that Pete Dunn will have a "conversation" with the Society at a meeting, as has been done in recent years. If you have suggestions for topics to be discussed, he suggests that you sent them to him or mention them in person.

His address is:

Dr. Pete J. Dunn  
Dept. of Mineral Sciences, NHB 119  
Smithsonian Institution  
Washington DC 20560

# MESSAGE FROM THE PRESIDENT

A. Lee Lowell  
53 Foxtail Lane  
Hamburg NJ 07419

It is my pleasure to serve as your president for the next two years. With the support of a capable group of officers and staff, I'm committed to carrying forward the great traditions of the F.O.M.S. For the past 35 years the Society has successfully pursued its primary goal, to perpetuate interest in the mineralogy, geology, and history of the Franklin-Sterling Hill Mining District. As we commence our 36th year, the society will continue this tradition by providing a quality journal under the editorship of Richard Bostwick and Tema Hecht, exciting field trips organized by Ed Wilk, and an interesting lecture program arranged by George Elling.

Several significant events will occur this year. In the spring the Franklin Mineral Museum will complete a new addition, including a new entranceway and lobby, and the Sterling Hill Mining Museum will dedicate the Edison Tunnel, giving a new dimension to the mine tour there. And plans are in progress for the publication of a major work on the Franklin-Sterling Mining District.

Other important activities scheduled for the coming months include the annual F.O.M.S. Spring Swap-and-Sell at Sterling Hill on May 6-7, and possibly another collecting trip to the Trotter mine property this summer.

The success of the F.O.M.S. rests on the continued efforts of all our members. I solicit suggestions from each of you for ways and means to improve our Society in all of its aspects.

All F.O.M.S. activities - the field trips, the mineral shows, the lecture programs, and the journal - are accomplished through the efforts of a relatively small group of dedicated individuals. To reiterate a persistent refrain of our past presidents, I ask that each of you adopt a New Year's resolution to become more proactive by offering ideas, suggestions, and people power for the great cause of keeping in the global arena the most prolific mineral deposit known to man.



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## LOCAL NOTES

### NEWS FROM THE FRANKLIN MINERAL MUSEUM

John Cianciulli  
Assistant to the Curator

The Museum has shown steady growth through 1994, with attendance up more than 10%. For 1995 we anticipate that by the time you read this, a new addition will be underway or near completion. New handicap-accessible restrooms will be constructed, and the lobby/sales area will be reconfigured to accommodate more stock and customers. A new route through the Museum to the picnic area and Buckwheat Dump is in the plans. No more will the meetings in Kraissl Hall be disrupted by people trying to find their way to the picnic benches and mineral dump!

There are still many fine mineral specimens in storage at the Museum waiting to be presented for sale. Cataloging the minerals to be sold has proven an effective buying tool for the collector, and we intend to continue this practice. In addition, the Museum now has an enhanced capacity for mineral identification, the result of acquiring a Leitz polarizing microscope and having access to a comprehensive set of refractive-index oils. Optical research at the Museum has already helped to find one new-to-the-area mineral species from Sterling Hill (fraisontite) as well as the second known specimen of sterlinghillite. (Both finds have been confirmed by Dr. Pete J. Dunn of the Department of Mineral Sciences, National Museum of Natural History, Smithsonian Institution, Washington, D.C.) In most cases, optical microscopy is effectively used to distinguish between mineral species whose characteristics are already known; more complex identification problems require more

sophisticated analytical methods. However, if you have a mineral problem you are trying to solve, we will take a crack at it!

Some of our staff members spent part of their winter breaks in training. Museum Manager Carol Hunsinger took a course in business management at Sussex County Community College, while Steve Sanford has been studying computers at a school in Passaic County. I successfully completed the workshop "Introduction to Public Programming" during a museum workshop series at the Office of Museum Programs of the Smithsonian Institution. In addition, Phil LaPorta and I attended a meeting at the Pequest fish hatchery, hosted by the New Jersey Department of Parks and Forestry, Division of Natural History, and Division of Fish and Game. This meeting was held on January 26, 1995, for the purpose of planning a June 1995 workshop on museum public programming and increasing travel and tourism to natural science museums.

If you wish to help support the Franklin Mineral Museum and its activities, consider becoming a member!

Annual membership for an individual is \$15.00.

Annual family membership is \$25.00.

Life membership for an individual is \$250.00.

Corporate membership is \$1000.00.

Sustaining membership consists of significant contributions of money, material, or services in the \$5000.00 range. Membership entitles you to free admission to the Museum. (There is still a charge for collecting on the dump.) If you wish to become a member, or would like to support the Museum through donation, please send your check or money order to:

Franklin Mineral Museum, Inc., P.O.Box 54,  
Franklin NJ 07461.

## FIELD TRIP REPORT

Steven M. Kuitems, D.M.D.  
272 Arnold Ave.  
North Plainfield NJ 07063

This is by no means an exhaustive report of all the specimen material recovered on F.O.M.S. field trips in the fall of 1994, but it does record those finds of note which were reported to me. I would appreciate collectors bringing special finds to my attention, either during field trips or afterwards; my home telephone number is (908) 757-5583.

### THE STERLING HILL MINING MUSEUM DUMP SEPT. 17, 1994

This location continues to provide extremely rich willemite/calcite fluorescent material, with some crystals of willemite and franklin still surfacing. From the recent adit-level tunneling project came a small find of red corundum, including a few crystals; these fluoresce red under longwave ultraviolet radiation.

### THE BUCKWHEAT DUMP, OCT. 15, 1994

While thought by many collectors to be played out, the dump still had some fine surprises. Hardystonite was found mixed with willemite in an untouched boulder two feet across. An exceptionally fine allanite crystal in microcline came from the pegmatite recently brought onto the Buckwheat Dump from the south end of the Trotter Dump property. Several collectors turned up grains and crystals of thorite and uraninite in old, blackened boulders which had been generally ignored by past collectors. Micromineral enthusiasts did very well breaking up dolomite, uncovering some nice sphalerite and brookite crystals.

### THE LIME CREST QUARRY, OCT. 1, 1994

This outing, by far the largest of the season, was prolific in specimens. However, the top honors go to a fine open-vein specimen of ferroaxinite crystals found on the lowest level of the quarry. More searching there found at least six large pegmatite boulders with thin seams of ferroaxinite. An upper level of the quarry produced surprisingly gemmy masses of "oil-green" sphalerite, including one unique example of near-faceting grade. Some specimens of this sphalerite contain white barite which fluoresces white under both shortwave and longwave ultraviolet radiation. While typical yellow-fluorescing norbergite grains were abundant, a few rich-orange-colored norbergite crystals up to 3 cm long were found in fine-grained calcite. Other species of note were spinel in crystals of several colors, diopside grains with typical blue fluorescence, and centimeter-sized blocky scapolite grains with two-tone fluorescence, cream and blue under shortwave ultraviolet radiation.

### THE FRANKLIN QUARRY, NOV. 19, 1994

This fall's highlight was a single specimen of purple fluorite crystals one-and-one-half centimeters on edge in a tennisball-sized cavity in calcite. From the southwest corner of the quarry came some distorted uvite crystals with bright yellow fluorescence under shortwave ultraviolet radiation. An interesting mix of phlogopite and margarite with rutile was found in the southern end of the quarry. Other species found included corundum, tremolite, spinel, norbergite, diopside, and an unidentified emerald-green amphibole.

## MICRO NEWS

Modris Baum  
173 Valley View Drive  
Rockaway NJ 07866

The October 1994 meeting of the F.O.M.S. Micro Group was well-attended, and provided many opportunities to view fine Franklin/Sterling Hill arsenates as well as interesting "xenoliths," i.e. micros from other localities.

The next meeting will be on Saturday, March 18, 1995, from ten to noon at the Franklin Mineral Museum. In case of snow the meeting will be postponed.

To provide a focus for our activities, our theme at this meeting will be *Micros from the Buckwheat Dump*. As this past summer amply demonstrated, the Buckwheat Dump is far from dead! Anyone with interesting Buckwheat material is especially encouraged to attend.

As always, our main goal is to bring together like-minded collectors. If the Buckwheat Dump theme does not appeal to you, come anyway, as these meetings usually attract plenty of other fine Franklin/Sterling Hill micros. In October we also had collectors with strong interests in minerals from Maine, Pennsylvania, and Mont Saint-Hilaire, and if you want to expand your horizons, some of this material will be present again in March. As always, the Standfast collection of micromounts is available for reference through the courtesy of the Franklin Mineral Museum.

It will help if you can bring your own microscope, illuminator, and extension cord; the more 'scopes we have set up, the more collectors we can accommodate.

As our ultimate goal is education, we will provide help with mineral identification, within reason. We encourage swapping, so bring your spares. Specimens may also be available for sale.

Ideas? Suggestions? Questions? Call Modris Baum at (201) 625-2229 between 7:30 and 9:30 P.M. on weekdays, or on weekends after 10:00 A.M.

## NEWS FROM THE STERLING HILL MINING MUSEUM

Joe Kaiser  
40 Castlewood Trail  
Sparta NJ 07871

Now in its fifth year of operation, the Sterling Hill Mining Museum will be enlarging the scope of its underground tour. The completion of the Edison Tunnel is the first leg in an ambitious program of underground expansion. A preliminary walk-through was held on "Progress Day," Nov. 17, 1994, but the tunnel will not be officially opened until Saturday, April 8, 1995. Edison Tunnel opening ceremonies will begin at 10:00 A.M. Governor Christine Whitman or her representative will be present to cut the ribbon, and the event is expected to receive major network TV coverage.

Rock blasting, scaling, and bolting in the Edison Tunnel have been completed, but now the difficult task of setting up exhibits and displays is starting. Here one will be able to see an ore-chute built exactly like those on the levels below. There there are also plans to put down some rails and install an original ore car, to illustrate how the broken ore was taken from the workplace *en route* to the surface. In addition there will be a

display of mining in progress: a miner runs a twin drill-rig, while his helper operates a "slusher," a winch which pulls a "slusher-bucket" back and forth, dragging pieces of ore into the top of an ore crib. Nearby is a ladderway (a ladder inside a metal structure called a manway) to show how miners got from their workplaces to the nearest mine level.

The next phase of the program will be to expand the tunnel system to include a stope which dates from the late nineteenth

century. This and the displays mentioned above will allow visitors to get the feel of what it was like in the working levels below when the mine was operating. Much has to be done, from scaling down loose rock to installing lights and developing more exhibits, before the public is safely allowed to come and see how mining is really accomplished. It will be some time before the total project is completed.



## SPRING 1995 ACTIVITY SCHEDULE

### Saturday, March 18, 1995

10:00 - 12:00 — Micro Group — Kraissl Hall, Franklin Mineral Museum, Franklin, N.J.

1:30 - 3:30 — Lecture — *Franklin Retrospective*, by George Elling

### Saturday, April 8, 1995

10:00 A.M. — The Opening of the Edison Tunnel

Sterling Hill Mining Museum, Ogdensburg, N.J.

### Saturday, April 15, 1995

9:00 - 12:00 — Field Trip — Collecting at the Sterling Hill Mining Museum, Ogdensburg, N.J. Fee \$1.00 per pound, \$10.00 minimum

1:30 - 3:30 — Lecture — *Tour through the Sterling Mine*, by Robert Svecz

### Saturday and Sunday, May 6 and 7, 1994

The Fifth Annual F.O.M.S. Swap-and-Sell, at Sterling Hill

Hours: Saturday, 7:30 to 6:00; Sunday, 9:00 to 5:00

### Sunday, May 7, 1995

12:00 noon — Old Miners' Day

Open House at the Franklin Mineral Museum, Franklin, N.J.

### Saturday, May 20, 1995

9:00 - 12:00 — Field Trip — Collecting on the Buckwheat Dump, Franklin, N.J.

1:30 - 3:30 — Lecture — *Prehistoric mine and mining technology, with a view towards the Wallkill Valley*, by Phil LaPorta

### Sunday, May 21, 1995

9:00 - 3:00 — Field Trip — Collecting at the Lime Crest Quarry, Sparta, N.J.

### Saturday, June 17, 1995

9:00 - 12:00 — Field Trip — Collecting at the Franklin Quarry, Franklin, N.J.

1:30 - 3:30 — Lecture — *The Fluorescent Minerals of Franklin and Sterling Hill*, by Richard C. Bostwick

Scheduled activities of the Society 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 lecture and a business meeting. Field trips are held on the mornings before regular meetings, unless specified otherwise. All meetings are held in Kraissl Hall at the Franklin Mineral Museum, 5 Evans Street, Franklin, N.J., and are open to the public.

Regular field trips are open only to F.O.M.S. members. The Lime Crest Quarry field trip is hosted by the F.O.M.S. and is open to members of clubs which have E.F.M.L.S. liability insurance or equivalent coverage. Proof of membership is required for all field trips, along with proper safety gear (a hard hat, protective goggles or safety glasses, gloves, and boots). The minimum age for field trips is 13.

# CLOSEST-PACKING AND HYDROGEN BONDS IN MINERALS OF THE FRANKLIN MARBLE

**Paul B. Moore**

Department of the Geophysical Sciences  
The University of Chicago  
Chicago, Illinois 60637 U.S.A.

---

## ABSTRACT

Closest-packing of anions places limitations on the nature of the hydrogen bond in crystal structures. This problem must be addressed in light of the plethora of recently revealed closest-packed structures from the famous Franklin Marble.

Many examples of structures based on closest-packing were not recognized as such in the earlier literature. Cell and atom coordinate transformations based on matrices facilitate the construction of projections of structures along the normal to the closest-packed layers,  $t^*$ . Five structures (brucite, clintonite, franklinfurnaceite, junitoite, and clinohedrite) are local and global closest-packings of non-H atoms. Six structures (akrochordite, willemite, ciangiulliite, chlorophoenicite, mooreite, and lawsonbauerite) are locally but not globally closest-packed. These are called the packet structures. In most cases, a plethora of hydrogen bonds obviates the formation of global closest-packing in such crystals.

## INTRODUCTION AND PROCEDURE

In the mineral sciences, certain concepts are so fundamental that they not only permeate pedagogy and description but are also believed to be manifest within the

underlying properties of Nature. One concept, the closest-packing of spheres, is so deeply entrenched that no contemporary mineralogy text exists which does not discuss it in due course. Pauling (1960) states "It is noteworthy that 46 of the 58 metallic elements crystallize with either the cubic closest-packed or the hexagonal closest-packed arrangement or with both." Closest-packing plays a central role among the 16,000 intermetallic and alloy phases listed in the grand compilations of Villars and Calvert (1985); over 367 and 267 phases are listed respectively for cubic copper and hexagonal magnesium closest-packed structure types! Nature clearly selects closest-packing for very important reasons, many of which are not obvious to us. Nor is the conjecture of closest-packing as the most economical and parsimonious allocation of space yet formally proved beyond the conjecture of the Lutheran mystic-astronomer-mathematician Johannes Kepler some 400 years ago, see Cipra (1991).

Recently I published a condensed but rather intense discussion of closest-packing among the myriad hydrothermal crack mineral oxysalts of the now-exhausted, peculiar, and famous Franklin and Sterling Hill zinc deposits of Sussex County, New Jersey, in *The Picking Table* (Moore, 1994). In that article, many crystals, some

quite complex, were listed which are based on anion oxide closest-packing. These anions include  $O^{2-}$ ,  $OH^-$  and  $H_2O^\circ$ , and I collectively symbolize them as  $\phi$ . As yet, no one has outlined the oxysalt structure types of mineral species which are in fact closest-packed, and such effort will not be easy for certain criteria must be met - including evidence such as derivations and proof. I will discuss these criteria shortly. Worse, closest-packing is often applied in a loose sense to structures which are not closest-packed at all. Some famous mineral structures are crystal-chemically very complex yet approach the closest-packed limit of anions: sapphirine, for example, has four formula units of *ca.*  ${}^6Mg_{3.5}{}^6Al_{4.5}O_2[{}^4Al_{4.5}{}^4Si_{1.5}O_{18}]$  (cation coordination numbers as superscripts) in its monoclinic  $P2_1/a$  cell and 34 non-equivalent atoms in the asymmetric unit (Moore, 1969)! Yet such phases appear to be in the minority among mineral oxysalts: in the now-classic book on rock-forming minerals by that name (Deer, Howie and Zussman, 1966), only about one-fourth of their structures are closest-packed. For such an important principle among the intermetallics and alloys, what conditions seem to work against it in the great tribe of oxysalt minerals?

I have covered many of these arguments in my earlier study on the Sussex Co. minerals, but several are worth repeating. The first is radius ratio, which states that for spheres in contact, the ratio of cation crystal radius to anion crystal radius has as a lower bound  $(\sqrt{3/2} - 1) = 0.225$  for tetrahedrally coordinated cations and  $(\sqrt{2} - 1) = 0.414$  for octahedrally coordinated cations by  $\phi$  (derive them!). Tetrahedral (T) and octahedral (M) coordinations define the interstices which remain in the closest-packings, the saturation limit being  $M:T:\phi = 1:2:1$  or  ${}^6M^4T_2\phi$ . Yet this criterion can be easily extended by a considerable margin in the upper bound which renders the radius ratio concept almost useless, as in cubic closest-packed BaO with  $r({}^6Ba^{2+})/r({}^6O^{2-}) = 0.971$ , a value calculated from the effective radii tables of Shannon and Prewitt (1969). Other contributions which work against closest-packing include valence electronic effects such as high spin  $4d^4Mn^{3+}$  and  $4d^9Cu^{2+}$ , and cations with lone-pair electron geometry such as  $Tl^{1+}$ ,  $Pb^{2+}$ ,  $Bi^{3+}$ ,  $Sb^{3+}$ ,  $As^{3+}$ ,  $Te^{4+}$ ,  $Se^{4+}$ , etc. Suspicions of the possible appearance of closest-packing should arise for ions which have favorable radius ratio and which are naked (i.e. have no valence electrons remaining and are therefore closed-shell and spherical), or spherical ions arising from balanced electron populations in suborbitals such as high spin  $4d^5Mn^{2+}$  and  $4d^5Fe^{3+}$ . The last important characteristic which tends to work against closest-packing is the hydrogen bond,  $O_d - H \cdots O_a$  ( $d$  = bond donor,  $a$  = bond acceptor), associated with the water molecule. The water molecule  $H - O - H \sim 105^\circ$  angle is geometrically difficult to accommodate in closest-packed systems and we would suspect possible disorder in such systems. In this essay, it is such compounds which are discussed. Compared with other chemical bonds in the crystal, the transfer of a single water molecule of liquid

$H_2O$  into a crystalline site costs about  $2 \text{ kcal mol}^{-1} \text{ K}^{-1}$  at 300K — a relatively small cost compared with the other chemical bonds in the crystal (Dunitz, 1994).

With the knowledge of many hundreds of oxysalt structure types of minerals involving hydroxyl ( $OH^-$ ), and aquo and hydrate ( $H_2O^\circ$ ) ligands, certain hierarchies seem to prevail. The foremost is that many observations of liquids and crystals suggest that polyhedral clusters or assemblies of ions already exist in the fluid from which the crystals grow. If these clusters were reflected somewhat in those of the growing crystals, then the hydrogen-bonding scheme would be expected to accommodate the original clusters. The limiting crystal symmetries will place restrictions on the arrangement, the hydrogen bonding adjusting to accommodate the limitations dictated by the cluster. When closest-packing criteria restrict even the nature of the hydrogen bond and accommodate it, then we would surmise that such packing is very fundamental indeed. The underlying question, yet unanswered, remains: why does Nature seem to select it? This deep question will not be answered in this study.

Representation of closest-packing in crystal structures is a challenge. As such systems are very condensed to begin with, careful construction of diagrams is required. Whether spoke diagrams, sphere packing diagrams, or Pauling polyhedra (where larger anions coordinated to smaller cations are connected to contiguous anions in the coordination sphere), each has advantages and disadvantages. I prefer the polyhedral representation which dominates mineral structure description to this day. In this paper, I construct polyhedra from real atom coordinates obtained from the experimental X-ray structure refinements.

To be precise, any projection of two crystallographic translations (say  $a$  and  $b$ ) on the plane is along reciprocal  $c^*$  which is orthogonal to this plane and the included translations. However, for the pseudo-orthogonal cells presented in this paper, the angles (say  $\alpha$ ,  $\beta$ , and  $\gamma$ ) are so close to  $90^\circ$  that deviation of the vector  $\bar{c}$  from  $\bar{c}^*$  is very small and the distortions are minor. Therefore, I selected the orthogonal approximation. This approximation led in every case to errors within  $\pm 0.02 \text{ \AA}$  of the difference between the real structure and the perfect closest-packed structure.

Hydrogen bonds  $O_d - H \cdots O_a$  where  $O_d$  or hydrogen bond donor is the oxide bonding to the hydrogen ( $O_d - H \sim 0.95 \text{ \AA}$ ), and  $O_a$  is the acceptor of that relatively weak electrostatic bond, are drawn as dashed lines with their starting point at  $O_d$  (or H) and their arrow terminating at  $O_a$ . Note that H is 2-coordinate somewhere between  $O_d$  and  $O_a$  in this example, and that the distance between  $O_d$  and  $O_a$  is about  $2.8 \text{ \AA}$ , or the sum of two oxide radii. Exceptions occur: oxygen may be on a mirror plane ( $xOz$ ) with two degrees of freedom, or on a 2-fold rotor ( $OyO$ ) with one degree of freedom, or on the inversion center (000) with no degrees of freedom and bonded to two

hydrogens. These are the so-called *symmetrical* hydrogen bonds,  $H - O_d - H$ . Or H may reside on a mirror plane or 2-fold rotor and form hydrogen bonds with two symmetry-related oxides in general position ( $O_a \cdots H \cdots O_a$ ) and this is called the *bifurcated* hydrogen bond. Examples are found in an interesting group of crystal structures, the relatively insoluble methoxyphenylacetic acid salts, see Moore et al. (1980).

In nearly every case, I have transformed closest-packed systems by matrices to provide (pseudo)-orthogonal cells. Many small proofs of interesting structural characters arise from the restrictions created by closest-packing. One of these is orthogonalization of the cell, which can be obtained for every closest-packed system, but the margins are too narrow to contain it in this paper. In Moore (1994) I showed the *orthohexagonal* unit, the full cell of which is  $pl \times q \sqrt{3} l \times r \sqrt{2/3} l$ ,  $l$  = polyhedral edge length or  $\phi - \phi'$  separation;  $(p, q, r)$  are integers which together define the edge translations for the full cell.

Some comment is in order about the tables on crystallographic details of the closest-packed structures although I discussed these already in my earlier paper. Instructions for cell and coordinate transformation occur in these tables, and the primed (') transformed cell is the basis for subsequent comparison. These new cell parameters are solved in terms of  $l$  for the integers  $(p, q, r)$ . A 'mean' in horizontal carets gives the edge value which is placed back into the ideal orthohexagonal relations with respect to  $l$ . The transformed cell is compared to 'mean' cell values as  $\Delta(\%)$  greater (+) or less (-) than the transformed cell. This gives an approximate estimate of the anisotropic distortion of the real cell as a result of bonding effects, cation-cation repulsion, etc. These values rarely deviate more than 5% (one part in twenty) from each other. The coordinates for perfect closest-packing are then obtained from algorithms which I derived and the deviations in  $\Delta(\text{\AA})$  from the real model are evaluated using the real cell and the interatomic distance equation. These deviations range from 0.0 to 0.9  $\text{\AA}$ , usually with a 'mean' around 0.3  $\text{\AA}$ .

In this study, five structures (brucite, franklinfurnaceite, clintonite, junitoite, and clinohedrite) are truly closest-packed—in fact, the last three are cubic closest-packed. Five other structures include sections which are closest-packed, usually condensed sheets. These sheets are bounded by hydrogen bonds which terminate the closest-packing. Selected are ciangiulliite, chlorophoenicite, akrochordite, mooreite and lawsonbauerite. All structures have been satisfactorily refined within the limits of the modern X-ray diffraction experiment, although hydrogen atom centroids were experimentally located only for brucite, clintonite, and mooreite. Experimentally located hydrogen atom centroids greatly aid in assigning correct  $O_d - H \cdots O_a$  (or  $O_d \cdots O_a$ ), which is always equal to or less than the distance sum  $O_d - H + H \cdots O_a$  hydrogen bonds in the crystal which otherwise are located from easily determined  $O_d \cdots O_a$  distances usually selected between 2.6 and 3.2  $\text{\AA}$ .

But closest-packings can create an ambiguity as more than one  $H \cdots O_a$  choice may occur, as in ciangiulliite. Usually the shortest  $H \cdots O_a$  (or  $O_d \cdots O_a$ ) distance is chosen. Note that such crystals tend to be locally disordered. Prior to discussing the structures at hand, some cursory observations on fundamental structure types are in order, and these follow.

## SOME PRELIMINARIES

### Brucite

Recent careful neutron diffraction pressure-induced H bonding study of deuterated (D) brucite,  $Mg(OD)_2$  by Parise et al. (1994) established some important properties in this closest-packed structure type. Brucite,  $Mg(OH)_2$ , isostructural portlandite,  $Ca(OH)_2$ , and pyrochroite,  $Mn(OH)_2$ , possess space group  $P\bar{3}1$  with  $a = 3.32$ ,  $c = 4.74 \text{\AA}$  for pyrochroite. The structure is based on ordered half-population of octahedral voids in hexagonal  $h h \bullet \equiv \bullet A B \bullet$  closest-packing of oxides leading to octahedral edge-sharing sheets alternating with octahedral vacancies, e.g.  $\square M\phi_2$ . The hydrogen (deuterium) atoms form hydrogen bonds between the populated sheets.

The Parise et al. (1994) study revealed several important qualities of the deuterated brucite structure. First, the D atom centroids are split off the 3-fold rotor from  $2(1/3, 2/3, z)$  to  $6(x, 2x, z)$ , each site being on the average 1/3-populated. Four sets of their refined coordinate parameters for pressures increasing from 4 kb to 93 kb revealed progressive D  $\cdots$  D separations of adjacent split pairs from 0.31 to 0.63  $\text{\AA}$ . Although there is no significant change in  $Mg\phi_6$  octahedral sheet thickness as pressure increases, D moves increasingly away from the 3-fold rotors,  $\phi - \phi'$  interlayer distances decrease, and H-bond strengths correspondingly increase. I computed  $O_d \cdots O_a = 3.25 \text{\AA}$ , which is less than  $O_d - D (=0.95) + D \cdots O_a (=2.42) = 3.37 \text{\AA}$  for the crystal at 4 kb, indicative of a weak bond. My D  $\cdots O_a$  distance computations range from 2.42 to 2.60  $\text{\AA}$  for disordered D and give bond valence sums from  $p_o = 2.04$  to 2.10 valence units (Brown and Altermatt, 1985) which are within error of the neutral sum of 2.0 valence units.

This digression is necessary because the closest-packed structures discussed herein include H-atom centroids which were usually not recovered owing to the limitations of the X-ray diffraction experiments. Because  $O_d \cdots O_a$  centroids can be easily determined, however, certain conclusions can be reached based on these distances. Unfortunately, without location of H atoms, any discussion on the nature of their bonding is tenuous owing to the possible H atom disorder. This caution must be exercised in the discussions which follow.

### Akrochordite

Akrochordite,  $(Mn, Mg)_5(OH)_4(H_2O)_4(AsO_4)_2$ , space group  $P2_1/c$ , is a packet structure recently announced by Moore et al. (1989). That paper discussed in considerable detail the bonding characters of this crystal, and three

structure drawings in that study obviate any repetition. A transformed cell can be found:  $a' = [100] = 5.68$ ,  $b' = [01\bar{2}] = 22.303$ ,  $c' = [114] = 32.228\text{\AA}$ ,  $\alpha' = 93^\circ 59'$ ,  $\beta' = 87^\circ 54'$ ,  $\gamma' = 84^\circ 12'$ ,  $|A| = 6$ . The approximate distance normal to the locally closest-packed packet is  $b' = t^*$ , and  $h = b'/9 = 2.48\text{\AA}$ .

The packet is a band of amphibole-like  $\infty[M_5\phi_{14}]$  octahedral walls decorated laterally, above and below by insular  $[AsO_4]$  tetrahedra. The arrangement is based on incomplete [ABCA] local cubic closest-packing. Extensive hydrogen bonding occurs around the periphery of these packets.

As with several structures reported here, one oxide, O(4), bonds only to  $As^{5+}$ . However, it apparently receives three rather short ( $\sim 2.6\text{\AA}$ )  $O_d \bullet \bullet \bullet O_a$  bonds from the aquo oxygens. Although the individual packet conserves the integrity of the formula unit and closest-packing, the  $c/2$ -glide plane interrupts this closest-packed sequence throughout the crystal, a likely result of the three H bonds to O(4).

### Willemite

Willemite,  $^4[Zn_2Si]_3O_4$ , has an extraordinary crystal structure. Crystallizing in symmetry space group  $R\bar{3}$ , Klaska et al.'s (1978) crystal gave  $a_w = 13.948\text{\AA}$ ,  $c_w = 9.315\text{\AA}$ ,  $18Zn_2SiO_4$ , all atoms in the formula unit (= asymmetric unit) in general positions. It is isostructural with phenakite,  $[Be_2Si]O_4$ , and eucryptite,  $[LiAlSi]O_4$ . Removing ordering among the cations, the structure reduces to that of the nitride  $2Si_3N_4$  ( $a \sim 1/\sqrt{3}a_w$ ,  $c \sim 1/3c_w$ ), a refractory and abrasive phase. Beyond the aforementioned authors, recent investigations included Hang et al. (1970) on willemite, and Zachariassen (1972) and Kogure and Takéuchi (1986) on phenakite.

Although willemite's structure is elegant, based on a three-connected system of  $(2Zn+Si)$  electrostatically neutral  $p_o = 2/4 + 2/4 + 4/4 = 2$  v.u. tetrahedra, it does not appear to be based on principles of global closest-packing. The investigators mentioned above left no word of an underlying principle, nor did I find one through diligent search for such a principle. Unlike franklinite,  $^6Fe_2^{3+}[^4ZnO_4]$ , which is based on the cubic closest-packed spinel structure, and zincite,  $^4ZnO$ , which is based on the hexagonal closest-packed wurtzite structure, willemite seems to stand alone in not possessing closest-packed oxides.

However, willemite has strips of structure which are indeed based on closest-packing, and these strips appear in one other structure discussed further on, junitoite. The transformation matrix for the new cell is  $A' = [10\bar{2}/120/101]$ ,  $a' = t^* = 23.273$ ,  $b' = 24.159$ ,  $c' = 16.772\text{\AA}$ ,  $\beta' = 86^\circ 55'$ ,  $|A| = 6$ . Note that  $h = a'/9 = 2.59\text{\AA}$  for this 9-layer repeat structure. The strip is shown in Figure a as the tetrahedral array drawn from the coordinate transformations from the parameters of Klaska et al. (1978). The closest-packed strips are related to the remaining formula unit design in the ratio of 2:1.

An alternative representation of willemite can be found. This exploits projection along the  $b' = a_2$  direction

in the orthohexagonal projection. Its transformation matrix is  $A' = [210/010/001]$ ,  $|A| = 2$ . This arrangement, too, is locally closest-packed; two-thirds of the arrangement is closest-packed, but one third is not. Affinities can be found with some of the over four polymorphs of  $^4Zn(OH)_2$  which are two-connected tetrahedral systems (the octahedral arrangements are not included). This suggests that willemite's crystal chemistry is probably elaborate, and I am presently conducting a separate study on this interesting problem.

## THE TRUE CLOSEST-PACKED STRUCTURES

### Clintonite

The brittle mica clintonite,  $Ca(Mg_2Al)(OH)_2[Al_3SiO_{10}]$ , was recently studied in considerable detail by MacKinney et al. (1988), who presented three well-refined crystal structures. While clintonite is the principal brittle mica, several earlier synonyms created much confusion in the literature. The mineral characteristically occurs in well-crystallized marble in association with humites, spinel, corundum, vesuvianite, diopside, and forsterite, and may be considered a metamorphic phase crystallized from rather basic peraluminous sediments.

The crystal structure representation in Figure 1 reveals pseudo-trigonally distorted  $\infty[T_4O_{10}]$  tetrahedral sheets, distinct from the more hexagonal sheets approximating the homogeneous  $\{6^3\}$  net for the mica minerals. The hydrogen atom, located by the aforementioned investigators in difference synthesis but not refined further, was retained in the final anisotropic refinement of the crystal structure, which representation was drawn from their Edenville, Orange Co., N.Y. results. Confusion remains in the literature regarding the type occurrence of the species named in honor of DeWitt Clinton, early Governor of New York State, builder of the Erie Canal, and American statesman. The town of Warwick includes the hamlets of Amity and Edenville, but Warwick village itself is built over Cambro-Ordovician sediments. The only authenticated occurrences of "type" clintonite are two recently rediscovered adjacent sites within the hamlet of Amity.

The bifurcated  $O_d \bullet \bullet \bullet O(1)_a = 3.119(x2)\text{\AA}$  and  $O_d \bullet \bullet \bullet O(2)_a = 3.092\text{\AA}$  constitute the three rather weak hydrogen bonds in the crystal. In the diagram (Figure 1) they are expressed as  $H \bullet \bullet \bullet O_a$  distances. Note that these bonds have a pronounced lateral component in the projection.

Deviations in the cell and atom coordinates from the perfect closest-packed model for non-H atoms in Table 1 indicate a structure with but slight distortions from ideality, the greatest deviant being O(1) which is only  $0.34\text{\AA}$  away from the perfect model. Although clintonite was long recognized as a closest-packed structure, that knowledge has received at best grudging acceptance. The structure emphasizes yet again the appearance of closest-packing in a basic paragenetic setting, distinct from the typical mica phases presented to us in more acid environments.

## Franklinfurnaceite

Like the MacKinney et al. (1988) study of clintonite, franklinfurnaceite was studied in considerable detail by Peacor et al. (1988). Good convergence, however, failed to educe the hydrogen atom positions in difference synthesis and, owing to the disordered nature of the H atom position in brucite, I considered it imprudent to derive the possible H atom positions through  $O_d \bullet \bullet \bullet O_a$  distance calculations. This rather new species occurs in a clearly basic crack mineral paragenesis with several other phases, most of which are closest-packed and some of which are rather complex in structure.

The Figure 2 series outlines the three principal polyhedral layers in franklinfurnaceite. The transformation in Table 2 reveals a structure based on 3 (•hhcccc•) 18-layer stacking which is reminiscent of the tight fitting to the perfect closest-packed model as found for clintonite, and, like clintonite, is best thought of as a structure based on an approach to the closest-packing limit. The greatest deviant from ideality is O(4) with  $\Delta = 0.36\text{\AA}$ . The transformed cell edge deviations are substantially greater than those of clintonite, doubtless a result of the more open nature, the ordered zincosilicate tetrahedral sheet, and the occurrence of Jahn-Teller distorted  $[Mn^{3+}\phi_6]$  in the crystal.

Figure 2a represents the brucite-like  $\overset{\infty}{\phi}[M_3\phi_6]$  trioctahedral layer at  $z' = o'_{12}$ . Here the divalent octahedral cations in M(1) and M(3) define the  $\overset{\infty}{\phi}[M_2\phi_6]$  dioctahedral component as found for M(4) and M(5) in the dioctahedral layer at  $z' = z'_{12}$  in Figure 2c. Jahn-Teller distorted M(2) $\phi_6$  octahedra complete the  $z' = o'_{12}$  ordered brucite-like layer. In Figure 2b at  $z' = z'_{24}$ , the  $Ca\phi_6$  octahedral and  $[Zn_2Si_2O_{10}]^{8-}$  tetrahedral layer is shown, comparable to the clintonite layer (Figure 1). Note the pseudo-trigonal distorted tetrahedral sheet and the fairly regular coordination of the octahedral site.

One wonders how many as yet undiscovered closest-packed phases are lurking in the very basic crack paragenesis, concealed by their mimetic relation to other well-known phases.

## Junitoite

The junitoite structure type was reported by Hamilton and Finney (1985). They made cursory discussion of certain bond distances and the appearance of corner-linked zincate chains. No hint was given, however, of the underlying structural principle.

This crystal is an excellent example of oxide closest-packing with six cubic layers in the repeat, with  $c' = 15.263\text{\AA}$  or •cccccc•, and  $h = 2.54\text{\AA}$  for the mean interlayer separation. Common with all closest-packed structures when projected along  $t^*$ , considerable polyhedral overlap occurs which, when combined with distortion, leads to a congested diagram. Therefore only selected polyhedra are featured in Figure 3. Table 3 summarizes the pertinent cell data and transforms. Note that  $[ZnO_4]$  tetrahedra are large,

with  $Zn-O = 1.95\text{\AA}$ , while  $[SiO_4]$  tetrahedra have  $Si-O = 1.62\text{\AA}$ .

The elegant structure shows one aquo bond to octahedrally coordinated  $Ca^{2+}$ ; this water molecule is an essential part of the anion ( $\phi$ ) packing. Therefore it is appropriate to include the water molecule parenthetically after  $Ca^{2+}$ , viz.  $Ca(H_2O)[Zn_2Si_2O_7]$ . Hydrogen bonding was not discussed by Hamilton and Finney (1985), presumably because the hydrogen centroids are usually difficult to locate in such a dense substance. I located two possibilities where the hydrogen atom is not close to the edge of an occupied polyhedron and where the  $W \bullet \bullet \bullet O$  distances ( $W =$  aquo oxide) are reasonable. These are  $W \bullet \bullet \bullet O(2) = 3.14\text{\AA}$ ,  $O(2)-W-O(2)'$  angle =  $61^\circ 53'$ , and  $W \bullet \bullet \bullet O(3) = 2.92\text{\AA}$ ,  $O(3)-W-O(3)'$  angle =  $64^\circ 07'$ , and correspond to edges of empty tetrahedra and octahedra. These angles are rather acute and, with somewhat long hydrogen bond distances between the oxide centroids, suggest that the Pauling bond strength is rather weak. As the  $W \bullet \bullet \bullet O(2)$ ,  $O(3)$  bonds are defined along edges of vacant polyhedra in this crystal, it suggests that the hydrogen bonding principle is preordained by the closest-packing of anions. Although Figure 3 presents the  $W \bullet \bullet \bullet O(2)$  bond, this is almost certainly not the correct one as it is not the shortest. In the sense of Pauling (1960), the bond strength sums without the  $\bullet \bullet \bullet O_a$  are  $p_o = 2.00, 1.83, 1.83, 2.33$  v.u. for O(1) through O(4) respectively. Yet  $Si-O(2) = 1.55\text{\AA}$  suggests an undersaturated case and  $Si-O(3) = 1.67\text{\AA}$  indicates slight oversaturation. The extra  $W \bullet \bullet \bullet O(3)$  bond is believed to be the correct one for this reason. The O(3) equivalence, not in this figure, is below the designated Si site in Figure 3. The decision is amplified by  $W \bullet \bullet \bullet O(3)$  being the shorter distance, and O(3) is almost certainly the designate acceptor of the hydrogen bond.

Hamilton and Finney (1985) comment on the corner-linked chains of zincate tetrahedra found in junitoite. This is suggested in Figure 3 although some tetrahedra were omitted because of congestion. In the following, the J subscript refers to the junitoite cell and the W subscript refers to the willemite cell. The chains run parallel to  $[101]_j$  and their sequence along that cell translation is six tetrahedra:  $Zn(1)-\bullet Zn(2)-Zn(1)-Zn(2)-Zn(1)-Zn(2)-Zn(1)-\bullet Zn(2)$ . The tetrahedra translate one repeat along  $a'_j$  and one repeat along  $c'_j$ . In willemite (Figure a), the repeat is nine tetrahedra:  $Zn(1)-\bullet Si-Zn(2)-Zn(1)-Si-Zn(2)-Zn(1)-Si-Zn(2)-Zn(1)-\bullet Si$  along  $[10\bar{1}]'_w$  or one repeat along  $a'_w$  and one repeat along  $-c'_w$ . A comparison can be made in terms of translation between two tetrahedra in these cubic closest-packed chain fragments. It is  $a'_j c'_w = 10.640\text{\AA}/6 = 1.77\text{\AA}$ ,  $16.772/9 = 1.86\text{\AA}$ ;  $c'_j a'_w = 15.263/6 = 2.54\text{\AA}$ ,  $23.273/9 = 2.59\text{\AA}$ . The greater distortion of the zincate tetrahedra in junitoite with respect to the silicozincate tetrahedra of willemite and the smaller mean tetrahedral size in willemite is evident, both in the inter-tetrahedral distances and in the figures. Note that junitoite

$\beta'$  deviates  $2^\circ 18'$  from orthogonality in the closest-packed representation.

Distortions of non-H cations and anions in junitoite from the perfect cubic closest-packing model are not severe. The greatest difference of 1.1% along  $a'_j$  is evidently a consequence of the twisting of the large zincate tetrahedra. The range in atom coordinate difference is 0.00–0.55 Å, within 39% of the oxide Pauling radius of 1.40 Å. The most distorted atom is O(1), the apex of the zincate tetrahedron in closest-packing.

Finally, assuming junitoite is a product of fluid hydrothermal refluxing of willemite and/or zincite, its formation must be reconstructive. Zincite is based on hexagonal closest-packing and the zincate chain in junitoite is cubic closest-packed. In addition, the silicozincate arrangement of the cubic closest-packed chain in willemite corresponds to the zincate chain in junitoite. Note, however, that zincite and junitoite crystals both enjoy polar symmetry.

### Clinohedrite

The approximate clinohedrite structure type was first reported by Nikitin and Belov (1963), and a much-improved refinement added by Venetopoulos and Rentzeperis (1976). Despite extensive discussion of the structure in these studies, the clinohedrite structural principle was missed; it is in fact a structure based on cubic closest-packing, a six-layer repeat with  $c' = 15.79 \text{ \AA}$  or  $\bullet\text{cccc}\bullet$ , and  $h = 2.63 \text{ \AA}$ . Table 4 summarizes the pertinent cell data and transform of this crystal. The water molecule in clinohedrite, like that in junitoite, is aquated and plays a fundamental role in the anion closest-packing; it is bonded directly to  $\text{Ca}^{2+}$  and therefore the formula should really be written  $\text{Ca}(\text{H}_2\text{O})[\text{ZnSiO}_4]$ . Hydrogen atom positions were inferred, and reported as calculations without errors in the 1976 refinement study.

Clinohedrite differs from junitoite in several respects. Zincate chains in junitoite appear as zincosilicate  $[\text{ZnSiO}_6]^{6-}$  chains in clinohedrite. These chains run parallel to  $a' = 5.09 \text{ \AA}$  in the latter compound, and their disposition is reminiscent of the pyroxene zig-zag chain. Figure 4 presents a transformed structure representation. Note that the correct transform for  $t^*$  normal to the closest-packed layers is  $A' = [100/010/103]$  applied to the cell of Venetopoulos and Rentzeperis (1976). This transformed cell presents  $\beta' = 84^\circ 59'$ . Figure 4 is based on the transform  $A' = [104/0\bar{1}0/100]$  which gives  $a' = 20.97 \text{ \AA}$  or an 8-layer repeat, and  $\beta' = 89^\circ 49'$ . Although this cell presents a  $\beta'$  angle closer to  $90^\circ$ , the closest-packed layers are offset in projection. This should be borne in mind when using Figure 4 even though the two representations are similar.

The inferred hydrogen bonds are dictated by the closest-packing principle as in junitoite. The computed distances are  $W(1) \bullet\bullet\bullet O(2) = 2.79 \text{ \AA}$  and  $W(1) \bullet\bullet\bullet O(5) = 2.69 \text{ \AA}$  with  $O(2) \bullet\bullet\bullet W(1) \bullet\bullet\bullet O(5)$  angle =  $102^\circ 0'$ . The  $W(1) \bullet\bullet\bullet O(2)$  and  $W(1) \bullet\bullet\bullet O(5)$  bonds correspond to the

edges of two independent empty tetrahedra, not one as proposed for junitoite.

In Figure 4, the Ca-centered octahedral edge-sharing *cis*-chains run parallel to  $[\bar{1}01]'$ . The  $[\text{Ca}(\text{W}_2\text{O}_4)]$  octahedra fuse at the W–W edge to form *cis*-chains. The bonding principle is different from the single  $[\text{Ca}^{2+}\text{WO}_5]$  octahedra in junitoite, even though both structures enjoy anion closest-packing.

Distortion of non-H cations and anions in clinohedrite from the perfect closest-packed model roughly parallels that of junitoite. The greatest axial deviation from the perfect model is  $\Delta a' = 5.8\%$ ; this results from twisting of the zincate tetrahedra in the chains, as in junitoite. Note that  $\Delta O(3) = 0.70 \text{ \AA}$  is the most distorted atom in the structure. As in junitoite, it is the apical zincate oxygen in the closest-packed representation.

## THE PACKET STRUCTURES

### Cianciulliite

The recent discovery, cianciulliite, was structurally investigated by Grice and Dunn (1991) who obtained  $R = 0.04$  for 675 independent reflections. I discovered that a cell transformation admitted a much easier discussion of the structure as the new cell is nearly orthogonal with  $t^*$  perpendicular to the projection in Figure 5. The transformation matrix (cell) is  $A' = [201/010/001]$  of order two, hence the cell contents are double that of the original description. The coordinate transform is  $[1/2\ 00/010/-1/2\ 0\ 2/2]$  and the new cell is  $a' = 30.222$ ,  $b' = 6.344$ ,  $c' = 5.562 \text{ \AA}$ ,  $\beta' = 90^\circ 50'$ . The formula for the new cell is  $Z' = 4$ ,  $\square \text{MnMg}_2(\text{OH})_2[\text{Zn}_2(\text{OH})_6(\text{OH})_2^*] \bullet 2 \text{H}_2\text{O}$ , i.e. a hydrated hydroxide of zinc, magnesium, and manganous ions. As  $a'/12 = 2.518 \text{ \AA}$ , cianciulliite is a twelve-layer structure but the closest-packing principle is interrupted at the hydrate,  $\bullet 2 \text{H}_2\text{O}$ , and zincate terminal hydroxide,  $(\text{OH})_2^*$ , layer.

Cianciulliite is a packet structure which is locally [CABC] closest-packed. For this reason, a table of the transformed cell and differences,  $\Delta$ , is not really hortative. The octahedral brucite-derived sheet is ordered with  $\text{Mn}^{2+}$  and vacancy  $\square$  alternating in an edge-sharing row, then a completely occupied  $\text{Mg}^{2+}$ -centered edge-sharing row, and so on. The vacancies are ordered in an orthogonal fashion and are capped above and below by zincate,  $[\text{Zn}(\text{OH})_4^{2-}]$ , tetrahedra, apical  $(\text{OH})^* = \text{O}(3)$  pointing into the hydrate layer. This package repeats three times, or 3[CABC], making up the 12-layer repeat in the cell. Figure 5 presents the closest-packed packet which shows remarkably regular polyhedra drawn from the transformed coordinates.

In the findings of Grice and Dunn (1991),  $O(5) = W(5)$  or the water molecule is disordered, only half-populated at its site which was taken as a general position. These authors propose a general coordinate which will permit accumulation of fully occupied  $W(5)$  in the cell. Unfortu-

nately I discovered this proposed position is much too short for any sensible H-bond, with  $O(3) \bullet \bullet \bullet W(5) = 1.60 \text{ \AA}$ .

On Figure 5 and from the structure refinement, the number of  $W(5)$  and  $O(3)$  in the cell are the same. This means that, for  $W(5) = H_2O$ , an average of two  $W(5)-H \bullet \bullet \bullet O(3)$  independent bonds occur. Because the centroids of the H atoms were not located in the earlier structure study, bond valence calculations have little meaning. However, the hydroxyl atoms  $\phi(1)$ ,  $\phi(2)$ ,  $\phi(3)$ , and  $\phi(4)$  can be roughly assessed according to Pauling bond strength, setting  $O_d$  (donor)  $s = 5/6$  and  $O_a$  (acceptor)  $s = 1/6$  valence unit. The anion  $\phi(1)$  is coordinated by  $Mg + Mg + Mn^{2+} + H_d$  or  $p_o = 2/6 + 2/6 + 2/6 + 5/6 = 1.83$  valence units;  $\phi(2)$  by  $Mg + Mg + Zn + H_d$  or  $p_o = 2/6 + 2/6 + 2/4 + 5/6 = 2.00$  valence units; and  $\phi(4)$  by  $Mn + Mg + Zn + H_d$  or  $p_o = 2/6 + 2/6 + 2/4 + 5/6 = 2.00$  valence units. Indeed, the cation-O(1) distances are the shortest for their polyhedra in Grice and Dunn (1991). Anion  $\phi(3)$ , the hydroxyl anion terminal to the zincate tetrahedron, receives  $Zn + H_d$  or  $2/4 + 5/6$ , or  $p_o = 1.33$  valence units, and is eminently capable of receiving  $H_a$  bonds from the  $W = \phi(5)$  water molecules. In Figure 5, I present at most four H-bonds to  $\phi(3)'$ . Of these, only two bonds to each  $\phi(3)'$  are allowed on stoichiometric grounds. Two  $W(5)$  donor configurations can be discerned:  $\phi(3) \bullet \bullet \bullet W(5) \bullet \bullet \bullet \phi(3)'$  with 2.89 and 2.90 Å, angle  $108^\circ 20'$ , and  $\phi(3) \bullet \bullet \bullet W(5) \bullet \bullet \bullet \phi(3)'$  with 2.89 and 2.72 Å distance, angle  $81^\circ 50'$ . These are believed to be the disordered hydrogen bonds from the water molecules which hold the adjacent packets together. Note that  $\phi(3)$  still remains undersaturated with bond strength sum  $p_o = 2/4 + 5/6 + 1/6 + 1/6 = 1.67$  valence units. It is gratifying to see that  $Zn - \phi(3) = 1.967 \text{ \AA}$  is the shortest distance for the zincate tetrahedron.

Cianciulliite is an interesting example where water molecules can seek an arrangement which is an alternative to the ligated molecules in the three-dimensional closest-packed frame as found in clinohedrite and junitoite. Here, the packet structures I discuss for cianciulliite, chlorophoenicite, akrochordite, mooreite, and lawsonbauerite terminate at apical oxides or hydroxyls bonded to tetrahedra. The apical oxide is very nearly saturated electrostatically through several short hydrogen bonds in addition to the attached hydrogen and bonded cation yet the packet itself retains all the character of a closest-packed unit.

### Chlorophoenicite

The crystal structure of chlorophoenicite was announced by Moore (1968). The sample studied was recognized then as disordered, and readily noticeable streaks appeared on  $b$ -axis rotation photographs requiring a doubling of that translation. These streaks are parallel to  $a^*$  on (hk0) Weissenberg photographs. Collection of a limited data set on a manual diffractometer with  $MoK_\alpha$  radiation led to  $R = 0.12$  for 330 independent  $F_o$ . Of ten independent non-H atoms in the asymmetric unit, four were disordered. These included one half-occupied As atom site and its three associated bonded oxygens  $O(2)$ ,  $O(5)$ , and  $O(6)$ ,

each then believed, on average, to be fully occupied. For this reason the anionic species, as in cianciulliite, are symbolized by  $\phi = O^{2-}$ ,  $OH^-$ ,  $\square$ . Disorder among these atom sites led to unrealistic As- $\phi$  distances ranging from 1.55 to 1.92 Å with a polyhedral mean of 1.80 Å, larger than a Shannon and Prewitt (1969) mean of 1.71 Å for 4-coordinate arsenic and 4-coordinate oxide. Remaining distances in the crystal appeared reasonable, including shared polyhedral edges, but errors ranged  $\pm 0.06 \text{ \AA}$  for this disordered crystal. In the following discussion, the subcell is retained but the doubled  $b$ -axis is used to suggest the cause of disorder in the crystal.

New insights on the closest-packed structures of Franklin crack minerals admit a more sensible interpretation of chlorophoenicite's crystal chemistry. The transformation matrix from the old cell in Moore (1968) to the new primed cell is  $A' = [10\bar{2} / 010 / 104]$ ,  $a' = 30.46$ ,  $b' = 3.32$ ,  $c' = 34.39 \text{ \AA}$ ,  $\beta' = 89^\circ 38'$ , atom coordinate transform  $[4/6\ 0/6\ -1/6 / 010 / 2/6\ 0/6\ 1/6]$ , with  $Z' = 6Z$  for  $Z = 2Mn_3(OH)_3[Zn_2(OH)_4AsO_4]$ . The vector normal to the closest-packed layer,  $t^*$ , is nearly parallel to  $a'$ , and  $a'/12 = 2.54 \text{ \AA}$ , a typical layer translation for closest-packed basic manganese zincoarsenate and zincosilicate structures. A spoke diagram in Figure 6 along  $[010]$  defines atom sites in the asymmetric unit and proposed  $O_d \bullet \bullet \bullet O_a$  bond distances for the original cell. Note that the As site is half-occupied on average and that H atom centroids could not be experimentally established in the structure study. Admissible bonds at the absent As site would be  $\phi(5) \bullet \bullet \bullet \phi(6) = 2.71(x2)$  and  $\phi(2) \bullet \bullet \bullet \phi(5) = 2.95 \text{ \AA}$ . The remaining plausible H-bonds in the structure would be  $\phi(4) \bullet \bullet \bullet \phi(6) = 2.80$ ,  $\phi(3) \bullet \bullet \bullet \phi(4) = 2.80$ , and  $\phi(1) \bullet \bullet \bullet \phi(5) = 3.19 \text{ \AA}$ . Projection of chlorophoenicite's packet along  $t^* = [100]^*$  reveals an elegant underlying principle. The  $Mn(1)-$  and  $Mn(2)-\phi$  octahedra form edge-sharing walls  $\infty l \times \sqrt{3}l$  in the  $b$ -direction, with corner-linked walls of  $(As\square)Zn_2\phi_{10}$  tetrahedra which run in the same direction as the octahedral walls. This rather busy Figure 7 includes the possible  $O_d \bullet \bullet \bullet O_a$  bonds. Note the  $\infty[(As\square)\phi_6]$  component has As-centered tetrahedra alternating with vacancies. This is because an As- $\phi(6)$ -As' link leads to unreasonable oversaturation of  $\phi(6)$  by bonding cations.

Assuming fully occupied anion sites, two ordered 'end-members' can be considered as summarized in Table 5. These lead to  $[Mn_3Zn_2(OH)_{12}]^{2-}$  (note the similarity to the cianciulliite formula!) and  $[Mn_3Zn_2(OH)_6(As_2O_6)]^{2+}$  respectively, or mean  $Mn_6Zn_4(OH)_{18}(As_2O_6) = Mn_6Zn_4(AsO_4)_2(OH)_{14}(H_2O)_2 = 2[Mn_3Zn_2(AsO_4)(OH)_7(H_2O)]$ . Such a formula for chlorophoenicite stipulates full site occupancy for all atoms save half-populated As. In light of the Foshag analysis in Foshag and Gage (1924), however, such a formula requires a water analysis about 24% higher than that reported. As there is no good reason to question this analysis, some other reason must be found for the discrepancy.

Several curious results in chlorophoenicite can be resolved if it is assumed that  $\phi(5)$  is only half-populated. If  $\phi(5)$  is present when As is present and absent otherwise, three of the five proposed  $\phi_d \cdots \phi_a$  bonds disappear when As is absent, namely those corresponding to  $\phi(5)$  in Figure 7. The high anisotropic thermal parameter  $B = 3.58 \text{ \AA}^2$  where other values range from  $0.51 - 1.41 \text{ \AA}^2$  in Moore (1968) again suggests partial occupancy at this site. Difference synthesis in that earlier study did not indicate a split atom position. The short As- $\phi(5) = 1.55 \text{ \AA}$  distance also suggests disorder. It is proposed that As and  $\phi(5)$  are each half-populated in chlorophoenicite leading to an average formula  $\text{Mn}_3\text{Zn}_2(\text{OH})_6(\text{OH}_{1/2}\square_{1/2})_2(\text{As}_{1/2}\text{O}_{1/2})_2 \text{O}_3$  or  $\text{Mn}_3\text{Zn}_2(\text{OH})_7\text{AsO}_4$ . This would mean that Mn(2) for the As-free end-member would be five-coordinated, and would improve valence balance about  $\phi(1)$  and  $\phi(2)$ .

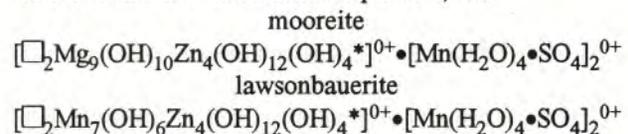
In short, all chlorophoenicite-related phases require considerable future in-depth study. Jarosewichite,  $\text{Mn}_3^{2+}\text{Mn}^{3+}(\text{OH})_6(\text{AsO}_4)$ , with  $a = 2 \times 3.28 \text{ \AA}$  and a related phase, the incompletely characterized unknown in Dunn et al. (1982), and magnesium-chlorophoenicite, ca.  $\text{Mg}_4\text{Mn}_1(\text{OH})_7\text{AsO}_4$ , are included here. In fact, the paragenetically associated phases gageite,  $(\text{Mn}, \text{Mg})_{42}\text{O}_6(\text{OH})_{40}[\text{Si}_4\text{O}_{12}]_4$  (see Ferraris et al., 1987, for an elegant study on this phase), leucophoenicite,  $\text{Mn}_7(\text{SiO}_4)_2[\text{SiO}_4(\text{OH})_2]$  (Moore, 1970), and ribbeite,  $\text{Mn}_5(\text{SiO}_4)[\text{SiO}_4(\text{OH})_2]$  (Freed et al., 1993) all involve disorder and half-occupancy over some of their populated tetrahedral sites. Individual T- $\phi$  distances for these half-populated sites are also anomalous in these structures. All such peculiar phases have pyrochroite,  $\text{Mn}(\text{OH})_2$ , as a common coexisting phase in their paragenesis, which was suggested by Moore (1994) as an indicator of a very basic and reducing environment [ $\text{pH} \sim 13$ ,  $E_h \sim -0.5 \text{ V}$ ] of formation. It follows, then, that such extreme conditions are conducive to the formation of hydrogen-bonded systems and local disorder of unusual character. For this reason, all these phases beg a more holistic in-depth study on their crystal chemistry and paragenesis.

### Mooreite and lawsonbauerite

Mooreite and lawsonbauerite are very complex packet structures. In many respects, their crystal-chemical discussion follows directly from cienciullite. Hill (1980), in a rather exhaustive and careful study on mooreite, reported  $R = 0.066$  for 3276 independent  $F_o$  which included anisotropic temperature refinement of 30 unique non-hydrogen atoms and coordinate refinement with fixed isotropic temperature factors for the 21 unique hydrogen atoms. Treiman and Peacor (1982) solved and refined lawsonbauerite but the mineral does not occur in good single crystals, so  $R = 0.12$  for 2112 independent  $F_o$  which included isotropic refinement for 23 unique non-hydrogen atoms and anisotropic refinement for the four oxygens of the sulfate group. Incidentally, typographical errors are evidently present in their  $x$  coordinate for M(5) and their

$z$  coordinate for O(18). As H centroids could not be located for this latter compound, I decided to consider  $\text{O}_d \cdots \text{O}_a$  distances only, where  $\text{O}_d$  is a hydrogen donor oxygen, ( $\cdots$ ) is the classical hydrogen bond, and  $\text{O}_a$  is the hydrogen acceptor of that bond. As Hill (1980) noted,  $\text{O}-\text{H} = 0.73 \text{ \AA}$  mean distance in mooreite is about  $0.2 \text{ \AA}$  shorter than  $\text{O}-\text{H} = 0.95 \text{ \AA}$  separation in typical refinement of neutron diffraction data in crystals. [This is because X-ray diffraction records the electron density of the covalent  $\text{O}-\text{H}$  bond while neutron diffraction, a nuclear interaction, records the atomic centroid.] A mean  $\text{O}_d \cdots \text{O}_a = 2.8 \text{ \AA}$  separation for oxygen donor-acceptor of the hydrogen atom is twice the Pauling oxide radius, but this value can vary significantly in crystals. Note that  $d(\text{O}_d \cdots \text{O}_a) \leq d(\text{O}_d-\text{H}) + d(\text{H} \cdots \text{O}_a)$  as deviations from the tetrahedral angle of  $109^\circ 28'$  can be considerable.

I prefer to recast the unit end-member formulas of mooreite and lawsonbauerite as packets, viz.:



The first set of brackets includes the closest-packed brucite (pyrochroite)-like layer which includes two cation vacancies ( $\square$ ) in that layer. The vacant sites are capped above and below by the corner-linked zincate,  $[\text{Zn}(\text{OH})_4]$ , tetrahedra. The  $(\text{OH})^*$  vertex of the zincate tetrahedron points into the contiguous tetra-aquated manganous sulfate layer. In closest-packing parlance, the  $(\text{OH})^*$  termini define the rarefied C-layer, and the remaining  $(\text{OH})^-$  bases the A- and B-layers in the closest-packed fragment [CABC] common to the two structure types. All hydrogen bonds are located and their distances are given in the contiguous tetra-aquated manganous sulfate layer, see Figure 8a (mooreite) and Figure 8b (lawsonbauerite). The 21 unique  $\text{O}_d \cdots \text{O}_a$  distances in mooreite range from  $2.71$  to  $3.66 \text{ \AA}$  (the next lower is  $3.34 \text{ \AA}$ ) and the 19 unique  $\text{O}_d \cdots \text{O}_a$  distances in lawsonbauerite range from  $2.54$  to  $3.23 \text{ \AA}$  (the next higher is  $2.70 \text{ \AA}$ ). Table 6 summarizes these bond distances for both structures.

A deeper phenomenon is found in the mooreite and lawsonbauerite structures and this derives from the valence-matching principle of Brown (1981). Can we partition cations of the same valence but different size in the same crystal? For four-coordinate oxide species, Brown proposes  $0.40$  valence units (v.u.) per oxide anion for  $\text{OH}^-$  and  $0.17$  v.u. in  $\text{SO}_4^{2-}$ , and for acid species,  $0.36$  v.u. for  $\text{Mg}^{2+}$  and  $\text{Mn}^{2+}$ , and  $0.2$  v.u. for  $\text{H}_2\text{O}$ . As bond strength or bond valence must diminish with increasing coordination number (or increasing cation radius), it follows that smaller  $\text{Mg}^{2+}$  would more favorably partition into the hydroxyl layers than larger  $\text{Mn}^{2+}$ , even though their acid strengths are similar. This is what I observed for mooreite and lawsonbauerite;  $\text{Mn}^{2+}$  favors the contiguous aquated layer and is coordinated by four  $(\text{H}_2\text{O})$  and two  $(\text{OH})^*$ . It should

be recalled that Pauling's (1960) bond strength rules and Brown's (1981) bond valences express *tendencies* or trends more than reality in absolute values; they work best for atom partitioning in the same crystal. Both  $Mg^{2+}$  and  $Mn^{2+}$  are spherical ions –  $Mg^{2+}$  is naked with no valence electrons and  $Mn^{2+}$  has five electrons in high spin distributed over all the available  $t_{2g}$  and  $e_g$  suborbitals – and the extension of the valence-matching principle of Brown is appealing. For four-coordination about oxide, it appears that  $SO_4^{2-}$  with  $\Delta p_o = 2 - 6/4 = 2/4$  leaves  $s = 1/6$  remaining for a bond to each oxide. This is balanced by about three  $O_d-H \bullet\bullet\bullet O_a$  bonds per sulfate oxygen in Table 6.

## CONCLUDING REMARKS

Of the ten structure types from the Franklin-Sterling Hill paragenesis which involve  $\phi = O^{2-}$ ,  $OH^-$ , and/or  $(H_2O)^+$  ligands in this study, five are based on classic closest-packed  $\phi$ , and five more are based on packets or thick layers of locally closest-packed units. The  $(H_2O)^+$  ligands in the closest-packed sequences occur at sites where  $O_d \bullet\bullet\bullet O_a$  bonds traverse edges of empty octahedral and tetrahedral sites. In the packet structures, the terminal Zn–OH and As–O bonds are electrostatically balanced by additional interlayer bonds with an extensive webbing of  $O_d-H \bullet\bullet\bullet O_a$  units.

Closest-packing of anionic units does not occur in the majority of hydrated and aquated oxysalt mineral structures. [Mr. Richard A. Bideaux informed me that of 3431 total mineral species in his mineral data file as of June 1993, 1262 contain  $OH^-$  (36.8% of total species), 1225 contain  $H_2O$  (34.2%), and 549 contain both  $OH^-$  and  $H_2O$  (16.0%). This emphasizes the importance of hydrogen bonding in mineral structures and a need to pay very close attention to them!] Rather, in these structures, one sees a condensation of fragments or *clusters* which presumably occurred in the fluid coexisting with the growing crystal. In such cases, the hydrogen bonds would probably be dictated by the nature of the clusters. Yet, in the closest-packed systems, a hierarchy appears to be operating in which the anions  $\phi$  remain as closest-packed arrays and all other bonds are dictated according to these arrays. Extensively basic and reducing systems appear to encourage such arrangements; of the 62 structurally known hydrothermally refluxed aquated-hydrated-(hydroxylated)-transition metal nesophosphates from the famous Palermo Pegmatite, Grafton Co., New Hampshire, only one of them, bermanite,  $Mn^{2+}(H_2O)_4[Mn_2^{3+}(OH)_2(PO_4)_2]$ , can be declared a locally closest-packed packet structure, namely the region in brackets! Yet of the 333 discrete mineral species from the famous Franklin/Ogdensburg zinc deposits (Dean, 1990), over 87 of them are based on principles of oxide closest-packing—the majority basic crack paragenesis minerals, at least 16 of which are found nowhere else in the world! One feature which distinguishes the packet structures from the true closest-packed structures is the relatively high water content in the formula unit of the former. The atom percentage of  $\phi$  as

water molecules per formula unit ranges from 16.7% to 25.0% in the packet structures ciangiulliite, akrochordite, mooreite, and lawsonbauerite. Only cubic closest-packed clinohedrite, with 20.0% of  $\phi$  as water molecules per formula unit, falls within this range; we have seen that this crystal accommodates the  $H_2O$  molecules in the  $\phi$  system through having two adjacent vacant tetrahedral sites and adjacent vacant octahedral sites so that hydrogen bonding is possible.

Throughout this study, high pH ~ 12-14 and relatively reducing conditions  $Eh < 0V$  are declared as the engine for the prevalence of closest-packed structures. Conditions of relatively high confining pressure can also achieve the same result. The Franklin Marble is a part of the Grenville orogeny, and is an upper amphibolite–lower granulite facies assemblage, with T(minimum) ~ 860°C and P(confining) ~ 4–7 kilobars, according to Kearns (1977) on the basis of his studies on the calcite-dolomite *solvus* for the Franklin Marble and the observed absence of wollastonite respectively. At present, the temporal appearance of the closest-packed minerals is not known. They could have formed many millions of years after the apex of the big metamorphic event. In fact, their crack associations suggest conditions of a more shallow nature. For the present, the Eh–pH model will be proposed as the central criterion toward the formation of such unusual phases.

Why is closest-packing so prevalent among aquated-(hydrated)-basic oxysalts at Franklin-Ogdensburg (and Långban, Sweden, by extension)? Are these observations telling us something about Kepler's *Harmonices Mundi* and Nature Herself? I believe the emergence of closest-packed structures is driven by the energy requirements of the fundamental equation which links oxidation potential with respect to the standard free energy of formation, and pH, viz.:

$$Eh = E^\circ - 0.0592 \text{ pH, see Moore (1994).}$$

I believe this relationship can be directly tested from a crystal structure via Patterson's famous *Faltung* (Glusker, et al., 1987). This can be obtained directly from structural information by way of the electrostatic energy of a crystal as discussed and derived by Ewald (1973). I envision a model arising from the invariant atomic structures of perfect hexagonal (e.g. Mg) and cubic closest-packings (e.g. Cu). The much more complicated closest-packed structures discussed herein have rather small ( $\Delta \sim 0.3\text{\AA}$ ) atom centroid deviations from these perfect models and it is expected that their electrostatic energies will be similar to each other. That is to say, their fields of stability in Eh–pH –composition space will be dense and compact, with many phases occurring over a narrow range of thermochemical criteria.

It is expected that very complex low temperature mineral assemblages such as at Franklin and Långban will reveal to us the ultimate link between crystal structure and mineral paragenesis.

Table 1 : Clintonite †

CaMg <sub>2</sub> Al(OH) <sub>2</sub> [Al <sub>3</sub> SiO <sub>10</sub> ]						
			(100/010/103)	cell		
			( <sup>3</sup> / <sub>3</sub> 0 - <sup>1</sup> / <sub>3</sub> / 0 1 0 / 0 0 <sup>1</sup> / <sub>3</sub> )	coordinate		
Z	2	Z'	6	<i>l</i>	< <i>b</i> >	Δ(%)
a	5.200	a'	5.200	√3 <i>l</i>	3.002	5.167 +0.6
b	9.005	b'	9.005	3 <i>l</i>	3.002	8.949 +0.6
c	9.779 Å	c' (t*)	28.864 Å	12 √ <sup>2</sup> / <sub>√3</sub> <i>l</i>	2.946 Å	29.227 Å -1.3%
β	100°18'	β'	89°55'	h=2.405 Å	<2.983 Å>	
C2/m	V <sub>E</sub> '	18.77 Å <sup>3</sup>	4(. c c c .)			

MacKinney et al. (1988), R = 0.039 / 673 F<sub>O</sub>

Difference:	Δ Ca	0.00	Δ O(1)	0.34
	Δ M(1)	0.00	Δ O(2)	0.32
	Δ M(2)	0.03	Δ O(3)	0.11
	Δ T	0.22	Δ OH	0.23 Å
			mean	0.17 Å
			range	0.00 — 0.34 Å

†Crystallographic characters. See Moore (1994) for details of transforms and calculations.

Table 2 : Franklinfurnaceite

Ca <sub>2</sub> Mn <sub>3</sub> <sup>2+</sup> Mn <sup>3+</sup> Fe <sup>3+</sup> (OH) <sub>8</sub> [Zn <sub>2</sub> Si <sub>2</sub> O <sub>10</sub> ]						
			(100/010/103)	cell		
			( <sup>3</sup> / <sub>3</sub> 0 - <sup>1</sup> / <sub>3</sub> / 0 1 0 / 0 0 <sup>1</sup> / <sub>3</sub> )	coordinate		
Z	2	Z'	6	<i>l</i>	< <i>b</i> >	Δ(%)
a	5.483	a'	5.483	√3 <i>l</i>	3.166	5.333 +2.7
b	9.39	b'	9.39	3 <i>l</i>	3.13	9.24 +1.6
c	14.51 Å	c' (t*)	43.20 Å	18 √ <sup>2</sup> / <sub>√3</sub> <i>l</i>	2.94 Å	45.25 Å -4.7%
β	97°02'	β'	89°48'	h=2.40 Å	<3.08 Å>	
C2	V <sub>E</sub> '	20.6 Å <sup>3</sup>	3(. h h c c c c .)			

Peacor et al. (1988), R = 0.035 / 920 F<sub>O</sub>

Difference:	Δ Ca	0.10	Δ Zn	0.15	Δ O(5)	0.24
	Δ M(1)	0.00	Δ Si	0.08	Δ OH(1)	0.24
	Δ M(2)	0.09	Δ O(1)	0.11	Δ OH(2)	0.13
	Δ M(3)	0.04	Δ O(2)	0.28	Δ OH(3)	0.29
	Δ M(4)	0.08	Δ O(3)	0.32	Δ OH(4)	0.25 Å
	Δ M(5)	0.08	Δ O(4)	0.36		
					mean	0.17 Å
					range	0.00 — 0.36 Å

Table 3 : Junitoite

Ca(H <sub>2</sub> O)[Zn <sub>2</sub> Si <sub>2</sub> OO <sub>6</sub> ]							
		(011/100/021)		cell			
		(0 1/3 2/3 / -100/0 1/3 -1/3)		coordinate			
Z	4	Z'	12	<i>l</i>	<i>&lt;β&gt;</i>	Δ(%)	
a	12.510	a'	10.640	2√3 <i>l</i>	3.072	10.756	-1.1
b	6.318	b'	12.510	4 <i>l</i>	3.127	12.420	+0.7
c	8.561 Å	c' (t*)	15.263 Å	6 $\frac{\sqrt{2}}{\sqrt{3}}$ <i>l</i>	3.116 Å	15.211 Å	+0.3%
Ama2		β'	87°42'	h 2.54 Å	<3.105 Å>		
Hamilton and Finney (1985)		V <sub>E</sub> 21.15 Å <sup>3</sup> , ·cccccc·					
R = 0.10 / 745 F <sub>0</sub>							
Difference:	Δ Ca	0.12		Δ O(1)	0.55		
	Δ Zn(1)	0.00		Δ O(2)	0.22		
	Δ Zn(2)	0.04		Δ O(3)	0.28		
	Δ Si	0.18		Δ O(4)	0.44		
				Δ OW(5)	0.17 Å		
				mean	0.22 Å		
				range	0.00 - 0.55 Å		

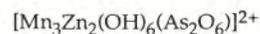
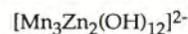
Table 4 : Clinohedrite

Ca(H <sub>2</sub> O)[ZnSiO <sub>4</sub> ]							
		[100/010/103]		cell			
		[10 -1/3 / 010/00 1/3]		coordinate			
Z	4	Z'	12	<i>l</i>	<i>&lt;β&gt;</i>	Δ(%)	
a	5.090	a'	5.090	√3 <i>l</i>	2.939	5.385	-5.8
b	15.829	b'	15.829	5 <i>l</i>	3.166	15.545	+1.8
c	5.386 Å	c' (t*)	15.787 Å	6 $\frac{\sqrt{2}}{\sqrt{3}}$ <i>l</i>	3.223	15.231 Å	+3.5
β	103°16'	β'	84°59'	h=2.63 Å	<3.109 Å>		
Cc		V <sub>E</sub> 21.1 Å <sup>3</sup> , ·cccccc·					
Venetopoulos and Rentzeperis (1976), R = 0.04 / 1294 F <sub>0</sub>							
Difference:	Δ Ca	0.39		Δ O(2)	0.45		
	Δ Zn	0.02		Δ O(3)	0.70		
	Δ Si	0.20		Δ O(4)	0.36		
	Δ OW(1)	0.21		Δ O(5)	0.42 Å		
				mean	0.34 Å		
				range	0.02 - 0.70 Å		

Table 5 : Chlorophoenicite

Pauling bond strength sums.†

Arsenic absent				Arsenic present			
Anion	Coordinating cations	bond strengths	P <sub>O</sub> φ	Coordinating cations	bond strengths	P <sub>O</sub> φ	
φ(1)	1Mn(1)+2Mn(2)+H(1) <sub>d</sub>	2/6+2(2/6)+5/6	1.83 OH <sup>-</sup>	" " "	" " "	1.83 OH <sup>-</sup>	
φ(2)	2Mn(1)+1Mn(2)+H(2) <sub>d</sub>	2(2/6)+2/6+5/6	1.83 OH <sup>-</sup>	2Mn(1)+1Mn(2)+As	2(2/6)+2/6+5/4	2.25 O <sup>2-</sup>	
φ(3)	2Mn(2)+Zn+H(3) <sub>d</sub>	2(2/6)+2/4+5/6	2.00 OH <sup>-</sup>	" " "	" " "	2.00 OH <sup>-</sup>	
φ(4)	2Zn+H(4) <sub>d</sub> +H(3) <sub>a</sub>	2(2/4)+5/6+1/6	2.00 OH <sup>-</sup>	" " "	" " "	2.00 OH <sup>-</sup>	
φ(5)	Mn(2)+H(5) <sub>d</sub> +H(1) <sub>a</sub> +H(2) <sub>a</sub> +H(6) <sub>a</sub>	2/6+5/6+1/6+1/6+1/6	1.67 OH <sup>-</sup>	Mn(2)+H(1) <sub>a</sub> +As	2/6+1/6+5/4	1.75 O <sup>2-</sup>	
φ(6)	Zn(1)+H(6) <sub>d</sub> +H(4) <sub>a</sub> +H(5) <sub>a</sub>	2/4+5/6+1/6+1/6	1.67 OH <sup>-</sup>	Zn+H(4) <sub>a</sub> +As+As	2/4+1/6+5/4+5/4	3.17 O <sup>2-</sup>	



† Calculations based on two ordered hypothetical end-members.

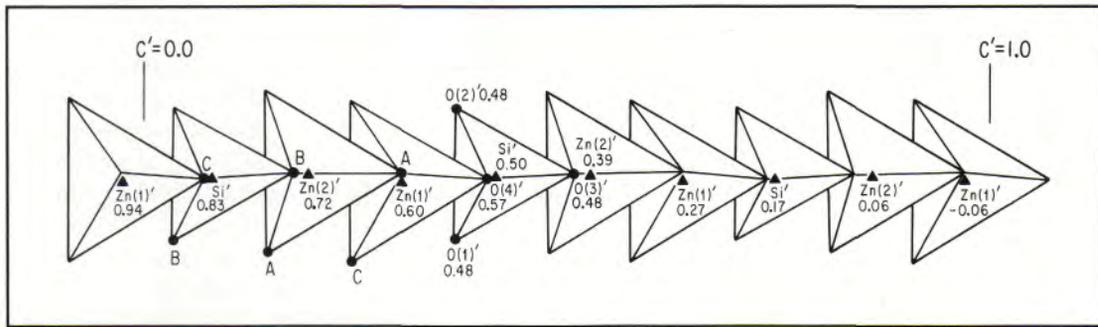
Table 6 : Mooreite and Lawsonbauerite

Proposed φ<sub>d</sub> ... φ<sub>a</sub> bonds. †

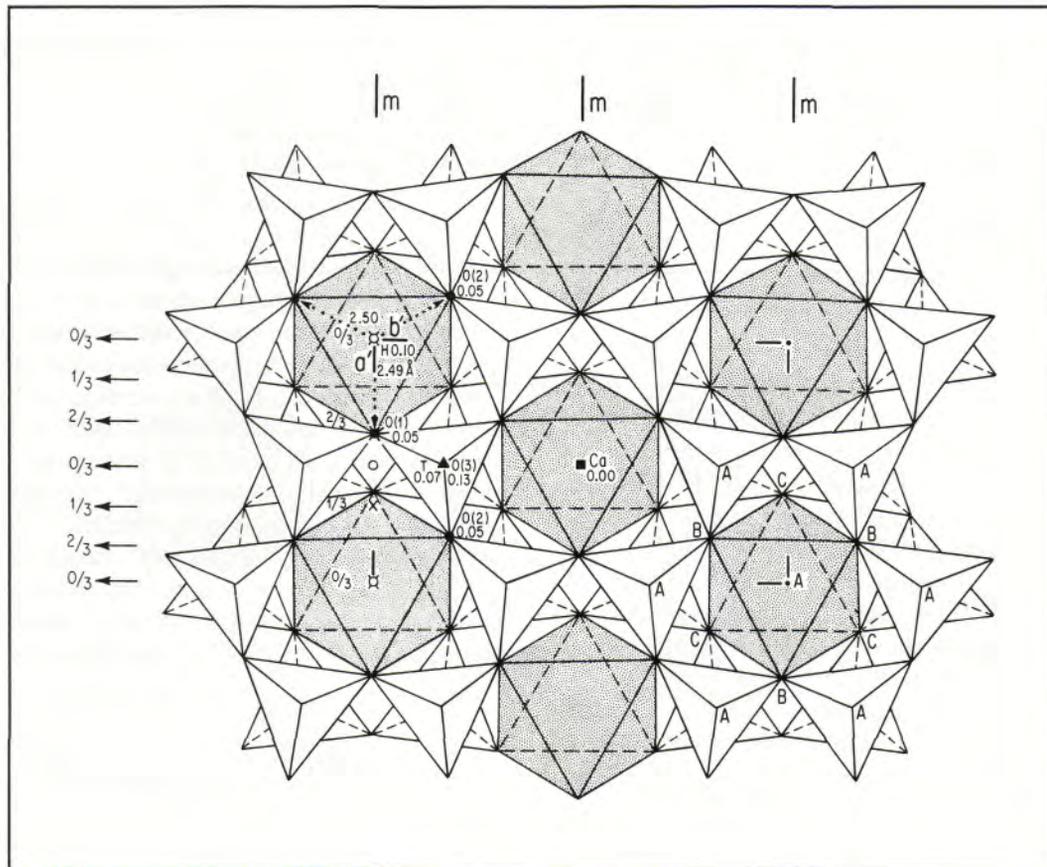
Mooreite		Lawsonbauerite	
φ <sub>a</sub>	φ <sub>d</sub>	φ <sub>a</sub>	φ <sub>d</sub>
OH(5) <sub>T</sub>	OH(13) 3.02, W(20) 2.80	OH(10) <sub>T</sub>	OH(6) 3.22, W(15) 2.70
OH(6) <sub>T</sub>	W(18) 2.71	OH(11) <sub>T</sub>	W(13) 2.54
O(1) <sub>S</sub>	OH(16) 3.12, OH(9) 3.11, W(18) 2.86	O(16) <sub>S</sub>	OH(2) 3.07, W(12) 2.83, OH(11) <sub>T</sub> 2.76
O(2) <sub>S</sub>	OH(11) 3.30, OH(7) 3.28, W(19) 2.74	O(17) <sub>S</sub>	OH(5) 3.04, W(13) 2.90, OH(9) 2.87, W(14) 2.78
O(3) <sub>S</sub>	OH(14) 3.66, OH(5) <sub>T</sub> 2.91, W(19) 2.73	O(18) <sub>S</sub>	OH(7) 2.92, W(15) 2.77
O(4) <sub>S</sub>	W(21) 3.13, W(21) 3.02, OH(6) <sub>T</sub> 2.85, W(20) 2.73	O(19) <sub>S</sub>	W(12) 2.96, OH(10) <sub>T</sub> 2.95, W(14) 2.72
W(18)	OH(10) 2.89	W(12)	OH(4) 3.05
W(19)	OH(8) 3.34, OH(12) 3.03	W(13)	OH(8) 3.02
W(20)	OH(17) 2.95	W(14)	OH(1) 3.23
W(21)	OH(15) 3.15 Å	W(15)	OH(3) 2.95 Å

† Apical zincate hydroxyls (T), sulfate oxygens (S), and aquo molecules (W) are listed. The

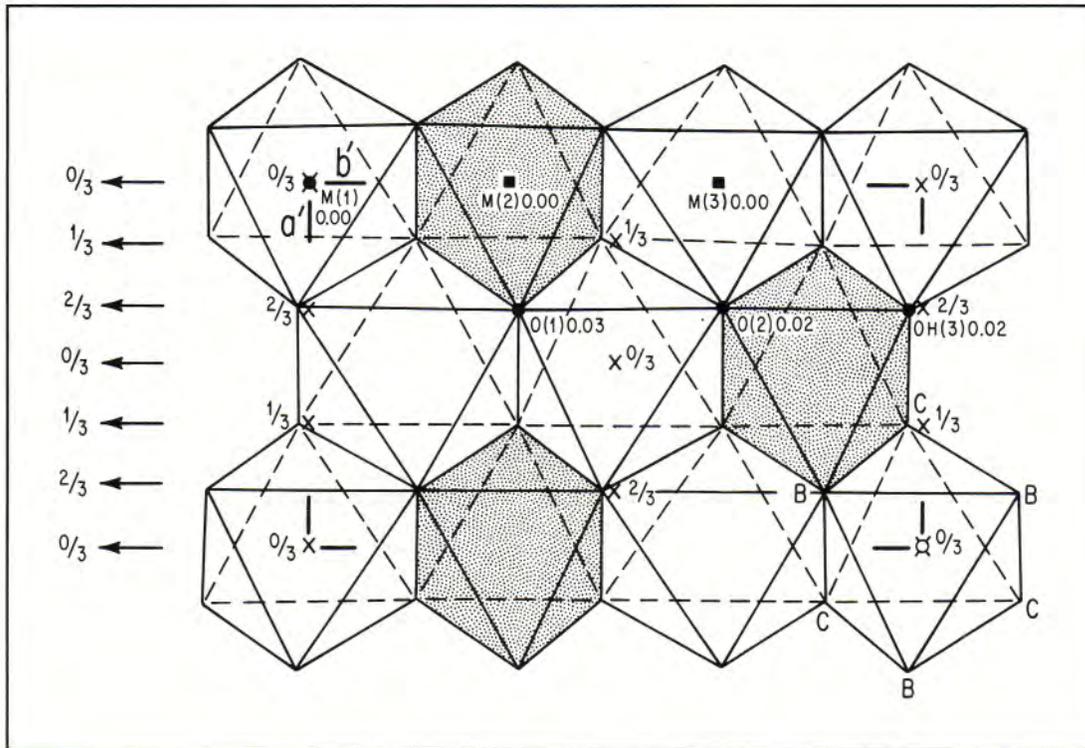
φ<sub>d</sub> ... φ<sub>a</sub> distances are listed in the φ<sub>d</sub> columns.



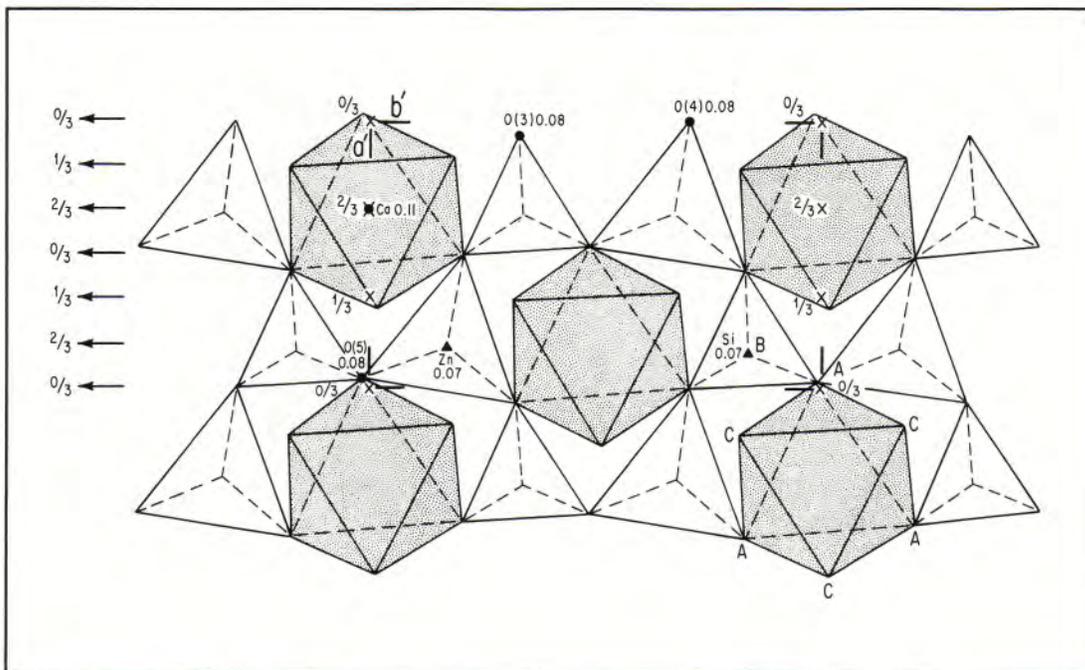
**Figure a.** The cubic closest-packed component of willemite with cell transform  $A' = [10\bar{2}/120/101]$ , projected along  $a' = r^* = 23.273 \text{ \AA}$ . Heights are given in fractional coordinates for  $x'$ . Cell parameters are from Klaska et al. (1978).



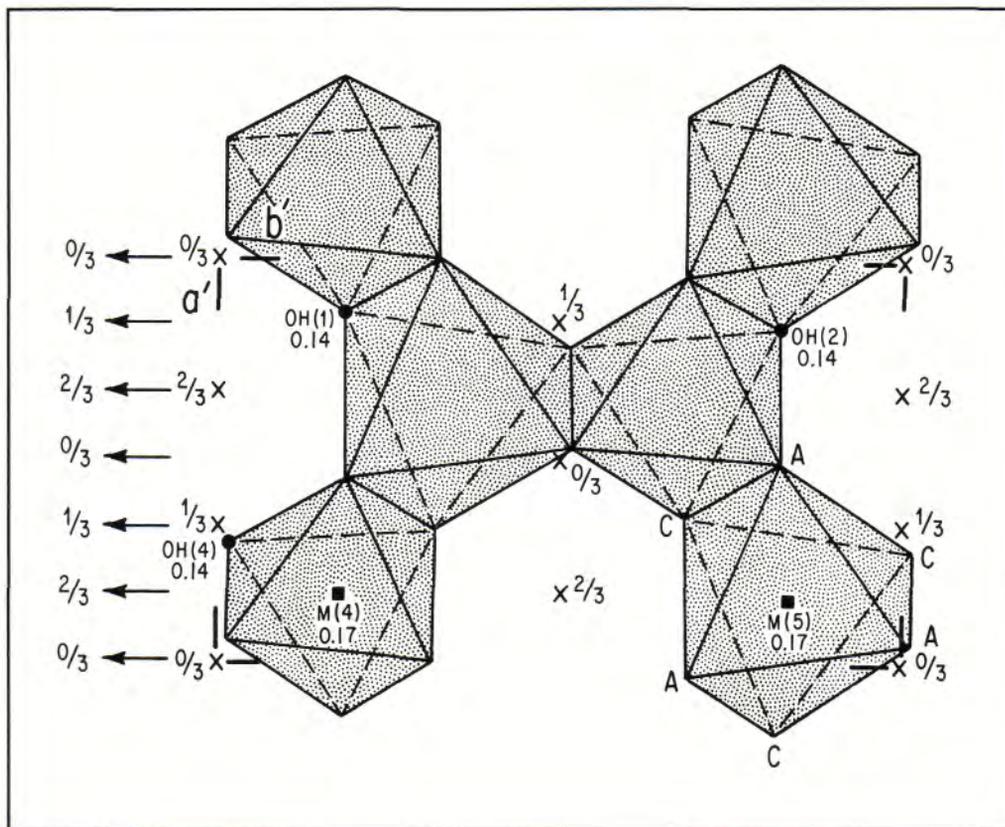
**Figure 1.** The cubic closest-packed arrangement of clintonite projected along  $c' = r^* = 28.86 \text{ \AA}$ . Heights are given in fractional coordinates for  $z'$ . Some elements of symmetry are included. Cell parameters are from MacKinney et al. (1988).



**Figure 2a.** Unique layers in franklinfurnaceite projected along  $c' = r^* = 43.20$  Å. Heights are given in fractional coordinates for  $z'$ . Some elements of symmetry are included. Cell parameters are from Peacor et al. (1988). The brucite-like trioctahedral layer at  $z' = 0/_{12}$ .

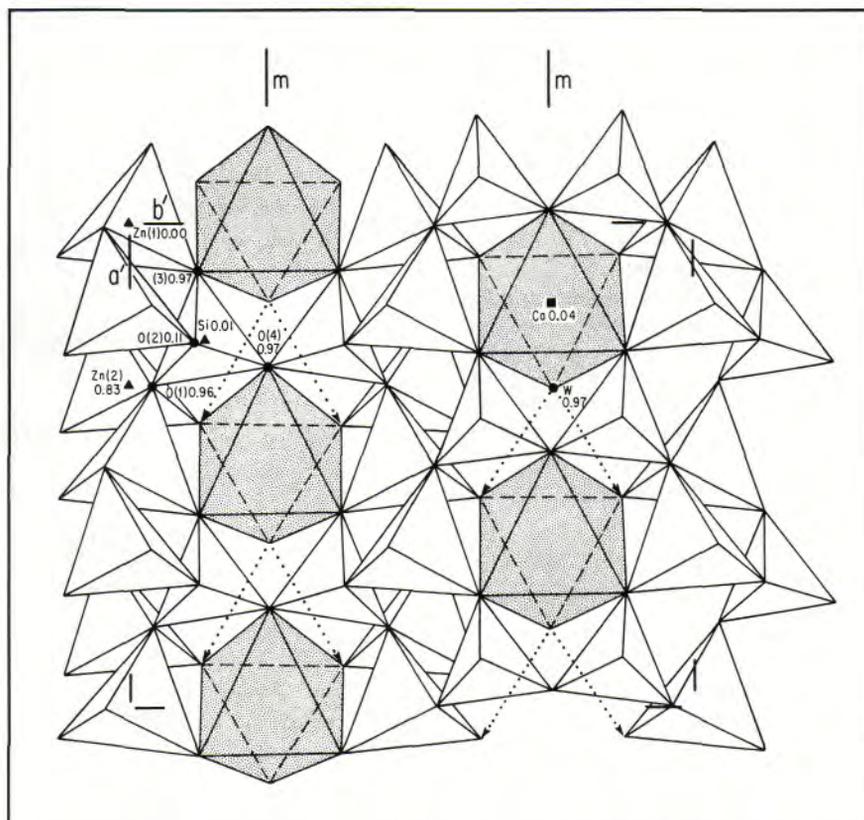


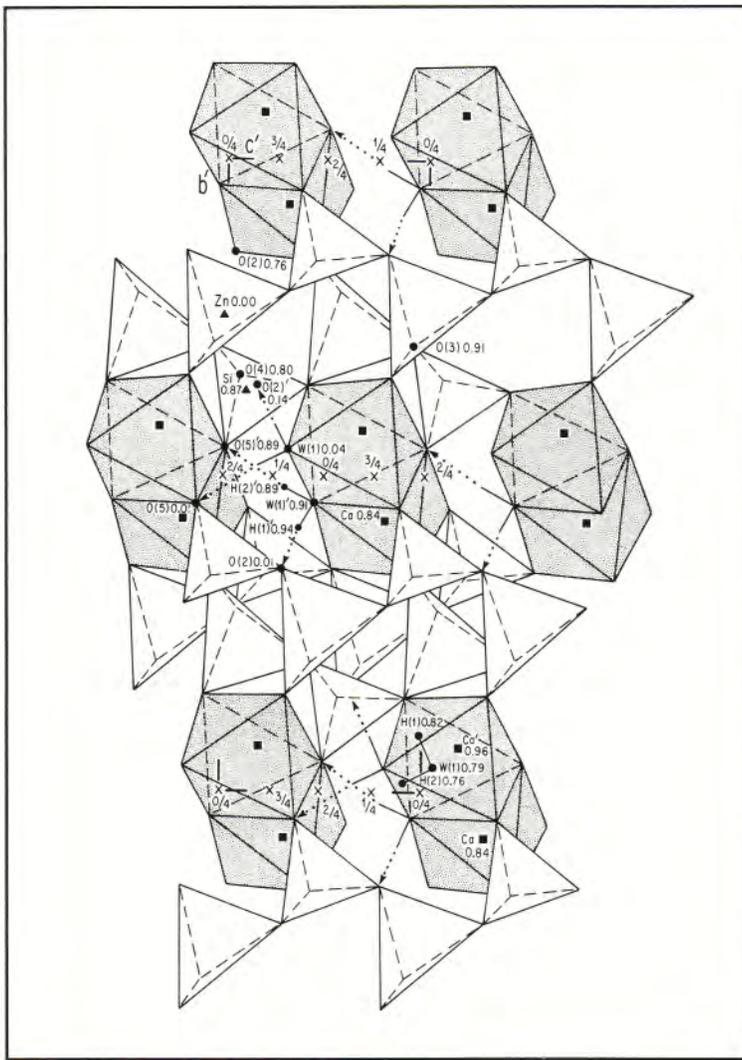
**Figure 2b.** Unique layers in franklinfurnaceite projected along  $c' = r^* = 43.20$  Å. Heights are given in fractional coordinates for  $z'$ . Some elements of symmetry are included. Cell parameters are from Peacor et al. (1988). The  $\text{Ca}\phi_6$  octahedral and  $[\text{Zn}_2\text{Si}_2\text{O}_{10}]$  tetrahedral layer at  $z' = 3/_{24}$ .



**Figure 2c.** Unique layers in franklinfurnaceite projected along  $c' = t^* = 43.20 \text{ \AA}$ . Heights are given in fractional coordinates for  $z'$ . Some elements of symmetry are included. Cell parameters are from Peacor et al. (1988). The dioctahedral layer at  $z' = 2/12$ .

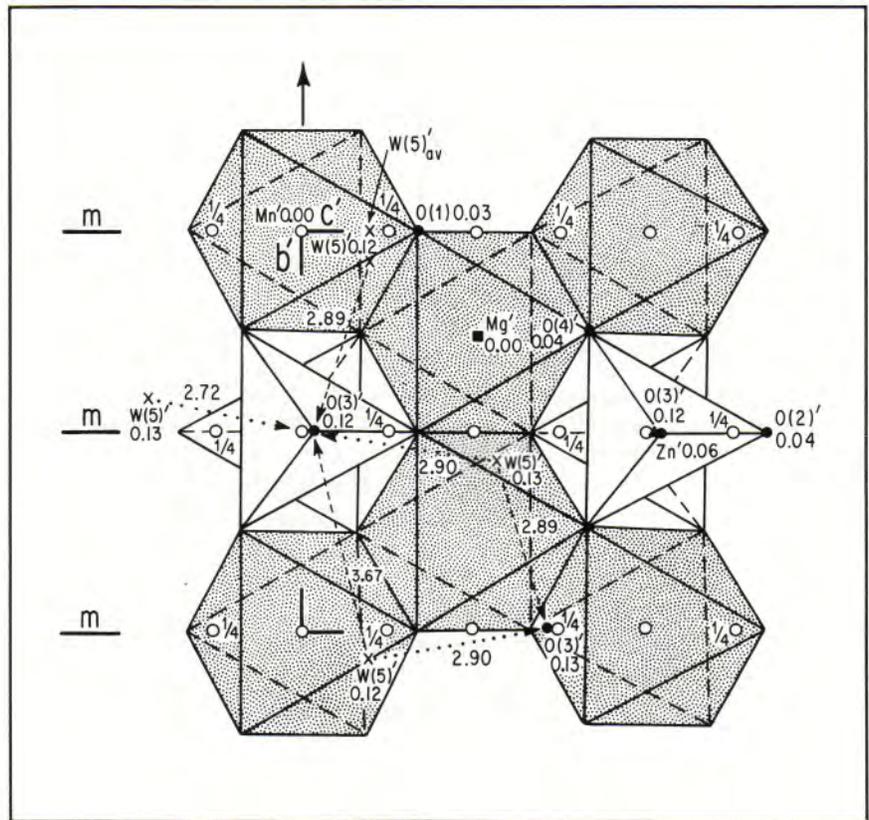
**Figure 3.** The cubic closest-packed arrangement of junitoite projected along  $c' = t^* = 15.26 \text{ \AA}$ . Heights are given in fractional coordinates for  $z'$ . Some elements of symmetry are included. Cell parameters are from Hamilton and Finney (1985). The W  $\bullet\bullet\bullet$  O(2) hydrogen bonds appear as dotted lines; the correct bond is probably to O(3), not in Fig. 3 but near the "Si" signature.



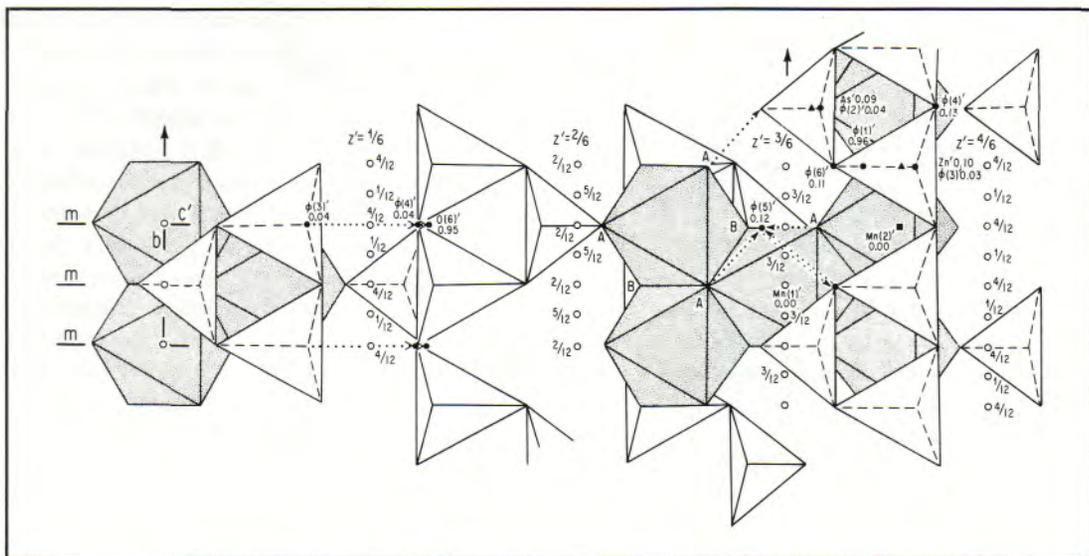
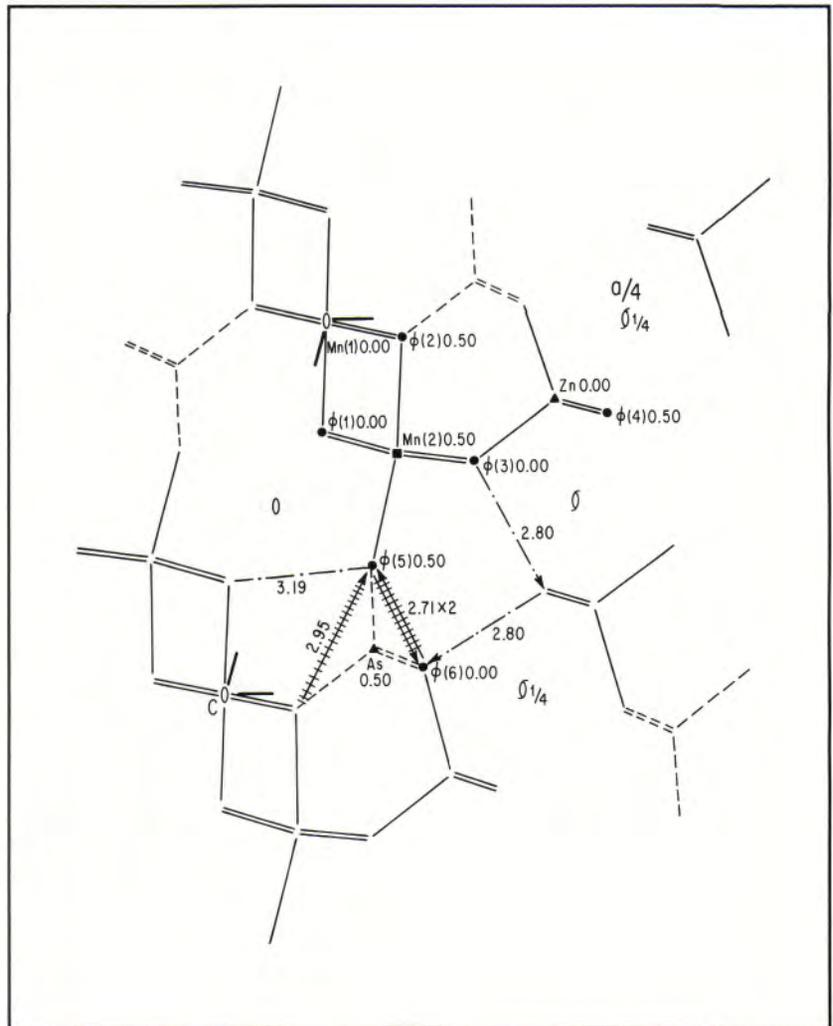


**Figure 4.** The cubic closest-packed arrangement of clinohedrite according to the  $A' = [104/0\bar{1}0/100]$  transformation,  $t^* = a'$ . Heights are given in fractional coordinates for  $x'$ . Cell centerings are designated as crosses. Hydrogen bonds occur as dotted lines and traverse empty tetrahedral sites. Cell parameters from Venetopoulos and Rentzeperis (1976).

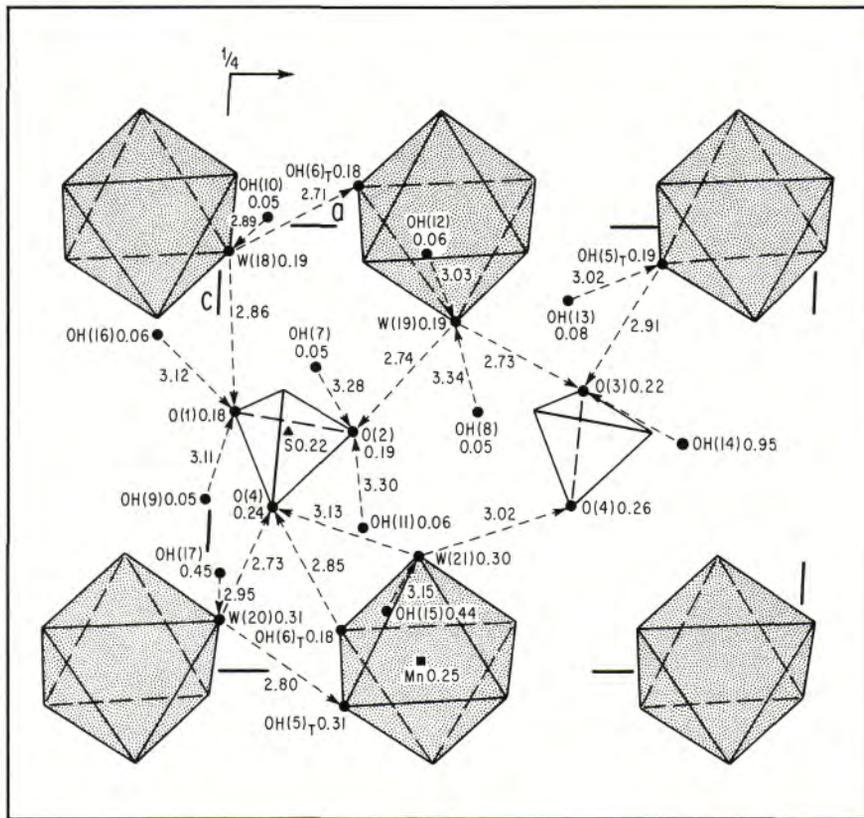
**Figure 5.** The packet structure of ciavucillite according to the  $A' = [201/010/001]$  transformation,  $t^* = a'$ . Heights are given in fractional coordinates for  $x'$ . Some elements of symmetry are included. Possible hydrogen bonds  $W(5)' \cdots O(3)'$  are drawn as thin dashed and dotted lines. Cell parameters from Grice and Dunn (1991).



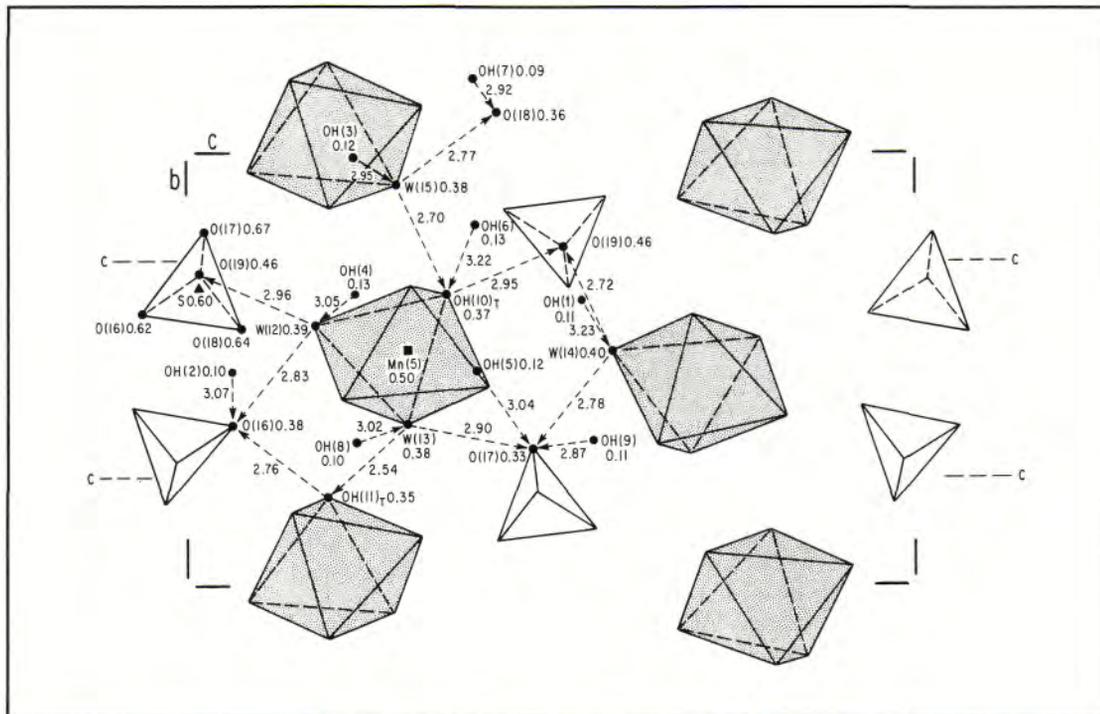
**Figure 6.** Spoke diagram of conventional quarter cell in chlorophoenicite, see Moore (1968). Heights are given in fractional coordinates for  $y$ . Possible H-bond distances are given along their  $\phi - \phi'$  connections. Note disordered As position.



**Figure 7.** The packet structure of chlorophoenicite according to the  $A' = [10\bar{2}/010/104]$  transformation,  $t^* = a' = 30.46\text{\AA}$ . Some elements of symmetry are included. Possible H-bonds are shown as dotted lines. Note zincate tetrahedral chains and ordered  $[\text{AsO}_4]$  tetrahedra which alternate with vacancies.



**Figure 8a.** The aquated  $[\text{Mn}(\text{H}_2\text{O})_4 \cdot \text{SO}_4]$  interlayer in mooreite showing proposed H-bond distances along dashed lines. Cell coordinates are from Hill (1980).



**Figure 8b.** The aquated  $[\text{Mn}(\text{H}_2\text{O})_4 \cdot \text{SO}_4]$  interlayer in lawsonbauerite showing proposed H-bond distances along dashed lines. Cell coordinates are from Treiman and Peacor (1982).

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## *The Fifth Annual FOMS Outdoor Spring Swap & Sell*

*May 6th & 7th 1995*

*at The Sterling Mine, Ogdensburg, New Jersey*

### ◇ Table Fee Schedule: ◇

Per 10 foot wide parking space; \$20 for one day,  
\$35 for both days. Participants must supply their own tables.

### ◇ Hours: ◇

Saturday: 7:30 A.M. to 6:00 P.M.

Sunday: 9:00 A.M. to 5:00 P.M.

Bus parking is available

### ◇ Area Museums: ◇

Franklin Mineral Museum

(regular fee)

Sterling Mining Museum & Mine Tours

(regular fees)

### ◇ For further information: ◇

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309 Massachusetts Road

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FOMS Publications and Information table

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Lots of Camaraderie

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Buckwheat dump, Evans Road, Franklin

(regular fee)

Sterling Hill dump (on site)

(regular fee)

### ◇ Important Notice ◇

In the event of severe weather, the event will be canceled  
for the adverse weather day ONLY.

**\*SEE YOU THERE!!!\***

## FRAIPONTITE FROM STERLING HILL

John Cianciulli  
Assistant to the Curator  
Franklin Mineral Museum  
P.O.Box 54  
Franklin NJ 07461

Fraipontite,  $(\text{Zn,Al})_3(\text{Si,Al})_2\text{O}_5(\text{OH})_4$ , is a monoclinic zinc-silicate member of the clay group. It is the zinc analogue of berthierine and is a rare mineral locally.

Fraipontite was found by the author on a Sterling Hill ore specimen (FMM #5169) preserved by the late Al Smith. This specimen is the only known example of this mineral from this locality and is 2.5cm x 5cm x 7cm in size.

Fraipontite was verified by Dr. Pete J. Dunn of the Department of Mineral Sciences, Smithsonian Institution, using both X-ray diffraction methods and semi-quantitative microprobe analysis. The approximate cation ratios for Zn:Mg:Fe:Mn are 66:27:5:2.

Optical information was obtained by the author using orthoscopic immersion and conoscopic techniques with a Leitz polarizing microscope. The samples studied are biaxial negative, with birefringence 0.002 to 0.004. Their refractive indices are  $n_a = 1.559$ ,  $n_b = 1.60$ , and  $n_y = 1.622$ . Optical orientation: elongation is positive. The 2V angle is slightly more than 15 degrees but less than 20 degrees; 2V was determined using two separate methods: the mertie diagram, and a visual estimate of the acute bisectrix figure using an 0.85 objective.

Fraipontite occurs as a late-stage mineral on a seam in massive-granular franklinite-willemite-calcite-sphalerite ore, similar in appearance to that which hosted the 340-level arsenates found in the 1970s and 1980s. Freipontite occurs as yellowish-white plates and needles with a pearly luster. The mineral is very soft. Individual crystals 1mm in size and smaller are randomly dispersed on the seam in asymmetrical clusters. In one area of the seam are small, sharp, modified dodecahedrons of franklinite with highly lustrous faces, and water-clear willemite needles occurring interstitially with fraipontite. Willemite is also present as translucent films on seams.

The ore contains franklinite and willemite grains with a fairly uniform size of about 1mm. The willemite grains fluoresce green in shortwave ultraviolet radiation. Sphalerite is present in the ore as sparsely distributed small grains, the largest 3mm in size, most of which fluoresce blue under longwave ultraviolet radiation. The pale-pink calcite present in the ore is nonfluorescent.

### References:

Ford, W.E. (1958) *Dana's Textbook of Mineralogy*, 4th ed., p.633.

Nesse, W. D. (1991) *Introduction to Optical Mineralogy*. "Biaxial Optics" color chart, and mertie diagram, p. 80.

Phillips, W. R. (1971) *Mineral Optics Principles and Techniques*, p. 144.

Fleischer, M, Wilcox, R.E., and Matzko, J.J. (1984) *Microscopic determination of nonopaque minerals*, U.S.G.S. Bulletin 1627, p. 247.



## STERLINGHILLITE

John Cianciulli  
Assistant to the Curator  
Franklin Mineral Museum  
P.O.Box 54  
Franklin NJ 07416

Sterlinghillite,  $\text{Mn}_3(\text{AsO}_4)_2 \cdot 4\text{H}_2\text{O}$ , has been confirmed by Dr. Pete J. Dunn on a specimen preserved by Mr. Lee Lowell. Mr. Lowell acquired the specimen from Mr. Ewald Gerstmann in the mid-1980s as an unknown.

The matrix consists largely of 1-3mm grains of franklinite and dark-colored willemite with lesser amounts of pale-pink calcite, grains of loellingite 0.5cm and larger, and occasional blebs of colorless to pale-yellow sphalerite 1 to 2 cm across; it is similar in appearance to the matrix of the arsenate suite from the 340 level at Sterling Hill. The surface of the specimen with the sterlinghillite is evidently one face of a thin seam which has a darkened surface characterized by yellow-tinted loellingite and iridescent franklinite. The sterlinghillite occurs in white-to-pale-pink hemispherical aggregates, about 0.2mm across, of platy crystals; their platy appearance is best observed on broken aggregates. Sterlinghillite is associated with white-to-pale-pink random aggregates of needle-like crystals from 0.5mm to 1.5mm in length; these are either koettigite or symplectite. The sterlinghillite and symplectite/koettigite crystals are scattered over a 7cm x 8cm area on a specimen which measures 5cm x 12.5cm x 12.5cm. Sterlinghillite is a very rare mineral of which only a few specimens are known; this is by far the largest.

Optics were performed by the author on both the platy and needle-like crystals. Optical characteristics for the needle-like crystals are consistent with koettigite and symplectite:  $n_a = 1.636$  and  $n_b = 1.67$ , with  $n_y$  being unobtainable due to the small size of the crystals. One index of refraction (1.71) was obtainable for the platy crystals. A slightly off-center but good interference figure was also obtained showing a pseudo-uniaxial figure which is optically negative. Single crystals of the platy mineral appear to be hexagonal and were too small to rotate for additional measurements. Extinction was gradual. Although the data for the platy mineral were consistent with those of sterlinghillite, more work was necessary to validate the species.

The specimen was forwarded to Dr. Pete J. Dunn for further study. The hemispherical aggregates of platy crystals were verified as sterlinghillite. The needle-like crystals are either koettigite or symplectite.

### Reference:

Dunn, Pete J. (1981) Sterlinghillite, a new hydrated manganese arsenate mineral from Ogdensburg, New Jersey. *American Mineralogist*, 66,182-84.



TREASURER JOHN ASKS:  
HAVE YOU PAID YOUR DUES?

## 1995 F.O.M.S. FIELD TRIP SAFETY RULES AND REGULATIONS

Field trips are an essential activity for the F.O.M.S., and every member should be aware of the rules which govern them. These rules last appeared in *The Picking Table* in 1967. After careful review by the F.O.M.S. Field Trip Chairman and officers, the 1967 rules and regulations have been updated for 1995. All members should be familiar with them, not only for their own safety and that of others, but also to maintain the excellent safety record of the F.O.M.S., which has given its members access to many unique and important collecting localities..

1. **INSURANCE COVERAGE.** The F.O.M.S. maintains liability insurance coverage for its members under a policy sponsored by the Eastern Federation of Mineralogical and Lapidary Societies (EFMLS). Non-F.O.M.S. members who are guests at any collecting event sponsored by the F.O.M.S. must be able to demonstrate that they are covered by club-sponsored EFMLS liability insurance or its equivalent.

A. Events are restricted to F.O.M.S. members unless otherwise advertised.

B. Participating organizations in F.O.M.S.-hosted collecting events must provide proof of liability insurance coverage in advance.

C. All participants in F.O.M.S.-hosted collecting events must be able to present proof of membership in a covered organization in order to be admitted.

NOTE: the F.O.M.S. maintains lists of current members and of organizations covered by EFMLS liability insurance. An EFMLS membership card alone is not sufficient.

2. **WAIVERS OF LIABILITY.** It is the responsibility of all F.O.M.S. members and authorized guests to sign Waiver of Liability statements before entering a collecting area. The privilege of collecting is dependent on fulfilling this requirement. All persons entering the collecting area must personally sign such a release or releases, absolving the property owner, the F.O.M.S., and its officers of any responsibility for injury, loss of life, and property damage or loss.

3. **POSTED TIMES.** Collecting begins no sooner than, and lasts no later than, advertised collecting times. The F.O.M.S. Field Trip Coordinator and/or his/her designated representative(s) are the only F.O.M.S. officials who may designate a variation of the advertised collecting hours.

4. **ELIGIBILITY.** Children under 13 years of age are ineligible for collecting events unless otherwise authorized by the F.O.M.S. official in charge. Persons who appear intoxicated or under the influence of drugs, or whose judgement or physical ability to collect appears to be impaired, are also ineligible to collect.

5. **COLLECTING AREA LIMITS.** Collecting is restricted to areas within boundaries. Areas which are off-limits to collecting may be indicated by signs, fences, ropes, etc., or the instructions of the F.O.M.S. safety staff. Collecting is strictly prohibited within 30 feet of a vertical or overhanging rock wall; in areas above mine entrances; within three feet of a cliff edge, ledge, or quarry bench; and on an incline either above or below a collector who is already in position.

Vehicles are restricted to authorized parking areas; exceptions may be made only by the F.O.M.S. official in charge.

6. **CLOTHING.** Proper footgear, headgear, gloves, and safety goggles or safety glasses are not only a good idea but mandatory! Your health is more important than any mineral specimen. Rugged boots or shoes, preferably with steel safety toes, should be worn. Collectors wearing sneakers, sandals, or other flimsy footgear will be denied access to the collecting area. Hard hats should be worn on all collecting trips, and **MUST** be worn on all trips to operating quarries or on other field trips so designated. Gloves should be worn to protect the hands when breaking or handling rock. Safety goggles or glasses (with shatterproof lenses) should always be worn when breaking rock, or when other collectors nearby are doing so.

7. **TOOLS:** Proper tools should be used. Choose substantial rock or masons' crack hammers, sledge hammers, and cold chisels for breaking rock. Common carpenters' hammers, wood chisels, screwdrivers and the like are unacceptable since they can break or chip when used on rock. Mushroom heads on chisels should be ground away to prevent flying metal chips.

8. **OTHER PRECAUTIONS:** Field collecting is a privilege, not an excuse to abandon common sense. Use caution when reaching between rocks and into crevices - snakes hide there! Familiarize yourself with poison ivy - the itch won't quit. When ascending or descending a rock pile, be extra careful; such rocks are often loose. Don't rely on grabbing a small rock for climbing leverage. Use the buddy system, and never collect alone; always remain within shouting distance of another collector. Carry a first aid kit. In hot weather, bring sun-blocker and carry a supply of drinking water plus salt tablets. If a hard hat is not required, wear a hat which provides protection from the sun. Walk carefully when ascending or descending; in particular, climb out of deep quarries slowly. And....don't throw anything, particularly rocks!

9. **RESPECT FOR PROPERTY.** Watch those cigarettes and matches in wooded or grassy areas. **DO NOT LITTER!** Carry all your trash out with you. Don't break glass bottles, as they can cause flats on quarry vehicles. Don't leave metal tools behind, as they can cause severe damage to rock-crushers. Above all, do not touch, deface, damage, or vandalize quarry equipment; this can not only terminate field trip privileges for the F.O.M.S. but also lead to lawsuits.

10. **COMPLIANCE AND PENALTIES.** F.O.M.S. safety staff members wear fluorescent green-yellow armbands, and have discretion to warn violators or expel them from the collecting area. Failure to observe F.O.M.S. safety rules and regulations and failure to obey the instructions of an F.O.M.S. safety staff member are alike considered violations of F.O.M.S. protocols and are grounds for immediate eviction from F.O.M.S. events. Repeat violators will be barred from future field trips.



Collecting under F.O.M.S. auspices is not a right but a privilege. Some field trip areas are open to collecting only because of the F.O.M.S.'s excellent safety record, and injury or property damage on a field trip could lead to permanent cancelling of that trip. When you collect, please watch out not only for yourself but also for your fellow collectors **AND** the F.O.M.S.; you are also protecting the collecting privileges of future generations of collectors.

# *The 39th Annual Franklin-Sterling Gem and Mineral Show*

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## **During the show, be sure to visit...**

THE POND Swap-and-Sell area on the Franklin School grounds. THE POND is sponsored by the Franklin-Ogdensburg Mineralogical Society, Inc. For further information about THE POND contact:

Chester Lemanski Jr., 309 Massachusetts Rd., Browns Mills NJ 08015, Phone: (609) 893-7366

## **After the show on Saturday night...**

Attend the F.O.M.S. banquet, held at the Lyceum Hall of the Immaculate Conception R.C. Church at the intersection of Church St. and Main St. in Franklin. Socializing begins at 6:30 P.M. and the buffet dinner at 7:00 P.M. Dress is informal and the atmosphere likewise. After dinner there will be a lecture by Dr. William Henderson, *Geological and Mineralogical Curiosities*. This will be followed by an auction of mineral specimens and memorabilia.

For banquet tickets and information, contact:

**Joe Cilen  
92 Westervelt Avenue  
Hawthorne NJ 07056  
Phone: (201) 427-4550**

## **HISTORICAL NOTES**

The following article appeared in *The New Jersey Sunday Herald* on August 20, 1964, giving some details of the strike at the Sterling mine. Among those put out of work was a Co-Editor of *The Picking Table*, who out of curiosity and through the assistance of John L. Baum had taken a summer job at Sterling Hill. All that fuss over a nickel! Thanks to Lee Lowell for submitting this historical tidbit.

*The Editors*

**AUGUST 20, 1964  
First Strike in 18 Years  
Hits NJ Zinc Company;  
230 Mine Workers Out**

OGDENSBURG - The New Jersey Zinc Company was struck for the first time in 18 years at midnight Tuesday when 230 members of Local 12846 of the United Mine Workers of America walked off their jobs.

The strike went into effect at the expiration of the current union and management contract and followed five negotiation meetings during which federal mediators were brought in at the last minute.

In a terse announcement from the company, issued yesterday (Wednesday) afternoon, Sterling S. Huyett, manager of the Ogdensburg operation, stated:

"The company announces today that employees of its Ogdensburg, New Jersey, mine, represented by district 50 of the United Mine Workers of America, have gone on strike.

"A collective bargaining agreement between the parties expired yesterday and negotiations, which began in July, have not resulted in agreement on a new contract. Approximately 230 employees are members of the bargaining unit."

Prior to going on strike, those working on night shift went into the plant and sealed off the mine to prevent flooding during the strike period.

Questioned on the cause of the strike, Huyett would only add that they comprised "monetary and fringe benefit issues" and said there were approximately 30 points of disagreement involved.

#### **Picketing Begun**

Representatives of the union, however, held a meeting at 8 a.m. yesterday after which picket lines were established at the plant.

Principals of the strike movement, including James May, of Ogdensburg, president of the local; Thomas O'Brien of Hamburg, Vice-President; and Stanley Ellefsen, of Ogdensburg, strike captain and chief steward, issued statements giving the union side of the disagreement.

#### **Strikers Collection**

#### **Benefits Charity**

OGDENSBURG - Striking miners turned their expressions of rejection of a company offer of a nickel an hour wage increase into an act of charity on the opening day of the strike at the New Jersey Zinc Company.

Union members passed the hat and collected a total of 121 nickels or \$6.05 which they donated to the Sussex County Society For Crippled Children and Adults. 

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From *Zinc*, vol. 19, no. 1, p. 14-15, Autumn 1939

#### **A VISIT TO THE FRANKLIN MINE - 1849**

Letter dated December 10, 1849, reprinted by permission of the *Philadelphia Inquirer*.

MR. EDITOR -

Some of those who sneer at the good State of New Jersey and consider her nothing but a sand flat, producing peas and watermelons, should take the jaunt from which I have just returned, to the mountains of Sussex county, and there see the mineral riches, as yet but partially developed, the extent of which, were they fully set forth, would be deemed almost fabulous.

My object was to examine the mines of the Sussex Zinc Companies, which have recently excited so much attention; and, in company with a party of friends, one of whom was an enthusiastic mineralogist, we visited, before starting for the mines, the trial furnace erected by the Companies, at Newark, for reducing the red oxide of zinc, termed by Phillips "sterlingite" and which, although it is shown by Bruce to contain 92 per cent of the oxide of zinc, has heretofore never been productively worked, although much money and time have been spent in the endeavor, until the science and zeal of the present companies, surmounting all obstacles, have accomplished that end in a manner both simple and economical.

They have recently purchased a well situated lot of ground in Newark, on the banks of the Passaic river, with the Morris Canal running directly through it, and are now erecting their permanent works, which will be in operation early in the ensuing spring. And from the results which we saw obtained, I feel confident they will be able to compete with the world in the manufacture of zinc, either as a metal in its various forms, or as a paint, with profit to themselves and benefit to the country, inasmuch as all zinc now used is imported.

Leaving Newark, we took the cars of the Morris and Essex Railroad, and passing through a pleasant country with numerous thriving towns and villages, we were soon among the rocky hills, teeming with Iron, and heard the forge hammer sounding from every stream of power sufficient to turn a wheel.

Jerseyman as I am, I was astonished at the number of Iron Works scattered over this part of the country. Most of them are what is called Blooming Forges, for converting the ores immediately into wrought iron, the quality of which is very superior, but the prices they get for it are most ruinously low, owing to the

excessive influx of English Iron, since the Tariff of '46 came into operation. We arrived at Dover, the present terminus of the Railroad, to supper, and were well entertained at the hotel of Mr. Stull, who, next morning, provided us with good teams and drivers, and we proceeded on to Franklin, the seat of the mines, where we were most kindly received at the mansion of Mr. Kemble, who with his whole family, by their attentions, nobly sustained the character of Old Sussex hospitality.

Arrived at the mines, our Mineralogist was in his element. Armed with his pick, he was soon deep in the mysteries of Troosite, Franklinite, or Algerite, and sighs as he consigns a small fragment to his basket, that he must leave so much behind.

The first mine we visited is called Sterling Hill; the vein of Red Oxide which crops out on its side is about six feet thick, and descends almost perpendicularly, growing thicker as it descends; its apex is about 175 feet above the foot of the hill, and from the nature of the strata that lies between it, is estimated by Geologists to be about two thousand feet in depth. We traced it for about six hundred feet in width, and there is no doubt of its extending much further. In fact, there is ore enough in this one mine, even with immense consumption, to last for several generations before arriving at water level.

Having satisfied our curiosity at this mine, we next visited the other mine of the Company, called Mine Hill, in the immediate vicinity of Franklin, and there saw even more startling developments of mineral resources, the vein being of great thickness and standing almost like a wall on the side of a hill, upwards of two hundred feet high. It can be mined at an expense almost trivial.

Besides these mines, the Companies have the mineral privileges of a large tract embracing every place where science indicates an extension of the veins; and, also, the strata immediately adjacent to the Red Oxide of Zinc is Franklinite, a peculiar kind of Iron Ore, which yields about sixty per cent of Iron of a superior quality, and of a nature well adapted to the manufacture of Cast Steel. This also, will eventually be worked by the Companies; but the necessity of greater protection to that branch of industry will no doubt cause some delay.

It is a fact which, no doubt, will prove of great benefit to the Companies, that the Red Oxide of Zinc is found in no other part of the known world, thus giving them the exclusive control of the richest ores of Zinc ever discovered.

The mines are situated about eight miles from the navigable feeder of the Morris Canal, with an easy road thereto, at Woodsport; consequently, they will be able to transport their

ores to Newark at comparatively small cost, where it will be cheaply converted into valuable and salable products, and yield a rich return for the capital invested. The metal they produce is of very superior quality, of which samples were exhibited at the late exhibition of the Franklin Institute, and no doubt will supersede the German Silver, as it retains its luster for a long time, and is not easily affected by acids.

The White Oxide of Zinc is now rapidly coming into use in Europe as a paint, and is said to be superior to White Lead; being a pure metallic oxide, it will retain its color for a long time, and I expect soon to see both of these products forming a prominent part of our Domestic Manufacturers and our Foreign Export.

After spending the night with our kinds hosts, we had a rapid ride over the hills to Dover, and at night I found myself safe at home, braced by the keen mountain air, and well pleased with my excursion.

Yours truly, A JERSEYMAN



### ❖ERRATA❖

In the article, "A Complex Base-Metal Assemblage from the Sterling Mine, New Jersey" by Jenkins and Misiur, which appeared in *The Picking Table*, vol. 35, no. 2, pp.16-24, there is an error on p. 16. This article is a reprint from *The Mineralogical Record*, vol. 25, no. 2, and the error was described and corrected on p. 386 of *The Mineralogical Record*, vol 25, no. 5: "...in the Introduction it states that the Chalcopyrite room ranges in depth 'from 770 to 870 feet.' That should read 'from 770 to 780 feet.'"

In "Notes from the laboratory" on p. 12 of *The Picking Table*, vol. 35, no. 2, the Greek letter  $\beta$  (beta) is omitted from the description of duftite, which should have read "Duftite...was reported to be the beta modification of duftite, known properly as  $\beta$ -duftite, duftite- $\beta$ , or duftite."



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*The Fluorescent Mineral Society*  
 P.O. Box 572694  
 Tarzana, CA 91357

# The Franklin Mineral Museum

Evans Road/P.O. Box 54, Franklin, NJ 07416  
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#### Operating Schedule:

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**March 1 to December 1**

**Monday through Saturday: 10AM - 4 PM**

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Groups by reservation, please

#### Admission fees:

Adults: \$4.00

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Separate admission fee to the Buckwheat Dump is the same as the Mineral Museum fee. Admission to museum includes guided tour.

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Open March & December on weekends or by appointment, weather permitting

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Adults: \$7.50

Children: \$5.00

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Call for group rates

#### Note:

On the last Sunday of each month (or other times for groups by prior arrangement) a collecting site will be open for a nominal additional fee. Contact the mine office for details.

❖ EDISON TUNNEL DEDICATION ON APRIL 8, 1995 AT 10:00 A.M. ❖



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## Books and other publications

**Fron del, Clifford and Baum, John L. (1974) *Structure and Mineralogy of the Franklin Zinc-Iron Manganese Deposit, New Jersey*. Economic Geology, 69, 2, pp. 157-180. Photocopies only are available.**  
\$2.50 (+\$1.25 postage)

**Horuzy, Paul (editor) (1990) *The Odyssey of Ogdensburg and the Sterling Zinc Mine*. Privately printed, Sterling Hill Mining Company.**  
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**Shuster, Elwood D. (1927) *Historical Notes of the Iron and Zinc Mining Industry in Sussex County, New Jersey*. Privately printed. Franklin Mineral Museum reprint.**  
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**Proceedings Volume, Lehigh-FOMS Symposium (1990): *Character and Origin of the Franklin-Sterling Hill Orebodies*, 118pp.**  
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