

# *Franklin Mineral Digest*

1959

# PARAGENETIC TABLE OF THE MINERALS OF THE FRANKLIN AREA

Primary Ore Minerals		Hydrothermal vein minerals	
Franklinite	Willemite	Albite	Loseyite
Zincite	Tephroite	Fowlerite	Quartz
Pegmatite Contact Minerals		Tremolite	Zincite
<i>Skarn:</i>	<i>Pneumatolytic products:</i>	Crocidolite	Hematite
Hyalophane	Margarosanite	Willemite	Hetaerolite
Diopside	Pectolite	Friedelite	Goethite
Jeffersonite	Willemite	Schallerite	Manganite
Schefferite	Barylite	Mcgovernite	Pyrochroite
Zinc schefferite	Nasonite	Leucophoenicite	Manganbrucite
Fowlerite	Barysilite	Gageite	Chalcophanite
Bustamite	Glaucochroite	Hodgkinsonite	Hedyphane
Zinc-manganese cum- mingtonite	Tephroite	Ganophyllite	Arseniosiderite
Manganiferous amphi- boles:	Larsenite	Apophyllite	Allactite
Hastingsite, Paragasite, etc.	Calcium larsenite	Calciothomsonite	Chlorophoenicite
Garnet, var. andradite	Beryllium vesuvianite	Stilbite	Magnesium chlorophoeni- cite
Hardystonite	Roebbingite	Heulandite	Holdenite
Tephroite	Hancockite	Chlorite	Sussexite
Roepperite	Prehnite	Manganiferous serpentine	Barite
Glaucochroite	Leucophoenicite	Bementite	Celestite
Vesuvianite, var. cyprine	Clinohedrite	Talc	Anhydrite
Xonotlite	Hodgkinsonite	Fluorborite	Galena
Biotite, var. Mangano- phyllite	Datolite	Mooreite	Sphalerite
Gahnite	Cahnite	Delta-mooreite	Greenockite
Magnetite	Sussexite	Aragonite	Pyrite
<i>Recrystallization prod- ucts:</i>	Manganoaxinite	Dolomite	Marcasite
Franklinite	Cuspidine	Siderite	Millerite
Zincite	Apatite	Rhodochrosite	Tennantite
Manganosite	Hedyphane	Smithsonite	
Hematite	Svabite	Surface oxidation products	
Willemite	Franklinite	Calamine	Psilomelane
Tephroite	Fluorite	Halloysite	Cerussite
	Barite	Neotocite	Malachite
	Silver	Manganiferous serpentine	Azurite
	Copper	Desaulesite	Aurichalcite
	Lead	Quartz	Hydrozincite
	Galena	Cuprite	Smithsonite
	Chalcocite	Hematite	Descloizite
	Niccolite	Hydrohetaerolite	Anglesite
	Chloanthite	Limonite	Gypsum
	Sphalerite	Chalcophanite	
	Chalcopyrite		
	Bornite		
	Pyrite		
	Lollingite		
	Arsenopyrite		
	Kentrolite		

# Franklin Mineralogical Association

AND

## FRANKLIN MINERAL DIGEST

BOX 408 — MIDDLEBURGH, N. Y.

The following statements are taken from letters received by the secretary from Association members during the past year regarding the FMA, its activities and the Digest:

"I want to compliment you on this Digest, because I am certain it represents a great deal of work on your part and it is something you may well take pride in." G.J.S., White Plains, N. Y.

"Enjoyed the Digest and wish to compliment the Association for the nice job. I certainly feel the Association is setting out to perform a very valuable and worthwhile work." J.M.P., Bountiful, Utah

"I want to congratulate you and your club there in N.Y. I have just finished your fine work (Digest) on the Franklin complex. It will make a nice textbook, and I treasure it." G.C.D., Overland, Missouri

"This is a mighty fine issue, carrying a great deal of valuable data, and printed on extra good paper with a mighty fine mechanical job. You have done a lot of work here and I do hope it gets the support so justly deserved." H.C.D., Portland, Oregon

"It's a great service you folks have done in reprinting the Palache article as well as the other items in the first issue of the Digest." R.G.H., Des Moines, Iowa

"The Digest seems to have gone over very big in this section. Many of my friends were interested so I was able to get several to join the FMA." R.H., Bloomfield, N.J.

"I think this a wonderful organization (FMA) and the Franklin Mineral Digest is a very interesting document. I am proud indeed to be a part of this fine organization." E.J.A., Pittstown, N.J.

"We found this Digest extremely interesting and useful and would like to distribute these extra copies to some friends. I feel that every member of the club owes you a sincere vote of thanks for your efforts in producing this book." F.Z.E., Sparta, N.J.

"It looks like you have done an excellent job, and you and your organization are to be commended for your efforts and objectives in wishing to preserve the information about the Franklin minerals." K.W., Trenton, N.J.

"Congratulations on the first FMA Digest. For a mineral association so young, this is a truly great accomplishment. The publications alone are worth the price of membership." D.H., Gettysburg, Pennsylvania

"I was more than pleased to learn of the aims of the new Franklin Mineralogical Association. I should think that these aims will certainly fill a long-felt need." H.K., Union, N.J.

"I was greatly interested in the copy of the Digest you sent us." E. L., Los Angeles, California

"The copies of the Digest have been very well received here at the North Jersey Mineralogical Society." J.J.D., Clifton, N.J.

"I must compliment you and tell you what a marvelous accomplishment you have in this volume. That this represents an enormous amount of spare-time work is evident. Your material is well chosen, well edited, apparently complete and current, and beautifully presented. Again, my congratulations." C.A.B., Lansdale, Pennsylvania





# *Franklin Mineral Digest*



*to my parents*

ANNA AND STEVE NAVRATIL

had they never lived  
the Franklin Mineralogical Association  
might never have been born

# Franklin Mineral Digest

Volume II

November 1959

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*Mailing Address*

FMA, Box No. 408, Middleburgh, New York

*Preamble to the Constitution of the Franklin Mineralogical Association*

We of the Franklin Mineralogical Association dedicate ourselves to the following principles and objectives:

- (1) to unite all individuals interested in the Franklin-Sterling Hill, Sussex County, New Jersey district and to coordinate independent activities for mutual benefit.
- (2) to gather and disseminate information relative to the district to all members via:
  - a) a circulating library
  - b) the Franklin Mineral Digest
  - c) other means as prove workable
- (3) to foster a spirit of individual responsibility to the group objectives.
- (4) to safeguard, preserve and transmit to posterity the historical, geological and mineralogical knowledge pertinent to the Franklin district.
- (5) to honor the memory of Bauer, Berman, Palache and the other giants of the Franklin era.
- (6) to promote a campaign of safety-mindedness among collectors visiting the Franklin collecting areas.
- (7) to aspire to a high order of scientific inquiry.
- (8) to perpetuate the prominent position enjoyed by the Franklin district in the mineralogical world.
- (9) to enhance the collections of individual members.
- (10) to confirm the authenticity of minerals from the district.
- (11) to establish a mineral museum representative of, and devoted exclusively to minerals from the Franklin district.
- (12) to cooperate with existing groups and societies of kindred spirit.



# Memorial of Charles Palache

by

CLIFFORD FRONDEL

*Department of Mineralogy, Harvard University,  
Cambridge, Massachusetts*

Charles Palache was born July 18, 1869, and died December 5, 1954, in the eighty-sixth year of his age. One of the most eminent crystallographers and mineralogists of the world, he lived in a period of revolutionary developments in mineralogical science.

Palache's ancestors belonged to a group of Sephardic Jews who at the end of the 15th Century were exiled from Portugal to Holland. Much later one family migrated to Jamaica where Charles Palache's grandfather, John, headed a plantation. For political reasons he abandoned that home in 1834, put his wife and three daughters on a ship sailing for New York, but died before he could follow them in the next boat. Three months later Palache's father, James, was born in New York City. Lured by reports of gold in California, James left his home at the age of fifteen to serve as cabin boy on a schooner rounding Cape Horn. He landed in San Francisco in 1849. There, established as a merchant, he married Helen D. Whitney, who had traveled from her home in Green Bay, Wisconsin, in a caravan of seven covered wagons. Their son, Charles Palache, was a sensitive boy who at an early age evidenced an intense interest in nature and collected objects of natural history. Palache graduated from Berkeley High School, and entered the University of California in 1887. He elected the four year course in mining, since in its content there was more natural history than in any other, and graduated at the top of his class. Andrew C. Lawson was appointed Professor of Geology in his senior year, and Palache returned the following year to assist Lawson in mineralogy and to study for the doctorate, which he received in 1894. Lawson, himself at the start of a long and distinguished career, was a stimulating teacher and it is to him that Palache credited the inspiration that took him from a career in mining into mineralogy. At first Palache's interests were in field geology and petrography, and with Lawson he did the field work for the first geologic maps of the San Francisco Peninsula and the Berkeley area.

In 1894, Palache left for a year of study abroad, first to work under Ferdinand Zirkel at Leipzig, where T. C. Walker and Bundjiro Koto were fellow students, and then to study with Paul Groth and Ernst Weinschenk at Munich. Other American students working in Groth's laboratory at the time were T. A. Jagger, A. B. Peck and A. S. Eakle. The winter in Munich was a happy and busy one; and it is recorded in Palache's journal that "the museums were good, the theatre excellent and there was opera all winter costing students next to nothing." A turning point in his life came the following spring, when he visited Heidelberg. Here he took courses in petrography under Harry Rosenbusch and Alfred Osann, and was introduced to morphological crystallography by Victor Goldschmidt. Palache threw himself with enthusiasm into the study of crystals, and laid the foundation for the work he pursued so vigorously for the next fifty-five years.

Palache returned to California in the fall of 1895, and in December a letter came from John E. Wolff offering him a small job as his assistant at Harvard. Wolff, Professor in the then newly organized Department of Mineralogy, and Curator of the Mineralogical Museum, succeeding Josiah P. Cooke, was one of a group of Harvard geologists that included William Morris Davis, Nathaniel S. Shaler and Josiah D. Whitney. Wolff's interests were primarily in petrography and in the year after his retirement in 1922 the instruction and research in this field was taken over by Esper S. Larsen, Jr., who with Palache constituted the Department for many years. Palache was named Assistant Professor of Mineralogy in 1902, Professor in 1910, and Professor Emeritus after his retirement in 1941.

### *Morphological Studies*

In his chief field of work, morphological crystallography, Palache brought himself and the Department of Mineralogy to a pre-eminent position in research on the external geometry of crystals. There is scarcely a crystallized mineral that he did not investigate. He introduced the first Goldschmidt two-circle goniometer into the United States, in 1896, and elaborated this method in a series of papers that with later amplifications by his students are standard references. The present general use in America of two-circle goniometric methods in the characterization of crystallized substances derives largely from his work.

Palache's publications deal chiefly with systematics and descriptive matters, and it is through the work of his students that we see the keen and stimulating interest he had in the genetic and interpretive aspects of mineralogy. His published papers, over 150 in number, include classical studies of the morphology of calcite, azurite, the gold tellurides, the lead oxyhalides, and definitive investigations of numerous less common minerals. His studies of calcite culminated in 1943 in a critical review of the morphology of this species that surpasses the early works of Bournon, Zippe and Irby. His study of the tantalizing mineral calaverite, done in cooperation with Martin Peacock and Victor Goldschmidt, is a masterpiece of the art of crystal measurement and projection. Peacock began the study of crystallography under Palache in 1926, and returned as Research Assistant to him over the period 1932-1937. A brilliant man, with a gift for conciseness in style and rigor in presentation, he gave to Palache a kindly affection and shared with him both a love of music and skill at the carpentry bench.

Palache's published studies are only a small part of the crystallographic work that he accomplished. In one project the available morphological data for all minerals was critically re-examined, recalculated in Goldschmidt's scheme of presentation, and tabulated on filing cards. This modern version of Goldschmidt's *Winkeltabellen* was not brought to full completion, however, partly from the realization that the new x-ray methods of study would in many instances necessitate a description different from that based on morphological grounds. There was further the growing realization, emphasized in the Harvard laboratory by Harry Berman, that the features of minerals were not isolated matters but should be described in context with the chemical composition and the crystal structure. Berman, the nearest to a son that Palache had, went to Harvard in 1924. He was versed in modern chemistry and physics, which Palache was not, and became a powerful stabilizing influence in the laboratory.

Berman installed the first x-ray equipment at Harvard in 1933. The purely geometrical point of view of earlier years, that at times yielded ornamentations of morphological crystallography bordering on numerology, became realistic and broadly based.

The preparation of the 7th edition of Dana's System of Mineralogy was started in 1937 under Palache's leadership. He gave close attention to the problems of organization and computation of the crystallographic data, with the help of C. W. Wolfe and Peacock, and the files of the Dana contain a large store of measurements and computations that came from his hand. Although he did not prepare any of the manuscript, his counsel and factual knowledge contributed greatly to the progress of the work.

Crystals had a deep significance to Palache. In their morphology he seems to have found almost an element of mysticism, a response to the facets of a crystal seen in glittering progression in the quietness of a goniometer room, that revealed a self-contained system of order in a random world. The resolution of this order in terms of atoms and forces did not attract him. The full impact on mineralogy of the new x-ray and physical techniques came midway in his career. As a scientist he welcomed and used the knowledge thus brought of the ultimate structure of crystals, yet this new understanding terminated a traditional approach to the constitution of crystalline solids, one followed in mineralogy for a century and more, and destroyed for him the wonders of a thing unknowable and long sought.

### *The Mineralogical Museum*

Palache's most lasting and most important contribution to the development of the Harvard Department of Mineralogy, and a great service to mineralogy in general, was in building the Mineralogical Museum to its present position as the leading research and exhibit collection of minerals in the world. When Palache first came to Cambridge, a few days before Christmas in 1895, it was to assist Wolff in arranging the mineral collection. Palache lived for a year in a small room in the University Museum where, armed with a rifle, he guarded the premises.

The collection he came to had started in 1784 and in 1895 contained about 55,000 specimens. Wolff continued as Curator until 1922, when he retired and Palache took charge both of the Department and of the Museum. The collection grew rapidly by field collecting, exchange and purchase. The great private collection of A. F. Holden, comparable in quality and extent to the collections of Roebling and Bement, was acquired by gift in 1913. This was followed by very

large funds given by A. F. Holden in 1922 and by J. E. Wolff in 1940 for the care and increase of the Museum. Much of the income from these gifts was diverted into the general funds of the University and only a small amount remained for minerals.

Beginning in 1904, Palache gradually built a definitive collection of the minerals of Franklin, New Jersey, and acquired together with a mass of other material the Hancock collection and, jointly with the U. S. National Museum, the Canfield collection. His monographic study of the mineralogy of the Franklin ores, published in 1935 by the United States Geological Survey as Professional Paper 180, is a landmark in American mineralogy. The work at Franklin was part of a lengthy association with the Geological Survey that included field studies in 1901 in the Bradshaw Mountains in Arizona and mineralogical studies in 1906 and 1919-1921 in the Lake Superior copper district.

Palache first became seriously interested in the mineralogy and paragenesis of the pegmatites of New England in 1912, although he had earlier described with C. H. Warren the pegmatite pipes of the Quincy granodiorite. In the summer of that year he collected in the pegmatites of Maine and New Hampshire, and secured the fabulous find of purple apatite at Mount Apatite near Auburn, Maine. During the next 20 years he collected, with the assistance of students and of F. A. Gonyer, extensive suites of material from pegmatites throughout New England, in part by leasing operations at important localities. This material served as the basis of important studies by himself and his students. Among these publications was Landes' well-known paper of 1925, "The paragenesis of the granite pegmatites of central Maine." Pegmatite mineralogy was strongly emphasized in Palache's course in mineral paragenesis, but he also was keenly interested in other types of mineral occurrence and it is a pity that only a small part of his store of knowledge in this field was ever published.

There were numerous other collecting activities, both at home and abroad. In 1922 he participated with R. A. Daly, F. E. Wright and G. A. Molengraaff in an expedition to South Africa, where he obtained a wealth of secondary zinc, copper and vanadium minerals. In 1924 he made a productive trip to localities in Norway and to Langban, Sweden, where the Flink collection was secured. In 1926 he went to Madrid for the XIV International Geological Congress, and to Lisbon, where he acquired the Bello collection of Portuguese minerals. Earlier, he had visited Russia for the VII International Geological Congress in 1897, and he traveled to Alaska in the Harriman Expedition

in 1898. In 1935, Palache visited Vienna to purchase 900 superlative specimens from the Karabacek collection, a transaction remembered to this day in Austria. Another large acquisition was the Ahlfeld collection of Bolivian minerals, purchased jointly with the National Museum. The collection of meteorites, originally acquired from J. Lawrence Smith in 1883, was increased as opportunity offered. Palache prepared a new catalogue of this collection, and described five new meteorites.

Numerous publications stemmed from these accessions, and a vast amount of research material remains untouched. There were many indirect yields from the collection. L. C. Graton paid tribute to Palache for his essential aid in assembling the reference collection of polished sections of ore minerals in the mining geology laboratory, that formed the basis of the works of J. Murdock, C. M. Farnham and M. N. Short in this field. Palache published joint descriptions with others of 17 new mineral species including the last two rock-forming minerals to be recognized, lawsonite and pumpellyite. Lawsonite was originally found by Palache and F. L. Ransome when as students at the University of California they went on a collecting trip to the glaucophane schists of the Tiburon Peninsula. Palache prepared a description of lawsonite in 1894 while working under Groth in Munich, and correspondence brought out that Ransome was working on the mineral in California; both had independently selected the name lawsonite, and a joint description was published in the *Zeitschrift für Kristallogie und Mineralogie*. Palacheite, named after him in 1903 by Eakle, was soon discredited as a variety of botryogen.

Palache was a connoisseur of minerals. He could evaluate the worth of a specimen as representative of a locality or type of occurrence; he knew the subtleties of crystal habit, color, association and size that distinguish a fine specimen from a good one; he was a keen judge of the factors that determine the aesthetic and scientific values. And, of course, he was a master at that virtually lost art, sight identification. Palache took a keen delight in a beautiful specimen, yet with sober deliberation he would yield any specimen to the dissecting chisel and hammer if new knowledge could be obtained. He took painstaking care in the arrangement, cataloguing and labelling of the collection to make it convenient for use by the investigator and the student. Palache's lectures were enlivened by anecdotes of his personal experiences with other mineralogists or of his visits to famous mineral localities. His students and assistants soon learned of his great knowledge and love of minerals and inevitably became imbued with his interest and spirit of research. The

laboratory work was thorough and emphasized the direct examination of specimens. His successive course assistants in the earliest years were A. S. Eakle, C. E. Lord, Hoyt S. Gale, H. O. Wood, R. W. Richards, H. E. Merwin, R. E. Somers, W. G. Foye and A. Wandtke, all of whom went on to distinguished careers.

Palache played an active part in the organization and later development of the Mineralogical Society of America. The Society was first organized on December 30, 1919, in a meeting in the mineralogical lecture room at Harvard. Palache became President of the Society in 1921, Honorary President in 1950, and was the first recipient of the Roebling Medal in 1937. In the words of Edward H. Kraus, the Roebling award was presented to ". . . America's foremost mineralogist, and one of the stalwarts of the Society, whose publications during a period of 40 years have covered a wide range of subjects and have contributed signally and enduringly to the advancement of our science." Palache's acceptance was a delightful account of his friendship with Colonel Roebling and of the circumstances through which he brought the Roebling endowment to the Society. Palache was loath to have the relatively large number of contributions from himself and his students and associates impose upon the limited resources of the journal of the Society. This brought the issuance of five independently financed Harvard numbers of the journal, including the Palache *Festschrift* of 1938, that supplemented the normal contributions of the Department.

The distinction of Palache's career brought him many honors. Aside from his recognition by the Mineralogical Society of America, he was a member of the National Academy of Sciences, the American Academy of Arts and Sciences, President of the Geological Society of America in 1937, and corresponding member of the Geologiska Foreningen, Stockholm. He was an Honorary Member of many societies, including the Sierra Club, the New York Academy of Science, the Mineralogical Society of Great Britain, the Royal

Geological Society of Cornwall, and the Societe Geologique de Belgique. In 1941, he was given an honorary LL.D. by the University of California. He was an associate editor for many years of the *Zeitschrift fur Krystallographie* and of the *American Journal of Science*. Palache encouraged the efforts of the amateur mineralogists, and was voted an Honorary Member of both the Boston Mineral Club and the New York Mineralogical Society.

In his office and laboratories Professor Palache seemed to many to be stern in attitude and almost forbidding in appearance. He was not easy of approach, although an effort always was rewarding, and he rarely was familiar in his relations with students or his associates. These characteristics may have stemmed from an acute and strongly disciplined shyness and sensitivity. Certainly he was a modest and considerate person, whose kindnesses were unobtrusive. At home he was a relaxed and charming host. He derived great satisfaction from symphonic music, a taste dating to concerts at the Gewandhaus in Leipzig heard as a student. His personal reserve was easily penetrated by discussions of music or through his interest, maintained over the years, in ornithology. Palache married Helen Markham in 1898, and he is survived by three daughters. It was a pleasant privilege to visit his home or his summer place at Jaffrey, New Hampshire. Vigorous in body and mind to the end, he died at his home near Charlottesville, Virginia, to which he had moved from Cambridge a few years before.

Such was the nature of the man, and of his work. Shortly before his death, in conversation with Reginald A. Daly, a friend and associate over many years, Palache remarked that his life had been fruitless—but this is a feeling given in great times, to great men.

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THE MINERALS  
OF FRANKLIN AND STERLING HILL  
SUSSEX COUNTY, NEW JERSEY

by

CHARLES PALACHE

Geological Survey Professional Paper No. 180

1935

SULPHIDES AND ARSENIDES

MOLYBDENITE

*Hexagonal*

Molybdenite forms scales and bluish-gray platy crystals, generally associated with the pegmatite contacts at both Franklin and Sterling Hill. At Franklin it was also abundant in the limestone of the east wall of the Buckwheat open cut, where the limestone contains much scapolite and edenite. Molybdenite and pyrrhotite were for the most part enclosed in the dull-green scapolite. Molybdenite was also found sparsely disseminated in the ore of the Gooseberry iron mine.

GALENA

*Isometric*

Galena is found only in coarse and fine granular masses, with the characteristic marked cubic cleavage, in small amounts in the pegmatite of the Trotter mine at Franklin, somewhat more abundantly in the coarse pegmatite at Sterling Hill, and in the limestone and jeffersonite near the pegmatite contact. It is interesting chiefly as the probable source of a number of secondary minerals, and as showing the presence of lead in the pegmatite magma. Spurr and Lewis record finding veins in the Kittatinny limestone containing galena with other sulphides.

CHALCOCITE

*Orthorhombic*

Chalcocite is very rare at Franklin. It was first brought to the author's attention in 1909 by Mr. McGovern, of Franklin, who sent a specimen for determination, showing a thin calcite vein containing granular sphalerite and galena, with a few imperfect crystals of chalcocite. Later in the same year was made the interesting discovery of massive chalcocite associated with silver and magnetite, described under silver.

SPHALERITE

*Isometric-tetrahedral*

*Habit.*—Crystals of sphalerite have been found in considerable abundance at Franklin. They are remarkable for the sharpness of their form and for the

variety of forms and combinations displayed. Several individual or twin crystals, some an inch across, were found in the Stanton collection. The distinction between the positive and negative forms is based on the presence of twinning, always assumed to be on the positive tetrahedron. There seems to be no rule governing the luster of the two tetrahedrons, either being the more lustrous or both being either bright or dull in different crystals. Both are generally developed, but the negative tetrahedron seems more likely to be dominant.

The mineral is found also in coarse granular form and in massive forms with medium to finest grain.

*Physical properties.*—The mineral has a wide range in color, from white or only faintly green or yellow, through deep oil-green, resinous yellow, gray, and brown, to black. At Sterling Hill it is generally a peculiar reddish brown, much like some willemite and friedelite. The specific gravity of cleiophane, the variety free from iron, was determined by Henry to be 4.063.

*Composition.*—The white sphalerite or cleiophane consists of almost pure zinc sulphide, with a trace of cadmium, but the colored material contains considerable iron and minute amounts of other elements. Some of the material contains an appreciable amount of manganese.

*Analysis of sphalerite*

	1	2	3
Zn	67.46	50.43	55.30
Fe	—	15.96	9.18
Cd	trace	.09	—
Mn	—	.51	2.00
Cu	—	.05	—
Pb	—	.07	—
S	32.22	30.97	33.52
SiO <sub>2</sub>	—	.99	—
	99.68	99.07	100.00

1. White sphalerite (cleiophane). Franklin. T. W. Henry, analyst.

2. Black sphalerite, picking table, Franklin. L. H. Bauer, analyst.

3. Black sphalerite, Franklin. L. H. Bauer, analyst.

Analysis 1 confirms the absence of iron indicated by the white color of the cleiophane. The black sphalerite (no 2) is rich in iron and is interesting because, like no 1, it contains a trace of cadmium. Analysis 3 was derived by computation from the analysis of a mixture of sphalerite and bornite in the ratio of 2 to 3.

*Occurrence.*—Sphalerite is fairly common at Franklin, though not common enough to be accounted an ore of zinc. It is found but rarely in the normal zinc ore body but is characteristic of secondary veins, of pneumatolytic zones, and of the pegmatite.

In the veins its commonest form is a dull-white or gray compact phase, associated with granular or chalcedonic quartz and with carbonates of calcium, magnesium, manganese, and zinc, rather commonly in alternate layers with a fine ribbon structure parallel to the vein walls. Where this white sphalerite is more coarsely crystalline it has the normal adamantine luster, and to this variety, noticed by the earliest writers on Franklin minerals, Nuttall gave the name cleiophane. It was especially abundant at the Trotter mine and could be collected freely on the old dump there. In the same mine was found a crystallized form of white sphalerite in flattened twin octahedrons, embedded with clear yellow prisms of willemite and cleavage fragments of calcite in thin veins, whose black matrix has the appearance of hardened mud.

A very different phase of sphalerite from the secondary veins, more common in collections, is the brilliant yellow, green and brown crystalline form found in the porous gray dolomite veins of the Buckwheat mine. The crystals are generally combinations of positive and negative tetrahedrons, some of them in perfect balance, forming apparent octahedrons. In most specimens there is repeated twinning on the octahedron, producing complex groups. Only a few showed the uncommon hextetrahedron or the trigonal tristetrahedron. The crystals are attached to the walls of the open cavities in the dolomite, other cavities being entirely filled with granular resinous sphalerite.

The sphalerite specimens in the Stanton collection were found in the mine at the 300-foot and 450-foot levels in the 1100 stope north and came from what must have been a series of dolomite veins. The crystals coat the walls of cavities, together with brilliant plates of specular hematite, dolomite, and quartz and a later coating of delicate plates of chlorite. The color is chiefly light greenish yellow, but in very coarse cleavage masses with grains an inch or more across the color ranges from beautiful oil-green to reddish yellow, the luster being wonderfully brilliant.

At Sterling Hill sphalerite is more widely distributed than at Franklin. It forms veins traversing the ore and in their vicinity may be distributed in fine grains throughout the ore. In places it is so abundant as to constitute nearly 1 percent of the willemite concentrate. The sphalerite of these veins, reddish to pale brown, and fine granular to crypto-crystalline, is quite unlike any other sphalerite and is easily mistaken for friedelite.

The principal pneumatolytic zone containing sphalerite was found in the Trotter mine, at a depth of 350 feet, where the mineral was abundantly developed in yellow granular form, with fluorite, chloanthite, nicolite, and arsenopyrite.

In the pegmatite sphalerite was noted megascopically as a subordinate constituent, generally visible only near the limestone contacts, at both Franklin and Sterling Hill. It is disseminated as cleiophane in minute grains with galena, amidst the normal pegmatite minerals. Concentration of the sphalerite was commonly evident in the vicinity of jeffersonite grains. It was also seen enveloped by rhodonite, and some granular masses several inches in diameter were seen in the pegmatite or admixed with yellow garnet at the limestone contact.

The conclusion has been reached that sphalerite, or at least the sulphur required for its formation, was introduced by the pegmatite magma, that from the pegmatite it found its way into pneumatolytic and other types of contact zones, and that from both those sources, by subsequent movement of solutions, it passed into secondary veins filling fissures that had in all likelihood been formed by the same pegmatite intrusion.

Sphalerite was listed by Spurr and Lewis among the sulphides found in late veins cutting the Kittatinny limestone.

## GREENOCKITE

### *Hexagonal*

Greenockite is not found in crystals but only as a lemon-yellow powdery incrustation on limestone containing franklinite and fibrous green willemite. From the very small amount of material available for a test, a distinct coating on charcoal was obtained indicative of cadmium; nevertheless the determination of the mineral is unsatisfactory.

Greenockite is known only on specimens from the Hamburg mine, an early and long-abandoned opening on the northernmost outcrop of the western leg of the ore body at Franklin.

## MILLERITE

*Hexagonal-rhombohedral*

Characteristic hairlike yellow metallic needles of millerite were found in the cavities of a single specimen of the gray porous dolomite from the Buckwheat mine, in which are found the well-known sphalerite crystals. On some of the needles tiny rhombohedrons of dolomite are threaded like beads on a string.

## NICCOLITE

*Hexagonal*

Niccolite, in rough pyramidal crystals and granular aggregates, was found in the mass of nickel-cobalt ores cut by the Trotter shaft at a depth of 340 feet. It was about equally abundant with chloanthite. Several hundred pounds of these two minerals are said to have been contained in this mass. Where in contact with calcite or fluorite some of the niccolite is in rude crystals. Many of these are cavernous, being partly or wholly replaced by a green or gray nickeliferous silicate called desautlesite, which is probably derived from the niccolite.

Chloanthite commonly forms a zone about isolated specks of niccolite in calcite. Most of the niccolite seen in specimens is compact and massive. It has not been analyzed. Koenig, who first noted the occurrence, received specimens in which were mere traces of niccolite; the larger masses of it were found later.

## PYRRHOTITE

*Hexagonal*

Pyrrhotite, in grains, rounded crystals, and irregular masses, is common in the white limestone in quarries near Franklin. It is generally associated with the metamorphic minerals of the limestone, such as graphite, fluorite, tourmaline, amphibole, and scapolite, and more intimately with pyrite and arsenopyrite, both of which occur in sharp crystals enclosed in pyrrhotite. No individual crystals of pyrrhotite were found with plane faces, though many of them presented two broader surfaces that suggested original basal planes of crystals, now rounded and deeply etched by resorption. Some of these rounded and etched crystals were several inches in diameter and entirely lacked the basal parting found in some pyrrhotite, breaking instead with a brilliant conchoidal fracture. Masses of pyrrhotite were found in immediate contact with tourmaline and titanite, evidently later and molded against the surface of those minerals.

Qualitative chemical tests showed that the pyrrhotite contains no cobalt and but a trace of nickel.

## BORNITE

*Isometric*

Bornite is uncommon at Franklin, though some specimens of chalcopyrite seem to contain minute grains of darker-colored bornite.

In a specimen analyzed sphalerite was visible as abundant dark-brown grains and was assumed to be the source of the zinc and manganese and part of the iron found. Computation based on such an assumption shows that about 40 percent of the material was sphalerite. Deducting it and the equivalent of the SiO<sub>2</sub> found, the molecular ratio of the remainder gives exactly the bornite formula. Many specimens of this bornite, in part almost pure, were found in the Stanton collection.

## CHALCOPYRITE

*Tetragonal*

Chalcopyrite is found very rarely at Franklin, in granular masses and disseminated grains in the pegmatite and also intermixed with zinc-ore minerals, as in the Buckwheat open cut. A vein of massive chalcopyrite without any other mineral, in coarse limestone, is shown in a specimen in the Holden collection.

Farrington described a 7-inch vein of chalcopyrite, galena and sphalerite cutting white limestone very near the zinc-ore body that was uncovered during the early stripping operations on the southeast side of Sterling Hill. The mineral is not otherwise known from Sterling Hill.

## PYRITE

*Isometric-pyritohedral*

*Composition.*—The composition of the mineral, is normal except for the presence of cobalt in about the same proportion as in the arsenopyrite from the same locality.

*Occurrence.*—Franklin: The most interesting occurrence of pyrite is in the Franklin limestone, notably in the Fowler and Furnace quarries and in that of the Franklin Iron Co. It is found in isolated crystals of brilliant luster and perfect symmetry developed on all sides, ranging from microscopic dimensions to more than one and a half inches in diameter. The habit of the crystals is extremely varied. Even in crystals from the same hand specimen different forms are dominant. The octahedron, cube and pyritohedron are the principal forms, and each occurs both alone and in combination with each or both of the others in balanced development and with all intermediate degrees. Combinations of the octahedron and the trapezohedrons,

the latter forms being dominant in some crystals, are peculiarly striking, the trapezohedrons being generally striated parallel to their intersection with the octahedron, owing to the development of two forms of oscillatory combinations. In the paper by Kraus and Scott in which these crystals are figured, nine types are recognized. It seems to the author, however, that the habits are endlessly varied and that the types recognized are limited only by the number of crystals examined.

The smaller crystals are readily removed from the limestone matrix but the larger ones are liable to break and have to be freed by careful tool work, an art much practiced by the mineral collectors of the vicinity. Series of carefully worked out crystals of pyrite are among the most valued ornaments of the local mineral collections. Large crystals are now found rarely but seem formerly to have been abundant. They are associated, as a rule intimately, with tourmaline, phlogopite, edenite, graphite, arsenopyrite, and pyrrhotite.

Pyrite is unknown in the zinc ores themselves but is not uncommon in secondary veins traversing them. Thus it was noticed in transverse veins at and near the Trotter mine, at the Parker shaft, and in the Buckwheat mines, everywhere associated with and subordinate in amount to sphalerite. In porous dolomite in the Buckwheat mine were minute crystals of extreme brilliancy, most of them simple pyritohedrons. The other occurrences noted above were in massive form or rough cubic crystals.

Sterling Hill: Although pyrite is listed by Kemp from Sterling Hill, its occurrence there could not be established either by record or by authentic specimens.

### CHLOANTHITE

#### *Isometric*

*Habit.*—Chloanthite is found both crystalline and massive. The crystals are rare, small, and much distorted and are mainly octahedron with minute modifying faces of the dodecahedron and pyritohedron. The color of the massive mineral is dull steel-gray, but the crystal faces are brilliant silver-white. The specific gravity is 6.833.

*Occurrence.*—Chloanthite is known only from the Trotter mine at Franklin. At a depth of 340 feet the Trotter shaft passed through a segregation of nickel ores, comprising chiefly chloanthite and niccolite and their oxidation products, together with calcite, yellow sphalerite, and dark-purple fluorite. The chloanthite was in general intimately intermixed with massive niccolite, and crystals were found only where it was in contact with calcite. In one specimen a felted mass of

bluish amphibole needles was cemented by massive chloanthite, crystals of that mineral being implanted on the rounded surface.

*Rammelsbergite.*—In some lists of Franklin minerals—Nason, Kemp, Dana—the name rammelsbergite appears. There is no good authority in the published literature for the listing of this mineral, and it is doubtless a mistake for chloanthite.

*Smaltite.*—No mention of smaltite has appeared in any publication on the district, hence its inclusion in the list of Hoadley and Broadwell is probably also to be considered a mistake for chloanthite.

### MARCASITE

#### *Orthorhombic*

Marcasite crystals were associated with corundum, rutile, and phlogopite in a limestone exposed during the erection of the furnace at Franklin. The crystals collected soon crumbled away, but specimens showing the remains of crystals were seen in the Hancock collection.

### LOLLINGITE

#### *Orthorhombic*

*Occurrence.*—Lollingite was found at Franklin in the Buckwheat mine, where granular masses intermingled with franklinite, were somewhat rare. It was also recorded, in brilliant tin-white crystals by Brush, accompanying the unique cubical gahnite that he described.

At the Trotter shaft tin-white crystals, too rough for measurement, were found sparsely with gahnite in the limestone wall rock. The specimens described by Bauer and Berman were found in 1926 in a drift on the 750-foot level, north. The crystals are sparsely embedded in white limestone of medium grain, together with crystals of gray pyroxene and scattered dots of franklinite. The lollingite crystals are complete individuals, of a brilliant tin-white color, and range in size from tiny specks to crystals with a diameter of an eighth of an inch. They break freely and cleanly from the matrix, and the brilliance of their luster marked them at once as suitable for crystallographic study.

### ARSENOPYRITE

#### *Orthorhombic*

*Habit.*—The crystals, of brilliant metallic luster, nearly an inch long and doubly terminated, are embedded in limestone but because of their brittleness can rarely be extracted without fracture. They are prismatic parallel to the vertical axis and are generally slender, but some are stout and thick. Brachydomes,



of which *n* and *q* are the commonest, are the chief terminal faces, as is ordinarily the case with this mineral. The most marked characteristic of these crystals, however, is the unusual development of pyramid faces, deep striations on the prism faces, parallel to the intersection of *m* and *e*. In this zone are found the pyramids *i*(312), *A*(532) (new to the species and seen chiefly in two zones—between *m*(110) and *e*(101) and between *m*(110) and *q*(011). The first zone is developed on every crystal and is generally marked by on all the crystals), and *B*(514) (seen but once). The existence of *A* and *B* has since been confirmed on crystals of arsenopyrite from Hiddenite, N. C.

**Composition.**—Crystals from the Franklin Iron Co.'s quarry were sent to the laboratory of the United States Geological Survey for analysis. The result is especially interesting as showing the presence of a small amount of cobalt, an element likewise found in small amount in the pyrite of the same locality. The specific gravity is 6.199.

A note by Sullivan states that the analysis was made on 0.25 gram, that the percentage of arsenic is probably too high, and that silica and organic matter were also present.

(Analysis of arsenopyrite)

	Per Cent
Fe .....	32.48
Co .....	1.16
As .....	48.72
S .....	18.80

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101.16

**Occurrence.**—Arsenopyrite was recognized at Franklin by Nuttall and has occasionally been reported by later writers. It is uncommon there and is sparsely represented in collections of Franklin minerals. The crystals just described, which are of unusual perfection and complexity, were collected by the author in 1905 in limestone at the quarry of the Franklin Iron Co. As they add materially to our knowledge of the crystallography of the mineral, they have been described in detail. Intimately associated with them in the limestone are pyrrhotite, pyrite, graphite, edenite, brown tourmaline, titanite, and norbergite. Similar crystals in the same association were found in the limestone of the east wall of the Buckwheat open cut and in the Fowler quarry, but they were neither so abundant nor so well developed.

In the collection of Mr. Fiss was seen a mount of microscopic crystals of arsenopyrite from a Franklin locality not exactly designated. The habit is rather different from that of the crystals collected by the author,

and most of the crystals are twinned in a manner somewhat rare for the mineral — in contact with the prism *m*(110).

Massive arsenopyrite was found in the Trotter mine near the deposit of nickel arsenides, and minute crystals were found there intermixed with desautite. Arsenopyrite is also recorded from the Parker shaft, associated in one place with roebbingite, in another with quartz, pyroxene, and molybdenite.

Minute crystals of arsenopyrite were seen in a specimen of massive epidote and axinite from the Gooseberry iron mine, but there seems to be no record of its occurrence at Sterling Hill.

## TENNANTITE

### Isometric-tetrahedral

**Occurrence.**—A narrow open vein found in 1927 on the 900-foot level of the mine at Sterling Hill contained a few crystals of tennantite, intimately intergrown with sphalerite and galena. With it were stilbite and a network of needles of actinolite and epidote with a few plates of barite. Qualitative tests for arsenic and copper made by Mr. Bauer determined the mineral as tennantite rather than tetrahedrite.

## HALOIDS

## FLUORITE

### Isometric

**Physical properties.**—Fluorite is rarely found at Franklin in cubic crystals but commonly in cleavage masses or in compact granular form. Its color ranges from rose-red to pale flesh-color, purple, gray, and white. Its specific gravity is 3.188.

**Composition.**—In the belief that the pale-red fluorite found enclosing franklinite in the Parker shaft is manganiferous, some of it, free from inclusions, was selected and was sent for analysis to the laboratory of the United States Geological Survey.

(Analysis of fluorite) (George Steiger, analyst)

	Per Cent
Ca .....	51.21
Mg .....	.24
Fe .....	.27
Mn .....	.09
Al .....	.18
F .....	45.85

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97.84

*Occurrence.*—Fluorite is fairly common in the ore body at Franklin as the matrix of ore minerals and other, rarer species. Thus a red variety, is found at the Parker shaft. In the Fiss collection microscopic pure-white, simple dodecahedrons implanted on axinite were seen. They are apparently fluorite and probably came from the Parker shaft. At the Trotter mine, where were found the nickel minerals, fluorite was abundant at one point, in dark purple and pink cleavage masses. Veinlike masses of red and purple fluorite from the Buckwheat mine were also seen.

In the white limestone of all the quarries about Franklin, gray to purple fluorite is locally abundant in compact granular form, and it is also seen in the pegmatite dikes cutting the limestone. The occurrence of fluorite in limestone was first described by Bruce and his mention of it is of historic interest as the first recorded observation of this mineral in America.

In the blue (Kittatinny) limestone near Franklin there are a few cavities in which have been found small cubes and octahedrons of purple fluorite, associated with crystals of quartz and calcite.

## OXIDES

### QUARTZ

#### *Hexagonal*

*Habit.*—Crystals of quartz are rare in the district, and the mineral is found mainly in massive granular form, as vein quartz or as jasper.

*Occurrence.*—Quartz is an abundant constituent of the pegmatite in all parts of the area. Secondary veins, the main filling of which is quartz—partly compact, partly comby and banded with drusy crystals—were seen at all the principal openings on Mine Hill. At the Parker shaft a small quantity, clearly a product of decomposition, was found in druses lining cavities in altered rhodonite. Clear glassy crystals are found in cavities in the Kittatinny limestone about Franklin.

In 1927 quartz of a wholly novel habit was found at Franklin. A specimen collected by Mr. Bauer shows a vein in ore, whose walls are lined with rhombohedral crystals of calcite on which are minute plates of hematite. The whole cavity of the vein is filled with a felted mass of the finest fibers of pale-blue crocidolite, and lying loose in the felt or slightly attached to a wall by one end are needles of quartz, colored faintly blue by inclusions of crocidolite. The needles, which range from minute spicules to slender rods 1.2 inches long and 0.12 inches in diameter, are of trigonal cross section and are extremely steep rhombohedrons, doubly terminated. They have no visible prism faces and hence

are much more like calcite forms than any other crystals of quartz known to the author. The tips of some are needle-sharp, and others are terminated by faces of the positive and negative rhombohedrons.

A silicified hematite or jasper of dull-red color was found occasionally in the Buckwheat mine. Amethyst, chalcedony, and agate, whose names appear in the older lists, were not confirmed by any specimens examined.

At Sterling Hill quartz appears to be of rare occurrence except in the pegmatite. A few milk-white crystals of the common form were seen, which came from the stripping of the calamine deposit and were obtained during the washing of the calamine, but they are said to have been great rarities.

## CUPRITE

#### *Isometric*

Films of massive cuprite were reported by Mr. Canfield to have been found at Franklin. The mineral is first mentioned in the list of Seymour and occurs in most of the later lists of Franklin minerals, but it is certainly very rare there, as in all the collections examined but one specimen was seen. It is, of course, very likely to have been formed together with the other oxidation products of copper-bearing minerals, which are known in small amounts from Franklin.

## MANGANOSITE

#### *Isometric*

*Physical properties.*—Manganosite is found in irregular grains and in octahedral crystals intimately intergrown with zincite and franklinite. Its color is dark green and in thin section is transparent emerald-green. The surface of the grains is usually coated with black manganese dioxide. Its fracture is apparently fibrous, but on close inspection a perfect cubic cleavage is seen. Its specific gravity is 5.364.

*Composition.*—Manganosite is practically pure manganous oxide.

*Occurrence.*—The rare mineral manganosite, found previously only at two localities in Sweden, was first identified in a single specimen in the laboratory collection of minerals at Harvard University. Nothing is known of the source of the specimen, which is a typical bit of granular franklinite-zincite ore that might have come from either Franklin or Sterling Hill. Mr. McGovern, of Franklin, told the author that he had seen considerable masses of an identical ore taken from the Taylor mine at Franklin, but that none of it was saved. The specimen therefore probably came from that mine. The occurrence of manganosite in the zinc ores is not

surprising and is interesting as presenting manganous oxide in two crystalline phases in immediate contact—the isometric form in manganosite and the hexagonal in the zincite molecule, which invariably contains some MnO.

In 1914 manganosite was found in place at Franklin in workings on the 900-foot level at the extreme north end of the mine. In this occurrence it is in large grains as much as an inch in diameter and in octahedral crystals, interspersed with strongly magnetic franklinite and coarsely bladed zincite. The cleavage is prominent, but the color is masked by the blackish coating that marks the beginning of oxidation. Octahedral parting is also well developed in some of the specimens. The author is indebted to Mr. G. L. Morse, then of Franklin, for the first specimens of this discovery.

## ZINCITE

### *Hexagonal-hemimorphic*

*Physical and optical properties.*—Zincite is commonly massive and granular, foliated, or compact. Crystals, which are rare, are large and have rounded, corroded surfaces. Twinning on the base has been observed. The cleavage is perfect parallel to the unit prism but is rarely seen. The fracture is conchoidal, the hardness is 4, and the specific gravity is 5.5 to 5.684. The color ranges from deep red in crystals to orange-yellow in the compact variety, and the streak is orange-yellow. The mineral is translucent, with a subadamantine luster, and is optically positive.

*Composition.*—Most zincite contains some manganese and iron. The determination of the state of oxidation of those metals is not easy, and this fact led to a controversy over the cause of the strong coloring of the mineral, as pure zinc oxide is white. Hayes maintained that the color is due to scales of hematite that can be isolated during solution. Dana and others denied this, pointing out that the scales of hematite are too irregularly disposed to produce uniform coloring. Dana ascribed the color to the content of manganese oxide, and that conclusion has been generally accepted.

Zincite was shown by Eliot and Storer to contain traces of other elements. They first analyzed zinc made from zincite and franklinite and found the following elements: lead, copper, iron, tin, arsenic, sulphur and carbon.

They also tested zincite qualitatively and obtained strong reactions for sulphur and arsenic. Zinc oxide prepared from zincite by them contained arsenic in abundance, sulphur, and traces of cadmium, iron, tin, lead, and possibly antimony but no copper. Metallic zinc prepared by reduction of this zinc oxide gave re-

actions for lead, tin, and arsenic. Interesting as are these results as possibly throwing light on the origin of the ore they have not, so far as known, been confirmed by later quantitative work.

*Occurrence.*—At Franklin, zincite in rounded, shot-like grains or in scales, specks, and splinters is a normal constituent of the ore body over the whole extent of Mine Hill. It is intermixed with franklinite and willemite but is generally much less abundant than they. Its distribution is very irregular, some layers being richer in zincite than others and individual layers differing widely in different parts. In the early history of the mine the ore was thought to be divisible into two layers—one without zincite, called the “franklinite vein”; the other, called the “zinc vein”, containing franklinite and zincite in about equal amount. This supposed distinction, which led to much of the prolonged litigation over the property, was, however, wholly fallacious.\*

Like the other primary minerals of the ore, zincite has undergone recrystallization in parts of the deposit, whereby larger masses were formed than are found in the normal ore, and rarely distinct crystals were produced. The most striking ore specimens found in the district came from such recrystallized masses; patches of bright-red zincite, crystals or masses of green or yellow willemite, and black octahedrons of franklinite, all embedded in snow-white calcite, make a striking color combination.

Crystals of zincite, so far as known, have been found only in the Buckwheat mine. They appear in three distinct types, all of which are found in secondary veins in the granular ore. In one type the crystals are large pyramids, some of them 4 inches long, based on massive zincite and embedded either in massive zincite or in manganiferous calcite. They are not very brilliant and are revealed only by most careful excavation of the surrounding matrix. The pyramid faces are commonly horizontally striated by oscillatory combination with the prism, but distinct prism faces are rarely seen. On crystals of this type, locally called “ruby zinc” or simply “ruby”, of which the author has seen perhaps 20, there is no distinct basal face other than the cleavage plane.

On one tiny fragment, collected by Mr. Cahn, is a fairly well defined twin crystal. A crystal of ordinary type a quarter of an inch long has, interpenetrating it, several similar but smaller parallel crystals with a common vertical axis but in reverse position—a mode of twinning well known on artificial crystals of zincite but seemingly very rare on the natural mineral.

\* (See the Association library article entitled: “The Franklinite Case” submitted by Louis H. Roth.)

The crystals of the second type are found projecting into open veins an inch or two wide. The largest crystals of this type in the Holden collection is 2 inches long and 1 inch in diameter at the base. Calcite and a very fibrous silky form of willemite are the associated minerals in these veins. The zincite crystals are clean-cut and have smooth faces, but they are dull and etched. In one specimen fibrous willemite is replacing the zincite.

The crystals of the third type are found in association with pyrochroite in a remarkable secondary vein. The zincite crystals are minute and sharply formed, with generally dull faces, but some of the faces are bright enough to reflect good signals. Their color is clear orange-yellow instead of the ordinary deep red of the mineral, probably indicating that they contain less manganese than most crystals of zincite. Massive zincite of the same color is seen in the walls of the cavity.

At Sterling Hill, to judge from the specimens preserved in collections, zincite was more abundant in the outcrop ore than at Franklin. It was found in a similar granular form intermixed with rounded granular franklinite. In some of the ore the bulk of the matrix was crystalline zincite, enclosed in which were rounded or sharply octahedral crystals of franklinite. It was to this phase of the ore, which appears to have cropped out in large masses at Sterling Hill, that Nuttall applied the very apt designation "metalliferous porphyry", and its richness in zinc was the basis of extravagant estimates of the total zinc content of the deposit. Another phase of the ore showed zincite in isolated masses in limestone unaccompanied by franklinite. Many of these zincite masses are large, and they generally consist of a single individual, but all are of rounded irregular form without a trace of crystal faces. They appear to have been rounded by solution or by resorption on the part of the matrix. The best specimens of this phase, as seen in the Canfield, Kemble, and Harvard collections, were taken from the hanging wall of the first New Jersey Zinc Co.'s mine in 1850.

Veinlike masses of recrystallized ore showing franklinite and troostite in well-formed crystals and large platy masses of zincite in very coarsely crystalline calcite, wholly similar to those still found in places at Franklin, are also preserved from Sterling Hill. Zincite crystals with definite form are, however, not known to have been found there.

*Calcozincite.*—The name "calcozincite" was applied by Shepard to mixtures of powdery yellow and reddish zincite and compact calcite in various proportions. Numerous embedded fibers of tremolite asbestos give the whole mass a columnar fibrous appearance.

*Historical notes.*—Zincite was the first of the remarkable minerals constituting these deposits to excite scientific interest, and its description and analysis by Dr. Bruce in 1810 constitute one of the earliest mineralogical investigations made in this country. He called it "red oxide of zinc" and gave a correct characterization of the substance. The name "zincite" was given by Haidinger in 1845 and was really preceeded by "sterlingite", proposed by Alger, which, however, never became current and is now used for a different substance—one of the micas. Alger's name "ruby zinc" is still current at Franklin. Brooke and Miller in 1852 proposed the name "spartalite", based on the occurrence of zincite in glacial boulders at Sparta, N. J., several miles south of Franklin, but the name is not found outside their work.

The cleavage and crystal form of zincite were not determined by Bruce, and its hexagonal nature was first established by Hausmann after a long controversy, induced, no doubt, by the variable perfection of the prismatic cleavage. Although so abundant in the Franklin district, zincite has been found nowhere else except in traces. It is reported from two localities in Russia as an oxidation product of zinc ores. Artificial zincite, however, is by no means uncommon as a product of zinc ovens.

## CORUNDUM GROUP

### CORUNDUM

#### *Hexagonal-rhombohedral*

*Habit.*—Corundum is found in crystals, more or less perfectly developed, some of them 5 inches long; the pyramidal and prismatic habits are about equally common. It also occurs in rounded grains without recognizable faces.

*Occurrence.*—Corundum does not occur in association with the zinc ores but is widely distributed in isolated pockets in the Franklin limestone. In the pockets the corundum is associated with one or more of the minerals spinel, rutile, graphite, edenite, pyroxene, garnet, titanite, and phlogopite.

In excavating in limestone for the foundation of the furnace on the west side of the pond at Franklin, a pocket was opened that contained many crystals of blue, gray and red corundum, some of them transparent and very sharply crystallized. With the corundum were phlogopite, spinel, rutile, and marcasite, but the marcasite crumbled soon after exposure. Similar blue and gray corundum crystals, were obtained from a pocket near the limestone quarry of the Franklin Iron Co.

In pockets near the western border of the ore body of Sterling Hill and in the loose material from the stripping of the calmine pits were found good crystals of blue and red corundum, associated with rutile. Many of these were found in washing the calamine ore for the removal of dirt and were doubtless derived from pockets in the neighboring limestone. An irregular chain of pockets containing corundum is said to have extended from Sterling Hill to Franklin.

## HEMATITE

### *Hexagonal-rhombohedral*

*Occurrence.*—The most characteristic form of hematite from Franklin consists of coarse granular masses showing exceptionally perfect rhombohedral parting. Some single parting surfaces have an area of several square inches, and large pseudocubic parting blocks of great brilliance, singularly resembling galena in color and structure, are often obtained.

One specimen of such material consists wholly of a uniform mixture of hematite with black franklinite that has an equally well developed octahedral parting, the whole having a most unusual mottled appearance. Commonly the hematite contains scattered grains of willemite, garnet, and calcite or it forms a crust surrounding crystals of franklinite. This granular hematite, which is not rare in the northern part of the mine, was found at times in masses weighing several hundred pounds. Moses states that it has the rhombohedral angle of hematite. One crystal an inch across, flattened parallel to the base and showing strong parting, was wholly embedded in limestone.

Minute brilliant crystals of hematite were seen in a specimen of porous dolomite from the Buckwheat mine, they being of tabular habit. Other specimens of the same dolomite showed hematite in minute globules of kidney-ore type, their surface coated with needles of goethite.

There is in the Fiss collection a specimen from the Trotter mine showing minute crystals of hematite of rhombohedral form with prism truncations. These tiny crystals, in part individuals of perfect form, in part groups aggregated to form spheroids, were embedded in calcite.

The most complex hematite crystals yet found at Franklin were discovered in 1926 and described by Palache and Berman. They were found coating the surface of ore in an open vein, associated with calcite and colorless sphalerite in flattened twin crystals. They are small, not exceeding a quarter of an inch in length, and brilliantly metallic, with an iridescent luster, although some were lightly coated with a film of red iron oxide.

Brilliant crystals of specular hematite are associated with the abundant specimens of sphalerite that were found in the northern part of the mine on the 300-foot level. The tiny plates stand free in cavities with sphalerite crystals. The base is brilliant, and the paper-thin plates show more or less complex modification.

It may be noted that none of the crystals from Franklin have a habit common to crystals of hematite from any other locality.

As the coloring matter of jasper and other siliceous rocks and as an alteration product of franklinite, hematite is of wide-spread occurrence at both Franklin and Sterling Hill but is not a conspicuous mineral at either locality.

## ILMENITE

### *Hexagonal-trirhombohedral*

*Habit.*—Tabular crystals embedded in limestone.

*Occurrence.*—Ilmenite is listed by Canfield as found at Franklin, but no specimens were found or seen confirming the report.

A specimen in the Canfield collection, from the stripping of the calamine deposit at Sterling Hill, shows jet-black crystals of ilmenite as much as an inch in diameter with black octahedrons of spinel, embedded in limestone. Qualitative chemical tests showed the presence of titanium oxide and manganese, as well as of iron.

In a specimen said to have been found in the Winsor limestone quarry at Rudeville, near Franklin, grains and distinct crystals of ilmenite, with altered spinel and pyroxene, are embedded in limestone.

## SPINEL GROUP

### SPINEL

#### *Isometric*

*Forms.*— $o(111)$ ,  $d(110)$ , and  $a(100)$ .

*Habit.*—Spinel forms octahedral crystals, some of them showing faces of the dodecahedron, and more rarely of the cube. Twinning, when it occurs, is on the spinel law. The color of the crystals is dark gray, green, or black.

*Occurrence.*—Most of the "spinel" found near Franklin is gahnite and is so described in this paper. Some true spinel has been found, but the distinction can be made only by chemical tests. A few octahedrons of green and brown spinel are found in the pegmatite associated with the ore body of the Buckwheat mine; one in the Hancock collection was originally coated with cleiophane.

In the Franklin limestone many so-called "pockets" have been found, in which spinel is associated with corundum, rutile, phlogopite, and hornblende. One of these pockets, on Wildcat Branch, south of the Goose-

berry iron mine, yielded sharp octahedrons of purplish spinel as much as an inch across, in limestone with serpentine. In the limestone quarries at Franklin small black crystals of spinel associated with norbergite were not uncommon in 1905, and at the Rudeville quarries brown crystals, with chondrodite, were at one time abundant.

The Canfield collection is especially rich in specimens of gray, green, and black spinel from several localities in the neighboring towns of Sparta and Newton, all in limestone near its contact with granite gneiss. The most noteworthy specimen is a large cluster of gray octahedrons from Sparta, the largest 17 inches around the base. Another large, isolated twin crystal of perfect symmetry came from the same town, and with it was found clear, red spinel, the only occurrence of the sort known in the region.

The large black crystals of iron spinel found in the towns of Amity and Warwick, N. Y., occur in the northward extension of the Franklin white limestone.

In the collection of Mr. Rowe at Franklin was seen a single specimen of yellow spinel embedded in limestone, which presents the form of a simple cube. The cube has been deformed by pressure but is capable of contact measurement and shows scarcely a trace of the octahedron. It is unique among Franklin specimens of spinel in its cubic form and is an interesting link with the rare cubic forms of gahnite and franklinite also found there.

### GAHNITE

#### *Isometric*

*Forms.*— $a(100)$ ,  $o(111)$ ,  $d(110)$ ,  $q(331)$ ,  $n(211)$ , and doubtfully  $?(411)$  and  $? (811)$ .

*Habit.*—Gahnite is found only in crystals, with the octahedron dominant, in some crystals truncated by the dodecahedron. The cube is dominant in exceptional crystals from Franklin. The color is greenish black, clear dark green, greenish yellow, yellow, and blue. The specific gravity is 4.5 to 4.9.

*Occurrence.*—At Franklin greenish-yellow or blue octahedral crystals are not uncommon in the limestone wall rock and the ore body at the Trotter mine and southward along the vein. The name "automolite" was used by the earlier writers, beginning with Nuttall and Vanuxem, for the greenish crystals but no analysis of them is recorded. There is no reason to doubt the correctness of Alger's conclusion that they were the same mineral as the dysluite from Sterling Hill. Abundant sapphire-blue octahedral crystals of gahnite, reaching a diameter of three-quarters of an inch, were collected by J. E. Wolff in the wall rock of the Trotter mine in 1896. They are associated with gray pyroxene, titanite, and lollingite, embedded in coarse white limestone.

Gahnite of very unusual cubic habit was found by Brush in 1869 in a tunnel driven from the Wallkill River through the wall rock of the Buckwheat mine. The gahnite was in the Franklin limestone at its contact with either the ore body or the gneiss; the exact mode of occurrence was not observed, and the locality could never be relocated afterward. These crystals, the better part of which are now in the Brush collection at New Haven, range in size from an eighth of an inch to one and one-half inches, most of them small, and are of blackish-green color. Their hardness is 7.5 and their specific gravity is 4.9. Associated with them in the limestone were biotite, apatite, roepperite, and lollingite. They are unique among spinels in their dominant cubic habit, the faces of the cube being as smooth and brilliant as those of the other forms. The cube is modified by the octahedron and dodecahedron and by minute planes of  $q,n,(411)$ , and  $(811)$ , the last two rounded and doubtful. The facts as to this occurrence of gahnite are reported by Brush, whose paper included the analysis by Adam and was later illustrated with figures of the most typical crystals by Penfield.

At Sterling Hill beautiful crystals of gahnite, with jeffersonite and small crystals of brown garnet, were found very early by mineral collectors, in a large pocket or series of pockets in the limestone on the west wall of the eastern leg of the ore body. The best specimens are preserved in the Canfield collection and are among its greatest ornaments. The largest single crystal is a perfect octahedron 5 inches on an edge, of dark greenish-black color, with smooth bright faces.

Among many other specimens from the same locality in this collection are groups and separate crystals of gahnite in octahedrons from 4 inches on an edge downward in size, some attached to large crystals of jeffersonite, and either still embedded in or quite freed from the limestone matrix. Of the many crystals only one shows all the faces of the dodecahedron as narrow truncations; others show single sporadic faces of that form.

Small crystals of similar green gahnite could in 1905 still be seen in the limestone wall of this part of the old Passaic mine, and at several other points spinel crystals of this type were seen, though not analyzed for zinc.

This mineral was first mentioned by Vanuxem and Keating as new, under the name of dysluite, a name still used in the district to describe this occurrence. Dysluite was recognized by Dana as a varietal type, although as long ago as the time of Alger the fact was recognized that there is no difference between it and the so-called "automolite" of Franklin.



## MAGNETITE

*Isometric*

*Forms.*— $o(111)$ ,  $d(110)$ .

*Habit.*—Crystals of magnetite, presenting various combinations of  $o$  and  $d$ , are rare. The mineral also occurs in massive granular form, both coarse and fine. It is very similar in appearance to franklinite, from which, without a chemical analysis, it can be distinguished only by its black streak and stronger magnetism.

*Occurrence.*—At Franklin magnetite is found here and there, associated with or taking the place of franklinite in parts of the zinc-ore deposit, or forming lenses of granular iron ore, or in some places disseminated in limestone. Good crystals showing  $o$  and  $d$  were found associated with chalcocite and silver in ore of the Parker mine.

In the iron-ore bed underlying the zinc-ore deposit on its west side magnetite is the principal ore mineral, massive for the most part but in places crystallized on the walls of vugs. In such a vug from the Gooseberry mine the crystals of magnetite are attached to hornblende together with pyrite, the hole having been filled with calcite. The ore of this bed contains merely traces of zinc and manganese.

Magnetite is a constituent of the pegmatite, at some places only in minute amount but at others in considerable abundance, giving the rock a dark color.

At Sterling Hill magnetite is found chiefly in the pegmatite. It also occurs disseminated in the limestone and in isolated bunches of ore between the two legs of the zinc-ore body. Analysis shows such ore to contain considerable amounts of zinc but little manganese. Other phases intermediate between magnetite and franklinite—namely, magnofranklinite, poor in zinc and high in iron and manganese—are referred to under the description of franklinite.

## FRANKLINITE

*Isometric*

*Forms.*— $a(100)$ ,  $o(111)$ ,  $d(110)$ ,  $m(311)$ ,  $n(211)$ ,  $f(310)$ ,  $e(510)$ ,  $v(531)$ , and doubtfully  $q(331)$  and  $p(221)$ .

*Habit.*—Franklinite occurs in crystals, dominantly octahedral, in isolated grains, and in coarse to fine or compact, massive granular form. Many crystals show narrow faces of the dodecahedron on edges of the octahedron, and on some the dodecahedron is dominant, but all show the octahedron more or less developed. More rarely faces of the trapezohedron  $m(311)$  appear, generally small but on some crystals in balance with the octahedron. The trapezohedron  $n(211)$  was seen on only one crystal but there with distinct faces.

The trisoctahedron  $q(331)$  was also found but once, with narrow rounded faces between the octahedron and the dodecahedron. The trisoctahedron  $p(221)$ , given by Dana, was not seen by the author on any crystal, and no published record of its observation was found.

An entirely aberrant habit was observed on two or three specimens, the best of which are in the Hancock collection. Their exact source is not known but is believed to have been the Hamburg mine at Franklin. These crystals, which do not exceed a tenth of an inch in diameter, are cubo-octahedrons with a few faces of the forms  $d$ ,  $m$ ,  $n$ , and  $f$ . They are of adamantine luster, and thin splinters are translucent, with a deep-red color. Their unique habit and general spinelloid appearance suggested a new type of spinel but analysis showed the normal composition of franklinite. Crystallized with them on the walls of cavities in massive calcite-franklinite ore are prisms of pale-yellow willemite and white sphalerite.

In 1913 a small cavity was discovered by Mr. McGovern, of Franklin, in which were brilliant crystals of this type, showing a new form in two habits. This form is the tetrahexahedron  $e(510)$ , established by the measurements of Phillips. In one habit  $e$  is combined with the cube alone; in the other with the cube and the octahedron, all three forms being about equally developed. These crystals are of splendid luster and ideal symmetry. They are associated with excellent crystals of willemite and tiny rosettes of talc, in a matrix of cavernous gray dolomite.

Small cubic crystals were found on the walls of a cavity containing leucophoenicite, with the faces etched but still measurable. The cubic habit for franklinite appears to be characteristic only for those rare specimens where it has crystallized in an open cavity, under pneumatolytic conditions.

Rounding of the crystal edges and angles is almost universal, the crystals passing thus into rounded grains. On some of the rounded crystals the apparently curved surfaces are made up of a multitude of facets, and measurement of some such crystals showed that the facets are either vicinal faces with highly complex symbols or are contact surfaces due to growth against the enclosing limestone. In one specimen, however, from the Canfield collection, a mass of limestone containing several crystals as much as an inch in diameter, the crystals yielded measurements showing positively the presence of the hexoctahedron  $v(531)$ , a characteristic magnetite form.

*Physical characters.*—An octahedral parting is marked in some material but is generally absent. The hardness is 5.5 to 6.5, and the specific gravity is 5.07

to 5.22. The color is black, rarely with an iridescent coating, and the luster is brilliant metallic to dull. The streak and thin fragments are reddish brown. The magnetism in some material, to which the local name of "magnofranklinite" was given by Canfield, is as strong as that of magnetite, but other material is not sensibly affected by a pocket magnet. This difference probably depends on the relative amount of ferrous iron present, and all varieties are strongly attracted by the electromagnets in the separating machines.

*Composition.*—Although conforming to the spinel formula, the composition of franklinite shows a wide range, both in the relative proportions of iron, manganese, and zinc and in the state of oxidation of the iron and manganese. Although but one analysis actually records the presence of ferrous iron, the ordinary magnetism of the substance leads to the conviction that some ferrous iron is usually present; its accurate determination is impossible in the presence of manganous and manganic oxides. Manganese is probably present in both states of oxidation and the general formula probably applies to most specimens of the mineral. Special tests for titanium made on samples of franklinite from different parts of the deposit showed its presence only in traces.

*Occurrence.*—Franklinite is the dominant mineral of the ore body at Franklin, either forming thick beds free from any other material or mixed with various amounts of calcite, willemite, zincite, or rhodonite. It is commonly granular, or in isolated grains. Crystals are rare and are confined chiefly to parts of the ore body which appear to have undergone recrystallization, the ore constituents being embedded in calcite. In such places the crystals are likely to be very sharply formed and of brilliant luster. Such crystals, scarcely more than half an inch in diameter and with most brilliant luster, were not rare in material from the Parker shaft. At the Trotter mine slightly larger crystals, as much as one and one-half inches in diameter, were found. They show a tendency toward the dodecahedral habit, and some dodecahedrons are striated like magnetite, parallel to the intersection edge with the octahedron, the faces being dull. Many similar groups, taken from the Buckwheat and Taylor mines, were also seen.

At Sterling Hill also franklinite is the dominant ore mineral and occurs prevailing in granular masses. In the first explorations of the mines, however, at the very surface, crystals of extraordinary dimensions were found, the best of which are now preserved in the Canfield collection. These crystals are octahedrons, alone or with slight modification by the dodecahedron,

measuring 7 inches or less on an edge. They are attached to massive franklinite and with them is troostite in dull, lusterless crystals. They are said to have been embedded in dark-brown or black claylike material or wad, presumably the residue left from solution of the manganiferous limestone in which they were originally developed. They are of dull luster but of wonderfully perfect form.

From the Noble mine also came many dodecahedral crystals of nearly perfect form, dull and somewhat rounded as if etched, with small or no octahedral faces and very rarely the faces of the trapezohedron *m*(311). Much of this material was almost wholly lacking in zinc and was correspondingly rich in ferrous iron. This was the so-called "magnofranklinite" and was used as an ore of iron and manganese without previous roasting for zinc oxide.

Lustrous octahedral crystals of franklinite with rounded angles, embedded in granular zincite, were also characteristic of much of the ore at Sterling Hill, especially of the outcrop of the front vein.

*Historical notes.*—Bruce, who discovered the zinciferous nature of zincite, considered the black mineral associated with it to be magnetite. This it was generally supposed to be, and several unsuccessful efforts were made to work this refractory material as an ore of iron.

The true character of the mineral was first determined by the French chemist Berthier, who named it franklinite "in order to remind us that it was first found in a place to which the Americans have given the name of a great man." He gave an approximate analysis and the correct mineralogic characters.

Although thus early recognized as a distinct species, with a considerable content of zinc, it was for many years ignored as an ore of zinc, the whole attention of the zinc miners being given to the richer zincite. This oversight and the persistent consideration of franklinite as an ore of iron led to the peculiar division of mineral rights in the Franklin deposits into ores of zinc and ores of iron, which resulted in the long-fought lawsuits that for years retarded the development of the mines.

The value of franklinite as an ore of zinc was not recognized until later, when the invention by Wetherill of a furnace in which the zinc could be roasted off to form zinc white revolutionized the local practice, and the further improvement in treatment brought about by the perfection of the magnetic separator established it as the major zinc ore of the district.



## HETAEROLITE

*Tetragonal*

*Forms.*— $c(001)$ ,  $p(111)$ .

*Crystallographic measurements.*—Minute pseudo-octahedral crystals with the base, either simple or twinned on (101), with four individuals grouped about a central crystal, were found in a few specimens. There is generally some inequality in the size of the individuals, and in many groups some of the five are lacking. The crystals, though brilliant, are somewhat faceted.

*Physical characters.*—The color of hetaerolite is shining black with a dark-brown streak, with a specific gravity of 4.85. Hetaerolite is unaltered in the blowpipe flame and yields a zinc coating when reduced with soda or charcoal.

*Occurrence.*—The shining black crystals, none more than a tenth of an inch in diameter, line druses in thin veins that traverse massive ore. The vein filling is a massive or platy brown jeffersonite. The druses are few and contain also brilliant wine-colored and pink hodgekinsonite crystals, beryl-colored willemite, and calcite. All these are later than the hetaerolite, and calcite, in some places entirely fills the middle of the vein, forming molds about the crystals of hetaerolite on the walls. The specimens containing this mineral were brought to the author's attention in 1914 by Mr. Cahn. The association with hodgekinsonite proves that they were found in the northern part of the mine at Franklin, the only place where hodgekinsonite has yet been found.

The crystals from Sterling Hill are unmodified pyramids implanted on massive franklinite and show no twinning.

*Historical notes.*—Hetaerolite was originally found in abundance at Sterling Hill in oxidized material and was first described by Moore somewhat doubtfully as a zinc hausmannite. No further examination of the mineral was made until 1910, when the author published a new analysis by Schaller and concluded that it is zinc hausmannite, but in doing so he ignored a considerable content of water that was not accounted for. In 1913 Ford and Bradley described hetaerolite from Leadville, Colo., where also it was found amid oxidized ores. They concluded that it should be regarded as a hydrous oxide, but their material was impure and to obtain that result 10 percent of calamine had to be deducted from the analysis.

Bauer analyzed hetaerolite from a new occurrence of the mineral at Sterling Hill, where it is associated with unoxidized franklinite. This analysis shows scarcely a trace of water and gives an almost ideal ratio for zinc hausmannite. Thus Moore's original conclusion

that the mineral is a zinc hausmannite is confirmed. Under these circumstances it seems quite justifiable to use his name "hetaerolite", for the anhydrous oxide.

## RUTILE

*Tetragonal*

*Forms.*— $a(100)$ ,  $m(110)$ ,  $e(101)$ , and  $s(111)$ .

*Habit.*—Minute crystals of rutile of black color and brilliant metallic luster are found with other minerals in several localities in the Franklin limestone—with brown tourmaline in the Furnace quarry, with corundum and titanite in the limestone at the old furnace at Franklin, and generally in those pockets in which corundum is found. Rutile was seen with the brown tourmaline from the limestone quarries at Rudeville. At Sterling Hill it was found attached to corundum crystals that came from the stripping of the calamine deposits. In no place was rutile found in direct association with the primary zinc ores.

## GOETHITE

*Orthorhombic*

Goethite is found in minute acicular crystals of dark-brown color, implanted on tiny globules of hematite in cavities of the gray dolomite at the Buckwheat mine, Franklin.

## MANGANITE

*Orthorhombic*

*Forms.*— $a(100)$ ,  $k(230)$ , and  $u(101)$ .

*Occurrence.*—Manganite was found at Franklin in pillar 859, 20 feet below the 800-foot level south, about 75 feet from the footwall, in a vein in limestone with a network of vugs lined with calcite crystals, some of which were very brilliant. Implanted on the calcite are clusters of slender radiating needles of black lustrous manganite. The crystals are much striated and gave poor measurements, but the presence of the forms listed above was established. In another specimen the manganite crystals lined cavities in massive yellow andradite. Chemical tests confirmed these crystals as manganite.

Manganite was doubtfully reported by Brush at Franklin, associated with sussexite. Examination of the original specimens makes it certain that his material is oxidized pyrochroite. A specimen of what is probably manganite, pseudomorphic after pyrolusite, was found in the Canfield collection, but its source is unknown.

## LIMONITE

*Amorphous*

Limonite is found in massive and ocherous form, commonly as an alteration product of franklinite and magnetite in the deposits of zinc and iron ores. It has

been found abundantly only in the calamine deposits of Sterling Hill, where it was associated with chalcophanite and hydrohetaerolite in characteristic forms—coatings, stalactites, and ocherous powder. The character of this alteration is discussed under chalcophanite and calamine.

## PYROCHROITE

### *Hexagonal-rhombohedral*

*Habit.*—Pyrochroite forms rhombohedral crystals with a small base, which are pseudocubic; prismatic crystals terminated by the base alone or by the base and rhombohedrons; scalenohedral crystals approximating the unit rhombohedron in form; and foliated masses filling thin veinlets.

*Physical properties.*—Pyrochroite is colorless to pale pink, generally changing rapidly on exposure to the air, first to olive-green and then to opaque black. The cleavage is basal and perfect. Cleavage flakes, when unaltered, show a uniaxial optical figure.

*Composition.*—Pyrochroite is manganous hydroxide.

*Occurrence.*—At Franklin pyrochroite was found in several places on Mine Hill, being first recognized by Roepper in specimens from the Hamburg mine. These now show rough rhombohedral crystals and platy aggregates, implanted on pale-pink rhodochrosite, the whole being clearly from a secondary vein in massive franklinite-zincite ore. Mr. Hancock saw some of this material when it was first taken out and reported it as transparent and of greenish color. The black manganese hydroxide noted by Brush from the same mine, associated with sussexite, and doubtfully referred by him to manganite, is undoubtedly to be placed under pyrochroite. As seen on the original sussexite specimens in the Brush collection, the cleavage and platy structure in the black material were unmistakable.

The second occurrence of pyrochroite to be described was in the Buckwheat mine. All the specimens are said to have been taken from a single pocket or series of pockets that were clearly openings along a secondary vein traversing massive granular ore. These cavities are extraordinary for the great diversity of their mineral contents. Although many specimens were seen in several collections, none were available for analytical study, and the minerals could be identified only by inspection.

The walls of the cavities consist of a granular mixture of clear red manganese garnet, pink leucophoenicite, franklinite, orange-tinted zincite, and calcite. All these minerals are freely crystallized in the cavities—

the garnet in simple dodecahedrons, the franklinite in octahedrons, the zincite in pale orange-yellow, sharply hemimorphic pyramids, and the calcite in beautiful transparent prisms of peculiar habit; the crystals of leucophoenicite are described elsewhere. In places the calcite completely fills the vein.

Implanted on all these are three minerals in acicular form—gaugeite, in white to light-brown needles of square cross section and without measurable terminations; white willemite, in excessively thin needles, in places filling the whole cavity like a mass of spun glass; and chlorophoenicite, as determined by measurement and chemical tests, in faintly yellowish to white flattened blades or needles, some of them doubly terminated. In one tiny cavity were seen minute pale-yellow scalenohedral crystals that may be smithsonite.

Later than the first-named group of minerals and coeval with the acicular growths appears the pyrochroite. It is in shining black cubelike crystals, rarely showing the base, implanted on the earlier minerals or suspended in the tangle of acicular ones. These crystals have faces too curved to yield satisfactory measurements on the goniometer, but they gave characteristic blowpipe reactions that established their nature.

Tiny white rosettes of a fibrous crystalline carbonate are of the same period of growth. In some cavities a glassy, faintly pinkish mineral, in etched orthorhombic (?) crystals, coats the walls and all earlier minerals with a drusy covering or forms sparkling drops pierced by the needles of white willemite and held in midair. This mineral could not be identified. Lastly, a second generation of calcite is rarely seen, the tiny crystals being doubly terminated and placed daintily on the tips of needles of brown gaugeite or on cubes of pyrochroite.

In 1909 a new locality for pyrochroite was discovered at Franklin but in what part of the mine is not known. The author is indebted to Mr. R. B. Gage for the opportunity to study the specimens. The crystals are in loosely aggregated crusts on a surface of matted fibers of sussexite that coats the wall of a vein in massive ore. Individual crystals do not exceed an eighth of an inch in length. On casual inspection they appear black, but close examination shows that they are really pale yellow and transparent, with a very thin coating of black oxide of manganese. In this permanence they differ from all other known occurrences of pyrochroite.

The second-order prism is generally dominant, some crystals being terminated by the base alone and others chiefly by rhombohedral faces variously developed. Scalenohedral crystals were also found, which are believed to be the result of solution of crystals of rhom-

bohedral type. Their faces are rough and rounded and permitted only approximate measurement; they also show traces of a rhombohedron near the unit form. The scalenohedrons, the first observed on pyrochroite, is not, then, to be regarded as a typical form but is rather to be classed as vicinal.

In 1913 pyrochroite was found in a variety of forms, especially in the new deep levels at the extreme north end of the mine. Most abundant are small seams, only a fraction of an inch thick, in massive ore, the pyrochroite being either massive granular or in small rhombohedrons on the walls of open portions of the vein, and pale brown when first taken out but soon blackening. With it are crystals of calcite and aragonite and white acicular willemite, the last two being commonly regarded by collectors as gageite.

A very abundant occurrence described by Mr. Hodgkinson was found by him near the hanging wall of the west leg of the ore body, near a mass of pegmatite and contact garnet rock. This mass was about the size and shape of a large watermelon, was surrounded by lean ore, and was associated with numerous carbonate veins as much as 5 inches thick, which trend at right angles to the layering of the ore. The specimens received from this find are composed of dull-pinkish limestone, with drusy interior surfaces of pale rhodochrosite, coated with felted masses of silky sussexite. The pyrochroite occurs in large individuals, rudely rhombohedral, with brilliant cleavage. Single subparallel groups of crystals are as much as one and one half inches in diameter. The mineral when found was pink or pale brown and transparent to translucent, but after some weeks it turned black, without, however, losing its brilliant luster. Minute grains of yellow and of red zincite are disseminated through the pyrochroite, the crystals of which were too rough to yield measurements.

This cavity was but a few feet from the locality of leucophoenicite, which is entirely similar in its paragenesis. There is no doubt that both are contemporaneous with the carbonate veins, and their close association with pegmatite suggests a pneumatolytic origin. Pyrochroite is also associated with hodgkinsonite.

Pyrochroite has also been found at Sterling Hill, associated with rhodochrosite and zincite in a vein in normal calcite-franklinite-willemite ore. The pyrochroite is partly altered and contains cavities, which are lined and some of them filled with crystals of the new mineral mooreite. The crystals of mooreite are covered with fluffy aggregates of fluoborite, and some of the cavities in the pyrochroite are partly filled with similar material. Further details regarding these associations are given in the descriptions of mooreite and fluoborite.

## MANGANBRUCITE

### *Hexagonal-rhombohedral*

A single specimen of manganbrucite has been found as a thin veinlet cutting the franklinite-willemite ore at Franklin. The crystals are acicular parallel to the *c* axis, and the individuals are closely compacted to form subparallel aggregates with curved terminations made up of basal planes not quite parallel to one another. The color ranges from pure white to deep brown, depending presumably on the amount of oxidation the manganese has undergone. The refractive index is not constant but is higher than that of pure brucite.

## CHALCOPHANITE

### *Hexagonal-rhombohedral*

*Habit.*—Chalcophanite forms minute crystals tabular parallel to the base, or with the base and rhombohedron in equal development, giving an octahedral habit. It is commonly in lamellar aggregates, either crusts or stalactites, the plates being nearly perpendicular to the surface of attachment. Much of it is deposited on botryoidal surfaces of hydrohetaerolite or limonite or lines cavities with drusy surfaces. Such drusy crusts have a peculiar bluish-black color and a brilliant metallic luster, especially on freshly broken surfaces, owing to the perfect basal cleavage.

*Occurrence.*—Chalcophanite is known only from Sterling Hill, where it was discovered and described by Moore, then chemist for the Passaic Zinc Co. He states that it was found in cavities and fissures in a mass of debris made up of waterworn fragments of quartz and other rocks and of more or less decomposed franklinite, willemite, and zincite. This mass of material was commonly called the "stripping" of the calamine deposit at the Passaic mine and was used to some extent as an ore of manganese.

In 1882 Roepper announced a new hydrous oxide of zinc, iron and manganese, found at Sterling Hill, in the form of octahedrons, and gave to it the name "hydrofranklinite." His investigation was unfinished at his death but Penfield and Kreider on analyzing similar material, found it to be the same as chalcophanite, its apparent octahedral form being due to the habit of the rhombohedral crystals.

Its composition and mode of occurrence indicate clearly that chalcophanite is an alteration product of franklinite. Moore believed that franklinite was first changed to hydrohetaerolite, the iron being partly eliminated as limonite, and then by oxidation and further hydration the hydrohetaerolite was in turn changed to chalcophanite. The facts that chalcophanite

(continued on page 22)

*The following explanation will help readers to understand the references to localities, indicated by numbers on the map, that are now for the most part no longer in existence. The localities are numbered serially in geographic order from north to south:*

1. The Palmer shaft is an inclined shaft, sunk in the footwall gneiss, through which all hoisting of ore from the mine has been done since 1909.

2. The Parker shaft was a vertical shaft, sunk through the limestone, from which a cross cut was run at a depth of about 1,000 feet to intersect the ore body. Somewhere, probably near the ore, this crosscut encountered abundant pegmatite and a pneumatolytic deposit of extraordinary complexity, whose form, however, is unknown and whose nature is known only from specimens collected on the dump. The minerals found include native lead and copper, clinochroite, roebbingite, hancockite, glaucocroite, franklinite, leucophoenicite, cyprine, nasonite, axinite, datolite, willemite in exceptional crystals, barite, rhodonite, garnet, phlogopite, and many others. The Parker shaft was for a long time one of the chief openings of the mine, and minerals brought out through it may have come from almost anywhere in a considerable underground area.

3. The Hamburg mine was a small open pit on the outcrop, in which were found transverse veins containing sussexite, pyrochroite, greenockite, rhodochrosite, and remarkable radiate masses of fibrous willemite.

4. The Trotter mine was an inclined shaft in which the ore body was cut by numerous dikes of pegmatite containing fine microcline, thorite, zircon, titanite, and allanite. Notable contact effects were revealed, with the development of much garnet, pyroxene, rhodonite, and biotite and its alteration to caswellite and axinite. At the depth of 340 feet the shaft penetrated a pneumatolytic deposit consisting of yellow sphalerite, purple fluorite, niccolite, and chloanthite, the niccolite being partly altered to desautelsite. Secondary veins of sphalerite and recrystallizations of the primary minerals are common in specimens that were found on the dump from the Trotter shaft.

5. Double Rock was the outcrop, no longer in existence, of a large mass of pegmatite near the Trotter shaft, where abundant large crystals of garnet and pyroxene were found in the adjacent limestone.

6. In the west wall of the Buckwheat open cut was exposed a vein-like mass of gray dolomite containing in its cavities crystals of quartz, dolomite, albite, sphalerite, pyrite, millerite, and goethite.

7. The tunnel to the Wallkill River from the Buckwheat open cut yielded the unique cubical crystals of gahnite described by Brush.

8. In the Buckwheat mine (Buckwheat open cut or Southwest opening) the ore body was exposed by stripping off the overlying limestone in the pitching trough. Both the ore and the stripping yielded many interesting minerals contained chiefly in the transverse secondary veins of great variety. The Taylor mine, the deeper workings of this area, yielded similar minerals.

9. The Franklin Iron Co.'s quarry is in white limestone cut by pegmatite veins. Abundant metamorphic minerals, notably graphite, pyrite, pyrrhotite, arsenopyrite, fluorite, edenite, titanite, norbergite, tourmaline, and spinel, have been found there.

10. Furnace locality. In excavating in limestone for the foundation of the old iron furnace, pockets were found containing corundum, spinel, rutile, marcasite, mica, hornblende and other minerals, according to Mr. Hancock.

11. The Furnace quarry is an abandoned quarry in white limestone, which formerly yielded numerous metamorphic minerals similar to those found at locality 9.

12. Ball's Hill is the site of numerous magnetite mines, including the Hill mine and the Gooseberry mine, where were found scapolite, zircon, pyroxene, black garnet, and many other minerals.

13. The Fowler quarry, in white limestone, was once noted for crystals of pyrite and green tourmaline isolated in limestone. More recently pyrrhotite, brown tourmaline, graphite, edenite, spinel, and phlogopite have been the chief minerals found.

14. At this locality were found loose boulders of limestone containing, according to Mr. Canfield, large crystals of phlogopite.

15. At this locality, on the east leg of the ore body at Sterling Hill, was found the pocket containing the largest crystals of franklinite and of troostite in the Canfield collection. The principal locality for roep-perite was nearby.

16. The calamine pit of the Passaic mine yielded most of the finer specimens of calamine and of large red garnets and the minerals chalcophanite and hydro-betaerolite.

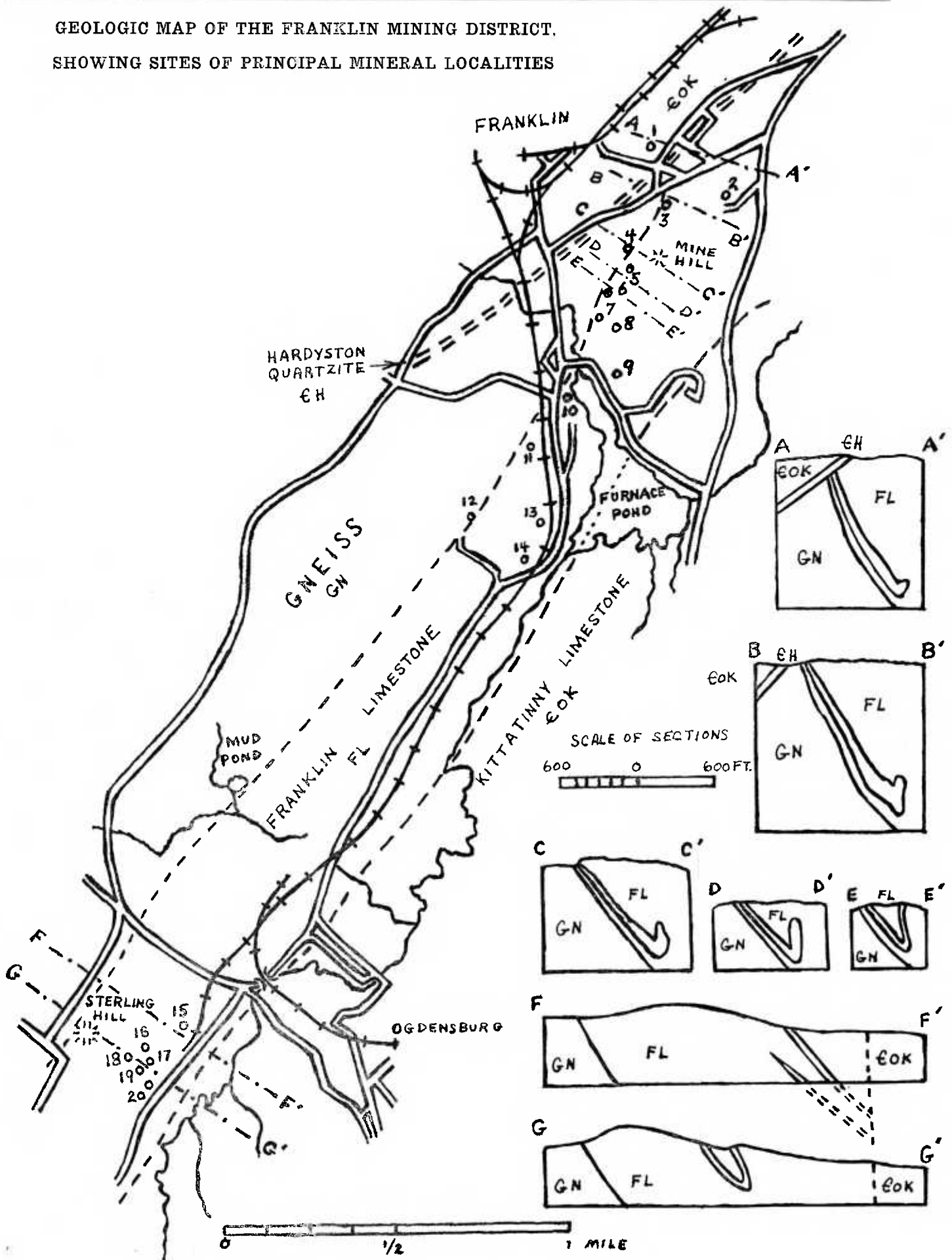
17. The Lord Stirling pits were those from which zincite was mined by Lord Stirling about 1772.

18. The calamine pit of the Noble mine, in which the calamine was mostly iron-stained, yielded corundum and the only tourmaline found in the zinc deposits.

19. The dysluite locality was an opening in the wall of the east leg of the ore body at Sterling Hill, where were found the remarkable large gahnites with garnet and jeffersonite, preserved in the Canfield collection.

20. At the mouth of a tunnel into the Noble mine was found a large pocket in limestone, containing large and complex crystals of aluminous pyroxene and amphibole.

GEOLOGIC MAP OF THE FRANKLIN MINING DISTRICT,  
SHOWING SITES OF PRINCIPAL MINERAL LOCALITIES



(continued from page 19)

is invariably found surrounding hydrohetaerolite where the two occur together and that some franklinite crystals, deeply etched, have been found coated in turn by hydrohetaerolite and chalcophanite give strength to Moore's theory of the origin of those peculiar and very local minerals.

### HYDROHETAEROLITE

#### *Tetragonal?*

*Habit.*—Hydrohetaerolite is found in fibers grouped in radiated masses with botryoidal or mamillary surfaces, also in massive granular and bladed forms.

*Physical characters.*—In mass the mineral is dark brown to black, with submetallic luster, and not unlike fibrous limonite in appearance. Under the microscope the fibers are dark brown, weakly pleochroic, and doubly refracting, with extinction parallel to their length. Cross sections of them show an obscure square form indicating a poor prismatic cleavage, and they give a faint uniaxial figure in convergent polarized light, indicating probable tetragonal crystallization. The streak is dark brown, the hardness is 5, and the specific gravity is 4.93(Moore) or 4.85(Schaller.)

*Composition.*—An analysis of type material from Sterling Hill, supplied by Mr. Hancock, shows the mineral to be a hydrous oxide of manganese and zinc. The ratio indicates a close approximation in composition to the accepted formula.

*Occurrence.*—Hydrohetaerolite is invariably associated with crusts of chalcophanite. This association was believed by Moore to be due to a progressive alteration of franklinite through hydrohetaerolite to chalcophanite, a theory for which there is strong confirmation in the observed facts of occurrence.

Hydrohetaerolite was found only at the Passaic mine, Sterling Hill, where it was abundant and was first recognized as a distinct mineral by Moore. As he gave no analysis and his description was incomplete, his conclusion that it is a zinc hausmannite was not accepted. For the further history of this mineral see hetaerolite.

### PSILOMELANE

#### *Amorphous*

On the dump of the Noble mine at Sterling Hill were found a few rather large, compact masses of coal-black manganese oxide which appear to be psilomelane. This mineral has never been recorded from the locality, but it is very likely a product of the alteration of franklinite, which has also led to the formation of chalcophanite and hydrohetaerolite.

Large amounts of black or brown claylike material, rich in manganese and probably of the nature of wad, intervened in places between the calamine bed and the limestone wall rock on which it rested. The instability of this layer of soft material caused much trouble in mining the calamine.

(to be continued)

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## "DESCRIPTION OF FRANKLIN FURNACE QUADRANGLE"

by

A. C. SPENCER, H. B. KUMMEL, J. E. WOLFF,  
R. D. SALISBURY and CHARLES PALACHE

1908

### GEOGRAPHY

by

A. C. SPENCER

#### *General Relations*

The Franklin Furnace quadrangle is bounded by parallels  $41^{\circ}$  and  $41^{\circ} 15'$  north latitude, and meridians  $74^{\circ} 30'$  and  $74^{\circ} 45'$  west longitude, covering one sixteenth of a square degree. It is approximately 17 miles in length and 13 miles in width, and has an area of about 225 square miles. The district lies in northwestern New Jersey, mainly in Sussex county, but including a small part of Morris county on the southeast. The principal towns are Newton, the county seat of Sussex County, Sussex (formerly Deckertown), and Branchville. Farming is the principal industry but zinc ores are mined and dressed at Franklin Furnace, limestone is quarried in several places, and slate quarries have been operated in Lafayette Township. The scenery and pure air of the Highlands and Kittatinny Mountain attract many visitors during the summer, the best-known resorts being Sparta, Stockholm, Branchville, and Sussex. The main line of the New York, Susquehanna and Western Railroad traverses the quadrangle from east to west and is joined at Sparta Junction by the Middletown division from the north. The Lehigh and New England Railroad and the Lehigh and Hudson River Railway extend across the quadrangle from southwest to northeast, and the Sussex branch of the Delaware, Lackawanna and Western Railroad connects Franklin Furnace, Branchville, and Newton with the main line at Netcong, N. J. The abandoned iron mines near Edison are reached by the High Bridge branch of the Central Railroad of New Jersey. The quadrangle is well netted with wagon roads, some of which, particularly in the Martinsburg shale belt, are excellent.

#### *Relief*

The Franklin Furnace quadrangle is divisible topographically into three parts—the Kittatinny Mountain region in the northwest corner; the Kittatinny Valley, a depression 7 to 10 miles wide and from 600 to 800 feet deep, lying immediately to the southeast; and the

Highlands, occupying somewhat less than one-half of the area, southeast of the valley. These several features have a northeast-southwest trend, which reflects the structure of the underlying formations.

Kittatinny Mountain slopes gently toward the northwest. Within the quadrangle its crest ranges in elevation from about 1400 feet to over 1600 feet, a single peak which reaches 1653 feet being the highest summit. The profile of the mountain crest, as a whole, is notably level, but this is not a marked feature within the quadrangle. The mountain heights represent an old surface of low relief, once extensive, but now preserved only in situations where resistant rocks have withstood erosion. The southeast side of the mountain presents a sharp declivity of 500 or 600 feet, below which the slope emerges into the floor of the wide valley.

The Kittatinny Valley is part of a broad longitudinal depression which bisects the Appalachian Province from Alabama to Lake Champlain. It is characterized geologically by rocks relatively less resistant to erosion than those of the bordering uplands. Within the quadrangle broken ridges, formed of many nearly parallel elongated hills, characterise those portions of the valley which are underlain by Martinsburg shale, and similar though less prominent features are present in the areas of the Kittatinny limestone. These ridges are parallel with the axis of the valley, with the general courses of the larger streams, and also with the average strike of the formations. In the central portion of the valley many of the summits rise to elevations between 750 and 800 feet, and a few are from 50 to 100 feet higher. These hilltops are remnants of a former topography which would be restored if the minor valleys of the wide depression were filled. The ancient surface thus defined rises gently from the southeast until it meets the steep slope of Kittatinny Mountain, and is obviously a feature of later origin than the Kittatinny Plateau. Within the several belts of Kittatinny limestone most of the hills rise from 50



to 150 feet above the stream grades, though a few summits are 50 to 60 feet higher. All the larger streams and many of the tributaries are bordered by extensive meadows and swamps, and the flows of the minor valleys taken together constitute a well-marked sublevel or platform below the general floor of the Kittatinny depression.

In New Jersey the Highlands occupy a belt about 25 miles wide lying between the Kittatinny Valley and the Piedmont Plateau. The district is roughly a plateau, as the component ridges and hills rise to a gently undulating surface. In the southern part of this quadrangle the general elevations of the summits is about 1200 feet; toward the northeast the hill tops are about 200 feet higher. Like the top of Kittatinny Mountain this upland surface was formerly a plain, and if the valleys were filled the plateau would be restored. Within the Franklin Furnace quadrangle most of the valleys are shallow and wide, and only the larger transverse streams occupy deep gorges. The Pimple Hills and Pochuck Mountain are outliers separated from the main area of the Highlands by the upper valleys of Wallkill River and Pochuck Creek. In the southeast corner of the quadrangle Green Pond Mountain, formed of resistant sandstones, rises to the general level of the Highlands Plateau, and between this mountain and the gneisses toward the northwest a broad valley has been excavated in soft Paleozoic formations.

#### *Drainage*

The quadrangle is drained by tributaries of three river systems, Wallkill River, flowing northward to the Hudson, receives the waters of more than half the area. Its valley heads just beyond the southern boundary, attains a width of about 5 miles south of Ogdensburg, and between this place and Franklin Furnace flares out to cover the whole of the Kittatinny depression.

West of an irregularly curving divide the northwestern slope of Kittatinny Mountain is drained by short streams to the Delaware, the western side of the area is occupied by the head waters of Paulins Kill, and the southwest corner drains to Pequest River. Musconetcong River, by way of Lake Hopatcong, receives the drainage of the south-central part of the quadrangle. All these streams flow by southwestward courses to the Delaware.

Two tributaries of Passaic River, the Rockaway and Pequannac, drain the southeast corner and a large part of the eastern side of the quadrangle. The northeast corner drains by way of Pochuck Creek to the Wallkill.

Though the district is one of considerable relief, to an important extent the platform of the stream valleys is imperfectly drained. Swamps and low meadows

border most of the streams, both within the Kittatinny depression and within the Highlands. The Wallkill descends but 340 feet in a distance of 20 miles. Near the northern edge of the quadrangle its fall is less than 20 feet in 6 miles, and here it flows through a strip of "drowned lands" which become more extensive farther north, in Orange County, N. Y.

Twenty natural ponds, lying within the area, owe their existence to drainage obstructions of glacial origin. Many small ponds and two of good size at Hamburg and Franklin Furnace are the work of man; and the level of several natural bodies of water has been artificially raised.

## DESCRIPTIVE GEOLOGY

### *General Relations*

by

A. C. SPENCER

The rocks of the Franklin Furnace quadrangle comprises a series of crystalline gneisses and limestone older than the Cambrian, stratified formations ranging in age from the Cambrian to Devonian, and intrusive rocks later than Ordovician.

The district exhibits the northeast-southwest trends of topography and areal geology which characterize the Appalachian Province southward from Hudson River. Red sandstone and shales occur in the northwest corner of the quadrangle, overlaying the more massive quartzites and conglomerates of Kittatinny Mountain. These formations, which are of Silurian age, dip to the northwest. Below them are Ordovician shales which cover the greater part of the Kittatinny Valley. Numerous dikes and a few stocks of nephelitesyenite cut the shale in the western part of Wantage Township.

The southeast side of the main Kittatinny Valley is occupied chiefly by a belt of Cambro-Ordovician limestone, separated from the old crystalline rocks by a thin basal sandstone of Cambrian age. Southeast of this belt and well within the general area of the older rocks are several outlying strips of limestone, in the upper Wallkill and Vernon valleys. Each of these strips is limited on the southeast by the basal sandstone and on the west by a fault of considerable displacement.

Between the Paleozoic stratified formations and the rocks of the ancient crystalline complex there is a great unconformity, the older rocks having been deeply eroded previous to the deposition of the Cambrian sandstone.

On both sides of the New York-New Jersey boundary the general area of the Highlands is divided longitudinally by a belt of Silurian and Devonian formations. This belt traverses the southeast corner of the Franklin Furnace quadrangle, where Green Pond and



Bowling Green mountains have been preserved by the presence of resistant Silurian sandstones and conglomerates.

Aside from the inlying strips of Cambro-Ordovician limestone and the belt of Silurian-Devonian rocks which have been mentioned, the rocks of the Highlands are gneisses and crystalline white limestones, with minor masses of coarse-grained granite or pegmatite and a few diabasic dikes. The highly metamorphosed limestones occur in a few minor areas west of Wallkill River, and in a zone extending from the vicinity of Ogdensburg northeastward well into Orange County, N. Y. The portion of the white limestone belt which falls within this quadrangle has a maximum width of nearly a mile and is 12 miles long.

That the quadrangle was occupied by the great ice sheet of the glacial epoch is shown by drift deposits of various sorts, by the absence of decayed rock material in place, and by scoured rock surfaces. All the natural ponds of the district are due to drainage obstructions of glacial origin.

## PRE-CAMBRIAN ROCKS

By: A. C. SPENCER

### *Introductory Statement*

#### General Relations

The Highlands of southeastern New York and New Jersey form a part of the Appalachian Province. They lie within an irregularly bounded and complexly interrupted area of rocks older than the Cambrian, which extends from Schuylkill River at Reading, Pa., northeastward across Hudson River into Putnam and southern Dutchess counties, N. Y.; Fairfield county, Conn.; and from Putnam County southward across Westchester County to Manhattan Island. This roughly hook-shaped area is bounded on the inside by the belt of Mesozoic rocks belonging to the Newark group, which extends from the Hudson Palisades southwestward across New Jersey and Pennsylvania. Around the periphery of the pre-Cambrian area on the northwest, north, and east, the rocks are Paleozoic. The boundary between the area of ancient crystalline rocks and the Newark belt is on the whole a simple one, but the line limiting the older rocks against those of Paleozoic age is sinuous in the extreme. The irregularity of this boundary and the occurrence of many strips of the Paleozoic formations within the general district occupied by the pre-Cambrian rocks result largely from the presence of many northeast-southwest corrugations of the sort characterizing the Appalachian region, to use that term in its broadest application.

The lower Cambrian formations may have been deposited over the whole region, but they now appear only in the areas where they were protected from erosion by having been infolded or downfaulted into the older rocks upon which they lie.

In Pennsylvania, New Jersey, and southeastern New York, from Reading on the Schuylkill to Hudson River, the Paleozoic rocks bordering on and included in the pre-Cambrian area are essentially unmetamorphosed. The Cambro-Ordovician limestone is nowhere changed to marble, and the overlying Ordovician shale, though exhibiting slaty cleavage in many places, has not been converted into schist. Throughout this zone the Paleozoic and pre-Cambrian rocks are invariably exhibited in sharp contrast, because the latter are so completely crystalline. Within the Paleozoic formations intrusive rocks other than diabase dikes of late Triassic age occur in one place only, namely at Beemerville, N. J.

East of Hudson River the aspect of the lower Paleozoic formations is very different. Immediately north of the pre-Cambrian area in Dutchess County, N. Y., the rocks of "Hudson" time are almost uniformly slaty, and the limestone which occurs between these slates and the pre-Cambrian rocks is crystallized to a considerable extent. In eastern Dutchess County and in northeastern Putnam County the Paleozoic rocks exhibit ever greater alteration. The shale and limestone have been completely crystallized, the former being converted into mica schist and the latter into marble. Still farther east, in Connecticut, intrusive rocks appear and are present generally beyond the eastern border of the Westchester county pre-Cambrian area. The Paleozoic rocks that lie within the general pre-Cambrian area in Putnam and Westchester counties, N. Y., are likewise highly metamorphosed, and locally are also invaded by igneous intrusions. In certain parts of this district the pre-Cambrian rocks, including the Fordham gneiss described in the New York City folio, have suffered the same deformation as the Paleozoic formations associated with them, and it is often a matter of difficulty to distinguish these gneisses in their altered form from phases of the Hudson schist.

In Pennsylvania, New Jersey, and southeastern New York the basement rocks comprise mainly several varieties of gneiss or massive feldspar-bearing rocks of a granular texture and foliated habit, rocks of similar composition but almost or quite free from foliation, very coarse granite or pegmatite, and crystalline limestones. Nearly all these ancient rocks are laminated in greater or less degree, and the different sorts are interlayered on both a large and a small scale in such a way that they usually appear at the surface as

relatively narrow bands. These bands have a general northeast-southwest trend throughout the region, and as a rule the dips of the structural surfaces are inclined toward the southeast.

Locally the gneisses carry valuable deposits of iron ore in the form of magnetite, and the same mineral is in some places associated with the white crystalline limestone. This limestone is especially noteworthy, however, because it forms the matrix of the unique deposits of zinc ore occurring in Sussex County, N. J.

Taken together, the pre-Cambrian rocks of this region show a close resemblance to the crystalline complex of the Adirondack Mountains and to the pre-Cambrian of the Green Mountain region, which in turn are like the rocks of the Laurentian area in Canada. They are different in their general make-up from some of the ancient rocks of the Philadelphia district and from the apparent correlatives of these rocks occurring in Maryland and Virginia.

#### *Character and Grouping of the Rocks*

The limestones, being composed essentially of calcite, are readily distinguished from the gneisses made up of silicate minerals in different combinations, but there are so many varieties of gneiss and the different sorts are so intricately mingled that detailed representation of their distribution is quite impracticable. As observed in the field, the most noteworthy differences of appearance presented by the elements of the gneissic complex are those of color, and inasmuch as color distinctions have been found to correspond broadly with fairly definite lithologic differences, they may be used as a guide in classifying the gneisses for the purposes of description and mapping.

All the dark gneisses which owe their color to the hornblende, pyroxene, or biotite which they contain, are grouped together under the name Pochuck gneiss. A second group, the members of which show brown-gray, bronzy, pink and ocherous tones, is called the Byram gneiss. Here are included a great variety of granitoid or granite-like rocks related to one another and distinguished from the other gneisses by the presence of potash feldspar as an essential ingredient. A third group, the Losee gneiss, includes light-colored granitoid rocks, many of them nearly white, which contain lime-soda feldspar as an essential and characteristic mineral component.

Rocks of intermediate composition do not in general constitute readily definable geologic masses, and as a rule it has not been found practicable to separate them from the other gneisses. However, several masses of coarse granite occurring in the northern part of the Pochuck Mountain are so distinct in appearance from

the surrounding rocks that their limits may be readily traced. This rock contains subequal amounts of potash and lime-soda feldspar and is like the granite of Mounts Adam and Eve in Orange County, N. Y., which invades the Franklin limestone.

All the rocks which have been mentioned are cut by irregular dike-like masses of pegmatite, but these rocks have not been mapped except within the general area of the white limestone.

The varieties of gneiss are seldom found in large masses free from intermixture with other sorts, but the different facies or varieties occur in tabular masses which are interlayered both on a large and on a small scale. The mingling is so intimate and the proportion of the lithologic facies are so various that even after bringing the varieties together in groups it is impossible to give a really faithful representation of their distribution on a map of small scale. As a matter of necessity, therefore, the bands which are distinguished on the geologic map represent merely the presence of varieties of gneiss resembling the designated type as the most abundant rocks in the area covered by the appropriate color or symbol. Mapping of the crystalline complex on this principle leads to the result that the boundaries shown are to a considerable degree arbitrary. They are therefore not to be considered in the same light as the hard and fast lines which can be drawn between the well-defined formations usually represented on detailed geologic maps. Furthermore, the various boundaries are arbitrary in different degrees, some of them being quite as definite as the boundaries between different sorts of granular igneous rocks, which one of these is intrusive into another, and others being located by personal judgment as to the most fitting line to indicate a general difference in the rocks occurring in adjacent areas. In many portions of the field, with a large-scale map, it would be possible to represent the occurrence of the different sorts of rock in great detail, but however minute the subdivisions might be made it would still be inevitable that the areas distinguished should represent preponderance of varieties rather than the occurrence of invariable rock masses.

#### *Structure of the pre-Cambrian*

The general structure of the Highlands pre-Cambrian complex rocks is monoclinical. The more or less well-defined layering between the various rock masses strikes on the average from southwest to northeast and dips usually toward the southeast, though rarely toward the northwest. Straight or gently curving structural features are the rule, but in many places individual layers or sets of layers, if followed along the

strike or along the dip, exhibit at intervals sharp, troughlike corrugations. These corrugations range in size from mere wrinkles to folds of considerable span. Usually they are very minor features compared with the notably great extent of the nearly straight layering which they modify, but in a few places they are of importance in determining the areal distribution of the different varieties of gneiss. Also, in some of the mines of the region, particularly in the zinc mines at Franklin Furnace and Sterling Hill, the ore bodies have the form of pitching troughs. Within the layers of gneiss, besides a commonly well-marked foliation due to the arrangement of the more or less flattened mineral constituents in parallel planes, there is in many places a distinct streaking or graining which runs diagonal to the strike and dip, in the same direction as the pitch of the corrugations referred to above. Locally the foliation may be observed to almost disappear and to give place to a pitching linear structure, produced by the grouping of mineral grains into pencils. The edges of some individual layers of gneiss exhibit a like pitch. The very general existence of obscure graining in this common direction, though usually not apparent to the eyes, is brought out by a topographic feature observable throughout the glaciated portion of the Highlands. The longitudinal profiles of the gneiss ridges are in many places like unsymmetrical sawteeth, with gentle slopes toward the northeast and a more abrupt falling off on the southwest. In many of the magnetite mines the ore layers are divided by pinches and swells into long pod-shaped shoots, nearly all of which, like the corrugations described, dip toward the northeast or east; and, where ore bodies are entirely capped or bottomed by barren rock, the edges of the shoots likewise pitch in the same direction.

Long faults running nearly parallel with the general strike of the crystalline rocks are known to exist mainly from the fact that movements along them have produced the existing insets of Paleozoic formations. Near these breaks the minerals of the gneisses are considerably decomposed, but the faults are ordinarily not traceable beyond the areas of younger rocks, owing to the presence of glacial drift north of the terminal moraine and to the deep mantle of decomposed rock farther south.

Cross breaks have been found in some of the mines but usually they are not important and few of them are discoverable on the surface.

#### *Origin and Relations of the Rocks*

The gneisses of the New Jersey Highlands, with few exceptions, correspond accurately in their mineralogical and chemical composition with common types of coarse-grained igneous rocks like the granites and

diorites. They differ from the usual igneous rocks in that they possess foliated or linear structures instead of evenly granular textures. The members of the gneissic complex which are present in the largest amounts are light-hued granitoid rocks, here included under the names Losee gneiss and Byram gneiss. There can be little doubt that these rocks have solidified in part out of silicate solutions or molten magmas, which moved while in a soft or plastic condition from the more or less distant regions in which they had originated into the positions now occupied by the resulting rocks. The fact that they comprise invading masses is shown locally by irregular crosscutting contacts, by the manner in which they inclose masses of older rocks, and in places by the development of metamorphic minerals along their borders. That large amounts of pre-existing rock material have been more or less completely dissolved and assimilated by the invading magmas is suspected but can not be affirmed.

In all the gneisses foliation is conditioned both by the interlayering of different varieties of rock and by the more or less elongated or flattened form of the component mineral grains and the arrangement of these grains in such a manner that their longer dimensions lie in sets of nearly parallel planes. Lamination of the first sort may be called structural foliation, and of the second sort textural foliation. Textural foliation may be developed during the first crystallization of a rock magma when consolidation takes place under the influence of some straining pressure, as for instance, while the material is flowing, or it may be induced through processes of recrystallization accompanying complete deformation of the rock after it had once solidified. Elsewhere in the pre-Cambrian rocks, notably in northern New York and Canada, foliation exists in different stages of development, leaving in certain localities no doubt of the secondary manner in which it has been produced. Throughout New Jersey, however, evidence of crushing in the minerals of the gneisses is almost entirely wanting and appearances strongly favor the belief that the gneissic foliation is original in the invading rocks of the pre-Cambrian complex.

Less abundant than the granitoid rocks, but still of considerable importance in the field at large, is the dark Pochuck gneiss. The rocks embraced under this term have the composition of igneous diorites or gabbros, but whether they have been derived from igneous or sedimentary originals, or, as is thought, in part from both, their present characteristics have in most places been acquired by metamorphism, involving secondary crystallization. In these dark rocks foliation is everywhere present, and parallel to this structure

the rocks are injected in all proportions by sheets of light-colored material similar in composition to phases of the Losee gneiss, with which these sheets are undoubtedly to be classed. In addition to being definitely injected by thin bodies of Losee rock, the dark gneisses are interlayered with both the Losee and the Byram gneisses on a broad scale, and the white crystalline limestones which occur here and there throughout the Highlands are similarly interlayered with the granitoid gneisses, so that these two sets of rocks—the dark gneisses and the limestones—together seem to constitute a matrix holding the intrusive granitoid rocks in the form of relatively thin but extended plates.

Apparently the dark rocks were already foliated before they were invaded, because the interlayering of the granitoid materials is so regular that the presence of some structural control would seem to have been a necessity. At the time of the injection, and perhaps as an effect of it, the dark rocks must have been reduced to a physical condition such that both in large masses and in thin plates their materials were able to adjust themselves to deforming pressure by solid flow instead of by rupture. During this deformation the early texture of the rock was broken down, important addition or subtraction of elements may have occurred, and a later crystallization ensued contemporaneous with the crystallization of the injected material. Both in the invading and in the invaded rock the process of crystallization went on subject to some widely operating control which, by allowing the mineral grains to grow more rapidly in certain directions than in others, gave them their flattened or elongated shapes and produced the observed foliated structure of the gneisses. The parallelism existing between the plates of rock and the foliation within them suggests as the most probable explanation that the forces causing flowage continued to operate after crystallization had begun, and practically until it was complete so that the injection of the granitoid material, the pressing out and kneading of the masses of the matrix, and the development of textural foliation in both were phenomena connected in origin with a single cause.

The Franklin limestone locally retains traces of original stratification, showing its sedimentary origin, but the lamination observed within masses of this rock is regarded mainly as a sort of flow structure developed through the crystallization of the limestone masses while they were being molded under the action of deforming stresses and at the same time traversed by mineral-charged waters derived from the invading Losee and Byram magmas.

Though it can not be claimed that determinable facts are sufficient to substantiate fully the relations and

history outlined above, yet the occurrence of the different sorts of rock as interlayered masses with generally parallel contacts, the pitch of various structures in a common direction, the interlocking of mineral grains along contacts, and the conformation of the foliation within individual layers with the general lamination of the complex as a whole are believed to warrant the conclusion that the white limestones and the various gneisses with which they are associated, together with the ore deposits which they inclose, came into their present state of crystallinity and received their present forms as geologic masses during a single period of regional deformation.

Subsequent to the crystallization of the gneisses and limestones, though perhaps before the period of general deformation had closed, the rocks were invaded by the irregular dikelike masses of pegmatite which now occur in them.

In past years the weight of opinion has been in favor of a sedimentary origin for the typical gneisses of the Highlands region, though it has been rather generally admitted that many of the more massive rocks which are associated with the highly laminated members might prove to have been formed in a purely igneous way. This view of the origin through the metamorphism of sedimentary rocks was advanced in 1836 by Rogers, the first official geologist of New Jersey, and although it was consistently upheld by his successors, Kitchell, Cook and Smock, the facts from which the conclusion was drawn now seem inadequate, and the conclusion itself appears not to have been based on strict deduction from observed facts. Investigation along this line of approach culminated in a report by Britton, published in 1886, in which the pre-Cambrian rocks of New Jersey (there designated Archean) were divided into three groups, separated primarily on the basis of differences in the perfection of gneissic structure, though for one group the presence of iron-ore deposits was taken as a distinguished feature.

The first geologist to throw well-sustained doubt on the sedimentary theory was Nason, who pointed out (1889) that existing knowledge was inadequate for a decision whether the gneisses in the Highlands have been derived from sedimentary or igneous rocks, or even possibly from a mixture of the two. A special study of the rocks in the vicinity of the iron mines at Hibernia, N. J., by Wolff (1893) led to the suggestion of a sedimentary origin for the rocks of this particular district, but the same geologist (1896) regards certain of the granitic rocks occupying extensive areas in the Franklin Furnace region as undeniably intrusive.

Two views have been held regarding the age of the white crystalline limestone of the Wallkill and Vernon valleys. It has been regarded on one side as a metamorphosed form of the blue Paleozoic limestone which occur in the same region, and on the other as a formation entirely distinct from this rock and of far greater antiquity. The latter view, which has been argued by Wolff and Brooks (1896) is here accepted without qualification.

#### *Local Distribution of the Formations*

Pre-Cambrian crystalline rocks, constituting a basement or floor upon which the Paleozoic sedimentary formations were deposited, underlie the whole of the Franklin Furnace quadrangle, but they appear at the surface only in the Highlands district. Though characteristic of that district, these rocks do not form all of its surface, but are locally covered by Paleozoic formations which appear at the surface in strips trending northeast and southwest, parallel with all the most noteworthy features of topographic and geologic structure throughout the general region.

The longest and widest inset of Paleozoic rocks within the Highlands contains formations of Silurian and Devonian age which are younger than any occurring elsewhere east of the Kittatinny Valley. These rocks, extending in a belt from one-half mile to 4 miles wide, from a point near Dover, N. J., to Green Pond, Bearfort, and Schunemunk mountains to Cornwall, N. Y., occupy the southeast corner of the Franklin Furnace quadrangle. Within New Jersey they meet the gneisses which lie to the west of them along a profound fault. In the Wallkill Valley are two narrow blocks of Kittatinny limestone, one 10 miles long and from one-half to three-fourths mile wide, the other 7 miles long and somewhat more than 1 mile in greatest width. A third strip of the limestone, occupying the Vernon Valley below McAfee, continues toward the northeast to the New Jersey-New York line, beyond which it widens into a broad area of lower Paleozoic formations west of which no pre-Cambrian rocks appear.

The various rocks, grouped and set apart in the manner outlined under a previous heading, are disposed upon the surface in relatively narrow northeast-southwest bands, which, like the inset strips of Paleozoic strata within the crystalline area, conform in direction with the principal features of the topography.

The rock groupings which have been represented on the map of the Franklin Furnace quadrangle, and which are described in the following pages, are as follows: Franklin limestone, Pochuck gneiss, Losee gneiss, Byram gneiss, granite and pegmatite.

#### *Franklin Limestone*

*Distribution.*—The Franklin limestone forms a band 22 miles long and from half a mile to 2 miles wide, extending from Mounts Adam and Eve, in Orange County, N. Y., in a southwesterly direction to the vicinity of Sparta, N.J. Throughout the 12 miles of this belt which lies within the Franklin Furnace quadrangle, its width between the gneisses which bound it on either side would seem to be rather uniform, but the surface outcrop of the limestone is far from regular, because of the presence of several strips of Paleozoic strata that partly hide the older rock. On the west side of Vernon Valley the width of the white limestone outcrop is less than one-half mile, its eastern side being capped by the blue Paleozoic limestone. At McAfee, where the whole band is seen, it is 1 mile wide, but a short distance to the south the limestone is again partly hidden by two strips of the Paleozoic strata, which probably unite under the covering of glacial drift in the vicinity of Hamburg, as represented on the areal geology map. Toward the south the western boundary of the white limestone against the gneiss is covered as far as Greenspot (Franklin Furnace post-office), where the northernmost surface workings of the zinc mines are situated. Here the total width of the band may be seen, though its continuity is interrupted by the wedge end of another strip of the Paleozoic strata, which a short distance farther south overlap the eastern side of the white limestone and cover both its contact with the gneisses of the Wallkill Mountains and the southern termination of the white limestone belt between Ogdensburg and Sparta.

Several detached masses of white limestone are present within the area of gneisses which lies southwest of Franklin Furnace and west of Wallkill River. The largest of these masses is about 3 miles due west of Newton, extending along the western base of the Pimple Hills from Pinkneyville nearly to Sparta Junction. The area in which this rock comes to the surface is spindle shaped, about 2 miles in length and one-fourth mile across in the widest place. On the west the white limestone passes beneath the overlapping Paleozoic beds. Three-fourths mile southwest of Franklin Furnace the rock is exposed in a club-shaped area, over a mile in length, lying about one-fourth miles west of the main belt. It is very likely that this area has a greater length than is proved by the outcrops. Possibly it connects beneath the mantle of glacial debris with exposures west of Sterling Hill, and these in turn may be part of a continuous band extending to the patch about 1 mile southwest of Sterling Hill, or even to the small outcrop 1 mile farther south. The area of limestone east of Woodruff Gap may extend farther to the

southwest than has been represented on the map, but there are no outcrops in this direction. So also the narrow belt which lies just to the south may run out into the swampy ground for some distance, and the next belt to the east may connect beneath the glacial mantle with the outcrops on the edge of the swamp three-fourths of a mile southwest of Sparta. The last-named outcrops are so situated in respect to the long, narrow band of the limestone which lies at the base of Briar Ridge that an actual connection between them seems to be very likely.

*Description.*—The Franklin limestone is a white, highly crystalline limestone or marble, varying greatly from place to place in texture and composition, and to a less degree in color. As a rule it is coarsely granular, being made up of large anhedral (crystalline grains not possessing the exterior faces characteristic of perfect crystals), which show a very perfect rhombohedral cleavage. Almost everywhere pressure twinning is observed, as indicated by parallel planes of parting distinct from the characteristic cleavage. Some of the rock is very finely granular or even nearly amorphous. The color is usually milky white and the cleavage surfaces of the calcite give the rock a lustrous aspect. Locally it has a pink or yellow tinge and elsewhere it is grayish. Where free from included minerals the limestone ranges in composition from a nearly pure carbonate of lime through magnesian limestone to dolomite. Some of it is rather siliceous, and in a few places thin beds of sandstone have been noted. Differences in composition, accompanied locally by textural changes, are recognized in all the quarries where the rock is worked for lime, and in many places the several varieties occur in layers having every appearance of true strata. Taken as a whole the rock contains a large number of minerals which present considerable interest to the mineralogist. The deposits of zinc ore inclosed in it are of great economic importance, and because of their unique characters are of very great scientific interest. Magnetite veins also are present in this limestone. Among the more common minerals is graphite, occurring in brilliant scales disseminated throughout the more coarsely crystalline rock in such a manner as to produce a foliated appearance. White or yellowish mica (phlogopite), pyroxene (diopside), and chondrodite are also common, and those minerals, like the graphite, are distributed in such a way as to give the rock a gneissic structure.

The white limestone has found a considerable use in the manufacture of lime and for furnace flux in iron smelting, as is more fully shown in the discussion of economic geology. The analyses appended show the

presence of both magnesian and pure calcium rocks in the white limestone belt.

*Mineralogy.*—The white limestone of Sussex County has for many years been famous for the variety and beauty of the minerals which it contains, and the zinc mines at Franklin Furnace and Sterling Hill have afforded several new mineral species, some of which are not known to occur elsewhere. Ninety-one authentic species have been noted. Fifteen of these were originally described from one or the other of the two localities named, and eleven have thus far been found nowhere else. The three minerals—zincite, franklinite, and willemite—which constitute the ores of zinc occurring in large deposits at Franklin Furnace and at Sterling Hill are not found at any other locality except in minor amounts. A fuller description of the minerals is given in the section on "Mineralogy", by Mr. Palache.

*Structure.*—Stratification is so obscure in the Franklin limestone that it is not ordinarily noted in the study of surface exposures. In the extensive quarries at Rudeville, and especially in those at McAfee, however, undoubted bedding may be observed, and indications of it can be made out in the quarries near Franklin Furnace. At McAfee, several layers of highgrade limestone have been worked for considerable distances along the northeast strike, and one bed which has been followed for more than 1200 feet was found to lie throughout this distance between persistent masses of rock quite different from it in physical properties and practically valueless for the manufacture of lime. At this place the beds, which lie in parallel position, strike northeast and southwest and dip from 60 to 75' SE. Bedding is observed also at the Rudeville quarry of the New Jersey Lime Company (formerly called the Hamburg Quarry). Here there is an anticlinal fold, and the valuable limestone forms a stratum approximately 60 feet thick, which in the workings may be seen to dip both to the northwest and to the southeast from the place where the quarry was first opened. On both sides the workable rock dips beneath a cap of siliceous limestone (locally known as bastard rock) and in the center of the quarry the bottom of the good rock has been reached. Careful study shows that the arch pitches toward the northeast. In the eastern corner of the excavation a stratum of limy sandstone about 6 inches thick was seen resting upon the good lime rock and grading into the overlying siliceous material. The presence of this sandy bed between the two varieties of limestone seems to prove definitely that these layers are true stratified beds.

One of the most striking exhibitions of stratification is to be seen in an abandoned quarry about one-fourth mile northeast of the one just mentioned, on the property of the Windsor Lime Company. Here two massive beds

of good lime rock about 20 feet apart have been worked out for a length of 200 or 300 feet and to a depth of 50 feet or so below the surface of the hill. These two beds are somewhat wavy, but they are essentially parallel, striking, as at McAfee, northeast and southwest and dipping steeply toward the southeast. The rock between them is distinctly bedded, the different layers varying in thickness, texture, and color, and probably in composition, as one of them has an earthy appearance.

The zinc ore bodies have been regarded by some geologists as representing true strata, which either originally contained the metals now found in them or, because of peculiar composition, were particularly liable to replacement by metal-bearing solutions not capable of similarly affecting adjacent strata of a different sort. Nothing besides the occurrence of the ore bodies in the form of layers can be cited in favor of this view, for there is no provable bedding in the limestone in the vicinity of the ore bodies.

Wherever undoubted stratification can be made out any foliated effect produced by the presence of silicate minerals is almost invariably parallel with the bedding, and throughout the main belt of limestone, as well as in other places, where the rock is found in small masses, these streaks of accessory minerals follow the northeast-southwest course of the bands of limestone, which in turn conform with the structural trends in the inclosing gneisses.

Much of the structure in the limestone is probably not bedding, but a secondary feature acquired during the great deformation which the limestones have undoubtedly suffered. Of this superinduced nature is a certain bluish banding which is to be observed in almost all localities where the limestone has been exposed to view by quarrying and which is due to streaks of amorphous carbonaceous matter distinct in character from the graphite. The general effect presented by the structure of the limestones can not be better or more definitely expressed than by mentioning that it closely resembles the structure of the inclosing gneisses.

*Age.*—The question in regard to the age of the limestone, which was long in dispute, has been settled by the work of Wolff and Brooks, published in 1896. These geologists have shown that the white limestone was metamorphosed to its present condition long before the deposition of the Hardyston quartzite, and that it is therefore entirely distinct from the blue limestone lying stratigraphically above the quartzite formation and could not have been derived from it. Apparent transitions between the white and blue limestone, which had been described by earlier investigators in support of the opposite view, are shown to be confined to localities where the blue limestone has been faulted

down against the white rock and thereby metamorphosed to a certain extent. A case of this sort may be seen in the hill east of McAfee. Where normal or unfaulted contacts are observed, the Hardyston quartzite, though locally very thin, is invariably present between the two limestones, being conformable to the bedding of the Kittatinny but not to the structure of the Franklin limestone or to the foliation of the gneisses where these rocks underlie the Paleozoic strata. The general westerly dip of the quartzite and the Kittatinny limestone is quite as noteworthy and persistent as the almost invariable easterly dip of the foliation in the older crystalline rocks. The white limestone contains intercalated masses of gneiss and is injected by numerous bodies of granite (pegmatite), but neither of these rocks is associated with the younger formation. On the other hand, the Hardyston quartzite locally contains fragments derived from these granites, and even fragments of the coarse-grained limestone itself. Those interested in the earlier views of this question and in the details supporting the present conclusions should consult the Eighteenth Annual Report of the United States Geological Survey, part 2, 1898, pages 431-437.

*Relations with the other rocks.*—In several places in the Franklin Furnace area the white limestone is unconformably overlain by the Hardyston quartzite and the Kittatinny limestone. This relation has been clearly indicated on the economic geology map and the accompanying cross sections. The strips of Paleozoic rocks which lie within the general area occupied by the gneisses and white limestones are bounded on the west by faults, so that on this side their contacts with the older rocks are not normal. On the east side of each of these strips the relations, so far as known, are everywhere those of sedimentary overlap. Contacts may be studied at several points, and the evidence of unconformable deposition of the Hardyston quartzite upon the Franklin limestone can not be doubted in any place where good exposures exist, as in the creek bed below the road at Hardystonville, and about three-fourths miles west of McAfee, on the eastern slope of the hill east of the old Pochuck mine. This relation is most clearly exhibited beyond the north end of Pochuck Mountain, along the wagon road leading from Pine Island to Unionville, at a bend about one-fourth mile southwest of the point where this road is joined by the one from Merritts Island. At this place a few inches of entirely unmetamorphosed shale, containing grains of quartz sand and flakes of graphite, may be seen resting upon coarsely crystalline white limestone. Unaltered blue limestone is exposed only a few feet away, and the same rock forms a knoll near by, on the



northwest side of the road, whereas to the east white limestone cut by massive pegmatite forms a somewhat higher hill.

At Mounts Adam and Eve, in Orange County, N. Y., near the north end of the Franklin limestone belt, masses of coarse granite invade the limestone, producing considerable metamorphism along their contacts. The pegmatites occurring throughout the belt and in some of the outlying masses are likewise intrusive. Next to them there is at many localities evidence of important metamorphism, though in this respect great differences are observed from place to place, and some of the masses seem to have had little effect on the inclosing limestone. Taken as a whole, the limestones are not more crystalline at the pegmatite contacts than at a distance, and silicate minerals are found generally distributed without any constant relation to the proximity of these invading rocks. It is held, therefore, that the limestones were already highly altered at the time the pegmatites were injected into them.

The earlier metamorphism, which affects both the Franklin limestone and the Pochuck gneiss, is regarded as one of the results of the general invasion of the field by the granitoid Losee and Byram gneisses. In many places where the dark Pochuck rocks are seen to be cut by the Losee gneiss, as along the crest of the Pochuck Mountain, layer-like fragments of the matrix have been floated off into the invading magma. What appear to be similar shreds of the dark rock are found throughout the areas occupied by the Losee gneiss, and only less commonly in the Byram gneiss, so that the intrusive relations of both classes of granitoid rocks with respect to the Pochuck gneiss are rather definitely recognizable. With respect to the limestone, the relations are less clear, but the distribution of minor masses of dark gneiss and of limestone in the region west of the main limestone belt and the Wallkill Valley strongly suggests that these rocks, perhaps originally interbedded and considerably folded, were broken and torn apart by the invasion of the Byram gneiss. Several of these small masses of limestone are bordered by layers of dark gneiss which may be regarded as products of contact metamorphism. One of the masses of limestone exposed along the railroad northwest of Sparta is divided longitudinally by a narrow belt of gneiss, which appears to be an injected sheet connected along the strike toward the northeast with the surrounding fine-grained Byram gneiss. Rather numerous belts of lithologically similar material occurring in the limestone of the main belt are probably intrusive sheets, but inasmuch as it can not be certainly shown that they may not have been formed by the metamorphism of material originally interbedded in the lime-

stone, they can not be used as evidence in the present connection. South and southeast of the Franklin Furnace area, in the Raritan and Passaic quadrangles, limestones are found in contact with Losee gneiss, which is probably, though not certainly intrusive into them.

The relations which have been stated lead to the conception that the dark gneiss and the limestone form a general matrix holding the granitoid rocks as intrusive masses. Their invasion by so great a bulk of magmatic material would afford an adequate explanation of the widespread or regional metamorphism by which they are affected.

Though the Pochuck gneiss and the Franklin limestone are both regarded as older than the granitoid gneisses, the original relations between them are not determinable.

*Associated quartzite.*—There remain to be described certain beds of siliceous rocks which occur with the white limestones at three localities. The most prominent development of these rocks is at the old Andover iron mine, near the southwest corner of the quadrangle. Here siliceous breccia and indurated carbonaceous shale occur in the form of strata having an aggregate maximum thickness of 80 to 100 feet. These rocks contain irregular masses of iron ore, both hematite and magnetite, and mining operations have revealed them in a continuous northeast-southwest band about 1300 feet in length. In the southwestern pits the strata stand nearly vertical, but in the more northerly workings they show a dip toward the southeast, locally as low as 25'. As a whole, the rocks thus associated form a tabular mass contact with the gneisses, which are seen in contact with them on the southeast and are exposed at several points a short distance to the northwest. Limestone is not known in actual contact with these rocks, but several narrow bands are present nearby, separated from them by layers of gneiss and locally in part by masses of coarse granite or pegmatite. Also a large mass of limestone occurs at the old flux quarries half a mile south of the mines on the road to Andover.

The attitude of these evidently fragmentary or elastic rocks with respect to the gneisses at the Andover mine suggests that the latter may be metamorphosed sediments. Being interlayered with the gneisses, the siliceous rocks are entirely distinct from the Hardyston quartzite, which in part they somewhat resemble. From this formation they are also further distinguished by the fact that they are highly impregnated with the iron ore and by the presence in them of irregular dikes or veins of feldspar which seem to be related to the ordinary pegmatites of the region.



The remaining localities of the quartzite are in the main belt of white limestone—one of them at the Simpson hematite mine, 2 miles northeast of Hamburg, and the other a mile farther north, near the top of the westward-facing slope just west of McAfee station, where two pits have been opened in search of iron ore. At both of these places the rock is a glassy quartzitic conglomerate, dull red in color from the presence of considerable amounts of hematite. At the Simpson mine the quartzite lies in layers separated by shaly material, and, besides the iron oxide which impregnates the sandy beds, masses of pure ore are interlayered with the shale and the indurated sandstone. The exposures are very meager, as the hill is covered extensively by glacial drift, but enough is visible to show that the strata have a southeast dip beneath the limestone, though from the northwest they are closely approached by the basal quartzite of the unmetamorphosed Paleozoic rocks, if indeed they are not actually overlapped. The Hardyston quartzite and the blue limestone which lies above it here dip in a direction opposite to the ore-bearing quartzite—that is, toward the northwest.

At the Cedar Hill mine opening near McAfee, a massive red conglomerate, from 40 to 50 feet thick, stands nearly on edge. The rock is intercalated in the white limestone and although the limestone shows no independent evidence of stratification, the quartzite may be traced with probable continuity for a distance of nearly 500 feet. The rock presents a very fresh appearance, and though highly ferruginous it is too lean to be worked as an iron ore. Considerable iron pyrites is distributed through the rock, and portions of it contain crystalline grains of iron carbonate, one-half inch or so in diameter, which have a pearly color when freshly broken but are rust red on exposed surfaces.

The rocks at the three places mentioned have a general resemblance among themselves, and they are similar in a general way to the rocks which carry the hematite ores at Marble Mountain, near Phillipsburg, N. J. A detailed study of the Marble Mountain rocks and of their relations to the crystalline limestones associated with them would in all probability throw light on the occurrences in the Franklin Furnace quadrangle, which are too scanty in extent to furnish facts leading to any complete theory of their nature.

#### *Pochuck Gneiss*

*General statement.*—The name Pochuck gneiss was first employed by J. E. Wolff in describing the rocks of Pochuck Mountain, which lies in the northeastern part of the Franklin Furnace quadrangle. It is here used to include all the gneisses occurring in the High-

lands region that contain hornblende, pyroxene, or mica as principal mineral constituents. Some of these rocks are probably of sedimentary origin, and others may be altered igneous rocks, but in general they are so completely metamorphosed that their original nature can not be ascertained. Their relations to the other rocks of the pre-Cambrian region are not fully determinable, but on the whole they appear to be older than the intrusive Losee and Bryam gneisses. It seems probable that the metamorphism of the Pochuck gneiss and of the white limestone as well was produced during their invasion by the granitoid rocks in association with which they now occur.

*Distribution.*—Though the dark gneisses enter in varying amounts into the make-up of a large part of the crystalline complex, they are represented on the map only where they appear as the most abundant rocks in areas of considerable extent. A band entering the quadrangle on the east, near Stockholm, extends southwestward to the vicinity of Hopewell Pond, and west of the Wallkill Valley, in addition to several minor patches, there are two bands—one lying next to the south end of the white limestone, the other extending diagonally across the quadrangle from the southwest to the northeast corner. In very many of the iron mines of the Highlands district the magnetite ores are associated with dark hornblende gneisses.

*Description.*—Detailed examination of thin sections under the microscope reveals many varieties among the rocks which have been grouped as the Pochuck gneiss, but all varieties are characterized by dark hues attributable to the presence of hornblende, pyroxene, or mica as important mineral constituents. Usually the only light mineral present is oligoclase, but some facies of the rock contain considerable scapolite. Microcline is observed occasionally; andesine and labradorite feldspar but rarely. Quartz, though known, is characteristically absent. Accessory minerals, occurring in relatively small amounts, are magnetite, titanite, zircon and apatite.

These rocks range from medium to fairly coarse grained, and their texture may be described as foliated granular. The foliation is produced by the more or less elongated or flattened form of the mineral grains and the arrangement of these grains so that their longer dimensions lie in sets of nearly parallel planes. Many facies of the rock containing mica are so eminently foliated that they may be properly called schists.

The textural foliation of these rocks everywhere accompanies and conforms to a larger structural foliation produced by the occurrence of different varieties of the dark gneiss as interlayered plates, which are further separated or divided by parallel sheets of in-

jected light-colored rock. This platy structure or gneissic lamination conforms in turn with the broad structure of the pre-Cambrian complex, striking in general from southwest to northeast and dipping steeply toward the southeast.

*Stockholm band.*—Two strips of the dark rock entering the quadrangle from the northeast unite near Stockholm to form a band there somewhat less than half a mile across. A short distance farther southwest this band attains a width of more than a mile, which it holds almost to its blunt ending north of Hopewell pond.

The most abundant variety of rock in the Stockholm area contains grass-green pyroxene as the principal dark constituent, though certain layers carry hornblende or mica in company with this mineral. Moderate amounts of scapolite are present in many layers, and quartz is noted in a few places. The composition of the feldspar ordinarily lies between that of andesine and oligoclase, but some layers carry microcline in place of this variety of plagioclase.

The light-hued gneisses interlayered in the dark gneiss of this band are mainly Losee varieties, though Byram varieties are also present. Southeast of the band many plates of dark micaceous gneiss are inclosed in the granitoid rock and cut by large irregular masses of coarse pegmatite. Similar pegmatite occurs here and there within the area in which the dark rocks predominate.

In the northeastern part of the Stockholm band the foliation and layering in the gneisses strike northeast and dip southeast, in conformity with the structural rule of the district, but toward the southwest, in the wider part of the band, the rocks lie in a broad trough or synclinal fold pitching toward the northeast. The blunt ending of the area north of Hopewell Pond results from this structure. The direction of strike follows the boundary as shown on the map, changing from northeast to northwest and back to northeast. Correspondingly, the dips vary from southeast to northeast, and finally to northwest. Here, as elsewhere in the region, the dark gneisses are apparently invaded by the granitoid rocks, but it is not apparent whether the fold existed prior to the incoming of these rocks or was produced during the intrusion.

*Franklin Furnace band.*—The dark gneisses occurring between the main belt of limestone and the strip to the west in the valley of Wildcat Branch show mainly hornblende to highly micaceous facies, but with these rocks are some layers of paler hue containing light-green pyroxene. The indicated western limit of the band is very arbitrary, and rocks other than the dark gneisses are so abundant that the propriety of

representing this band on the map might be questioned. The interleaving layers are made up of granitoid material, in places quite like the Losee gneiss, but ordinarily pinkish and more like the Byram rock, microcline being their characteristic feldspar. Near Franklin Furnace the injected plates are narrow and as a rule not extensive. Here the feldspar is pink orthoclase and the rock is more than ordinarily coarse grained suggesting that it may be related to the pegmatites of the region rather than to the Byram gneiss. Irregular masses of very coarse-grained pegmatite, in respects like that inclosed by the white limestones, are prominent features throughout the band.

Within the Franklin Furnace band the structures strike northeast and dip southeast, so that the gneiss passes beneath the adjacent Franklin limestone, as is shown by the workings of the zinc mines at Franklin Furnace. Between the two rocks there is a sharply defined and essentially regular surface of contact, which conforms in attitude with the layering in the gneiss. There are, however, no features that would indicate the geologic relation between the gneiss and the limestone. Though the western leg of the deposit of zinc ore outcrops only a few feet from the gneiss-limestone boundary and runs parallel with it for several hundred feet, this conformity of structure is lost where the bend in the ore body begins. The fact that the contact line holds its course toward the southwest shows clearly that the surface between the two rocks does not partake of the synclinal structure which is shown by the ore body. This leads to the belief that the limestones have been deformed independently of the gneisses, and suggests that the existing relations along the contact may have been produced by flowage of the limestone against the gneiss.

*Western band.*—The prevailing rock in the Pochuck Mountain is hornblende-pyroxene gneiss, but layers composed mainly of hornblende and others rich in mica are interleaved with this rock in many places. Scapolite-bearing rock occurs on the eastern lower slopes between one and one half and two miles northeast of Hamburg, and the presence of cyanite schist along the eastern base of the mountain has been reported by N. L. Britton, though the present writer observed this rock only in the form of loose boulders.

In the northeast corner of the Franklin Furnace quadrangle the western band of Pochuck gneiss is divided by a wedge of Losee gneiss. On the east it is bounded by the white Franklin limestone, and on the west by Losee gneiss. Shreds or wisps of the dark rock are found in many places within the Losee gneiss of this part of the district. Interlayering of the dark and light gneisses is a prominent feature along the crest of

Pochuck Mountain, and both here and round about the dividing wedge the intrusive nature of the Losee rock with respect to the gneisses of the Pochuck can be readily observed.

Contacts between the dark gneisses of Pochuck Mountain and the white limestone of the Franklin belt are nowhere exposed, but the structures of the gneiss strike parallel with the boundary and dips on the average about 75' SE, so that the rock evidently passes beneath the adjacent limestone.

Beyond the narrow strip of Paleozoic rocks which hides the Pochuck gneiss southwest of Hamburg, northeast of the road leading from the grist mill above Hamburg to North Church, several outcrops may be observed in the narrow angle between the inset band of Kittatinny limestone on the east and the overlap of the Hardyston quartzite on the west. To the southwest, as far as the railroad tracks, there is but one exposure. Beyond the railroad the dark gneisses appear, and along the crest of the ridge opposite Monroe station they are bounded by white gneiss, a strip of which lies between them and the western edge of the pre-Cambrian area. From knobs of bed rock rising out of the sand plain east of Lake Grinnell, it is known that this westerly band of white gneiss continues beneath the glacial drift in the direction of Woodruff Gap. In the knoll northeast of Woodruff Gap (elevation 690 feet), and in the next knoll to the southwest (elevation 713 feet), a considerable amount of light gneiss occurs with layers of hornblende. The 713-foot knoll contains large amounts of pegmatite.

Associated with the Franklin limestone east of the 713-foot knoll are layers of gneiss containing pyroxene and scapolite, which have probably been formed by the metamorphism of sedimentary material. Layers of similar scapolite-bearing gneiss are present at several places in the continuation of the Pochuck band toward the southwest. At the Andover flux quarry, one-half mile south of the Franklin Furnace quadrangle, this rock is intimately associated with a mass of white limestone, and in the vicinity of the Andover and Tar Hill iron-ore mines it occurs in company with narrow plates of limestone and in places seems to pass into this rock by gradation along the strike. Both limestone and quartzite are present in the mine workings, and layers of garnet-bearing gneiss occur around Tar Hill.

The southwestern part of the western band of Pochuck gneiss is very poorly defined against the rocks which lie toward the east, the location of the boundary shown being very arbitrary. On the west, except for the strip of white limestone extending from Pinkneyville to Sparta Junction, the rock is limited by the overlap of Hardyston quartzite.

In the old mine workings north of Sussex Mills the limestone of the Pinkneyville area can be seen to come against the dark gneiss along a clean parting which dips about 50' SE, so that the limestone passes beneath the gneiss. At this place there is no appearance of gradation between the two rocks.

The structures in this portion of the western band strike northeast and dip southeast as a rule, although in the 1048-foot hill south of the New York, Susquehanna and Western Railroad a synclinal structure is observed.

The approximate mineral make-up of two examples of dark gneiss from Pochuck Mountain is shown in columns 6 and 7 of the table given under the heading "Description".

*Minor areas.*—The curved and forked strip of Pochuck gneiss which crosses the New York, Susquehanna and Western Railroad two miles east of Sparta Junction is composed mainly of rather coarse grained hornblende gneiss, but certain layers contain green pyroxene and others nearly colorless pyroxene and a blue-brown mica. Considerable magnetite is present in some specimens.

#### Mineral Composition of Pochuck Gneiss

	1	2	3	4	5	6	7
Quartz			33	52			5
Hornblende			8		20	52	2
Pyroxene	36	35	22		22	7	
Plagioclase	61		35	46	54	40	52
Biotite					trace	1	41
Magnetite	2	1	2	1	4		
Microcline		58					
Scapolite		5					
Titanite	1	1		1			
	100	100	100	100	100	100	100

1, 2, 3, 4. Gneisses from Stockholm band.

5: Dark gneiss occurring in Losee gneiss two and one half miles northeast of Stockholm.

6, 7. Dark gneiss from Pochuck Mountain.

The peculiar shape of this area reflects the structure of the gneisses, the layers of which are thrown into a northeastward-pitching anticlinal fold. The rock above and below the arch is Byram gneiss, inclosing the wisps of the dark rock. This structure may have existed before the granitoid rock invaded the dark gneisses, or it may have developed during the disturbance caused by that invasion; the point is not clear. It seems, however, that the distribution of the Pochuck and white-limestone masses with reference to the granitoid rocks must be interpreted as indicating the intrusive nature

of the latter, so that the dark gneisses and the white limestone may be regarded as together constituting a greatly disrupted matrix.

The dark gneisses which enter the Franklin Furnace quadrangle from the southwest at the head of Wallkill River have been arbitrarily mapped as occupying a narrow triangular area northwest of the fault which limits the strip of Kittatinny limestone.

*Dikes in the Franklin limestone.*—Thin plates of dark gneissoid rock are of common occurrence in the white limestone of the Franklin Furnace belt. In general there seems to be no way to determine their origin, but in a few places it is evident that they are really intrusive dikes. This relation can be clearly seen in the Rudeville quarries, where narrow plates of black rock fork in such a manner as to show definitely that the limestone has been invaded by them. The rock of most of these dikes is made up mainly of hornblende and scapolite, or of hornblende and oligoclase, but pyroxene and mica also occur in some of them. Titanite, magnetite, and pyrite are common accessory minerals. In the old Furnace quarry, southwest of Franklin Furnace, a narrow dike of dark rock contains microcline in place of the ordinary oligoclase.

The texture of the rock is invariably foliated by reason of a more or less tabular development of hornblende, magnetite, and pyrite are common accessory minerals in parallel planes conforming with the walls of the dike.

In Norway scapolite dikes essentially similar to those have been shown to be the result of a chemical alteration of rocks that were originally gabbros. A like alteration may have produced the scapolite-bearing rocks here, but the steps of such a change have not been recognized and it seems quite as likely that during the intrusion the invading material absorbed lime from the matrix and retained chlorine originally present in the magma, in this way acquiring the elements necessary to produce the unusual mineral scapolite.

#### *Losee Gneiss*

*General statement.*—The group of foliated granitoid rocks here called the Losee gneiss include the "Losee Pond granite" described by Wolff and Brooks. It is named from Losee Pond two miles northeast of Ogdensburg. The rocks of the group are mainly light in color and in many slightly weathered exposures nearly white. They are distinguished lithologically from the varieties of Byram gneiss by containing oligoclase (soda-lime feldspar) instead of microcline or micropertite (potash feldspars). They differ from the Pochuck gneiss in that they contain much quartz and only minor amounts of dark minerals.

The Losee gneiss is regarded as an intrusive igneous rock younger than the Pochuck gneiss and the Franklin limestone. Its relation to the Byram gneiss is not known, but it is cut by granite and by masses of pegmatite.

*Distribution.*—In this quadrangle there are four fairly well defined areas of the white Losee gneiss and two others less readily set apart. In the band from one to one and one-half miles wide next to the fault which limits the southeastern area of sedimentary rocks, the Losee gneiss includes many narrow layers of dark gneiss and a large amount of coarse pegmatite. This band is not sharply defined against the Byram gneiss to the northwest, so that the boundary given on the map is an arbitrary one. A second belt, which begins a short distance north of the Hamburg-Stockholm wagon road and runs southwestward through Losee and Morris ponds to the edge of the quadrangle, has a width of one-half mile to one and one half miles, and is known to be 20 miles in length. Though actual contacts between the Losee and the surrounding Byram rocks have not been observed, the limits of this band are closely determinable. In many places, but particularly along the edges of the mass, the white gneiss incloses innumerable layers of Pochuck rock, into which it has been intruded.

West of the Wallkill Valley an ill-defined belt of white gneiss about one mile wide lies between the Byram gneiss of Briar Ridge and the western band of Pochuck gneiss. Within this belt are many shreds of Pochuck gneiss and several strips of Byram gneiss. On the map the northern termination of this belt has been represented in an arbitrary way. The narrow strip of white gneiss extending for five miles northeast of Woodruff Gap is limited on the west by the Paleozoic formations with the area of the Losee rocks lying west of the dark gneisses of Pochuck Mountain. A triangular area of the Losee gneiss, greatly broken by strips of Pochuck, is inclosed within the band of dark gneisses in the northeast corner of the quadrangle. Toward the north this area widens, and in the northern part of Pochuck Mountain includes two strips of granite.

*Description.*—The Losee gneiss is recognized in the field by its lack of strong coloration. It is generally white in natural outcrops, and slightly tinged with green in artificial exposure where the fresh rock is brought to view. The rock is composed mainly of oligoclase (a soda-rich variety of soda-lime or plagioclase feldspar) and quartz. These minerals occur in variable proportions and are accompanied by minor amounts of mica, hornblende, pyroxene, and magnetite.

There are many variations in the mineralogical make-up from place to place. Locally in the western areas the oligoclase decreases in amount and is replaced by orthoclase and microcline. In other places considerable amounts of garnet are present, and still elsewhere a slight increase in the percentage of biotite, pyroxene, or hornblende is noted. The dark minerals occur singly or associated in more or less sharply defined bands, some of which closely resemble the black Pochuck gneiss, and it seems very likely that although some of the dark layers may be magmatic segregations, others may be partly dissolved shreds torn off from masses of the dark gneiss.

The Losee gneiss consists of more or less foliated, medium to coarse-grained granular rocks, in texture closely resembling granite. Though foliation is discoverable almost everywhere in the rock, lamination is not a striking feature to the eye because of the usual lack of color contrast in the component minerals. Examined under a magnifying glass or in thin sections under the microscope, the foliation is seen to be due to the disc-shaped grains of quartz and their arrangement in parallel position. The layering and foliation both follow the same trend as the boundaries of the belts, and the dip of these structures, as in the other rocks of the region, is ordinarily toward the southeast.

#### BYRAM GNEISS

*General statement.*—The rocks here grouped as Byram gneiss, named from their characteristic occurrence in Byram Township, Sussex County, include several varieties of granitoid gneiss which are lithologically related by the presence of potash-bearing feldspars among their principal components. As thus defined, the formation includes the "Hamburg," "Sand Pond," and "Edison" gneisses, which were separately mapped by Wolff in the Franklin Furnace district; the "Oxford type" of gneiss, described by Nason, and the gneissoid granite of Breakneck Mountain, on the Hudson, described by Merrill.

The composition of the Fordham gneiss of the New York City quadrangle corresponds with that of the Byram gneiss, and eventually the two may be proved to be equivalent.

The geologic relations of the Byram gneiss to the Pochuck gneiss and the Franklin limestone are very obscure, but the Byram appears to invade the other rocks. The structural relationship between it and the Losee gneiss is not known. In common with all the other pre-Cambrian rocks the Byram gneiss is cut by irregular masses of pegmatite. In many places the gneiss incloses minable deposits of magnetic iron ore.

*Distribution.*—West of the Wallkill Valley the Byram gneiss is the most abundant rock in a belt including Briar Ridge and the central part of the Pimple Hills. On the east it occupies a general belt including the Wallkill, Hamburg, and Wawayanda mountains, though in Sparta and Hardyston townships this belt is divided longitudinally by the Losee Pond band of the Losee gneiss.

*Description.*—The rocks here classed together are granitoid gneisses composed essentially of quartz and microcline or microperthite (potash feldspars), with variable proportions of hornblende, pyroxene and mica. Oligoclase (soda-lime feldspar) is usually very subordinate in amount, but here and there it equals the potash feldspar. Accessory minerals are magnetite, zircon, apatite, and titanite. Though considerable amounts of garnet are present in places, the occurrence of this mineral is sporadic. Cyanite occurs in the old mine workings at Edison. There are several facies of the rock which vary greatly in appearance as seen in the field, though almost without exception these facies show greater resemblance to each other than to varieties of the other gneisses with which they are associated. In a broad way the different varieties may be separated into two groups, according to the lighter or darker appearance of the rocks. The darker gneisses are the most widespread, but locally the light-colored varieties are prominently developed.

In the dark facies of the Byram gneiss the general tone in natural outcrops is ordinarily gray, but on freshly broken surfaces the rock shows a brownish hue, varying in depth according to the proportion of dark minerals present. This brown tone is accompanied by a bronzy effect produced by the luster of the feldspar cleavages. The bronzy rocks are moderately coarse to coarse grained, and in those which contain dark minerals the latter are more commonly hornblende or pyroxene than mica. Much of the rock is comparatively free from dark minerals, but even where these are absent the brownish color remains. A common dark variety contains considerable hornblende in crystals of moderate size grouped together in the form of pencils. These pencils, being arranged parallel to a common axis, give the rock a banded appearance on all sections except transverse to the axis, where the texture is essentially even granular. In the ledge these pencils almost invariably pitch toward the northeast, in conformity with the pitch of the ore bodies in the iron and zinc mines and the lines of corrugation in the gneisses. In other facies of hornblende rock the dark mineral is so distributed that the texture is merely foliated, or in some places simply granular.

The hornblende, pyroxene, and mica facies are widely distributed, but they grade into and are surrounded by larger amounts of rock containing only small proportions of the iron—and magnesia—bearing minerals.

The light varieties of the Byram are yellowish as seen in outcrop, and pink, light gray, or whitish when freshly broken. They are ordinarily somewhat fine grained and less foliated than the dark facies, and usually carry mica rather than hornblende or pyroxene. They are the most abundant rocks in the Pimple Hills and in three prominent knolls lying northeast of Sand Pond. In specimens of the Byram made up mainly of feldspar and quartz, the texture is commonly almost perfectly granular, but in the field some structure is usually to be detected.

The relations between the different facies of the Byram gneiss are regarded as closely resembling those observable in granites and other coarse-grained intrusive rocks. It has not been found possible, however, to determine the relative age of different facies of this

granitoid gneiss where they are found in association, and so far as present information goes all the varieties must be regarded as geologically contemporaneous and equivalent.

(to be continued)

Reprinted from: Spencer, A. C., Kummel, H. B., Wolff, J. E., Salisbury, R. D., and Palache, Charles, U.S. Geol. Survey Geol. Atlas, Franklin Furnace folio (no. 161). "Description of Franklin Furnace Quadrangle."

(Part Two of the Description of Franklin Furnace Quadrangle to be presented in Vol. III of the 1960 Digest will include the following: a continuation of Descriptive Geology; description of the magnetite iron ores of the district; description of the zinc-bearing ores; a summary with brief descriptions of the 91 minerals then known from the Franklin-Sterling district by Charles Palache with a paragenesis of the minerals of the zinc deposits.)

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The following publications and periodicals have printed information relative to the activities of the Franklin Mineralogical Association during the past 18 months:

*Rocks And Minerals Magazine*, Box 29, Peekskill, N.Y.: Jan.-Feb. 1958, p. 44; May-June 1958, pp. 227-228; Sept.-Oct. 1958, pp. 435-436; Nov.-Dec. 1958, pp. 523-524; Jan.-Feb. 1959, p. 43; May-June 1959, p. 242.

*Gems And Minerals Magazine*, Box 687, Mentone, California: Aug. 1958, pp. 70-73; Jan. 1959, p. 83; Feb. 1959, p. 78.

*Keystone Newsletter* (Mineralogical Society of Pennsylvania): May 1958, Vol. 7, No. 5, p. 6; March 1959, Vol. 8, No. 3, p. 8; May 1959, Vol. 8, No. 5, p. 6.

*The Mineralogist Magazine*, 329 S.E. 32nd Avenue, Portland 15, Oregon: Sept. 1958, pp. 195-197.

"The Exciting World of Rocks and Gems" by Elsie Lee, *A Trend Book* (No. 137), 5959 Hollywood Blvd., Los Angeles 28, California: pp. 120-123.

*Newsletter, The Geological Society of New Jersey* (Dept. of Conservation & Economic Development, 520 E. State St., Trenton 25, N.J.) Jan. 1959, p. 4.

## THE POST-PALACHE FRANKLIN AND STERLING HILL MINERALS

### PART II

The following descriptions are supplementary to an article begun with volume one of the 1958 Franklin Mineral Digest. The material here included is drawn from a number of authoritative sources and is presented to our readers as highly factual.

#### KUTNAHORITE

Kutnahorite occurs at Franklin as anhedral masses with curved cleavage surfaces up to three centimeters in size in a small veinlet cutting the normal franklinite ore. It is translucent, with a pale pink color. The vein is bordered by a thin layer of dark pink rhodochrosite(1).

#### ROWEITE

The new mineral was found on a single small specimen from the Franklin zinc mines, collected a number of years ago by Mr. George Rowe and preserved since then as an unidentified species. The specimen, of which about a quarter was used in the study, is a narrow veinlet of almost pure roweite with only small fragments of attached ore. The new mineral is intimately associated with a silky white fibrous material, which, from its optical properties and a qualitative chemical examination, appears to be thomsonite. Franklinite, willemite and zincite are present in small amounts, the willemite rather more intimately associated with the vein material, the other two minerals presumably part of the wall of the vein.

Crystals of roweite are light brown in color, lath shaped and without measurable terminations. It is orthorhombic with a strongly striated prism zone. The hardness of the mineral is about 5. The crystals are brittle and break with an even fracture across the elongation.(2)

The mineral was named by Harry Berman and F. A. Gonyer of Harvard University after Mr. George Rowe of Franklin, for many years Mine Captain and for as many years an ardent collector of Franklin minerals.

#### BRANDTITE

Brandtite has been identified among specimens collected at the Sterling Hill mine in 1940. So far as is known, this marks the first time that brandtite has been recognized from a U. S. locality, and adds one more mineral to the ever-growing list of species that have been found at the Franklin and Sterling Hill mines.

The brandtite was found at Sterling between the 1400 and 1500 foot levels. This portion of the ore

body contained ore of two distinct types, which were mined and processed separately: the "black willemite" and the "brown willemite" ores. The former is a very fine-grained intergrowth of franklinite and willemite; the latter is coarse-grained and consists essentially of brown willemite and calcite, with some franklinite. Sphalerite is also usually present up to several percent, as an ore constituent. The brandtite-containing vug was found in the hanging wall of a black willemite stope, at a point where over-breakage had trespassed slightly into the adjacent brown willemite ore body. The cavity was a crack about two inches long lined with drusy and hairlike crystals of several minerals. It was in the roof, which was very solid and hardly accessible and only a few small specimens of matrix containing less than a gram of brandtite altogether could be collected.

The crystals are colorless, up to 8 mm, in their longest dimension, seldom as much as 1 mm, or 0.2 mm or less in thickness. Associate minerals are rhodochrosite as a fine grayish-pink drusy coating; chalcopyrite, as minute groups of crystals; and an unidentified pink mineral as a thin powdery coating of crystals. These latter are square, tabular, apparently tetragonal, and have a luster and color similar to proustite. The ground-mass consisted of a coarse intergrowth of calcite, franklinite, brown willemite and sphalerite.

The brandtite crystals are simple and show the following forms in the unit and orientation of Dana (1951): *b*, *a*, *m*, *p*. Their habit is slender, prismatic and unlike the crystals from Harstig, Sweden which are more nearly equant. Cleavage (010) perfect and (001) good. Colorless and transparent.

X-ray powder photographs and single-crystal rotation and Weissenberg photographs confirmed that the material is identical with brandtite from Langban, Sweden. Insufficient material was recovered for chemical analysis, and the observed optics were close enough to those of brandtite from the type locality so that no major variation in the constituents would be expected.(3)

#### ARSENIC

Two microscopic natural arsenic crystals were examined in the Zinc Company laboratory at Franklin. The specimen was from Sterling Hill and the authen-



ticity confirmed by the late Lawson Bauer. A piece of calcite from near the ore body had been immersed in acid until only material, mostly silicates, not attacked by the acid was left. From this residue Mr. Bauer separated the two arsenic crystals.(4)

#### REALGAR

There were apparently at least two occurrences of this mineral, both at Sterling Hill. Realgar was associated with the arsenic as described under arsenic, in microscopic crystals along with arsenopyrite and graphite.

In 1940 some calcite which was uncovered had typical realgar along the cleavage planes of the calcite rhombs.(5)

#### BROOKITE

A mass of porous dolomitic limestone, recovered from the dump of the Buckwheat mine, was broken up into small fragments for examination under a binocular microscope. Many fine crystals of a number of minerals were found, including crystals of brookite.

The brookite occurred sparingly as small, lustrous, coal-black crystals, rarely more than 2 mm. in length.(6)

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(3) Gaines, Richard V. Brandtite at the Sterling Hill mine, New Jersey. *American Mineralogist*, Vol. 44, p. 199-200, 1959.

(4) Fisher, Kenneth. Help With Franklin Minerals. From the FMA library series.

(5) Same as (4).

(6) Gordon, Samuel G. Brookite crystals from Franklin, N.J. *Rocks & Minerals Magazine*, Vol. 26, Nos. 9-10, pp. 510-511. 1951.

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#### CORRECTION:

*Franklin Mineral Digest*, 1958, Vol. 1, page 31

ANDRADITE, Variety CEYLONITE, should read:

ANDRADITE, Variety MELANITE

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# A COMPARISON OF THE ORE DEPOSITS OF LANGBAN, SWEDEN WITH THOSE OF FRANKLIN, NEW JERSEY

by

CHARLES PALACHE, *Harvard University*

Readers of the *American Mineralogist* will recall that quite recently Dr. Flink(1) published in its pages an account of Langban and its minerals. He gives a description of the geology and ore minerals and a list of the very large number of species found there. However, he makes no attempt to describe the genesis of the ores nor does he segregate the numerous and peculiar minerals into paragenetic groups.

The genetic history of these deposits is the principal theme of a paper by Dr. Magnusson(2) which was made available to American readers in a review by Dr. Geijer(2a) in *Economic Geology*. This review does not, however, reproduce the paragenetic table which is of peculiar interest.

The author had the good fortune to spend two days at Langban a few years since under the guidance of Dr. Magnusson. He desires to briefly summarize the facts concerning the Langban mines in order to bring out their similarities to, and differences from those of Franklin. Geijer's review is so concise and clear that it will be quoted in large part; and by reproducing Magnusson's genetic table the details of the mineralogy will be clearly evident.

"The Langban deposit contains iron ores and manganese ores. Although closely associated they are well separated from each other, there being rarely more than two per cent manganese in the iron ores and the same amount of iron in the manganese ore. The country rock is dolomite. Both kinds of ore are clearly replacement deposits. The iron occurs as specular hematite and magnetite. Brick red jasperoid is associated with the hematite, while the magnetite is accompanied by skarn silicates, as diopside, amphibole and garnet. The magnetite ore and skarn surround the bodies of hematite and jasperoid. The relations clearly indicate that the former association is developed by a recrystallization and alteration of the hematite-jasperoid combination. An early stage in this is marked by the appearance of porphyroblasts of magnetite in the hematite.

"The manganese ore is braunite and hausmannite. The latter is accompanied by a skarn of manganese silicates, pyroxene, amphibole, garnet, and olivine. The relations between braunite and hausmannite (with

skarn) form an exact counterpart to those of hematite and magnetite. The development of hausmannite porphyroblasts is well illustrated.

"The parageneses now shown to belong to two distinct periods are explained as follows. At first iron was deposited as oxide, manganese as oxide and partly carbonate, some of which is also still left. With the iron came the silica of the jasperoid. The geological facts admit of no other explanation than that the iron and manganese ores belong to the same period of mineralization. The salient problem, then, is the explanation of their deposition as separate ore bodies. The presence of abundant oxygen appears to account for the separate deposition of iron and manganese, the occurrence of manganese oxide and carbonate but no ferrous carbonate, the presence of lead as silicates instead of sulphide, and of arsenic as acid radicals, etc. Later, a rise of temperature has caused the change of hematite to magnetite, of braunite to hausmannite, and the accompanying skarns.

"Lead, arsenic and antimony occur constantly in all the ores of Langban. Of the lead silicates, kentrolite and melanotekite occur with the primary ores, gano-malite and hyalotekite with the skarn ores. Similarly, the primary arsenate, karyinite is replaced by berzeliite. Therefore, also the lead and arsenic minerals can be divided into those of primary deposition and those of the second or skarn period. The same holds true of the antimony.

"Later than the skarn minerals are the 'fissure-minerals' representing a third period . . . regarded as an end phase of the skarn period. In this group is found a great part of the famous Langban minerals, as arsenites, native lead, pyrochroite, thaumasite, tilasite, margarosanite."

With this very clear picture of the general nature of the Langban deposit before us and with Magnusson's detailed paragenetic table it is possible to get some insight into the development of the remarkable complex of minerals found at Langban. The primary replacements were composed of few minerals, the chief ones of very simple composition. The rise of temperature which followed their deposition caused widespread chemical interactions of the original minerals with a great increase in the mineral complexity of the result-

## PARAGENETIC CLASSIFICATION OF LANGBAN MINERALS (AFTER MAGNUSSON)

ORE AND SKARN MINERALS		VEIN MINERALS
1st Period	2nd Period	3rd Period
<i>Iron Ores</i>	<i>Iron Ores</i>	<i>Both types of ore</i>
Hematite	Magnetite	Calcite
Jasper	Garnet	Aragonite
	Actinolite	Hydrocerussite
	Malacolite	Barite
	Forsterite	Gypsum
		Pyrochroite
<i>Manganese Ores</i>	<i>Manganese Ores</i>	Backstromite
Braunite	Hausmannite	Manganite
Rhodochrosite	Mn-Garnet	Sphenomanganite
	Rhodonite	Quenselite
	Schefferite	Pyroaurite
	Richterite	Barysilite
	Mn-Biotite	Pectolite
	Tephroite	Margarosanite
	Forsterite	Barylite
		Nasonite
<i>In Ores of both Types</i>	<i>In Ores of both Types</i>	Apophyllite
Kentrolite	Ganomalite	Inesite
Melanotekite	Hyalotekite	Thaumasite
Karyinite	Molybdophyllite	Ektropite
Langbanite	Trimerite	Dixenite
	Jakobsite	Armangite
	Plumboferrite	Tilasite
	Magnetoplumbite	Ekdemite
	Manganosite	Finnemannite
	Periclase	Ochrolite
	Bromellite	Allactite
	Pinakiolite	Sarkinite
	Berzeliite	Trigonite
	Hedyphane	Acrochordite
	Monimolite	Pyrobelonite
	Atopite	Lead
	Weslienite	Copper
	Swedenborgite	Silver
	Molybdenite	Bismuth
	Galena	Fluorite
	Chalcocite	Scheelite
	Sphalerite	
	Chalcopyrite	
	Bornite	
	Pyrite	

ing aggregate. Magnusson believes that nothing of importance was added to the deposit after the primary mineralization. Nevertheless, several elements appear in the skarn period which were not found in the earlier minerals. Boron in hyalotekite and pinakiole; beryllium in trimerite and bromellite; chlorine in hedyphane; are suggestive of magmatic additions. The sulphides, too, found in nests in skarns and magnetite appear to be additions. Manganosite and periclase are interpreted as resulting from the breakdown of rhodochrosite and dolomite, respectively.

The third period, that of vein formation, is marked by still greater mineral diversity. The veins are for the most part small gash veins, often with open vugs and generally containing abundant calcite. They are found in skarn, in both types of ore, and especially in the narrow spaces separating iron and manganese ore bodies, so they contain materials drawn from both sources. The author's impression gained during his brief visit to the mine and from the study of many specimens was that the vein material had not travelled far. Many of the minerals have been found in but a single vein or small group of them and Flink's description of the hundreds of specimens which have been preserved for study, in each of which occurs a single mineral or even a single crystal, indicates very local chemical reactions.

There is a noteworthy development of hydrous minerals which is in agreement with the lower temperature assumed by Magnusson to have prevailed during their formation. Barite is abundant and fluorine appears in fluorite and tilasite. Reducing conditions are indicated by the occurrence of native metals, lead especially being found in masses as great as fifty pounds in weight; and by the presence of arsenites like armangite and manganites like quenselite. The multiplicity of lead compounds and of arsenates and silicoarsenates of manganese is the chief feature of the mineralogy of the veins.

The idea has frequently found expression that the Langban deposits have much in common with those of Franklin. It is based on the fact that not only do both consist largely of iron and manganese ores but that a number of rather complex minerals are common to both and are practically unknown elsewhere. Such minerals are shown in the list that follows.

Schefferite, Mn-pyroxene  
Manganophyllite, Mn-biotite  
Tephroite, Mn-olivine  
Manganosite  
Pyrochroite  
Hedyphane  
Barysilite  
Margarosanite  
Nasonite  
Allactite

Dixenite, Langban, close to McGovernite,  
Sterling Hill

If we include with Langban in this comparison the closely similar deposits of manganese ore at Harstigen, Pajsberg and Jacobsberg we may add to this list:

Hyalophane  
Caryopillite—bementite of Franklin  
Ectropite—bementite of Franklin, probably  
Friedelite  
Ganophyllite

Those minerals then, common to both deposits, include manganese silicates, oxides and arsenates; and lead silicates. The list is not impressive. The principal ore minerals of the two localities are different. And there is the important difference that zinc is wholly absent from the Langban ores.

The geological history of the Franklin deposits is more diversified. There is, however, the striking analogy between the two that manganese-rich skarn has formed in great quantity at both, due to an increase in temperature after the primary minerals were implanted; at Langban this rise was apparently regional while at Franklin it was due to contact metamorphism of a local sort. At Langban the rarer elements whose presence led to the formation of a host of minerals, lead, arsenic and antimony, seem to have been introduced with the ore; at Franklin on the other hand the comparable elements, lead, arsenic, chlorine and sulphur, came in with the later pegmatite. If the mineralogical complexity of the two ore deposits is based on the length of the respective mineral lists, there is no great difference between them unless we include the as yet undescribed minerals from Langban in which case the balance lies heavily in favor of the latter. It is of course to be remembered that the deposits in New Jersey are vastly more extensive than those of Sweden so that the mineral richness of Langban is proportionately much more remarkable.

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- This paper which is in English gives much additional material on the geology of the mines, with a map.
- (Courtesy of: Contributions from the Department of Mineralogy and Petrography, Harvard University, No. 56.—From *American Mineralogist*, Vol. 14 (Feb. 1929) pp. 43-47).





*In memory of Bauer, Berman, Palache and  
the other giants of the Franklin era.*