The Minerals of Franklin and Sterling Hill Sussex County, New Jersey

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By CHARLES PALACHE

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

By Charles Palache

ABSTRACT

The mineral deposits of the Franklin area are remarkable alike for their great size, their wealth of mineral species, and the unusual character of the minerals composing them. More than 140 minerals, described in this paper, have been found in the district, 32 of which were first found there, and 30 are not known elsewhere in the world. This proportion is the more noteworthy because among the 30 are included 2 of the 3 principal ore minerals of the district.

The chemical composition of the ore bodies is not less unusual than their mineral complexity. Oxides of zinc, iron, and manganese, in a ratio of 3 to 2½ to 1, make up two thirds of their mass, and the remainder consists chiefly of calcite and silicates in a ratio of about 3 to 1. No other ore has an even remotely similar composition. It is therefore not remarkable that the interest of mineralogists has long been attracted to the deposits.

Geologists, too, find interesting problems in the area. The occurrence of similar deposits of roughly identical form at Franklin (formerly called Franklin Furnace) and at Sterling Hill, the age of the limestone containing them and its relation to other rock formations, the genesis of the ores and the processes through which they have acquired their present peculiar characters, and several minor problems—all have been and in part still are subjects of interested study and speculation.

Investigation of the Franklin ore deposits and minerals has extended over more than a century, but none of the many papers published concerning them includes an adequate description of both the deposits as a whole and of all the minerals found in them. Especially is there no comprehensive statement of the grouping of the minerals, as the lists of species issued from time to time give the reader little clue to the association of the minerals in the rocks. The preparation of this paper was first suggested by the realization of this lack, and the knowledge that the local collections are exceptionally complete and yet are inadequately described inspired the hope that it might be possible, even after a century of mining, to prepare a fairly complete and detailed description of the mineralogy of these remarkable deposits, in many respects the most interesting that this country possesses.

This paper contains a full description of the minerals of the district, preceded by a brief statement of their occurrence, geologic relations, and associations in the rocks and a résumé of the several hypotheses of the origin of the ore deposits.

INTRODUCTION

SOURCES OF MATERIAL

The study of the minerals of the Franklin area spans more than a century and is still far from complete. In this paper, data scattered through a score of journals have been compiled and combined to prepare a consistent and detailed description of the many minerals already found. The author has endeavored to summarize what has been published on the minerals known in the area and has therefore made many references to the literature. In order to avoid numerous footnotes, the papers in the practically complete bibliography are listed chronologically and numbered serially, and references are made by inserting in the text, in parentheses, the numbers, as listed in the bibliography, of the papers cited.

It has also been possible, through the study of collections, to fill many gaps in the knowledge of some species, and the data regarding the place and mode of occurrence of all known species were obtained as completely as possible.

Of the numerous collections studied, four stand out preeminently. Easily first is the Canfield collection, now in the United States National Museum. Begun about 1850 by Frederick Canfield and actively increased by his son, Frederick A. Canfield, it was long preserved in the family home near Dover, N.J. The suites of specimens from the earliest workings at both Mine Hill and Sterling Hill are very complete and are quite unrivaled. The collection is also rich in representative specimens of later discoveries. The frequent references to this collection in the mineral descriptions give some idea of the importance of the Canfield collection to the student of Franklin minerals.

The collection of Mr. E. P. Hancock, of Burlington, N.J., was particularly informing because most of its specimens were personally collected by him. During annual visits each mineral locality was watched and studied by him in company with Mr. Losey, of Franklin, and many new finds were made. Mr. Hancock was therefore able to furnish much valuable information regarding the occurrence of several minerals. After his death in 1916 his collection was acquired by Harvard University, where it is preserved intact as part of the Holden collection.

The Losey collection was long one of the mineralogic sights of Franklin. It had about the same range as the Hancock collection, as regards the earlier finds, but as the maker was no longer living when it was studied by the author it had to be viewed through Mr. Hancock's knowledge of it alone. It was acquired by Mr. A. F. Holden in 1911 and came to Harvard University as part of his bequest.

The collection of Mr. W. J. I. Kemble, at Newton, N.J., was also interesting, particularly for its personal associations. It was rich in series of the earlier mineral discoveries, and as Mr. Kemble's memories of Franklin reached back to the days when its mineral treasures were first being brought to light, and as many of his specimens had been collected on trips with visiting mineralogists of that earlier period, much valuable information was gained from study of this collection with its owner. The collection was dispersed after Mr. Kemble's death in 1915.

Other collections that furnished valuable data regarding Franklin minerals were those of J. J. McGovern, T. Lang, G. Rowe, E. D. Shuster, H. H. Hodgkinson, and G. Stanton, all in Franklin; that of W. A. Roebling, of Trenton, N.J., now in the National Museum; the collection at Rutgers College; the Bement, Caswell, and Columbia School of Mines collections in New York; the Brush collection at New Haven, with its many types of Franklin species; the Fiss collection of microminerals at Philadelphia; and the collections at Harvard University, among which the Stanton collection is now included.

ACKNOWLEDGMENTS

Through a variety of circumstances unnecessary to enumerate, this study has extended over a period of 25 years, and several of those to whom I am personally indebted are no longer living. Certain obligations, however, are too great to remain unmentioned.

Dr. John E. Wolff first suggested that I undertake the comprehensive study of the mineralogy of the Franklin district, my first visit to which was made in his company, and his aid has always been freely given. His intimate knowledge of the geology and mineralogy of the New Jersey Highlands, gained by years of close study, scant credit for which was given in the reports dealing with the area, has made his counsel particularly valuable.

To Mr. F. A. Canfield, who died in 1927, thanks were due for hospitality extended on repeated occasions, for invaluable information, for material for study, and for an excellent collection of photographs of his choicest specimens. Col. W. A. Roebling, until his death in 1927, repeatedly supplied material for investigation and comparison, and the study of his collection on more than one occasion yielded valuable data. Mr. Lazard Cahn has brought to the Harvard mineral collection, through a long term of years, many unusual specimens which his keen and discriminating eye had discovered in the local collections at Franklin, and these were placed freely at my disposal for study.

Mr. R. B. Gage, chemist of the Highway Commission of New Jersey, has supplied valuable chemical analyses and much material for study. Dr. C. H. Warren has contributed some unpublished analyses, and his friendly counsel has often been sought. During the last few years the most prolific source of information has been the staff of the chemical laboratory of the New Jersey Zinc Co. at Franklin. Mr. David Jenkins and Mr. L. H. Bauer have collaborated with me in many investigations, and several chemical analyses of Franklin minerals, made by them, are published here with the permission of the company.

To my colleague, Prof. E. S. Larsen, I am indebted for numerous optical determinations and for kindly advice, freely given. Also my assistants, Harry Berman and L. W. Lewis (died, 1933), have given me constant and unfailing help in optical and crystallographic determinations, in the separation of samples for chemical analysis, and in the preparation of many of the figures of crystals. Mr. Berman has also collaborated in the preparation of several papers on the minerals of the district. Mr. F. A. Gonyer has made several of the most recent analyses. Dr. Laurence LaForge has made a critical revision of the whole manuscript and has done much to eliminate from it the discrepancies resulting from repeated rewriting of parts of the text through a long period of years. He also made several of the drawings of crystals.

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1810

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2. Bruce, Archibald, Mineralogical notice respecting American fluates of lime: Am. Mineralog. Jour., vol. 1, pp. 32–33 (vol. pub. 1814). First mention of fluorite at Franklin.

1819

3. Berthier, P., Analyse de deux minéraux zincifères des États-Unis de l'Amérique: Annales des mines, 1st ser., vol. 4, pp. 483–494. Translated by Benjamin Silliman in Am. Jour. Sci., 1st ser., vol. 2, pp. 319–326, 1820. Mentions and confirms Bruce's analysis of zincite, stating that material examined had been sent by Maclure to Vauquelin in 1811. Names it manganesian oxide of zinc. Describes for the first time and names franklinite.

1820

4. Pierce, James, Account of the geology, mineralogy, scenery, etc., of the Secondary region of New York and New Jersey and the adjacent regions: Am. Jour. Sci., 1st ser., vol. 2, pp. 181–199. Describes the white limestone as "not Archean." No particular mention of Franklin.

1822

5. Pierce, James, Geology, mineralogy, scenery, etc., of the Highlands of New York and New Jersey: Am. Jour. Sci., 1st ser., vol. 5, pp. 26–33. Mentions occurrence of red oxide of zinc with "iron ores."
6. Silliman, Benjamin, Miscellaneous notices in mineralogy and geology: Am. Jour. Sci., 1st ser., vol. 5, pp. 39–42. Brief mention of sphalerite mixed with red oxide of zinc and "shot ore" (franklinite).

7. Nuttall, Thomas, Observations and geological remarks on the minerals of Paterson and the valley of Sparta in New Jersey: Am. Jour. Sci., 1st ser., vol. 5, pp. 239-248. Taken from New York Medical and Phys. Jour., vol. 1, pp. 194-204. Brief account of the geology of the ore beds at both Franklin and Sterling Hill. Mentions for the first time many of the commoner minerals of both localities.

8. Vanuxem, Lardner, and Keating, W. H., Account of the jeffersonite, a new mineral discovered at the Franklin Iron Works, near Sparta, in New Jersey: Acad. Nat. Sci. Philadelphia Jour., vol. 2, pp. 194-204. Describes and names jeffersonite, failing to recognize its true character as a pyroxene but giving an analysis.

9. Vanuxem, Lardner, On a new locality of the automolite: Acad. Nat. Sci., Philadelphia Jour., vol. 2, pp. 249-251.

10. Seybert, Henry, Analysis of the maclureite or fluosilicate of magnesia, a new mineral species from New Jersey: Am. Jour. Sci., 1st ser., vol. 5, pp. 336-344. First published analysis of chondrodite containing fluorine.

11. Torrey, John, Mineralogical notices: Am. Jour. Sci., 1st ser., vol. 5, pp. 399-403. Describes (p. 400) octahedrons of franklinite and reports occurrence at Franklin of "siliceous oxyd of zinc" (willemite) and "manganesian feldspar" (rhodonite).

12. Vanuxem, Lardner, and Keating, W. H., On the geology and mineralogy of Franklin, in Sussex County, N.J.: Acad. Nat. Sci. Philadelphia Jour., vol. 2, pp. 277-288. An excellent geologic account of the ore bed and the white limestone and a list of 29 mineral species found in the vicinity. First mention of dysluite, a new spinel.

1823

13. Troost, Gerard, Account of the pyroxene of the United States and descriptions of some new varieties of its crystalline forms. Acad. Nat. Sci. Philadelphia Jour., vol. 3, pp. 105-124. Describes and figures crystals of pyroxene and jeffersonite from Franklin, correcting Vanuxem and Keating's description of the form of the latter. One of the first American papers on descriptive crystallography.

14. Troost, Gerard, Notice of the yenite of Rhode Island and several other American minerals: Acad. Nat. Sci. Philadelphia Jour., vol. 3, pp. 222-224. Mentions several minerals from Franklin presented by Fowler.

15. Gibbs, George, Ittro cerite: Am. Jour. Sci., 1st ser., vol. 6, p. 379. Statement of the discovery of yttrocerite at Franklin. This reported discovery has never been confirmed.

16. Breithaupt, August, Charakteristik des Mineral-systems, p. 278. Describes and names, but without analysis, the mineral tephroite.

1824

17. Vanuxem, Lardner, and Keating, W. H., Observations upon some of the minerals discovered at Franklin, Sussex County, N.J.: Acad. Nat. Sci. Philadelphia Jour., vol. 4, pp. 3-11. First correct description of "siliceous oxide or silicate of zinc" (willemite), with analysis.

18. Troost, Gerard, Observations on the zinc ores of Franklin and Sterling, Sussex County, N.J.: Acad. Nat. Sci. Philadelphia Jour., vol. 4 (for 1824), pp. 220-231, 1825. Erroneous description of the crystal form of willemite and of zincite.

19. Seybert, Henry, Analysis of the pyroxene found at the Franklin Iron Works, near Sparta, N. J. Am. Jour. Sci., 1st ser., vol. 7, pp. 145-149. Analysis of jeffersonite, better than Keating's and confirming its nature as a pyroxene.

20. Seybert, Henry, Analysis of the melanite from Franklin Furnace, Sussex County, N.J.: Am. Jour. Sci., 1st ser., vol. 8, pp. 300-301. A poor analysis of black garnet.

1825

21. Fowler, Samuel, [Letter to the editor]: Am. Jour. Sci., 1st ser., vol. 9, p. 244. Adds several species to the Franklin list of minerals.

22. Robinson, Samuel, A catalogue of American minerals with their localities. (See Franklin, N.J., p. 162.) A list of the minerals recorded from Franklin, chiefly compiled from Nuttall (7).

1828

23. Thomson, Thomas, Chemical examination of some minerals. chiefly from America, with notes by John Torrey: Lyceum Nat. History New York Annals, vol. 3, pp. 9-86. Analyses, mostly poor, made by Thomson in Glasgow on material supplied by Torrey and by Nuttall. First analysis of tephroite and of rhodonite (impure fowlerite) and an incorrect analysis of willemite that led to much confusion regarding the nature of that mineral.

1829

24. Thomson, Thomas, [Analysis of polyadelphite]: Lyceum Nat. Hist. New York Annals, vol. 3, p. 9. This variety of garnet named by Thomson in his Mineralogy, vol. 1, p. 134, 1836.

1831

25. Breithaupt, August, Ueber die zinkhaltigen Mineralien aus New Jersey: Schweigger's Jour., Band 62, pp. 383-384. Corrects determination of cleavage of zincite and of tephroite.

26. Abich, Hermann, Chemische Untersuchungen des Spinells und der Minerale von analoger Zusammensetzung: Poggendorff's Annalen, Band 23, pp. 305-354. Gives analyses of gahnite and of franklinite, with a discussion of the formula of franklinite.

1832

27. Von Kobell, Franz, Ueber die chemische Zusammensetzung des Franklinits: Schweigger's Jour., Band 64, p. 430. A discussion of the formula without new analyses.

28. Shepard, C. U., Sketch of the mineralogy and geology of the counties of Orange, N.Y., and Sussex, N.J.: Am. Jour. Sci., 1st ser., vol. 21, pp. 321-334. Name fowlerite here first appears for a variety of rhodonite.

29. Shepard, C. U., Treatise on mineralogy, 1st ed., vol. 1, pt. 1, p. 154. Name troostite first appears for the manganesian willemite of Franklin. Identity with willemite not established until much later.

1836

30. Fowler, Samuel, Of the white crystalline limestone [of Sussex County, N.J.] and the minerals and ores connected with it: Gordon's Gazetteer of New Jersey, p. 247. Reprinted in New Jersey Geol. Survey Rept., 1836, 2d ed., pp. 118-122. An incomplete descriptive list of the Franklin minerals.

31. Rogers, H. D., [Reprint from [First] Report on the Geological Survey of the State of New Jersey, 1836]. Geology of the white limestone, which he regards as a metamorphic phase of the blue limestone. All the iron and zinc ore veins are regarded as of igneous origin, and are thought to have caused the alteration of the limestone by their intrusion

32. Thomson, Thomas, Outlines of mineralogy, etc., vol. 1, p. 220. Analysis of dysluite (zinc spinel). Also a reprint of most of the material of Thomson (23).

1840

33. Rogers, H. D., [Reprint from Description of the geology of the State of New Jersey, Final Rept.] Reprints Fowler's mineral list (30). Repeats much of the report (31) of 1836, describing the gneiss and white limestone in more detail. The gneiss is regarded as an altered sedimentary series.

1843

34. Hausmann, J. F. L., Ueber die Krystallisationen und die Structur des Zinkoxydes: Karsten's Archiv Min., Band 17, pp. 784–788, 1843. Review of the literature on zincite and artificial zinc oxide. Correct determination of the cleavage of zincite.

35. Rammelsberg, C. F., Analysis of tephroite: Handbuch der Mineral-Chemie, 1st ed., 1st suppl., p. 80, 1843. (Also in Poggendorff's Annalen, Band 62, p. 137, 1844.)

36. Thomson, Thomas, Notice of some new minerals; Jeffersonite: Philos. Mag., vol. 22, p. 193. Analysis of impure jeffersonite.

1844

37. Dana, J. D., System of mineralogy, 2d ed., p. 44. A list of 34 species of minerals found at Franklin. This list was reprinted without change in the Manual of mineralogy, new ed., 1857.

38. Alger, Francis, in Phillips, William, An elementary treatise on mineralogy, 5th ed., Boston. Notes on the characteristic minerals, with little that was new. Name sterlingite here suggested for zincite but never accepted.

1845

39. Alger, Francis, On the zinc mines of Franklin, Sussex County, N.J.: Am. Jour. Sci., 1st ser., vol. 48, pp. 252–264. Historical and geologic notes on the two deposits.

40. Hayes, A. A., Analysis of zincite: Am. Jour. Sci., 1st ser., vol. 48, p. 260. Thought the color to be due to scales of hematite.

1846

41. Alger, Francis, Dysluite identical with automolite· Am. Jour. Sci., 2d ser., vol. 1, pp. 121–122. Also in Boston Soc. Nat. Hist. Proc., vol. 2, p. 88, and in Boston Jour. Nat. Hist., vol. 5, pp. 303–305.

42. Delesse, Achille, and Des Cloizeaux, Alfred, Sur la villemite: Annales des mines, 4th ser., vol. 10, p. 211. Analysis of willemite from Franklin, confirming that of Vanuxem and Keating (17).

1847

43. Whitney, J. D., Analyse des Rothzinkerzes aus Sterling in New Jersey: Poggendorff's Annalen, Band 71, pp. 169–172. Two analyses of zincite.

1849

44. Hunt, T. S., Chemical examination of algerite, a new mineral species, including a description of the mineral by F. Alger: Am. Jour. Sci., 2d ser., vol. 8, pp. 103–106. Also in Boston Jour. Nat. Hist., vol. 6, pp. 118–123.

45. Hermann, Rudolph, [Analyses of Franklin minerals]: Jour. prakt. Chemie, Band 47, pp. 5, 12. Analyses of rhodonite and willemite. Shows the identity of willemite and troostite, of jeffersonite and pyroxene, and points out the relation of tephroite to the olivine group. Written to correct the errors of Thomson's analyses.

1850

46. Dana, J. D., On some minerals recently investigated by M. Hermann: Am. Jour. Sci., 2d ser., vol. 9, pp. 408–412. Review of the analyses of Hermann (45).

47. Hayes, A. A., On the red zinc ore of New Jersey: Am. Jour. Sci., 2d ser., vol. 9, p. 424. Discusses the nature of the coloring material of zincite.

48. Crossley, Richard, Analysis of algerite: Am. Jour. Sci., 2d ser., vol. 10, pp. 77–78.

49. Silliman, Benjamin, Jr., Optical examination of several American micas: Am. Jour. Sci., 2d ser., vol. 10, pp. 372–383. Among others examined phlogopite from Franklin.

50. Wurtz, Henry, On the troostite of New Jersey: Am. Assoc. Adv. Sci. Proc., 4th meeting, 1850, pp. 146–147, 1851. Gives an analysis of willemite.

51. Jackson, C. T., Description and analysis of allanite from Franklin, N.J.: Am. Assoc. Adv. Sci. Proc., 4th meeting, 1850, pp. 323–324, 1851; Boston Soc. Nat. Hist. Proc., vol. 3, p. 326, 1851.

52. Jackson, C. T., On the manufacture of zinc white: Am. Assoc. Adv. Sci. Proc., 4th meeting, 1850, pp. 335–337, 1851; Boston Soc. Nat. Hist. Proc., vol. 3, p. 321, 1850, and vol. 4, pp. 295–296, 1853. Describes the mines and the processes of manufacture of the products.

1851

53. Henry, T. H., On the white blende of New Jersey, U.S.: Philos. Mag., 4th ser., vol. 1, p. 23; abstract in Am. Jour. Sci., 2d ser., vol. 12, p. 221. Analysis of colorless sphalerite (cleiophane) from Franklin.

54. Farrington, A. C., Metamorphic condition of a part of the large vein of franklinite in New Jersey: Am. Assoc. Adv. Sci. Proc. 6th meeting, 1851, pp. 241–242, 1852. Describes the contact action of a pegmatite dike on the vein.

1852

55. Blake, W. P., On the occurrence of crystalline zinc oxyd as a furnace product in New Jersey: Am. Jour. Sci., 2d ser., vol. 13, pp. 417–418.

56. Blake, W. P., Mineralogical notices: Am. Jour. Sci., 2d ser., vol. 14, p. 105. Describes the mode of occurrence of zincite.

57. Camac, W., Analysis of fowlerite: Am. Jour. Sci., 2d ser., vol. 14, pp. 418–419.

58. Jackson, C. T., Report of the New Jersey Zinc Co. (See p. 10.) Geologic report by Jackson. Estimate of ore in sight, etc. Analysis of franklinite by Dickerson.

59. Farrington, A. C., Historical sketch of the zinc mines of New Jersey, in Report of the New Jersey Zinc Co., p. 16. The only accurate account of the early and traditional workings of the deposit.

60. Rammelsberg, C. F., Mineralanalysen; Rhodonite: Poggendorff's Annalen, Band 85, p. 297.

61. Tamnau, Friedrich, [Occurrence of fowlerite]: Deutsche geol. Gesell. Zeitschr., Band 4, p. 10.

1853

62. Dana, J. D., Algerite: Am. Jour. Sci., 2d ser., vol. 15, p. 440. Regards algerite as an alteration product of scapolite.

1854

63. Whitney, J. D., Chemical composition of the minerals algerite and apatite: Am. Jour. Sci., 2d ser., vol. 17, pp. 206–210. A new analysis confirms Dana's conclusion (62).

64. Hunt, T. S., Remarks on the mineral species algerite: Am. Jour. Sci., 2d ser., vol. 17, pp. 351–352. Upholds the validity of the species.

65. Dana, J. D., On the alteration of scapolite: Am. Jour. Sci., 2d ser., vol. 18, p. 272. Classes algerite as an alteration of scapolite.

66. Kenngott, G. A., Mineralogische Notizen, 9te Folge; 4, Jeffersonit, Krystallform desselben: K. Akad. Wiss. Wien Sitzungsber., Band 12, p. 26.

67. Whitney, J. D., The metallic wealth of the United States, p. 348. Gives a vague geologic sketch of the ore bed at Sterling Hill. Regards the white limestone as metamorphic Silurian.

68. Kitchell, William, General remarks on the physical geography and geologic formation of Sussex County: New Jersey Geol. Survey First Ann. Rept., for 1854, p. 43, 1855. Describes the deposits at Franklin and Sterling Hill, including the minerals franklinite and zincite. Gives an incomplete section of the formations at Franklin.

68–a. Jackson, C. T., [Informal communication]: Boston Soc. Nat. Hist. Proc., vol. 4, pp. 308–309. Gives the date of the earliest working of the Sterling mines.

1855

69. Brush, G. J., Franklinite: Am. Jour. Sci., 2d ser., vol. 19, p. 360. Note concerning the formula of franklinite.

70. Dauber, H., Untersuchungen an Mineralien der Sammlung des Herrn Dr. Krantz in Bonn: Poggendorff's Annalen, Band 94, pp. 398–411. Determines the triclinic form of fowlerite (p. 402).

71. Jenzsch, Gustav, Fluor im Kalkspath und Aragonit: Poggendorff's Annalen, Band 96, pp. 145–151. Shows the presence of fluorine in the calcite gangue of zincite.

72. Kitchell, William, Report on the northern division of the State: New Jersey Geol. Survey Second Ann. Rept., for 1855, p. 111, 1856. Describes the white limestone as cut by intrusions of granite and syenite. Regards the white limestone as of the same age as the gneiss and older than the blue limestone.

1858

73. Breithaupt, August, Beschreibung neuer Mineralien; Spartait: Berg- und hüttenm. Zeitung, Band 17, p 53. Gives the name to the manganese calcite of Sterling Hill.

1859

74. Rammelsberg, C. F., Ueber die wahre Zusammensetzung des Franklinits und die Isodimorphie der Monoxyde und Sesquioxyde: Poggendorff's Annalen, Band 107, pp. 312–322. New analyses and a long discussion lead him to the rejection of the spinel formula for franklinite. (See Rammelsberg (93).)

75. (Anonymous), Franklinite iron ores; their uses and quantity: Mining Mag., vol. 10, pp. 105–108. Paper not seen.

1860

75. Blake, W. P , Analysis of red oxyd of zinc—zincite: Min. Mag., 2d ser., vol. 2, pp 94–95 (1861). Analysis of very pure material from a large crystal.

76. Brush, G. J., [Analysis of franklinite]: Am. Jour. Sci., 2d ser , vol. 29, p 371.

77. Eliot, C. W , and Storer, F. H., On the impurities of commercial zinc, with special reference to the residue insoluble in dilute acids, to sulphur, and to arsenic: Am. Acad. Arts and Sci. Mem., vol. 8, pp. 57–96, 1860 [1861]. Zinc made from zincite is shown to be relatively highly impure, containing traces of copper, arsenic, sulphur, lead, and tin.

78. Mason, C., Report of the special committee on franklinite: Am. Inst. Trans , 1859–60, pp. 565–569. Discussion of the properties of the so-called franklinite metal, a manganiferous cast-iron then made at Franklin.

79. Rammelsberg, C. F., Handbuch der Mineralchemie. Analyses of polyadelphite from Franklin, p. 693. Analysis of manganese calcite from Franklin by Richter, p. 209. (See Jenzsch (71).) Analysis of ceylonite spinel, by Vogel, p. 163.

80. Steffens, Dr., and Dahlgren, J. A., Der Franklinit als Eisenerz: Berg- und hüttenm. Zeitung, Jahrg. 19, pp. 463–465; Sci. Am., vol. 2, p. 66, 1860. Describes the manufacture of franklinite metal. (See Mason (78).) Gives a résumé of accounts of the Franklin deposits; not very accurate.

1861

81. Alger, Francis, [On zincite from Mine Hill, Franklin, Sussex County, N.J.]: Boston Soc. Nat. Hist. Proc., vol. 6, p. 145. Discussion of the cause of the color, which is held due to manganese.

82. Cook, G. H., Note on the probable age of the white limestone at Sussex and Franklin zinc mines, New Jersey: Am. Jour. Sci., 2d ser., vol. 32, pp. 208–209. Discusses the nature of the contact with the gneiss and with the Cambrian quartzite.

83. Hunt, T. S., Allanite: Boston Soc. Nat. Hist. Proc., vol. 8, p. 57. Analysis of material reported by Jackson (51).

84. The Franklinite case, New York. Report of the testimony offered in the first suit of the New Jersey Zinc Co. vs. the New Jersey Franklinite Co., etc. Gives many facts about the early workings of the mines. Testimony by Blake, Farrington, Jackson, Kitchell, Cook, and others.

1862

85. Des Cloizeaux, Alfred, Note sur la forme cristalline et les propriétés optiques de la téphroite: Annales des mines, 6th ser., vol. 2, pp. 339–342; Minéralogie, vol. 1, pp. 69–70. First determination of the form of tephroite, with a figure. The crystals were at first mistaken for rhodonite.

86. Deville, Henri, [Analysis of tephroite], in Des Cloizeaux, Alfred, Minéralogie, vol 1, p. 38.

1864

87. Brush, G J , On tephroite: Am. Jour. Sci., 2d ser., vol. 37, pp. 66–70. Three new analyses and a summary of the properties of tephroite, which he shows conforms to the olivine formula.

88. Jackson, C. T., Notice of the death of Francis Alger, of Boston: Boston Soc. Nat. Hist. Proc., vol. 10 [for 1864], pp. 2–6, 1865. Notes Alger's part in making known the Franklin minerals (p. 3).

1865

89. Shepard, C. U., and Tyler, S. W., Analysis of a carbonate of lime and manganese (spartaite of Breithaupt) from Sterling, Sussex County, N.J.: Am. Jour. Sci., 2d ser., vol. 39, pp. 174–175. Similar to the material of Jenzsch (71) and of Richter (80). Shepard calls it calcimangite, a name never again used.

1866

90. Credner, Hermann, Beschreibung von Mineralvorkommen in Nordamerika; c, Franklinit und Rothzinkerz im krystallinischen Kalksteine: Berg- u. hüttenm. Zeitung, Jahrg. 25, pp. 29–30. Good description of the geology of the deposits, with some notes on the minerals.

91. Fizeau, A. H. L., [Expansion of zincite by heat]: Compt. Rend., vol. 62, pp. 1146–1147; Poggendorff's Annalen, Band 128, p. 587.

92. Von Kobell, Franz, Ueber Franklinit und Thomsonit: Jour. prakt. Chemie, Band 98, pp. 129–136. Discussion of formula and new analysis, supporting the spinel ratio.

1867

93. Rammelsberg, C. F., Ueber die Zusammensetzung des Franklinits: Poggendorff's Annalen, Band 130, pp. 146–149. Gives new analyses, rejects previous results, and adopts the spinel formula. (See Rammelsberg (74).)

1868

94. Dana, J. D , System of mineralogy, 5th ed., p. 776. Repeats the list given in former edition with a few added names, making 39 species then recorded.

95. Brush, G. J., On sussexite, a new borate from Mine Hill, Franklin Furnace, Sussex County, N.J.: Am. Jour. Sci., 2d ser., vol. 46, pp. 240–243; Yale Bicent. Pub., Contr. to Mineralogy and Petrography, pp. 33–36, 1901. Gives a description and analysis of this new species.

96. Cook, G. H., Geology of New Jersey. (See especially chapter 2, Zinc ores, pp. 69 et seq.) Notes on calamine, franklinite, zincite, and willemite. Maps and sections of the mines, but no general description of the mineralogy. Supports Kitchell's view of the Azoic age of the white limestone. Gives full descriptions of that formation and its relation to the gneiss. All the gneiss, together with the included beds of iron and zinc ores, is assigned to the group of metamorphic sediments.

97. Seymour, E., List of minerals in New Jersey: New Jersey Geol. Survey Geology of New Jersey, appendix D, pp. 743–750. Gives a list of 41 minerals found at Franklin or at Sterling Hill.

98. Mixter, W. G., On willemite and tephroite: Am. Jour Sci., 2d ser., vol. 46, pp. 230–232. Two analyses of willemite and one of tephroite.

1870

99. Roepper, W. T., Notice of some minerals from New Jersey: Am. Jour. Sci., 2d ser , vol 50, pp. 35–38 First description of the mineral afterward called roepperite and one of a manganesian dolomite, with analyses of both.

1871

100. Brush, G. J., On gahnite from Mine Hill, Franklin Furnace, N.J.: Am. Jour. Sci., 3d ser., vol. 1, pp. 28–29; Yale Bicent. Pub., Contr. to Mineralogy and Petrography, pp. 42–44, 1901. Describes crystals of unusual habit, with analyses by J. S. Adam. Crystal figures in the reprint only.

101. Credner, Hermann, Ueber den Mineralreichtum des Alleghanysystems: Berg- u. hüttenm. Zeitung, Jahrg. 30, p. 369. Places the Franklin white limestone in the Laurentian.

1872

102. Brush, G. J., Roepperite, in Dana's System of mineralogy, Appendix 1, p. 13. Names roepperite in honor of the discoverer.

103. Kenngott, G. A., [Letter to the editor]: Neues Jahrb., 1872, p. 188. Names Roepper's zinc chrysolite, stirlingite, and the manganesian dolomite, roepperite. The name sterlingite had already been used for zincite. (See Alger (38).)

104. Brush, G. J., Stirlingite, roepperite: Am. Jour. Sci., 3d ser., vol. 4, p. 146. States the priority of Kenngott's name.

105. Hayes, A. A., On the red oxide of zinc of New Jersey: Am. Jour. Sci., 3d ser., vol. 4, pp. 191-198. Renews the discussion as to the color of zincite being due to scales of hematite.

1873

106. Cornwall, H. B., Mineralogical notes: Am. Chemist, vol. 4, pp. 126–127. Gives the specific gravity of willemite and an analysis of a supposed pseudomorph of franklinite after calcite.

107. Pisani, F., Analyse d'une jeffersonite de Franklin, N.J.: Compt. Rend., vol. 76, pp. 237–238. Gives an analysis and the optical character of a jeffersonite rich in zinc.

1875

108. Moore, G. E., On chalcophanite, a new mineral species: Am. Chemist, vol. 6, pp. 1-2. First account, with analyses, of this species from Sterling Hill

1876

109. Seyms, G. H., On the relation of franklinite to the spinel group of minerals· Am. Jour. Sci., 3d ser., vol. 12, pp. 210–212. Analyses show a diversity in magnetism with the amount of iron. This confirms the spinel type of formula.

110. Shepard, C. U., New minerals· Am. Jour. Sci., 3d ser., vol. 12, p. 231; Contributions to mineralogy, Amherst College Analyses of vanuxemite, keatingine, and calcozincite, which were later proved to be mixtures of known minerals.

1877

111. Beco, Jean, De l'état des industries du zinc et du cuivre aux États-Unis d'Amérique: Rev. univ. mines, 2d ser., vol. 2, pp. 129–282. An account of the Franklin deposits, after Cook (96), and details of metallurgical practice on the Franklin ores. (See pp. 171–185.)

112. Shepard, C. U., Contributions to mineralogy, Amherst College. Analysis of a serpentine from Franklin containing manganese.

113. Cross, C. W., Vanuxemite. Naturalist's Bull , March, p. 5 Analysis of Shepard's supposed species (110) shows it to be a mixture of calamine and halloysite.

114. Moore, G. E., Preliminary notice of the discovery of a new mineral species [hetaerolite]: Am. Jour. Sci., 3d ser., vol. 14, p. 423.

115 Platt, J. C., Jr., The franklinite and zinc litigation concerning the deposits of Mine Hill, at Franklin Furnace, Sussex County, N.J.: Am. Inst. Min. Eng Trans., vol. 5, pp. 580–584. A brief account of the litigation up to the decision in favor of Taylor in *Taylor* vs. *New Jersey Iron & Zinc Co.*

1878

116. Roepper, W. T., On a pseudomorph after anorthite, from Franklin, N.J.: Am. Jour. Sci., 3d ser., vol. 16, pp. 364–365. Analysis of a pseudomorph, probably zoisite, after microcline.

1879

117. Koenig, G. A., Anomalite; Naturalist's Leisure Hour, vol. 3, p. 1, Philadelphia. A name proposed for unusual pseudomorphs after augite.

118. Laspeyres, Hugo, Mineralogische Bemerkungen (5), Zoisit: Zeitschr. Kryst. Min., Band 3, pp. 525–576. Discusses zincite, p. 576.

1880

119. Penfield, S. L., Analyses of some apatites containing manganese: Am. Jour. Sci., 3d ser., vol. 19, pp. 367–369. Analysis of an apatite from Franklin showing a little manganese.

1881

120. Baker, G. W., Geological report on the mineral belt of Sussex County, N.J., Sterling Hill-Mine Hill, published by the Manganese Iron Ore Co., Philadelphia. A mining report, with numerous photographs and maps, illustrating conditions at Franklin about 1880.

1882

121. Emerson, B. K., On the dikes of micaceous diabase penetrating the bed of zinc ore at Franklin Furnace, Sussex County, N.J.: Am. Jour. Sci., 3d ser., vol. 23, pp. 376–379. Describes the metamorphism of the ore minerals by the intrusion of the diabase.

122. Von Lasaulx, Arnold, Ueber die Mineralien der Willemitgruppe: Niederrhein. Gesell. Bonn Sitzungsber., 1882, pp. 46–47. Describes inclusions of unknown character in troostite crystals.

123. Ricketts, P. de P., Analysis of the franklinite ores of New Jersey and methods for the separation of the red oxide of zinc: New York Acad. Sci. Trans., vol. 2, pp. 26–34. Results of commercial experiments to determine the mineral composition of the Franklin ores.

124. Roepper, W. T., Hydrofranklinite, in Dana, System of mineralogy, 5th ed., appendix 3, p. 61. Preliminary announcement of a supposed new species, afterward proved to be chalcophanite. (See Penfield and Kreider (157).)

125. Darton, N. H., On the genesis of the ores and the minerals in the granular limestone of Sussex County, N.J.: New York Acad. Sci. Trans., vol. 2, p. 25. Title only; the paper never published.

1883

126. Darton, N. H., The zinc mines of Sussex County, N.J.: Sci. Am. Suppl., vol. 16, p. 6278. Account of the Sterling Hill mines at the time of the mining of the large body of calamine. Mentions copper silicate in the ore.

1885

127. Bemis, F. P., and Woolson, I. H., [Unpublished thesis presented to the faculty of the Columbia School of Mines, New York.] Referred to by Kemp (152).

1886

128. Dana, E. S., Mineralogische Notizen: Zeitschr. Kryst. Min., Band 12, p. 460; Am. Jour. Sci., 3d ser., vol. 32, p. 388. First measurements of natural crystals of zincite.

129. Kloos, J. H., Über eine manganreiche und zinkhaltige Hornblende von Franklin, N.J.: Neues Jahrb., 1886, Band 1, pp. 211-223. Complete description, with analysis, of the black hornblende from Sterling Hill, afterward named gamsigradite by Dana.

130. Koenig, G. A., Manganese zinc serpentine from Franklin, N.J.: Acad. Nat. Sci. Philadelphia Proc., 1886, pp. 350–351. Gives an analysis.

1887

131. Stone, G. C., Analyses of franklinite and some associated minerals: School of Mines Quart., vol. 8, pp. 148–152. Analyses and careful specific-gravity determinations of zincite, franklinite, willemite, and tephroite.

132. Koenig, G. A., On zinc-manganese asbestos: Acad. Nat. Sci. Philadelphia Proc., 1887, pp. 47–48. Gives an analysis of impure tremolite.

133. Koenig, G. A., Preliminary note on a new mineral species from Franklin, N.J.: Acad. Nat. Sci. Philadelphia Proc., 1887, pp. 310–311. Gives an incomplete description of bementite.

1888

134. Riggs, R. B., The analysis and composition of tourmaline: Am. Jour. Sci., 3d ser., vol. 35, pp. 35–51. Analysis of brown tourmaline from Hamburg, N.J., on p. 43.

135. Penfield, S. L., and Sperry, E. S., Mineralogical notes; Sussexite from Mine Hill, Franklin, N.J.: Am. Jour. Sci., 3d ser., vol. 36, p. 323. New analysis of the original material, Brush (95).

1889

136. Canfield, F. A., Catalog of minerals found in New Jersey: New Jersey Geol. Survey Final Rept., vol. 2, pt. 1, p. 3, 1889. A list of 74 mineral species found at Franklin and Sterling Hill, including some doubtful ones and some duplications.

137. Koenig, G. A., Chloanthite, niccolite, desaulesite, annabergite, tephroite, willemite, fluorite, and apatite from Franklin: Acad. Nat. Sci. Philadelphia Proc., 1889, pp. 184–189. Description of an interesting find of arsenic compounds from the Trotter mine.

1890

138. Browning, P. E , Analysis of rhodochrosite from Franklin Furnace, N.J.: Am. Jour. Sci., 3d ser., vol. 40, pp. 375–376.

139. Clarke, F. W., Report of work done in the division of chemistry and physics; Willemite from the Trotter mine, Franklin, N J.: U.S. Geol. Survey Bull. 60, p. 130. Gives an analysis.

140. Pirsson, L. V , On the fowlerite variety of rhodonite from Franklin and Stirling, N.J. Am. Jour. Sci., 3d ser., vol. 40, pp. 484–488. Describes the crystal form and gives an analysis.

141. Nason, F. L., The post-Archean age of the white limestones of Sussex County, N.J.: New Jersey Geol. Survey Ann. Rept. for 1890, pp. 25–50, 1891. An important paper, describing in detail the relations of the white limestone, which is regarded as a metamorphic phase of the Cambrian blue limestone. This molded geologic opinion on the matter until disproved by Wolff (177). Describes the scapolite rock and the contact minerals of the Rudeville quarries.

142. Nason, F. L., Scapolite rock: Am. Jour. Sci., 3d ser., vol. 39, p. 407. Announces discovery of this mineral at Franklin.

1891

143. Nason, F. L., The post-Archean age of the white limestones of Sussex County, N.J. Am. Geologist, vol. 7, pp. 241–253. An elaboration of the arguments of Nason (141).

144. Nason, F. L., The post-Archean age of the white limestones of Sussex County, N.J.: Am. Geologist, vol. 8, pp. 166–171. A reply to a criticism by Dana of Nason (143).

145. Genth, F. A., Contributions to mineralogy, 50; Axinite from Franklin, N.J.; Crystallographic notes by Penfield and Pirsson: Am. Jour. Sci., 3d ser., vol. 41, p. 394. Gives the crystal form and an analysis of axinite from the Trotter mine.

1892

146. Dana, E. S., The system of mineralogy, of James Dwight Dana, 6th ed., p. 1066. Gives a list of 56 species from Franklin and Sterling Hill. Few changes from former lists.

147 Roepper, W. T., Pyrochroite, in Dana's System of mineralogy, 6th ed., p. 253. Reports the mineral as found in the Franklin district.

148. Grosser, P., Zinkitkrystalle von Franklin, N.J.: Zeitschr. Kryst. Min., Band 20, pp. 354–356. Gives the crystal measurements and an analysis of zincite.

149. Hussak, Eugen, Über brasilienische Leucitgesteine. Neues Jahrb., 1892, Band 2, pp. 146–158. Refers to leucite tephrite from Hamburg, N.J., and regards the analcite spheroids as derived from leucite (p. 153). (See Kemp (154).)

1893

150. Eakle, A. S., On allanite crystals from Franklin Furnace, N.J.: New York Acad. Sci. Trans., vol. 13, pp. 102–107; Am. Jour. Sci., 3d ser., vol. 47, pp. 436–439; Zeitschr. Kryst. Min., Band 23, pp. 209–211, 1894. Crystal form of allanite from the Trotter mine.

151. Emmons, S. F., Geological distribution of the useful metals: Am. Inst. Min. Eng. Trans., vol. 22 [for 1893], pp. 53–95, 1894. A brief description of the geology of Franklin, in which the white limestone is regarded as probably Archean (p. 80).

152. Kemp, J. F., The ore deposits at Franklin Furnace and Ogdensburg, N.J.: New York Acad. Sci. Trans., vol. 13, pp. 76–96 [1894]. Bibliography, history, and general geologic relations of the district, and an annotated list of 66 species of minerals, without duplication. Regards the white limestone as post-Cambrian. An excellent paper, giving the best account of the deposit that had so far appeared.

153. Nason, F. L., [Trotter mine minerals]. New York Acad. Sci. Trans., vol. 13 [for 1893], pp. 97–98, 1894. Notes, communicated by A. H. Chester and appended to Kemp (152), on the pegmatite contact at the Trotter mine and contact minerals developed.

154. Kemp, J. F., A basic dike near Hamburg, Sussex County, N.J., which has been thought to contain leucite Am. Jour. Sci., 3d ser., vol. 45, pp. 298–305. Determines the spheroids to be analcite, probably derived from leucite. (See Hussak (149).)

1894

155. Kemp, J. F., Additional note on leucite in Sussex County, N.J.: Am. Jour. Sci., 3d ser., vol. 47, pp. 339–340. Announces leucite in diabase from Rudeville, which may be in the same dike as that at Hamburg.

156. Penfield, S. L., Contributions to the crystallization of willemite: Am. Jour. Sci., 3d ser., vol. 47, pp. 305–309. Describes new forms of Franklin willemite and establishes the identity of willemite and troostite.

157. Penfield, S. L., and Kreider, D. A., On the identity of hydrofranklinite and chalcophanite. Am. Jour. Sci., 3d ser., vol. 48, pp. 141–143. (See Roepper (124).)

158. Pratt, J. H., Mineralogical notes on cerusite, calamine, and zircon: Am. Jour. Sci., 3d ser., vol. 48, p. 213. Gives the angle measurements and a figure of a crystal of calamine from Sterling Hill.

159. Blake, W. P., Notes on the structure of the franklinite and zinc ore beds of Sussex County, N.J.: Am. Inst. Min. Eng. Trans., vol. 24 [for 1894], pp. 521–524, 1895. Describes the geologic structure of the deposits at Franklin and Sterling Hill. Regards the ore beds as of the same age as the gneiss.

160. Blake, W. P., The zinc ore deposits of southwestern New Mexico Am. Inst. Min. Eng. Trans., vol. 24 [for 1894], pp. 187–195, 1895. Finds an analogy between the New Jersey deposits and those of New Mexico in that both are in bedded masses in white limestone. The minerals, however, are different, as those in New Mexico are sulphides.

161. Chester, A. H., On caswellite, an altered biotite from Franklin Furnace, N.J.: New York Acad. Sci. Trans. vol. 13, pp. 181–184. Description with analysis. The material is a mixture.

162. Eakle, A. S., Ueber Allanit und Turmalin aus New Jersey: Zeitschr. Kryst. Min., Band 23, pp. 209–211; New York Acad. Sci Trans., vol 13, p. 185. Lists the forms and gives a figure of the brown tourmaline analyzed by Riggs (134).

163. Nason, F. L., The franklinite deposits of Mine Hill, Sussex County, N.J.: Am. Inst. Min. Eng. Trans., vol. 24 [for 1894], pp. 121–130, 1895. Excellent account of the form of the ore body at Mine Hill as revealed by diamond-drill borings, with a stereogram, map, and sections.

164. Nason, F. L., The chemical composition of some of the white limestones of Sussex County, N.J.: Am. Geologist, vol. 13, pp. 154–164. Analyses supposed to show the general magnesian character of the limestone.

165. Nason, F. L., Summary of facts proving the Cambrian age of the white limestones of Sussex County, N.J.: Am. Geologist, vol. 14, pp. 161–169. A further el boration of the arguments of Nason (141 and 143).

166. Dürre, E. F., Metallurgische Notizen aus New Jersey und dem Lehigh-Thal; 3, Die Franklinitlagerstätten in New Jersey und ihre metallurgische Ausbeutung: Ver. deutsch. Ing. Zeitschr., Band 38, pp. 184–190. A sketch of the deposit, after Nason (163), giving averages of the ore content from the mill samples and full details of the metallurgy.

167. Groth, Paul, Die Zinkerzlagerstätten von New Jersey: Zeitschr. prakt. Geologie, 1894, pp. 230–233. Translation of paper by Nason (163).

168. Westgate, L. G., The age of the crystalline limestones of Warren County, N.J.: Am. Geologist, vol. 14, pp. 369–379. Argues for the pre-Cambrian age of the white limestone.

169. Williams, H. S., The age of the white limestones near Warwick, Orange County, N.Y.: Am. Jour. Sci., 3d ser., vol. 47, pp. 401–402. Review of Nason (141), denying the validity of Nason's evidence for the Cambrian age of the white limestone.

1895

170. Moses, A. J., Contributions from the mineralogical department of Columbia College—21, The pyramids of zincite: School of Mines Quart., vol. 6, pp. 226–227. Gives measurements of zincite crystals.

1896

171. Wilkens, H. A. J., and Nitze, H. B. C., The magnetic separation of nonmagnetic material: Am. Inst. Min. Eng. Trans., vol. 26 [for 1896], pp. 351-370, 1897. A study of the working of the Wetherill magnetic separator on Franklin ores.

1897

172. Wetherill, J. P., The Mine Hill ore deposits in New Jersey and the Wetherill concentrating plant: Eng. and Min. Jour. vol. 64, pp. 65–66, 98–100. The first part is an admirable account of the whole mining history of the Franklin deposits and of the development of the metallurgical treatment of the ore. There is also a clear account of the long litigation of the "Franklinite case." The second part is a technical description of the working of the concentrating plant.

173. Penfield, S. L., and Foote, H. W., On roeblingite, a new silicate from Franklin Furnace, N.J., containing sulphur dioxide and lead: Am. Jour. Sci., 4th ser., vol. 3, pp. 413–415; Zeitschr. Kryst. Min., Band 28, pp. 578–580. A complete mineralogical description of this new species from the Parker shaft.

1898

174. Wolff, J. E., Occurrence of native copper at Franklin Furnace, N.J.: Am. Acad. Arts and Sci. Proc., vol. 33, pp. 429–430.

175. Penfield, S. L., and Foote, H. W., On clinohedrite, a new mineral from Franklin, N.J.: Am. Jour. Sci., 4th ser., vol. 5, pp. 289–293; Zeitschr. Kryst. Min., Band 30, pp. 587–591, 1899; Yale Bicent. Pub., Contr. to Mineralogy and Petrography, pp. 291–296, 1901.

176. Foote, W. M., Note on the occurrence of native lead, with roeblingite, native copper, and other minerals at Franklin Furnace, N.J.: Am. Jour. Sci., 4th ser., vol. 6, pp. 187–188.

177. Wolff, J. E., and Brooks, A. H., The age of the Franklin white limestone of Sussex County, N.J.: U.S. Geol Survey 18th Ann. Rept., pt. 2, pp. 425–457. The final and conclusive proof of the pre-Cambrian age of the white limestone, with an excellent résumé of the literature relating to the topic.

178. Wolff, J. E., [Note, without title, recording the existence of intrusive pegmatite in the Parker shaft at Franklin]: Science, new ser., vol. 8, p. 560.

1899

179. Penfield, S. L., and Warren, C. H., Some new minerals from the zinc mines at Franklin, N.J., and note concerning the chemical composition of ganomalite· Am. Jour. Sci., 4th ser., vol. 8, pp. 339–353; Zeitschr. Kryst. Min., Band 32, pp. 227–242, 1900; Yale Bicent. Pub., Contr. to Mineralogy and Petrography, pp. 325–342, 1901. The first descriptions of hancockite, glaucochroite, nasonite, and leucophoenicite, from the Parker shaft.

180. Wolff, J. E., On hardystonite, a new calcium-zinc silicate from Franklin Furnace, N.J.: Am. Acad. Arts and Sci. Proc., vol. 34, pp. 477–481. The first description of this species, from the Parker shaft.

1900

181. Chester, A. H., Mineralogical notes and explorations [Minerals from Franklin Furnace]: New Jersey State Geologist Ann. Rept. for 1900, p. 185, 1901. Gives an analysis of massive vesuvianite and one of brown willemite from the Parker shaft.

182. Clarke, F. W., and Steiger, George, Experiments relative to the constitution of pectolite, pyrophyllite, calamine, and analcite; Calamine: U.S. Geol. Survey Bull. 167, pp. 17–19; Am. Jour. Sci., 4th ser., vol. 8, pp. 248–250, 1899. Gives an analysis of calamine from Sterling Hill.

183. Hillebrand, F. W., Mineralogical notes; Jeffersonite: U.S. Geol. Survey Bull. 167, pp. 68–69, 1900. Gives an analysis of fresh brown zinc schefferite.

184. Kemp, J. F., The ore deposits of the United States and Canada, 3d ed., p. 251. Description of the deposits in much the same manner as in Kemp (152), with further speculations as to origin, based on the hypothesis of the post-Cambrian age.

185. Wolff, J. E., Hardystonit und Zincschefferit von Franklin Furnace, N.J ; mit einer Notiz über die Brechungindices des Schefferit, by G. Melczer: Zeitschr. Kryst. Min., Band 33, pp. 147–151; Am. Acad. Arts and Sci. Proc., vol. 34, pp. 111–115. An additional analysis of hardystonite and a description of a new form of pyroxene from the Parker shaft.

1901

186. Warren, C. H., Mineralogical notes; Anorthite crystals from Franklin Furnace, N.J.: Am. Jour. Sci., 4th ser., vol. 11, pp. 369–373. Gives the form and composition of anorthite from the limestone.

1903

187. Ford, W. E., On the chemical composition of axinite: Am. Jour. Sci , 4th ser., vol. 15, pp. 195–201; Zeitschr. Kryst. Min., Band 38, pp. 82–88. A reexamination of the axinite described by Genth (145).

188. Wolff, J. E , Zinc and manganese deposits of Franklin Furnace, N.J.: U S. Geol. Survey Bull. 213, pp. 214–217. A brief account of the form and structure of the vein and the relations of the chief minerals of the Mine Hill deposit. Their origin is considered to be metamorphic, and contemporaneous with the white limestone.

1904

189. Valiant, W. S., New Jersey mineral localities: Mineral Collector, vol. 11, pp. 122–125, 137–141, 150–154, Gives a list, containing many synonyms and duplications, of minerals from Franklin and Sterling Hill.

1905

190. Moses, A. J., The crystallization of luzonite and other crystallographic studies; 4, Hematite parting from Franklin Furnace, N.J.: Am. Jour. Sci., 4th ser.. vol. 20, pp. 283–284, 1905. Gives an analysis of hematite from the Parker shaft.

190a. Kümmel, H. B., The chemical composition of the white crystalline limestones of Sussex and Warren Counties: New Jersey Geol. Survey Ann. Rept. for 1905, pp. 173–191, 1906. Description of the distribution, physical characteristics, and chemical composition of the white limestone. Gives many analyses, including those of samples of drill cores taken in exploration for locating the Parker shaft.

1907

191. Kraus, E. H., and Scott, I. D., Ueber interessante amerikanische Pyritkrystalle: Zeitschr. Kryst. Min., Band 44, pp. 144–153. Gives an analysis and the form of pyrite from the limestone.

192 Canfield, F. A., Mineralogical notes; Willemite: Am. Jour. Sci., 4th ser., vol. 23, pp. 20–23. A brief note correcting the figure of willemite published by Penfield (156). The lower end of the crystal, when cleared of the matrix, is shown to be quite differently developed from the upper end.

1908

193. Spencer, A. C., Kümmel, H. B , Wolff, J. E., Salisbury, R. D., and Palache, Charles, U.S. Geol. Survey Geol. Atlas, Franklin Furnace folio (no. 161). Spencer gives full descriptions of the form, structure, composition, and geologic history of the zinc ore deposits, with maps, sections, and stereograms, and postulates an igneous origin of the ores as probable. Palache gives an annotated list of 91 mineral species recognized in the district, with a discussion of the paragenesis, showing the several groups of mineral deposits into which they may be divided.

194. Spencer, A. C., The Mine Hill and Sterling Hill zinc deposits of Sussex County, N.J.: New Jersey Geol. Survey Ann. Rept. for 1908, pt. 2, pp. 23–52, 1909. An abbreviated account of the deposits, based on the folio (193).

1909

194a. Leith, C. K., Magnetite and zinc ores of Franklin Furnace quadrangle: Econ. Geology, vol. 4, pp. 265–269, 1909. Reviews Spencer's work (193) published in the Franklin Furnace folio and accepts the possibility of igneous injection of the zinc ores.

1910

195. Palache, Charles, Contributions to the mineralogy of Franklin Furnace, N J.: Am. Jour. Sci , 4th ser., vol. 29, pp 177-187; Zeitschr. Kryst. Min., Band 47, pp. 576–585. Preliminary report on the more interesting facts brought to light up to that time in the studies leading to the present paper. Notes on the crystallography, composition, or occurrence of arsenopyrite, fluorite, manganosite, zincite, gahnite, franklinite, hetaerolite, pyroxene, nasonite, glaucochroite, bementite, willemite, friedelite, vesuvianite, datolite, cuspidine, humite, and leucophoenicite.

196. Phillips, A. H., Gageite, a new mineral from Franklin, N.J.: Am. Jour. Sci., 4th ser , vol. 30, pp. 283–284. Preliminary description of a new manganese silicate from the Parker shaft.

1911

197. Phillips, A. H., Notes on a recent find of zincite crystals: Am. Jour. Sci., 4th ser , vol. 31, pp. 464–465.

198. Ungemach, H., Über den Datolith: Zeitschr. Kryst. Min., Band 49, pp. 459–476. A correction of Palache's description of datolite (195), in a larger paper on that mineral (pp. 475–476).

199. Ford, W. E , and Crawford, R. D., On a rhodonite (fowlerite) crystal from Franklin, N.J.: Am. Jour. Sci., 4th ser., vol. 32, pp. 289–290. Description of forms new for the mineral.

1912

200. Eberhard, G., in Liebisch, Thomas, Über die Fluoreszenz der Sodalith- und Willemit-gruppe im ultravioletten Licht: Akad. Wiss. Berlin Sitzungsber., Jahrg. 1912, Halbband 1, pp. 229–240. Records tests with X-rays and radium rays on troostite and willemite from the Taylor mine, showing the fluorescent effects. Also records the presence of beryllium in troostite.

1913

201. Ford, W. E., and Bradley, W. M., On hetaerolite from Leadville, Colo.: Am. Jour. Sci., 4th ser , vol 35, pp. 600–604; Zeitschr. Kryst. Min., Band 53, pp. 219–224. An analysis of material from a new locality for the mineral and a discussion of Palache's formula (195).

202. Umpleby, J. B., Schaller, W. T., and Larsen, E. S., Custerite; a new contact-metamorphic mineral Am. Jour. Sci , 4th ser., vol 36, pp. 385–394; Zeitschr. Kryst. Min., Band 53, pp. 321-331, 1914. Discusses the composition of cuspidine and its relation to other minerals.

203. Palache, Charles, and Schaller, W. T., Hodgkinsonite, a new mineral from Franklin Furnace, N J.: Washington Acad. Sci. Jour., vol. 3, pp 474–478; Zeitschr. Kryst. Min., Band 53, pp. 529–532 and 675–676, 1914. Description of a new manganese-zinc silicate from the Parker shaft.

204. Palache, Charles, and Graham, R. P. D., On the crystallization of willemite: Am. Jour. Sci., 4th ser., vol. 36, pp. 639–644; Zeitschr. Kryst. Min., Band 53, pp. 332–336, 1914. Description of new forms and complex crystals of willemite from Franklin, and a new axial ratio.

1914

205. Palache, Charles, Supplementary note on the crystal form of hodgkinsonite: Washington Acad. Sci. Jour., vol. 4, pp. 153–154. Description of a new find of crystals, and a new axial ratio.

205a. Ford, W. E., Mineral notes; The index of refraction of manganosite: Am. Jour. Sci., 4th ser., vol 38, pp. 502–503. The index was measured on a prism of 15° angle which showed strong absorption of the whole spectrum except two bands in the red and green regions. For these the indices as found were: Green, $n=2\ 19$; red, $n=2.16$; for sodium light, $n=2.18$ (estimated).

1916

206. Levison, W. G., Columnar manganocalcite from Franklin Furnace, N.J.: Am. Mineralogist, vol. 1, p. 5. Description and analysis of a fibrous form of calcite.

207. Aminoff, Gregori, Note on nasonite from Långbanshyttan: Geol. Fören. Stockholm Förh., Band 38 [for 1916], pp. 473–476, 1917. Description of nasonite from the Swedish locality, confirming the characters determined on the Franklin mineral. Second known occurrence.

208. Ford, W. E., and Bradley, W. M., Margarosanite, a new lead-calcium silicate from Franklin, N J : Am. Jour. Sci., 4th ser., vol. 42, pp 159–162. First description of this new mineral.

209. Schaller, W. T., The composition of hodgkinsonite: U.S. Geol. Survey Bull. 610, pp. 159–160. A reprint of the data contained in Palache and Schaller (203) and Palache (205).

1917

210. Flink, Gustav, Margarosanit von Långbanshyttan: Geol. Fören. Stockholm Förh., Band 39, pp. 438–446. Description of the crystal form of the mineral and of the second known locality of its occurrence

211. Phillips, A. H , A rare habit and new form of franklinite: Am. Mineralogist, vol. 2, p. 5. Describes cubic crystals with a new form.

212. Honess, A. P., A study of the etching figures of the hexagonal-alternating type of crystals; Willemite: Am. Mineralogist, vol. 2, p. 58. Describes, with a plate of photographs, the etch figures produced by different reagents on the rhombohedron and prism faces of small crystals of clear green willemite.

213. Haight, C. M., and Tillson, B. F., Zinc mining at Franklin, N.J.: Am. Inst. Min. Eng. Trans., vol. 57 [for 1917], pp. 720–825, 1918. An elaborate and fully illustrated paper on the methods of mining at Franklin and all the mining operations and appliances. Some historical notes.

1918

214. Levison, W. G., Notes on gageite from Franklin Furnace, N.J.: Am. Mineralogist, vol. 3, p. 153. Describes specimens of supposed gageite but gives no new facts concerning the species.

1919

215. Aminoff, Gregori, Mineralogische Studien an Material aus der Sjögren'schen Mineraliensammlung; 6, Manganaxinit von Franklin Furnace, N.J.: Arkiv för Kemi, Band 7, no. 17, pp. 45–57. Description of axinite crystals, with complete computation of a new axial ratio, and full angle table for manganaxinite.

216. Flink, Gustav, [Margarosanite from Långbanshyttan]: Neues Jahrb., 1919, pp. 30–31. Abstract of Flink (210), giving revised values for the axial ratio of the mineral.

1921

217. Pardee, J. T., Larsen, E. S., and Steiger, George, Bementite and neotocite from western Washington, with conclusions as to the identity of bementite and caryopilite: Washington Acad. Sci. Jour., vol. 11, pp. 25–32. Discussion of the chemical character of bementite.

218. Palache, Charles, Holdenite and cahnite, two new minerals from Franklin Furnace, N.J.: Am. Mineralogist, vol. 6, p. 39. Title without text. First publication of the two names. (See Palache and Shannon (248) and Palache and Bauer (249).)

219. Larsen, E. S., The microscopic determination of the nonopaque minerals: U.S. Geol. Survey Bull. 679. Contains optical data for 19 minerals found at Franklin. These data are all incorporated in this paper.

1922

220. Larsen, E. S., and Shannon, E. V., Bustamite from Franklin Furnace, N.J.: Am. Mineralogist, vol. 7, pp. 95–100. Optical data and an analysis establishing the finding of bustamite at Franklin.

221. Larsen, E. S., and Shannon, E. V., Notes on some new rhodonite specimens from Franklin Furnace, N.J.: Am. Mineralogist, vol. 7, pp. 149–152. Analysis of rhodonite and description of a parallel growth of rhodonite and bustamite.

222. Gordon, S. G., Crystallographic notes on glaucochroite, willemite, celestite, and calcite from Franklin, N.J.: Acad. Nat. Sci. Philadelphia Proc., vol. 74 [for 1922], pp. 105–112, 1923. Describes, with figures, crystals of the four minerals.

223. Ries, Heinrich, and Bowen, W. C., Origin of the zinc ores of Sussex County, N.J.: Econ. Geology, vol. 17, pp. 517–571. An important discussion of the geologic conditions of the ore bodies at Mine Hill and Sterling Hill. The paper gives a description of thin sections of the ore minerals, showing the sequence of their deposition, and a discussion of the origin of the zinc ores.

224. Shannon, E. V., Note on the cyprine from Franklin Furnace, N.J.: Am. Mineralogist, vol. 7, pp. 140–142. Gives an analysis and the optical characters of cyprine.

225. Lewis, J. V., and Bauer, L. H., Cyprine and associated minerals from the zinc mine at Franklin, N.J.: Am. Jour. Sci., 5th ser., vol. 4, pp. 249–251.

1923

226. Gordon, S. G., A correction; recently described crystals of glaucochroite from Franklin, N.J., are tephroite: Am. Mineralogist, vol. 8, pp. 33–34. A correction of a statement in Gordon (222).

227. Gordon, S. G., Crystallographic notes on hodgkinsonite, datolite, and calciothomsonite from Franklin, N.J.: Acad. Nat. Sci. Philadelphia Proc., vol. 75 [for 1923], pp. 271–274, 1924. Describes crystals of hodgkinsonite and datolite, with figures, and reports, with analyses, the occurrence of calciothomsonite.

228. Rastall, R. H., Geology of the metalliferous deposits, Cambridge, England. (See pp. 131 and 305.) First publication of the theory of the origin of the New Jersey zinc deposits as metamorphosed metasomatic emplacements in limestone.

228a. New Jersey Zinc Company, A record of accomplishment, New York, privately printed, 1923. A short history of the company.

228b. Salton, G. H., Mining practice at Sterling Hill mine [Franklin Furnace district], New Jersey Zinc Co.: Canadian Inst. Min. and Met. Monthly Bull., no. 137, pp. 567–593. Paper not seen.

1924

229. Poitevin, Eugene, and Ellsworth, H. V., New optical data for analyzed sussexite: Am. Mineralogist, vol. 9, pp. 188–190. New analysis of sussexite and optical data on the analyzed material.

230. Larsen, E. S., and Shannon, E. V., Ganophyllite from Franklin Furnace, N.J.: Am. Mineralogist, vol. 9, pp. 238–240. New optical data and analysis for ganophyllite from Franklin.

231. Foshag, W. F., and Gage, R. B., Chlorophoenicite, a new mineral from Franklin Furnace, N.J.: Washington Acad. Sci. Jour., vol. 14, pp. 362–363. Preliminary description, with analysis, of a new arsenate of manganese and zinc.

232. Magnusson, N. H., Långbansmineralen från geologisk synpunkt: Geol. Fören. Stockholm Förh., Band 46, pp. 284–300. Discusses the formation of zinciferous periclase and of manganosite at Långban, and thus throws light on genetic conditions at Franklin.

1925

233. Gage, R. B., Larsen, E. S., and Vassar, H. E., Schallerite, a new arsenosilicate mineral from Franklin Furnace, N.J.: Am. Mineralogist, vol. 10, pp. 9–11. First description of this new species, which is a new chemical type.

234. Spurr, J. E., and Lewis, J. V., Ore deposition at Franklin Furnace, N.J.: Reprint from Eng. and Min. Jour.-Press, vol. 119, pp. 317-328. A description, with many illustrations, of the geologic relations at Mine Hill and Sterling Hill, and a theory of the mode of origin of the deposits.

235. Hoadley, C. W., and Broadwell, W. H., The minerals of the Franklin, N.J., district, leaflet published by the Newark Mineralogical Society. An alphabetic list of 150 minerals known to occur at Franklin.

236. Levi, G. R., Il reticolo cristallino dell' ossido manganoso: Gazz. chim. ital., vol. 54, pp. 704–708; abridged translation in Zeitschr. Krist. Min., Band 61, pp. 557-559. Manganosite from Franklin, N.J., and artificial MnO, when examined by the X-ray powder method, showed the rock-salt type of structure, with $a=4.4$ angstroms. The density deduced from this value is 5.46.

237. Dittler, E., Analytische-synthetic Untersuchungen am Rotzinkerz: Zeitschr. anorg. Chemie, Band 148, p. 332. Zincite from Franklin becomes brown when heated in air, regaining its original color when heated in hydrogen, and on further reduction becomes emerald-green. Experiments with artificial zincites containing different amounts of manganese suggest that the color of the mineral is due to Mn_3O_4, which might have been formed during contact metamorphism.

238. Foshag, W. F., and Gage, R. B., Hedyphane from Franklin Furnace, N.J.: Am. Mineralogist, vol. 10, pp. 351-353. First description of this mineral from Franklin, with an analysis.

239. Larsen, E. S., The identity of ectropite and bementite: Am. Mineralogist, vol. 10, pp. 418–421. Discusses the composition of bementite and points out its relation to serpentine.

1926

240. Shannon, E. V., and Larsen, E. S., A peculiar manganiferous serpentine from Franklin Furnace [N.J]: Am. Mineralogist, vol. 11, pp. 28–30. Gives the chemical composition and optical characters of a serpentine close to bowlingite and antigorite, but containing more than 7 percent of manganese.

241. Foshag, W. F., Radiated chrysotile from Franklin Furnace, N.J.: Am. Mineralogist, vol. 11, pp. 38–39. Gives the composition and optical characters of a fibrous mineral in radiated groups that has been mistaken for wavellite in most of the collections. Also discusses the origin of chrysotile.

242. Zachariasen, W. H., Notiz über die Krystallstruktur von Phenakit, Willemit und verwandten Verbindungen: Norsk Geol. Tidssk., Bind 9, pp. 65–73. Willemite from Franklin, phenakite from Kragerö, Norway, and several isomorphous salts were examined by X-ray methods. They are all trigonal-rhombohedral, with space group $C_{1/3i}$. The elementary cell of willemite, containing six molecules, has dimensions: $a = 8.04$ angstroms, $c = 9.34$ angstroms, $c \div a = 1.161$.

243. Jenkins, David and Bauer, L. H., [Analyses of Franklin minerals]. Analyses, many of them unpublished, made in the laboratory of the New Jersey Zinc Co. and included in this paper with the permission of the company.

244. Shannon, E. V., and Berman, Harry, Barysilite from Franklin Furnace, N.J.: Am. Mineralogist, vol. 11, pp. 130–132. Gives the composition and optical characters of the mineral, not before reported from Franklin.

245. Bauer, L. H., and Palache, Charles, Hyalophane from Franklin Furnace, N.J.: Am. Mineralogist, vol. 11, p. 172. Gives the chemical and optical character of the mineral.

245a. Geijer, Per, Norbergite and fluoborite, two new minerals from the Norberg mining district: Geol. fören. Stockholm Förh., Band 48, Heft 1, pp. 84–85. First description of these two minerals, later found at Franklin. This paper listed here because referred to in comparing the minerals at the two localities.

1927

246. Foshag, W. F., Berman, Harry, and Gage, R. B., The occurrence and properties of chlorophoenicite, a new arsenate from Franklin, N.J: U S. Nat. Mus. Proc., vol. 70, art. 20, 6 pp. Describes more fully (see Foshag and Gage, 231) the occurrence, crystallography, physical and optical characters, composition, and relationships of the mineral.

247. Bauer, L. H., and Berman, Harry, Löllingite from Franklin, N.J.; Am. Mineralogist, vol. 12, pp. 39–43. Describes the occurrence and crystal form of the mineral, gives the composition and the results of the measurement of the crystal angles, and discusses the new values established for the crystal elements.

248. Palache, Charles, and Shannon, E. V., Holdenite, a new arsenate of manganese and zinc from Franklin, N.J.: Am. Mineralogist, vol. 12, pp. 144–148. Describes and names the mineral, previously regarded as leucophoenicite. Gives the results of crystallographic measurements, the axial ratio, the optical character, and the composition, and discusses the derived formula.

249. Palache, Charles, and Bauer, L. H., Cahnite, a new boro-arsenate of calcium from Franklin, N.J.: Am. Mineralogist, vol. 12, pp. 149–153. Describes the mineral, gives the occurrence, crystal form, results of crystallographic measurements, optical constants, and composition, with the derived formula, of this new chemical type.

250. Berman, Harry, The optical properties of zincite from Franklin, N.J.: Am. Mineralogist, vol. 12, pp. 168–172. Gives briefly the results of a chemical analysis and the determination of the refractive indices of very nearly pure material.

251. Palache, Charles, and Berman, Harry, Crystallographic notes—1, 2, Hematite; 3, willemite; 4, hedyphane: Am. Mineralogist, vol. 12, pp. 180–187. Gives the results of crystallographic measurements of fine specimens from the Franklin district.

252. Palache, Charles, and Bauer, L. H., Mcgovernite, a new mineral from Sterling Hill, N.J.: Am. Mineralogist, vol. 12, pp. 373–374. Describes for the first time and names the mineral; gives its occurrence, optical character, and composition; and discusses the complex formula derived.

253. Shuster, E. D., Historical notes of the iron and zinc mining industry in Sussex County, N.J., Franklin, N.J., privately printed. An elaborate compilation of the history of the discovery, development, and ownership of and the litigation regarding the iron and zinc mines of Sussex County, by a member of the surveying staff of the New Jersey Zinc Co.

254. Spencer, L. J., South African occurrences of willemite; fluorescence of willemite and some other zinc minerals in ultraviolet rays: Mineralog. Mag., vol. 21, pp. 388–396. The second part of the paper describes the fluorescence of willemite, including material from Franklin. See Palache (258).

254a. Gordon, S. G., The probable identity of gageite with tephroite: Acad. Nat. Sci. Philadelphia Proc., vol. 79 [for 1927], pp. 207-208, 1928. Suggests identity on the basis of optical and chemical resemblances that are not convincing.

1928

255. Van Horn, F. R., Large magnetite and franklinite crystals from Franklin Furnace, N.J.: Am. Mineralogist, vol. 13, pp. 171-173. Describes some unusually large crystals.

256. Palache, Charles, Bauer, L. H., and Berman, Harry, Larsenite and calcium larsenite, a new member of the chrysolite group from Franklin, N.J.: Am. Mineralogist, vol. 13, pp. 142–144. Preliminary notice. Describes the two minerals briefly for the first time and gives their composition. (See Palache, Bauer, and Berman (259).)

257. Palache, Charles, Mineralogical notes on Franklin and Sterling Hill, N.J.: Am. Mineralogist, vol. 13, pp. 297–329. Crystallographic, physical, and chemical data regarding azurite, bornite, cahnite, clinohedrite, clinozoisite, crocidolite, gageite, glaucochroite, hetaerolite, hodgkinsonite, leucophoenicite, manganite, quartz, smithsonite, sussexite, tephroite, tennantite, and willemite.

258. Palache, Charles, The phosphorescence and fluorescence of Franklin minerals: Am. Mineralogist, vol. 13, pp. 330–333. A description of the apparatus used for observing fluorescence and of the reactions under ultraviolet light of ten of the minerals of the district and the colors they emit when fluorescing.

259. Palache, Charles, Bauer, L. H., and Berman, Harry, Larsenite, calcium larsenite, and the associated minerals at Franklin, N.J.: Am. Mineralogist, vol. 13, pp. 334–340. A fuller statement than that in Palache, Bauer, and Berman (256) of the occurrence, crystal form, physical properties, and composition of the two new minerals described.

260. Bauer, L. H., and Berman, Harry, Friedelite, schallerite, and related minerals: Am. Mineralogist, vol. 13, pp. 341-348. Discusses the general characters of the friedelite group, gives tables of the composition of friedelite and schallerite and of their physical and optical constants and those of related minerals, and discusses a few of the related minerals.

261. Larsen, E. S., Bauer, L. H., and Berman, Harry, Norbergite from Franklin, N.J.: Am. Mineralogist, vol. 13, pp. 349–353. Much of the material from Franklin labeled chondrodite or humite proves to be norbergite. The paper describes the occurrence, optical character, crystallography, and composition of that mineral.

262. Larsen, E. S., The optical properties of the humite group: Am. Mineralogist, vol. 13, pp. 354–359. Discusses the optical properties of the minerals of the group, from many localities, including material from the Franklin district.

262a. Fitch, A. A., The origin of the zinc deposits of Franklin Furnace, N.J.: Mining Mag., vol. 39, pp. 82–84. Gives a theory of magmatic origin of the deposits by the contact action of the gneiss on the limestone similar to the theory of Ries and Bowen (223).

1929

263. Palache, Charles, Paragenetic classification of the minerals of Franklin, N.J.: Am. Mineralogist, vol. 14, pp. 1-18. An elaborate discussion of the occurrence and association of the minerals, classified under five paragenetic groups, according to geologic occurrence. Special attention is given to the minerals of the zinc ores, arranged under four subgroups according to stage of development and time of formation. The several previous theories of the origin of the zinc ores are discussed and rejected, and the author gives a full statement of and supports the theory of metasomatic emplacement of the ores in the Franklin limestone and their subsequent metamorphism. (See Rastall (228).)

264. Spencer, L. J., Fluorescence of minerals in ultraviolet rays: Am. Mineralogist, vol. 14, pp. 33–37. Appeared originally in Nat. Hist. Mag., vol. 1, pp. 291-298, 1928. Describes the fluorescence of willemite.

265. Palache, Charles, A comparison of the ore deposits of Långban, Sweden, with those of Franklin, N.J.: Am. Mineralogist, vol. 14, pp. 43–47. A study in which it is pointed out that, despite the occurrence in both districts of numerous minerals known nowhere else, the two deposits have very different geologic histories.

266. Bauer, L. H., and Berman, Harry, Loseyite, a new Franklin mineral: Am. Mineralogist, vol. 14, pp. 150–153. The first description of a new basic hydrous carbonate of manganese, zinc, and magnesium.

267. Bauer, L. H., and Berman, Harry, Mooreite, a new mineral, and fluoborite from Sterling Hill, N.J.: Am. Mineralogist, vol. 14, pp. 165–172. The first description of a new basic hydrous sulphate of magnesium, manganese, and zinc, and the first description of fluoborite from the locality.

268. Tarr, W. A., The origin of the zinc deposits at Franklin and Sterling Hill, N.J.: Am. Mineralogist, vol. 14, pp. 207-221. In this paper the author adopts the theory that the deposits are metamorphosed metasomatic emplacements in limestone and attempts to deduce the nature of the original metasomatic minerals from the present mineralogical constitution of the deposits.

269. Hey, M. H., The variation of optical properties with chemical composition in the rhodonite-bustamite series: Mineralog. Mag., vol. 22, pp. 193–205. A detailed statement of a rather elaborate study of the minerals of the series, including material from Franklin.

270. Taylor, W. H., and West, J., The structure of norbergite: Zeitschr. Krist., Band 70, pp. 461–474, 1929. Confirms the place of norbergite in the humite group and shows that structurally olivine fits into the series.

1930

271. Barth, Tom, and Berman, Harry, Neue optische Daten wenig bekannter Minerale: Chemie der Erde, Band 5, pp. 22–42. Contains an account of the determination of the optical constants of apatite and svabite, as an illustration of the application of their method.

272. Palache, Charles, and Bauer, L. H., On the occurrence of beryllium in the zinc deposits of Franklin, N.J.: Am. Mineralogist, vol. 15, pp. 30–33. A description of beryllium-rich vesuvianite and of barylite at Franklin. Beryllium had not previously been found in vesuvianite.

273. Bauer, L. H., and Berman, Harry, Notes on some Franklin minerals: Am. Mineralogist, vol. 15, pp. 340–348. Analyses and new optical and crystallographic data on zinc-manganese cummingtonite, apophyllite, barysilite, celestite, datolite, ferroschallerite, manganbrucite, and svabite. The mineral previously described as probably clinozoisite is shown to be chlorophoenicite.

274. Bragg, W. L., and Zachariasen, W. H., The crystalline structure of phenacite, $BeSiO_4$, and willemite, $ZnSiO_4$: Zeitschr. Krist., Band 72, pp. 518–528, 3 figs., 1929. Phenacite and willemite have similar unit cells and belong to the same space group. (See Zachariasen (242).)

275. Warren, B. E., and Trautz, O. R., The structure of hardystonite, $Ca_2ZnSi_2O_7$: Zeitschr. Krist., Band 75, pp. 525–528. The chemical composition of hardystonite is closely analogous to that of melilite. X-ray examination shows that the unit cell, space group, and atomic arrangement are the same as in melilite, and that the structure differs only in having (Mg,Al) in place of Zn. The space group is D^3_{2d}, and there are two molecules in the unit cell.

276. Palache, Charles, Davidson, S. C., and Goranson, E. A., The hiddenite deposit in Alexander County, N.C.: Am. Mineralogist, vol. 15, pp. 280–302. Describes, among others, crystals of arsenopyrite and compares them with those found at Franklin. (See p. 299 and fig. 11.)

277. Unpublished analyses of minerals, made in the chemical laboratory of the Department of Mineralogy and Petrography at Harvard University by F A. Gonyer and others.

278. Parsons, A. L., A chemical and optical study of amphibole, in Contributions to Canadian mineralogy, 1930: Toronto Univ. Studies, Geol. ser., no. 29, pp. 29–33. Contains an analysis of an amphibole from Franklin, by M. C. Haller.

278a. Krieger, Philip, Notes on an X-ray diffraction study of the series calcite-rhodochrosite: Am. Mineralogist, vol. 15, pp. 23–29. Manganocalcite from Franklin and other localities was studied, and the variation of X-ray diffraction patterns was correlated with chemical, physical, and optical characters.

1931

279. Berman, Harry, and Larsen, E. S., Composition of the alkali amphiboles: Am. Mineralogist, vol. 16, pp. 140–144. Discusses the composition, relations, and classification of the amphiboles from a new point of view of their molecular structure.

280. Manchester, J. G., Minerals of New York City and its environs: New York Mineralogical Club Bull., vol. 3, no. 1. Gives a brief account of the mines at Franklin and Sterling Hill, and a list of minerals found there comprising 140 species and 78 varieties (but with many synonyms). Also a bibliography including many of the papers treating of the locality.

281. Sundius, N., On the triclinic manganiferous pyroxenes: Am. Mineralogist, vol. 16, pp. 411–429, 488–518. Relations of bustamite and rhodonite.

281a. Blix, Ragnar, The chemical composition of roeblingite: Am. Mineralogist, vol. 16, pp. 455–460.

281b. Warren, B. E., and Biscoe, J., The crystal structure of the monoclinic pyroxenes: Zeitschr. Krist., Band 80, p. 400, 1931.

281c. Buerger, M. J., The crystal structure of löllingite, $FeAs_2$: Zeitschr. Krist., Band 82, pp. 165–187.

1933

282. Bauer, L. H., and Berman, Harry, Barium-muscovite from Franklin, N.J.: Am. Mineralogist, vol. 18, p. 30. Description of a muscovite containing barium, with analysis.

283. Schaller, W. T., A tephroite crystal from Franklin Furnace, N.J.: Am. Mineralogist, vol. 18, pp. 59–62.

284. Kerr, P. F., Zinc-deposits near Franklin, N.J.: XVI Internat. Geol. Cong. Guidebook 8, pp. 2–13.

1934

285. Haff, J. C., Crystallized native copper from Franklin, N.J.: Am. Mineralogist, vol. 19, p. 480.

THE FRANKLIN MINING DISTRICT

GENERAL FEATURES

GEOLOGY

The geologic relations of the ore deposits were described by A. C. Spencer in the Franklin Furnace folio (no. 161) of the Geologic Atlas of the United States, issued in 1908. The rocks of the district comprise limestone, sedimentary gneiss, igneous gneiss, and intrusive lenses of pegmatite, all of pre-Cambrian age, overlain on the west by the Hardyston quartzite (Cambrian) and Kittatinny limestone (Cambrian and Lower Ordovician). The pre-Cambrian rocks are cut by a few camptonite dikes of post-Ordovician age, and on the east the Kittatinny limestone is faulted down against the Franklin limestone. Glacial deposits of several sorts mask the bedrock of considerable areas.

The structure and composition of the ore bodies and the enclosing rocks are fully described in the folio, with maps and sections showing the extent and form of the ore bodies as known in 1908. The geologic map of the mining district published in the folio is reproduced as plate 1 in this paper, with the addition of the mineral localities most frequently referred to in the description of the minerals.

Little has been published since 1908 regarding the geology, and there has been no detailed description of the extensive mining developments of recent years, but the papers by Ries and Bowen (223) and by Spurr and Lewis (234) contain some valuable new information.

The two main ore bodies are essentially alike in form and composition. Both are tabular masses, folded in warped synclines with hook-shaped outcrops (see pl. 1), and both are wholly enclosed in Franklin limestone, their folds pitching northeastward in accord with the general structure of the pre-Cambrian rocks. Both consist chiefly of franklinite, willemite, zincite, and calcite, the first three commercially valuable ores of zinc, manganese, and iron, and the fourth the only important gangue mineral. Normally these minerals are intimately intermixed in granular form, the grains of the ore minerals being in general noticeably rounded and the interlocking calcite grains forming the matrix of the mass. Generally also one or more of the ore minerals is somewhat concentrated in layers roughly parallel to the walls of the deposit, giving a markedly banded appearance to the mass of the ore.

HISTORY

Scientific knowledge of the Franklin minerals began with the discovery of zincite by Bruce in 1810, but scanty records of earlier date show that the deposits had long before attracted the attention of miners. Old deeds exist in which Sterling Hill, then known as the "Stirling tract," when returned to the heirs of Anthony Rutgers in 1730, was called the "copper tract." According to Farrington (59), mining engineer to the first New Jersey Zinc Co., the locality was probably first exploited by Dutch miners from the Hudson Valley, who worked copper deposits in the Delaware River drainage basin in 1640, sending their product through the Wallkill Valley to the Hudson at what is now Kingston. What ore they sought at Sterling Hill is not certain, but to them are assigned considerable mine workings there that were already ancient when Lord Stirling owned the property about 1770. They had probably mistaken the red zinc oxide for copper oxide, as did Lord Stirling, who about 1772 shipped some tons of it to England for smelting as an ore of copper. The ore shipped seems neither to have been smelted nor to have been recognized as really a zinc ore. Pieces of it, however, found their way into English mineral collections and later, their origin having been forgotten, were credited to various localities where zincite has never been found. Lord Stirling's attempt to utilize the abundant franklinite on his property as a source of iron was similarly unsuccessful. He sent a large amount of it to his furnace at Charlottesburg at great expense, but the unsuspected zinc and manganese in the ore prevented its successful smelting, and for years it lay on the ground unused. In spite of this failure an iron furnace was erected at Franklin about 1770, which was unsuccessful for the same reason and by 1820 had fallen into ruin.

The paper of Dr. Bruce (1), an enthusiastic mineralogist of New York City, describing the zincite and calling attention to its abundance and value as a zinc ore, was the first step toward a right understanding of its chemical composition. He did not, however, discover the true character of the more abundant franklinite, which he mistook for magnetite, as all before him had done. Still, Bruce's description of zincite caused the geologist Maclure to send abroad specimens of it, which contained franklinite. Some of these reached the French chemist Berthier, by whom that mineral was properly described as an oxide of iron, manganese, and zinc. He named it from its place of origin and pointed out its value as an ore of all three of the contained metals.

In 1816 the mineral-bearing property came into the hands of Dr. Samuel Fowler, a man of scientific attainments and business talent of a high order. He was the first to appreciate the unusual character and great potential value of his mineral deposits, and he took every means of informing himself about them. His son, Col. Samuel Fowler, who later inherited the tract, resumed mining operations. The two Fowlers interested many leading chemists and geologists of the period, who visited the locality and recorded their observations in a number of papers, listed in the accompanying bibliography. Between 1820 and 1844 the district was visited by Alger, Gibbs, C. T. Jackson, Keating, Maclure, Nuttall, Seybert, Torrey, Troost, and Vanuxem, and doubtless others of similar tastes made the pilgrimage to the hospitable home of the Fowlers. Nuttall and Torrey, especially, were deeply interested, visited the area frequently, and sent many specimens abroad, which were studied by European mineralogists and added much to our knowledge of the minerals. Vanuxem and Keating discovered willemite, the third important ore mineral, and they and Troost described jeffersonite and other new minerals. Alger, who about 1844 became part owner of the property, was also interested in the minerals, experimented at his Boston foundry on the reduction of the ores—unsuccessfully, it must be said—and was active in distributing broadcast to the scientific world specimens of the unique minerals of the district.

Dr. Fowler also attempted to develop his property commercially. Failing to enlist capital to work the deposits on a large scale, he used his own means to experiment on the uses of the newly discovered ores. He was not very successful, but Ballou, one of his associates, was able to prepare white zinc oxide directly from zincite and, grinding it in oil, to make paint that was used on the Fowler house at Franklin some years before that pigment was developed in Europe. In 1838 metallic zinc was reduced from zincite on a small scale, at Colonel Fowler's suggestion, to make brass for a new set of standard weights and measures for the United States Government. Ultimately Colonel Fowler sold the mineral properties, reaping but a scanty reward for his unceasing labor in making them known.

In 1850 the ore bodies were first successfully exploited by the first New Jersey Zinc Co., and since then there has never been a question of their value and usefulness. The complicated history of the mining and litigation during the development of the district to its present flourishing status will not be given here, but that history and that of the progress in the dressing and metallurgical treatment of the ores has been related by Wetherill (172), one of the participants in the events described. Further details of the early history of the mines may be found in the pamphlet by Shuster (253). Those interested in the present methods of mining the ores will find an excellent account in the paper by Haight and Tillson (213).

The outlines of the geologic structure and the principal minerals in the ore deposits having been described in the early papers, considerable time ensued during which little of scientific interest appeared. Local collectors, however, were actively watching developments at the mines, and several new and interesting minerals were found and preserved during those years. Colonel Fowler, Frederick Canfield, Woodruff, Losey, Hancock, and Kemble were the best known among the collectors of that period.

The exploitation of the calamine deposits at Sterling Hill in 1870 led to the discovery of several new minerals, with whose description are associated the names of Moore, Roepper, and Brush. Active interest in the geology of the deposits was renewed with the sinking of the Trotter shaft in 1880 and the opening and stripping of the hook-shaped mass of ore in the Buckwheat open cut on Mine Hill. The discussion of the age of the ores and the white limestone containing them was settled only with the paper by Wolff and Brooks in 1898. The many minerals developed in pneumatolytic zones about the pegmatite at the Trotter shaft were described by Koenig and Penfield and reawoke mineralogic interest in those unique deposits, which was further heightened by the remarkable suite of new species found by Hancock and Ferrier in the workings at the Parker shaft in 1896 and described by Penfield and Wolff.

Since 1900 there have been many interesting additions to the list of Franklin minerals. As the bibliography shows, new species are frequently discovered and described. Every large collection of Franklin minerals contains much material not yet identified, and there seems to be almost no end to the variety of chemical compounds that might be formed under the peculiar conditions attending the development of this mineral deposit.

MINES AND MINERAL LOCALITIES

More than a century has passed since minerals from this area were first described. Few of the earlier papers gave details of the localities and the mode of occurrence of the minerals, and changing conditions of mining operations have made obsolete some of the locality names formerly used. In order to make clear many of the references to such localities a brief statement of the mining operations in the district seems necessary.

The original outcrop at Franklin (named Franklin Furnace until 1913), in the township of Hardyston, was on a small eminence named at an early date Mine Hill. (See pl. 1.) The outcrop, half a mile long, of the western leg of the ore body was first opened by cuts and inclined shafts worked independently. Such were the Hamburg mine, the Trotter mine, and the Dingdong shaft. In 1852 the eastern leg of the ore body was discovered in what was then called the Buckwheat field. The pitching synclinal connection of the two legs was laid bare much later and came to be known as the Buckwheat mine or Southwest opening, and still later, when worked by stripping, as the Buckwheat open cut. The Taylor mine was on the eastern leg of the ore body near the north end of the outcrop. About 1890 diamond drilling on the east side of Mine Hill proved the northward extension underground of the eastern leg of the ore body, which was reached by sinking the vertical Parker shaft, nearly 1,000 feet deep. In 1897 all the properties at Mine Hill were consolidated under the management of the present New Jersey Zinc Co. and a new method of mining was established.

The Palmer shaft, an incline 1,500 feet long sunk in the footwall gneiss near the north end of the western outcrop of the ore body, was driven to the bottom of the syncline, and through it all ore is hoisted to a single concentrating plant. The ore is removed by a system of stope slicing and topslicing introduced by R. M. Catlin and described in a paper by Haight and Tillson (213), engineers of the mine. The ore as it reaches the shaft head is thrown on a grizzly, and the oversize passes on, after being washed, to a circular picking table, where waste is removed by several men. Specimens found on the picking table may therefore have come from any part of the mine, and only specimens actually found in the mine and located by the finder can be assigned to any definite locality other than merely Franklin. Many exact locations in the mine are given, however, in recent papers. Localities are designated by the depth and by pillar numbers, north or south of an east-west line through the Palmer shaft.

As pillars and slices are emptied of ore they are filled with waste, part of which is tailings and waste from the picking table but much more of which is rock broken from the mass of limestone between the two legs of the ore body and conveyed into the mine by chutes. All the older localities on and about Mine Hill that were within the original outcrops of the ore body, including all the older mines, have been obliterated by the later operations.

At Sterling Hill, in the township of Sparta, where the ore originally cropped out, as at Franklin, in an eastern and a western leg or "vein", were the earliest authentically known workings, the Lord Stirling pits. The space between the two legs of the ore body was worked for calamine by two open-cut mines called the Passaic and the Noble. Work on the main ore body ceased about 1900, and the property was idle for a time. About 1913 a shaft was sunk and extensive underground development was begun. At Sterling Hill also there is a picking table, on which specimens are sometimes found. Caving operations to obtain filling material have obliterated the evidence of earlier mining in considerable parts of the Sterling Hill area, as at Franklin.

The following explanation will help readers to understand the references to localities, indicated by numbers on plate 1, 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 crosscut 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, clinohedrite, roeblingite, hancockite, glaucochroite, 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 desaulesite. 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 veinlike 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 (100).

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 transverse secondary veins of great variety. (See the detailed description, particularly under pyrochroite and willemite, pp. 49–50, 86–87.) 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 roepperite 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 hydrohetaerolite.

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.

THE ORE DEPOSITS

AVERAGE COMPOSITION OF THE ORE

The average mineral and chemical composition of the ore of the Franklin district, as established by many hundred mill and assay tests, is approximately as follows:

Average mineral and chemical composition of the ore of the Franklin district

Mineral composition	Percent	Chemical composition	Percent
Franklinite	43	ZnO	31
Zincite	1	FeO	25
Willemite	26	MnO	10
Other silicates, such as garnet and rhodonite	5	SiO_2	9
Calcite	25	$CaCO_3$	25
	100		100

The data in the first column were kindly supplied by the New Jersey Zinc Co., with permission to publish them. The chemical composition was computed from them and is not exact, as some of the iron and manganese should be stated as sesquioxide.

In contrast to the rather simple mineral composition of the ore bodies as a whole are the number and variety of the minerals they contain in very minor amount. Of the more than 140 minerals found in the district, at least 120 are found in the zinc-ore deposits, and nearly 100 are found only in those deposits. (See list below.) In the following sections the association of the minerals in groups according to their geologic occurrence is described, with special reference to the further grouping of the minerals in the zinc ores according to their genetic relations. In order to concentrate attention on the problem of the origin of the zinc ores, the minor mineral associations will be described first.

Alphabetic list of the minerals of the Franklin district, showing their geologic occurrence

[Occurrence in the zinc ores is indicated by A, in the pegmatite bodies by B, in the magnetite ores by C, in the Franklin limestone by D, and in the Kittatinny limestone by E Minerals seen only as essential constituents of the rocks of the district are not included]

Actinolite—A, B, C, D.
Albite—A, D, E.
Allactite—A.
Allanite—B, C.
Andradite—A, B, C, D.
Anglesite—A.
Anhydrite—A.
Anorthite—D.
Apatite—A, B, C, D.
Apophyllite—A.
Aragonite—A.
Arseniosiderite—A.
Arsenopyrite—A, C, D, E.
Aurichalcite—A.
Azurite—A.
Barite—A.
Barylite—A.
Barysilite—A.
Bementite—A.
Beryllium vesuvianite—A.
Bornite—A.
Bustamite—A.
Cahnite—A.
Calamine—A.
Calciothomsonite—A.
Calcite—A, D, E.
Calcium larsenite—A.
Celestite—A.
Cerusite—B.
Chalcocite—A.
Chalcophanite—A.
Chalcopyrite—A, B, D.
Chloanthite—A.
Chlorite—A.
Chlorophoenicite—A.
Chondrodite—D.
Clinohedrite—A.
Copper—A.

Corundum—D.
Crocidolite—A.
Cuprite—A.
Cuspidine—A.
Cyprine—A.
Datolite—A.
Desaulesite—A.
Descloizite—A
Diopside—A.
Dolomite—A, D.
Edenite—D.
Epidote—A, B, C.
Ferroaxinite—C.
Ferroschallerite—A.
Fluoborite—A.
Fluorite—A, B, D, E.
Fowlerite—A, B.
Franklinite—A.
Friedelite—A.
Gageite—A.
Gahnite—A, D.
Galena—A, B, D, E.
Ganophyllite—A.
Glaucochroite—A.
Goethite—A.
Graphite—D.
Greenockite—A.
Gypsum—A.
Halloysite—A.
Hancockite—A.
Hardystonite—A.
Hastingsite—A.
Hedyphane—A.
Hematite—A, D.
Hetaerolite—A.
Heulandite—A.
Hodgkinsonite—A, D.
Holdenite—A.
Hyalophane—A.
Hydrohetaerolite—A.
Hydrozincite—A.
Ilmenite—D.
Jeffersonite—A, B.
Kentrolite—A.
Larsenite—A.
Lead—A.
Leucaugite—A, C, D.
Leucophoenicite—A.
Limonite—A.
Löllingite—A.
Loseyite—A.
Magnesium chlorophoenicite—A.
Magnetite—A, B, C, D.
Malachite—A.
Manganbrucite—A.
Manganite—A.
Manganoaxinite—A.
Manganophyllite—A, C.
Manganosite—A.
Marcasite—D.
Margarosanite—A.
Mcgovernite—A.
Microcline—B, C.
Millerite—A.
Molybdenite—C, D.
Mooreite—A.
Muscovite—B, D.
Nasonite—A.
Neotocite—A.
Niccolite—A.
Norbergite—D.
Pargasite—A.
Pectolite—A.
Phlogopite—C, D.
Prehnite—A.
Psilomelane—A.
Pyrite—A, C, D.
Pyrochroite—A.
Pyrrhotite—D, E.
Quartz—A, B, D, E.
Rhodochrosite—A.
Roeblingite—A.
Roepperite—A, D.
Rutile—C, D.
Scapolite—C, D.
Schallerite—A.
Schefferite—A.
Serpentine—A.
Siderite—A.
Silver—A.
Smithsonite—A.
Sphalerite—A, B, E.
Spinel—B, C, D.
Stilbite—A, B.
Sussexite—A.
Svabite—A.
Talc—A, D.
Tennantite—A.
Tephroite—A.
Thorite—B.
Titanite—B, C, D.
Tourmaline—D.
Tremolite—A, D.
Willemite—A.
Xonotlite—A.
Zincite—A.
Zinc cummingtonite—A.
Zinc schefferite—A.
Zircon—B, C.
Zoisite—B.

UTILIZATION OF THE ORES

The minerals that are saved as ore concentrates or that are recognized in milling operations as considerable constituents of the waste are not numerous. The ore minerals are franklinite, willemite, and zincite, and the chief waste minerals are calcite, garnet, fowlerite, tephroite, zinc schefferite, and sphalerite.

Franklinite, the most abundant mineral in the ore, is removed from the crushed ore by magnetic separators, and the concentrate, shipped to the smelting works as franklinite, constitutes about 36 percent of the crude mineral ore. The concentrate from the Franklin mine contains 14 to 18 percent of zinc, 34 to 40 percent of iron, and 12 to 16 percent of manganese. The franklinite from Sterling Hill has about the same composition, but some of it runs higher in both zinc and iron, and it is generally lower in manganese. The silica rarely exceeds 3 percent. The variation in the composition of the concentrate is due partly to the wide range in the composition of franklinite itself and partly to tiny particles of various silicates that may still be attached to the grains of franklinite after the crushing. Franklinite is used in the manufacture of zinc oxide and of spiegeleisen.

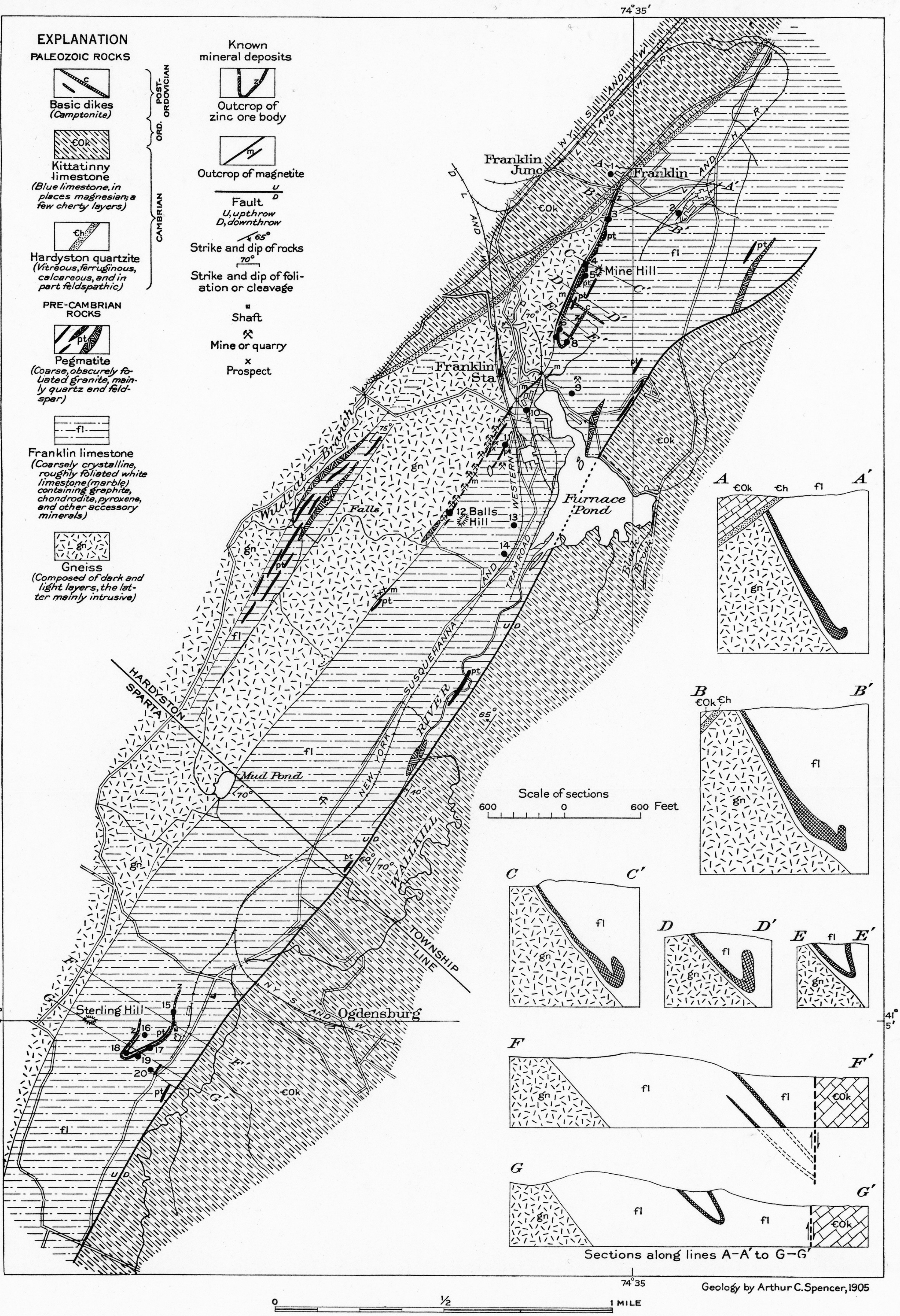
Willemite is the most abundant constituent of the nonmagnetic part of the ore. It is separated from the waste minerals by treatment in jigs for the coarser material and on tables for the finer material. The willemite concentrate from the Franklin mine, which constitutes about 18 percent of the crude milled ore, contains 44 to 49 percent of zinc, 1.2 to 3 percent of iron, 4 to 6 percent of manganese, and 3 to 7 percent of lime. From willemite is made a high-grade spelter.

Zincite constitutes less than 1 percent of the crude ore and in the milling is separated with the willemite.

Besides these definite mineral concentrates, about 25 percent of the crude ore is comprised in products known as half-and-half, dust fines, and slimes. The first is an intermediate magnetic product consisting of mixed grains of franklinite and silicates; the other two are mill products and are, of course, not of simple mineral composition.

The minerals separated as waste in milling constitute at the Franklin mine about 20 percent of the crude milled ore. Calcite, more or less manganiferous, forms 92 to 96 percent of the tailings, and next in abundance is andradite garnet, which sometimes is scarcely appreciable and at other times forms as much as 2 percent of the crude ore. Part of it is separated with the magnetic fraction and part with the willemite concentrate, in both of which it is an undesirable impurity. Fowlerite and tephroite are rarely present in large amounts. Both are separated mainly with the willemite and are undesirable because they increase the manganese content of the concentrate. Zinc schefferite is rare at Franklin, but at Sterling Hill it is in places sufficiently abundant to lower the grade of the willemite concentrate. Sphalerite is rare at Franklin but is common at Sterling Hill, both disseminated in the ore and as a vein filling. It may at times amount to nearly 1 percent of the willemite concentrate, in which it is separated. As it is not reduced in the smelting process it can be regarded only as a waste product.

Another element of economic importance in the mineralogy of the ore deposits is the presence of minute amounts of compounds of lead and arsenic, as even a trace of lead in the concentrate is objectionable. Besides its sparse occurrence as native lead and in



Geology by Arthur C. Spencer, 1905

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

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galena, lead is found in the very rare silicates margarosanite, barysilite, nasonite, calcium larsenite, larsenite, and roeblingite and in the arsenate hedyphane. Of more importance is its persistent presence in hardystonite, as that mineral is much less rare than the true lead compounds. The arsenic compounds, though rather numerous, are rare and local. They include the arsenides chloanthite, löllingite, and niccolite; the arsenates allactite, arseniosiderite, cahnite, chlorophoenicite, hedyphane, holdenite, and svabite; and the arseniosilicates schallerite and ferroschallerite and some of the friedelite.

All the minerals listed in the preceding paragraph are removed from the crude ore wherever possible, both in the mine and on the picking table. Their total amount in the ore as mined is inconsiderable, and such are the pains taken to check the lead content of the concentrate before smelting that the zinc manufactured from the ore is practically lead free.

PARAGENESIS OF THE MINERALS

MINERALS IN THE PEGMATITE BODIES

Masses of pegmatite, ranging from rather large lenses to small dikes, form a considerable part of the pre-Cambrian complex. They cut both the gneiss and the limestone, and some of them at least are younger than the zinc-ore deposits, hence their intrusion probably continued through a long period. Spurr and Lewis (234) pointed out that in some places the pegmatite dikes have been squeezed into lenses or even sheared into blocks that have reacted on their whole surface with the enclosing limestone. A shearing movement sufficient to dissect the pegmatite dikes so effectively could hardly have failed similarly to affect the nearby ore bodies had they then been in existence. As they are not so dislocated, it seems more reasonable to suppose that they were formed after the intrusion and deformation of the older pegmatites. The later pegmatites, on the contrary, cut the ore deposits and are not extensively deformed.

The pegmatites are of granitic composition and consist essentially of dominant microcline and oligoclase, subordinate quartz, and accessory apatite, muscovite, titanite, epidote, and allanite and rarely thorite and zircon. Magnetite is rarely absent and may be dominant, as described in the next section. Galena and sphalerite in minute grains are common and are believed to be original constituents. Zoisite occurs as an alteration product of microcline. At the contacts of the pegmatite with the limestone and with the zinc-ore bodies, groups of reaction minerals and of pneumatolytic minerals have generally been developed. They are described on the next few pages.

MINERALS IN THE MAGNETITE DEPOSITS

Minable deposits of magnetite are found at several places in the Franklin district, both in the Franklin limestone and in the gneiss, and so intimately associated with the pegmatite bodies that the genetic relation of the two can scarcely be doubted. The minerals composing the iron ores, most of them except magnetite being in small amounts or very locally developed, are magnetite, microcline, leucaugite, epidote, allanite, biotite, phlogopite, scapolite, iron axinite, iron garnet, iron spinel, apatite, pyrite, arsenopyrite, molybdenite, rutile, titanite, and zircon. This grouping of minerals makes highly probable the genetic relations of the magnetite bodies to the pegmatites that is indicated by their geologic relation. The absence of zinc and manganese compounds is also a noteworthy feature of the iron ores, although minute traces of both those metals have been detected in the magnetite. (See appendix, *a*, p. 130.)

MINERALS IN THE FRANKLIN LIMESTONE

The Franklin limestone, commonly called the "white limestone" from its color, is a coarsely crystalline rock, ranging in composition from nearly pure calcium carbonate to a magnesian carbonate with almost the ratio of dolomite. The differences in composition do not affect its appearance or degree of crystallinity. Near the ore deposits the rock is manganesian and weathers black.

The white limestone, long quarried as a flux at Franklin, Sterling Hill, and Rudeville, is well exposed and has yielded much material to mineral collectors. It contains a group of minerals that carry neither zinc nor manganese and are either very rare or unknown in the zinc-ore deposits. In some places these minerals are found near dikes of pegmatite or of basic rocks, and their formation was probably due to interaction with the igneous material. More commonly, however, they are quite isolated in the limestone and either are products of its recrystallization during metamorphism or were formed by the introduction from intrusive rocks of new elements that had migrated far from their source.

The minerals in the pegmatite contact zone in the limestone include amphiboles, mainly tremolite and edenite; pyroxenes, especially diopside and leucaugite; scapolite; green and brown magnesian tourmaline; and chondrodite and norbergite, intergrown or separate. The author has never seen garnet in the limestone away from the zinc ores, though Spurr and Lewis (234) describe it from the wall of the ore body. All the minerals named above except pyroxene contain some "mineralizer" such as hydroxyl, chlorine, fluorine, or boron--a fact that hardly supports the statement of Spurr and Lewis that the minerals are due to simple heat reactions without the presence of gas.

The minerals found in isolated crystals or grains in the Franklin limestone include all those named in the preceding paragraph and also graphite, molybdenite, chalcopyrite, pyrite, pyrrhotite, arsenopyrite, fluorite, quartz, corundum, hematite, ilmenite, magnetite, spinel, rutile, anorthite, phlogopite, titanite, and apatite. This group is typical of such highly metamorphosed limestones, and it is duplicated, with minor changes, at the well-known mineral localities in Orange County, N.Y., a score of miles to the north in the same belt of Franklin limestone, and in many other limestones. In its formation it clearly owed nothing to the agencies that produced the ore bodies.

MINERALS IN THE KITTATINNY LIMESTONE

The Paleozoic strata have not been notably metamorphosed or mineralized, but they were invaded, presumably late in Triassic time, by dikes of camptonite and nephelite syenite, and they have been profoundly faulted, probably late in the Paleozoic era and again at the end of the Triassic period. Spurr and Lewis (234) record "irregular subsequent impregnations of fluorite, arsenopyrite, pyrrhotite, sphalerite, galena, and many other minerals" of the sort associated with such dikes cutting limestone. At several places in the limestone there are irregular cavities on whose walls are crystals of fluorite, quartz, calcite, albite, and sphalerite.

These occurrences are of minor significance in the mineralogy of the district but show the presence of sulphide-bearing solutions, probably during the latest marked deformation. To such solutions, quite possibly, are due the small and rare veins of quartz, pyrite, sphalerite, and carbonates that cut the ore deposits. (See p. 22.)

MINERALS IN THE ZINC ORES

GENETIC CLASSIFICATION

There remain for consideration the minerals found in the zinc-ore deposits, by far the most valuable as well as the most numerous association found in the district. They have been grouped for discussion as follows:

- Primary minerals.
- Minerals of the pegmatite contact zones.
  - Reaction and recrystallization products, or "skarn."
  - Pneumatolytic products.
- Minerals of the hydrothermal veins.
- Minerals resulting from surface oxidation, hydration, and carbonatization.

In the accompanying table the minerals have been arranged in the above groups, the name of each mineral being accompanied by its chemical formula, the better to bring out the chemical nature of the groups. It is clearly recognized that the several groups merge more or less, as all stages of alteration are represented, and several of the minerals are found in more than one group.

This suggested classification in genetic groups is of course hypothetical, but it serves to simplify the description of the paragenesis. Most of the conclusions here presented are based primarily on the study of hand specimens, as no detailed or systematic study of the ores in place has been made by the author nor, so far as he is aware, by any other geologist or mineralogist of the many who have visited or who have written about these deposits.

PRIMARY MINERALS

The minerals certainly to be regarded as primary are the four—franklinite, willemite, zincite, and calcite—that make up nearly the whole mass of the two ore bodies, at Franklin and at Sterling Hill. To these may be added tephroite as a rare, probably primary associate of willemite. The average percentage of each of the four principal minerals in the ore is given on page 17. There are, however, several wide departures from the average. Franklinite, alone or with calcite, forms some large masses of ore, and zincite is segregated in some masses almost to the exclusion of the other minerals. Willemite is in a few places the only ore mineral in the calcite gangue. The typical ore, however, is a layered mass of all four minerals in rather coarse grains.

The relative age of the four ore minerals was determined by Ries and Bowen (223) through the study of thin sections of the ore. These show that tephroite and willemite are the earlier minerals and that their formation was followed by that of the franklinite and zincite but with some overlap in time.

Of the four ore minerals, only tephroite and willemite have been found elsewhere, and only as subordinate constituents of ores of manganese and zinc. The exceptional mineral character of the Franklin ores is convincing evidence of unusual conditions controlling their deposition.

MINERALS IN THE PEGMATITE CONTACT ZONES

General features.—The minerals in the pegmatite contact zones form a complex group that includes more than half of the species peculiar to the district, as listed below.

Minerals found only at Franklin or Sterling Hill, N.J.

[Species found at Franklin, F; at Sterling Hill, S. Margarosanite and nasonite, first found at Franklin, are known elsewhere only at Långban, Sweden]

Cahnite, F.
Calcium larsenite, F.
Chalcophanite, S.
Chlorophoenicite, F.
Magnesium chlorophoenicite, F.
Clinohedrite, F.
Desaulesite, F.
Ferroschallerite, F.
Franklinite, F, S.
Gageite, F.
Glaucochroite, F.
Hancockite, F.
Hardystonite, F.
Hetaerolite, F.
Hodgkinsonite, F.
Holdenite, F.
Jeffersonite, F, S.
Larsenite, F.
Leucophoenicite, F.
Loseyite, F.
Mcgovernite, S.
Mooreite, S.
δ-Mooreite, S.
Roeblingite, F.
Roepperite, S.
Schallerite, F.
Sussexite, F.
Zincite, F, S.
Zinc cummingtonite, F.
Zinc schefferite, F, S.

There is a lack of detailed observations in most of the mines to support conclusions based on the chemical

Paragenetic table of the minerals of the Franklin area

Primary ore minerals

- Franklinite, $(Zn,Fe,Mn)O.(Fe,Mn)_2O_3$
- Zincite, $(Zn,Mn)O$
- Willemite, $2ZnO.SiO_2$
- Tephroite, $2(Mn,Zn,Fe)O.SiO_2$

Pegmatite contact minerals

- Skarn:
  - Hyalophane, $(K_2,Na_2,Ba)O.Al_2O_3.4SiO_2$
  - $\left.\begin{array}{l}\text{Diopside}\\ \text{Jeffersonite}\\ \text{Schefferite}\\ \text{Zinc schefferite}\end{array}\right\}(Ca,Mg)O.(Fe,Mn,Zn)O.2SiO_2$
  - Fowlerite, $(Mn,Fe,Ca,Zn)O.SiO_2$
  - Bustamite, $(Mn,Ca)O.SiO_2$
  - Zinc-manganese cummingtonite, $7(Mg,Mn,Zn)O.8SiO_2.H_2O$
  - Manganiferous amphiboles: Hastingsite, Pargasite, etc.
  - Garnet, var. andradite, $3(Ca,Mn)O.(Fe,Al)_2O_3.3SiO_2$
  - Hardystonite, $2CaO.ZnO.2SiO_2$
  - Tephroite, $2(Mn,Zn,Fe)O.SiO_2$
  - Roepperite, $2(Fe,Mn,Zn,Mg)O.SiO_2$
  - Glaucochroite, $MnO.CaO.SiO_2$
  - Vesuvianite, var. cyprine, $3(Al,Fe)_2O_3.6(Ca,Zn,Cu,Mn)O.5SiO_2.2H_2O$
  - Xonotlite, $Ca_3Si_3O_8(OH)_2$
  - Biotite, var. Manganophyllite
  - Gahnite, $(Zn,Fe)O.(Al,Fe)_2O_3$
  - Magnetite, $FeO.Fe_2O_3$
- Recrystallization products:
  - Franklinite, $(Zn,Fe,Mn)O.(Fe,Mn)_2O_3$
  - Zincite, $(Zn,Mn)O$
  - Manganosite, MnO
  - Hematite, Fe_2O_3
  - Willemite, $2ZnO.SiO_2$
  - Tephroite, $2(Mn,Zn,Fe)O.SiO_2$
- Pneumatolytic products:
  - Margarosanite, $PbO.2CaO.3SiO_2$
  - Pectolite, $Na_2O.4(Ca,Mn)O.6SiO_2.H_2O$
  - Willemite, $2ZnO.SiO_2$
  - Barylite, $2BeO.BaO.2SiO_2$
  - Nasonite, $5PbO.4CaO.PbCl_2.6SiO_2$
  - Barysilite, $3(Pb,Mn)O.2SiO_2$
  - Glaucochroite, $MnO.CaO.SiO_2$
  - Tephroite, $2(Mn,Zn)O.SiO_2$
  - Larsenite, $PbO.ZnO.SiO_2$
  - Calcium larsenite, $(Pb,Ca)O.ZnO.SiO_2$
  - Beryllium vesuvianite, $3(Al,Fe)_2O_3.BeO.6(Ca,Zn,Mn)O.5SiO_2.2H_2O$
  - Roeblingite, $7CaO.2PbO.2SO_3.6SiO_2.5H_2O$
  - Hancockite, $4(Pb,Ca)O.4Al_2O_3.6SiO_2.H_2O$
  - Prehnite, $2CaO.Al_2O_3.3SiO_2.H_2O$
  - Leucophoenicite, $7(Mn,Zn,Ca)O.3SiO_2.H_2O$
  - Clinohedrite, $CaO.ZnO.SiO_2.H_2O$
  - Hodgkinsonite, $3(Zn,Mn)O.SiO_2.H_2O$
  - Datolite, $2CaO.B_2O_3.2SiO_2.H_2O$
  - Cahnite, $4CaO.B_2O_3.As_2O_5.4H_2O$
  - Sussexite, $2(Mn,Mg,Zn)O.B_2O_3.H_2O$
  - Manganoaxinite, $2Al_2O_3.4(Ca,Mn)O.B_2O_3.8SiO_2.H_2O$
  - Cuspidine, $3CaO.CaF_2.2SiO_2$
  - Apatite, $9CaO.(Ca,Mn)F_2.3P_2O_5$
  - Hedyphane, $9(Ca,Pb)O.PbCl_2.3As_2O_5$
  - Svabite, $9CaO.(Ca,Mn)F_2.3As_2O_5$
  - Franklinite, $(Zn,Fe,Mn)O.(Fe,Mn)_2O_3$
  - Fluorite, CaF_2
  - Barite, $BaO.SO_3$
  - Silver, Ag
  - Copper, Cu
  - Lead, Pb
  - Galena, PbS
  - Chalcocite, Cu_2S
  - Niccolite, $NiAs$
  - Chloanthite, $NiAs_2$
  - Sphalerite, ZnS
  - Chalcopyrite, $CuFeS_2$
  - Bornite, Cu_5FeS_4
  - Pyrite, FeS_2
  - Löllingite, $FeAs_2$
  - Arsenopyrite, $FeAsS$
  - Kentrolite, $3PbO.2Mn_2O_3.3SiO_2$

Hydrothermal vein minerals

- Albite, $Na_2O.Al_2O_3.6SiO_2$
- Fowlerite, $(Mn,Fe,Ca,Zn)O.SiO_2$
- Tremolite, $2CaO.5MgO.8SiO_2.H_2O$
- Crocidolite, $Na_2O.3MgO.(Fe,Al)_2O_3.8SiO.H_2O$
- Willemite, $2ZnO.SiO_2$
- Friedelite, $7MnO.MnCl_2.6SiO_2.4H_2O$
- Schallerite, $16MnO.As_2O_3.12SiO_2.8H_2O$
- Mcgovernite, $21(Mn,Mg,Zn)O.3SiO_2.\tfrac{1}{2}As_2O_3.As_2O_5.10H_2O$
- Leucophoenicite, $7(Mn,Zn,Ca)O.3SiO_2.H_2O$
- Gageite, $8(Mn,Zn,Mg)O.3SiO_2.3\tfrac{1}{2}H_2O$
- Hodgkinsonite, $3(Zn,Mn)O.SiO_2.H_2O$
- Ganophyllite, $7MnO.Al_2O_3.8SiO_2.6H_2O$
- Apophyllite, $2(Ca,K)O.3SiO_2.3\tfrac{1}{2}H_2O$
- Calciothomsonite, $(Na_2,Ca)O.Al_2O_3.2SiO_2.2\tfrac{1}{2}H_2O$
- Stilbite, $(Na_2,Ca)O.Al_2O_3.6SiO_2.6H_2O$
- Heulandite, $CaO.Al_2O_3.6SiO_2.5H_2O$
- Chlorite, $5MgO.Al_2O_3.3SiO_2.4H_2O$
- Manganiferous serpentine, $3(Mg,Mn,Zn)O.2SiO_2.2H_2O$
- Bementite, $8MnO.7SiO_2.5H_2O$
- Talc, $3MgO.4SiO_2.H_2O$
- Fluoborite, $6MgO.B_2O_3.3(F_2,H_2O)$
- Mooreite, $8(Mg,Zn,Mn)O.SO_3.11H_2O$
- Delta-mooreite, $7(Mg,Zn,Mn)O.SO_3.10H_2O$
- Aragonite, $CaO.CO_2$
- Dolomite, $(Ca,Mg)O.CO_2$
- Siderite, $FeO.CO_2$
- Rhodochrosite, $MnO.CO_2$
- Smithsonite, $ZnO.CO_2$
- Loseyite, $7(Mn,Zn,Mg)O.2CO_2.5H_2O$
- Quartz, SiO_2
- Zincite, ZnO
- Hematite, Fe_2O_3
- Hetaerolite, $ZnO.Mn_2O_3$
- Goethite, $Fe_2O_3.H_2O$
- Manganite, $Mn_2O_3.H_2O$
- Pyrochroite, $MnO.H_2O$
- Manganbrucite, $(Mg,Mn,Zn)O.H_2O$
- Chalcophanite, $(Mn,Zn)O.2MnO_2.2H_2O$
- Hedyphane, $9(Ca,Pb)O.PbCl_2.3As_2O_5$
- Arseniosiderite, $6CaO.4Fe_2O_3.3As_2O_5.9H_2O$
- Allactite, $7MnO.As_2O_5.4H_2O$
- Chlorophoenicite, $10(Mn,Zn)O.As_2O_5.7H_2O$
- Magnesium chlorophoenicite, $10(Mn,Zn,Mg)O.As_2O_5.7H_2O$
- Holdenite, $8MnO.4ZnO.As_2O_5.5H_2O$
- Sussexite, $2(Mn,Mg,Zn)O.B_2O_3.H_2O$
- Barite, $BaO.SO_3$
- Celestite, $SrO.SO_3$
- Anhydrite, $CaO.SO_3$
- Galena, PbS
- Sphalerite, ZnS
- Greenockite, CdS
- Pyrite, FeS_2
- Marcasite, FeS_2
- Millerite, NiS
- Tennantite, $4Cu_2S.As_2S_3$

Surface oxidation products

- Calamine, $2ZnO.SiO_2.H_2O$
- Halloysite, $Al_2O_3.2SiO_2.3H_2O$
- Neotocite, $MnO.SiO_2.nH_2O$
- Manganiferous serpentine, $3(Mg,Mn,Zn)O.2SiO_2.2H_2O$
- Desaulesite, $4\ (Ni,Zn,Fe)O.3SiO_2.6H_2O$
- Quartz, SiO_2
- Cuprite, Cu_2O
- Hematite, Fe_2O_3
- Hydrohetaerolite, $2ZnO.2Mn_2O_3.H_2O$
- Limonite, $2Fe_2O_3.3H_2O$
- Chalcophanite $(Mn,Zn)O.2MnO_2.2H_2O$
- Psilomelane, Mn oxide
- Cerusite, $PbO.CO_2$
- Malachite, $2CuO.CO_2.H_2O$
- Azurite, $3CuO.2CO_2.H_2O$
- Aurichalcite, $5(Zn,Cu)O.2CO_2.3H_2O$
- Hydrozincite, $3ZnO.CO_2.2H_2O$
- Smithsonite, $ZnO.CO_2$
- Descloizite, $4(Pb,Zn)O.V_2O_5.H_2O$
- Anglesite, $PbO.SO_3$
- Gypsum, $CaO.SO_3.2H_2O$

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nature of the minerals, but in the Trotter mine the relations displayed were definite and conclusive. Plainly the great heat of the intrusive pegmatite not only caused recrystallization of the primary minerals of the ore but also set up a vigorous interaction between those minerals and the constituents of the pegmatite magma near the contact, and the magma was rich in volatile constituents, differing from place to place, which combined with the ore minerals in a variety of new compounds. These reactions seem to have continued through a long period of falling temperature to merge at length with purely hydrothermal processes, whose products are classed in another group.

The group of contact-zone minerals comprises two overlapping subgroups. One, to which the convenient Swedish mining term "skarn" is applied, includes silicates and oxides, which are conspicuous, especially at Franklin, for their abundance and brilliant colors. Most of them are direct reaction products between ore minerals and the silica and alumina of the pegmatite. The other subgroup is termed pneumatolytic because it includes mostly minerals that contain volatile elements or metals clearly derived from the pegmatite magma.

Skarn and recrystallization products.—The skarn minerals, as shown in the second column of the table opposite page 20, are chiefly characterized by containing zinc, iron, or manganese, or all three. Rhodonite is particularly abundant at Franklin, in great masses crystallized against calcite. At Sterling Hill the skarn was composed chiefly of jeffersonite and gahnite, but roepperite was abundant in places, as were large crystals of manganese hornblende. The cyprine variety of vesuvianite occurs at Franklin, intergrown with pegmatite and with rhodonite. Hardystonite, found only at Franklin, seems to be transitional to the next subgroup, as it invariably contains traces of lead.

The primary ore minerals, in coarse aggregates and large well-formed crystals, are found with skarn in many places and also in independent masses. Franklinite in octahedrons and dodecahedrons as much as 6 inches in diameter; willemite, particularly the manganiferous variety troostite, in stout hexagonal prisms a foot or more long; and zincite in broad plates as much as 6 inches across, are examples of recrystallization. Their association with skarn in some places indicates that they are related to the pegmatite intrusions, but in some places they have no such visible relation. The most notable occurrence of the latter sort was found in the early workings at Sterling Hill, where pegmatite is less abundant than at Mine Hill. At such places local accumulations of water may have become an active solvent through heating by intrusions at some distance.

In a few places recrystallization seems to have been accompanied by some breaking down of the original minerals. This is indicated by the occurrence of manganosite, although the MnO molecule is usually present only as a constituent of franklinite or in solid solution in zincite. Another example of it is the development of masses of hematite with a remarkable cubelike parting, intergrown with franklinite. These masses may have been formed by the separation of some of the iron of franklinite during the recrystallization.

Pneumatolytic products.—The subgroup composed of pneumatolytic products, which is practically confined to Franklin, includes a great variety of minerals, chiefly silicates, containing some element not normally present in either the ore or the pegmatite, such as lead, chlorine, fluorine, boron, arsenic, and sulphur, with or without hydroxyl. A number of metallic sulphides are placed in this subgroup with considerable doubt.

The mode of occurrence of these minerals is various. Some of them form irregular masses mingled with skarn minerals, which they seem to replace; others fill definite veins in ore or skarn, along whose walls more or less replacement of the older minerals has occurred. The detailed paragenesis is almost infinitely variable, and only a few examples are mentioned.

The early development of the Trotter mine brought to light a pegmatite which was notable for the presence of green microcline and allanite. At the surface about the mine there was an abundance of garnet skarn, and throughout the mine rhodonite and manganese axinite were plentiful. Niccolite and chloanthite were found in considerable masses mingled with sphalerite and purple fluorite.

The ore body in the vicinity of the Parker shaft contained great masses of garnet-rhodonite-axinite skarn, associated with which were many lead silicates. Here were first found nasonite, margarosanite, roeblingite, and hancockite, and with them the hydroxyl silicates leucophoenicite, clinohedrite, pectolite, and prehnite. At this locality fluorine is a constituent of fluorite, cuspidine, and apatite, and copper occurs native and in cyprine. Much the same suite of minerals was found in the replacement veins containing the recently found lead silicates, larsenite and calcium larsenite. Cahnite, a calcium boroarsenate, was found in cavities in axinite, in veins with willemite, hedyphane, and datolite, and in open vugs in rhodonite veins.

Veins with the succession garnet, tephroite, willemite, barite, calcite seem to belong in this subgroup. Hodgkinsonite and leucophoenicite, the latter especially likely to be associated with sussexite, are widespread both as replacement and as vein minerals. Willemite in particularly fine, complex crystals is characteristic of the subgroup, and franklinite, where developed in open veins, has a rare cubical habit.

The metallic sulphides of this subgroup occur mostly in ill-defined masses that apparently have replaced normal ore. They rarely show any relation to the pegmatites and may be of much later introduction. As typical examples of their grouping may be mentioned chalcocite surrounding octahedrons of magnetite and separated from them by films of native silver; films of native copper and of native lead in axinite-willemite-barite veins; and granular aggregates of galena, chalcopyrite, bornite, pyrite, löllingite, and sphalerite, alone or variously mingled. All these occurrences of sulphides are small and rare.

There is no sharp delimitation between the pneumatolytic veins and those of the next or hydrothermal group. Some species of minerals are found in both, but in the hydrothermal group there is less evidence of replacement in the walls, the veins being in general clearly fissure veins.

MINERALS OF THE HYDROTHERMAL VEINS

The mineralogy of the hydrothermal veins is scarcely less complex than that of the pneumatolytic veins. Many of the minerals, however, were obviously formed at lower temperatures than the pneumatolytic minerals and either farther from the pegmatitic intrusions or during later fissuring. The fissures are either wholly filled or are open and crystal-lined, and the veins are of characteristic form with clean-cut walls. They are generally short and small, as a rule but a few inches thick, and many are mere seams less than an inch thick. Thus, although they are fairly numerous, their total bulk is insignificant compared to the great mass of the ore bodies. Their most notable characteristic is their great variety of mineral contents, as may be gathered from the following selected examples of associations found in the collections.

A typical example is the paragenesis garnet, willemite, zincite, leucophoenicite, gageite, chlorophoenicite, pyrochroite, calcite. Another is the combination hodgkinsonite, willemite, hetaerolite, calcite. Rhodonite, friedelite, schallerite, and mcgovernite are each found as the sole filling of numerous fissures. Friedelite is ordinarily followed by barite and calcite. Willemite, especially the light-green or white fibrous variety, low in manganese and highly phosphorescent, is a common vein filling. Zincite is known in crystals only from vugs in calcite veins, and the form called "calcozincite" is really a mixture of granular zincite with fibrous calcite, generally coating slickensides in ore.

The arsenates hedyphane, holdenite, and allactite are found in veins with calcite, whereas chlorophoenicite is found with gageite and acicular willemite. Ganophyllite and heulandite are found in veins with rhodonite or sulphides. The other zeolites of the list are minor vein minerals. Sussexite is typically a vein mineral, its asbestiform fibers filling narrow cracks or coating slickensides in ore. It is closely simulated by veins of fibrous tremolite mixed with calcite.

Another type of vein common at Franklin consists dominantly of some carbonate, as a rule strikingly layered parallel to the walls. In some places the filling is calcite with or without fibrous willemite, in other places it is siderite or an intermediate calcium-magnesium-iron carbonate, and in still others it is rhodochrosite or smithsonite. Dolomite constitutes the filling of a few veins with open vugs lined with crystals of dolomite, calcite, albite, quartz, or sphalerite, and more rarely with millerite, marcasite, or the oxides goethite, manganite, and hematite. Pyrochroite and chalcophanite are also found in calcite veins, and aragonite, in radiating needles, coats cracks.

Compact quartz, alone or with massive sphalerite or pyrite, forms thin clean-cut veins and in places shows crystals on free surfaces. On the whole, quartz is rare at Franklin. The parageneses calcite, sphalerite, and calcite, sphalerite, quartz, willemite, crocidolite are common and conspicuous vein formations. In fact, it is only in these veins that sphalerite occurs in any noteworthy amount at Franklin, except in the mass at the Trotter mine.

Bementite and the closely related manganese-bearing serpentine are not uncommon as vein fillings, alone or more commonly with a carbonate such as rhodochrosite or smithsonite.

It seems highly probable that the carbonate and quartz veins containing sulphides were formed during the much later post-Paleozoic deformation, as suggested in an earlier paragraph.

MINERALS RESULTING FROM SURFACE OXIDATION AND OTHER ALTERATION

With one notable exception the minerals formed by surface alteration are of minor interest in the Franklin district. Manganese-bearing serpentine forms pseudomorphs after rhodonite, and desaulesite has replaced niccolite and chloanthite at the Trotter mine. Quartz, hematite, and limonite form gossans on a few pyritic veins at Franklin, and small amounts of calamine and hydrozincite are found in the gossans of veins of sphalerite. The ordinary copper oxidation minerals form about the rare copper sulphides, and descloizite, cerusite, and anglesite are the alteration products of galena in a pyroxene skarn at Sterling Hill.

The exception noted above was so remarkable that it requires special description. During the seventies the Noble and Passaic mines, open pits in two great bodies of calamine lying in the angle between the two legs of the ore body (see pl. 1), were the chief sources of zinc ore mined at Sterling Hill. When mining was begun there that area was a shallow watercourse, and the pits were carried to a depth of more than 40 feet below the original surface. In 1906 the sites of the ore bodies were occupied by two great excavations, having roughly the shape of inverted cones, separated by a wall of barren pegmatite. The bare limestone walls of the ore bodies then remained as they were left by the stripping and were clearly seen to be solution surfaces, probably the result of long-continued action by ground water. These exposures have long since been caved in by the later mining at Sterling Hill.

Mr. O. J. Conley, superintendent of the Noble mine in 1878, kindly went over the ground with the author and described the deposit, of which no contemporary account was published. According to Mr. Conley the calamine formed a layer 6 to 12 inches thick, lying directly on the limestone. The principal filling of the excavated mass was more or less fragmental, consisting of sand, clay, limestone fragments, and loose and broken crystals of franklinite, willemite, garnet, and the like, all stained by oxides of iron and manganese. Separating this loose material from the calamine layer on the north side of the pit was a layer, as much as 4 inches thick, of greasy black mud, rich in manganese, which was the cause of dangerous slides in the pit. On the south side, in a similar relation to the calamine, were found the deposits of chalcophanite and hydrohetaerolite characteristic of this locality. Excellent specimens of the calamine are preserved in collections, and nearly all those examined showed considerable harsh brown or yellow clay adhering to their lower surfaces. This clay is rich in zinc and has been called vanuxemite.

The relations of the calamine deposits to the main ore bed, as described by Mr. Conley, fully establish their secondary nature. There is, however, other direct evidence in the presence, in the fragmental material from the pit, of crystals of willemite still retaining their form but wholly covered with needles of calamine stained with manganese and of deeply corroded franklinite crystals enclosed by and embedded in calamine. These zinc and manganese ore deposits resulted from the weathering of a part of the outcropping ore body, the products of solution being carried to a lower position, where they replaced the limestone with zinc silicate and hydrous oxides of zinc, iron, and manganese. The reason for describing this deposit at such length is that it seems to throw some light on the origin of the major deposits, as shown in the next section.

ORIGIN OF THE ZINC ORE DEPOSITS

The vexed question of the origin of these unique ore deposits has often been discussed, and a full treatment of the matter will not be attempted here. The paper by Ries and Bowen (223) contains an excellent summary of the several hypotheses that have been proposed, and this may well be repeated with some comments. Among these hypotheses those outlined below are outstanding.

Igneous-injection hypothesis.—This hypothesis was first offered by Rogers (31) in 1836 and was suggested by Spencer in the Franklin Furnace folio in 1908 as the best of several alternatives. It was rejected by Ries and Bowen in 1922 on the ground that it does not account for the admixture of grains of Franklin limestone with the ore minerals. Nevertheless it was advocated by Spurr and Lewis (234) in 1925, the ores being regarded by them as igneous vein dikes of sulphide magma that lost their sulphur by a later distillation at a temperature above that of fusion. How the required oxygen was supplied is not revealed. To the present author it seems that the strongest evidence against this hypothesis lies in the mineral and chemical character of the ores.

Sedimentary-deposition hypothesis.—The hypothesis that the zinc ores were originally sediments deposited with the enclosing limestone and since metamorphosed with it was first proposed by Kitchell (72) in 1855 and was maintained by the geologists of the New Jersey Survey as late as 1896. It is difficult to establish, as there is no way of determining whether the layering of the ore is parallel to the original bedding of the limestone, and it does not explain the structure of the Sterling Hill deposit as now developed by more recent mining operations.

Contact-metamorphism hypothesis.—The hypothesis of the development of the ores through contact metamorphism due to the intrusion of the pegmatites was first proposed by Nason (143) in 1890 and was advocated in 1893 by Kemp (152), who misinterpreted the relations of the pegmatite dikes, then poorly exposed, to the ore bodies. It was rejected by Ries and Bowen (223) on evidence similar to that given above, proving that the pegmatites that are in contact with the zinc-ore bodies are intrusive into them.

Hypothesis of replacement from magmatic solutions.—This hypothesis was adopted by Ries and Bowen. They were in some doubt whether the replacement preceded or followed the folding of the limestone but decided that it preceded the folding. According to them the "primary" minerals—willemite, franklinite, and zincite—were deposited directly, in the order given, from magmatic solutions.

The chemical nature of these minerals is such that it seems unlikely to the author that they originated through deposition from magmatic solutions. As far as he is aware, wherever zinc ores have indubitably been so deposited, it was the sulphide that was formed, and the absence of metallic sulphides is one of the characteristics of the primary ores of the Franklin district.

Metasomatic-emplacement hypothesis.—The author has reached the conclusion that the ore bodies were formed by metasomatic emplacement in the limestone in pre-Cambrian time, before its regional metamorphism. He believes also that they were deposited near the surface under oxidizing conditions, and that they probably consisted largely of the hydrous zinc silicate, calamine, together with hydrous oxides of iron and manganese and perhaps carbonates of zinc and manganese. The depositing solution is believed to have derived its metallic contents from the products of oxidation of a previously existent mass of mixed sulphides.

These oxidized minerals were probably deposited in more or less well layered masses whose form may have been determined by a previous folding of the limestone, which directed the flow of the depositing solution. The minerals at present constituting the deposits were, on this hypothesis, formed by dehydration and recrystallization during later profound and long-continued regional metamorphism of all the pre-Cambrian rocks of the region. Thus the minerals of the ore deposits acquired their characteristic texture and structure, so very like those of the enclosing limestone. The established sequence in the ages of the minerals, the oxides being developed after the silicate, seems entirely consonant with the suggested mode of origin.

That these ore bodies originated through metasomatic emplacement was first suggested to the writer by the characters of two other deposits of zinc ores having a related origin. The first is a small-scale illustration that has the advantage of being situated in the Franklin area—the calamine deposit at Sterling Hill, described on page 23. There had been accumulated a rich ore deposit made up of parallel layers of calamine, smithsonite, zinciferous clay, and hydrous oxides of iron and manganese, and the layering followed the walls of the cavity in the limestone by whose solution a place for the new ore was formed. The source of this ore was the nearby franklinite-willemite mass, and the new ore was constituted in such a fashion that, had it and the surrounding limestone been subjected to a vigorous deep-seated, high-temperature metamorphism, there might well have resulted from its dehydration and recrystallization a new deposit closely analogous to the parent mass.

The second illustration is drawn from the published descriptions of the well-known deposits of zinc ore at Moresnet, Belgium, where there are vast sphalerite replacement deposits in Paleozoic dolomite. The sphalerite has undergone profound oxidation, and the soluble products have been transferred to the nearby dolomite and have there been accumulated in synclinal folds that halted the circulation. Extensive deposits consisting principally of calamine, with some smithsonite and limonite, have thus been formed in bodies whose shape, although in general determined by the structure of the dolomite, is independent in detail of anything except the solvent action of the depositing solution. It seems not unlikely that the Belgian deposits of desulphurized zinc and iron ores are in all respects except in the absence of manganese a good presentment of the New Jersey zinc ores before the great metamorphism.

This hypothesis of metasomatic emplacement of the ore seems to account for the observed facts without essential conflict. The localization in the limestone is necessary, and the duplication is not remarkable. The form of the ore bodies may be quite independent of the sedimentary structure. The pitching synclines conform in attitude to the general structure of the gneiss, but how much of the folding may have been effected during metamorphism cannot be determined. However, that does not matter, as the original form of the deposits may have been anything from a simple layer to a mass whose form was not unlike that now seen. The identical texture of ore and country rock, the layering of the ore, the abrupt passage from ore to barren limestone, the dying out of the ore northward along the strike at Mine Hill, the sporadic occurrence of disseminated ore within the fold in the limestone at Sterling Hill—all are satisfactorily accounted for by the suggested process.

The chemical composition of the ore is unusual, chiefly in the association of zinc with both iron and manganese, but metamorphosed metasomatic deposits of iron and manganese ore are not unknown, and the addition of the third metal merely indicates deposition under unusual original conditions. The mineral composition of the ore is conformable to the hypothesis—there is no comparable example for willemite, but franklinite is a spinel and is therefore to be expected as a product of the postulated mode of formation. Light is thrown on the presence of zincite in the recent study by Magnusson (232) of the Långban deposits, where manganosite (MnO) and periclase (MgO with a trace of ZnO) are shown to have been formed from the carbonates of manganese and magnesium, respectively, by high-temperature metamorphism. In such fashion zincite may have been formed by the breaking down of smithsonite in these deposits.

The modifications that have affected the ore bodies since their primary crystallization in their present form are relatively insignificant and have been sufficiently illustrated in the foregoing paragenetic study. The only clear evidence of the direct introduction of magmatic materials is found in the contact zones about the pegmatites, which were certainly far later than the ore deposits themselves.

This theory, originally outlined about 1915, was first published by the author in 1929. It was followed a month later by the paper of Tarr (258), in which the same mode of origin is postulated, but the effort is made to determine quite exactly the mineralogic nature of the metasomatic deposit before metamorphism. In Tarr's paper attention is drawn to Rastall's brief formulation of a similar theory (228), which had escaped the notice of the author.

THE MINERALS

FORM OF DESCRIPTION

The minerals are, with a few exceptions, described under the same classification and in the same serial order as in Dana's "System of mineralogy", sixth edition, 1892. For each the order of treatment is, in general, first, crystallography, including both facts previously noted by other authors and new observations, if any, made in the course of this investigation;

second, physical and optical properties, including the latest data obtainable; third, composition, with tabulated chemical analyses and for some species a discussion of the chemical formula; fourth, occurrence at Franklin and at Sterling Hill; and lastly, for the more important species, notes on the history of the minerals as known at Franklin.

This paper contains descriptions of 148 minerals, many of which, of course, are of slight importance and require but brief notes. Minerals seen only as essential constituents of the local rocks are not included. Many species already known elsewhere were added to the list of those found in the district, and 18 new species were discovered and described in the course of this investigation. Much new information on the crystallography, optical constants, and composition of the already known minerals was acquired during the course of the work, and the more important data of the sort have already been published in scientific periodicals (see especially 195, 251, 257, and 273).

In the table below all the species and varieties of minerals that have been definitely identified in the district and described in this paper are listed in alphabetic order.

Alphabetic list of minerals described

[Names in italic are those of varieties; names followed by (v) are those of species represented by more than one variety or only by an uncommon variety]

Actinolite
Albite
Allactite
Allanite
Amphibole (v)
Andradite
Anglesite
Anhydrite
Anorthite
Apatite
Apophyllite
Aragonite
Arseniosiderite
Arsenopyrite
Aurichalcite
Axinite (v)
Azurite

Barite
Barylite
Barysilite
Bementite
Beryllium vesuvianite
Biotite (v)
Bornite
Brucite (v)
Bustamite

Cahnite
Calamine
Calciothomsonite
Calcite
Calcium larsenite
Celestite
Cerusite
Chalcocite
Chalcophanite
Chalcopyrite
Chloanthite
Chlorite
Chlorophoenicite
Chondrodite
Clinohedrite
Copper
Corundum
Crocidolite
Cummingtonite (v)
Cuprite
Cuspidine
Cyprine

Datolite
Desaulesite
Descloizite
Diopside
Dolomite

Edenite
Epidote

Ferroaxinite
Ferroschallerite
Fluoborite
Fluorite
Fowlerite
Franklinite
Friedelite

Gageite
Gahnite
Galena
Ganophyllite
Garnet (v)
Glaucochroite
Goethite
Graphite
Greenockite
Gypsum

Halloysite
Hancockite
Hardystonite
Hastingsite
Hedyphane
Hematite
Hetaerolite
Heulandite
Hodgkinsonite
Holdenite
Hyalophane
Hydrohetaerolite
Hydrozincite

Ilmenite

Jeffersonite

Kentrolite

Larsenite
Lead
Leucaugite
Leucophoenicite
Limonite
Löllingite
Loseyite

Magnesium chlorophoenicite
Magnetite
Malachite
Manganbrucite
Manganite
Manganoaxinite
Manganophyllite
Manganosite
Marcasite
Margarosanite
Mcgovernite
Microcline
Millerite
Molybdenite
Mooreite (v)
δ-Mooreite
Muscovite

Nasonite
Neotocite
Niccolite
Norbergite

Pargasite
Pectolite
Phlogopite
Prehnite
Psilomelane
Pyrite
Pyrochroite
Pyroxene (v)
Pyrrhotite

Quartz

Rhodochrosite
Rhodonite (v)
Roeblingite
Roepperite
Rutile

Scapolite
Schallerite
Schefferite
Serpentine
Siderite
Silver
Smithsonite
Sphalerite
Spinel
Stilbite
Sussexite
Svabite

Talc
Tennantite
Tephroite
Thomsonite (v)
Thorite
Titanite
Tourmaline
Tremolite

Vesuvianite (v)

Willemite

Xonotlite

Zincite
Zinc cummingtonite
Zinc schefferite
Zircon
Zoisite

NATIVE ELEMENTS

GRAPHITE

C. Hexagonal-rhombohedral

Graphite is abundant in the Franklin limestone, in cleavage scales and plates, at both Franklin and Sterling Hill, and in the iron ores in the limestone. At all the limestone quarries near Franklin it is more or less abundant wherever metamorphism through invasion by pegmatite has been effective. It has been found occasionally in the immediate wall rocks of the zinc-ore bodies but not in either ore body.

In a unique specimen in the Canfield collection graphite forms spheroids about half an inch in diameter, with fibrous structure and mammillary surface. The specimen is labeled from Franklin, but its exact source is not known.

SILVER

Ag. Isometric

Silver is exceptionally rare at Franklin, having been found there, so far as known, only once. This occurrence, according to Mr. E. D. Shuster, was on the 1,050-foot level of the mine, about 400 feet south of the Parker shaft and a few feet from the footwall but entirely within the ore body. The total amount of material was probably not more than a few pounds, of which silver formed an insignificant part.

The specimens, of which but a few are preserved and which were received in 1909, consist chiefly of massive steel-gray chalcocite. Fracture surfaces reveal scattered, sharply formed octahedrons of magnetite, whose faces are faintly marked with triangular striations. The silver forms thin sheets or films between the chalcocite and the magnetite, exactly outlining the form of the octahedrons. It does not coat all the crystals nor does it completely envelop all on which it is present. The silver is discolored when freshly exposed, but it is perfectly malleable and possesses the typical color and other characteristics.

The specimens contain a little massive white quartz, which is later than the magnetite and is of the same age as the chalcocite. There is, however, no evidence of a distinct vein, and all the minerals merge insensibly into typical, massive franklinite-willemite ore.

It is stated by Mr. Nitchie, spectroscopist in the Palmerton laboratory of the New Jersey Zinc Co., that silver is present in spectroscopic traces in many of the Franklin minerals.

COPPER

Cu. Isometric

Forms.—*a*(100), *o*(111), *d*(110), and an undetermined tetrahexahedron (*h*01).

Habit.—Copper crystals are very rare. Foote (176) describes minute distorted dodecahedrons, and in the collection of Mr. Shuster are two crystals a quarter of an inch in diameter—one a cube modified by the dodecahedron and a flat tetrahexahedron, the other a dodecahedron modified by the octahedron. These crystals are but thin shells of copper enclosing cores of granular datolite, and they are embedded in a matrix of massive axinite, datolite, and willemite.

Occurrence.—Commonly the copper is found in irregular hackly masses, films, wires, or spangles, generally associated with one or more of the minerals willemite, hancockite, roeblingite, datolite, axinite, cyprine, garnet, caswellite, or barite. It was first known from the Parker shaft and was apparently fairly common there, some pieces weighing a pound having been found in the crushed ore after it had passed through the rolls.

Copper was first noted by Wolff (174) in specimens taken from a depth of about 800 feet in the Parker shaft. He regarded it as surely later than the zinc ore and as having been introduced along shear zones by solutions. In some specimens, however, it is embedded in clear crystalline willemite and must have been contemporaneous with that mineral. The associated minerals indicate a pneumatolytic origin and a derivation from the intrusive pegmatite. It has also been found in thin veins containing hodgkinsonite, with barylite, and with the recently discovered arsenate hedyphane.

LEAD

Pb. Isometric

Lead is found, in minute amount, as scales, globules, and irregular branching masses, among the rare minerals of the Parker shaft, associated especially with the lead silicate roeblingite and with hancockite, native copper, and garnet. It was first noted by Foote (176). The author has seen it in several specimens, together with barite and the altered mica caswellite, and in one specimen as faint films in cracks in green willemite. It is also found in thread-like disseminations in rhodonite, which it stains gray, and as scales in veins of manganese serpentine.

SULPHIDES AND ARSENIDES

MOLYBDENITE

MoS_2. 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

PbS 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 (234) record finding veins in the Kittatinny limestone containing galena with other sulphides.

CHALCOCITE

Cu_2S. 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. (See p. 26.)

SPHALERITE

ZnS. Isometric-tetrahedral

Forms.—$a(100)$, $d(110)$, $o(111)$, $o_1(1\bar{1}1)$, $q(331)$, $\beta(522)$, $\theta_1(5\bar{1}1)$, $\tau_1(7\bar{2}2)$, $m_1(3\bar{1}1)$, and $x_1(7\bar{5}3)$.

Combinations on crystals of sphalerite

	Forms	Illustrations
1	o, o_1, with o dominant.	
2	o, o_1, with o_1 dominant; twin lamellae parallel to (111).	
3	o, d. Twin flattened parallel to (111)	
4	d, o, o_1, with equal development of o and o_1	
5	a, d, o, o_1	
6	o (bright), o_1 (dull), twinned	
7	d, o, o_1, with d dominant	
8	d, o, o_1, q, with o dominant	Fig. 1
9	o, o_1, m_1. Twinned on o	Fig. 2
10	a, o, o_1, τ_1. With uncommon habit	Fig. 3
11	d, o_1, θ_1, with o dominant	
12	a, o, d. Twinned on o	
13	o, o_1, β	Fig. 4
14	a, o, o_1, x_1	Fig. 5

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. All the forms listed were determined by measurement, the distinction between positive and negative forms being 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 (53) 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.

Analyses 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_2	--------	.99	--------
	99.68	99.07	100.00

1. White sphalerite (cleiophane), Franklin. T. W. Henry (53), analyst.
2. Black sphalerite, picking table, Franklin. L. H. Bauer (243), analyst.
3. Black sphalerite, Franklin. L. H. Bauer (243), analyst.

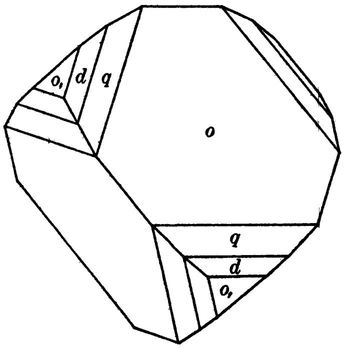

FIGURE 1

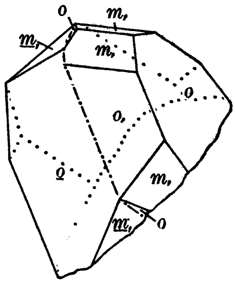

FIGURE 2

FIGURE 1.—Crystal of sphalerite showing $d(110)$, $o(111)$, $o_1(1\bar{1}1)$, and $q(331)$, with o dominant. Franklin.

FIGURE 2.—Crystal of sphalerite twinned on the octahedron, showing $o(111)$, $o_1(1\bar{1}1)$, and $m_1(3\bar{1}1)$. Franklin.

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, the complete analysis of the mixture being given under bornite (p. 29).

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.

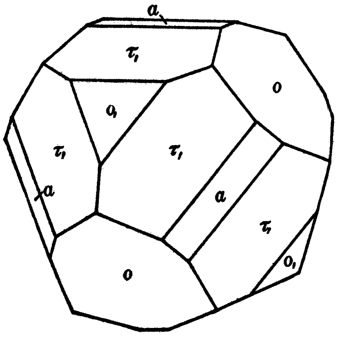

Figure 3.—Crystal of sphalerite of uncommon habit, showing the forms $a(100)$, $o(111)$, $o_1(1\bar{1}1)$, and the rare form $\tau_1(7\bar{2}2)$. Franklin

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 $(7\bar{5}3)$ or the trigonal tristetrahedron (522), as shown in figures 4 and 5, illustrating combinations 13 and 14. 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 crystals are of the various combinations numbered 3 to 12 in the list of combinations, as well as of an almost infinite variety of intermediate types. 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 cryptocrystalline, 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, niccolite, 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 pegmatitic intrusion.

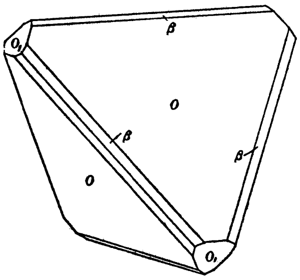

Figure 4

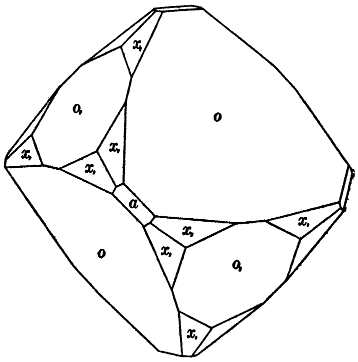

Figure 5

Figure 4.—Crystal of sphalerite showing the positive and negative tetrahedrons and the trigonal tristetrahedron $\beta(522)$ Buckwheat mine, Franklin.

Figure 5.—Crystal of sphalerite showing the positive and negative tetrahedrons, the cube, and an uncommon hextetrahedron $x_1(7\bar{5}3)$. Buckwheat mine.

Sphalerite was listed by Spurr and Lewis (234) among the sulphides found in late veins cutting the Kittatinny limestone, referred to on page 20.

GREENOCKITE

CdS. 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

NiS. 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

NiAs. 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. (See p. 31.) 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 desaulesite (see p. 119), 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 (137), who first noted its occurrence, received specimens in which were mere traces of niccolite; the larger masses of it were found later.

PYRRHOTITE

FeS+S. 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

Cu_5FeS_4. Isometric

Bornite is uncommon at Franklin, though some specimens of chalcopyrite seem to contain minute grains of darker-colored bornite. The following analysis of a specimen from Franklin proves the presence of bornite mixed with sphalerite.

Analysis of mixture of bornite and sphalerite

[L. H. Bauer (243), analyst]

	Percent	Molecular ratio	Ratio deducted (sphalerite)		Molecular ratio of remainder (bornite)
Cu	38. 16	0. 600			0. 600=5×0. 120
Zn	22. 17	. 338	0. 338	0. 419	
Fe	10. 41	. 186	. 066		. 120=1× . 120
Mn	. 80	. 015	. 015		
SiO_2	. 60	. 010	. 010	. 010	
S	28. 38	. 885	. 409	. 409	. 476=4× . 119
	100. 52				

In the 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_2 found, the molecular ratio of the remainder gives exactly the bornite formula: Cu_5FeS_4. Many specimens of this bornite, in part almost pure, were found in the Stanton collection.

CHALCOPYRITE

$CuFeS_2$. 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 (54) 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

FeS_2. Isometric-pyritohedral

Forms.—*a*(100), *o*(111), *d*(110), *e*(210), *f*(310), *p*(221), *χ*(433), *μ*(411), *m*(311), *n*(211), *t*(421); doubtful: ?(744) and ?(655).

Combinations on crystals of pyrite

[Letters marked with an asterisk (*) indicate the dominant forms]

	Forms	Illustrations
1	*o*	Fig. 4.
2	*o* and *a*, equant	Fig. 5.
3	*o* and *a*, equant, and *e*	Kraus and Scott (191), fig. 5.
4	*o*, *a*, and *e*, all equant	Fig. 6
5	*o* and *e*, equant	
6	*o*, *m*	Figs. 7 and 8.
7	*o**, *a*, *n*	Kraus and Scott (191), fig 7
8	*o**, *m*, *μ*	
9	*o*, *e*, *a*, *n*, *m*	Idem, fig. 8
10	*o*, *e*, *a*, *m*, ? (744), ? (655)	
11	*a*	
12	*a**, *o*, *e*	Idem, fig 13.
13	*a** and *o**, equant, and *m*	Fig 9
14	*a**, *o**, *e*, *χ*, *n*, *m*	Kraus and Scott (191), fig. 6
15	*a* and *e*, equant, and *o*, *n*, *μ*, *m*.	Idem, fig 12.
16	*e*	
17	*e**, *o*, *a*, *m*	Fig. 10
18	*e**, *o*, *p*, *n*, *t*	Fig 11
19	*μ*, *a*, *o*	Kraus and Scott (191), fig 9
20	*m**, *μ*, *o*, *e*, *a*	Idem, fig 10
21	*t**, *a**, *d**, *f*, *e*	Idem, fig 11

Composition.—The composition of the mineral, as shown by the analysis, is normal except for the presence of cobalt in about the same proportion as in the arsenopyrite from the same locality. (See p. 34.)

Average of two analyses of pyrite

[Kraus and Scott (191), analysts]

S	53. 30
Fe	45. 20
Co	1. 25
Ca	Trace
SiO_2 (residue)	. 03
	99. 78

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 1½ inches in diameter. (See pl. 2, *B*.) The habit of the crystals is extremely varied, as shown by the table of combinations. 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 (191), 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.

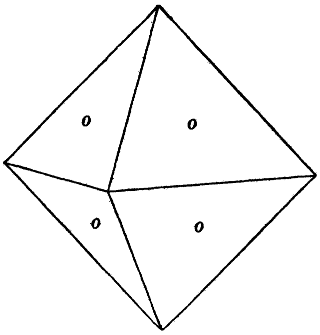

FIGURE 6

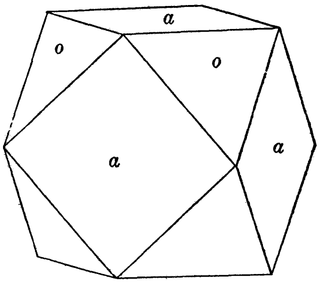

FIGURE 7

FIGURE 6.—Crystal of pyrite showing the octahedron alone Fowler quarry, Franklin.

FIGURE 7.—Crystal of pyrite showing the octahedron and the cube in balance Fowler quarry.

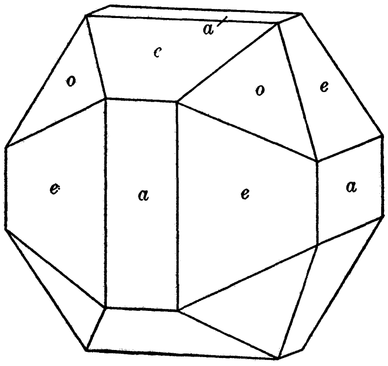

FIGURE 8.—Crystal of pyrite showing the octahedron, the cube, and the pyritohedron equally developed Fowler quarry.

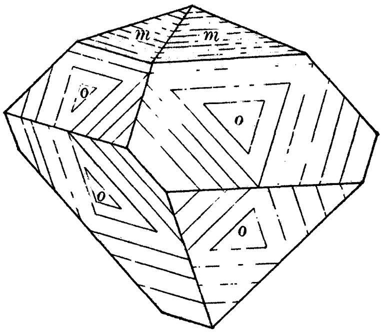

FIGURE 9 —Crystal of pyrite, showing the octahedron modified by unequally developed faces of a trapezohedron Fowler quarry.

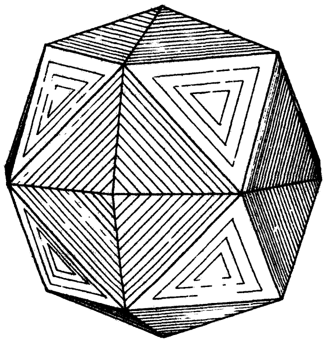

FIGURE 10 -Crystal of pyrite, showing the octahedron and a trapezohedron in balanced combination, with striae Fowler quarry

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.

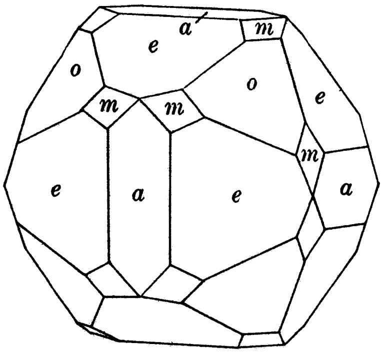

Figure 11.—Crystal of pyrite, showing the octahedron, the cube, and the pyritohedron modified by small faces of a trapezohedron.

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 mine, 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, but a few showing the interesting combination no. 18, a coign of which is shown in figure 12. The other occurrences noted above were in massive form or rough cubic crystals.

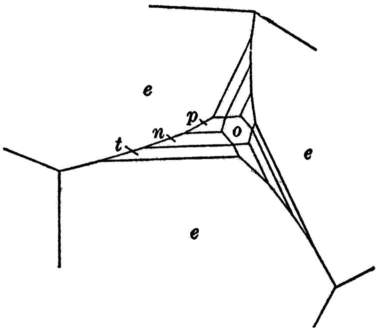

Figure 12.—One coign of a crystal of pyrite showing the pyritohedron modified by faces of the octahedron, a trisoctahedron, and two trapezohedrons. Buckwheat mine.

Sterling Hill: Although pyrite is listed by Kemp (152) from Sterling Hill, its occurrence there could not be established either by record or by authentic specimens.

CHLOANTHITE

$NiAs_2$. Isometric

Forms.—*a*(100), *o*(111), and *e*(210).

Habit.—Chloanthite is found both crystalline and massive. The crystals are rare, small, and much distorted and are mainly octahedrons 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 (Koenig).

Composition.—The chemical composition of chloanthite is shown by the following analysis:

Analysis of chloanthite

[G A Koenig (137), analyst]

	Percent	Molecular ratio
As	70. 66	0. 943} 0. 991
S	1. 54	. 048
Ni	18. 63	. 318} . 467
Co	6. 37	. 108
Fe	2. 31	. 041
Zn	Trace	------------
$CaCO_3$	. 89	------------
	100. 40	------------

The molecular ratio of (Ni,Co,Fe) to (As,S)—1:2.12—indicates a chloanthite very low in sulphur, with a ratio of nickel to cobalt, as shown by the analysis, of about 3 to 1.

Occurrence.—Chloanthite is known only from the Trotter mine at Franklin, the foregoing description being taken from a paper by Koenig (137). 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.

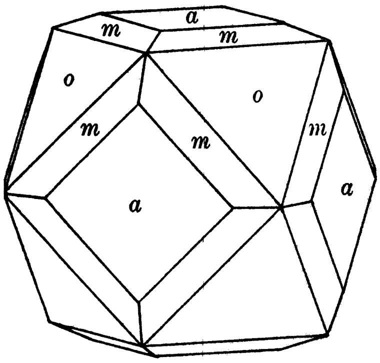

Figure 13—Crystal of pyrite, showing the octahedron and the cube modified by a trapezohedron. Fowler quarry

Rammelsbergite.—In some lists of Franklin minerals—Nason (153), Kemp (152), Dana (146)—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. (See appendix, *b*, p. 130.)

Smaltite.—No mention of smaltite has appeared in any publication on the district, hence its inclusion in the list of Hoadley and Broadwell (235) is probably also to be considered a mistake for chloanthite.

MARCASITE

FeS_2. 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.

LÖLLINGITE

$FeAs_2$. Orthorhombic

Forms.—*c*(001), *a*(100), *b*(010), *m*(110), *e*(101), *l*(011), *z*(012), and *s*(111).

Combinations on crystals of löllingite

	Forms	Localities	Illustrations
1	*m, e, z*	Buckwheat mine	Fig. 14.
2	*m, e, l*	Trotter shaft	Fig. 15.
3	*c, b, m, e, l, z, s*	Franklin	Fig. 16.

Crystals of löllingite measured by Berman (247) bore the forms of combination 3, shown in figure 16. The crystals were of unusually fine quality for this mineral, and the axial ratio—$a:b:c=0.5438:1:1.130$—derived from their measurement, is thought to be better than any previously computed.

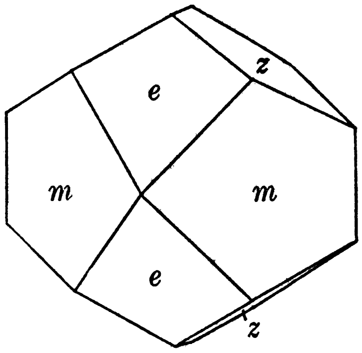

FIGURE 14

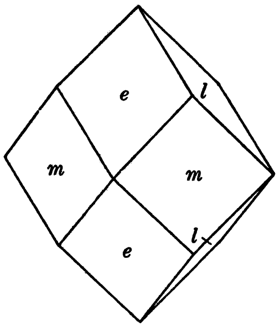

FIGURE 15

FIGURE 14.—Pseudo-dodecahedral crystal of löllingite showing the prism *m*(100), the macrodome *e*(101), and the brachydome *z*(012). Buckwheat mine.

FIGURE 15.—Crystal of löllingite of dodecahedral habit, showing the forms *m*(110), *e*(101), and *l*(011). Trotter shaft.

Composition.—A chemical analysis of the Franklin löllingite was made by Bauer, using 0.4 g of carefully selected crystals, with the following result:

Analysis of löllingite

[L. H. Bauer (247), analyst]

	Percent	Molecular ratio
As	69. 80	0. 933 } 1. 78
S	. 21	. 007 }
Fe	29. 40	. 530 } 1
	99. 41	

The slight deficiency of the analysis is due to the presence of a small and undetermined amount of calcite. Sulphur is practically negligible. There is insufficient arsenic, as shown by the molecular ratio, to give quite the 2 to 1 ratio of löllingite. Such a deficiency is common in analyses of this mineral and has usually been accounted for by assuming the presence of more or less of the leucopyrite molecule, Fe_3As_4. In this analysis computation indicates the assumed presence of 14 percent of leucopyrite. The specific gravity is 7.505 (Buerger).

Occurrence.—Löllingite 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 (see fig. 14), by Brush (100), accompanying the unique cubical gahnite that he described.

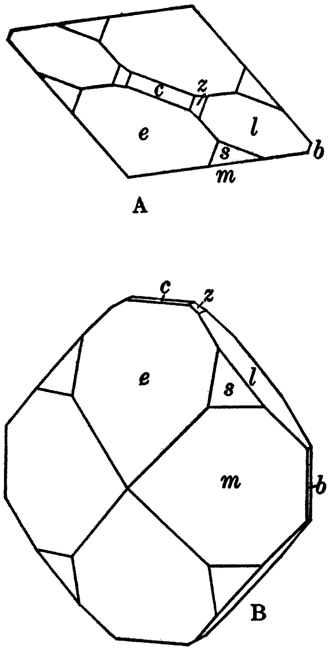

FIGURE 16.—Crystal of löllingite showing the forms *c*(001), *b*(010), *m*(110), *e*(101), *l*(011), *z*(012), and *s*(111). Trotter shaft. A, Plan, B, clinographic projection.

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 (247) 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 löllingite 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. They are shown in figures 15 and 16.

ARSENOPYRITE

FeAsS. Orthorhombic

Forms.—*c*(001), *b*(010), *m*(110), *e*(101), *ξ*(0.1.16), *u*(014), *ω*(027), *t*(013), *n*(012), *q*(011), *k*(021), *τ*(031), *g*(111), *w*(212), *i*(312), *x*(321). New forms: *o*(112), *A*(532), *B*(514), *d*(754), *p*(143), and *f*(132). Doubtful forms: (154), (594), (188), (275).

Combinations on crystals of arsenopyrite

	Forms	Locality	Illustrations
1	*m, n, q, k, e, w, i, A, B*	Franklin Iron Co. quarry.	
2	*m, n, q, e, w, i, A*	do	Fig. 17.
3	*m, n, q, k, e, w, A*	do	
4	*m, u, ω, n, q, k, e, w, i, A*	do	Fig. 18.
5	*b, m, u, q, n, t, k, τ, e, o, g, A, p, f,* (154), (275), (594).	do	Fig. 19.
6	*m, n, e, w, i, A, d*	Fowler quarry	Fig. 20.
7	*m, t, q*	Trotter mine	
8	*m, n, q, k, e, w, i*	Buckwheat mine wall.	
9	*c, m, ξ, q, k, e, A, x*	do	
10	*m, u*		Figs. 21, 22.

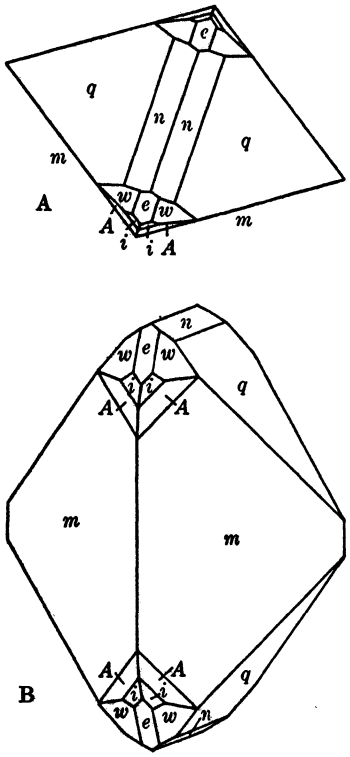

FIGURE 17.—Prismatic crystal of arsenopyrite, showing the forms *q*(011), *n*(012), *e*(010), *m*(110), *w*(212), *i*(312), and the new pyramid *A*(532). Franklin Iron Co. quarry. A, Plan; B, clinographic projection.

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. (See fig. 19.) 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, chiefly in two zones—between *m*(110) and *e*(101) and between *m*(110) and *q*(011). The first

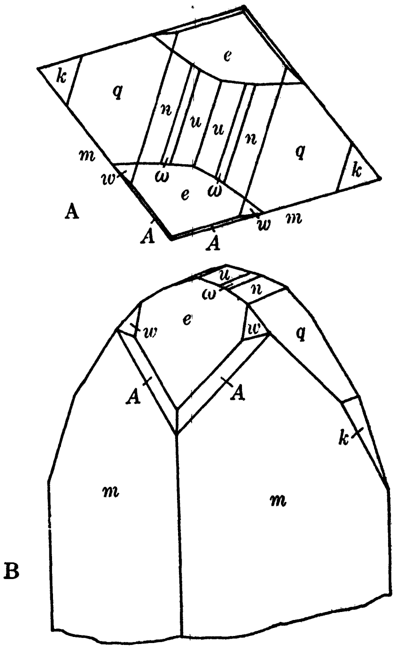

FIGURE 18.—One end of a prismatic crystal of arsenopyrite, showing the forms *u*(014), *ω*(027), *n*(012), *q*(011), *k*(021), *e*(101), *w*(212), and the new pyramid *A*(532). Franklin Iron Co. quarry. A, Plan; B, clinographic projection.

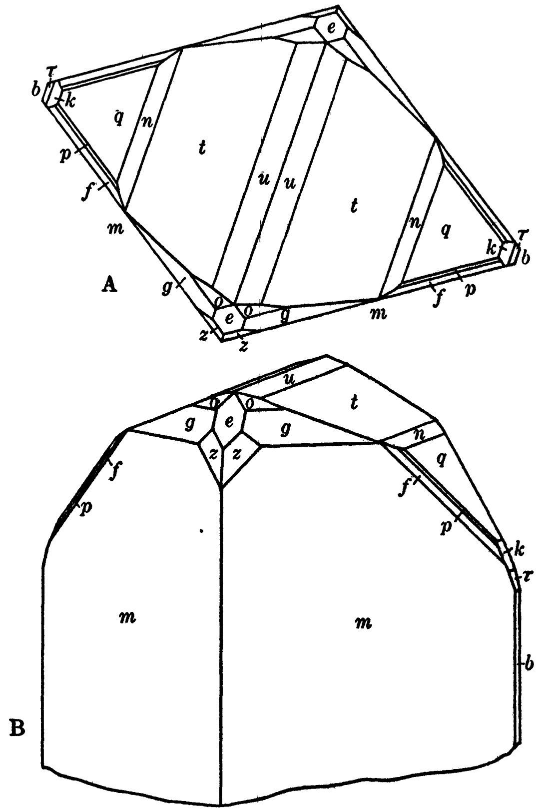

FIGURE 19.—A stout prismatic crystal of arsenopyrite showing the forms *b*(010), *m*(110), *e*(101), *u*(014), *t*(013), *n*(012), *q*(011), *k*(021), *τ*(031), *o*(112), *g*(111), and the new forms *A*(532), *p*(143), and *f*(132). Franklin Iron Co. quarry. A, Plan; B, clinographic projection.

zone is developed on every crystal and is generally marked by 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 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. (Palache, Davidson, and Goranson, 276).

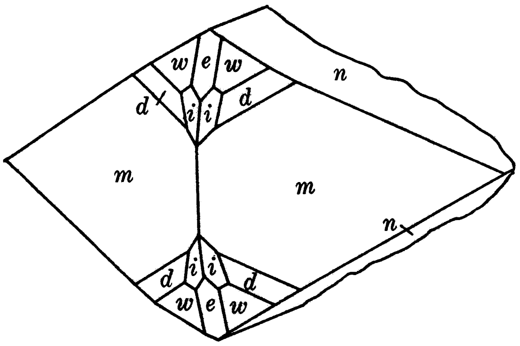

FIGURE 20.—Crystal of arsenopyrite showing the forms *m*(110), *e*(101), *n*(012), *w*(212), *i*(312), and the new form *d*(754). Fowler quarry.

The forms of the second zone, marked like the other by striations on the prism faces, were seen only on a large brilliant crystal (fig. 19), one of whose terminations was destroyed in freeing it from the matrix. They are *p*(143), *f*(132), and the doubtful forms (154), (275), and (594), each seen but once.

The pyramid *w* is characterized by distinct plane facets; the forms *o*(112) and *g* of the unit series were seen only on the crystal of figure 19 as small facets, and on the same crystal was seen the doubtful form (188), probably to be regarded as vicinal to *q*(011).

Figures 17 and 18 show characteristic crystals of the common habit, accurately illustrating the perfect symmetry that many of them possess. Figure 20 shows a crystal from the Fowler quarry with new pyramid *d*(754), lying between *m* and *w* (212).

The crystal elements, computed from measurements of 30 faces of the forms *m*, *q*, *e*, and *g*, on 6 crystals, gave the following values for the axial ratio of the crystals, which agree closely with those used in Dana's "System."

Axial ratio of crystals of arsenopyrite

	a.b c	p_0	q_0
Arsenopyrite, Franklin	0.6702 : 1 : 1.189	1.775	1.189
Arsenopyrite (Dana)	.6773 : 1 : 1.188	1.754	1.188

The data upon which the new forms are established are presented in the following table of angles:

Angles of faces on crystals of arsenopyrite

	Calculated		Measured		Limits		Number and quality of readings
	φ	ρ	φ	ρ	φ	ρ	
	° ′	° ′	° ′	° ′	° ′ ° ′	° ′ ° ′	
o(112)	55 46	46 39	56 15	46 51			1 good.
A(532)	67 48	78 3	67 55	78 24	67 19–68 13	78 4–78 50	9 very good.
d(754)	64 5	73 39	64 27	73 57			1 good.
p(143)	20 11	59 25	20 27	59 27	20 31–20 24	59 9–59 46	2 good
f(132)	26 6	63 19	26 7	63 27	25 53–26 33	63 14–63 45	3 very good.
B(514)	82 15	65 39	81 54	65 58			1 poor.
?(188)	10 24	50 28	10 0	50 23			1 poor.
?(154)	16 23	57 13	17 33	57 43			1 good.
?(275)	22 47	61 4	22 51	60 50			1 good.
?(594)	39 14	73 53	39 0	73 40			1 poor.

Composition.—Crystals from the Franklin Iron Co.'s quarry were sent to the laboratory of the United States Geological Survey for analysis. The result, given below, 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. (See p. 30.) The specific gravity is 6.199 (Buerger).

Analysis of arsenopyrite

[E C Sullivan (195), analyst]

	Percent	Molecular ratio	
Fe	32. 48	0. 581	1
Co	1. 16	. 02	
As	48. 72	. 65	1. 08
S	18. 80	. 587	. 98
	101. 16		

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.

Occurrence.—Arsenopyrite was recognized at Franklin by Nuttall (7) 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. As shown in figures 21 and 22, 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).

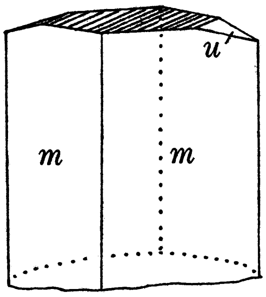

FIGURE 21.—Simple prismatic crystal of arsenopyrite showing the forms *m*(110) and *u*(014). Fiss collection.

Massive arsenopyrite was found in the Trotter mine near the deposit of nickel arsenides described on page 29, and minute crystals were found there intermixed with desaulesite. Arsenopyrite is also recorded from the Parker shaft, associated in one place with roeblingite, in another with quartz, pyroxene, and molybdenite.

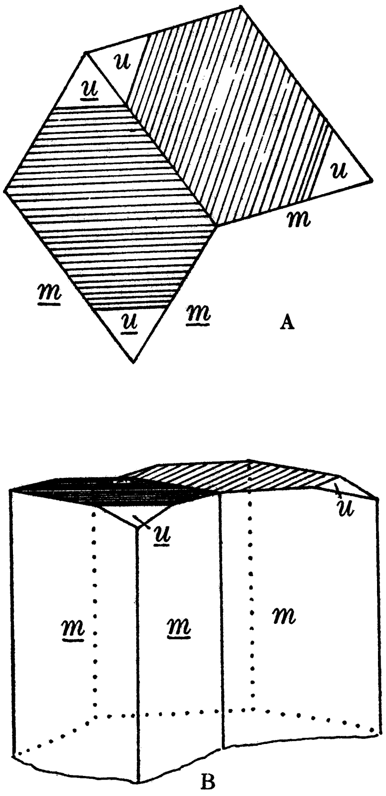

FIGURE 22.—Two crystals of arsenopyrite of the form of figure 21, twinned on the prism plane *m*(110). A, Plan, B, clinographic projection. Fiss collection.

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

$Cu_8As_2S_7$ Isometric-tetrahedral

Forms.—*d*(110), *o*(111), *n*(211). (See fig. 23.)

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.

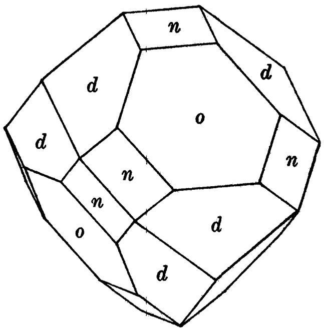

FIGURE 23.—Crystal of tennantite, showing the forms *d*(110), *o*(111), and *n*(211). Sterling Hill.

HALOIDS

FLUORITE

CaF_2. 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 (195), analyst]

	Percent	Molecular ratio	
Ca	51. 21	1. 28	1. 303
Mg	. 24	. 01	
Fe	. 27	. 005	
Mn	. 09	. 002	
Al	. 18	. 006	
F	45. 85		2. 412
	97. 84		

Steiger states that the deficiency in the analysis is undoubtedly to be assigned to fluorine, also that the Al, Fe, Mg, and Mn are computed as fluorides, although they may be present as oxygen salts.

The amount of manganese reported is not sufficient to be remarkable. If the total deficiency, 2.16 percent, is computed as fluorine there is still slightly less of that element than is needed to form RF_2 with all the bases, but almost exactly enough to satisfy calcium. This suggests, but of course does not prove, that the bases other than calcium are present as impurities or as unknown oxygen salts.

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, as described above, 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 (2), 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

SiO$_2$. Hexagonal

Forms.—$m(10\bar{1}0)$, $r(10\bar{1}1)$, $z(01\bar{1}1)$, $s(11\bar{2}1)$, and $Y(18.0.\overline{18}.1)$.

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.

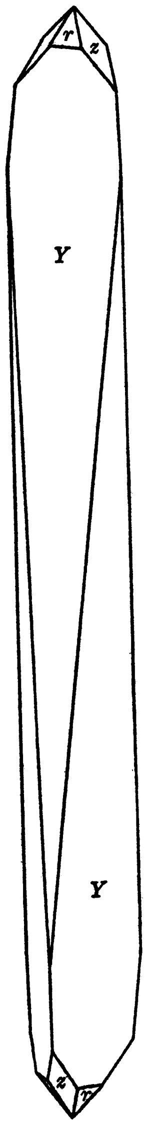

FIGURE 24.—Acicular crystal of quartz showing the forms $r(10\bar{1}1)$, $z(01\bar{1}1)$, and $Y(18.0.\overline{18}.1)$. Franklin.

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 with the forms *m*, *r*, *z* 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 and described by Palache (257) 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 inch 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, as shown in figure 24.

Although the crystal planes are dull and there are no visible prism faces, faint reflections were observed at 90°, the prism position, doubtless caused by minute striations. Readings were obtained from the rhombohedron faces only by wetting them with alcohol or by attaching glass slips with a film of liquid. The average reading obtained was $\rho = 87°30'$, which agrees most nearly with the form Y $(18.0.\overline{18}.1)$, $\rho = 87°29'$ It might, however, almost equally well be that for the form Ω $(0.17.\overline{17}.1)$, $\rho = 87°21'$. In the lack of evidence as to whether the form is positive or negative it was taken as Y and is so drawn in figure 24.

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

Cu$_2$O. 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 (99) 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

MnO. 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, and its refractive index for red light is 2.16 ± 0.01 (Ford).

Composition.—Manganosite is practically pure manganous oxide. Material for analysis was obtained by crushing the ore and separating the powder magnetically. The franklinite, strongly attracted in a weak field, was wholly removed, and manganosite, being slightly magnetic in a strong field, could thus be separated from zincite. Powder so obtained was handpicked under a microscope, but it was impossible to eliminate all traces of zincite or the film of manganese dioxide on the grains. The analysis accordingly shows some Zn and MnO_2, which are regarded as impurities.

Analyses of manganosite

	1	2	3
MnO	94. 59	99. 61	93. 33
ZnO	3. 41	--------	4. 89
Fe_2O_3	. 26	. 27	. 23
FeO			
MnO_2	1. 30	--------	1. 05
MgO	. 11	. 12	. 61
H_2O-	. 38	--------	--------
H_2O+	. 40	--------	--------
	100. 45	100. 00	100. 11

1. George Steiger (Palache, 195), analyst.
2. Same analysis as no. 1, recomputed to 100 percent after eliminating unessential ZnO, MnO_2, and H_2O.
3. L. H. Bauer, New Jersey Zinc Co. (243), analyst.

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. (See pl. 2, *A*.) 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. The optical characteristics of this manganosite were studied by Ford (285).

ZINCITE

(Zn,Mn)O. Hexagonal-hemimorphic

Forms.—Positive pole: $p(10\bar{1}1)$, $\alpha(40\bar{4}5)$, $\beta(50\bar{5}4)$, $m(10\bar{1}0)$. Negative pole: $c_1(000\bar{1})$.

Combinations on crystals of zincite

	Forms	Illustrations
1	*p*	
2	α	Fig. 25.
3	*m*	
4	c_1, α, *p*	Fig. 26.

Crystallographic measurements.—Measurements of natural crystals of zincite are few and poor, and the generally accepted axial ratio for zinc oxide is based on artificial crystals. The author has obtained measurements on one crystal of zincite from Franklin, however, which are very satisfactory and has computed an axial ratio based on them. In the following table are given the measurements made on natural crystals and the corresponding angles computed from the new ratio, from Dana's ratio, and from Traube's ratio for artificial crystals. The author's measurements were made on four faces of the pyramid $\alpha(40\bar{4}5)$, the average angle to the base being 55°42′, with a deviation of only 4′. A single reading on $p(10\bar{1}1)$ of the angle to the base was also obtained in close agreement. The resulting value, $c = 1.587$, is lower than any previously obtained, but there is little doubt that the crystal measured had faces superior to any natural crystal before studied.

Angles of zincite

	Computed			Measured				
	1	2	3	4	5	6	7	8
	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
(0001) to $(10\bar{1}1)$	61 23	61 54	61 41				62 0	61 22
$(10\bar{1}1)$ to $(01\bar{1}1)$	52 4	52 21	52 14				52 0	
(0001) to $(40\bar{4}5)$	55 42	56 17	56 3		55 38	55 40		55 42
$(40\bar{4}5)$ to $(04\bar{4}5)$	48 48	49 9	49 0		48 50			
(0001) to $(50\bar{5}4)$	66 25	66 52	66 41	65 20				
$(50\bar{5}4)$ to $(05\bar{5}4)$	54 33	54 46	54 40	53 53		54 42		

1. Computed from the new ratio, $c=1\ 587$, of Palache.
2. Computed from the old ratio, $c=1.6219$, of Dana.
3. Computed from the ratio, $c=1.6077$, determined by Traube from artificial crystals.
4. Measured by Dana (128) in 1886.
5. Measured by Grosser (148) in 1892.
6. Measured by Moses (170) in 1895.
7. Measured by Palache (contact measurements).
8. Measured by Palache (reflection measurements).

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. In thin section it is deep red and not perceptibly pleochroic. In sodium light $\omega=2.013$ and $\epsilon=2.029$ (Berman).

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 (40, 47, 105) 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. In 1925 Dittler (237) presented a new view of the matter. On the basis of new analyses and of comparative studies of artificial mixtures he concluded that, although most of the manganese is present as MnO, a part of it is in the form of Mn_3O_4 and that the color is due to the presence of that substance. His conclusion seems to be well established.

Zincite was shown by Eliot and Storer (77) to contain traces of other elements. They first analyzed zinc made from zincite and franklinite and found the following elements:

Elements present in zinc made from zincite and franklinite

Lead	0.079 percent.
Copper	0.1298 percent.
Iron	0.2088 percent.
Tin	Abundant qualitative reaction.
Arsenic	Do.
Sulphur	Traces.
Carbon	Do.

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 reactions 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.

Analyses of zincite

	1	2	3	4	5	6	7
ZnO	92. 00	93. 48	94. 45	96. 19	99. 47	93. 28	94. 30
MnO		5. 50		3. 70		6. 50	5. 54
FeO	8. 00						
Mn_2O_3					. 68		
Fe_2O_3		. 80				. 44	. 36
H_2O			1. 09		. 23		
Franklinite			4. 49	. 10			
	100. 00	99. 78	100. 03	99. 99	100. 38	100. 22	100. 20

	8	9	10	11	12	13	14
ZnO	96. 20	94. 85	93. 79	93. 14	93. 06	93. 72	99. 63
MnO	3. 33	4. 83	5. 14	6. 20	5. 46	3. 21	. 27
FeO					1. 14	. 69	. 01
Fe_2O_3	. 43	. 30	. 62	. 38	. 24	2. 32	
Mn_3O_4			. 50	. 34			
SiO_2							. 08
	99. 96	99. 98	100. 05	100. 06	99. 90	99. 94	99. 97

1. Archibald Bruce (1), analyst.
2. A. A. Hayes (40), analyst.
3. Franklin. J. D. Whitney (43), analyst.
4. Sterling Hill. J. D. Whitney (43), analyst.
5. Sterling Hill. W. P. Blake (75), analyst.
6, 7. Sterling Hill. G. C. Stone (131), analyst.
8. Schutz, in Grosser (148), analyst.
9 Franklin. Jenkins and Bauer (243), analysts.
10–13. Franklin. E. Dittler (237), analyst.
14. Sterling Hill. L. H Bauer (243), analyst.

Occurrence.—At Franklin, zincite in rounded, shotlike 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. Plate 3, *D*, shows an unusually rich specimen of zincite from the Trotter mine.

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. Plate 3, *C*, shows such crystals. 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. The upper base described by Phillips (197) is also believed by the author to be a cleavage plane. The measurements recorded on page 38, except those of the last column, were all made on crystals of this type and are highly unsatisfactory, the reflecting faces being of the poorest. The different pyramids cannot be distinguished by the eye because the apparent angle of slope of a pyramid may be abnormal on account of oscillatory development with the prism.

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.

The crystals of the second type are found projecting into open veins an inch or two wide. The largest crystal of this type in the Holden collection is 2 inches long and 1 inch in diameter at the base. It is shown in plate 3, *A*. 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, described under that mineral on page 50. The zincite crystals are minute and sharply formed, with generally dull faces, but some of the faces are bright enough to reflect good signals. As shown in figures 25 and 26, many of them, which stand quite free in the cavity, are sharply hemimorphic, with the pyramids $\alpha(40\bar{4}5)$, or α and $p(10\bar{1}1)$, above and the base alone below. The measurements recorded in the table on page 38 were made on two such crystals. 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.

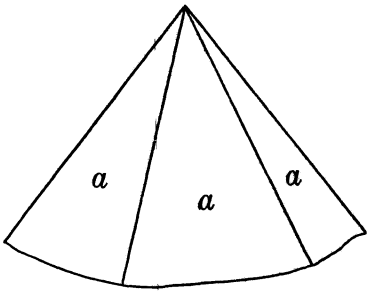

FIGURE 25.—Crystal of zincite showing the pyramid $(40\bar{4}5)$. Buckwheat mine.

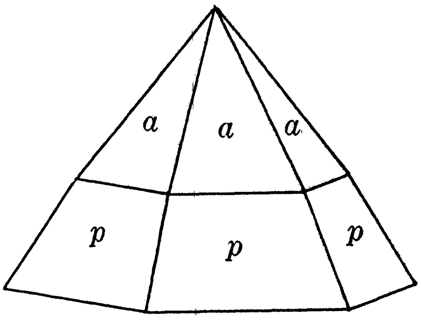

FIGURE 26.—Crystal of zincite showing the pyramids $(40\bar{4}5)$ and $p(10\bar{1}1)$ above and the base $c_1(000\bar{1})$ below Buckwheat mine.

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 (7) 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. Blake's analysis of zincite was made on material of this sort. Plate 3, *B*, shows an excellent example in the Canfield collection.

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 (110) 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 (1) 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 preceded by "sterlingite", proposed by Alger (38), which, however, never became current and is now used for a different substance—one of the micas. Alger's name "ruby zinc" (81) 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 (34) 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

Al_2O_3. Hexagonal-rhombohedral.

Forms.—$c(0001)$, $a(11\bar{2}0)$, $r(10\bar{1}1)$, $d_1(01\bar{1}2)$, $\eta(01\bar{1}1)$, $n(22\bar{4}3)$, and k $(7.7.\overline{14}.6)$.

Combinations on crystals of corundum

	Forms	Illustrations
1	c, r, k	Fig. 28.
2	c, a, r, d_1, n	Fig. 27.
3	c, a, r, d_1, n, k	Fig. 30.
4	c, a, r, η, n, k	Fig. 29.

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.

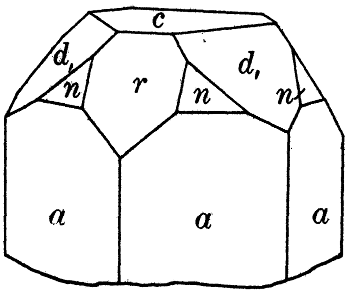

FIGURE 27

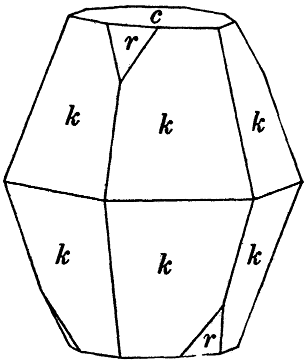

FIGURE 28

FIGURE 27.—End of prismatic crystal of corundum showing $c(0001)$, $a(11\bar{2}0)$, $r(10\bar{1}1)$, $d_1(01\bar{1}2)$, and $n(22\bar{4}3)$ Furnace quarry, Franklin.

FIGURE 28.—Barrel-shaped crystal of corundum showing the forms $c(0001)$, $r(10\bar{1}1)$, and $k(7.7.\overline{14}.6)$ Calamine pit, Sterling Hill.

Occurrence.—Corundum does not occur in association with the zinc ores but is widely distributed in isolated pockets in the Franklin limestone. The principal localities for the mineral in Sussex County are not in the Franklin district. In the pockets the corundum is associated with one or more of the minerals spinel, rutile, graphite, edenite, pyroxene, garnet, titanite, and phlogopite.

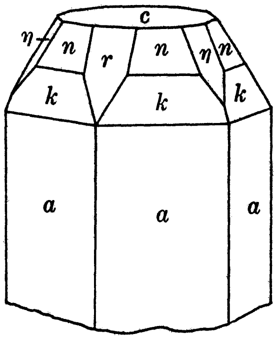

FIGURE 29

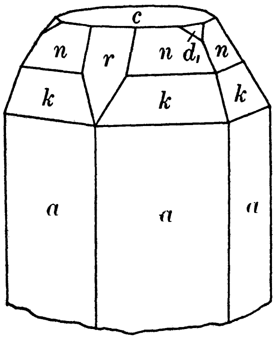

FIGURE 30

FIGURE 29.—End of prismatic crystal of corundum showing the forms $c(0001)$, $a(11\bar{2}0)$, $n(22\bar{4}3)$, $k(7.7.\overline{14}.6)$, $r(10\bar{1}1)$, $\eta(01\bar{1}1)$ Calamine pit, Sterling Hill

FIGURE 30.—End of prismatic crystal of corundum showing the forms $c(0001)$, $a(11\bar{2}0)$, $n(22\bar{4}3)$, $k(7.7.\overline{14}.6)$, $r(10\bar{1}1)$, $d(01\bar{1}2)$. Furnace quarry, Franklin

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, like those shown in plate 4, *B*, 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 calamine 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

Fe_2O_3. Hexagonal-rhombohedral

Forms.—$c(0001)$, $a(11\bar{2}0)$, $u(10\bar{1}4)$?, $r(10\bar{1}1)$, $\mathfrak{e}(20\bar{2}5)$, $\mu(01\bar{1}5)$, $e(01\bar{1}2)$, $N(05\bar{5}4)$, $n(22\bar{4}3)$, $z(22\bar{4}1)$, $i(42\bar{6}5)$, $\chi(12\bar{3}2)$, $\psi(12\bar{3}5)$, and $P(24\bar{6}7)$.

Combinations on crystals of hematite

	Forms	Illustrations
1	*c, r, z*	Fig. 31.
2	*c, r, e, n, z.* Twin on *c*(0001)	Fig. 32.
3	*c, r, e, n, z, χ, ψ, P*	Fig. 33.
4	*μ, z*	Fig. 34.
5	*a, r, μ, z*	Fig. 35.
6	*c, r, n, z*	Fig. 36.
7	*c, r, $\mathfrak{e}$, e, N, n, i, χ*	
8	*a, u?*	
9	*c, e, r, n, i*	

Composition.—As shown by the analyses, manganese is found only in traces, a remarkable fact in view of the immediate association of hematite with franklinite.

Analyses of hematite

	1	2
Fe_2O_3	98.20	98.14
FeO	1.80	1.29
Mn_2O_3		.54
MnO		.38
	100.00	100.35

1. Hematite, Franklin. A. J. Moses (190), analyst.
2. Hematite, Franklin. L. H. Bauer (243), analyst.

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. Such a mass is illustrated in plate 4, *A*.

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 (190) states that it has the rhombohedral angle of hematite, which as measured between the parting planes is 94° 13′ and as computed for hematite is 94°. One crystal an inch across, flattened parallel to the base and showing strong parting, was wholly embedded in limestone.

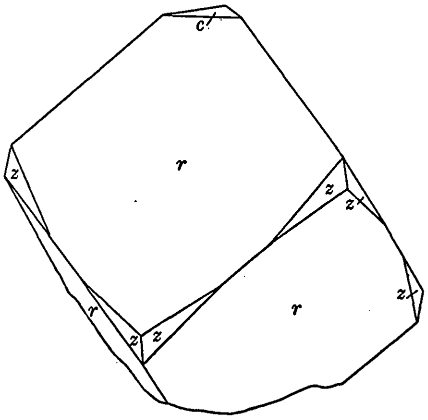

FIGURE 31.—Pseudocubic crystal of hematite showing the rhombohedron $r(10\bar{1}1)$ slightly modified by $c(0001)$ and $z(22\bar{4}1)$. Franklin.

Minute brilliant crystals of hematite were seen in a specimen of porous dolomite from the Buckwheat mine. They bore the forms of combination no. 8, 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.

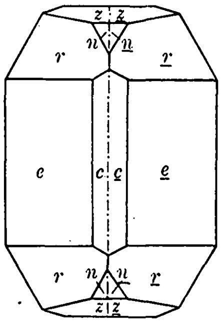

FIGURE 32

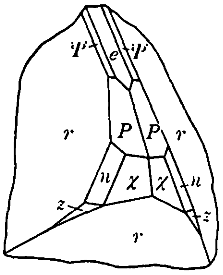

FIGURE 33

FIGURE 32.—Plan of a twin crystal of hematite showing the forms $c(0001)$, $r(10\bar{1}1)$, $e(01\bar{1}2)$, $n(22\bar{4}3)$, and $z(22\bar{4}1)$. The twin plane is (0001), and the composition plane is $(10\bar{1}0)$. Franklin.

FIGURE 33.—One coign of a rhombohedral crystal of hematite like that of figure 31 but showing the forms $r(10\bar{1}1)$, $e(01\bar{1}2)$, $n(22\bar{4}3)$, $z(22\bar{4}1)$, and the rare scalenohedrons $\chi(12\bar{3}2)$, $\psi(12\bar{3}5)$, and $P(24\bar{6}7)$. Franklin.

There is in the Fiss collection a specimen from the Trotter mine showing minute crystals of hematite of rhombohedral form with prism truncations, the dominant form probably being *u* $(10\bar{1}4)$. 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 (251). 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. The dominant form is the unit rhombohedron $r(10\bar{1}1)$, which gives them a cuboid habit, as shown in figure 31. The enlarged detail of one coign of a similar crystal is shown in figure 33. The forms $\chi(12\bar{3}2)$, $\psi(12\bar{3}5)$, and $P(24\bar{6}7)$ are negative scalenohedrons constituting a radial zone. Forms of that type are always rare on hematite. Although exceedingly minute, these faces are clean-cut and brilliant, giving excellent readings on the goniometer.

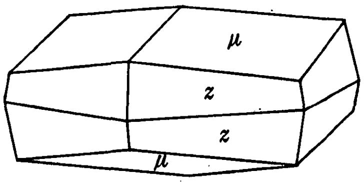

FIGURE 34.—Hexagonal tabular crystal of hematite showing the forms $\mu(01\bar{1}5)$ and $z(22\bar{4}1)$. Franklin.

Several of the crystals are twins, the twinning being on the common law for hematite—twinned on the base with a face of the first-order prism as the composition plane. Figure 32 shows a twin crystal with forms the same as those found on the simple crystals, but symmetrical distortion parallel to the composition plane gives an oblong or in some crystals a hexagonal habit to the twin groups.

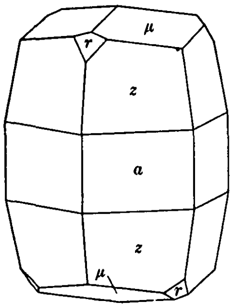

FIGURE 35

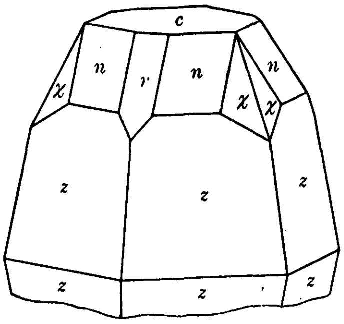

FIGURE 36

FIGURE 35.—Prismatic crystal of hematite showing the forms $a(11\bar{2}0)$, $z(22\bar{4}1)$, $r(10\bar{1}0)$, and $\mu(01\bar{1}5)$. Franklin. The steep pyramid z is uncommon on hematite.

FIGURE 36.—One end of a barrel-shaped crystal of hematite showing the forms $c(0001)$, $r(10\bar{1}1)$, $n(22\bar{4}3)$, $z(22\bar{4}1)$, and $\chi(12\bar{3}2)$. Franklin.

Crystals of hematite associated with friedelite in an open seam in ore show the variable habits of figures 34, 35, and 36. Although rather rough, the crystals were sufficiently brilliant to give measurements establishing the forms shown.

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. Combination no. 7 is an example of this type.

It may be noted that none of the figured 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

$(Fe,Ti)_2O_3$. Hexagonal-trirhombohedral

Forms.—$c(0001)$, $r(10\bar{1}1)$, $s(02\bar{2}1)$, $n(22\bar{4}3)$, and doubtfully $u(10\bar{1}4)$, and $\zeta(20\bar{2}5)$.

Combinations on crystals of ilmenite

1. *c, r, s, n, u, ζ.*
2. *c, r, s.*

Habit.—Tabular crystals embedded in limestone.

Occurrence.—Ilmenite is listed by Canfield (136) 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. The crystals were measured and gave the forms of combination 2. 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. The crystals show the forms of combination 1 and have the proportions of the crystal figured in Dana.[1]

SPINEL GROUP

SPINEL

$(Mg,Fe)O.(Al,Fe)_2O_3$. 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.

Composition.—The following analysis shows the composition of spinel:

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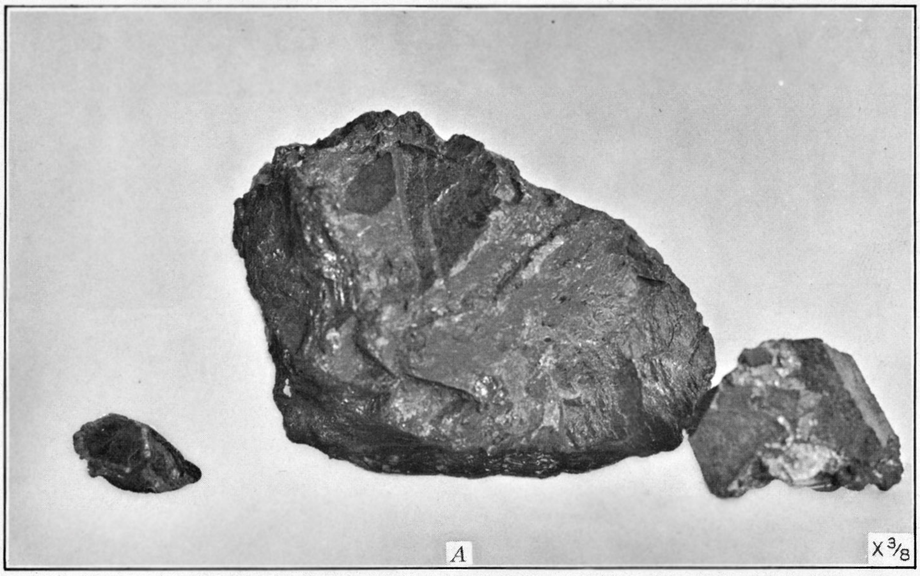
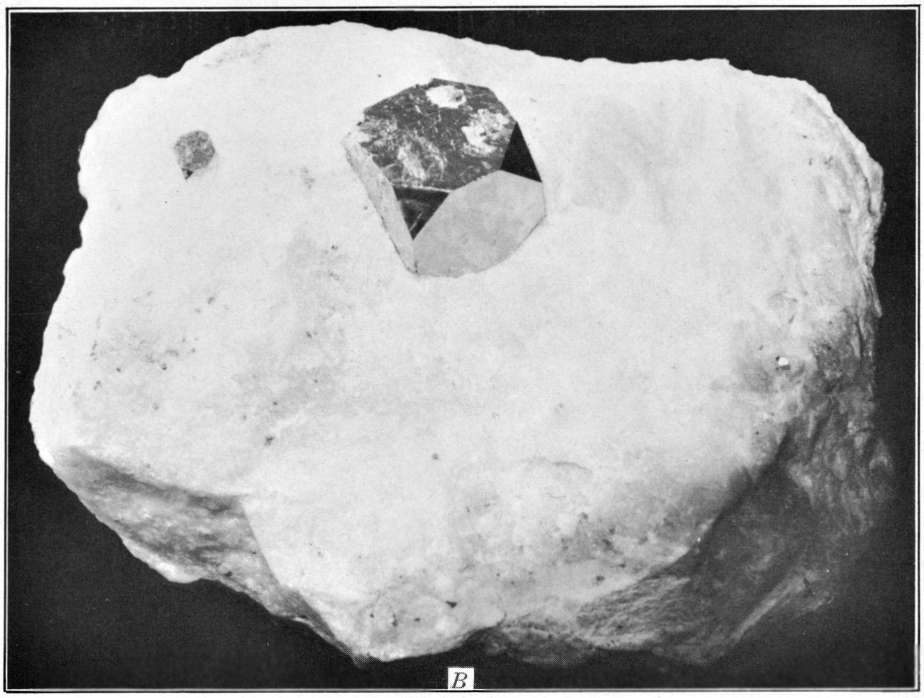
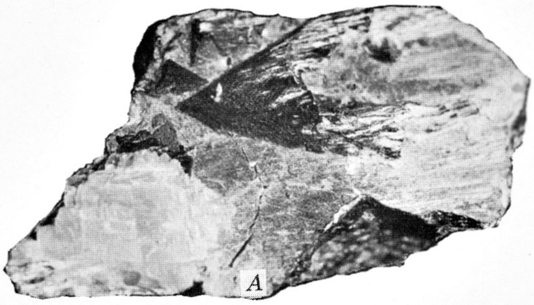
[1] System of mineralogy, 6th ed., fig. 1, p. 218, 1911.

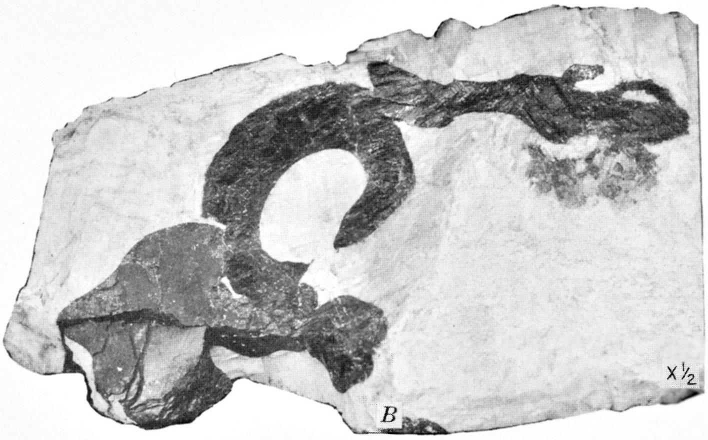


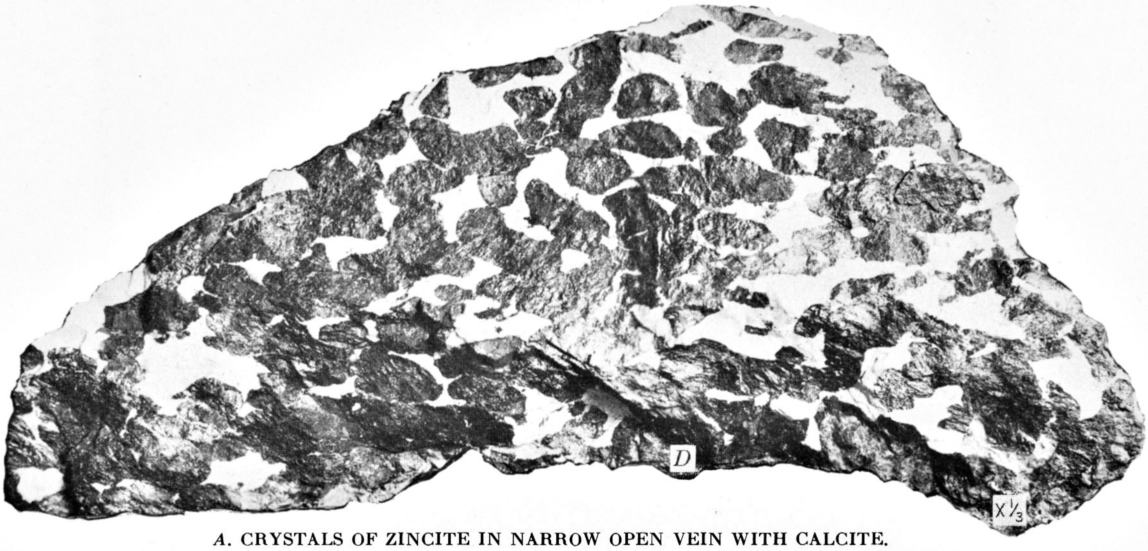
A. OCTAHEDRAL CRYSTALS OF MANGANOSITE IN ZINCITE.
Franklin. Harvard collection.



B. CRYSTAL OF PYRITE IN LIMESTONE.
Franklin. Canfield collection.





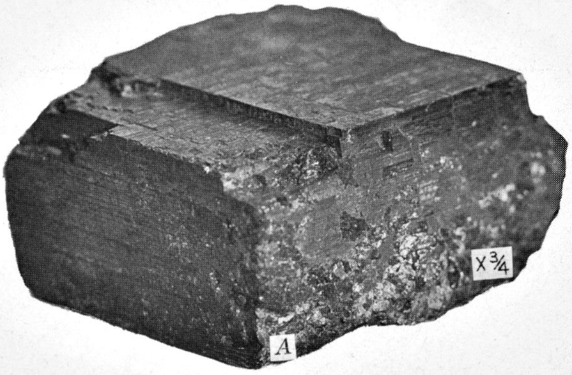


A. CRYSTALS OF ZINCITE IN NARROW OPEN VEIN WITH CALCITE.
Franklin. Holden collection.

B. SPECIMEN OF ZINCITE SHOWING CORRODED CRYSTALS IN LIMESTONE.
Sterling Hill. Canfield collection.

C. CRYSTALS OF ZINCITE EMBEDDED IN MASSIVE ZINCITE.
Franklin. Holden collection.

D. COARSE GRAINS OF ZINCITE IN LIMESTONE.
Trotter mine, Franklin. Harvard collection.



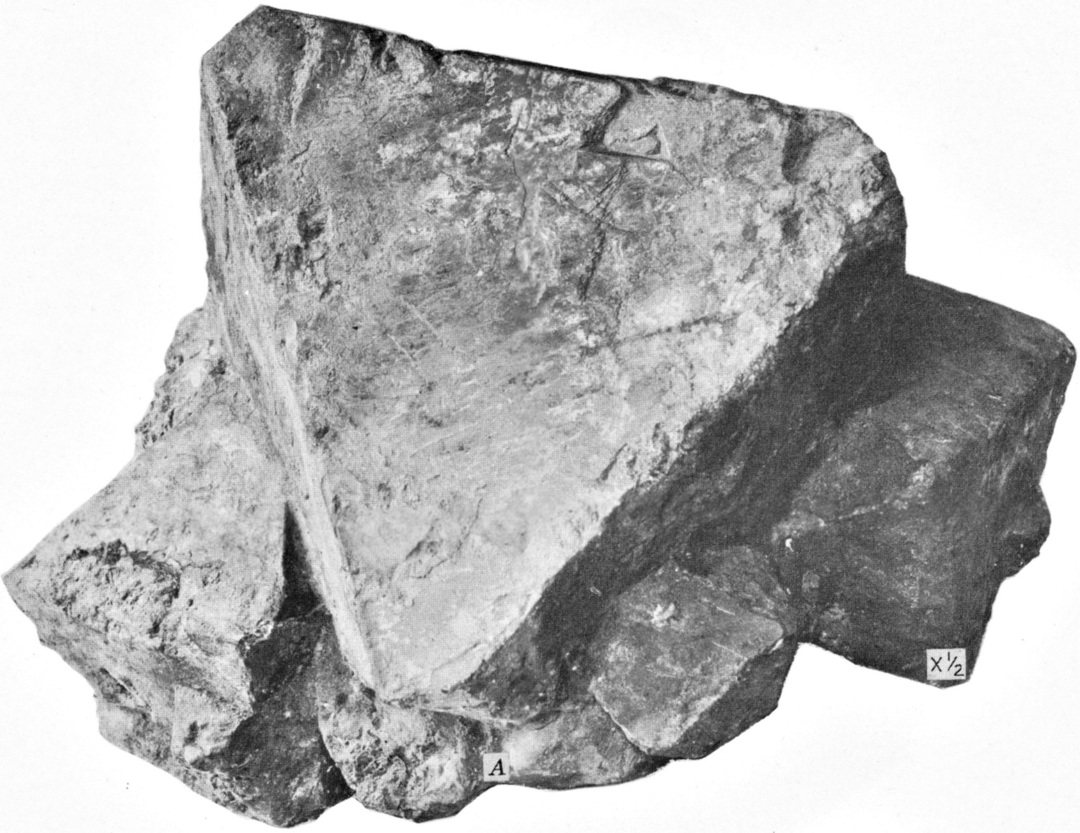
A. CUBELIKE RHOMBOHEDRON OF HEMATITE DUE TO PARTING.
Franklin. Harvard collection.

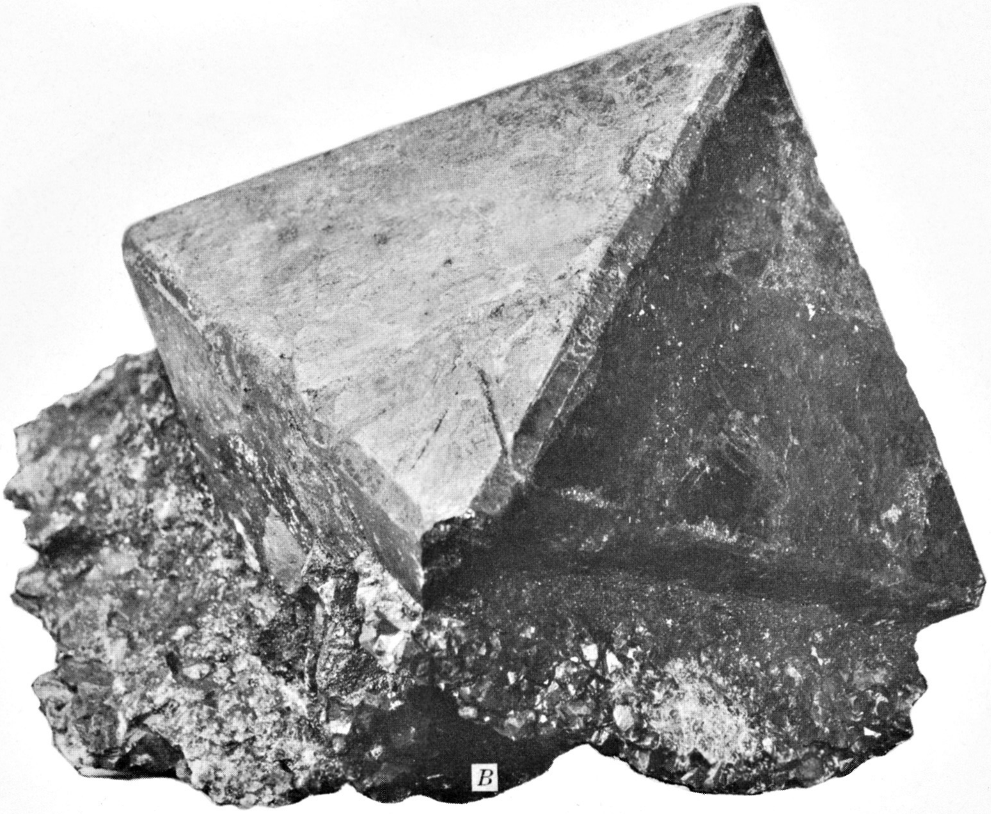
B. CRYSTALS OF CORUNDUM (c) WITH GARNET (g), TOURMALINE AND AMPHIBOLE (a).
Canfield collection.

A. GROUP OF OCTAHEDRAL CRYSTALS OF GAHNITE FROM STERLING HILL.

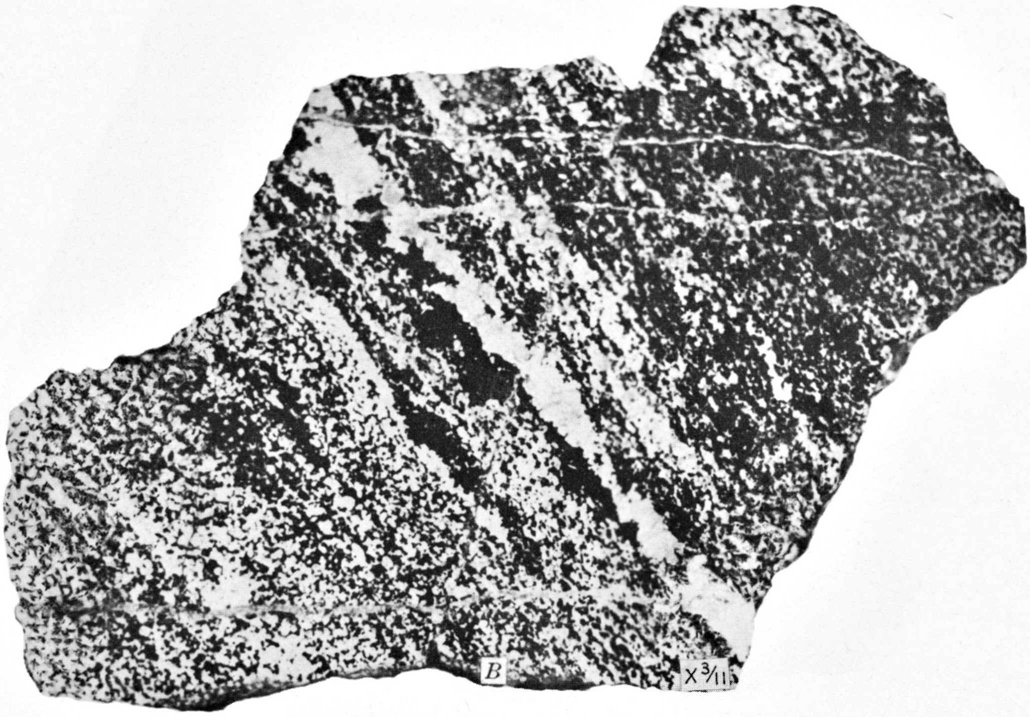
B. LARGEST AND MOST PERFECT CRYSTAL OF GAHNITE (DYSLUITE) PRESERVED FROM STERLING HILL.

Specimens in Canfield collection.





A. LARGEST OCTAHEDRON OF FRANKLINITE PRESERVED FROM STERLING HILL.
B. LARGE OCTAHEDRON OF FRANKLINITE FROM STERLING HILL TRUNCATED BY THE DODECAHEDRON.
Specimens in Canfield collection.



A. DODECAHEDRAL CRYSTAL OF FRANKLINITE.

Sterling Hill. Canfield collection.

B. FRANKLINITE ORE, SHOWING PRONOUNCED LAYERING AND CROSS VEINLETS OF RHODONITE.

The lighter areas are made up mostly of grains of willemite. Franklin. Harvard collection.

Analysis of spinel

	1	2	3
Al_2O_3	66. 09	67. 17	0. 659 } 0. 671
Fe_2O_3		1. 91	. 012
FeO	10. 64	8. 91	. 124 } . 670
MgO	21. 66	22. 01	. 546
SiO_2	. 80		
H_2O	. 96		
	100. 15	100. 00	

1. Ceylonite. Vogel (79), analyst.
2. Same analysis, recomputed to 100 percent after omitting SiO_2 and H_2O and distributing the iron between the ferrous and ferric oxides so as to give the spinel ratio.
3. Molecular ratio calculated from the analysis.

The analysis, made by Vogel in Rammelsberg's laboratory, is of crystals described as green-black octahedrons, associated with zincite and calcite, an association that suggests gahnite. The analysis, however, shows no zinc but, until recomputed as in column 2, gives poor ratios for the spinel formula. An earlier analysis of Franklin spinel by Thomson (23) must be rejected as giving a composition wholly abnormal for the species.

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 Gooseberry 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

Variety dysluite or automolite (Zn, Fe, Mn)O $(Al,Fe)_2O_3$. 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, and the refractive index is 1.818 ± 0.005.[2]

Composition.—The following analyses show the composition of gahnite:

Analyses of gahnite

	1	2	3	4	5
Al_2O_3	57. 09	30. 49	49. 78	47. 27	48. 81
Fe_2O_3		41. 93	8. 58	9. 90	10. 22
ZnO	34. 80	16. 80	39. 62	37. 10	38. 31
FeO	4. 55				
MnO	Trace	7. 6	1. 13	. 93	. 97
MgO	2. 22		. 13	1. 09	. 12
CaO				1. 01	. 57
CO_2				. 38	
SiO_2	1. 22	2. 96	. 57	1. 47	
H_2O		. 4		1. 21	
	99. 88	100. 18	99. 81	100. 36	100. 00

1. "Gahnite von Amerika." Hermann Abich (26), analyst. Although assigned by Dana (146, p. 223) to Franklin, there is no good evidence that the material came from there except that the analysis is cited by Alger (38).
2. Dysluite, presumably altered material, Sterling Hill. Thomas Thomson (32), analyst.
3. Gahnite, Franklin. Average of two analyses. J. S. Adam (Brush, 102), analyst.
4. Dysluite, Sterling Hill. W. T. Schaller (Palache, 195), analyst.
5. No. 4, recomputed to 100 percent after deducting SiO_2, H_2O, and $CaCO_3$; state of oxidation of iron not known.

The close agreement of analyses 3 and 5, of material from Franklin and Sterling Hill, respectively, is noteworthy—both give ratios closely approximating the theoretical composition. Analysis 3 showed a larger percentage of zinc than any other gahnite yet analyzed.

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 (7) and Vanuxem (9), for the greenish crystals, but no analysis of them is recorded. There is no reason to doubt the correctness of Alger's conclusion (41) that

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Schaller, W. T., personal communication.

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 löllingite, 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 1½ 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 löllingite. They are unique among spinels (but see the description of franklinite, p. 45) 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 (100) included the analysis by Adam (no. 3, p. 43) and was later illustrated with figures of the most typical crystals by Penfield (100, reprint).

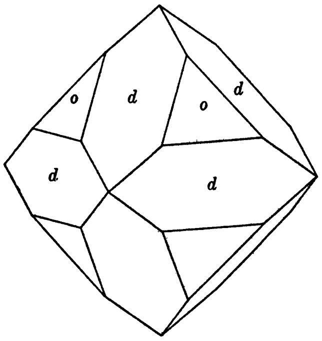

FIGURE 37

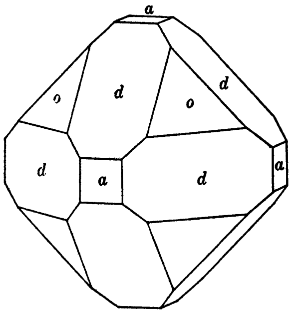

FIGURE 38

FIGURE 37.—Crystal of gahnite, showing the dodecahedron and octahedron. Buckwheat mine, Franklin.

FIGURE 38.—Crystal of gahnite showing the dodecahedron, octahedron, and cube.

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. It is illustrated in plate 5, *B*. It is the crystal, collected by Mr. F. Canfield, to which Jackson refers in his paper (52).

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. Plate 5, *A*, illustrates some of these specimens.

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 (12) 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 (41) the fact was recognized that there is no difference between it and the so-called "automolite" of Franklin. The crystal whose analysis is presented above (no. 4, p. 43) was given for analysis by Mr. Canfield.

MAGNETITE

$FeO.Fe_2O_3$. 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.

Composition.—No complete analyses of magnetite from the district seem to have been made. The following partial analyses were made in the laboratory of the United States Geological Survey.

Partial analyses of magnetite

	1	2
Fe	70.26	65.67
MnO	.40	.12
ZnO	.06	4.68
TiO_2	Trace	.20
S	.11	--------

1. From the magnetite ore bed underlying the zinc-ore deposit, at the Franklin Iron Co.'s mine, Franklin.
2. Lean ore from the zinc-ore deposit, Sterling Hill.

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 (see p. 26) 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, as shown by analysis 1 above, 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 2 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

(Fe,Mn,Zn)O.(Fe,Mn)$_2$O$_3$. 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).

Combinations on crystals of franklinite

	Forms	Illustrations		Forms	Illustrations
1	*o*		8	*a, e*	Fig. 45.
2	*o, d*	Fig. 39.	9	*a, o, e*	Fig. 46.
3	*o, m, d*	Fig. 40.	10	*o, a*	
4	*d, o, m*	Fig. 41.	11	*o, a, d*	
5	*d, o, n*	Fig. 42.	12	*o, d, m, v*	Fig. 47.
6	*a, o, d, m, n, f*	Fig. 43.	13	*d, o*	Fig. 48.
7	*a, d, o, m*	Fig. 44.			

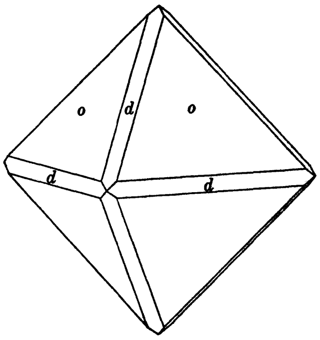

Figure 39

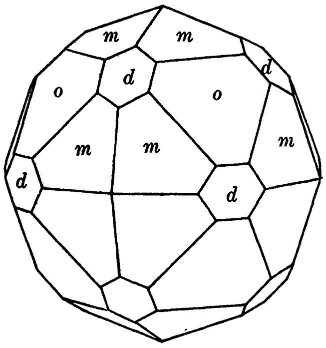

Figure 40

Figure 39.—Crystal of franklinite showing the octahedron with a narrow truncation by the dodecahedron—a common type.

Figure 40.—Crystal of franklinite showing the octahedron in balance with a trapezohedron, *m*(311), and small faces of the dodecahedron.

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.

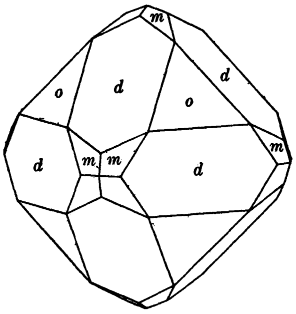

Figure 41

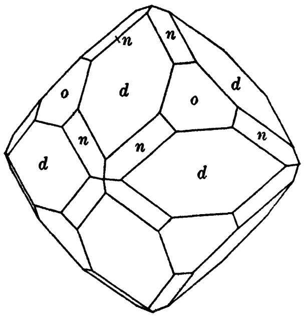

Figure 42

Figure 41.—Crystal of franklinite showing the dodecahedron and the octahedron and small faces of the trapezohedron *m*(311).

Figure 42.—Crystal of franklinite showing the dodecahedron, the octahedron, and the trapezohedron *n*(211).

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* (fig. 43). 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 the analysis (no. 16, p. 47) 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.

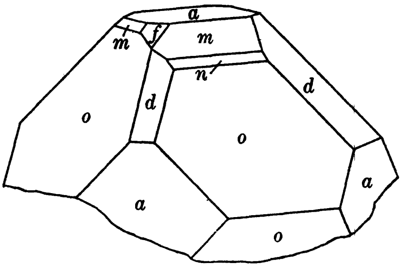

Figure 43

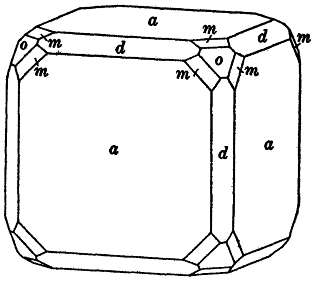

Figure 44

Figure 43.—Crystal of franklinite showing the octahedron, cube, and dodecahedron, and some faces of the forms *m* (311), *n*(211), and *f*(310). Hamburg mine.

Figure 44.—A cubic crystal of franklinite, showing also the dodecahedron, the octahedron, and the trapezohedron *m*(311) Hamburg mine.

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 (211). In one habit *e* is combined with the cube alone (fig. 45); in the other with the cube and the octahedron, all three forms being about equally developed (fig. 46). These crystals are of splendent luster and ideal symmetry. They are associated with excellent crystals of willemite and tiny rosettes of talc, in a matrix of cavernous gray dolomite.

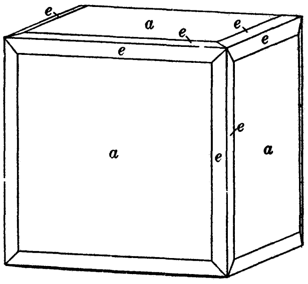

FIGURE 45

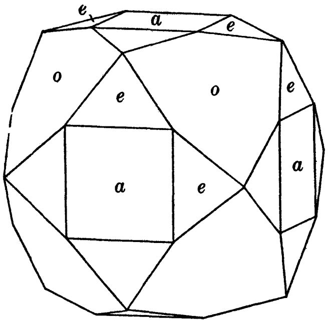

FIGURE 46

FIGURE 45.—A cubic crystal of franklinite, showing only the cube and the tetrahexahedron *e*(510). Franklin.

FIGURE 46.—Crystal of franklinite showing the cube, the octahedron, and the tetrahexahedron *e*(510). Franklin.

Small cubic crystals showing the forms of figure 44 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. (See, however, the description of the unusual phase on p. 45.) Index of refraction, $n_{Li} = 2.36 \pm 0.02$. 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 in the following table 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.[3] Manganese is probably present in both states of oxidation, and the general formula given at the head of this description 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.

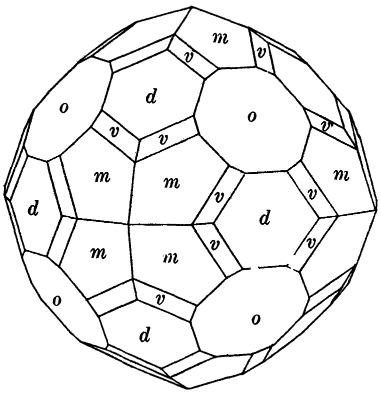

FIGURE 47.—Crystal of franklinite showing the octahedron, the dodecahedron, the trapezohedron *m* (311), and the rare hexoctahedron *v*(531) Sterling Hill.

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[3] Schaller, W T., personal communication.

Analyses of franklinite

	1	2	3	4	5	6	7	8
Fe_2O_3	66.00	66.10	68.88	66.07	66.12	65.05	65.93	66.05
Mn_2O_3	16.00	14.96		12.24	11.98	14.77	11.34	12.23
ZnO	17.00	17.42	10.81	21.39	21.77	23.30	21.82	21.88
MnO			16.32					
Al_2O_3			.73					
SiO_2		.20	.40	.29	.13	.30		
H_2O		.56						
	99.00	99.24	97.14	99.99	100.00	103.42	99.09	100.16

	9	10	11	12	13	14	15	16
Fe_2O_3	63.40	67.42	60.52	56.57	67.38	66.34	66.20	66.58
Mn_2O_3	4.44		6.79	10.52			12.40	
ZnO	23.11	6.78	19.44	15.91	16.28	20.26	21.00	20.77
MnO	10.46	9.53	12.81	16.37	16.38	12.31		9.96
FeO		15.65						
Al_2O_3		.65					.80	None
SiO_2	.17	.08						.72
H_2O								.71
CaO								.43
MgO								.34
	101.58	100.11	99.56	99.37	100.04	98.91	100.40	99.51

1. Franklinite, Franklin. P. Berthier (3), analyst. (Original description.)
2. Franklinite, Sterling Hill. Thomas Thomson (23), analyst.
3. Franklinite. Hermann Abich (26), analyst.
4, 5. Franklinite. Dickerson, analyst, in C. T. Jackson (58).
6. Franklinite. G J. Brush (76), analyst.
7. Franklinite crystals. C. F. Rammelsberg (93), analyst.
8. Average of three specimens of massive franklinite. C. F. Rammelsberg (93), analyst.
9 Average of two feebly magnetic crystals, Franklin. G. H. Seyms (109), analyst.
10. Average of four strongly magnetic crystals, Sterling Hill. G H. Seyms (109), analyst.
11. Granular ore, specific gravity 5.215, Franklin. G. C. Stone (131), analyst.
12. Massive ore, specific gravity 5.187, Franklin. G. C. Stone (131), analyst.
13. Crystals, specific gravity 5.136, Sterling Hill. G. C. Stone (131), analyst.
14. Crystals, specific gravity 5.074. G. C. Stone (131), analyst.
15. Franklinite. Franz von Kobell (92), analyst.
16. Crystals, specific gravity 5.09. State of oxidation of iron and manganese not known. W. T. Schaller (Palache, 195), analyst.

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, as shown in plate 7, *B*, 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 1½ 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.

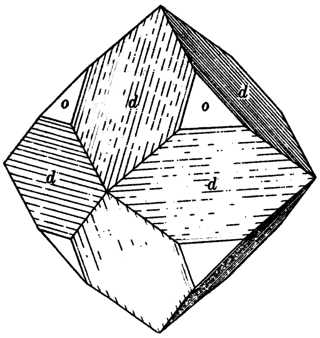

FIGURE 48.—Dodecahedral crystal of franklinite modified and striated by the octahedron Sterling Hill

At Sterling Hill also franklinite is the dominant ore mineral and occurs prevailingly 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. Several of the finest are illustrated in plate 6, *A*, *B*. The crystals shown in the photographs 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). One of them is shown in plate 7, *A*. 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. (See appendix, *c*, p. 130.)

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 (3), 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

$ZnO.Mn_2O_3$. Tetragonal

Forms.—*c*(001), *p*(111).

Crystallographic measurements.—Minute pseudo-octahedral crystals with the base, either simple or twinned on (101), as shown in figure 49, 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, so that measurements are not satisfactory. On one simple crystal, however, four identical readings were obtained for the angle of the pyramid to the base, 57°55′, making the axial ratio *a* : *c*=1:1.128. These values differ considerably from the established elements for hausmannite, which are, angle *c* to *p*=57°32′, and *a* : *c*=1:1.155.

Physical characters.—The color of hetaerolite is shining black with a dark-brown streak. Below are given in tabular form for comparison the optical characters, observed specific gravity, and computed specific gravity (Gladstone and Dale) for the minerals of this group. The last-named values are a measure of the effect produced by the introduction of water in the hetaerolite molecule.

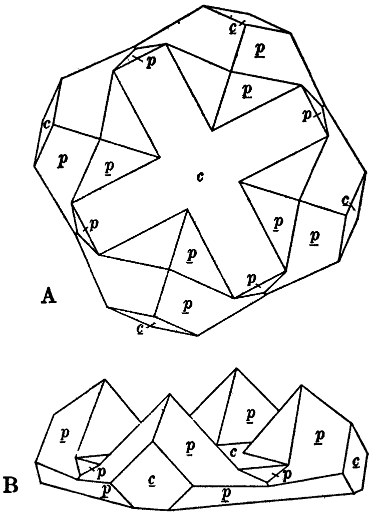

FIGURE 49.—Twin group of five crystals of hetaerolite, showing the forms *c*(001) and *p*(111); four of the individuals twinned to the fifth one on faces of the second-order pyramid. Franklin. A, Plan; B, clinographic projection.

Optical characters and specific gravity of hetaerolite

	Optical indices		Specific gravity	
	ω	ε	Observed	Computed
Hausmannite	2. 46	2. 15	4. 86	------
Zinc hausmannite or hetaerolite (Sterling Hill)	2. 35	2. 10	4. 85	4. 810
Hydrohetaerolite (Colorado)	2. 26	2. 10	4. 55	4. 537

Composition.—A sample of hetaerolite from Sterling Hill of specific gravity 4.85, purified by Berman, was analyzed and found to have the following composition:

Analysis of hetaerolite

[L. H. Bauer (Palache, 257), analyst]

	Percent	Molecular ratios	
Mn_2O_3	64. 21	0. 407	0. 409
Fe_2O_3	. 24	. 002	
ZnO	32. 46	. 399	. 425
MnO	1. 86	. 026	
MgO	. 49		
SiO_2	. 18		
H_2O	. 19		
	99. 63		

The composition is that of an anhydrous oxide, and it gives molecular ratios close to those demanded by the formula adopted for the mineral, which is $ZnO.M.n_2O_3$

Hetaerolite is unaltered in the blowpipe flame and yields a zinc coating when reduced with soda on 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 hodgkinsonite 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 hodgkinsonite proves that they were found in the northern part of the mine at Franklin, the only place where hodgkinsonite 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 (114) somewhat doubtfully as a zinc hausmannite. No further examination of the mineral was made until 1910, when the author published (195) 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 (201) described hetaerolite from Leadville, Colo., where also it was found amid oxidized ores. They concluded that it should be regarded as a hydrous oxide, with the formula $2ZnO.2Mn_2O_3.H_2O$, 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 (257), where it is associated with unoxidized franklinite. This analysis shows scarcely a trace of water and gives an almost ideal ratio for zinc hausmannite, $ZnO.Mn_2O_3$. 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. The hydrous variety is described on page 53 under the name "hydrohetaerolite."

RUTILE

TiO_2. 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 deposit. In no place was rutile found in direct association with the primary zinc ores.

GOETHITE

$Fe_2O_3.H_2O$. 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

$Mn_2O_3.H_2O$. 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.

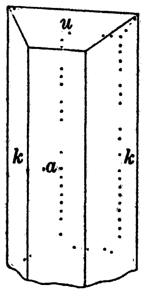

FIGURE 50.—Simple prismatic crystal of manganite showing the forms *a*(100), *k*(230), and *u*(101). Franklin.

Manganite was doubtfully reported by Brush (95) 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

$2Fe_2O_3.3H_2O$. 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. (See pp. 53 and 23.)

PYROCHROITE

$MnO.H_2O$. Hexagonal-rhombohedral

Forms.—*c*(0001), *a*$(11\bar{2}0)$, *r*$(10\bar{1}1)$, *s*$(30\bar{3}2)$, *t*$(90\bar{9}4)$, and *x*$(71\bar{8}6)$?.

Crystallographic measurements.—All the crystallographic data were determined from crystals loaned by R. B. Gage. The crystals are small and somewhat dull, so that measurements are unsatisfactory. The new forms were established on the following data:

Angles of pyrochroite

[New forms are marked with an asterisk (*)]

Symbol	Calculated φ	Calculated ρ	Measured φ	Measured ρ	Quality of signals	Number of readings
	° ′	° ′	° ′	° ′		
$r(10\bar{1}1)$	30 0	58 16	30 0	58 46	Poor	5
$s^*(30\bar{3}2)$	30 0	67 35	30 0	67 52	Very poor	1
$t^*(90\bar{9}4)$	30 0	74 38	30 0	74 53	Good	5
$x^*(71\bar{8}6)$	23 25	63 49	22 58	63 37	Very poor	3

Habit.—Pyrochroite forms rhombohedral crystals with a small base, which are pseudocubic, as the rhombohedral angle (95°) is close to 90°; 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. The following analyses of crystals from Franklin and Sterling Hill are in fair agreement with the accepted formula, $MnO.H_2O$.

Analyses of pyrochroite

	1	2
MnO	66. 98	70. 80
ZnO	3. 08	3. 70
MgO	6. 56	4. 59
FeO	1. 39	....
H_2O	20. 57	19. 29
CaO	. 32	. 16
MnO_2	. 89	....
CO_2	. 37	....
SiO_2	....	. 32
	100. 16	98. 86

1. Franklin. R. B. Gage, analyst (private communication).
2. Sterling Hill. L. H. Bauer (243), analyst.

On the label of an original specimen of pyrochroite from the Hamburg mine, in the Brush collection, is Roepper's manuscript statement of his determination of water, H_2O, average of two analyses, 16.45 percent. The theoretical value for pyrochroite is 20.3 percent, hence his material must have been somewhat altered, or else he failed to allow for increase of weight of MnO consequent on partial oxidation.

Occurrence.—At Franklin pyrochroite was found in several places on Mine Hill, being first recognized by Roepper (147) 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 (95) 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—gageite, 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 gageite 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 as well as for the analysis given above. 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 (the MnO_2 of the analysis). In this permanence they differ from all other known occurrences of pyrochroite.

The crystals that yielded the new forms described above differ in habit on the same specimen in the way shown in figures 52, 53, and 54. 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 rhombohedral type. Their faces are rough and rounded and permitted only approximate measurement; they also show traces of a rhombohedron near the unit form. The scalenohedron, the first observed on pyrochroite, is not, then, to be regarded as a typical form but is rather to be classed as vicinal.

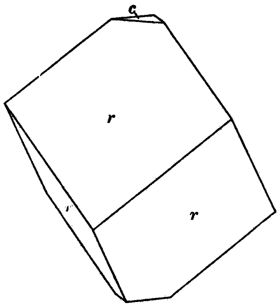

FIGURE 51

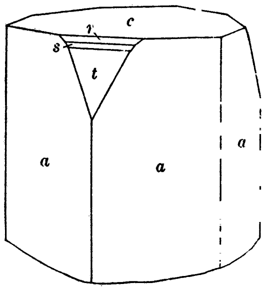

FIGURE 52

FIGURE 51.—Rhombohedral crystal of pyrochroite showing the rhombohedron and the base. Buckwheat mine, Franklin.

FIGURE 52.—Prismatic crystal of pyrochroite showing the forms $c(0001)$, $a(11\bar{2}0)$ $r(10\bar{1}1)$, $s(30\bar{3}2)$, and $t(90\bar{9}4)$. Franklin.

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 1½ 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.

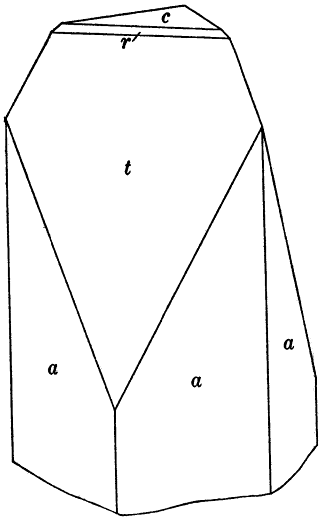

FIGURE 53

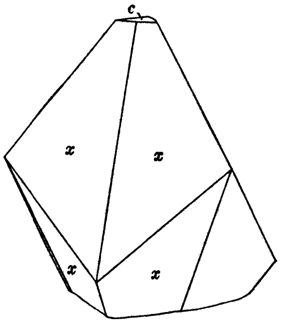

FIGURE 54

FIGURE 53.—Crystal of pyrochroite showing the forms $c(0001)$, $a(11\bar{2}0)$, $r(10\bar{1}1)$, and a large development of $t(90\bar{9}4)$. Franklin.

FIGURE 54.—Scalenohedral crystal of pyrochroite showing the forms $x(71\bar{8}6)$? and $c(0001)$ Probably a solution form derived from crystals of the form of figure 53. Franklin.

This cavity was but a few feet from the locality of leucophoenicite described on page 105, 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, as described on page 109.

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

$(Mg,Mn,Zn)(OH)_2$. 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. The average values determined were $\omega=1.59$, $\epsilon=1.60$.

The following chemical analysis was made by Bauer on light-colored material and yields a magnesium to manganese ratio of 5 to 1. The material from Jakobsberg has a ratio of 7 to 1.

Analysis of manganbrucite from Franklin

[L. H. Bauer (273), analyst]

H_2O	25. 97
MnO	17. 58
ZnO	3. 56
MgO	49. 94
CaO (present as $CaCO_3$)	Undetermined
	97. 05

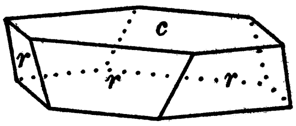

FIGURE 55

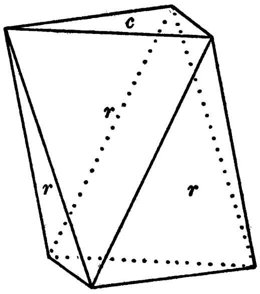

FIGURE 56

FIGURE 55.—Hexagonal tabular crystal of chalcophanite showing the forms *c*(0001) and *r*(10$\bar{1}$1). Sterling Hill.

FIGURE 56.—Rhombohedral crystal of chalcophanite of octahedronlike habit, showing the forms *c*(0001) and *r*(10$\bar{1}$1). Sterling Hill.

CHALCOPHANITE

$(Mn,Zn,Fe)O.2MnO_2.2H_2O$. Hexagonal-rhombohedral

Forms.—*c*(0001), *r*(10$\bar{1}$1).

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. The specific gravity is 3.903 (Moore, 108), and that of hydrofranklinite is 4.01 to 4.09 (Penfield and Kreider, 157). The mineral is uniaxial, negative, nearly opaque, and strongly pleochroic—ϵ=deep red, ω=nearly opaque; $\omega>2.7$ (Larsen).

Composition.—The following analyses show the composition of chalcophanite:

Analyses of chalcophanite

	1		2		3	
	Percent	Ratio	Percent	Ratio	Percent	Ratio
MnO_2	59. 94	2	61. 57	2	58. 48	2
MnO	6. 58	1. 04	4. 41	. 9	------	------
ZnO	21. 70		20. 80		18. 25	1. 07
FeO	------	------	------	------	10. 00	
H_2O	11. 58	1. 87	12. 66	2	11. 85	1. 94
Fe_2O_3	. 25	------	------	------	------	------
Insoluble	------	------	------	------	. 25	------
	100. 05	------	99. 44	------	98. 83	------

1. Crystals. G. E. Moore (108), analyst.
2. Stalactitic masses, after deducting 1.27 percent for limonite. G. E. Moore (108), analyst.
3. Hydrofranklinite, minute crystals. Penfield and Kreider (157), analysts.

Analysis 3 differs from the others in the presence of much FeO, but all three approximate closely in ratios the same expression: $RO:MnO_2:H_2O=1:2:2$, giving the formula as adopted.

Occurrence.—Chalcophanite is known only from Sterling Hill, where it was discovered and described by Moore (108), 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 (124) 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 (157), 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 (fig. 56).

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—$2ZnO.2Mn_2O_3.H_2O$, the iron being partly eliminated as limonite—and then by oxidation and further hydration the hydrohetaerolite was in turn changed to chalcophanite.[4] The facts that chalcophanite 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

$2ZnO.2Mn_2O_3.H_2O$. Tetragonal?

Habit.—Hydrohetaerolite is found in fibers grouped in radiated masses with botryoidal or mammillary surfaces, also in massive granular and bladed forms. The appearance of a typical specimen is well shown in plate 19, *A*.

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 mineral is uniaxial and negative, with faint pleochroism in red-brown colors. In absorption $\epsilon > \omega$; $\omega = 2.34 \pm 0.02$ and $\epsilon = 2.14 \pm 0.02$ (Larsen). The streak is dark brown, the hardness is 5, and the specific gravity is 4.93 (Moore) or 4.85 (Schaller).

Analysis of hydrohetaerolite

	1	2	3
Mn_2O_3	60. 44	61. 34	0. 393=1. 88
Fe_2O_3	. 77	. 78	
ZnO	33. 43	33. 93	. 416=2. 00
H_2O-	2. 47	3. 95	. 220=1. 05
H_2O+	1. 42		
SiO_2	1. 71	--------	
	100. 24	100. 00	

1. Type material from Sterling Hill. W. T. Schaller (Palache, 195), analyst.
2. Same analysis recomputed to 100 percent after omission of SiO_2.
3. Molecular ratio, computed from the analysis.

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. (See first column on this page.)

Hydrohetaerolite was found only at the Passaic mine, Sterling Hill, where it was abundant and was first recognized as a distinct mineral by Moore (114). 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 under hetaerolite on page 49.

PSILOMELANE

Hydrous manganese oxide. 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.

CARBONATES

CALCITE

$CaCO_3$. Hexagonal-rhombohedral

Forms.—$c(0001)$, $a(11\bar{2}0)$, $b(10\bar{1}0)$, $\alpha(44\bar{8}3)$, $\gamma(8.8.\overline{16}.3)$, $*a\cdot(10\bar{1}5)$, $b\cdot(3.0.\bar{3}.16)$, $\beta:(0.3.\bar{3}.16)$, $\delta\cdot(01\bar{1}2)$, $p\cdot(10\bar{1}1)$, $\phi\cdot(02\bar{2}1)$, $t:(21\bar{3}4)$, $A:(11.1.\overline{12}.10)$, $K:(21\bar{3}1)$, $Q:(19.13.\overline{32}.6)$, $S:(11.18.\overline{19}.3)$, $T:(43\bar{7}1)$, $V:(6.5.\overline{11}.1)$, $S:(8.7.\overline{15}.1)$, $*W:(18.4.\overline{22}.5)$. (Letters after Goldschmidt, Atlas, vol. 2.) The two forms marked with an asterisk (*) are new; their position angles are as follows.

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[4] From a note by Moore, appended to a specimen of hydrohetaerolite in the Roebling collection.

Position angles of new forms of calcite

Form	Measured		Computed		Number of faces
	φ	ρ	φ	ρ	
	° ′	° ′	° ′	° ′	
a·(10$\bar{1}$5)	30 00	10 52 11 7	30 00	11 9	2.
W: (18.4.$\overline{22}$.5)	20 12	75 58	20 10½	75 59	10 on 3 crystals.

Combinations on crystals of calcite

	Forms	Localities	Illustrations
1	*b*, δ·	Buckwheat mine	
2	*c*, *a*, *b*, δ·	do	
3	*c*, *a*, *b*, *p*·, δ·	do	Fig. 57.
4	*c*, *a*, *b*, *p*·, δ·, *k*:	do	
5	*c*, *a*, *b*, α, *p*·, φ·	Parker shaft	Fig. 58.
6	*c*, *a*, γ, δ·, *p*·	do	Fig. 59.
7	*a*, γ, *p* , *A*:, *K*:	do	
8	*a*, *b*, δ , *p* , φ , *S*:	do	
9	*c*, *b*, δ·, *p* , φ , *V*:, *a*	do	
10	*c*, *p* , *V*:, *b* , β		Gordon (223), fig. 7.
11	*p* , *V*:	With manganite; Sterling Hill	Fig. 60.
12	*a*, *p* , *Q*: *V*:, *W*:	do	Fig. 61.
13	*a*, *p* , *Q*:, *S*·, *V*:, *W*	do	
14	*a*, *b*, *p* , *K*:	With larsenite	
15	*k*:	Cavities of porous dolomite; Franklin	
16	*k*:, *t*:	do	
17	*p* , *T*:	do	
18	*b*, δ	In Kittatinny limestone; Franklin	
19	δ·, φ	do	
20	δ	do	

Habit.—Crystals of calcite are rare, and the mineral is generally coarse to fine granular or compact, with cleavage rhombohedrons as much as 6 inches thick, showing distinct striations due to pressure twinning. A parting parallel to the twinning plane is nearly as perfect as the cleavage. When freshly broken the mineral is gray or white or in manganiferous varieties generally pink. On exposure to sunlight the manganiferous calcite becomes at first yellowish brown and finally black.

Under the iron-arc spark the pure calcite shows no fluorescence, but the manganiferous varieties show various shades from vivid red to pale pink. Some material that is apparently calcite has a violet fluorescence, but the nature of the impurity is unknown.

In a recent paper Krieger (278a) has shown that the manganocalcite varies uniformly in specific gravity, refractive indices, and X-ray diffraction pattern with the chemical composition, increase of manganese causing increase of density and of both refractive indices.

Composition.—Much of the white Franklin limestone is essentially pure calcium carbonate. It shows, however, all gradations to dolomite, the amount of magnesium present not markedly affecting the physical appearance of the limestone. Many analyses have been published by Nason (141) and by Kümmel (190a), which are not here reproduced.

The gangue of the zinc ores is, however, commonly manganiferous, so that the waste dumps, when they have lain but a few months exposed to the weather, become superficially quite black through oxidation of the manganese. For such manganiferous calcite several names have been proposed—spartaite (Breithaupt, 73), manganocalcite and calcimangite (Shepard, 89), and roepperite (Kenngott, 103). The analyses listed below show that the composition is diverse, and only those specimens with relatively low manganese are shown here, others being classed as rhodochrosite. The cleavage angle of "spartaite", as recorded by Breithaupt, is 75°2½′. Material described by Levison (206) is in tough, hard, fibrous masses and in splinters as much as 6 inches long, with a specific gravity of 2.81.

Analyses of calcite

	1	2	3	4	5	6	7
$CaCO_3$	77. 94	79. 96	85. 57	50. 40	82. 23	63. 90	85. 96
$MnCO_3$	22. 35	11. 09	11. 55	43. 54	16. 57	17. 43	2. 98
$MgCO_3$	------	1. 94	2. 54	5. 69	------	11. 05	. 59
$FeCO_3$	------	. 60	------	. 76	. 50	. 30	------
$ZnCO_3$	------	. 58	------	------	------	. 32	2. 88
CaF_2	------	[a] 5. 35	------	------	------	------	------
H_2O	------	. 32	------	------	1. 00	------	------
Insoluble	------	------	------	. 08	. 20	7. 00	[b] 7. 70
	100. 29	99. 84	99. 66	100. 47	100. 50	100. 00	100. 11

[a] Estimated from deficiency of CO_2 for bases

[b] Including SiO_2 0.50, ZnO 1.86, Fe_2O_3 0.17, Al_2O_3 0.24, and Mn_2O_3 4.93 percent.

1. Spartaite-calcimangite, gangue of zincite. C. U. Shepard (89), analyst.
2. Spartaite, Sterling Hill. G. Jenzsch (71), analyst.
3. Spartaite, Sterling Hill. Richter, analyst, in Rammelsberg (71).
4. Manganesian dolomite. W. T. Roepper (99), analyst.
5. Crystalline calcite, Sterling Hill. Van Dyke, analyst, in Cook (96).
6. Manganocalcite, Franklin. W. G. Levison (206), analyst.
7. "Black calcite", Franklin. Jenkins and Bauer (243), analysts.

Occurrence.—Granular crystalline calcite is the sole gangue mineral of both zinc-ore deposits, is the principal constituent of the wall rocks and of the Franklin limestone as a whole, and is the chief material filling the secondary transverse veins in the Franklin ore body. It is in the veins that crystals are found, the few noteworthy occurrences being described below.

In veins in the Buckwheat mine containing, among other species, zincite and pyrochroite (see p. 39), calcite was found partly as poorly crystallized masses filling the vein, and partly as exquisite transparent crystals of slender prismatic habit, peculiar in the equal development of prisms of both orders. Combinations 1–4 and figure 57 illustrate this occurrence.

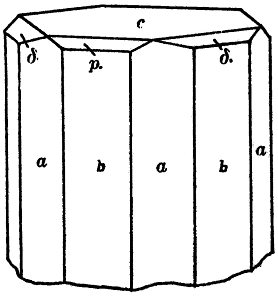

FIGURE 57

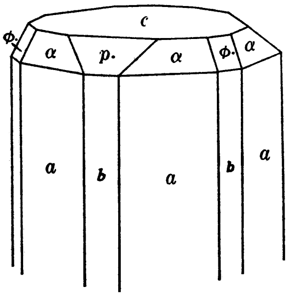

FIGURE 58

FIGURE 57.—Prismatic crystal of calcite showing the forms $c(0001)$, $a(11\bar{2}0)$, $b(10\bar{1}0)$, $p{\cdot}(10\bar{1}1)$, and $\delta{\cdot}(01\bar{1}2)$. Buckwheat mine.

FIGURE 58.—Prismatic crystal of calcite showing the forms $c(0001)$, $a(11\bar{2}0)$, $b(10\bar{1}0)$, $p{\cdot}(10\bar{1}1)$, $\alpha(44\bar{8}3)$, and $\phi(02\bar{2}1)$. Parker shaft.

Crystals of similar habit, with additional faces of the pyramids of the second order and rare scalenohedral forms, were found with the specimens of pyrochroite and hodgkinsonite from the Parker shaft. Some of them have the base replaced by flat positive rhombohedrons, of which the form $a{\cdot}(10\bar{1}5)$ may be regarded as certain, and a number of others of flatter slope are regarded as indicated. Combinations 5–11 and figures 58 and 59 illustrate these forms.

Gordon (222) has figured a crystal from Franklin showing the new forms $b{\cdot}(3.0.\bar{3}.16)$ and $\beta\colon(0.3.\bar{3}.16)$—very flat rhombohedrons. Crystals of calcite of the habit of combination 14 were abundant in the cavities containing larsenite.

A small specimen of manganite from Sterling Hill showed also brilliant crystals of calcite. They were in part simple scalenohedrons, as shown in figure 60, and in part more complex, with the new positive scalenohedron $W\colon(18.4.\overline{22}.5)$, as shown in figure 61.

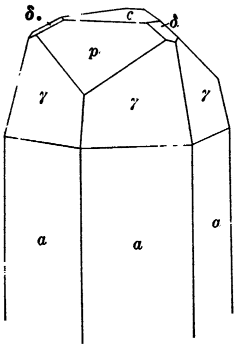

FIGURE 59

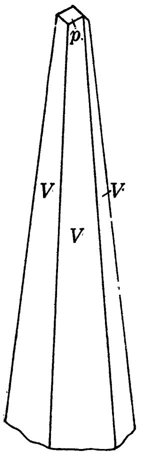

FIGURE 60

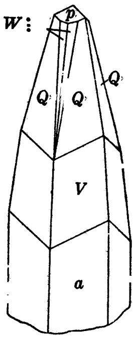

FIGURE 61

FIGURE 59.—Crystal of calcite showing the forms $c(0001)$, $a(11\bar{2}0)$, $p{\cdot}(10\bar{1}1)$, $\delta{\cdot}(01\bar{1}2)$ and $\gamma(8.8.16.3)$. Parker shaft.

FIGURE 60.—Very acute scalenohedral crystal of calcite showing the forms $p{\cdot}(10\bar{1}1)$ and $V(6.5.\overline{11}.1)$ Sterling Hill.

FIGURE 61.—Scalenohedral crystal of calcite showing the forms $p{\cdot}(10\bar{1}1)$, $a(11\bar{2}0)$, $V(6.5.\overline{11}.1)$, $Q(19.13.\overline{32}.6)$, and the new scalenohedron $W\colon(18.4.\overline{22}.5)$. Sterling Hill.

Scalenohedral crystals (combinations 15–17) were found in the porous dolomite of the Buckwheat mine and in the Hamburg and Parker mines. Rhombohedral crystals (combinations 18–20) were found in cavities in the Kittatinny limestone removed in building the foundations of the mill at Franklin.

DOLOMITE

$CaMg(CO_3)_2$. Hexagonal-rhombohedral

Crystals of dolomite are rare, and only simple unit rhombohedrons were seen. The mineral is found also in massive granular form.

The only well-defined occurrence of dolomite was in the Buckwheat mine at Franklin, where the stripping exposed a zone of gray dolomitic limestone, fine granular to compact and porous in places, which cut across the white limestone between the two legs of the ore body. Some cavities, several inches across, were lined with drusy rhombohedral crystals of white pearly dolomite. In the cavities and of later formation were calcite, quartz, albite, sphalerite, pyrite, millerite, hematite, and goethite, mostly well crystallized.

In many secondary veins in the ore body at Franklin are found rhombohedral carbonates that are more or less magnesian but that contain also, besides calcium, some manganese, iron, and zinc. Some of them may properly belong under dolomite, but in the absence of analyses they cannot be exactly defined.

SIDERITE

$FeCO_3$. Hexagonal-rhombohedral

Siderite is known only in massive form associated with the carbonates of the transverse veins at Franklin. A specimen of light-brown color and distinct rhombohedral cleavage had a specific gravity of 3.82 (Canfield) and met other characteristic tests for siderite. No analyses have been made of this mineral.

Some thin veins are lined with drusy crystalline coatings of a light-brown carbonate showing only the unit rhombohedron. This may be siderite, although again no analyses have been made to show its exact composition.

RHODOCHROSITE

$MnCO_3$. Hexagonal-rhombohedral

Habit.—Rhodochrosite forms rhombohedral crystals with curved faces, also drusy coatings and granular masses.

Composition.—Rhodochrosite generally contains more or less calcium, magnesium, zinc, and iron; hence no sharp distinction can be made between it and the other rhombohedral carbonates. The varieties rich in manganese tend to be of deeper pink color, and the name "manganocalcite" (see calcite) has been used for the manganiferous calcite containing less than 50 percent of manganese carbonate.

Analyses of rhodochrosite

	1		2
MnO	45.02	$MnCO_3$	74.99
CaO	11.28	$CaCO_3$	20.59
ZnO	2.32	$ZnCO_3$	.26
MgO	1.76	$MgCO_3$	3.80
FeO	.22	$FeCO_3$	.36
Fe_2O_3	.16		
SiO_2	.32		100.00
CO_2	38.92		
	100.00		

1. Bright-pink material, specific gravity 3.47, Franklin. P. E. Browning (138), analyst.
2. Same with the composition expressed as carbonates, after deducting ferric oxide, willemite equivalent to the silica found, and the excess of zinc oxide, presumably zincite.

Occurrence.—At Franklin rhodochrosite was fairly common at the openings on Mine Hill, chiefly in secondary veins in the ore body. The best crystallized specimens, associated with pyrochroite and radiate fibrous willemite, seem to have come from the Hamburg mine. In the Buckwheat mine rhodochrosite was abundant in veins and granular masses, the matrix of pale-green crystals of willemite. Crystallized druses from the Parker shaft were also seen.

Rhodochrosite was recorded from Sterling Hill by Canfield (136) but was not seen in authentic specimens and must be exceptional.

SMITHSONITE

$ZnCO_3$. Hexagonal-rhombohedral

Forms.—$m(10\bar{1}0)$, $f(02\bar{2}1)$, and $v(21\bar{3}1)$.

Physical properties.—Crystals of smithsonite are rare at Franklin, but some were described by the author (257) in 1928. They were in a fragment of coarse franklinite-willemite ore from the picking table at Franklin that contained a few solution cavities, some lined with needles of calamine and one with pure-white crystals of smithsonite. The crystals are of typical calcite habit, as shown in figure 62. The scalenohedron is dominant, with small faces of the prism and the rhombohedron. The faces are brilliant and, unlike most crystals of smithsonite, gave excellent angle readings, agreeing perfectly with those computed from the accepted elements based on the cleavage angle. The refractive indices are $\omega=1.850$, $\epsilon=1.625$, and the specific gravity is 4.43. Although not analyzed, the crystals are almost certainly practically pure zinc carbonate.

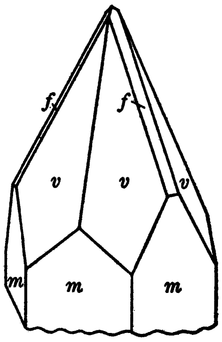

FIGURE 62.—End of prismatic crystal of smithsonite showing the forms $m(10\bar{1}0)$, $f(02\bar{2}1)$, and $v(21\bar{3}1)$. Franklin.

Occurrence.—Smithsonite was observed very early at both Franklin and Sterling Hill as an earthy white film on the fracture surfaces of zincite, the result of surface carbonatization. At Franklin, however, it is more abundant in secondary transverse veins associated with other carbonates and willemite, quartz, and sphalerite. Probably no such material is pure zinc carbonate, as all specimens tested show the presence of some manganese, calcium, and magnesium. No analyses of carbonates rich in zinc have been made at Franklin.

The limestone on the west side of the zinc-ore body, near the Trotter shaft, was cut by a vein about a foot thick, consisting almost wholly of massive smithsonite, together with a little hydrozincite and calamine and much limonite. Traces of sphalerite and pyrite were also visible, affording proof that there, at least, the smithsonite was formed by the oxidation of zinc sulphide.

At Sterling Hill more or less smithsonite was found in the calamine deposit, partly earthy, partly in stalactitic masses. Rarely these are translucent and pale blue.

ARAGONITE

CaCO$_3$. Orthorhombic

Aragonite forms needlelike crystals and white fibrous incrustations. It was found rarely as a secondary mineral in cross veins and other openings in the ore at Franklin. One specimen from the Buckwheat mine was seen in which distinct crystals of the slender, tapering type, familiar from Frizington, England, coat the surface of a seam in zincite ore. In others the mineral forms a coating of columnar fibrous texture.

CERUSITE

PbCO$_3$. Orthorhombic

Forms.—*b*(010), *m*(110), *r*(130), *y*(102), *π*(302), *x*(012), *k*(011), *q*(023), *j*(053), *i*(021), *v*(031), *z*(041), *n*(051), *o*(112), *p*(111), *s*(121), and *w*(211). The form *j*(053) is new; *ρ* measured 50°41′ (computed 50°18′).

Combinations on crystals of cerusite

	Forms	Illustrations
1	*b, m, r, y, π, x, k, j, i, v, z, n, o, p, s*	Fig. 63.
2	*b, m, y, x, k, i, o, p.* Twin on (110)	Fig. 64.
3	*b, m, y, x, q, k, i, o, p, w.* Twin on (110)	Fig. 65.

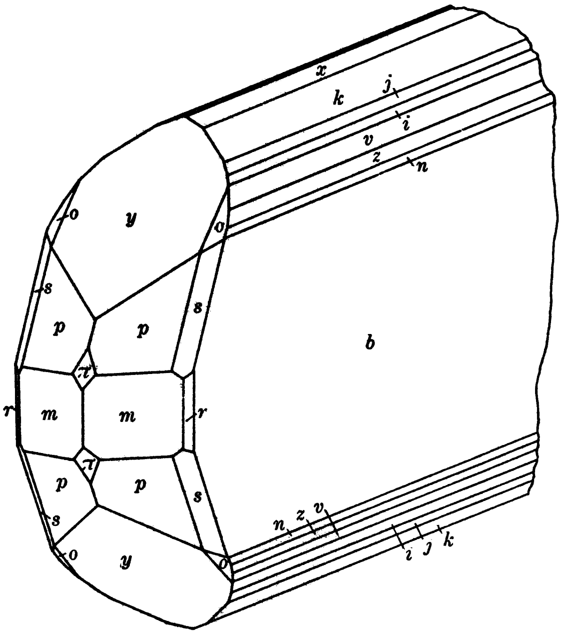

FIGURE 63.—Crystal of cerusite. Prismatic parallel to the brachyaxis, showing the forms *b*(010), *x*(012), *k*(011), *j*(053), *i*(021), *v*(031), *z*(041), *n*(051), *y*(102), *π*(302), *m*(110), *r*(130), *p*(111), *s*(121), and *o*(112). Sterling Hill.

Occurrence.—Cerusite forms clear white or gray crystals encrusting galena. It was found as a scarce alteration product of galena at Sterling Hill. The measured crystals, collected there in 1905, are prismatic parallel to the brachyaxis (fig. 63), with a richly developed zone of brachydomes. Others are twinned in the ordinary cerusite habits.

MALACHITE

CuCO$_3$.Cu(OH)$_2$. Monoclinic

Green stains or coatings of fibrous malachite, formed by the oxidation of chalcopyrite, are rarities at both Franklin and Sterling Hill. Reports of silver silicate at Sterling Hill made by several observers have not been confirmed and are probably to be assigned to malachite.

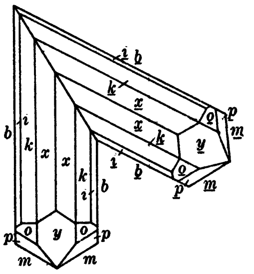

FIGURE 64

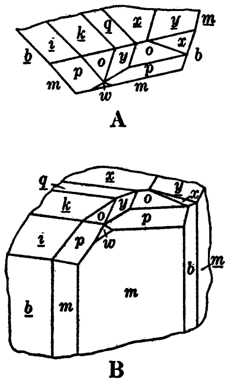

FIGURE 65

FIGURE 64.—Plan of a crystal of cerusite like that of figure 63, twinned on the prism (110). Sterling Hill.

FIGURE 65.—Fragment of a complex crystal of cerusite twinned on the prism (110). A, Plan; B, clinographic projection.

AZURITE

2CuCO$_3$.Cu(OH)$_2$. Monoclinic

Forms.—*c*(001), *b*(010), *a*(100), *m*(110), *w*(120), *l*(023), *f.*(034), *f*(011), *p*(021), *σ*(101), *I*($\bar{2}$05), *θ*($\bar{1}$01), *η*($\bar{3}$02), Ψ($\bar{3}$01), *h*(221), *P*(223), *R*($\bar{2}$41), *d*($\bar{2}$43), and *e*($\bar{2}$45).[5]

Combinations on crystals of azurite

	Forms	Locality	Illustrations
1	*c, a, m, p, θ, ψ, d*	Franklin	Fig. 66.
2	*c, a, m, l, w, f, σ, I, θ, η, h, R, e*	do	Fig. 67.
3	*c, a, m, l, f., p, σ, η, h, P, R, e*	Sterling Hill	Fig. 68.
4	*c, b, a, m, p, σ, θ*	do	Fig. 69.

Occurrence.—Azurite is rare at both Franklin and Sterling Hill. Although included in the earliest list of Franklin minerals, the first published description of it is that of the author (257) in 1928. The crystals were in thoroughly oxidized vein material found in the mine in pillar 720 on the 200-foot level. The small crystals, which line cavities in limonitic calcite along with malachite and fine rosettes of aurichalcite, are rich in forms. The crystals are elongated parallel to the orthoaxis with *θ*($\bar{1}$01) dominant in the orthodome zone, and they bear the forms of combinations 1 and 2, shown in figures 66 and 67.

At Sterling Hill specimens of massive, coarse-granular franklinite ore were found intersected by veins of calcite and azurite that appear to have replaced the ore. As a whole azurite followed calcite, but the deposition of the two overlapped in part. The veins are

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[5] Letters used are those of Stecher, Paul, Neues Jahrb., Beilage-Band 59, Abt. A, pp. 159-204, 1929.

generally granular, but a few cavities in the franklinite, representing the complete solution of large grains, are lined with brilliant crystals of azurite. Figure 68 illustrates a small doubly terminated crystal with ideal development of the forms of combination 2. The form shown in the drawing as (1̄.3.24) is an etch face found symmetrically developed on most of the crystals. The form f:(034), not shown in the figure, was present with two faces. As this rare form requires confirmation its angle measurements are appended:

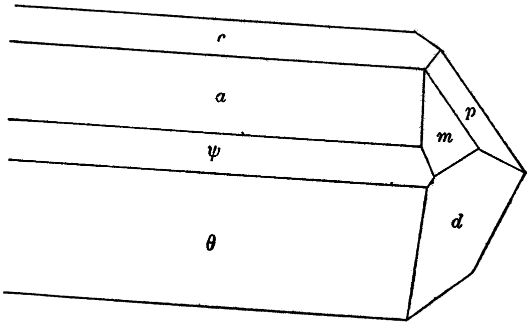


FIGURE 66.—Clinographic projection, rotated forward to show the base, of a crystal of azurite, prismatic parallel to the orthoaxis, showing the form *c*(001), *a*(100), *p*(021), *ψ*(101), *θ*(3̄01), *m*(110), and *d*(2̄43). Franklin.

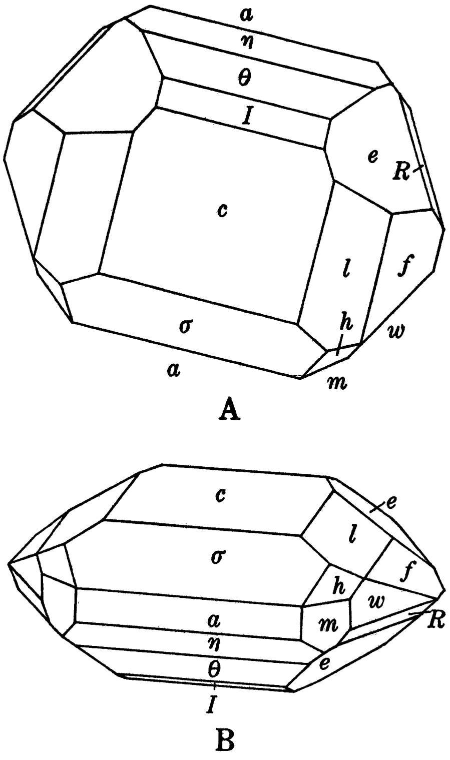


FIGURE 67.—Crystal of azurite tabular parallel to the base, showing the forms *c*(001), *a*(100), *l*(023), *f*(011), *σ*(101), *I*(2̄05), *θ*(1̄01), *η*(3̄02), *m*(110), *w*(120), *h* (221) *R* (2̄41), and *e* (2̄45) Franklin. A, Plan, B, clinographic projection.

Position angles of (034) with (010) as pole

	φ		ρ	
	°	′	°	′
Computed	87	35	56	28
Measured	88	48	55	38
Do	86	58	56	55

Figure 69 illustrates the habit of some paper-thin plates of azurite, flattened parallel to the base, with the forms of combination 3, the relative thickness of the crystal having been exaggerated in order to show the forms that are developed only as small faces.

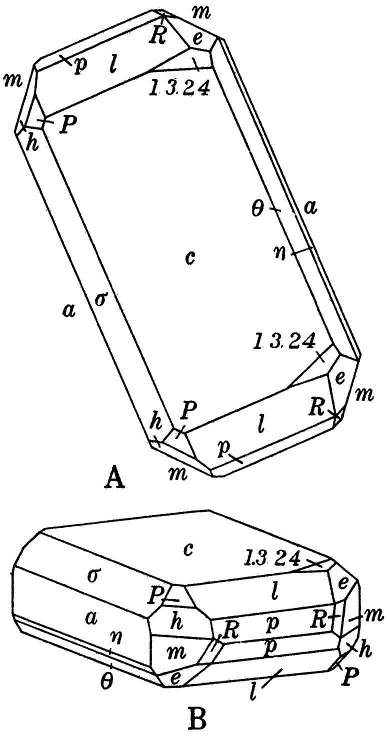


FIGURE 68.—Crystal of azurite showing the forms *c*(001), *a*(100), *m*(110), *p*(021), *l*(023), *σ*(101), *θ*(101), *η*(3̄02), *P*(223), *h*(221), *R*(2̄41), *e*(2̄45), and (1̄.3.24) The figure is drawn with the orthoaxis in front instead of in the customary position. Sterling Hill. A, Plan, B, clinographic projection.

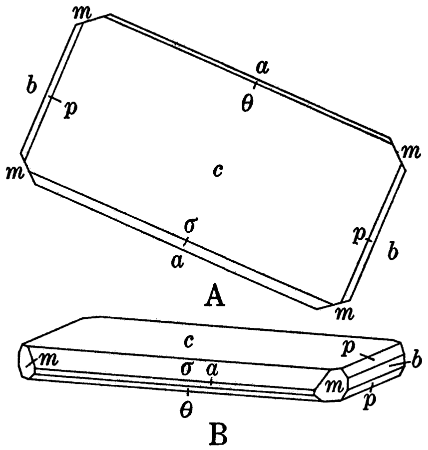


FIGURE 69.—Crystal of azurite thin-tabular parallel to the base, showing the forms *c*(001), *b*(010), *a*(100), *m*(110), *p*(021), *σ*(101), and *θ*(101). Sterling Hill A, Plan; B, clinographic projection.

AURICHALCITE

$2(Zn,Cu)CO_3.3(Zn,Cu)(OH)_2$. Orthorhombic?

Aurichalcite forms rosettes in a friable limestone and a thin coating of acicular crystals on limestone. Its color is pale bluish green. It has been found, associated with limonite and malachite, in numerous specimens from Franklin, apparently parts of an originally single mass, with what appear to be remains of franklinite crystals. There is in the Hancock collection a sinlgle specimen of the mineral from Sterling Hill, showing rosettes on limestone with black dendrites of manganese dioxide.

HYDROZINCITE

$ZnCO_3.Zn(OH)_2$

Hydrozincite forms flaky incrustations of pale yellowish-white color and pearly luster. It has been found only as an alteration product of sphalerite in a cross vein near the shaft house of the Trotter mine at Franklin. The vein—sphalerite and pyrite in a calcite gangue—is reduced to a cavernous mass of calcite, the openings in which are partly filled with ocherous smithsonite. In some of the cavities, however, hydrozincite takes the place of the normal carbonate. Although it might be expected, this mineral was not detected on any of the many specimens of calamine from Sterling Hill that were examined.

LOSEYITE

$2(Mn,Zn,Mg)CO_3.5(Mn,Zn,Mg)(OH)_2$. Monoclinic

Forms.—*c*(001), *d*(101), *e*(011), *s*(130), $p(\bar{1}36)$, and $r(\bar{7}.14.2)$.

Habit.—Loseyite is found as small, lath-shaped, bluish-white crystals, elongated in the direction of the orthoaxis, more or less loosely grouped in radiate bundles in the cavities of a thin vein composed chiefly of altered pyrochroite and sussexite.

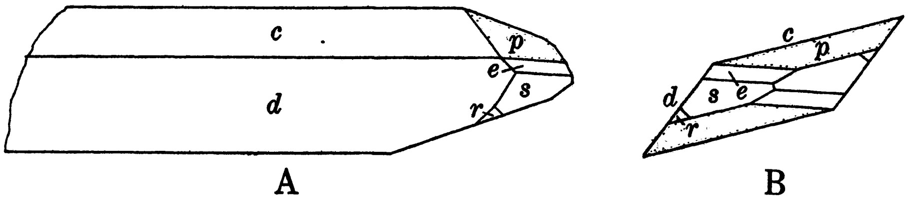


FIGURE 70.—Crystal of loseyite prismatic parallel to the orthoaxis, showing the forms *c*(001), *e*(011), *d*(101), *s*(130), *p*(136), and *r*(7.14.2). A, Projection on the vertical plane through the orthoaxis, the crystal being rotated forward to show the base, B, projection on the clinopinacoid

Crystallography.—No crystals of loseyite were found that would yield really satisfactory angle measurements, but some very minute lath-shaped crystals were used for approximate data. Several of them, ranging in length from 0.008 to 0.02 inch, were measured, and the angles finally used were those of the best two of these crystals.

Figure 70 illustrates the habit of loseyite. The orthodome zone is striated parallel to the direction of elongation. The form $p(\bar{1}36)$ is the largest terminal form, but poor images were reflected by its faces because they are etched. The prism *s*(130) is small but gives brilliant reflections.

Physical properties.—The optical properties are biaxial and positive; $2V$ is 64°; $Y=b$; $\alpha=1.637$, $\beta=1.648$, $\gamma=1.676$; r>v (weak). The specific gravity as determined is 3.27 and as computed according to the rule of Gladstone and Dale is 3.25, an indication that the chemical formula adopted is probably correct.

Composition.—Loseyite is a hydrous carbonate of manganese and zinc in about equal molecular proportions, with a slight amount of magnesium. The formula adopted was deduced from the following analysis, with a molecular ratio of MnO:ZnO:MgO of 5:4:1.

Analysis of loseyite

	1	2	3
MnO	34. 94	0. 493 } 0. 990 = 7×0. 141	36. 40
FeO	. 64	. 009	-----
ZnO	32. 77	. 403	33. 38
MgO	3. 42	. 085	4. 14
CO_2	12. 59	. 286 = 2×0. 143	12. 90
H_2O	13. 83	. 768 = 5×0. 154	13. 18
SiO_2 (insoluble)	. 16	. 003	-------
Mn_2O_3	1. 03	. 007	-------
	99. 38		100. 00

1. Loseyite, Franklin. L. H. Bauer (266), analyst.
2. Molecular ratio of 1, omitting silica and manganic oxide.
3. Composition computed from the formula adopted.

Occurrence.—Loseyite is found in cavities in a thin vein composed chiefly of altered pyrochroite and sussexite and associated with a few crystals of calcite and a coating of minute hairlike needles that were identified as chlorophoenicite by optical tests. The mineral was discovered in the examination of the material in the Stanton collection. Mr. Stanton, who had collected the specimen in some now inaccessible part of the old mine workings, had made no record of the find, so the exact location is unknown. The mineral is named for S. R. Losey, who had for many years been an ardent collector of the local minerals. It is fully described in the paper by Bauer and Berman (266), who studied and named it in 1929.

SILICATES

FELDSPAR GROUP

HYALOPHANE

$(K_2Ba)Al_2Si_4O_{12}$. Monoclinic

Dark-red coarse-granular hyalophane, associated with black manganese-biotite and yellow garnet, was found in the old dump of the Parker shaft. In thin section it proved to be monoclinic and negative, with a small extinction angle; $2V$ large; and the refractive index β about 1.54. The specific gravity is 2.90 and the hardness is 6.

The material is very impure, the color being due to grains of hancockite and to a network of microscopic veinlets of an alteration product, apparently bementite. Analysis 1 below was made of this mixed material and in its interpretation the assumption was made that the sulphur was contained in barite, the lead in hancockite, and the manganese in bementite. After deducting 2.89 percent of barite, 5.48 percent of hancockite, 15.71 percent of bementite, and 1 percent of excess water, the remaining 75 percent, constituting the feldspar, was recomputed to 100 percent, as shown in column 2, and the molecular ratios computed therefrom are given in column 3.

The result approximates the composition of a sodium-rich hyalophane but is deficient in silica. The optical data are thus supported by the analysis. An attempt was made to purify some of the material, finely ground, in a heavy solution, but it was futile, as even the finest particles of the powder were penetrated by the network of alteration products. In view of the abundance of bementite the computed amount of impurity, 25 percent, does not seem too large.

The material containing the hyalophane was discovered by the chemists of the New Jersey Zinc Co., who also found other impure feldspars containing barium, the composition of which is given in columns 4 and 5 of the table. The chemists also supplied material for the optical tests made by Berman.

Analyses of barium feldspars

	1	2	3		4	5
SiO_2	45. 40	49. 51	0. 824	0. 824	62. 33	52. 34
Al_2O_3	20. 82	25. 48	. 250	. 250	20. 94	19. 35
Fe_2O_3	------	------	------	------	1. 20	------
FeO	1. 54	------	------	------	------	. 77
MnO	2. 67	------	------	------	. 97	. 91
MgO	. 76	------	------	------	1. 25	. 54
CaO	2. 70	------	------	------	. 46	6. 24
Na_2O	2. 69	3. 56	. 057		9. 06	1. 02
K_2O	7. 54	9. 98	. 106		2. 80	10. 43
ZnO	1. 36	------			------	1. 00
PbO	1. 15	------		. 237	------	------
SO_3	. 99	------			. 37	1. 02
H_2O	2. 35	------			------	. 16
BaO	10. 58	11. 47	. 074		1. 34	6. 05
	100. 55	100. 00	------	------	100. 72	99. 83

1. Hyalophane, dump of Parker shaft, Franklin. Bauer and Jenkins (245), analysts.
2. Same analysis recomputed to 100 percent after deducting 25.08 percent of impurities.
3. Molecular ratio computed from 2.
4. Anorthoclase, same locality. Bauer and Jenkins (243), analysts.
5. Grayish-white feldspar, same locality. Bauer and Jenkins (243), analysts.

The material of no. 4 is reported by Berman to be biaxial and negative; $2V$ is about 80°; $\alpha=1.522$, $\beta=1.525$, $\gamma=1.529$. It shows polysynthetic twinning with a small extinction angle and appears to be anorthoclase with a small amount of barium.

The material of no. 5 is reported by Berman to be biaxial and negative; $2V$ is large; $\alpha=1.525$, $\beta=1.528$, $\gamma=1.530$. This seems to be nearer hyalophane, but the barium content and the indices of refraction are too low for that species.

It is interesting to note that the discovery of hyalophane adds another mineral to the list of those common to the Franklin district and to the manganese mines of Långban and Jakobsberg, Sweden. The Swedish hyalophane is also a granular red feldspar and is associated with manganese-epidote.

MICROCLINE

$KAlSi_3O_8$. Triclinic

Forms.—$c(001)$, $b(010)$, $m(110)$, $M(1\bar{1}0)$, $f(130)$, $z(1\bar{3}0)$, $x(\bar{1}01)$, $y(\bar{2}01)$, $e(021)$, $n(0\bar{2}1)$, $p(\bar{1}11)$, and $o(\bar{1}\bar{1}1)$.

Combinations on crystals of microcline

	Forms	Illustrations
1	*c, b, m, M, x, y, p, o*	Fig. 71.
2	*c, b, m, M, f, z, y, e, n, p, o*	Fig. 72.

Occurrence.—Microcline is a normal constituent of the local pegmatites, in which, especially at contacts with limestone, many crystals of microcline are well formed and some are more than a foot long. Characteristic combinations are shown in the figures, but the habit has a wide variety of detail. The color ranges from brilliant green in the amazon stone to muddy yellowish green and yellowish white. The finest green crystals were found during the sinking of the Trotter shaft, where microcline was abundant. Large and well-formed but poorly colored crystals were abundant at Sterling Hill also.

Alteration.—Feldspar pseudomorphs from Mine Hill were described by Roepper (116) as slightly altered crystals of anorthite. They were found, with crystals of hornblende and titanite, in limestone and were from an eighth of an inch to 3 inches across. They display typical feldspar habits and are tabular parallel to the base. Their surfaces are deeply pitted, and some are coated with a drusy crystalline layer appearing like prehnite, but others are smooth and of talcose appearance. Traces of feldspar cleavage are still visible. Crystals from this locality were seen in the Hancock collection and had all the external appearance of microcline from the district. They are so rough

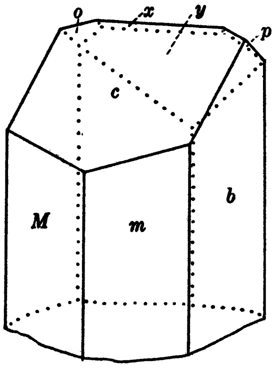


FIGURE 71

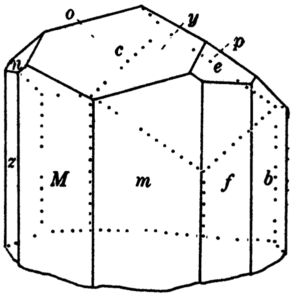


FIGURE 72

FIGURE 71.—Crystal of microcline showing the forms $c(001)$, $b(010)$, $m(110)$ $M(1\bar{1}0)$, $x(\bar{1}01)$, $y(\bar{2}01)$, $p(\bar{1}11)$, and $o(\bar{1}\bar{1}1)$. Trotter mine.

FIGURE 72.—Crystal of microcline showing the forms $c(001)$, $b(010)$, $m(110)$, $M(1\bar{1}0)$, $f(130)$, $z(\bar{1}30)$, $y(\bar{2}01)$, $e(021)$, $n(0\bar{2}1)$, $p(\bar{1}11)$, and $o(\bar{1}\bar{1}1)$. Trotter mine.

that contact measurements, such as Roepper gives to prove their derivation from anorthite, have little weight.

In thin section this material is heterogeneous, showing a mosaic made up of zoisite, epidote, talc, and possibly feldspar, and minute crystals of apatite and titanite. The crystalline coating resembling prehnite could not be identified in the section. The composition and specific gravity given by Roepper approximate zoisite more nearly than anorthite, and the crystals are probably replacement pseudomorphs after microcline, consisting largely of zoisite.

ALBITE

$NaAlSi_3O_8$. Triclinic

Forms.—$c(001)$, $b(010)$, $m(110)$, $M(1\bar{1}0)$, $f(130)$, $z(1\bar{3}0)$, $x(\bar{1}01)$, $r(\bar{4}03)$, $y(\bar{2}01)$, $\gamma(\bar{1}12)$, and $p(\bar{1}11)$.

Occurrence.—Albite, in sharp glassy-white crystals twinned on the albite law and showing the forms listed, was found sparsely in cavities of the gray porous dolomite in the Buckwheat mine at Franklin, with calcite, quartz, and spalerite. The only specimens seen were in the collection of Mr. Shuster.

Massive white albite was recognized by Larsen and Shannon (220), as the chief gangue of bustamite crystals from Franklin. Although this albite was said to present some unusual features, no detailed statement of its character has been published.

ANORTHITE

$CaAl_2Si_2O_8$. Triclinic

Forms.—$c(001)$, $b(010)$, $m(110)$, $M(1\bar{1}0)$, $y(\bar{2}01)$, $p(\bar{1}11)$, and $o(\bar{1}\bar{1}1)$.

Combinations of crystals of anorthite

	Forms	Illustrations
1	*c, b, n, M*	Fig. 73 (Warren).
2	*c, b, m, M, y, p, o*	Fig. 74 (Warren).

Habit.—Gray tabular crystals of anorthite, not more than 1.25 inches in greatest diameter, were found embedded in white limestone. Their edges and angles are rounded and their faces are dull, yielding poor measurements. They have striations on the base caused by pericline twinning, and they contain included grains of calcite and graphite and droplets of water.

Optical properties.—The average extinction angle on the base is −37°; $2V$ near 90°; $r>v$ (perceptible); $\alpha = 1.1573$, $\beta = 1.579$, $\gamma = 1.585$.

Composition.—An analysis of some of the crystals by Warren showed a molecular ratio of alumina to lime to silica almost exactly that demanded by theory—1 : 1 : 2. Hence the mineral is unusually pure anorthite with but a trace of soda.

Occurrence.—The anorthite crystals were discovered by E. P. Hancock and were described by Warren (186), from whose paper the facts and data given above were taken. They were found in limestone of the Fowler quarry south of Franklin, near the contact of a pegmatite dike.

Analysis of anorthite

	1	2	3
SiO_2	40.16	43.04	0.706
Al_2O_3	34.89	37.39	.367
CaO	18.26	19.57	.349
Na_2O	Trace	--------	--------
$CaCO_3$	5.30	--------	--------
H_2O	1.69	--------	--------
C (graphite)	.18	--------	--------
	100.48	100.00	--------

1. Anorthite, Franklin. C. H. Warren (186), analyst.
2. Same, recomputed to 100 percent after deducting unessential constituents.
3. Molecular ratio computed from 2.

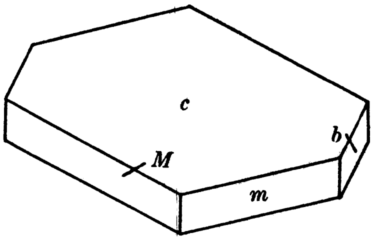


FIGURE 73.—Crystal of anorthite tabular to the base, showing the forms $c(001)$, $b(010)$, $m(110)$, and $M(1\bar{1}0)$. Fowler quarry.

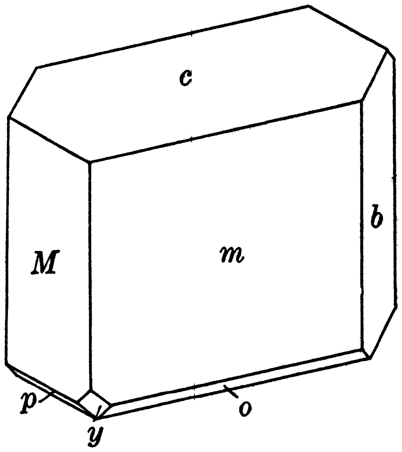


FIGURE 74.—Prismatic crystal of anorthite showing the forms $c(001)$, $b(010)$, $m(110)$, $M(1\bar{1}0)$, $y(\bar{2}01)$, $p(\bar{1}11)$, and $o(\bar{1}\bar{1}1)$. Fowler quarry.

PYROXENE GROUP

PYROXENE

Monoclinic

Varieties.—The following varieties of pyroxene have been found in the district:

Diopside	$CaMgSi_2O_6$.
Schefferite	$Ca(Mg,Fe,Mn)Si_2O_6$.
Zinc schefferite	$Ca(Mg,Mn,Zn)Si_2O_6$.
Jeffersonite	$Ca(Mg,Fe,Mn,Zn)Si_2O_6$.
Leucaugite	$Ca(Mg,Fe,Al)(Al,Si)_2O_6$.

Forms.—$a(100)$, $b(010)$, $c(001)$, $m(110)$, $y(101)$, $p(\bar{1}01)$, $G(\bar{2}01)$, $e(011)$, $z(021)$, $u(111)$, $s(\bar{1}11)$, $o(\bar{2}21)$, and $R(\bar{1}32)$.

Combinations on crystals of pyroxene

	Forms	Varieties	Illustrations	Locality
1	*b, c, m, u, s* (pseudomorph)	Diopside		Sterling Hill.
2	*a, b, c, m, p, s, o*	Schefferite	Fig. 75	Do.
3	*a, b, c, m, p, z, u, s*	do	Fig. 76	Do.
4	*a, b, c, m, p, u, s*	do		Do.
5	*a, b, m, s*	Jeffersonite	Fig. 77	Do
6	*a, b, m, p, s;* twin	do	Fig. 78	Do.
7	*a, b, m, p, z, s, o*	do	Fig. 79	Do
8	*a, b, c, m*	Leucaugite	Fig. 82	Do
9	*a, b, c, m, p, s, o;* twin	do	Fig. 83	Do.
10	*a, b, c, m, p, u, s, o*	do		Do
11	*a, b, c, m, p, e, u, s, o*	do	Fig. 84	Do
12	*a, b, m, p, u, s*	do	Fig. 80	Franklin.
13	*a, b, c, m*	do		Balls Hill.
14	*a, b, c, m, s*	do	Fig. 81	Do.
15	*a, b, m, y, G, R*	Pyroxene(?)	Fig. 85	Sterling Hill.

Composition.—The following analyses show the composition of the varieties of pyroxene listed:

Analyses of pyroxene

	1	2	3	4	5	6	7
SiO_2	52. 06	49. 80	51. 20	52. 86	51. 70	45. 95	49. 03
CaO	26. 30	21. 07	21. 09	24. 48	23. 68	21. 55	19. 88
MgO	15. 56	12. 35	12. 70	13. 24	12. 57	3. 61	5. 81
MnO	4. 57	9. 69	9. 96	5. 31	7. 43	10. 20	7. 91
ZnO	[a]Trace.	Trace.		3. 38	3. 31	10. 15	7. 14
FeO	1. 41	1. 61	1. 65			8. 91	3. 95
Al_2O_3		. 26	. 27	1. 08	. 36	. 85	. 86
Fe_2O_3		1. 46	1. 50		. 37		4. 22
H_2O+		1. 31	1. 35	. 45	. 65	. 35	. 70
H_2O-		1. 55					. 60
Na_2O		. 09	. 09		. 12		
CO_2		. 43					
F		. 32	. 32				
	99. 90	99. 94	100. 13	100. 80	100. 19	101. 57	100. 10
$O=F_2$		. 13	. 13				
		99. 81	100. 00				

[a] Zinc present as willemite.

1. Diopside, Franklin. Jenkins and Bauer (243), analysts.
2. Schefferite, Sterling Hill. W. T. Schaller (195), analyst.
3. Same recomputed to 100 percent after deducting $CaCO_3$ equivalent to CO_2.
4. Zinc schefferite, Franklin. J. E. Wolff (185), analyst
5. Zinc schefferite, Franklin, specific gravity 3.39. W. F. Hillebrand (183), analyst
6. Jeffersonite, Franklin, specific gravity 3.63. F. Pisani (107), analyst.
7. Jeffersonite, Franklin, specific gravity 3.55. George Steiger (195), analyst.

DIOPSIDE

Character.—The first well-established evidence of diopside at Franklin is furnished by analysis 1, above, made by L. H. Bauer, of the New Jersey Zinc Co. The material, which is associated with franklinite, is known locally as "white schefferite" and yields a ratio near that of diopside with a little manganese in place of some of the magnesium. The physical properties of this material, as determined by Berman, are as follows: It has a basal parting and shows polysynthetic twinning on the base. It is colorless and nonpleochroic; optically biaxial and positive; $2V=60° \pm 1°$; $r>v$ (weak); $Z \wedge c=37° \pm 1°$; $Y=b$; $\alpha=1.673$, $\beta=1.680$, and $\gamma=1.700$, all ± 0.003.

History.—Diopside and some of its subvarieties are named in all the older lists of Franklin minerals, and many specimens so labeled were seen in the older collections. On careful examination all proved to be either leucaugite, tremolite, or edenite. A specimen from Sterling Hill, in the Roebling collection, proved, however, to be a pseudomorph of tremolite after a pyroxene of diopside habit, and the original may well have been diopside.

Pyrallolite, which was listed by Robinson (22) and by Alger (39), is a talcose pseudomorph after pyroxene.

SCHEFFERITE

Habit.—Schefferite is found as isolated crystals in limestone, doubly terminated and sharply formed but with dull faces, the largest 2.3 inches in diameter. It is grayish brown, glassy, and transparent. The basal parting is distinct, and the cleavages on the prism and the clinopinacoid are equally perfect. The habit of the crystals is shown in figures 75 and 76.

Optical properties.—Schefferite is optically biaxial and positive. $2V=60° \pm$; $r>v$ (weak); $Z \wedge c=43°$; $\alpha=1.690$, $\beta=1.699$, $\gamma=1.721$, all ± 0.003 (Berman).

Occurrence.—The crystals were found, with dodecahedral crystals of franklinite, in coarse limestone at Sterling Hill. They were not abundant, and the author is indebted to Mr. T. Lang, the finder, for material for the analysis (no. 2), which shows that the mineral is near zinc schefferite, of which it was at first thought to be the crystallized form. It contains no zinc, however, and a rather large content of manganese, which brings it close in composition to the typical schefferite of Sweden.

ZINC SCHEFFERITE

Habit.—Zinc schefferite forms coarse granular or foliate masses, mixed with willemite and franklinite. A basal parting, due to lamellar twinning parallel to the base, is so perfect as to give the mineral a foliated appearance strongly suggesting feldspar, and there is also a poor parting parallel to the orthopinacoid. The cleavage is good parallel to the prism and in traces parallel to the clinopinacoid. The hardness is 5.5, and the specific gravity is 3.3 to 3.39. The color ranges from white (very rarely) to light brown and rich dark brown. The optic axis is approximately normal to the base. $Bx_a \wedge c' = 4°35'$ in obtuse angle. The indices are $\alpha = 1.676 \pm 0.0008$, $\beta = 1.683 \pm 0.0006$, $\gamma = 1.705 \pm 0.0008$, for sodium light. $2V = 60°0'$; r > v.

Composition.—Analyses 4 and 5 (see p. 62) show that the mineral is close in composition to jeffersonite, from which it differs chiefly in the practical absence of iron and in the greater amounts of calcium and magnesium and less amounts of manganese and zinc.

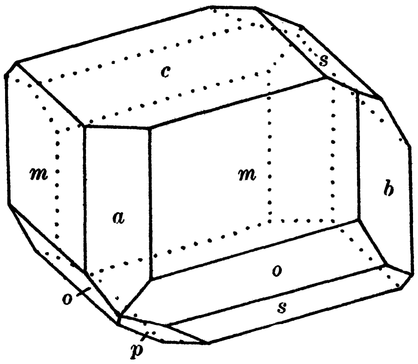


FIGURE 75.—Crystal of schefferite showing the forms $c(001)$, $b(010)$, $a(100)$, $m(110)$, $p(\bar{1}01)$, $s(\bar{1}11)$, and $o(\bar{2}21)$ Sterling Hill.

Occurrence.—At Franklin zinc schefferite was abundant in massive ore in parts of the Parker shaft workings. It was first described by Wolff (185), from whose paper the data given above were taken. The same material had previously been analyzed by Hillebrand (183), who, however, had not separated the mineral from jeffersonite.

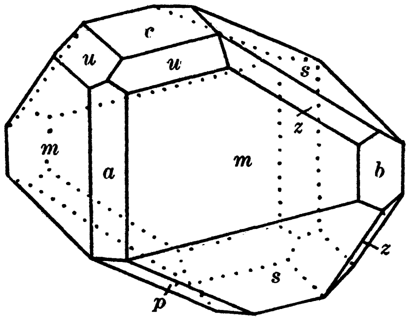


FIGURE 76.—Crystal of schefferite showing the forms $c(001)$, $b(010)$, $a(100)$, $m(110)$, $z(021)$, $p(\bar{1}01)$, $u(111)$, and $s(\bar{1}11)$. Sterling Hill.

With the development of mining at Sterling Hill on a large scale and the operation of a separate mill, zinc schefferite has been found abundantly in the ore there. As it is nonmagnetic it comes out in milling with the willemite.

JEFFERSONITE

Habit.—Jeffersonite is found in large crystals of simple habit, some more than 12 inches long and many doubly terminated. It occurs also in granular and platy masses. Contact twins on the orthopinacoid are not rare, and some lamellar twins on that plane give a good parting. Lamellar twinning on the base with perfect parting is the rule. There is a poor cleavage parallel to the prism and in traces parallel to the clinopinacoid. The hardness is 5.5, and the specific gravity is 3.55 to 3.63. The color is dark olive-green to brown and on weathered surfaces is gray to chocolate-brown and black. The mineral is translucent and in thin section is yellowish.

Optical properties.—The jeffersonite of analysis no. 7 is optically biaxial and positive; $2V = 74°$ (on Fedorof stage); $Z \wedge c = 55°$; r < v (easily perceptible); an optic axis emerges from the basal parting. $\alpha = 1.713$, $\beta = 1.722$, $\gamma = 1.745$, all ± 0.003. Pleochroism: X and Y = olive-green, Z = brownish-green (Berman).

Composition.—Analyses 6 and 7 (see p. 62) show the composition of a pyroxene containing manganese, zinc, and iron in different proportions in addition to calcium and a little magnesium. Jeffersonite is distinguished from schefferite by the presence of zinc and of more than traces of iron.

Occurrence.—Jeffersonite is abundant, both in the pegmatite and in the contact deposits in the limestone.

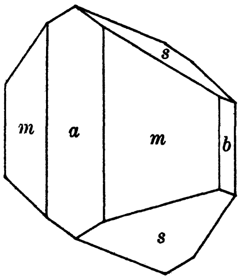


FIGURE 77

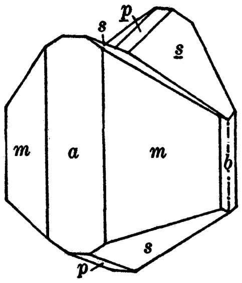


FIGURE 78

FIGURE 77.—Crystal of jeffersonite showing the forms $b(010)$, $a(100)$, $m(110)$, and $s(\bar{1}11)$ Sterling Hill.

FIGURE 78.—Crystal of jeffersonite twinned on the orthopinacoid, showing the forms of figure 77 Sterling Hill.

At Franklin it was found chiefly in granular form as the principal dark mineral of the pegmatite dikes at the Trotter mine and at the Parker shaft. It was also abundant in limestone in those mines, near pegmatite contacts, either in coarse granular masses or in rude crystals isolated in the limestone, commonly with garnet, rhodonite, microcline, franklinite, and gahnite. The striking characteristics of jeffersonite are its dark-green color, its vitreous to greasy luster, and its brilliant basal parting.

A rare mode of occurrence of jeffersonite was observed in the veins containing hetaerolite and hodgkinsonite, described on page 49, where it forms a matrix for those minerals and where its dark color caused it to be mistaken at first for a manganese oxide such as hetaerolite.

At Sterling Hill jeffersonite is one of the most typical minerals of the contact deposits about the pegmatite. Thence came the abundant crystals, many of them large and doubly terminated, that early drew attention to the species. Plate 8, *A*, shows one of unusual size. Most of the crystals are deeply pitted or have rounded edges and a dull coating of altered material. They were found in limestone pockets or in the residual clay of the limestone, with dysluite (gahnite), garnet, and apatite. The pegmatite also contains jeffersonite along with black manganiferous hornblende, and much of the jeffersonite contains grains of galena and sphalerite.

Alteration.—Crystals of dark-brown jeffersonite, perfectly preserved in form but as light as pith and showing a porous texture when broken, were once very abundant at Sterling Hill. To them Koenig (117) gave the provisional name "anomalite" but without publishing any exact description of the analyzed material. He regarded the material as being the last stage of the alteration of jeffersonite and stated that it consists of iron and manganese hydroxides with small amounts of cobalt and nickel. The name referred to its supposed anomalous behavior when dissolved in a borax bead—the red color that should have been given by the manganese oxide being neutralized by the nickel and cobalt oxides, so that the bead was colorless. No further analytical study of these pseudomorphs has been made.

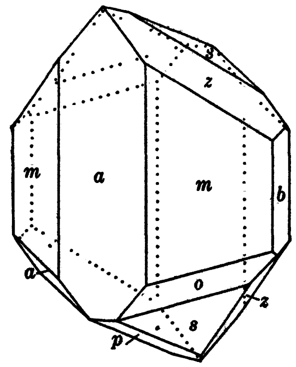


FIGURE 79

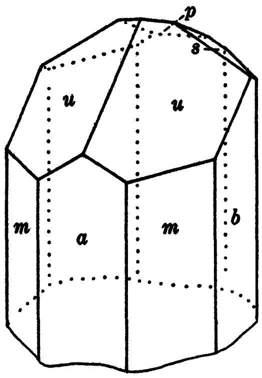


FIGURE 80

FIGURE 79.—Crystal of jeffersonite showing the forms $b(010)$, $a(100)$, $m(110)$, $z(021)$, $p(\bar{1}01)$, $s(\bar{1}11)$, and $o(\bar{2}21)$. Sterling Hill.

FIGURE 80.—Crystal of leucaugite showing the forms $b(010)$, $a(100)$, $m(110)$, $p(\bar{1}01)$, $u(111)$, and $s(\bar{1}11)$. Franklin.

In the Hancock collection is a specimen of jeffersonite of ordinary crystal form and dull luster showing patches of jet-black hornblende with brilliant facets, embedded in but not projecting above the pyroxene surface. The mineral appears to be the result of alteration to amphibole, but it has not been more closely studied.

Historical notes.—Jeffersonite was first described from Sterling Hill by Vanuxem and Keating (8), who named it for President Jefferson. They gave analyses and recognized it as a pyroxene, but they had no crystals and could not prove its relation to augite. That was done in the following year by Troost (13), who gave figures of the crystals and showed their pyroxene nature. He described the abundance of the mineral at Sterling Hill in the pegmatite and in the contact ore deposits. The paper by Troost is of much interest to American mineralogists as being among the first published in this country treating of crystallography and giving crystal figures. Seybert (19) also gave an analysis and confirmed the pyroxenic nature of jeffersonite. These early analyses are too poor to justify republication here.

The variable but never-failing content of zinc in this pyroxene throughout its wide range of occurrence in the deposits marks it as a distinct variety. Also it is a very characteristic member of the contact zones of the district.

LEUCAUGITE

Character.—Under leucaugite are included generally light-colored pyroxenes that contain aluminum with little or no iron or manganese. The variety as here described is ill-defined, as there are no analyses of such pyroxenes from Franklin, and their assignment has depended wholly on qualitative chemical tests.

Occurrence.—At Franklin large pyroxene crystals of the prismatic habit shown in figure 80 were found in abundance in a pocket in limestone between the two legs of the ore deposit, not far from Double Rock, a formerly existing prominent outcrop of pegmatite near the Trotter mine. This pyroxene is best represented by two very large matrix specimens in the Kemble collection, the larger one being 18 inches square. The stout prismatic crystals, which have been carefully excavated from the enclosing calcite, are grayish white and commonly reach a length of 2 to 3 inches. They are associated with dark-brown garnet in dodecahedral crystals.

Groups of similar appearance were found at the Gooseberry mine on Balls Hill, associated with scapolite and black garnet. Crystals of this habit, illustrated by figure 81, are best represented in the Canfield collection now in the United States National Museum.

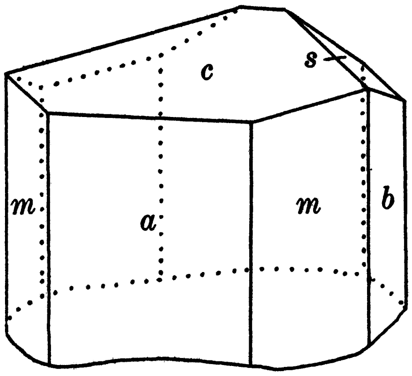


FIGURE 81.—Crystal of leucaugite showing the forms $c(001)$, $b(010)$, $a(100)$, $m(110)$, and $s(\bar{1}11)$. Balls Hill, Franklin.

At Sterling Hill gray to pale greenish-white, opaque crystals, sharply formed and of large dimensions, reach a length of 10½ inches. The habit—long to short prismatic—is shown in figures 82, 83, and 84. Such crystals were seen in the Canfield collection in great variety of form and habit, and one is shown in plate 8, *B*. They were found in a single large pocket in limestone, associated only with edenite of peculiar habit, during the construction of a tram road near the mouth of the tunnel that gave access to the Noble mine. They are remarkable for their perfection of form associated with large size and complex habit.

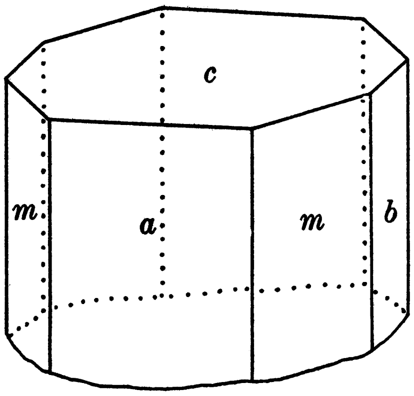


FIGURE 82.—Crystal of leucaugite showing the forms *c*(001), *b*(010), *a*(100), and *m*(110). Sterling Hill.

A crystal in the Canfield collection, from another locality of pyroxene crystals of peculiar habit, placed in this variety doubtfully in the absence of chemical tests, is shown in figure 85. The medium-sized crystals are blackish and are peculiar in their domatic terminations. They come from the ore body at Sterling Hill, probably from the locality that yielded abundant roepperite.

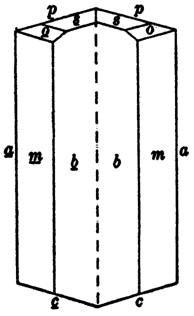


FIGURE 83

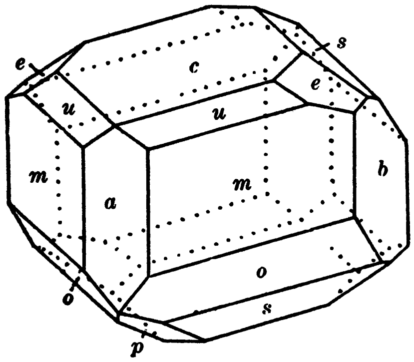


FIGURE 84

FIGURE 83.—Projection on the clinopinacoid of a crystal of leucaugite twinned on the orthopinacoid, showing the forms *c*(001), *b*(010), *a*(100), *m*(110), *s*($\bar{1}$11), and *o*($\bar{2}$21). Sterling Hill.

FIGURE 84.—Crystal of leucaugite showing the forms *c*(001), *b*(010), *a*(100), *m*(110), *e*(011), *p*($\bar{1}$01), *u*(111), *s*($\bar{1}$11), and *o*($\bar{2}$21). Sterling Hill.

PECTOLITE

$HNa(Ca,Mn)_2(SiO_3)_3$. Monoclinic

Forms.—*a*(100), *c*(001), *h*(540), *q*(340), *ω*(140), *v*(101).

Habit.—Pectolite is found as transparent colorless crystals and grains implanted on and mixed with prehnite and as pinkish coarse-fibrous aggregates associated with brown garnet, willemite, and biotite. The crystals are elongated parallel to the vertical axis, unlike all those of this mineral hitherto described. The cleavage is highly perfect parallel to the base and to the orthopinacoid. The orthopinacoidal cleavage is the better (Berman). Most of the crystals were coated with a thin film of powdery barite, which dulled the faces and hindered measurement.

The forms listed above were established on the following measurements made on three crystals:

Angles of crystals of pectolite

	Computed				Measured			
	φ		ρ		φ		ρ	
	°	′	°	′	°	′	°	′
a (100)	90	0	90	0	91	0	90	0
c (001)	90	0	5	20	90	0	5	17
h (540)	48	25	90	0	48	24	90	0
q (340)	34	4	90	0	33	45	90	0
ω (140)	12	42	90	0	13	40	90	0
v (101)	90	0	44	30	90	0	[a] 45	0

[a] Approximate.

Recent research has shown (Warren and Biscoe, 281b) that pectolite is triclinic. In a study by M. A. Peacock, shortly to be published in the Zeitschrift für Kristallographie, this conclusion is confirmed and pectolite is shown to be more closely related to wollastonite than to the monoclinic pyroxenes. Peacock adopts an orientation showing this relation, which changes the form *ω*(140) to the side pinacoid *b*(010) and the form *h*(540) to the unit prism *H*(110). The changes in symbols for the forms listed above and shown in figure 86 will then be as follows:

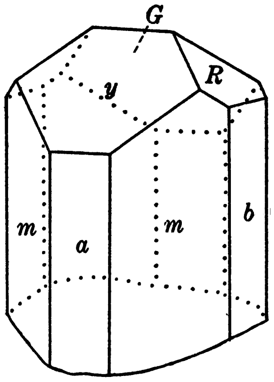


FIGURE 85

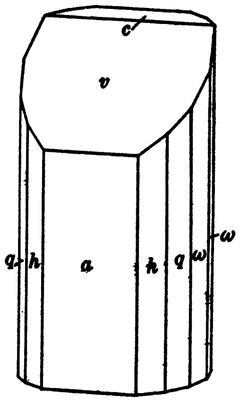


FIGURE 86

FIGURE 85.—Crystal of pyroxene showing the forms *b*(010), *a*(100), *m*(110), *y*(101), *G*($\bar{2}$01), and *R*($\bar{1}$32). Sterling Hill.

FIGURE 86.—Crystal of pectolite showing the forms *a*(100), *c*(001), *h*(540), *q*(340), *ω*(140), and *v*(101) Franklin.

Symbols of forms of pectolite in triclinic interpretation

Monoclinic	Triclinic	Monoclinic	Triclinic
a(100)	*a*(100)	*ω*(140)	*b*(010)
c(001)	*c*(001)	*ω′′′*(1$\bar{4}$0)	*A*(120)
h(540)	*H*(110)	*v*(101)	*v*(101)
q(340)	*Q*(120)		

The letters *H* and *Q* correspond to analogous forms of wollastonite. (See appendix, *d*, p. 130.)

Optical properties.—Under the iron-arc spark pectolite gives a pure-yellow fluorescence. It is optically biaxial and positive; $\alpha \wedge c = 19°$, $\gamma \wedge b = 13°$; $2V$ medium; r>v (perceptible); $\alpha = 1.604$, $\beta = 1.610$, $\gamma = 1.636$.

Composition.—Crystals of pectolite were crushed and separated as completely as possible from the associated minerals by heavy solution. The material analyzed was not entirely pure, however, the alumina found indicating some prehnite and the barium oxide found showing a trace of barium as present in some form. After correction by eliminating the BaO and SrO and 3.7 percent of prehnite the remainder gives a fairly close approximation to the theoretical ratio of pectolite—that is, $SiO_2 : CaO : Na_2O : H_2O = 6 : 4 : 1 : 1$.

Analysis of pectolite

[R. B. Gage (private communication), analyst]

SiO_2	52. 04	BaO	0. 13
Al_2O_3	. 92	SrO	. 12
CaO	31. 15	Na_2O	7. 97
MgO	. 05	K_2O	. 90
MnO	2. 31	H_2O	3. 07
FeO	1. 29		
ZnO	. 26		100. 21

Occurrence.—Pectolite was first determined in fibrous form on a specimen sent by the Foote Mineral Co. for examination. The crystals were on a large specimen of prehnite sent by Mr. W. F. Ferrier for determination, which he kindly presented for study on being told of the puzzling problem regarding the nature of the prehnite and the then unknown mineral mixed with it. Both specimens undoubtedly came from the Parker shaft, but pectolite appears to be among the rarest and least known minerals there.

RHODONITE

Variety fowlerite. $(Mn,Zn,Ca)SiO_3$. Triclinic

Forms.—$a(100)$, $b(010)$, $c(001)$, $m(110)$, $M(1\bar{1}0)$, $f(130)$, $\mu(401)$, $K(\bar{4}03)$, $\rho(\bar{2}01)$, $\phi(\bar{4}01)$, $v(0\bar{4}1)$, $p(111)$, $q(221)$, $\epsilon(441)$, $\mathfrak{M}(\bar{1}11)$, $k(\bar{2}21)$, $i(\bar{4}41)$, $r(\bar{1}\bar{1}1)$, $l(\bar{4}\bar{4}3)$, $n(\bar{2}\bar{2}1)$, $\kappa(2\bar{2}1)$, and doubtful forms (445), (883), (661). (Position and letters of Dana's System of Mineralogy.)

Combinations on crystals of rhodonite

	Forms	Illustrations
1	*c, a, m, M, k, n*	Fig. 87.
2	*c, a, b, m, M,* μ, ρ, ϕ, *k, r, l, n*	Fig. 88.
3	*c, a, b, m, M,* μ, ρ, ϕ, *K, q, k, r, n*	Fig. 89.
4	*c, m, M,* ρ, ϕ, *p, q, k, r*	Fig. 91.
5	*c, a, b, m, M, k, n.* Prismatic parallel to *c* and *M.*	Pirsson (142), fig. 3.
6	*c, a, m, M,* μ, ρ, ϕ, *q, k, r, n.* Tabular parallel to *c.*	Pirsson (142), fig. 4.
7	*c, a, m, M,* μ, ρ, *k, r, n.* Prismatic parallel to *c* and *m.*	Pirsson (142), fig. 5.
8	*c, a, b, m, M, k,* ϵ, *n.* Tabular parallel to *c.*	Pirsson (142), fig. 6.
9	*c, a, b, m, M,* μ, ρ, *v, q,* $\mathfrak{M}$, *k, i, r, l, n.*	Ford and Crawford (200), fig. 1.
10	*c, a, b, m, M, f, p, q, k, i, r, l, n.* Tabular parallel to *M.*	Fig. 90.

Habit.—Most fowlerite crystals are square prismatic parallel to the edge between the base and the negative prism, but some are thin-tabular parallel to the base, to the prism $M(1\bar{1}0)$, or to some other plane. Complete individuals are rare, as the crystals are commonly in parallel groups implanted on a base of massive rhodonite; some single crystals are 8 inches long and 2 inches square. Fowlerite is also found foliated, in coarse granular form, either massive or friable, and in isolated rounded grains. It is rarely twinned polysynthetically parallel to the base.

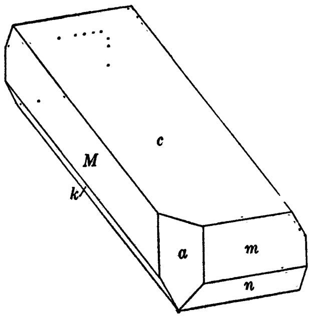


FIGURE 87.—Crystal of rhodonite showing the forms $c(001)$, $a(100)$, $m(110)$, $M(1\bar{1}0)$ $k(\bar{2}21)$, and $n(\bar{2}\bar{2}1)$ Franklin.

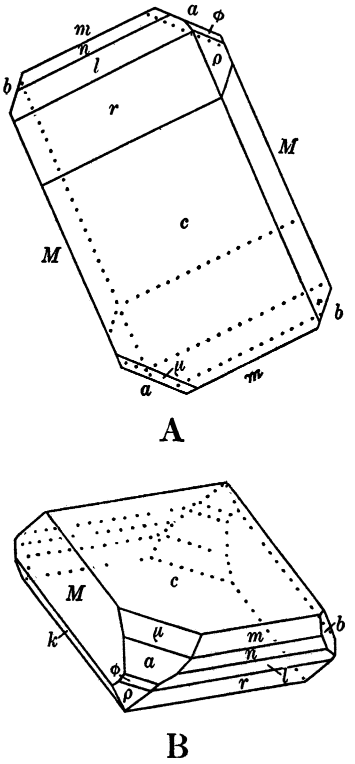


FIGURE 88

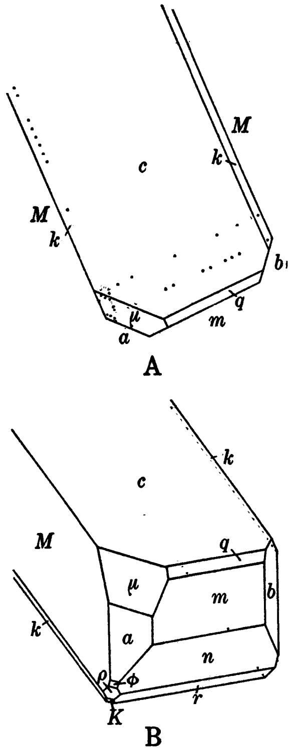
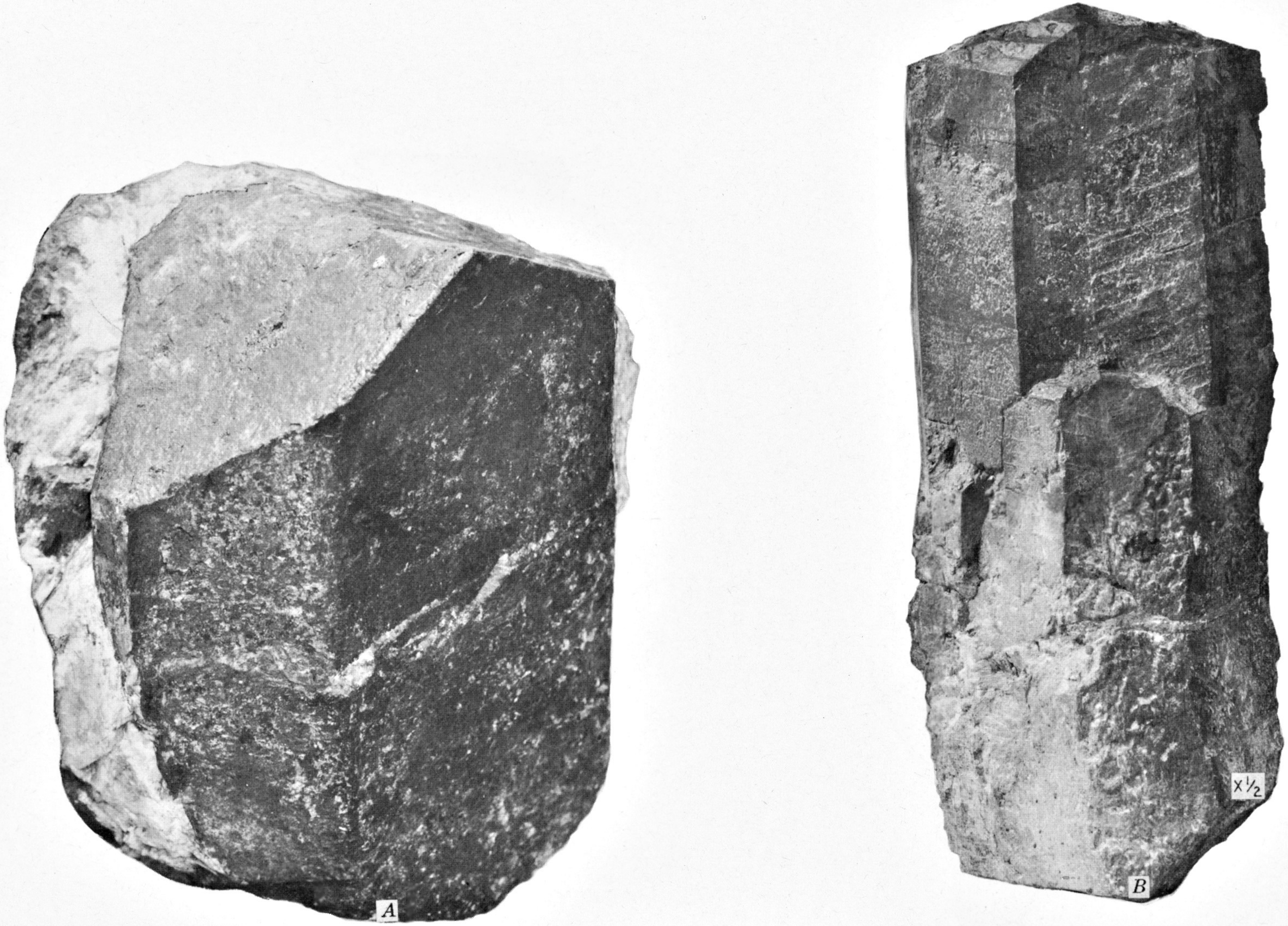


FIGURE 89

FIGURE 88.—Crystal of rhodonite (variety fowlerite) showing the forms $c(001)$, $b(010)$, $a(100)$, $m(110)$, $M(1\bar{1}0)$, $\mu(401)$, $\phi(\bar{2}01)$, $\rho(\bar{4}01)$, $k(\bar{2}21)$, $r(\bar{1}\bar{1}1)$, $l(\bar{4}\bar{4}3)$, and $n(\bar{2}\bar{2}1)$ Franklin A, Plan, B, clinographic projection.

FIGURE 89.—Crystal of rhodonite (variety fowlerite) showing the forms $c(001)$, $b(010)$, $a(100)$, $m(110)$, $M(\bar{1}10)$, $\mu(401)$, $\phi(\bar{4}01)$, $\rho(\bar{2}01)$, $K(\bar{4}03)$, $q(221)$, $k(\bar{2}21)$, $r(\bar{1}\bar{1}1)$, and n $(\bar{2}\bar{2}1)$ Franklin. A, Plan, B, clinographic projection.

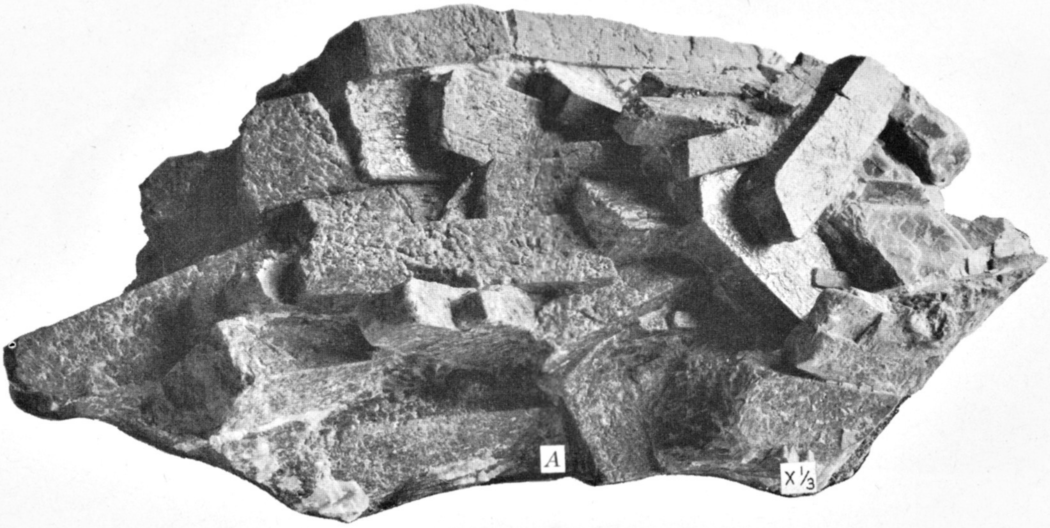
Fowlerite crystals commonly have dull faces, but on a few the forms *c, m, M,* and *n* are lustrous. All

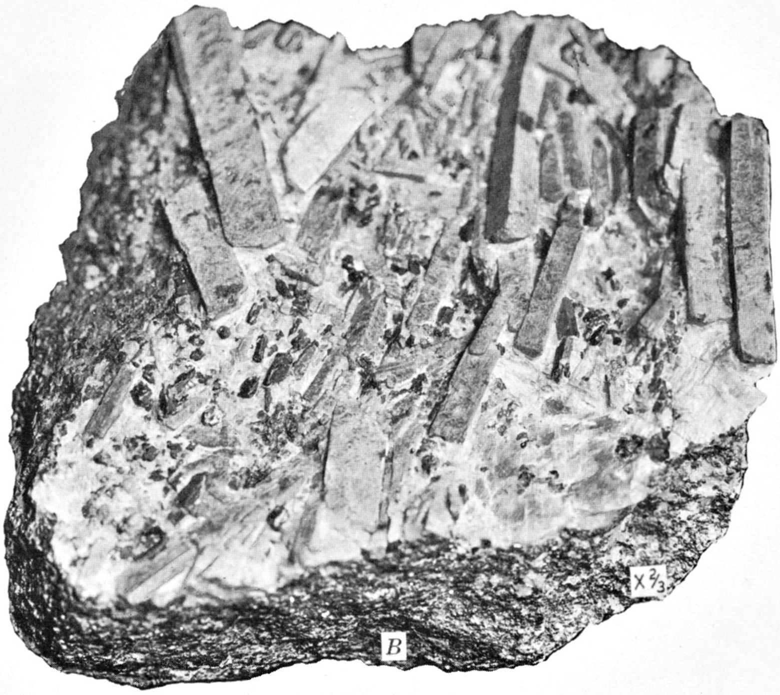


A. CRYSTAL OF JEFFERSONITE IN LIMESTONE.

B. TWIN CRYSTAL OF PRYOXENE VIEWED FROM THE SIDE.

Specimens from Sterling Hill in Canfield collection.





A. GROUP OF CRYSTALS OF RHODONITE (FOWLERITE) FREED FROM CALCITE.
Franklin. Bement collection, American Museum of Natural History.

P. SQUARE PRISMATIC CRYSTALS OF RHODONITE (FOWLERITE) IN CALCITE.
Franklin. Hancock collection.

edges are apt to be more or less rounded, partly because of obscure truncating planes but chiefly because of the apparent resorption that affects almost all the minerals embedded in limestone and that also causes irregular pitting on the crystal faces. Rarely the crystals are developed in open cavities and may there be brilliant and lustrous.

The cleavage parallel to the prisms *m* (110) and *M* $(1\bar{1}0)$ is perfect, and that parallel to the base is less perfect but good. A parting parallel to the brachypinacoid is very good, and there are traces of parting parallel to the macropinacoid. The hardness is 5.5 to 6, and the specific gravity is 3.4 to 3.68. The crystals are very brittle, owing to innumerable minute cracks. The color is bright to pale rose-pink, brownish red, or gray; it is blackened on weathered surfaces and quickly bleached to dirty pinkish white or gray by direct sunlight. The luster is vitreous and the mineral is translucent or rarely, in small crystals, transparent.

Fowlerite is optically biaxial and positive; $2V$ moderately large; dispersion easily perceptible; crossed dispersion rather strong; $\alpha=1.716, \beta=1.720, \gamma=1.732$. These optical data are for the fowlerite of analysis 4 (Larsen, 221). The orientation of the axial ellipsoid of fowlerite has not been determined but is probably similar to that of rhodonite, which has been determined by Hey (269). (See p. 69, under bustamite.)

Composition.—Fowlerite is a manganese silicate with considerable amounts of calcium, iron, magnesium, and zinc in place of part of the manganese. The zinc is peculiar to the rhodonite from the district and justifies the early local name of fowlerite for the zinciferous variety of rhodonite. Most of the early analyses were made on altered material and are of little value; the only trustworthy ones are given below.

Analyses of fowlerite

	1	2	3	4	5	6	7
SiO_2	46. 48	46. 70	46. 06	44. 76	45. 06	46. 87	45. 00
MnO	31. 52	31. 20	34. 28	40. 83	36. 57	38. 22	30. 80
FeO	7. 23	8. 35	3. 63	. 99	2. 54	Trace.	10. 18
ZnO	5. 85	5. 10	7. 33	3. 26	7. 25	6. 38	1. 86
CaO	4. 50	6. 30	7. 04	10. 12	7. 48	7. 61	10. 50
MgO	3. 09	2. 81	1. 30	. 76	1. 11	. 79	1. 01
H_2O	1. 00	. 28	-------	. 06	-------	-------	------
	99. 07	100. 74	99. 64	100. 78	100. 01	99. 87	99. 35

1. Fowlerite. R. Hermann (45), analyst.
2. Fowlerite. C. F. Rammelsberg (60), analyst.
3. Fowlerite. Average of two analyses of L. V. Pirsson (140), analyst.
4. Fowlerite. Franklin. Larsen and Shannon (221), analysts.
5, 6. Fowlerite. Franklin. Jenkins and Bauer (243), analysts.
7. Gray rhodonite, specific gravity 3 63, Franklin. Jenkins and Bauer (243), analysts.

The analyses show a considerable range in the extent to which other elements take the place of manganese. Analyses 4 and 7 are interesting especially as showing compositions nearer to that of bustamite. Probably analyses of more material would show other intermediate compositions. The material for analysis 4 consisted of the centers of fowlerite crystals that were coated with a parallel growth of bustamite in crystallographic continuity with the core.

Alteration.—The alteration of fowlerite to a manganiferous serpentine is described on page 117. All stages of the change were noted, from crystals showing only small spots of altered material to true alteration pseudomorphs in which the whole mass was changed, without loss of crystal form, into harsh, dirty-white serpentinous material. No special study of this process was attempted. The name "hydrorhodonite" is given locally to this alteration product, some of which is very hard as the result of cementation by silica set free during the alteration.

Under the name "dyssnite" Von Kobell quotes a description and analysis given by Thomson (23) of an oxidized rhodonite, which he styled "sesquisilicate of manganese"—a scaly black, metallic-looking substance. Thomson (32) afterward withdrew this analysis as untrustworthy and gave another, of supposedly fresher material, under the same name "dyssnite." These analyses are not exact enough for determination of the kind of chemical changes that the fowlerite had undergone.

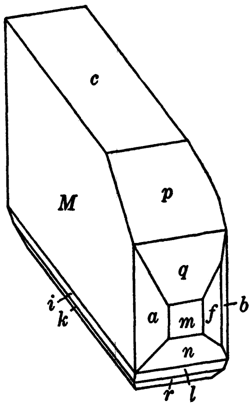


FIGURE 90.—Crystal of rhodonite (variety fowlerite) tabular parallel to the prism *M*$(\bar{1}10)$, showing the forms *c*(001), *b*(010), *a*(100), *m*(110), *M*$(\bar{1}10)$, *f*(130), *p*(111), *q*(221), *k*$(\bar{2}21)$, *i*$(\bar{4}41)$, *r*$(\bar{1}\bar{1}1)$, *l*$(\bar{4}\bar{4}3)$, and *n*$(\bar{2}\bar{2}1)$ Franklin.

Occurrence.—At Franklin large masses of fowlerite are embedded in calcite, generally near the boundary of the ore body and as a rule demonstrably at or close to the contact of an igneous intrusion. The enclosing calcite is in general coarsely crystalline, white or bluish, and commonly in veinlike masses intersecting the ore body and more or less completely interpenetrated by fowlerite, alone or with franklinite, willemite, and zincite. Fowlerite is also found not infrequently as isolated grains in the mass of the pegmatite.

The great abundance of the mineral where pegmatite is prominent, as at the Parker shaft and the Trotter and Buckwheat mines, and its scarcity elsewhere in the mines confirm the conclusion that fowlerite is exclusively a metamorphic mineral formed through the influence of the pegmatite intrusions. In the mine workings opened near the walls of the ore body blasts sometimes stripped surfaces square yards in extent covered with this beautiful pink mineral. Groups of crystals, such as those preserved in the Bement, Kemble, and Lang collections, taken from such localities, represent the finest known development of this mineral. Most specimens of rhodonite seen in collections have been freed from the enclosing limestone by treatment with acid—a process that is very destructive to the beauty of the mineral, as it is itself attacked slightly and more or less decolorized. Crystals freed from the matrix by a chance blow of the hammer or by the laborious method of scraping away the calcite bit by bit with a steel point are in every way finer in appearance. The splendid group in the Bement collection, illustrated in plate 9, *A*, was so prepared, and plate 9, *B*, shows some of the best of Mr. Hancock's work.

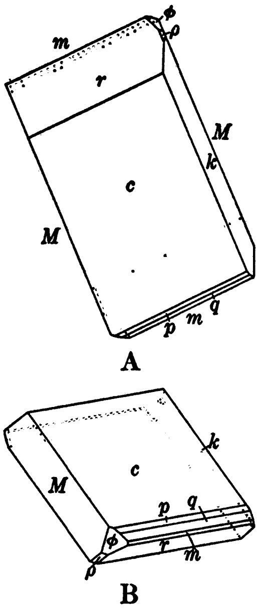


FIGURE 91.—A, Plan, and B, clinographic projection of a tabular crystal of rhodonite showing the forms $c(001)$, $m(110)$, $M(1\bar{1}0)$, $\rho(\bar{2}01)$, $\phi(\bar{4}01)$, $p(111)$, $q(221)$, $k(\bar{2}21)$, and $r(\bar{1}\bar{1}1)$ Franklin.

Where developed in cavities the crystals are generally small, of a clear transparent pink color, and brilliantly lustrous. Such a crystal is shown in figure 91, and combination 10, flattened parallel to the prism $M(1\bar{1}0)$ (fig. 90), is from a similar setting. The most commonly associated minerals in such places are yellow garnet, in crystals or massive, and manganoaxinite. Calcite and barite also occur with it.

The fowlerite crystals coated with bustamite in parallel growth, described by Larsen and Shannon (221), are apparently also a vein product. They are associated with manganoaxinite, barite, willemite, and ganophyllite.

At Franklin fowlerite was found by the earliest mineralogical explorers, has always been abundant, and unlike the other common minerals of the deposit is still found in specimens equal to or better than those taken from the earlier workings. On the other hand, it was never found in abundance at Sterling Hill, and only two or three poor specimens from there were seen in all the collections studied.

Historical notes.—The first analysis of rhodonite from Franklin was made by Thomson (23), who called it "ferrosilicate of manganese." Other early names used for it are "siliceous oxide of manganese" (Fowler, 21) and "manganesian feldspar" (Torrey, 11). The first analyses were made on very impure material.

The name "fowlerite," first found in Shepard's "Mineralogy" (28), was bestowed on the mineral by Nuttall in the early twenties of the past century, in honor of Dr. Fowler, of Franklin, one of the first collectors of the local minerals. The probable identity of the mineral with rhodonite was first pointed out by Hermann (45) and afterward by Dauber (70), who measured crystals and showed them to be triclinic. The name "fowlerite" is still in use for the zinciferous variety of rhodonite.

BUSTAMITE

$CaMn(SiO_3)_2$. Triclinic

Habit.—Definite crystals of bustamite have not been seen, but it is found in parallel growth with crystals of fowlerite and presenting the common forms of that variety, also in prismatic groups and in masses of coarse fibers several inches long. Its color is white to pale pink. Hey (269) observed a vivid red fluorescence in bustamite from Franklin, but no fluorescence has been seen on any of the specimens in the mineral collections at Harvard University.

Physical characters.—Cleavages in four directions in one zone are parallel, respectively, to the clinopinacoid (good, with strong pearly luster); to the unit prisms (slightly poorer but with pearly luster); and to the orthopinacoid (with vitreous luster). The cleavage parallel to the base, characteristic of fowlerite, is not developed in bustamite. The two pinacoidal cleavages had not been recorded for rhodonite until the description by Larsen and Shannon (220) appeared. They were identified long ago by the author on a fibrous form of rhodonite known to Franklin collectors as "manganese wollastonite" and were also measured by him on crystals of fowlerite but with very weak development. This fibrous rhodonite now appears, by analysis and by study of its optical constants, to be bustamite. The "keatingine" of Shepard (112) likewise is bustamite.

The cleavage angles of bustamite were measured by Larsen and Shannon, as shown in the table given on page 69.

Larsen and Shannon point out a close relation between the cleavage of bustamite and that of the monoclinic wollastonite.

The specific gravity of a bustamite determined by Hey is 3.302.

Cleavage angles of bustamite

	Bustamite, measured			Rhodonite, computed			
	ϕ	ρ		ϕ		ρ	
		°	′	°	′	°	′
b(010)	0°0′–1°17′; average of 7, 0°21′	90	0	0	0	90	0
m(110)	44°45′–45°6′; average of 7, 44° 58′	90	0	45	53	90	0
a(100)	93°52′–95°12′; average of 8, 94°33′	90	0	94	26	90	0
M(1$\bar{1}$0)	139°14′–140°21′; average of 8, 139° 53′	90	0	138	21½	90	0

Optical properties.—The optical properties of bustamite have been studied by Larsen (220), by Hey (269), and by Sundius (281). Hey also gives comparative values for rhodonite from the Swedish localities. Bustamite is optically biaxial and negative. Hey regards this property as the most convenient and natural one by which to separate bustamite and rhodonite, as that mineral is optically positive. The Franklin bustamite shows great dispersion of the bisectrices. The refractive indices are:

$\alpha=1.662$, $\beta=1.674$, $\gamma=1.676$, all ± 0.003 (Larsen).
$\alpha=1.664$, $\beta=1.675$, $\gamma=1.679$, all ± 0.003 (Hey).

As determined by Larsen, $2V=44° \pm 3°$; dispersion slight, $r<v$; crossed dispersion considerable.

The orientation of the axial ellipsoid was also determined by Hey and was stated in terms of the position angles on a projection on the clinopinacoid. In the following table some of Hey's data are given, transferred to the normal projection position as used by Dana.

Orientation of axial ellipsoid in bustamite

	Bustamite (Franklin)		Rhodonite (Harstigen)	
	ϕ	ρ	ϕ	ρ
	°	°	°	°
X	275	81	277	80
Y	12	70	14	62
Z	170	20	161	12

Composition.—The following analyses show the composition of bustamite:

Analyses of bustamite from Franklin

	1	2	3
SiO_2	48.44	46.72	47.68
Al_2O_3		1.34	.25
Fe_2O_3			.06
FeO	.27	.46	
CaO	25.20	22.24	24.86
MnO	25.20	26.51	27.65
MgO	.65	1.27	.03
ZnO	.53	1.34	.26
Ignition	.34		.06
	100.63	99.88	100.85

1. E. V. Shannon (220), analyst.
2. L. H. Bauer (243), analyst.
3. M. H. Hey (269), analyst.

The ratio derived from analysis 1 shows that molecularly $CaSiO_3:MnSiO_3$ is approximately 4:3. On chemical grounds the mineral might therefore be regarded as either calcium rhodonite or as manganese wollastonite, but the triclinic crystallization shown by the cleavage inclines one to regard it as related to rhodonite.

The recent work by Sundius (281) shows that bustamite is a distinct species of rather definite chemical composition (as above given) with only a comparatively small range therein. Winchell likewise has pointed out this fact. Between rhodonite and bustamite an apparently well-established break in chemical continuity occurs—that is, rhodonite may have as high a ratio as Ca:Mn=3:7. Bustamite may likewise approach the ratio Ca:Mn=4:6. However, as Sundius has proved, no optical continuity can be shown. Nevertheless, the optical elements in both species (rhodonite, bustamite) lie in closely similar positions with respect to the crystallographic elements.

Occurrence.—Most of what is certainly known of the occurrence of bustamite is the information contained in the papers by Larsen and Shannon (220, 221), and Hey (269). Their material was of two sorts. The first, which yielded the greater part of the data given, was in prismatic grains embedded in albite with brown garnet, biotite, and cyprine. It came from Franklin, but nothing is known of the detailed locality. The second lot described consisted of zones of bustamite coating crystals of fowlerite that lined seams in massive ore, together with manganoaxinite, barite, willemite, and ganophyllite. Similar specimens in the Harvard collections show the same association but with bustamite so situated on the vein wall as to appear to have been the first mineral to form after fowlerite. These specimens also came from Franklin.

It has, however, been shown by optical tests that the fibrous light-pink form of rhodonite, long known at Franklin as manganese wollastonite, is bustamite. The former abundance of this form of the mineral, first found during the sinking of the Parker shaft, suggests that bustamite may be much more widely developed there than has been suspected. In the lack of chemical analyses of material carefully studied optically, this cannot be stated positively, and more work is needed to decide the matter.

These specimens commonly contain hardystonite, and on transverse fractures there is in many specimens a whitish coating yielding a yellow fluorescence that resembles that of pectolite. The presence of pectolite could not, however, be proved optically.

MARGAROSANITE

$PbCa_2(SiO_3)_3$. Triclinic

Crystal form.—Margarosanite is found at Franklin only in lamellar masses composed of thin plates packed closely together and showing individually a rhombic outline that is due to cleavage. The crystal form is known, however, from the description by Flink (216) of crystals from Långban. At Långban the crystals are found with schefferite, apophyllite, calcite, nasonite, and thaumasite, in veins cutting dolomite. Most of the margarosanite is massive, but in vugs a few slender crystals were found with faces somewhat curved or striated, yielding poor measurements. The habit, as shown by figure 92, is pyroxenelike, and the mineral is regarded by Flink as an independent species of the pyroxene group, a conclusion in which the author fully concurs.

Angle table of margarosanite

$a\ b\ c = 0.8442\ 1.1.2838$, $p_0 = 1.4943$, $q_0 = 1.0097$, $\alpha = 74°37'$, $\beta = 129°30'$, $\gamma = 101°6'$, $\lambda = 100°52'$, $\mu = 51°49'$, $\nu = 88°10'$]

	Computed				Measured			
	ϕ		ρ		ϕ		ρ	
	°	′	°	′	°	′	°	′
c(001)	106	48	40	43				
a(100)	88	10	90	0	*88	10	90	0
b(010)	0	0	90	0				
m(110)	54	42	90	0	*54	42	90	0
n(1$\bar{1}$0)	122	47	90	0	119	30	90	0
d(011)	37	15	53	42				
e(0$\bar{3}$4)	146	34	56	14				

Angles marked with an asterisk (*) used in computing crystallographic elements.

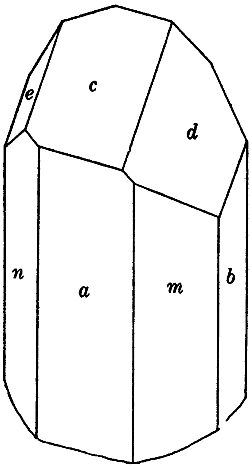


FIGURE 92.—Crystal of margarosanite from Långban, showing the forms *c*(001), *b*(010), *a*(100), *m*(110), *n*(1$\bar{1}$0), *d*(011), and *e*(0$\bar{3}$4). Figure drawn from description of Flink (217)

Flink's measurements were not two-circle measurements. The computation of the crystallographic elements was based on the angles in the table marked with the asterisk (*) and on the following measurements, the first of which has been amended from the published figure after correspondence with Dr. Flink: $(001) \wedge (010) = 100°52' = \lambda$, $(001) \wedge (100) = 51°49' = \mu$, $(011) \wedge (010) = 50°06'$.

Physical properties.—The cleavage is perfect parallel to the brachypinacoid and is good parallel to the base and to the macrodome ($\bar{5}$04) (Flink). The hardness is 2.5 to 3, the specific gravity is 3.991, and the mineral is colorless and transparent, showing a pearly luster on cleavage surfaces. Under the iron-arc spark it fluoresces with a rather lively pale-violet tint.

Margarosanite is optically negative; $2V = 83° \pm 5°$; r>v (perceptible); $\alpha = 1.729 \pm 0.005$, $\beta = 1.773 \pm 0.003$, $\gamma = 1.807 \pm 0.005$ (Larsen). The plane of the optic axes is nearly normal to the best cleavage, with an axis revolving just outside the field of vision.

Composition.—Margarosanite is a silicate of lead and calcium with a derived formula $Pb(Ca,Mn)_2Si_3O_9$.

Analyses of margarosanite

	1	2	3
SiO_2	33. 71	34. 72	34. 95
PbO	43. 50	41. 74	43. 29
CaO	21. 73	20. 28	21. 76
MnO	1. 14	2. 17	
MgO		. 20	
BaO		. 69	
H_2O	. 58	. 10	
	100. 68	99. 90	100. 00

1. Margarosanite, Franklin. W. M. Bradley (208), analyst.
2. Margarosanite, Långban, Sweden. G. Flink (216), analyst.
3. Composition computed from the derived formula.

Pyrognostics.—Margarosanite fuses in the oxidizing flame with some difficulty, the fragment assuming an amethyst color, but in the reducing flame it fuses easily and quickly at about 2 to an opaque grayish glass and colors the reducing flame pale azure-blue. With fluxes on charcoal it forms a metallic globule of lead and a lead oxide coating, and it gives manganese colors in soda and borax beads. It is decomposed by nitric acid, yielding separated silica.

Occurrence.—Margarosanite was one of the many species found at the Parker shaft in 1898, along with barite, garnet, hancockite, roeblingite, nasonite, franklinite, willemite, axinite, datolite, and manganophyllite.

It was partly investigated by Penfield and Warren (179); the study was later completed and the name given by Ford and Bradley (208). The name is derived from Greek words meaning a pearl and a tablet or board, in reference to its pearly luster and lamellar structure.

In 1919 Flink (216) announced the occurrence of margarosanite at Långban in Sweden.

AMPHIBOLE GROUP

Monoclinic

The amphiboles found in the district are tremolite (including asbestos and actinolite), cummingtonite (zinc-bearing), edenite, hastingsite, pargasite, and crocidolite. Their relation in composition, according to the classification of Berman and Larsen (279), is as follows:

1. Alkali-free members:
    Tremolite (actinolite), $Ca_2(Mg,Fe'')_5Si_8O_{22}(OH)_2$.
    Zinc cummingtonite $(Mg,Fe'',Mn,Zn)_7Si_8O_{22}(OH)_2$.
2. Alkali-bearing members:
    a. Deficient in silicon·
        Edenite, $Ca_2Na(Mg,Fe'')_5AlSi_7O_{22}(OH,F)_2$.
        Hastingsite (gamsigradite), $Ca_2Na(Mg,Fe'',Mn)_4(Al,Fe''')_3Si_6O_{22}(OH)_2$.
        Pargasite, $xCa_2Na(Mg,Fe'',Mn)_4Al_3Si_6O_{22}(OH,F)_2 + yNa_3Fe''_4Fe'''Si_8O_{22}(OH,F)_2$.
    b. With normal amount of silicon:
        Crocidolite, $Na_2Mg_3(Fe''',Al)_2Si_8O_{22}(OH)_2$.

Forms.—*a*(100), *b*(010), *m*(110), *t*(101), *p*($\bar{1}$01), *r*(011), *i*(031), *d*($\bar{1}$11), *k*($\bar{2}$11), *z*($\bar{1}$21), and *v*($\bar{2}$31). (Dana's position.)

Combinations on amphibole crystals

	Forms	Varieties	Localities	Illustrations
1	*b, m, r*	Tremolite	Franklin	
2	*a, b, m, r*	do	Sterling Hill	
3	*m, r*	Edenite	Franklin	Fig. 93.
4	*b, m, r, v, z*	do	Fowler quarry	Fig. 94.
5	*b, m, p, r, i, z*	do	do	Fig. 95.
6	*b, m, p, r, v, z*	do	Sterling Hill	Fig. 96.
7	*a, b, m, t, p, r, i, k, v, z*	do	do	Fig. 97.
8	*b, m, p, r, i, k, v, z*	do	do	Fig. 98.
9	*b, m, t, r, i, k, v.* Twin	do	do	Fig. 99.
10	*b, m, t, p, r, i, k, v, z.* Twin	do	Franklin	Fig. 100.
11	*b, m, p, r, i*	do	do	Fig. 101.
12	*b, m, p, r, i, k, v, z*	Hastingsite	Sterling Hill	Fig. 102.
13	*b, m, p, k*	do	do	
14	*b, m, p, r, z*	do	do	
15	*b, m, p, r, k*	do	do	
16	*b, m, p, r, i, k, z*	do	do	

TREMOLITE AND ACTINOLITE

Tremolite is found rarely as simple isolated gray or white crystals in the limestone wall rock of both ore bodies. It is common in the form of asbestos, the white or pinkish fibers being mixed with calcite in stiff columnar masses that form a transverse filling of secondary veins. Such material is often found in collections mistakenly labeled sussexite, which it much resembles.

Koenig's analyses show that the fibers are of variable composition, but samples tested by the author showed no trace of iron or manganese and are certainly true tremolite.

In many references to supposed tremolite from the district the mineral is doubtless edenite (see p. 72); also a part of the diopside and sahlite of earlier lists was probably edenite, though a part of it may have been tremolite.

A pseudomorph of tremolite, probably after diopside, is described on page 62.

Analyses of tremolite

[G A Koenig (132), analyst]

	1	2
SiO_2	55. 84	53. 50
Al_2O_3		1. 36
Fe_2O_3		8. 12
FeO	2. 40	4. 68
MgO	19. 58	14. 58
CaO	10. 00	6. 62
MnO	4. 79	1. 70
ZnO	4. 59	7. 10
H_2O	3. 20	3. 34
	100. 40	101. 00

Both samples had been treated with hydrochloric acid to remove calcite. The molecular ratio of silica to total bases approximates 1 to 1, and the material is tremolite containing considerable manganese and zinc.

Typical fibrous actinolite was seen in veins in the limestone of the Buckwheat mine in the stripping between the two legs of the ore body. It was also found with magnetite in the Gooseberry iron mine. It is, however, rare in the area, and the name as used in earlier lists applies, according to Mr. Canfield, to stout gray crystals of an amphibole that is probably edenite.

CUMMINGTONITE

An analysis of an amphibole found at Franklin, long called actinolite because of external resemblance to that variety, has shown that it is really a zinc-manganese cummingtonite having the formula given on page 70, the molecular ratio of MgO:FeO:MnO:ZnO being approximately 3:3:3:2. The specific gravity is 3.44.

Analysis of cummingtonite

[L H Bauer (273), analyst]

SiO_2	49. 74	CaO	. 49
Al_2O_3	1. 72	Na_2O	. 22
FeO	12. 80	H_2O	2. 16
MgO	8. 31		
ZnO	10. 46		99. 69
MnO	13. 79		

The mineral forms large green prismatic crystals with a cleavage angle $m \wedge m' = 54°28'$, embedded in rhodonite or garnet, in one specimen in feldspar, and accompanied by ferroschallerite.

This variety of cummingtonite is optically biaxial and negative; $2V = 75° \pm 2°$; $Z \wedge c = 15°$; $Y = b$; $\alpha = 1.657$, $\beta = 1.674$, $\gamma = 1.685$.

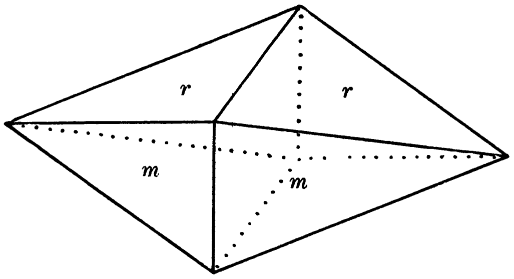


FIGURE 93 —Crystal of edenite showing the forms *m*(110) and *r*(011). Franklin.

EDENITE

Habit and occurrence.—The commonest amphibole in the district is an aluminous variety, both in crystals and granular, that ranges in color from white and light gray to bright green and dull gray-green. Qualitative tests on several specimens showed them to contain abundant alumina but to be low in iron and manganese; hence they are appropriately assigned to edenite.

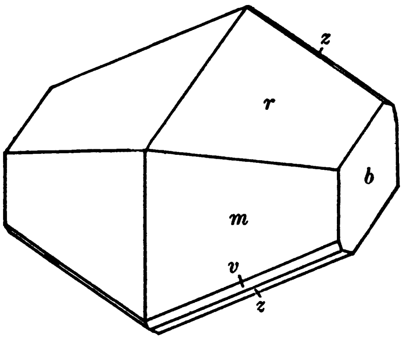


FIGURE 94.—Crystal of edenite showing the forms $b(010)$, $m(110)$, $r(011)$, $z(\bar{1}21)$ and $v(\bar{2}31)$ Fowler quarry

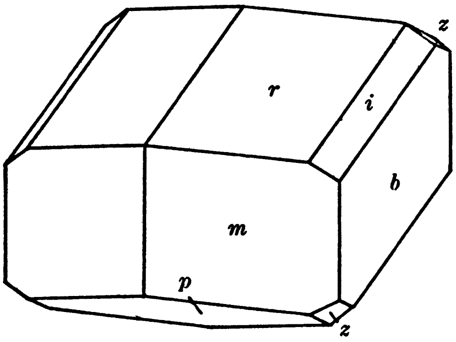


FIGURE 95.—Crystal of edenite showing the forms $b(010)$, $m(110)$, $r(011)$, $i(031)$, $p(\bar{1}01)$, and $z(\bar{1}21)$ Fowler quarry.

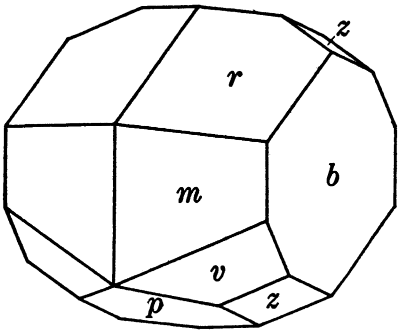


FIGURE 96.—Crystal of edenite showing the forms $b(010)$, $m(110)$, $r(011)$, $p(\bar{1}01)$, $v(\bar{2}31)$, and $z(\bar{1}21)$ Sterling Hill

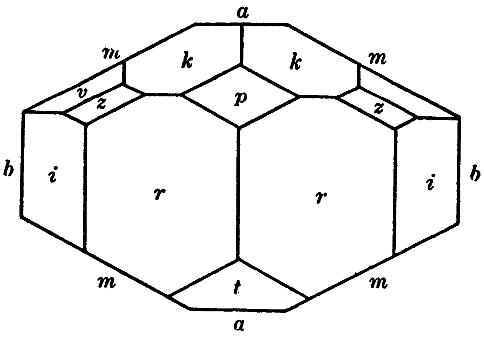


FIGURE 97.—Plan of a crystal of edenite showing the forms $b(010)$, $a(100)$, $m(110)$, $r(011)$, $i(031)$, $t(101)$, $p(\bar{1}01)$, $k(\bar{2}11)$, $v(\bar{2}31)$, and $z(\bar{1}21)$ Sterling Hill

Edenite is not found in connection with the ore deposits but is widely disseminated in the Franklin limestone, especially near pegmatite contacts. Crystals of simple type from the Fowler quarry at Franklin are shown in figures 94 and 95 and in plate 10, *A*.

Figures 96 to 99 illustrate the complex and sharply formed crystals that were found, together with aluminous pyroxene, in a pocket in limestone near the Noble mine at Sterling Hill (locality 17). They are dull gray to dark grayish black, and as much as 6 inches in greatest diameter, the habit being generally equidimensional or shortened in the direction of the vertical axis.

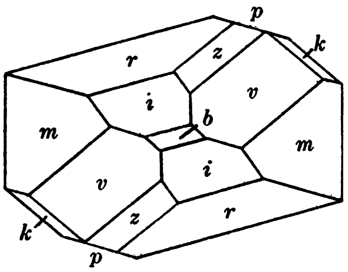


FIGURE 98.—Projection on the clinopinacoid of a crystal of edenite showing the forms $b(010)$, $m(110)$, $r(011)$, $i(031)$, $p(\bar{1}01)$, $k(\bar{2}11)$, $v(\bar{2}31)$, and $z(\bar{1}21)$. Sterling Hill.

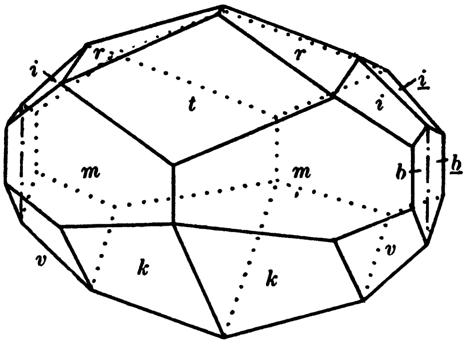


FIGURE 99.—Crystal of edenite twinned on the orthopinacoid, showing b (010), $m(110)$, $r(011)$, $i(031)$, $t(101)$, $k(\bar{2}11)$, and $v(\bar{2}31)$ Sterling Hill.

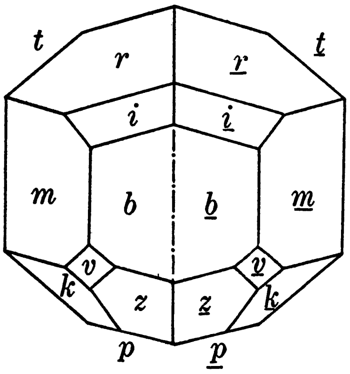


FIGURE 100.—Projection on the clinopinacoid of a crystal of edenite twinned on the orthopinacoid and showing the forms $b(010)$, $m(110)$, $r(011)$, $i(031)$, $t(101)$, $p(\bar{1}01)$, $k(\bar{2}11)$, $v(\bar{2}31)$, and $z(\bar{1}21)$ Franklin.

The Canfield and Kemble collections are especially rich in these unique crystals of amphibole. A very similar occurrence of edenite, on the Munson farm east of Mine Hill, Franklin, is shown in figure 100, drawn from a single crystal in the Kemble collection.

The diallage of earlier lists, described as gray to bright green, probably was edenite, so far as could be determined by specimens in old collections. Figure 101 shows the crystal type.

Optical properties.—A crystal from the Noble mine at Sterling Hill was studied in the mineralogical laboratory at Harvard University by Messrs. Berman and Gonyer. Edenite is optically biaxial and positive; $2V$ medium (60° ±); $r<v$; $Z \wedge c = 27° \pm 1°$; $Y = b$; absorption, $\gamma > \beta > \alpha$. Indices and pleochroism, $\alpha = 1.622$, colorless; $\beta = 1.630$, light violet-blue; $\gamma = 1.645$, light violet-blue (Berman).

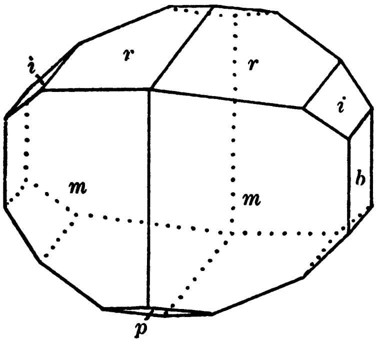


FIGURE 101.—Crystal of edenite showing the forms *b*(010), *m*(110), *r*(011), *i*(031), and *p*($\bar{1}$01). Franklin.

Composition.—The following analysis shows the composition of edenite:

Analysis of edenite from Sterling Hill

[F A. Gonyer (277), analyst]

SiO_2	47.33	K_2O	.86
TiO_2	.42	H_2O-	.04
Al_2O_3	8.68	H_2O+	1.04
Fe_2O_3	1.02	P_2O_5	None.
FeO	3.38	F	.69
MnO	.13		100.17
MgO	21.38	O=F_2	.29
CaO	12.36		
Na_2O	2.84		99.88

The analysis shows a composition closely comparable to that of the type edenite from Edenville, N.Y., according to Dana.[6] The following discussion interprets the analysis in terms of the method of Berman and Larsen (279).

The relation of the composition found to the formula required by the method is as follows:

Found----$Ca_{1.9}(Na,K)_1(Mg,Fe'',Mn)_5(Al,Fe''')_{1.5}(Si,Ti)_{6.9}O_{22.7}(OH,F)_{1.3}$.
Required--$Ca_2Na_1(Mg,Fe'')_5(Al,Fe''')_1Si_7O_{22}(OH,F)_2$.

The type edenite from Edenville has approximately the composition $Ca_2Na_1Mg_5Al_1Si_7O_{22}(OH)_2$; hence the Sterling Hill mineral is undoubtedly of the same type.

The edenite formula may be considered as related to that of tremolite in the following manner:

Edenite, $Ca_2NaMg_5(Al,Si)_8O_{22}(OH)_2$.
Tremolite, $Ca_2Mg_5Si_8O_{22}(OH)_2$.

Thus, edenite is equivalent to tremolite in which an atom of aluminum and one of sodium compensate the deficiency of silicon and balance the valences.

HASTINGSITE (GAMSIGRADITE)

Black hornblende, both granular and in large and complex crystals, was found in abundance at Sterling Hill in immediate association with the ore body. It was recorded first by Credner (90) as a constituent of the pegmatite there but was doubtless often mistaken for jeffersonite, with which it is associated. The crystals, which are black but not uncommonly have a dull-gray coating, are generally prismatic parallel to the clinoaxis and reach dimensions that are very large for the species. The largest one seen, in the collection of T. Lang, is 18 inches long parallel to the clinoaxis and 6 inches across in the directions parallel to the other two axes. A similar one is shown in plate 10, *B*, and figure 102.

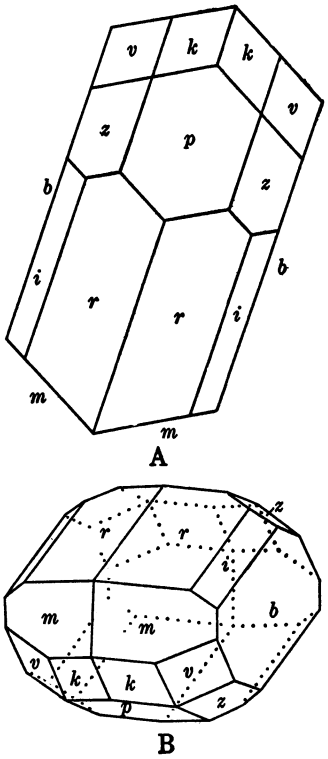


FIGURE 102.—Crystal of hastingsite showing the forms *b*(010), *m*(110), *p*($\bar{1}$01), *r*(011), *i*(031), *k*($\bar{2}$11), *v*($\bar{2}$31), and *z*($\bar{1}$21). Sterling Hill. A, Plan, B, clinographic projection.

Similar material, found with franklinite and sold as jeffersonite, was described by Kloos (121) from Franklin. Local collectors could give no information of such material from Franklin, but as Kemp also mentions finding such crystals there it seems probable that the mineral has been found at both localities. The following data were taken from the full description of this hornblende by Kloos: The crystals are unsymmetrical, are prismatic parallel to the vertical axis, are flattened parallel to the clinopinacoid, and are a fifth of an inch to an inch long parallel to the vertical axis.

---

[6] System of mineralogy, 6th ed., p. 395 (analysis 100), 1892.

The edges are rounded, the faces and cleavage surfaces are lustrous, and the color is deep leek-green where not coated with manganese oxide. Very thin sections are translucent green; the axial colors are, parallel to *X*, honey-yellow; to *Y*, yellowish green; to *Z*, bluish green. The extinction angle to the vertical axis is 17° 15′. The specific gravity is 3.352. The powder is soluble in hydrochloric acid.

Analysis of hastingsite

[J. H. Kloos (129), analyst]

SiO_2	39.59	MgO	8.42
TiO_2	1.76	CaO	12.85
Al_2O_3	11.20	Na_2O	3.31
Cr_2O_3	.13	K_2O	1.95
Fe_2O_3	5.97	H_2O	1.02
FeO	11.31		
MnO	3.07		101.11
ZnO	.53		

This amphibole was called by Dana "gamsigradite", a name first applied in 1861 by Breithaupt to a closely similar manganiferous hornblende from Gamsigrad, in Serbia. It differs from hastingsite only in containing a little manganese.

PARGASITE

Parsons (278) has published an analysis of pargasite from Franklin, which is described as possessing the following physical characters: $(110)\wedge(1\bar{1}0)=55°50'$; extinction angle 18½°; refractive indices, $\alpha=1.644$, $\beta=1.657$, $\gamma=1.663$; specific gravity 3.256.

Analysis of pargasite

[M. C. Haller (278), analyst]

SiO_2	43.90	K_2O	2.18
TiO_2	1.20	H_2O	.52
Al_2O_3	8.27	F	2.06
Fe_2O_3	5.95		
FeO	9.80		101 20
MnO	.34	$O=F_2$	.86
MgO	13.48		
CaO	10.24		100.34
Na_2O	3.26		

The analyses of hastingsite and pargasite, interpreted by the method of Berman and Larsen (279), yield the formulas given at the beginning of the section on the amphibole group (p. 70). It is evident that a more complete study of these alkaline amphiboles from Franklin than has yet been made is needed, but it seems likely that the several varieties cannot be certainly distinguished except by analysis.

CROCIDOLITE

Physical characters.—Veins filled with a bright-blue fibrous mineral, mixed with calcite and sphalerite, were found by the author in 1906 in blocks of waste ore on the dumps of the Trotter mine at Franklin. The mineral fuses readily to a black bead, giving a strong sodium flame, reactions which, with its blue color and fibrous form, seem to indicate crocidolite or a related sodium amphibole. The following optical characters, determined by Berman, confirm this conclusion: Biaxial and positive; $2V$ medium large; extinction nearly parallel to fiber length; $\alpha=1.67$ in the direction of deep-blue pleochroism and $\beta=1.68$ in the direction of purplish-blue pleochroism.

The Stanton collection contained numerous specimens showing the association of the mineral, and more recently it has been found in abundance. It is a very pale blue variety, in excessively fine needles, more or less felted together or contained as inclusions in other minerals. It appears to have formed veinlike masses in which the chief mineral is calcite in perfectly colorless anhedrons, their exteriors rounded and coated with crocidolite.

Willemite is also found in similarly rounded crystals of considerable size, pale green or perfectly colorless, but some of it is blue from included needles of crocidolite. Sphalerite also is found in these veins in pale-green to white cleavage masses. The occurrence of needlelike crystals of quartz in one specimen is described on page 36.

Composition.—A sample of the crocidolite, of specific gravity 3.195 and hardness 2.5 to 2.75, was analyzed by Mr. Bauer. It showed the presence of willemite by the fluorescence, so the zinc oxide was deducted as willemite—8.91 percent—and the analysis was recomputed to 100 percent.

Analysis of crocidolite

	1	2	3		
SiO_2	53.61	56.20	0.937		$=20\times0.047$
Fe_2O_3	18.45	20.25	.127	0.151	$=3\times$ .050
Al_2O_3	2.23	2.44	.024		
FeO	2.16	2.36	.033	.286	$=6\times$ .048
MgO	9.11	10.00	.248		
CaO	.24	.26	.005		
ZnO	6.50	--------			
Na_2O	4.86	5.33	.086		$=2\times$ .043
Ignition	2.90	3.17	.177		$=4\times$ .044
	100.06	100.01			

1. Crocidolite, Franklin. L. H. Bauer (257), analyst.
2. Same recomputed to 100 percent after deducting 8.91 percent of willemite, equivalent to the ZnO found.
3. Molecular ratio computed from analysis.

From the molecular ratios, which are fairly close to whole numbers, was derived the formula adopted (see p. 70), which, although hardly a typical crocidolite formula, represents the composition of the mineral fairly well and shows that it is a metasilicate, apparently an isomorphous mixture of crocidolite and a small amount of some less sodic amphibole.

GARNET

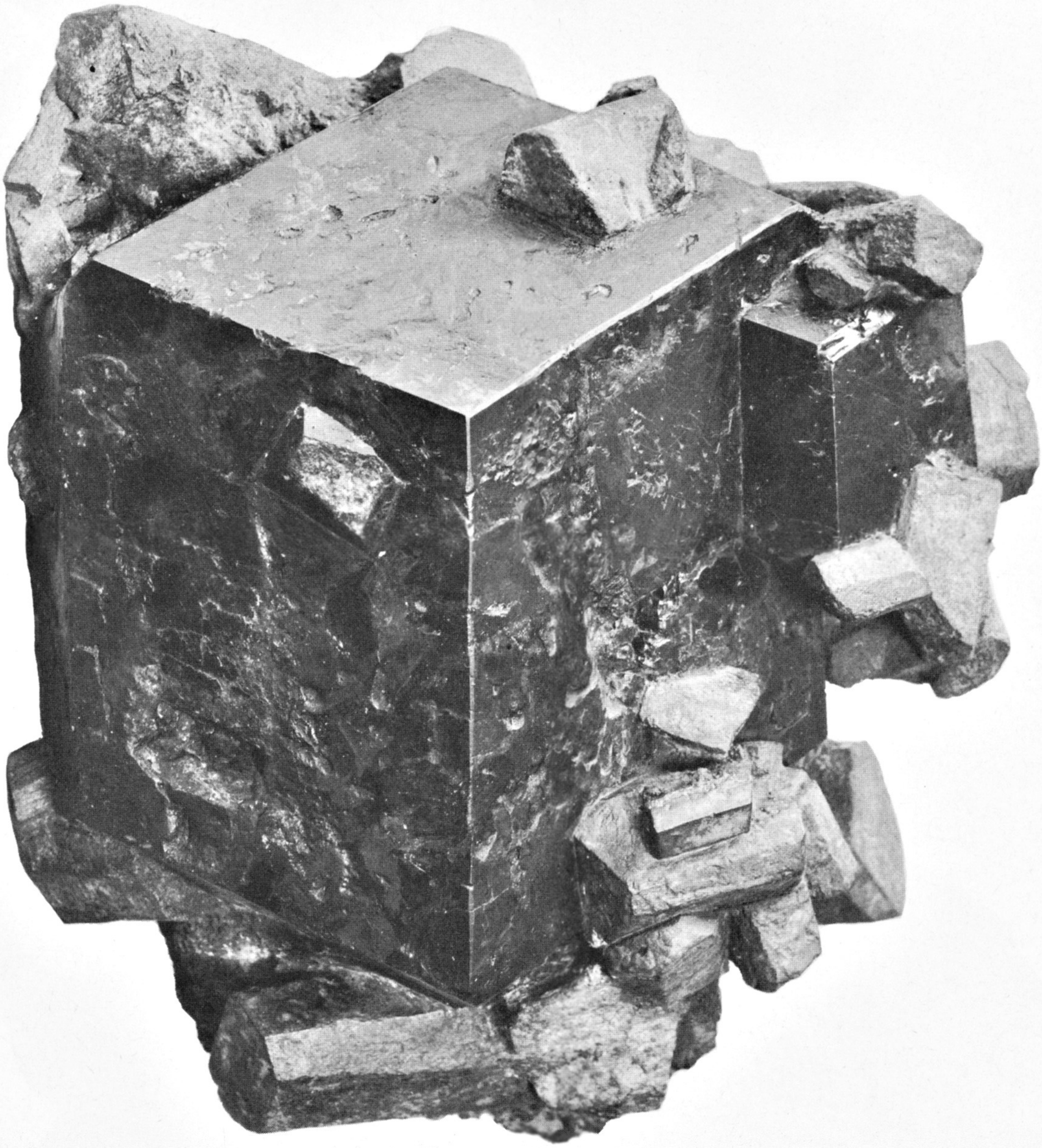
Variety andradite. $(Ca,Mn)_3(Fe, Al)_2(SiO_4)_3$. Isometric

Forms.—*d*(110).and *n*(211).

Habit.—Garnet is found in dominantly dodecahedral crystals, some of which are narrowly truncated by the trapezohedron, and on a few crystals that form is dominant. The mineral is found much more commonly in massive granular or compact forms.

A. LARGE CRYSTALS OF EDENITE FREED FROM CALCITE.
Franklin. Canfield collection.

B. LARGE TWIN CRYSTAL OF HASTINGSITE.
Sterling Hill. Canfield collection.

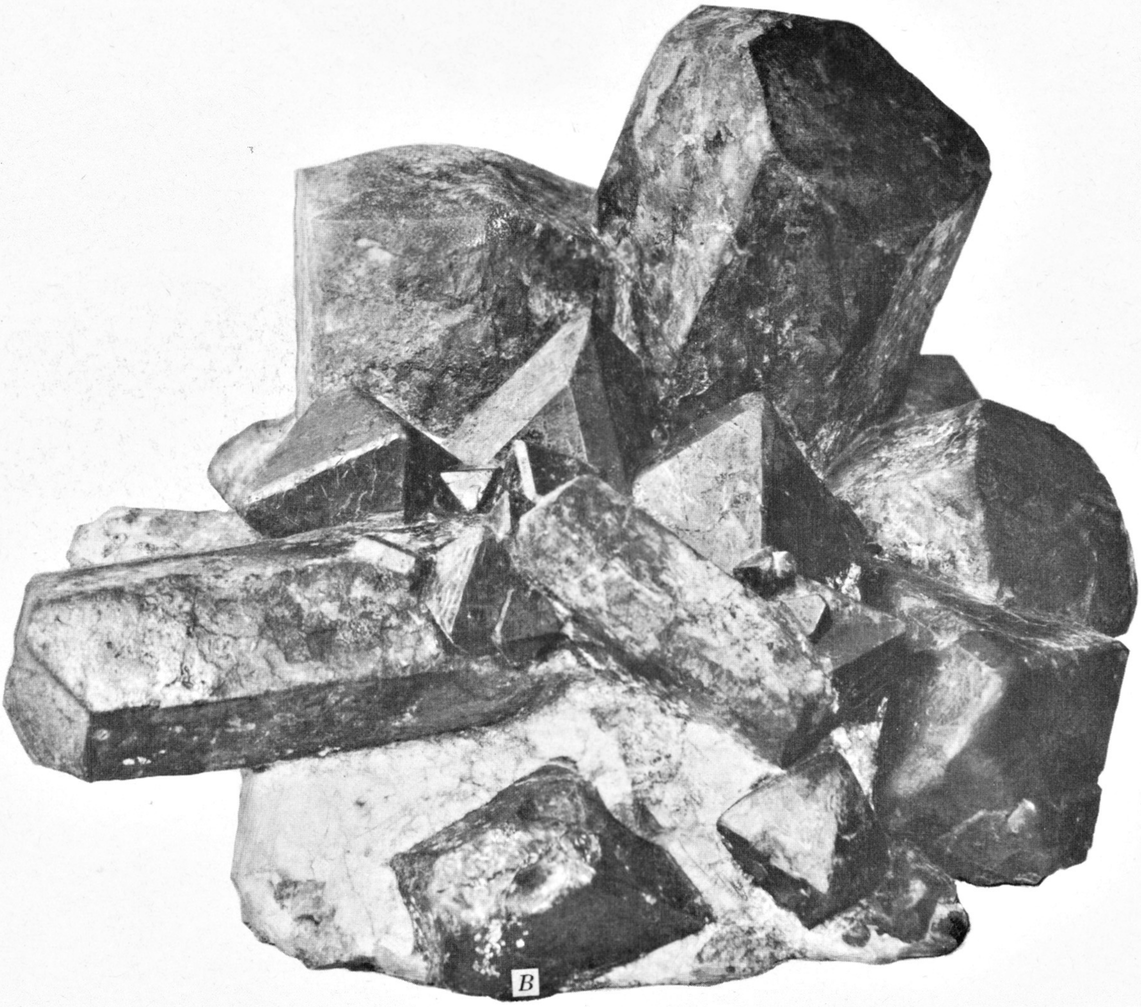


CRYSTALS OF GARNET AND PYROXENE FREED FROM LIMESTONE.

Double Rock, Franklin. Canfield collection.

A. CRYSTALS OF TEPHROITE (t) WITH ZINCITE (z) IN LIMESTONE.
Sterling Hill. Canfield collection.

B. GRANULAR TEPHROITE WITH ZINCITE IN LIMESTONE.
Franklin. Harvard collection.



A. PALE-YELLOW PRISMS OF WILLEMITE.
Trotter mine.

B. LARGE CRYSTALS OF WILLEMITE (TROOSTITE) WITH FRANKLINITE.
Sterling Hill.

Composition.—The wide range of composition indicated by the local color varieties has not been established by the later analyses, and the earlier analyses are unsatisfactory. In the table below are given the published analyses of Franklin garnet that deserve consideration. They give molecular ratios of garnet type and represent manganiferous andradite or iron-calcium garnet.

Analyses of garnet

	1	2	3	4	5	6
SiO_2	34.83	35.47	34.28	34.44	34.34	33.50
TiO_2						Present.
Al_2O_3	1.12	3.10	3.12	.53	7.20	1.10
Fe_2O_3	28.73	28.55	25.53	31.72	24.01	26.92
MnO	8.82	5.41	7.41	1.14	5.94	3.92
CaO	24.05	26.74	29.20	31.74	27.36	30.97
MgO	1.42	2.13	.39	.60	1.29	.89
ZnO						[a] 1.45
H_2O						.80
	98.97	101.40	99.93	100.17	100.14	99.55

[a] Inclusion of zincite.

1, 2. Polyadelphite. C. F. Rammelsberg (79), analyst.
3. Polyadelphite. L. H. Bauer (225), analyst.
4. Andradite, greenish-yellow, $n = 1.92$. Jenkins and Bauer (243), analysts.
5. Polyadelphite, brownish-black, $n = 1.89$. Jenkins and Bauer (243), analysts.
6. Andradite, dark purplish-red, $n = 1.89$, specific gravity 4. L. H. Bauer (243), analyst.

Occurrence.—At Franklin garnet was one of the most abundant minerals found in the pegmatite contact zones in parts of the ore body. Great masses of yellow, green, or brown massive garnet, mingled with biotite, franklinite, rhodonite, calcite, and other minerals, were characteristic especially of the Trotter and Parker shafts. This garnet, which was all somewhat manganiferous, rarely occurred in crystals, though here and there rough crystals were found embedded in the calcite. The material analyzed and named "polyadelphite" by Thomson (24) was probably of this nature.

Sharp dodecahedral crystals of black, brown, and yellow garnet embedded in calcite have been recorded from Franklin but without definite statement of locality. Abundant rough brownish dodecahedrons, some of them several inches in diameter, were found with pyroxene in a pocket in limestone near Double Rock and are illustrated in plate 11, *A*. Some of the garnet was embedded in colorless sphalerite.

Small translucent raspberry-red and pale-yellow dodecahedrons, together with massive granular garnet of the same colors, form a considerable part of the specimens from the pockets at the Buckwheat mine in which were found, among other species, the rare mineral pyrochroite. (See p. 50.) This garnet is manganiferous, but sufficient material for analysis could not be obtained, and the refractive index is that of andradite.

At the Gooseberry iron mine on Balls Hill there was opened at one time a large pocket containing several bushels of garnet crystals of great beauty. As seen in the Losey and Canfield collections these garnets are black, very brilliant, large, and very symmetrical, being dodecahedrons with narrow faces of the trapezohedron. One in the Canfield collection measures 23 inches around a central section. They were associated with pyroxene, zircon, and scapolite. Red and cinnamon-brown massive garnet were also found there with magnetite. It showed but a trace of manganese, differing in that respect from all the samples tested of garnet found near the zinc ores, which are rich in manganese.

At Sterling Hill garnet is not so abundant as at Franklin. Dodecahedral crystals of rough brown garnet, an inch or more in diameter, were fairly numerous in the pockets containing dysluite, and both single crystals and groups, with jeffersonite and dysluite, are preserved in the Canfield collection.

Bright-red dodecahedrons partly embedded in limestone were found in the stripping of the calamine bed in the Noble mine. The best of these—a splendid crystal measuring nearly 3 inches on the edge of the very regular dodecahedron—is in the collection at Princeton University.

CHRYSOLITE GROUP

The chrysolite group is an important one at Franklin. It includes the manganese olivines (tephroite and roepperite), the calcium tephroite (glaucochroite), and the recently described lead-bearing members of the group (larsenite and calcium larsenite). Their relations of composition and form are shown in the following comparative statement.

Comparison of members of the chrysolite group

Species	Composition	Axial ratio *a* : *b* : *c*	Specific gravity
Tephroite	$(Mn,Mg,Zn)_2SiO_4$	0.461 : 1 : 0.589	4.12
Roepperite	$(Fe,Mg,Mn,Zn)_2SiO_4$	.466 : 1 : .586	4.00±
Glaucochroite	$CaMnSiO_4$	.441 : 1 : .581	3.41
Larsenite	$PbZnSiO_4$	.434 : 1 : .532	5.90
Calcium larsenite.	$(Pb,Zn,Ca)SiO_4$	Unknown	4.42

TEPHROITE

$(Mn,Mg,Zn)_2SiO_4$. Orthorhombic

Forms.—*a*(100), *b*(010), *c*(001), *m*(110), *n*(210), *s*(120), *r*(130), *j*(270), *d*(101), *ω*(103), *h*(011), *k*(021), *e*(111), *f*(121), *l*(131), and *q*(122).

Combinations on crystals of tephroite

	Forms	Localities	Illustrations
1	*b, d, e*	Sterling Hill	Fig. 106.
2	*b, m, d*	do	Fig. 107.
3	*a, b, m, d, e*	do	Fig. 108.
4	*a, m, s, d, e, f*	Franklin	
5	*a, b, m, s, h, e, f, l*	do	
6	*a, b, m, n, s, d, h, k, e, f, l*	do	
7	*a, b, m, s, d, h, k, e, f, l*	do	
8	*c, a, b, m, n, s, ω, d, h, k, e, f, l*	do	Fig. 104.
9	*a, b, m, s, d, h, k, e, f, l*	do	Gordon (222), fig. 1.
10	*a, b, m, s, d, k, e, f*	do	Idem, fig. 2.
11	*a, m, s, f*. Twin on (011)	do	Fig. 103.
12	*b, c, s, d, k*	do	Fig. 105.

Crystallographic measurements.—Accurate crystallographic data on tephroite from Franklin were first published by Gordon (222). The following table contains the results of measurements of 8 excellent crystals obtained by the author in 1915 but not yet published:

Angle table of tephroite

Symbol	Calculated		Measured		Number of faces	Limits	
	φ	ρ	φ	ρ		φ	ρ
	° ′	° ′	° ′	° ′		° ′ ° ′	° ′ ° ′
c(001)	0 0	0 0	0 0	0 0	2		
a(100)	90 0	90 0	90 0	90 0	5		
b(010)	0 0	90 0	0 0	90 0	5		
m(110)	65 15	90 0	65 16	90 0	10	65 3–65 29	
n(210)	77 1	90 0	76 32	90 0	3	75 13–77 49	
s(120)	47 20	90 0	47 19	90 0	9	47 6–47 28	
ω(103)	90 0	23 5	90 0	22 43	3		22 0–23 26
d(101)	90 0	51 58	90 0	52 6	4		52 0–52 18
h(011)	0 0	30 53	0 0	30 24	3		30 2–30 40
k(021)	0 0	49 41	0 0	49 34	3		49 34–50 26
e(111)	65 15	54 37	65 16	54 36	13	65 2–65 40	54 17–54 50
f(121)	47 20	60 6	47 19	60 6	15	47 6–47 34	59 56–60 23
l(131)	35 52	65 22	35 52	65 23	12	35 48–35 56	65 12–65 40

The axial ratio was calculated from 40 readings on terminal faces of 8 crystals, which yielded the values: $p_0=1.278$, and $q_0=0.589$; or $a:b:c=0.461:1:0.589$.

Gordon's axial ratio, derived from the measurement of four crystals, is practically identical and is $a:b:c=0.4606:1:0.5899$.

The form *ω*(103) is new for tephroite.

Habit.—Crystals of tephroite are rare, and the mineral is commonly found in coarse granular form, breaking into rectangular blocks with rudely striated faces. The cleavage is distinct parallel to the base and to the brachypinacoid and is therefore rectangular. The hardness is 5.5 to 6, and the specific gravity is 3.87 to 4.1. The crystals are bluish-green by daylight and pink by artificial light, resembling in this respect the closely related mineral glaucochroite. The color of the granular material is ash-gray, brown, red-brown, and flesh-red and is darker or black on weathered surfaces. Some of the color is due to included zincite. The luster is vitreous to greasy. Tephroite is easily mistaken in some of its forms for willemite, as it has the same luster and color range as the variety troostite. Its better and distinctly rectangular cleavages are a definite means for its identification.

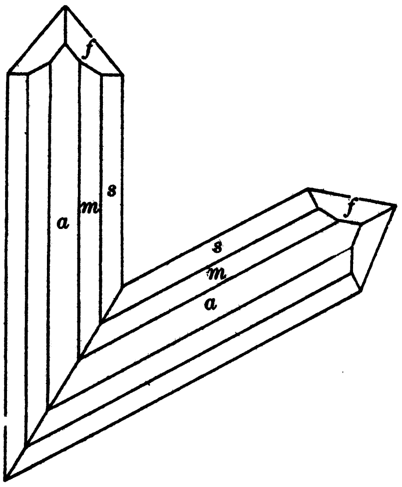


FIGURE 103.—Projection on the macropinacoid of a crystal of tephroite, twinned on the brachydome *h*(011), showing the forms *a*(100), *m*(110), *s*(120), and *f*(121). Franklin.

Contact twins on *h*(011), the common twinning plane for this group of minerals, were described by the author (257) and are shown in figure 103.

Optical properties.—Tephroite is biaxial and negative; $X=b$ and $Z=c$; $2V=60°$; r>v (perceptible, nearly colorless in section); $\alpha=1.77$, $\beta=1.807$, $\gamma=1.825$, all ± 0.001 (Berman).

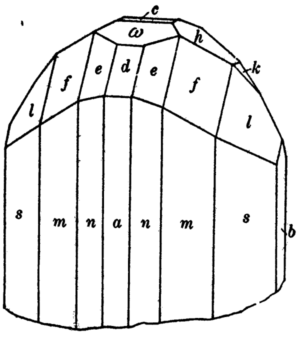


FIGURE 104

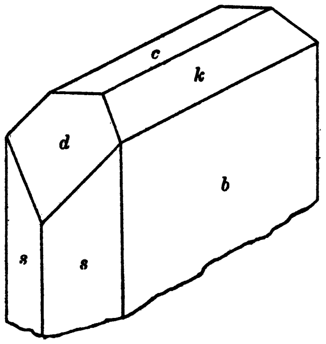


FIGURE 105

FIGURE 104.—Crystal of tephroite showing the forms *c*(001), *a*(100), *b*(010), *m*(110) *s*(120), *n*(210), *ω*(103), *d*(101), *h*(011), *k*(021), *e*(111), *f*(121), and *l*(131). Franklin.

FIGURE 105.—Large crystal of tephroite showing the forms *c*(001), *b*(010), *s*(120), *k*(021), and *d*(101) Franklin

Composition.—Tephroite is essentially an orthosilicate of manganese, commonly containing more or less magnesium, zinc, iron, or calcium, or several of those metals. The following analyses of Franklin tephroite show its range in composition in that respect. It gelatinizes easily with acids and fuses at 3.5 to a black mass; magnesian varieties are less easily fused.

Analyes of tephroite

	1	2	3	4	5	6	7	8	9	10	11	12	13
SiO_2	29.64	28.66	28.37	29.95	30.19	30.55	31.73	29.44	30.63	29.96	29.53	26.92	29.13
MnO	66.60	68.88	59.31	36.43	65.59	52.32	47.62	57.31	49.80	30.00	43.64	49.65	66.81
MgO	------	------	2.16	18.60	1.38	7.73	14.03	2.50	10.16	15.19	9.64	7.86	.46
ZnO	------	------	7.58	11.61	.27	5.93	4.77	7.36	5.74	18.90	12.15	10.16	1.53
FeO	.92	2.92	2.16	1.96	1.09	1.52	.23	.87	3.33	1.54	4.41	2.50	.31
CaO	------	------	.39	------	1.04	1.60	.54	2.51	------	1.20	------	2.70	------
Al_2O_3	------	------	------	------	------	------	------	------	------	1.25	------	------	1.48
H_2O	2.70	------	------	1.71	.37	.28	.35	.27	------	1.38	------	------	.20
	99.86	100.46	99.97	100.26	99.93	99.93	99.27	100.26	99.66	99.42	99.37	99.79	99.92

1. Franklin. Thomas Thomson (23), analyst.
2. Sterling Hill. C. F. Rammelsberg (35), analyst.
3. Sterling Hill. Henri Deville (86), analyst.
4. Sterling Hill. Damour (85), analyst.
5. Sterling Hill. G. J. Brush (87), analyst.
6. Sterling Hill. Collier (87), analyst.
7. Sterling Hill. Hague (87), analyst.
8. Franklin. W. G. Mixter (98), analyst.
9. Franklin. G. C. Stone (131), analyst.
10. Sterling Hill. L. H. Bauer (243), analyst.
11, 12. Franklin. L. H. Bauer (243), analyst.
13. Franklin. L. H. Bauer (257), analyst.

In all the analyses there is sensible conformity to the accepted ratios for the orthosilicate formula—different amounts of magnesium and zinc and, to a less extent, iron and calcium taking the place of part of the manganese. Brush was of the opinion that the zinc found in all analyses is present in included zincite, but that this is not invariably true is shown by the fact that the molecular ratios in some analyses more nearly satisfy the orthosilicate formula when zinc is regarded as essentially a part of the mineral rather than as a constituent of mechanical inclusions.

Occurrence.—At Franklin tephroite is in places an important constituent of the ores, being found in considerable abundance mixed with zincite, willemite, and franklinite in a calcite gangue. In 1905 and again in 1911, it was thus seen by the author in large masses in ore being taken from the west leg of the ore body in the Buckwheat open cut. Such material is illustrated in plate 12, *B*.

The crystals described above form part of the filling of a thin vein. They were obtained by Mr. Cahn, but the locality where they were found is unknown. The largest was nearly an inch long; the others were much smaller. Their bluish color caused them to be mistaken for glaucochroite, which they were supposed to be until Gordon's similar error was discovered. (See p. 80.) The crystals are singly terminated and either stand free in the vein or are embedded in granular calcite. The main filling of the vein is reddish manganesian garnet partly coated with dark-red friedelite in stalactitic form. Crystals of tephroite and clear green willemite are implanted on the friedelite. Later there was deposited a fibrous brown mineral somewhat doubtfully determined as friedelite.

Almost all the free crystals of tephroite are marked by a later growth in parallel position of pale-brown pyramidal crystals, forming a serrate edge along the outer margin of their terminal faces. These pyramids are evidently orthorhombic and are strictly parallel to the tephroite beneath and to one another. Their faces are dull but give poor measurements, with an average value for six faces of $\phi = 66°7'$ and $\rho = 73°2'$.

There was too little of this material to yield more than a tiny fragment from which the presence of manganese could be proved.

If it is assumed that these crystals are also tephroite, in parallel position to the older tephroite, computation shows that the pyramid (221) of tephroite (a form not known) would have the position $\phi = 65°18'$, $\rho = 70°37'$. The agreement is poor, but as the measurements were very poor it is possible that the discrepancy is not too great to be allowed.

Gordon's crystals of tephroite likewise lined veins in massive ore together with greenish crystals of willemite. From specimens of this sort in the Harvard collection it is clear that the locality is different from that of the material just described. The veins, some of them 2 inches thick, consist chiefly of massive brown garnet, which is crystallized on the walls of what appear to be solution cavities. On the garnet are implanted numerous crystals of bluish tephroite, many of their faces, especially the terminal ones, being dull through etching. The largest crystal seen was scarcely one-third of an inch long. Later than the tephroite are scalenohedral crystals of calcite and slender crystals of willemite, white or pale green, with darker terminations, and brilliantly crystallized with third-order rhombohedrons. In a few cavities is a still later deposit of very dark brown friedelite in wormlike stalactitic aggregates.

This tephroite was analyzed, as shown in analysis 13. Except for the earliest (and hence unreliable) analyses of tephroite, this is the nearest to pure manganese orthosilicate yet found. The alumina is probably to be assigned to intermixed garnet, though its amount is puzzling. The optical properties given on page 76 are for this pure mineral.

Individual crystals of tephroite of unusual size have been found at Franklin on the picking table. Figure 105 was drawn from a fragment measuring 1.2 by 3.5 by 3.5 inches, which is broken on three sides and obviously was once much larger. It is embedded in coarse limestone and is quite isolated. Others of similar dimensions have been found.

At Sterling Hill, besides being in the granular ore, tephroite has been found in rough isolated crystals embedded in limestone. These crystals have commonly been regarded as chondrodite by the local collectors, and certainly they resemble that mineral superficially. Their form, as shown in figures 107 and 108, is like that of olivine.

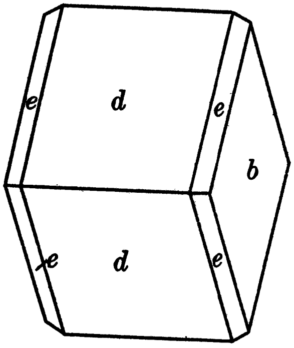


FIGURE 106

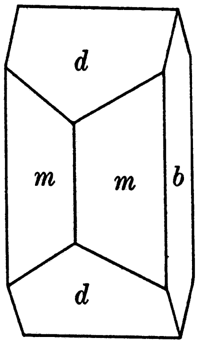


FIGURE 107

FIGURE 106.—Pseudocubic crystal of tephroite showing the forms *b*(010), *d*(101), and *e*(111) Sterling Hill. This figure follows the description of Des Cloizeaux (87)

FIGURE 107.—Simple crystal of tephroite showing the forms *b*(010), *m*(110), and *d*(101) Sterling Hill.

Analysis 10, made by Jenkins and Bauer on a crystal of this type from the collection of T. Lang, is the highest in magnesium of all the analyses of tephroite except no. 4, the source of which was doubtful. Thus it is highly probable that the figure of tephroite given by Des Cloizeaux (85), reproduced in figure 106, with which is given the analysis by Damour of a magnesian tephroite, represents one of these crystals from Sterling Hill. They are also illustrated in plate 12, *A*.

Historical notes.—Tephroite was first analyzed by Thomson (23) under the name "silicate of manganese", the material having been supplied by Torrey from Franklin and reported "not scarce." Breithaupt (16) had given the name "tephroite" to material from Sterling Hill obtained from a private collector in Dresden, and this material was later analyzed by Rammelsberg (35), who recognized its identity with Thomson's mineral. For many years thereafter the mineral was quite overlooked by Franklin collectors, until Brush (87) again called attention to its abundance at Sterling Hill.

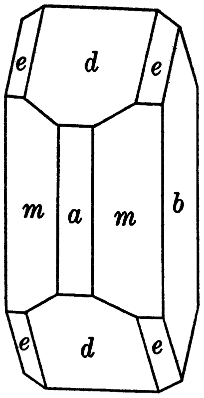


FIGURE 108

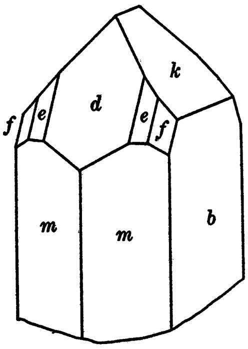


FIGURE 109

FIGURE 108.—Prismatic crystal of tephroite showing the forms *b*(010), *a*(100), *m*(110), *d*(101), and *e*(111). Sterling Hill.

FIGURE 109.—Crystal of roepperite showing the forms *b*(010), *m*(110), *d*(101), *k*(021, *e*(111), and *f*(121) Sterling Hill.

ROEPPERITE

$(Fe, Mn, Zn, Mg)_2SiO_4$. Orthorhombic

Forms.—*c*(001), *a*(100), *b*(010), *m*(110), *d*(101), *k*(021), *e*(111), *f*(121), and *ω*(211).

Combinations on crystals of roepperite

	Forms	Localities	Illustration
1	*b, m, d, k*	Sterling Hill	
2	*b, c, m, d, k*	do	
3	*b, c, m, d, k, e, f*	do	Fig. 109.
4	*b, m, d, k*	Franklin	

Physical properties.—Roepperite is found commonly in crystals, either prismatic or tabular parallel to the brachypinacoid. They are rarely sharp, the terminations being rounded and uneven or the faces being notched and grooved, as if by solution. It is found also in massive granular form. The cleavage is perfect parallel to the base and to the brachypinacoid and splintery parallel to the macropinacoid, and the cleavage surfaces show a greasy luster. The exterior of the crystals is black, but broken surfaces are dark green mottled with yellowish green and the mineral is translucent. The hardness is 5.5 to 6, and the specific gravity is 3.95 to 4.08.

Roepperite is optically negative; $2V=77°\pm5°$; $r>v$ (rather strong); $\alpha=1.758$, $\beta=1.768$, $\gamma=1.804$, all ±0.003 (Larsen).

Composition.—Roepperite is a member of the chrysolite group, characterized by a high content of iron and zinc. When described it was the first known zinc-bearing member of the group, but tephroite has since been found to have so wide a range in content of zinc that no sharp line can be drawn between the two.

Analyses of roepperite

[W T Roepper (99), analyst]

	1	2	3
SiO_2	30. 76	30. 23	30. 54
FeO	33. 78	35. 52	34. 78
MnO	16. 25	16. 91	17. 74
ZnO	10. 96	10. 68	9. 48
MgO	7. 60	5. 63	6. 09
Insoluble (spinel)	--------	1. 04	2. 02
	99. 35	100. 01	100. 65

1. Crystals.
2. Average of two crystals.
3. Average of two powders of the massive variety

Occurrence.—Roepperite was first described by Roepper (94) and was named for him by Brush (102). It was named "sterlingite" by Kenngott at the same time, but the name "roepperite" was finally adopted. The type material was found associated with franklinite, jeffersonite, and gahnite. According to Mr. Canfield, there was a large deposit of it high on the east leg of the ore body at Sterling Hill, more than 100 tons of which was mined and shipped as iron ore. It was not noticed at the time, however, as a new or peculiar mineral, and the deposit was exhausted without many specimens having been saved. Roepper's specimens were stray fragments picked up years later. The best specimens seen are in the Canfield collection (see fig. 109 and pl. 15, *A*), where there are single crystals as much as 5 inches long and 2 inches broad, as well as groups of crystals implanted on the matrix.

At Franklin Brush (100) identified roepperite in association with gahnite from the tunnel from the Buckwheat mine to the Wallkill River. It is in black crystals that are dark green on fractured surfaces. Brush did not publish his partial analysis, and little of the material was preserved.

GLAUCOCHROITE

$CaMnSiO_4$. Orthorhombic

Forms.—*a*(100), *b*(010), *m*(110), *s*(120), *x*(103), *h*(011) (as twinning plane only), *k*(021), *e*(111), and *f*(121).

Combinations on crystals of glaucochroite

	Forms	Illustrations
1	*m*, *s*, nonterminated	
2	*a*, *m*, twinned on *h* (Penfield, 179)	
3	*b*, *m*, *s*, *x*	Fig. 110
4	*a*, *b*, *m*, *s*, *k*, *e*, *f*	Fig. 111

Habit.—Glaucochroite is generally found in crystals of long prismatic habit, either single or in columnar aggregates, and it is rarely massive. Terminated crystals are scarce, the crystals generally showing poor basal cleavage or irregular contact faces. Penetration twins and contact twins, with *h*(011) as the twinning plane, are found, the vertical axes of the individuals crossing at an angle of about 59°.

Penfield (179), who discovered and first described the species, was unable to find terminated crystals on his material. However, he obtained an approximate axial ratio by measurement of prisms and of the inclination of individuals in twin position.

The author was so fortunate as to obtain two minute crystals having excellent terminations from a specimen presented by the Foote Mineral Co., and the elements given below were computed from the following measurements made upon them. These crystals also gave the optical data of the mineral.

Angle table of glaucochroite

[$a\ \ b\ \ c=0.4409\ \ 1\ \ 0.5808$; $p_o=1.3174$, $q_o=0.5808$]

Form	Number of readings	Measured				Computed			
		ϕ		ρ		ϕ		ρ	
		°	′	°	′	°	′	°	′
(110)	[a] 4	66	9	90	0	66	12	90	0
(120)	[a] 4	49	14	90	0	48	36	90	0
(103)	1	94	12	23	11	90	0	23	42
(021)	1	0	0	49	30	0	0	49	16
(111)	1	66	14	55	12	66	12	55	13
$(1\bar{1}1)$	1	113	47	55	18	113	48	55	13
(121)	1	49	22	60	29	48	36	60	21

[a] Average.

Physical characters.—The properties of glaucochroite as determined by Penfield are as follows: Basal cleavage very poor, hardness 6, specific gravity 3.407, luster vitreous, color delicate bluish green and of small crystals white or pinkish. It is optically negative, the axial plane being parallel to the base. $Bx_a \perp (010)$; $r > v$ (marked); $2V$ over $X = 60°51'$; $\alpha = 1.686$, $\beta = 1.722$, $\gamma = 1.735$, $\gamma - \alpha = 0.049$.

Composition.—Glaucochroite is a calcium manganese orthosilicate, analogous to tephroite, calcium taking the place of half the manganese.

Analyses of glaucochroite

	1	2	3
SiO_2	31.48	31.23	31.72
MnO	38.00	34.46	33.13
CaO	28.95	23.25	29.04
ZnO	--------	3.28	2.40
PbO	1.74	--------	.31
MgO	--------	3.17	2.23
FeO	Trace	--------	.11
Fe_2O_3	--------	1.25	.95
Al_2O_3	--------		
Na_2O	--------	.39	--------
K_2O	--------		--------
H_2O	--------	3.18	--------
	100.17	100.21	99.89

1. Crystals, Franklin. C. H. Warren (179), analyst.
2. Massive mineral (average of two analyses), Franklin. R. B. Gage, analyst (unpublished).
3. Franklin. L. H. Bauer (257), analyst.

The first analysis gives excellent molecular ratios for the formula $CaMnSiO_4$. The third is closely similar, the zinc being known to be present in willemite. The second analysis is of dull-gray, very fine grained, massive material, which under the microscope is seen to be of somewhat doubtful homogeneity. It is intermixed with areas of franklinite that it is apparently replacing.

Occurrence.—Very few specimens of glaucochroite have been preserved. The mineral came from the same part of the Parker shaft as clinohedrite and like it was found only on the mine dump. The crystals are embedded in nasonite or willemite, from which they are readily separated, but owing to their extreme brittleness they are generally in fragments. They are intimately associated also with garnet and yellow axinite. The terminated crystals described here were embedded in transparent green willemite or were implanted upon it, together with minute crystals of clinohedrite.

Crystals described by Gordon (222) as glaucochroite were shown by Schaller (Gordon, 226), by determination of the optical characters, to be tephroite.

The only other discovery of glaucochroite at Franklin was made in 1927, when specimens from the deep levels of the mine were found on the picking table. The glaucochroite here is a coarse granular form of bluish color, intimately mixed with willemite, hardystonite, tephroite, and franklinite. Analysis 3, in the table above, represents this material.

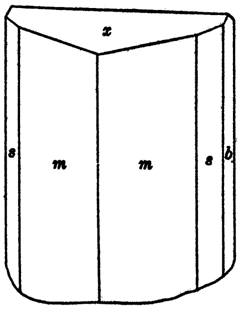


FIGURE 110

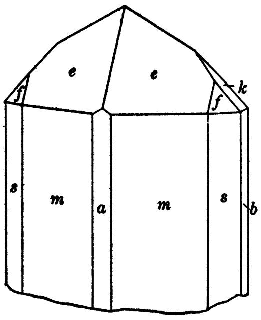


FIGURE 111

FIGURE 110.—Crystal of glaucochroite showing the forms *b*(010), *m*(110), *s*(120), and *x*(103) Franklin.

FIGURE 111.—Crystal of glaucochroite showing the forms *a*(100), *b*(010), *m*(110), *s*(120), *k*(021), *e*(111), and *f*(121). Franklin.

Material known locally as "calcotephroite" was found abundantly at Franklin about 1924 and was analyzed as shown above in no. 2. It is very dense and fine grained, white when first taken from the mine but soon turning dark brown upon exposure to the light. It appears to be a very impure variety of glaucochroite.

LARSENITE

$PbZnSiO_4$. Orthorhombic

Crystallographic elements.—Computation based on the measurement of 40 faces, distributed among 5 forms, gives the result $a : b : c = 0.4339 : 1 : 0.5324$; $p_0 = 1.2268$, $q_0 = 0.5324$.

Forms.—*a*(100), *b*(010), *m*(110), *n*(210), *s*(120), *y*(150), *d*(101), *w*(012), *e*(111), *q*(122), *t*(132), *A*(142), *l*(131), *C*(252), and *B*(9.8.18).

Combinations on crystals of larsenite

	Forms	Illustrations
1	*b, a, m, s, A, B*	Fig. 112.
2	*b, m, s, w, A, C, B*	Fig. 113.
3	*b, m, s, y, q, t, A*	Fig. 114.
4	*b, s, A*	Fig. 115.
5	*a, n, m, s, w, e, A, B*	
6	*b, m, s, w, e, A, C, B*	
7	*n, m, s, t, A, l*	
8	*b, m, d, e, A, B*	

Habit.—The crystals of larsenite are slender needles 10 to 20 times as long as they are thick, forming an interlacing network in vein cavities. Many of them reach from wall to wall and show no terminations, but a few stand with one end free and can be detached for measurement. Rarely the mineral has the form of thin lustrous plates.

The prism zone is generally rounded by striation, only one measured crystal showing a pronounced flattening parallel to the brachypinacoid. The prism *s*(120), to which the cleavage is parallel, was seen on all the crystals and gives good reflections, whereas *m*(110), *n*(210), and *y*(150) are only narrow linear faces.

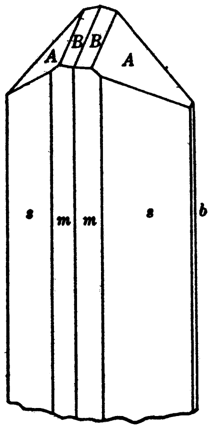


FIGURE 112

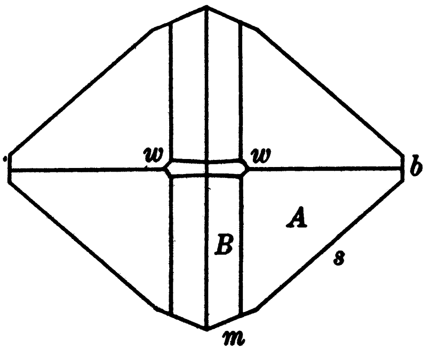


FIGURE 113

FIGURE 112.—Prismatic crystal of larsenite showing the usual termination, with the forms *b*(010), *m*(110), *s*(120), *A*(142), and *B*(9.8.18). Franklin.

FIGURE 113.—Plan of a prismatic crystal of larsenite showing the forms of figure 112 and also *w*(012). Franklin.

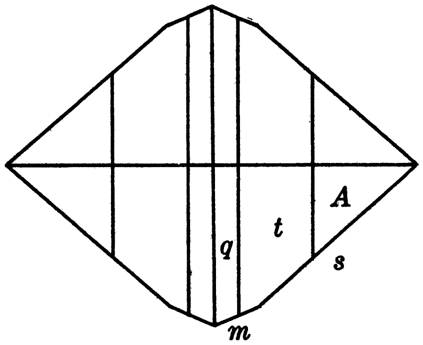


FIGURE 114

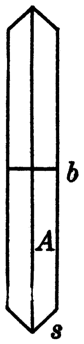


FIGURE 115

FIGURE 114.—Plan of a prismatic crystal of larsenite showing the forms *m*(110), *s*(120), *q*(122), *t*(132), and *A*(142). Franklin.

FIGURE 115.—Plan of a crystal of larsenite of tabular habit, showing the forms *b*(010), *s*(120), and *A*(142) Franklin.

The termination is generally dominated by the pyramid *A*(142), whose faces are excellent and give consistent readings.

Figure 112 shows the prevailing habit; in figure 113 the brachydome is added; figure 114 shows a habit seen on but one crystal; and the platy habit is illustrated in figure 115. Forms not shown in the figures are subordinate and are generally seen only as linear faces. The needles are very slender, so that the terminal faces on all crystals are exceedingly minute.

Because of the high luster of the mineral, however, they give good measurements despite their small size.

Physical properties.—Larsenite is white and transparent with adamantine luster. The cleavage is good parallel to the prism $s(120)$. The specific gravity is 5.90. Larsenite is optically biaxial and negative; $2V$ is about 80°; r>v (easily perceptible). The axial plane is across the elongation with an optic axis practically normal to the prismatic cleavage, hence $Y=c$ and $X=a$. $\alpha=1.92$, $\beta=1.95$, $\gamma=1.96$, all ±0.01 (immersion) (Berman). Under the iron-arc spark gap larsenite shows either a pale-violet fluorescence or none at all.

Composition.—The following analysis shows the composition of larsenite:

Analysis of larsenite

	1	2
SiO_2	16. 87	16. 47
PbO	56. 66	61. 21
ZnO	22. 74	22. 32
FeO	. 10	-------
MnO	. 14	-------
CaO	2. 42	-------
MgO	. 20	-------
H_2O	. 76	-------
	99. 89	100. 00

1. Larsenite, containing 9.26 percent of clinohedrite. L. H. Bauer (256), analyst.
2. Composition computed from formula adopted.

The material analyzed was known to contain clinohedrite, and the lime and water found were regarded as due to that mineral. After deducting 9.26 percent of clinohedrite, the remainder gave a ratio fairly close to that required by the formula $PbZnSiO_4$, which is therefore adopted as the formula of larsenite.

Occurrence.—Larsenite was first found in 1928 and, with the closely related calcium larsenite, was described in papers by Palache, Bauer, and Berman (256, 259). The first specimens were found on the picking table at Franklin, and the mineral was afterward located in the mine at the north end, 20 feet above the 400-foot level in top slice 1080. Part of the specimens are in veins cutting ore, and part have replaced rather coarse, massive willemite-franklinite ore. The veins are sharply bounded against the granular ore and differ in their contents from place to place.

The earliest mineral to form was a massive pink garnet, identical in appearance and refractive index (1.885) with garnet from another specimen, shown by partial analysis to be andradite. Upon this is a coating of hodgkinsonite of the same pink color as the massive garnet. Most surfaces of the open veins show rather indistinct crystals, with rounded faces, of pale-pink to almost colorless hodgkinsonite. In several specimens devoid of lead silicates the only minerals later than hodgkinsonite are calcite in slender needles or clear prismatic crystals, botryoidal coatings of smithsonite, granular orange-colored zincite, and a last coating of snow-white needles of willemite forming delicate rosettes. In other parts of the open veins hodgkinsonite was followed by an abundant layer of crystalline clinohedrite with which the slender needles and plates of larsenite are contemporaneous. A few spots of dull-white massive roeblingite (?), covering clinohedrite crystals, were found in one of the specimens. Larsenite is far less abundant than calcium larsenite, and in most specimens the two are not associated, but in two places crystals of larsenite were found in cavities with calcium larsenite. Furthermore, larsenite is found only in the vein material and not in the replaced ore.

It is worthy of note, in view of the discovery of these lead silicates, that in two analyses of glaucochroite (see p. 79) some lead is reported, indicating the possible presence of the larsenite molecule.

CALCIUM LARSENITE

$(Pb,Ca,Zn)_2SiO_4$. Orthorhombic

Habit.—Calcium larsenite is found in coarse granular massive form, and crystals are unknown.

Character.—Calcium larsenite is white and opaque, with a greasy luster, and the cleavage is indistinct. Its specific gravity is 4.421. Under the iron-arc it shows a strong lemon-yellow fluorescence, more vivid than and easily distinguished from that of willemite and so strong that the mineral can be instantly detected. A specimen of hardystonite collected by Professor Wolff at the Parker shaft before 1898 was thus shown to contain calcium larsenite.

Hardly any calcium larsenite found is fresh, because it alters easily on exposure and becomes darker. The darkening is possibly due to the separation of native lead (?), which Bauer has found associated with calcium larsenite. A specimen in the Harvard collection shows a fresh core of calcium larsenite surrounded by a thick dark-brown zone of altered material.

Analysis of calcium larsenite

	1	2	
SiO_2	24. 10	0. 401	
FeO	. 48		
MnO	. 57		
CaO	16. 36	. 292	
ZnO	30. 61	. 376	0. 792
PbO	27. 63	. 124	
MgO	. 23		
H_2O-	. 12		
	100. 10		

1. Calcium larsenite. L. H. Bauer (256), analyst.
2. Molecular ratio of essential constituents.

The mineral is optically biaxial and negative. The material analyzed was almost uniaxial, as $2V=5°$, and $\alpha=1.760$ and $\beta=\gamma=1.769$, all ±0.001. Another sample, apparently fresher than the analyzed material, gave $2V=40°$, and $\alpha=1.762$, $\beta=1.770$, and $\gamma=1.774$ (Berman).

Composition.—Calcium larsenite is an orthosilicate of calcium, lead, and zinc.

Occurrence.—Calcium larsenite was found at Franklin, closely associated with larsenite, as described under that mineral. It was also found later in the 1,100-foot level in pillar 80, replacing a mixture of hardystonite and glaucochroite with franklinite.

WILLEMITE

$(Zn,Mn)_2SiO_4$. Hexagonal-trirhombohedral

Forms.—$c(0001)$, $a(11\bar{2}0)$, $m(10\bar{1}0)$, $h(3\bar{1}\bar{2}0)$, $F(31\bar{4}0)$ $u(2\bar{1}\bar{1}3)$, $s(11\bar{2}3)$, $f(4\bar{2}\bar{2}3)$, $b(22\bar{4}3)$, $g(01\bar{1}5)$, $e(01\bar{1}2)$, $r(10\bar{1}1)$, $n(02\bar{2}1)$, $C(5\bar{2}\bar{3}4)$, $o(5\bar{1}\bar{4}3)$, $k(4\bar{1}\bar{3}2)$, $x(3\bar{1}\bar{2}1)$, $y(21\bar{3}1)$, $A(5\bar{2}\bar{3}1)$, $j(7\bar{3}\bar{4}1)$, $i(43\bar{7}1)$, $B(8\bar{2}\bar{6}1)$, $t(13.\bar{5}.\bar{8}.3)$, $w(14.\bar{5}.\bar{9}.1)$, $G(\bar{1}7\bar{6}5)$, $d(12\bar{3}2)$, $D(\bar{1}3\bar{2}2)$, $H(13\bar{4}4)$, $q(13\bar{4}1)$, $l(15\bar{6}1)$.

Combinations on crystals of willemite

	Forms	Localities	Illustrations and references
1	*a, u, s, b, e, r, k, x, y, B, d, D.*	Franklin	
2	*a, u, s, r, n, k, x, y, d, D, q*	do	
3	*a, m, u, s, e, r, n, k, x, y, d, D.*	do	
4	*a, u, s, b, e, r, k, x, y, A, d*	do	
5	*a, b, r, k, x, y, d, D*	do	
6	*a, u, s, b, e, r, k, x, y, A, d, D.*	do	
7	*a, u, s, b, r; k, x, y, A, B, d, D.*	do	
8	*a, m, h, u, s, b, e, r, C, k, x, y, d, D.*	do	
9	*a, e, r, x*	do	Fig. 116.
10	*a, m, r, n, k, x, y, d, D, q*	do	Fig. 117.
11	*a, m, r, n, o, x, y*	do	Fig. 118.
12	*a, m, r, x, t, j*	do	Fig. 119.
13	*a, m, u, s, r, n, o, k, x, y, d, D, q.*	do	
14	*a, m, r, n, o, k, x, y, q*	do	
15	*a, m, r, n, k, x, y, j, i, d, D*	do	
16	*a, m, u, r, n, o, k, x, y, d, D*	do	
17	*a, m, r, n, o, k, x, y, j, d, D, q, l.*	do	
18	*a, m, u, s, r, n, k, x, y, d, D, q, l.*	do	
19	*c, a, u, e, r, n, x, y, D*	do	Fig. 120.
20	*a, b, r, k, x, y, A, d*	do	Fig. 121.
21	*c, a, e, r*	do	Fig. 122.
22	*a, m, r, x, y, t, w*	do	
23	*c, a, u, s, e*	do	Fig. 128.
24	*a, m, u, e*	do	
25	*c, a, u, e*	do	
26	*a, u, s*	do	Fig. 129.
27	*a, u*	do	Fig. 130.
28	*c, a, s, e*	do	Fig. 123.
29	*c, a, e, r*	do	Fig. 124.
30	*a, r, k, x, y*	do	Fig. 125.
31	*a, s, f, g, e, r, k, x, y, d, D*	do	Fig. 126.
32	*a, s, f, e, r, k, x, y, G, d, D*	do	
33	*c, a, s, g, e, r, k, x, y, D, q*	do	
34	*c, a, m, F, u, s, b, e, r, n, x, y, d, H.*	do	Fig. 127.
35	*a, m, e, r, x*	Sterling Hill	Penfield (156).
36	*a, m, h, u, s, e*	do	Do.
37	*c, a, e*	do	
38	*c, a*	do	
39	*a, m, e, r*	do	
40	*a, e, r*	do	Fig. 131.
41	*a, r*	do	Fig. 132.

Crystallographic elements.—No accurate measurements of willemite crystals from Franklin were recorded before 1910. The elements adopted by Dana were based on contact measurements of troostite crystals from Sterling Hill. Other authors use elements determined by Lévy on crystals from Moresnet, Belgium, on which the sole form is a rhombohedron not known on Franklin crystals.

A number of measurable crystals passed through the hands of the author during the time of this study, and the data from them permit the establishment of a satisfactory axial ratio. The measured crystals were colorless and pale-green prisms, small and variously terminated. The later crystals especially gave excellent and consistent readings for the several faces. Part of the results obtained have been published (Palache, 195, 204).

The following axial ratios have been used for willemite:

$a:c=1:0.6696$; Moresnet, Belgium. Lévy, 1830.
$a:c=1:0.6675$; troostite, Sterling Hill. Dana (46), 1850.
$a:c=1:0.6612$; Franklin. Palache (195), 1910.
$a:c=1:0.6679$; Franklin. Palache and Graham (204), 1913.

Of these the latest is the best and is the one adopted in this paper; from it is derived the element $p_0=0.4453$. For the relations of the several forms and for further details of the crystallography the reader is referred to the papers by Palache and Graham (204) and by Palache (251, 257).

Habit.—Stout to slender prisms, with basal or more commonly rhombohedral terminations, are abundant. Many of the crystals are rounded and pitted as if by solution. Willemite is also found in coarse to fine granular form, in rounded disseminated grains, and in parallel or radiate fibrous aggregates. Although the ordinary crystals of the troostite variety apparently have rhombohedral symmetry, the presence on the better crystals of rhombohedrons of the second and third orders leaves no doubt of the trirhombohedral symmetry of the species, which is further established by the character of the etch figures that have been fully illustrated by Honess (212).

Physical character.—The cleavage is indistinct parallel to the base and to the prism $a(11\bar{2}0)$ but is not always evident unless the fracture is carefully directed. The fracture is irregular to conchoidal, the hardness is 5.5, and the specific gravity is 3.89 to 4.19. The luster is vitreous in the purest crystals to resinous in the colored varieties. The color is extremely diverse; the most perfect transparent crystals are colorless to pale green, bright green, or wine-yellow; the opaque crystals and the massive mineral are snow-white, gray, apple-green, all shades of yellowish green and greenish yellow, flesh-red, mahogany-red, and dark brown; the weathered surfaces are not uncommonly black.

Willemite is optically uniaxial and positive. The refractive indices, determined on a prism cut parallel to the vertical axis of a clear wine-yellow crystal, are, for sodium light, $\omega = 1.694$, $\epsilon = 1.725$; for lithium light, $\omega = 1.689$, $\epsilon = 1.718$. The unusually pure willemite of analysis 21 gave the following indices for white light by the immersion method: $\omega = 1.691$, $\epsilon = 1.719$.

Willemite is generally fluorescent, and some specimens are strongly phosphorescent with a green color, but the purest white willemite, like troostite, gives little or no reaction. The so-called "black willemite" does not fluoresce.

Chemical composition.—Willemite is an orthosilicate of zinc, containing more or less manganese, iron, and magnesium in place of part of the zinc. The published analyses of the mineral are given below.

Analyses of willemite

	1	2	3	4	5	6	7	8	9	10	11
SiO_2	25. 44	25. 00	27. 40	26. 80	27. 91	27. 92	27. 40	27. 20	26. 92	28. 30	27. 48
ZnO	68. 06	71. 33	68. 83	60. 07	59. 93	57. 83	66. 83	65. 82	65. 04	66. 68	63. 88
MnO	6. 50	2. 66	2. 90	9. 22	3. 73	12. 59	5. 73	6. 97	7. 78	4. 92	8. 33
FeO		. 67	. 87	Trace	5. 35	. 62	. 06	. 23	. 51	. 31	. 49
MgO				2. 91	1. 66	1. 14					
CaO					1. 60						
H_2O		. 34		1. 00		. 28	. 18				
	100. 00	100. 00	100. 00	100. 00	100. 18	100. 28	100. 20	100. 22	100. 25	100. 21	100. 18

	12	13	14	15	16	17	18	19	20	21
SiO_2	27. 14	27. 75	27. 41	27. 74	27. 25	27. 18	25. 64	26. 56	28. 37	26. 55
ZnO	64. 38	60. 61	68. 86	69. 86	65. 85	69. 83	64. 74	61. 38	62. 24	72. 11
MnO	6. 30	10. 04	3. 48	. 55	2. 55	1. 38	7. 66	8. 96	2. 29	. 12
FeO	1. 24	1. 80		. 40	1. 71	. 29		. 81	1. 93	. 08
MgO				. 21	. 58	. 65	. 64	1. 05	4. 32	. 13
CaO		Trace		. 88	. 17	. 20	. 80	. 75	. 74	
H_2O			. 25		Trace		Trace			
Fe_2O_3					1. 39	. 23	. 20	. 23		
Mn_2O_3					. 32	. 09	. 12			
Al_2O_3										1. 00
PbO								. 005		
	99. 06	100. 20	100. 00	99. 64	99. 82	99. 85	99. 80	99. 74	99. 89	99. 99

In analyses 1, 2, and 3 the ZnO was estimated "by difference." In analysis 13 the MnO+FeO was estimated "by difference." All the analyses are stated in percent of each oxide.

1. Red mineral, Sterling Hill. W. H. Keating (17), analyst.
2. Red mineral, Sterling Hill. Lardner Vanuxem (17), analyst.
3. Willemite, Sterling Hill. Achille Delesse (42), analyst.
4. Red mineral, Sterling Hill. R. Hermann (45), analyst.
5. Dark-brown mineral, Sterling Hill. Henry Wurtz (50), analyst.
6. Yellow mineral, Sterling Hill. W. G. Mixter (98), analyst.
7. Apple-green mineral, Franklin. W. G. Mixter (98) analyst.
8. White mineral, Franklin. G. C. Stone (131), analyst.
9. Pale-green mineral, Franklin. G. C. Stone (131), analyst.
10. Red and white mineral, Franklin. G. C. Stone (131), analyst.
11. Greenish-yellow mineral, Franklin. G. C. Stone (131), analyst.
12. Dark-red mineral, Franklin. G. C. Stone (131), analyst.
13. Gray mineral, Franklin. G. A. Koenig (137), analyst.
14. White mineral, Franklin. F. W. Clarke (139), analyst.
15. White fibrous mineral, Franklin. R. B. Gage (unpublished), analyst.
16. Gray mineral, Franklin. L. H. Bauer (243), analyst.
17. Yellow-brown mineral, Franklin. L. H. Bauer (243), analyst.

18, 19. Green mineral, Franklin. L. H. Bauer (243), analyst.

20. Asbestiform mineral, Franklin. L. H. Bauer (243), analyst.
21. Transparent mineral, Franklin. L. H. Bauer (243), analyst.

Computation of the molecular ratios of the analyses shows that the departure from the orthosilicate formula is hardly noticeable. Manganese and zinc are interchangeable in the mineral in all proportions up to about 12 percent of manganese, and other elements are rarely present in more than insignificant amounts.

It is noteworthy that the radiated fibrous material contains less manganese (see analysis 15) than any other willemite analyzed except the transparent crystals (see analysis 21), which contain only 0.12 percent of MnO. It seems probable that this small amount of what may be regarded as an impurity in the mineral is the cause of the extreme sensitiveness to ultraviolet light shown by the fibrous white willemite. Some specimens of the fibrous variety remain phosphorescent 15 minutes or more after exposure to the iron-arc spark or to the light of burning magnesium. It is well known that many compounds that are not phosphorescent if either absolutely pure or very impure are strongly excited if they contain but a trace of impurity.

Occurrence.—At Franklin willemite is a constant and abundant constituent of the whole ore body and is that one of the valuable zinc ores from which spelter is chiefly made. It is normally in the form of greenish, yellowish, or reddish rounded grains intimately mixed, generally in layers, with franklinite, calcite, and a little zincite. Crystals of willemite of definite form are practically unknown in the primary ore. Crystals of great variety of color and habit are, however, found in the various secondary deposits associated with the main ore body.

In the pneumatolytic zone of the Parker shaft willemite was found in transparent crystals of fine green color, intimately associated with nasonite, glaucochroite, leucophoenicite, datolite, and the other silicates peculiar to that part of the mine. Some crystals are an inch long, but most of them are minute. Their prism faces are brilliant, but many are marked by natural etch figures of a characteristic asymmetric form. Terminal faces are commonly less brilliant but on some specimens are of the most perfect quality, and on such crystals the many forms listed herein have been seen.

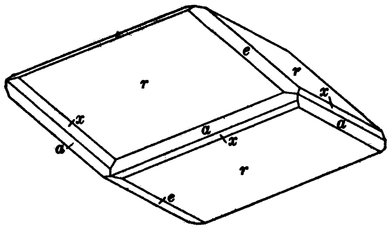


Figure 116.—Doubly terminated rhombohedral crystal of willemite showing the forms $a(11\bar{2}0)$, $e(01\bar{1}2)$, $r(10\bar{1}1)$, and $x(3\bar{1}\bar{2}1)$ Franklin

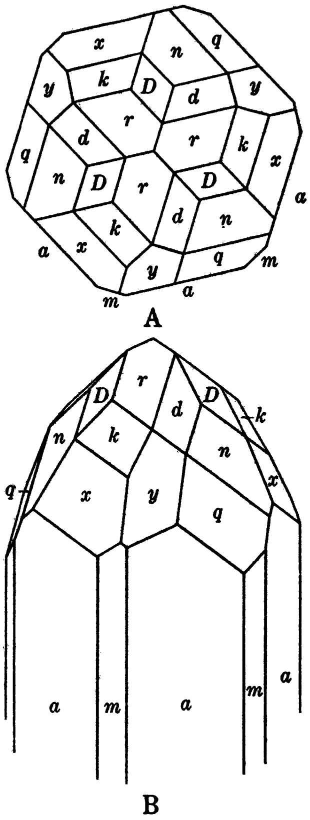


Figure 117

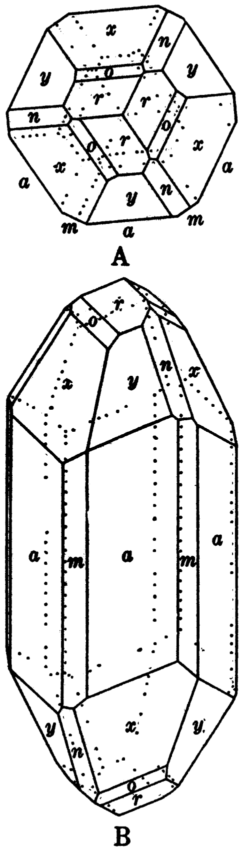


Figure 118

Figure 117.—Crystal of willemite showing the forms $a(11\bar{2}0)$, $m(10\bar{1}0)$, $r(10\bar{1}1)$, $n(02\bar{2}1)$, $k(4\bar{1}\bar{3}2)$, $x(3\bar{1}\bar{2}1)$, $y(21\bar{3}1)$, $d(12\bar{3}2)$, $D(\bar{1}3\bar{2}2)$, and $q(13\bar{4}1)$. Franklin. A, Plan, B, clinographic projection

Figure 118.—Crystal of willemite showing the forms $a(11\bar{2}0)$, $m(10\bar{1}0)$, $r(10\bar{1}1)$, $n(02\bar{2}1)$, $o(5\bar{1}\bar{4}3)$, $x(3\bar{1}\bar{2}1)$, and $y(21\bar{3}1)$ Franklin. A, Plan, B, clinographic projection.

Masses of transparent, glassy yellowish-green willemite, weighing a pound or more and measuring several inches through, were mined in the Parker shaft. Clear portions of this material furnished handsome cut stones, although much of it was marred by inclusions of franklinite in the form of minute octahedrons.

Similar beautifully crystallized willemite of a clear, deep-green color has been found at Franklin during recent years in a number of associations. Most of these specimens were found on the picking table, and the part of the ore body from which they came is unknown. The willemite is generally in open secondary veins and was the latest mineral to form. The crystals are generally minute but show complex groups of forms. Thus willemite was found with the crystals of franklinite, described by Phillips (211), associated with rhodonite and talc (see p. 46), with crystals of tephroite together with garnet, calcite, friedelite, and bementite (see p. 77), and with leucophoenicite and sussexite (see p. 105).

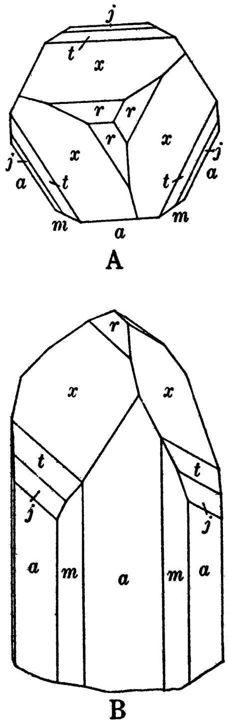


Figure 119

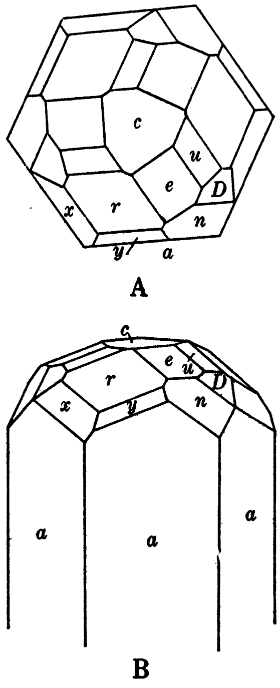


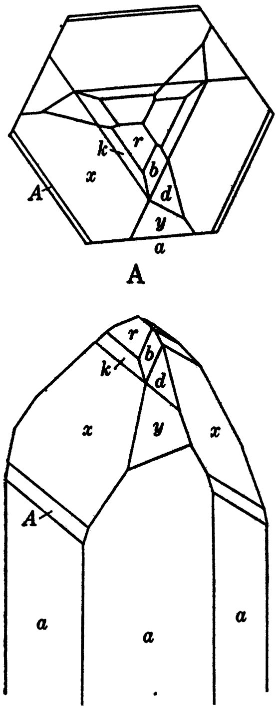
Figure 120

Figure 119.—Crystal of willemite showing the forms $a(11\bar{2}0)$, $m(10\bar{1}0)$, $r(10\bar{1}1)$, $x(3\bar{1}\bar{2}1)$, $t(13.\bar{5}.\bar{8}.3)$, and $j(7\bar{3}\bar{4}1)$ Franklin. A, Plan; B, clinographic projection.

Figure 120.—Crystal of willemite showing the forms $c(0001)$, $a(11\bar{2}0)$, $u(2\bar{1}\bar{1}3)$, $e(01\bar{1}2)$, $r(10\bar{1}1)$, $n(02\bar{2}1)$, $x(3\bar{1}\bar{2}1)$, $y(21\bar{3}1)$, and $D(\bar{1}3\bar{2}2)$ Franklin. A, Plan; B, clinographic projection.

In 1926 Palache and Berman (251) described pure-white willemite with the form of figure 123, remarkable as showing for the first time the negative rhombohedron $e(01\bar{1}2)$ as the dominant terminal face. In the same paper the crystals illustrated in figure 124 were described. They are white, transparent, and of thin tabular form with scarcely a trace of prism faces. They were associated with axinite, rhodonite, cahnite, hedyphane, and barite.

In 1928 Palache (257) described the most beautiful crystals of willemite yet found at Franklin. They came from a vein that was open for at least part of its length but was probably little more than a crevice. Coating the vein wall is a crust of drusy yellow garnet and on it are pink hodgkinsonite crystals of unusual habit (see p. 109), bluish tephroite crystals with tips blackened by manganese oxide, crystals of clear or snow-white barite, and a few microscopic needles of a vanadate, believed to be a manganiferous descloizite. Many of the specimens from this vein are studded with willemite crystals of peculiar beauty. They are prisms of absolute transparence, colored a fine uranium-green, the largest 0.4 inch long and 0.08 inch in diameter. Their habit is dominated by a stepwise development of the third-order rhombohedron $x(3\bar{1}\bar{2}1)$ in combination with the second-order prism. Figure 125 shows in part the deeply striated appearance of these crystals. So clear is the material that striations on the back of a crystal are plainly visible through its thickness. Some crystals, attached by a prism face, are doubly terminated, giving the effect of enormously elongated rhombohedrons. As shown in the plan, figure 125, A, the upper part of the crystal is bounded by three alternate faces of *a*, which step down with *x* and become smaller as the other three faces of *a* become larger, and in the middle of the crystal the six faces of the prism are in equal development. In figure 126 is shown in plan the distribution of faces on the more highly modified crystals, where the rhombohedral aspect is not so pronounced.



A

B

FIGURE 121

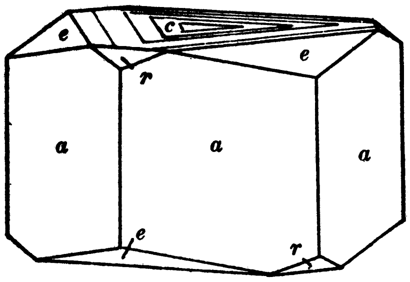
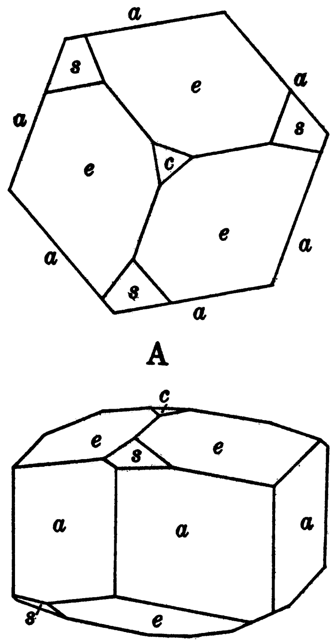


FIGURE 122

FIGURE 121.—Crystal of willemite showing the forms $a(11\bar{2}0)$, $b(22\bar{4}3)$, $r(10\bar{1}1)$, $k(4\bar{1}\bar{3}2)$ $x(3\bar{1}\bar{2}1)$, $y(21\bar{3}1)$, $A(5\bar{2}\bar{3}1)$, and $d(12\bar{3}2)$. Franklin. A, Plan; B, clinographic projection.

FIGURE 122.—Short prismatic crystal of willemite showing the forms $c(0001)$, $a(11\bar{2}0)$, $r(10\bar{1}1)$, and $e(01\bar{1}2)$. Franklin.

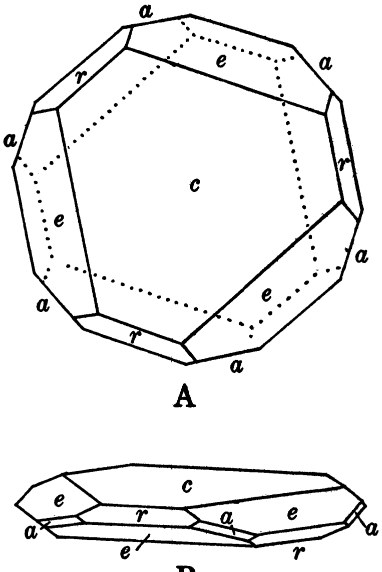
Among the many specimens of crystallized willemite acquired by the Harvard Mineralogical Museum with the Stanton collection was one group of colorless crystals implanted on rhodonite, distinguished by their extraordinary complexity of form. The prism zone is rounded and vertically striated, and the terminal forms are dominantly flat, as shown in figure 127.



A

B

FIGURE 123.—Short prismatic crystal of willemite showing the forms $c(0001$, $a(11\bar{2}0)$, $e(01\bar{1}2)$, and $s(11\bar{2}3)$ Franklin. A, Plan; B, clinographic projection.



A

B

FIGURE 124.—Hexagonal tabular crystal of willemite showing the forms $c(0001)$, $a(11\bar{2}0)$, $e(01\bar{1}2)$, and $r(10\bar{1}1)$ Franklin. A, Plan; B, clinographic projection.

Many phases of crystallized willemite were found in the contact zone of the Trotter mine and are preserved in collections. Most of them are due to recrystallization of the ore under the influence of pegmatite intrusions.

Dull red-brown crystals with broad base, an inch high and of slightly greater diameter, embedded in calcite with good crystals of franklinite. are typical. Similar crystals with small additional faces of $(10\bar{1}1)$ and of a peculiar yellow-green color, implanted on massive ore and projecting into a veinlike mass of calcite, were also found. Great masses of doubly terminated green crystals, so large that they were for the most part not recognized as distinct crystals (Canfield), were found near the bottom of the north end of the Trotter mine.

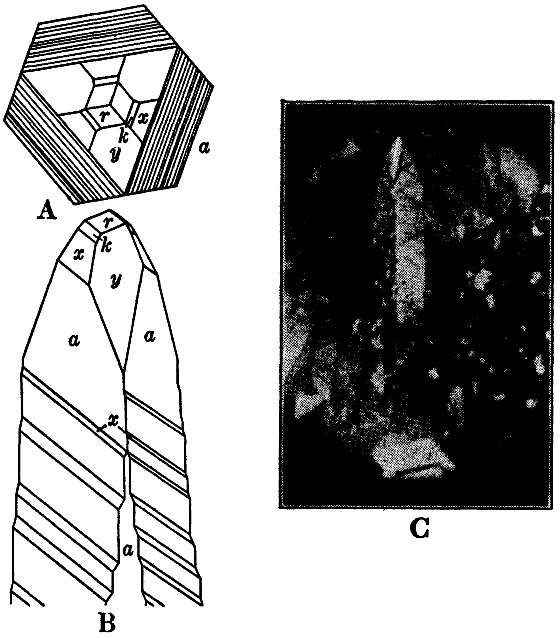


FIGURE 125.—Tapering prismatic crystal of willemite showing the forms $a(11\bar{2}0)$, $r(10\bar{1}1)$, $x(3\bar{1}\bar{2}1)$, $y(21\bar{3}1)$, and $k(4\bar{1}\bar{3}2)$. Franklin A, Plan, B, clinographic projection, C, photograph

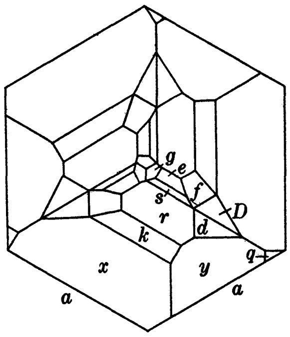


FIGURE 126

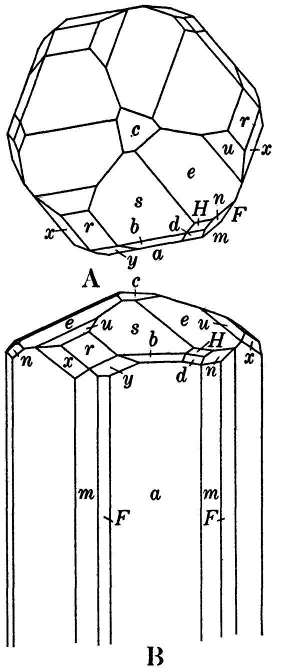


FIGURE 127

FIGURE 126.—Plan of a crystal of willemite showing the forms $a(11\bar{2}0)$, $s(11\bar{2}3)$, $f(4\bar{2}\bar{2}3)$, $e(01\bar{1}2)$, $g(01\bar{1}5)$, $r(10\bar{1}1)$, $k(4\bar{1}\bar{3}2)$, $x(3\bar{1}\bar{2}1)$, $y(21\bar{3}1)$, $d(12\bar{3}2)$, $D(\bar{1}3\bar{2}2)$, and $q(13\bar{4}1)$ Franklin

FIGURE 127.—Crystal of willemite showing the forms $c(0001)$, $a(11\bar{2}0)$, $m(10\bar{1}0)$, $F(31\bar{4}0)$, $u(2\bar{1}\bar{1}3)$, $s(11\bar{2}3)$, $b(22\bar{4}3)$, $r(10\bar{1}1)$, $e(01\bar{1}2)$, $n(02\bar{2}1)$, $x(3\bar{1}\bar{2}1)$, $y(21\bar{3}1)$, $d(12\bar{3}2)$, and $H(13\bar{4}4)$ Franklin. A, Plan, B, clinographic projection.

The most peculiar find of willemite at this mine was in the form of long, slender clear-yellow prisms, whose various terminations are shown in figures 128, 129, and 130. The crystals, which are nearly 3 inches long and less than a quarter of an inch thick, lie firmly embedded in a brownish-black claylike mass, apparently the filling of a narrow crevice. Plate 13, *A*, shows one of these specimens. The long axes of the crystals lie in the plane of the vein; some of them abut upon one another and some are terminated. With them in the matrix are rhombs of calcite and flattened octahedrons of white sphalerite. The willemite crystals show distinct basal cleavage, but all faces are dull and give poor readings.

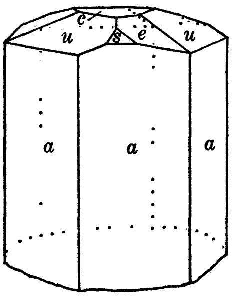


FIGURE 128

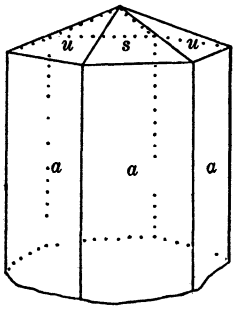


FIGURE 129

FIGURE 128.—Slender prismatic crystal of willemite showing the forms $c(0001)$, $a(11\bar{2}0)$, $u(2\bar{1}\bar{1}3)$, $s(11\bar{2}3)$, and $e(01\bar{1}2)$. Trotter mine.

FIGURE 129.—Slender prismatic crystal of willemite showing the forms $a(11\bar{2}0)$, $u(2\bar{1}\bar{1}3)$, and $s(11\bar{2}3)$ Trotter mine.

In the Taylor and Buckwheat mines, especially, there were numerous secondary carbonate veins transverse to the ore body, which in many places contained crystallized willemite. In an opening in such a vein in the wall of the Buckwheat mine Mr. Canfield found a number of transparent topaz-yellow crystals, the largest 2 inches long and nearly as broad. Terminal faces are wanting, but the crystals have a high luster, and from some of the material beautiful gems have been cut. One of these crystals, supplied by Mr. Canfield, was used in measuring the refractive indices of the mineral.

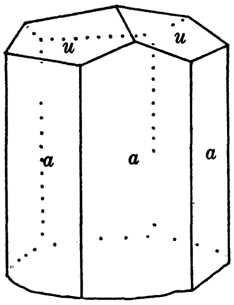


FIGURE 130.—Slender prismatic crystal of willemite showing the forms $a(11\bar{2}0)$, and $u(2\bar{1}\bar{1}3)$ Trotter mine.

Similar material, which shows two periods of crystal growth, was found, seemingly in great abundance, in the open-cut quarry (the old Buckwheat mine) in 1917. The first period produced stout, rounded, and commonly very large crystals of the habit of figure 130; on the ends of some of these is developed a cluster of needlelike crystals in parallel position, each crystal terminated by faces of the most complex type, with rhombohedrons of all three orders. From these crystals, also, gems of great beauty have been cut.

The crystal figured by Penfield (156) was also found in this mine. Almost transparent pale-green prisms embedded in calcite were attached to massive ore, clearly part of a transverse vein.

In the Losey and Hancock collections were specimens from the Hamburg mine, with slender beryl-colored crystals of willemite, some 4 inches long and not more than an eighth of an inch across, embedded in pale rose-tinted manganiferous calcite, from which, by most careful chiseling, the prisms had been freed.

Fibrous forms of willemite—white, pale green, and reddish, the fibers parallel or radiate—are confined to the transverse carbonate veins, layers of willemite with fibers normal to the vein wall generally alternating with carbonate layers. Such veins were seen in abundance in the Buckwheat open cut in 1905. This fibrous form of willemite is prized for its high sensitiveness as a luminous screen for ultraviolet rays, as it gives a higher luminosity than the massive forms. Plate 14, *A*, *B*, and *D*, shows this mode of occurrence.

At Sterling Hill also willemite was widely distributed in granular form throughout the ore body. It appears, however, to have been neither so abundant nor so regularly distributed as at Franklin. The more characteristic mode of occurrence there was in well-formed crystals isolated in the limestone or mingled with crystals of franklinite. It was to these reddish or flesh-colored crystals that the name "troostite" was applied. Figures 131 and 132 and plate 13, *B*, show their ordinary forms. The prismatic crystals reach a length of 10 inches with a diameter of 4 inches or more.

From the deep workings of the Sterling Hill mines were obtained a few specimens of richly colored green willemite showing well-developed crystals embedded in pale pink manganiferous calcite. These specimens, preserved in the Canfield collection, include the unique crystal (combination 23) first figured by Penfield (156), which is terminated by the third-order rhombohedron $x(3\bar{1}\bar{2}1)$ only. This crystal was afterward excavated more fully by Canfield and the lower end exposed. Canfield (192) gives a figure that shows a striking hemimorphism. In the absence of corroboration on other crystals the importance of this hemimorphic development in its bearing on the true symmetry of willemite crystals must remain doubtful.

Only two finds of material of this sort are certainly known from Sterling Hill, and there is no doubt that such types of crystallization are less common than at Franklin.

Alteration.—Beyond a surface blackening from separation of manganese oxide, not infrequently seen on troostite crystals, willemite rarely shows signs of alteration. However, from the calamine deposit at Sterling Hill were obtained crystals of troostite covered or completely replaced by a sheath of glassy needles of calamine blackened by manganese oxide. It is highly probable, in view of the well-preserved specimens of this sort in several collections, that much of the calamine of that great deposit was formed at the expense of willemite. Specimens of massive willemite that were found in the Buckwheat mine showed a gradual marginal alteration into a carbonate of pinkish-white color. This change is, however, not a common one, and indeed, considering the easy solubility of willemite in acids, its stability is surprising.

Historical notes.—Willemite was first recognized as a mineral species by the Philadelphia mineralogists Vanuxem and Keating (17), who published a full and accurate description of its physical and chemical characters under the name siliceous oxide of zinc. Thomson (23) followed this description with an incorrect analysis which made it out to be a silicate of manganese, and his reputation as a chemist served to fix the blunder on the discoverers. To the supposed manganese silicate Shepard (29) gave the name "troostite", and about that time (1830) Lévy discovered and named the willemite of Moresnet, Belgium. Later investigators, Delesse (42), Hermann (45), Dana (46), and Wurtz (50), discovered Thomson's mistake and established the essential identity of the mineral with Lévy's willemite.

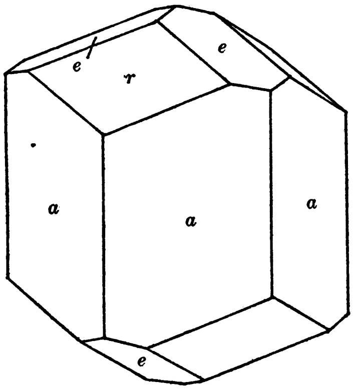


FIGURE 131

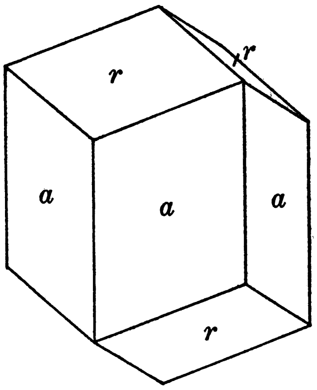


FIGURE 132

FIGURE 131 —Crystal of willemite, variety troostite, showing the forms $a(11\bar{2}0)$, $r(10\bar{1}1)$, and $e(01\bar{1}2)$ Sterling Hill.

FIGURE 132 —Crystal of willemite, variety troostite, showing the forms $a(11\bar{2}0)$ and $r(10\bar{1}1)$ Sterling Hill

The name "troostite" continued to be used, however, for the dark manganiferous varieties, especially the stout crystals from Sterling Hill that were supposed to have a different cleavage from that of willemite. Hintze, in his Handbuch der Mineralogie, maintains this difference, but no sharp distinction is possible, and Dana, in the "System of mineralogy", has quite properly merged the two.

The trirhombohedral symmetry of willemite was first shown by Penfield (156), being established in part by crystals from the Franklin district. Tephrowillemite, a name given by Koenig (137) to a brown manganiferous willemite supposed to be transitional to tephroite, is to be regarded simply as a synonym for troostite.

FRIEDELITE GROUP

$R_8(OH,Cl)_x(As_2O_5)_y(SiO_3)_6.3H_2O$

Although the minerals of the friedelite group are rare at Franklin, the group is well represented numerically, as 3 species have been found there, 2 of which are not known elsewhere. Mcgovernite, for which a satisfactory formula has not been derived, although chemically rather different from the minerals of the group, is nevertheless a basic arseniosilicate and seems to be akin to the group in its optical properties, so it is provisionally included therein. Pyrosmalite, so far not reported from Franklin, is included to show the parallel relations of friedelite and pyrosmalite and of schallerite and ferroschallerite. The following tabular statement brings out the chemical affinities of the group.

Friedelite	$Mn_8(OH,Cl)_4(SiO_3)_6.3H_2O$
(Pyrosmalite)	$(Fe,Mn)_8(OH,Cl)_4(SiO_3)_6.3H_2O$
Schallerite	$Mn_8(OH)_{1.2}.(As_2O_5)_{0.7}.(SiO_3)_6.3H_2O$
Ferroschallerite	$(Mn,Fe,Zn)_8(OH)\ (As_2O_5)_{0.85}(SiO_3)_6.3H_2O$
Mcgovernite	(?)$21(Mn,Mg,Zn)O.\frac{1}{2}As_2O_3.As_2O_5.3SiO_2.10H_2O$

FRIEDELITE

$Mn_8(OH,Cl)_4(SiO_3)_6.3H_2O$ Hexagonal-rhombohedral-hemimorphic

Forms.—Positive pole: $c(0001)$, $q(40\bar{4}5)$, and m_1 $(01\bar{1}0)$. Negative pole: $r_1(10\bar{1}\bar{1})$, $s_1(15.0.\overline{15}.\bar{2})$, and $t_1(0.15.\overline{15}.\bar{2})$.

Combinations on crystals of friedelite

	Forms	Illustrations
1	c, m_1, r_1	Fig. 133.
2	c, q, s_1, t_1	Fig. 134.
3	c, m_1, s_1	Fig. 135.

Habit.—Friedelite is found in markedly hemimorphic crystals, generally as minute tables but rarely in slender needles. The basal pinacoid is brilliant, but the other crystal faces are dull and give poor reflections on the goniometer. Friedelite is also found in fibrous aggregates coating other minerals or forming stalactites, in lamellar aggregates, and in cryptocrystalline massive form filling veins.

Crystallography.—Friedelite crystals have been described heretofore only from Harstigen, Sweden. They are rather rough but were measured by Flink and show no trace of hemimorphism. His value for $c = 0.5317$, based on measurement of the unit rhombohedron, is here accepted. All the crystals are implanted by an end, and the free end was taken as the positive pole.

Partial angle table of friedelite

	ρ			Number of readings
	Computed		Measured	
	°	′		
$r_1(10\bar{1}\bar{1})$	31	33	32° 00′	1
$q(40\bar{4}5)$	27	0	26° 15′	2
$t_1(0.15.\overline{15}.\bar{2})$	78	10	78° 00′	4
$s_1(15.0.\overline{15}.\bar{1})$	84	2	83° 00′ to 85° 00′	6

The rhombohedron t_1 clearly truncates symmetrically the rhombohedron s_1 of the opposite sign and gave better readings than s_1, which was assumed to be the form previously determined by Flink, although the readings agree but poorly with it. In no crystal was any measurable face except the base and the rhombohedron q seen on the free end. The base is generally plane, brilliant, and sharply triangular in outline, but the crystals analyzed by Schaller were hexagonal.

Physical properties.—The basal cleavage is very perfect, giving a pearly luster to the pinacoid. The color of the mineral ranges from palest pink through darker flesh tints to brownish-red or brown; light and dark yellow varieties are also found. The specific gravity is 3.041 to 3.059.

Friedelite is optically negative and uniaxial but with optical anomalies. $2V$ is very small; $\omega = 1.654$, 1.656; $\epsilon = 1.625$, 1.620; $\epsilon = c$.

Composition.—Friedelite is a hydrous basic manganese silicate generally containing more or less chlorine in place of part of the hydroxyl, as shown by some of the analyses. The computed composition of the chlorine-free mineral and that of the mineral with a normal amount of chlorine are also given in the table. The arsenic trioxide found in one analysis may be regarded as derived from a small amount of included schallerite.

The composition of friedelite and its relation to other members of the group have been treated by Bauer and Berman (260). The following statement is abstracted from their paper.

The formula of friedelite as given by Groth, by Dana, and by Palache (195), is in the orthosilicate form, but Zambonini and later Aminoff considered the mineral as metasilicate, as did Gage, Larsen, and Vassar (233) in comparing the composition of schallerite with that of friedelite. The metasilicate formula appears to give simpler results for the group and is here adopted. The orthosilicate formula of Palache converted into a metasilicate form becomes $Mn_8(OH,Cl)_4(SiO_3)_6.3H_2O$.

Analyses of friedelite

	1	2	3	4	5	6
SiO_2	34. 45	35. 36	34. 69	33. 99	36. 35	34. 73
MnO	51. 48	55. 80	48. 00	50. 73	46. 67	54. 80
MgO	1. 54		. 98	1. 45	. 05	
FeO	. 68		1. 45	. 54	5. 27	
ZnO	1. 43		1. 05	. 77	. 32	
CaO			. 63		Trace.	
Cl	. 29		3. 43	2. 32	3. 08	3. 42
H_2O	9. 74	8. 84	11. 02	9. 40	8. 86	7. 82
As_2O_3				1. 15		
Al_2O_3	Trace.				. 03	
	99. 61	100. 00	101. 25	100. 35	100. 63	100. 77
O= Cl	. 06		. 77	. 52	. 69	. 77
	99. 55		100. 48	99. 83	99. 94	100. 00

1. Chlorine-low friedelite, specific gravity 3.041, Franklin. L. H. Bauer (260), analyst.
2. Computed composition of chlorine-free friedelite.
3. Normal friedelite, Franklin. W. T. Schaller (195), analyst.
4. Normal friedelite, Franklin. L. H. Bauer (260), analyst.
5. Normal friedelite, Franklin. R. B. Gage (233), analyst.
6. Computed composition of normal friedelite.

Occurrence.—Friedelite was first identified among the Franklin minerals by the author (195) on a specimen in the Kemble collection, found by Mr. Kemble many years ago in the Buckwheat mine. The mineral covers a surface of 2 or 3 square inches of massive granular franklinite-willemite ore and is apparently part of one wall of a thin transverse vein. The friedelite, massive beneath the surface and in tiny crystals on it, is largely covered with a botryoidal coating of magnesian calcite which, in turn, bears on its surface a few platy crystals of barite. The specimen has the appearance of rhodochrosite, for which it was at first mistaken. It is now in the Harvard mineral collection.

Friedelite was also identified in extremely small amounts in two small specimens in the Canfield collection. It had the same form as that already described—flattened crystals, with narrow rhombohedral faces and no evidence of hemimorphism, in that respect being like the friedelite found in Europe.

A remarkable specimen of friedelite, now in the Hancock collection at Harvard University, was found in 1909 in the Taylor mine. The specimen contains a triangular cavity, 1½ by ½ by ½ inch, shown in plate 14, *C*. The walls consist of a dark-green slickensided chloritic mineral mixed with magnetite, on which is a lining of more definite crystals, set edgewise, of the same chloritic substance. Within the cavity are white tetrahedrons of sphalerite as much as a quarter of an inch on an edge; rhodochrosite in platy rhombohedrons lines one inner surface and massive granular yellow friedelite another; and upon the massive friedelite and last to form in the cavity are implanted crystals of friedelite, which are sharply hemimorphic, the largest being not quite half an inch in diameter, and each is attached to the wall by the rhombohedral end, with a brilliantly lustrous base as the upper termination. These crystals are the first on which evidence of hemimorphism had been seen (fig. 133). On a part of the same specimen, belonging to Mr. Gage, tiny crystals of friedelite were completely embedded in barite, from which they were easily removed uninjured. Though rough and striated they yielded the measurements recorded here. One of them is shown in figure 134. A part of the massive friedelite lining this specimen was analyzed by Gage. (See analysis 5.)

Since 1910 numerous specimens of friedelite have been found at Franklin, representing a variety of forms and associations. Fibrous crusts of a dark-red form of the mineral are associated with the fine crystals of tephroite that were found in 1915. (See p. 77.) In the Harvard mineral collection there are, besides the specimens already described, one showing films of dark-red friedelite in columnar masses cutting massive garnet with later calcite and willemite, another showing granular yellow friedelite in patches in massive light-green willemite, and another showing a light-yellow crust of crystalline friedelite covering the bases of crystals of green willemite.

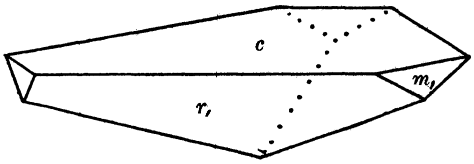


FIGURE 133.—Tabular hemimorphic crystal of friedelite showing at the positive pole the form $c(0001)$ and at the negative pole the forms $r_1(10\bar{1}\bar{1})$, and $m_1(01\bar{1}0)$ Franklin.

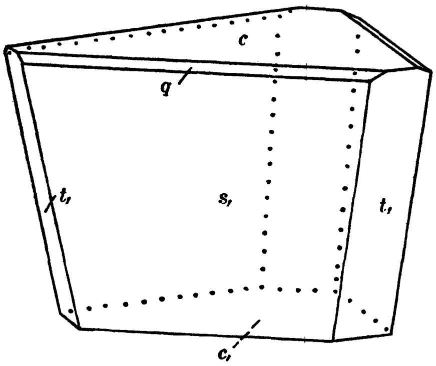


FIGURE 134

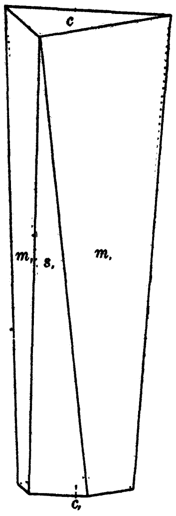


FIGURE 135

FIGURE 134.—Stout prismatic crystal of friedelite showing at the positive pole the forms $c(0001)$ and $q(40\bar{4}5)$ and at the negative pole the forms c_1 $(000\bar{1})$ (as cleavage), $s_1(15.0.\overline{15}.\bar{1})$, and $t_1(0.15.\overline{15}.\bar{2})$ Franklin.

FIGURE 135.—Slender hemimorphic crystal of friedelite showing the form $c(0001)$ at the positive pole; the forms $c_1(000\bar{1})$, as cleavage, and $s_1(15.0.\overline{15}.\bar{1})$ at the negative pole; and $m_1(01\bar{1}0)$

Solid veins of compact friedelite as much as 2 inches thick have been found since 1925. In the Stanton collection there were abundant specimens of pale-red friedelite showing thin veins with many cavities, their walls lined with tiny crystals. These specimens came from the 200-foot level south in footwall pillar 854.

Analysis 4 in the table was made on this material. The crystals are similar to those of figure 134 but lack the positive rhombohedron *q*. Calcite and barite are the only associated minerals in these veins.

In another group of specimens veins of compact brown friedelite have open spaces whose walls are covered with light-yellow crystalline crusts. Although not measurable, the slender needles are clearly hemimorphic and are well represented by figure 135, except that they appear more slender. With them are the hematite crystals described on page 42.

At Sterling Hill friedelite has also been found forming veins and stringers and mixed with calcite, cutting the massive ore. It is of lively pink color and is mostly compact but with scattered drusy cavities. A specimen from the 1,300 foot level, stope 720, with a specific gravity of 3.014, was analyzed by Mr. Bauer. Although it differs somewhat in composition from the other analyzed material in its high magnesia and alumina, it is undoubtedly to be regarded as a low-chlorine friedelite.

SCHALLERITE

Hexagonal?

Physical character.—Schallerite is found in granular form and no crystals are known. It is provisionally regarded as hexagonal because of its uniaxial character and its similarity in composition and other characters to friedelite.

Schallerite is red-brown, with a somewhat waxy fracture surface showing minute cleavage facets with pearly luster. The cleavage is basal, the hardness is about 5, and the specific gravity is 3.368. It is optically uniaxial and negative; $\omega = 1.704$, $\epsilon = 1.679$.

Schallerite and friedelite are so similar in general appearance that the only way of distinguishing them is by chemical analysis or by measurement of their optical constants. The higher refractive indices of schallerite serve as a sure means of identifying it.

Composition.—Schallerite is a hydrous basic manganese arseniosilicate allied to friedelite.

Analyses of schallerite

	1	2	3	4	5
SiO_2	31. 20	31. 44	31. 82	32. 42	32. 76
MnO	44. 20	44. 70	50. 20	49. 21	51. 68
FeO	1. 33	2. 12	--------	. 62	--------
MgO	2. 13	2. 19	--------	. 71	--------
CaO	--------	. 36	--------	--------	--------
ZnO	. 39	. 54	--------	Trace	--------
Cl	--------	. 08	--------	. 60	--------
As_2O_3	--------	12. 24	12. 25	7. 50	9. 01
As_2O_5	13. 81	--------	--------	--------	--------
Al_2O_3	--------	--------	--------	1. 59	--------
H_2O	6. 93	6. 55	5. 73	7. 24	6. 55
	99. 99	100. 22	100. 00	99. 89	100. 00
O= Cl	--------	. 02	--------	. 13	--------
	--------	100. 20	--------	99. 76	--------

1. Schallerite, type 1, Franklin. H. E. Vassar (233), analyst.
2. Material of no. 1, reanalyzed. L. H. Bauer (260), analyst.
3. Composition of type 1 computed from the formula.
4. Schallerite, type 2, Franklin. L. H. Bauer (260), analyst.
5. Composition of type 2 computed from the formula.

The formula for schallerite derived by Bauer and Berman (260) from analysis 2 is

$$Mn_8[(SiO_3)_6(OH)_{1\ 2}(As_2O_3)_{.7}].3H_2O.$$

That analysis made it certain that the arsenic in the mineral is trivalent rather than pentavalent as reported in the original description (233). A trace of chlorine was also found. The composition differs from that of friedelite in that the pyroarsenious acid radical takes the place of part of the hydroxyl and chlorine, the total valency remaining the same. The computed composition given in column 3 agrees well with the result of analysis 2.

The second type of schallerite, with less arsenic, whose composition is given in column 4, yields to Bauer and Berman (260) the analogous formula

$$Mn_8[(SiO_3)_6(OH)_2(As_2O_3)_{.5}].3H_2O.$$

The refractive indices and the specific gravity of material of the second type are somewhat lower than in the original type, in agreement with its lower content of arsenic.

Occurrence.—Schallerite was found in 1924 by R. B. Gage and was described by Gage, Larsen, and Vassar (233) and named for W. T. Schaller, mineralogist of the United States Geological Survey. Most of the specimens known seem to have come from the same small vein, which cuts ordinary massive ore, is composed of solid granular schallerite, and is from half an inch to 2 inches thick. The only other mineral in the vein is a bordering layer, here and there, of calcite. The mineral is said to have been found at a depth of 700 feet, but the exact part of the mine is not known.

The second type of schallerite, mentioned in a preceding paragraph, is seen in a vein an inch thick, composed chiefly of fowlerite. On one wall is massive granular schallerite, and similar material is scattered through the rhodonite in rounded masses suggesting crystal individuals but seen, when broken, to be aggregates. This type is distinctly yellower than the original schallerite.

FERROSCHALLERITE

Hexagonal?

Physical character.—Ferroschallerite is found only in coarse grains having perfect cleavage in a single direction. One such grain shows a rudely hexagonal outline in such relation to the cleavage as to indicate a prismatic form and pinacoidal cleavage; hence there is little doubt that the mineral is hexagonal. The grains reach a maximum diameter of half an inch.

Ferroschallerite is yellowish-brown to clove-brown, with a pearly luster on the cleavage. Some grains are clear and glassy. The hardness is about 5, and the specific gravity is 3.44. It is optically uniaxial and negative; $\omega = 1.718$, $\epsilon = 1.700$.

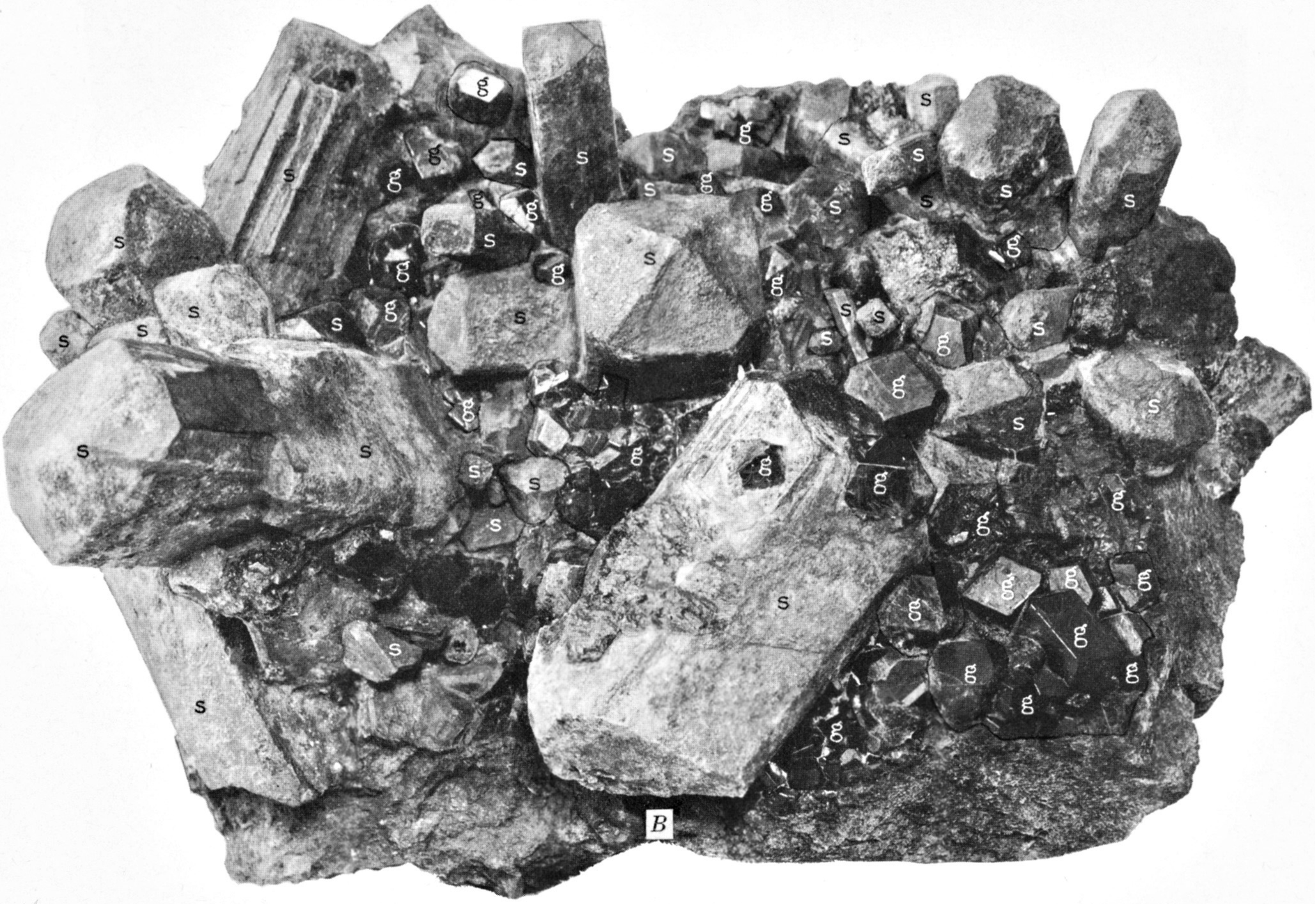
A. PALE-GREEN FINELY FIBROUS FORM OF WILLEMITE.

B. WHITE RADIATE-FIBROUS FORM OF WILLEMITE.

C. FRIEDELITE (f) WITH SPHALERITE (s) IN A CARBONATE VEIN.

D. WHITE FIBERS OF WILLEMITE COATING FRANKLINITE ORE.

All specimens from Franklin.



A. GROUP OF CRYSTALS OF ROEPPERITE.
Sterling Hill.

B. SCAPOLITE (s) AND GARNET (g).
Gooseberry iron mine.

Composition.—The chief difference between schallerite and ferroschallerite chemically is that in the latter mineral ferrous iron takes the place of about half the manganese of the former. Hence the two are related chemically much as are friedelite and pyrosmalite. The formula of ferroschallerite derived from the analysis is $(Mn,Fe,Zn)_8[(SiO_3)_6(OH)(As_2O_5)_{.75}]. 3H_2O$, in which Mn is to Fe as 2 to 1.

Analysis of ferroschallerite

	1	2
SiO_2	31. 12	31. 38
MnO	29 22	30. 94
FeO	17. 12	15. 69
MgO	. 12	----------
ZnO	3. 63	3. 55
As_2O_5	12. 46	12. 94
H_2O	6. 42	5. 50
	100. 09	100. 00

1. Ferroschallerite, Franklin. L. H. Bauer (273), analyst.
2. Composition computed from the formula adopted.

Occurrence.—All the specimens of ferroschallerite known seem to have been collected by the late George Stanton in 1925 in the mine at Franklin, in pillar 1597, about 50 feet south of the old Trotter shaft. There are three types of association—as coarse clear grains with coarse prisms of zinc cummingtonite in calcite, as a layer of grains between zinc cummingtonite and fibrous gray willemite, and as a layer of grains between coarse crystals of zinc cummingtonite and granular feldspar. The specimens suggests the contact phases of one of the abundant pegmatite masses of that part of the mine.

MCGOVERNITE

Hexagonal?

Physical character.—Crystals of mcgovernite are not known. It is found in coarse granular form, the individual grains showing pronounced micaceous cleavage. In reflected light it is bronzy red, and in transmitted light it is deep red-brown. It is optically uniaxial and positive; $\omega = 1.754$. The cleavage is basal, very perfect, like that of friedelite, and the mineral is therefore presumably hexagonal. Its specific gravity is 3.719.

Composition.—Mcgovernite is a complex basic manganese, magnesium, and zinc arseniosilicate.

Analysis of mcgovernite

[L. H. Bauer (252), analyst]

	Percent	Molecular ratio	
SiO_2	8. 92	0. 148	$= 3\times 0.049$
MnO	42. 73	. 603	1 029 $= 21\times 0.049$
FeO	1. 53	. 021	
MgO	11. 27	. 280	
ZnO	10. 22	. 125	
As_2O_3	4. 45	. 023	$= \frac{1}{2}\times 0.046$
As_2O_5	12. 48	. 054	$= 1\times 0.054$
H_2O	8. 49	. 472	$= 10\times 0.047$
	100. 08		

The presence of arsenic in two states of oxidation, which is unique among minerals, was carefully established by the analyst and must be accepted as a fact in attempting to interpret the analysis. No simple formula can be derived from the stated composition, and until the results of more analyses are available and the true nature and relations of the mineral are better known it is not feasible to derive a formula showing the chemical structure. The following provisional formula was suggested in the paper by Palache and Bauer (252): $21(Mn,Mg,Zn)O.3SiO_2.\frac{1}{2}As_2O_3.As_2O_5.10H_2O$. The possible relation of the mineral to dixenite and the minerals of the friedelite group is treated in the paper by Bauer and Berman (260).

Occurrence.—Mcgovernite was found in 1927 in the mine at Sterling Hill, in the north drift, 900-foot level. It forms the principal filling of a vein in massive ore, as a rather uniformly coarse-grained mass. But few specimens of it have been preserved.

The mineral is named for J. J. McGovern, of Franklin, who died in 1915. For many years he was in charge of the picking table at the shaft head, and he was one of the foremost of the local collectors and added much to the knowledge of Franklin mineralogy.

SCAPOLITE

$Ca_4Al_6Si_6O_{25}$ with $Na_4Al_3Si_9O_{24}Cl$. Tetragonal

Forms.—*a* (100), *m* (110), *r* (111).

Occurrence.—Slender, prismatic, white or light-greenish crystals of scapolite from Franklin, some of them 2 inches long, were seen in several collections. They came from two small finds—one in a pocket in limestone between the two legs of the deposit on Mine Hill, the other in the large cavity in limestone that yielded black garnet so abundantly on Balls Hill near the Gooseberry iron mine. Specimens from the latter locality are illustrated in plate 15, *B*. Excellent crystals were found in 1914 in limestone in the Fowler quarry also. Massive greenish scapolite was found in 1905 in some abundance in the east wall of the Buckwheat open cut, which was then being quarried for limestone. It was associated with fluorite and edenite and enclosed scales of molybdenite.

A doubly terminated crystal of scapolite in limestone from Sterling Hill is in the Hancock collection.

Scapolite is an abundant constituent of the rock of basic igneous dikes in the limestone at several localities near Franklin, which were described by Nason (142). So far as known scapolite has not been found in direct association with the zinc ores.

Alteration.—Under the name "algerite" Hunt (44) described as a new mineral species an altered scapolite found in long, slender distorted prisms in loose blocks of limestone on the hillside below what was later the Trotter mine. The name "kembleite" has been used locally for the same substance.

Hunt's analysis showed that algerite contains water and carbon dioxide, and those by Crossley (48) and by

J. D. Whitney (63) gave widely variant results, showing the substance to be undergoing alteration. The species was therefore not accepted and was placed by Dana (146) among the pinite pseudomorphs after scapolite.

BARYSILITE

$(Pb,Mn)_3Si_2O_7$. Hexagonal

Physical properties.—Barysilite is found in massive granular form, intimately mixed with garnet and willemite and associated with axinite and hardystonite. Its color is faintly pinkish white. The perfect cleavage is basal. It is uniaxial and optically negative, and, for sodium light, $\omega=2.033$ and $\epsilon=2.015$, both ± 0.004.

Composition.—The original barysilite from Franklin (244) was so scarce that difficulty was encountered in getting enough for analysis, and the sample analyzed contained garnet and willemite. Later an adequate sample was obtained and was analyzed by Mr. Bauer. Both analyses are given below.

Analyses of barysilite

	1	2	3	
SiO_2	18. 73	16. 84	0.280	$=2\times0.140$
Al_2O_3	1. 76	. 59	.006	
PbO	71. 14	77. 35	.347	$0.424=3\times0.141$
MnO	3. 97	3. 33	.047	
FeO	. 24	. 23	.003	
CaO	. 10	. 21	.004	
MgO	1. 02	. 78	.019	
ZnO	1. 69	. 30	.004	
H_2O	. 73	. 07	.004	
	99. 38	99. 70		

1. Barysilite, Franklin. E. V. Shannon (244), analyst.
2. Barysilite, Franklin. L. H. Bauer (273), analyst.
3. Molecular ratio of no. 2.

The molecular ratio shows the mineral to be a subsilicate of lead, containing some manganese and small amounts of magnesium, zinc, calcium, and iron.

Barysilite is easily fusible to a blackish-purple glass. It is slowly decomposed by hot concentrated hydrochloric acid with the separation of silica.

Occurrence.—Barysilite was found in a few small masses on the picking table at Franklin, and its lead-bearing nature was first recognized by the chemists of the New Jersey Zinc Co. It occurs as thin films or veinlets in the ore, associated with garnet, willemite, axinite, and hardystonite.

Barysilite is one of the typical lead silicates of the Långban and Pajsberg mineral associations, and its discovery at Franklin marked the first time that it has been found at any other locality.

BARYLITE

$Be_2BaSi_2O_7$. Orthorhombic

Character.—At Franklin barylite is found in plates embedded in hedyphane with some willemite. The plates are more or less brecciated and are cemented with thin films of serpentine. The mineral is white, of hardness 7, and of specific gravity 4.066 ± 0.002. It shows two good cleavages, one basal and the other parallel to the macropinacoid. It has a vivid blue fluorescence in ultraviolet light.

Barylite is optically biaxial and negative; $2V=70°\pm2°$ (measured on a Fedorof stage); $\alpha=1.695$, $\beta=1.702$, $\gamma=1.708$, all ±0.002; the cleavages are normal to γ and β (Berman).

The above data differ somewhat from those given by Aminoff for the Långban mineral, which has somewhat lower refractive indices, a slightly lower specific gravity, and in most specimens is positive. Also Aminoff reports but one cleavage.

Composition.—Barylite is a silicate of beryllium and barium of simple composition. The material analyzed was extremely pure and gave an almost exact molecular ratio of BeO : BaO : $SiO_2=2:1:2$. It is worthy of note that the beryllium content of barylite is slightly higher than that of beryl, the commonest beryllium mineral.

Analysis of barylite

	1	2	3
SiO_2	36. 42	0. 606=2. 00	37. 14
BeO	15. 77	. 630=2. 08	15. 47
BaO	46. 49	. 303=1. 00	47. 39
FeO	. 19		
MgO	. 29		
ZnO	([a])		
PbO	. 11		
H_2O at 110°	. 40		
	99. 67		100. 00

[a] Present.

1. Barylite, Franklin. L. H. Bauer (272), analyst.
2. Molecular ratio of no. 1.
3. Composition computed from the formula.

Occurrence.—Barylite was first found at Franklin in 1929, on the picking table. Later it was located in the mine in pillar 960, 20 feet below the 400-foot level north and about 15 feet from the hanging wall. The specimens seen by the author are clearly part of a well-layered vein, the succession of layers from a surface of ore being brown calcite and native copper; gray calcite; a thin zone of willemite and serpentine; white calcite in curved rhombohedrons, strongly fluorescent in ultraviolet light; and barylite, hedyphane, and willemite. Attention was first called to the barylite by its vivid blue fluorescence.

Barylite was first described in 1880 as an aluminum-barium silicate found at Långban with hedyphane. In 1923 Aminoff discovered that the supposed alumina is really beryllia. The discovery at Franklin, described by Palache and Berman (272), is the second reported occurrence of this mineral.

NASONITE

$Pb_4(PbCl)_2Ca_4(Si_2O_7)_3$. Hexagonal

Forms.—$a(11\bar{2}0)$, $m(10\bar{1}0)$, $p(10\bar{1}1)$, and $x(90\bar{9}2)$?

Habit.—Nasonite is ordinarily found in massive granular form, and crystals are very rare. The only ones seen were on a specimen in the Canfield collection that had been carefully worked out of the barite matrix. Mr. Canfield recognized their hexagonal form and permitted the removal from the specimen of one crystal for measurement. The first-order prism is dominant and has bright faces, broken on several crystals by a deep, irregular vertical groove, and the prism edges are narrowly truncated by the second-order prism. The pyramid *p* merges below with the prism through a curved surface, upon which a distinct facet gave the readings determining the doubtful form $x(90\bar{9}2)$. The pyramid is sharply formed above, the habit of the crystals strongly recalling that of witherite. On this crystal, shown in figure 136, the following angles were measured.

Angles on crystal of nasonite

	Measured				Computed			
	ϕ		ρ		ϕ		ρ	
	°	′	°	′	°	′	°	′
$p(10\bar{1}1)$ (2 faces)	30	0	56	40	30	0	56	40
$x(90\bar{9}2)$ (1 face)	30	0	81	36	30	0	81	40

From the coordinates of *p* was derived $p_o = 0.8788$ (G_2), from which was computed the axial ratio $a : c = 1 : 1.317$.

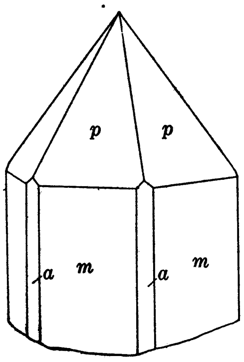


FIGURE 136.—Crystal of nasonite showing the forms $a(11\bar{2}0)$, $m(10\bar{1}0)$, and $p(10\bar{1}1)$. Parker shaft, Franklin.

The identity of the measured crystal with nasonite was assured by decisive tests for lead, chlorine, and silica made on it after the measurement of the angles was completed.

Crystals of nasonite from Långban, Sweden, which showed both prisms and the base and which were for the most part composite, with rounded faces, have recently been described by Aminoff (207). The material was mostly in lamellar masses.

Physical properties.—Nasonite breaks into rudely rectangular blocks, owing to good basal and indistinct prismatic cleavages. Its hardness is about 4, and its specific gravity is 5.425 (5.5 to 5.59, Aminoff).

Nasonite is white, with a greasy to adamantine luster. It is uniaxial and positive, and fragments tend to lie on a cleavage surface parallel to the optic axis. $\omega = 1.917$, $\epsilon = 1.927$, both ± 0.005 (Larsen).

Composition.—Nasonite is a silicate and chloride of lead and calcium, $Pb_4(PbCl)_2Ca_4(Si_2O_7)_3$, analogous to ganomalite, which is $Pb_4(PbOH)_2Ca_4(Si_2O_7)_3$, according to Penfield. The material from Franklin, the composition of which is given in analysis 2, in the table below, was known to contain clinohedrite, and so, in interpreting the analysis, 2.16 percent of clinohedrite, equivalent to the ZnO found, was eliminated. Also the molecular equivalent of CaO was substituted for those of MnO and FeO and that of Cl for OH, and the analysis was then recomputed to 100 percent, as shown in column 3. In column 4 the theoretical composition is given.

Analyses of nasonite

	1	2	3	4
SiO_2	18. 23	18. 47	18. 32	18. 21
PbO	67. 67	65. 68	67. 32	67. 68
ZnO	--------	. 82	--------	--------
MnO	. 14	. 83	--------	--------
FeO	. 04	. 10	--------	--------
MgO	. 20	--------	--------	--------
CaO	11. 29	11. 20	11. 59	11. 33
Cl	2. 90	2. 81	3. 57	3. 59
H_2O	. 24	. 26	--------	--------
Total	100. 71	100. 17	100. 80	100. 81
$O = Cl_2$	. 65	. 63	. 80	. 81
	100. 06	99. 54	100. 00	100. 00

1. Nasonite, Långban. Mauzelius (207), analyst.
2. Nasonite, Franklin. C. H. Warren (99), analyst.
3. No. 2 recomputed to 100 percent after the elimination and substitutions described above.
4. Theoretical composition computed from the formula.

Occurrence.—Nasonite is one of the silicates from the Parker shaft, Franklin, described by Penfield and Warren (179). To their description are added here only the crystallographic data and Larsen's optical data. Nasonite commonly forms the matrix of glaucochroite crystals, and in the few specimens seen is also associated with garnet, axinite, and barite.

The recent discovery of nasonite at Långban by Aminoff (207) adds interest to the species. He describes it as associated with a group of minerals—schefferite, native lead, apophyllite, margarosanite, and thaumasite—essentially younger than the ores and found in fissures filled with calcite. The study of the Swedish nasonite confirms in all respects the characters described for the Franklin mineral. Aminoff's new data and analysis are given above.

HARDYSTONITE

$Ca_2ZnSi_2O_7$. Tetragonal

Physical properties.—Hardystonite is found in granular masses and in isolated grains in limestone, and crystals are not known. The cleavage is good parallel to the base and poor parallel to both prisms, and cleavage fragments may thus have a prismatic or even a cubic appearance. The hardness is 3 to 4, and the specific gravity is 3.39. The mineral is white to faintly pinkish, semitransparent, and has a vitreous luster. Under the iron-arc spark gap it fluoresces a dull, faint violet or not at all. It is optically negative; the refractive indices are, for sodium light, $\omega = 1.6691$ and $\epsilon = 1.6568$; for lithium light, $\omega = 1.6758$ and $\epsilon = 1.6647$, both ± 0.0002.

Composition.—Hardystonite is a calcium zinc silicate allied to the tetragonal lead silicate ganomalite. It may contain small amounts of magnesium and manganese in place of part of the calcium and zinc, respectively.

Analyses of hardystonite

	1	2	3	4
SiO_2	38.10	37.78	36.59	38.30
Al_2O_3		.91	.77	
Fe_2O_3	.57	.43		
FeO			.42	
ZnO	24.30	25.38	22.47	25.94
MnO	1.50	1.26	1.23	
CaO	33.85	34.22	35.16	35.76
MgO	1.62	.26	1.47	
K_2O		.78		
Na_2O		1.10		
PbO			[a] 1.99	
Ignition	.52	.34		
	100.46	100.46	100.00	100.00

[a] Jenkins and Bauer state "We have found from 0.66 to 3.55 percent of lead oxide in all the hardystonite analyzed."

1. Grains separated from massive granular ore by heavy solution. J. E. Wolff (185), analyst.
2. Coarse columnar masses. J. E. Wolff (185), analyst. (Minute inclusions seen in thin section may account for the large amount of alkalies found.)
3. Hardystonite, specific gravity 3.443. Jenkins and Bauer (243), analysts.
4. Composition computed from the formula.

The ratios, shown in the analyses, of ZnO to CaO to SiO_2 are close to 2 : 1 : 2, leading to the formula $Ca_2ZnSi_2O_7$. The lead is probably present in a calcium larsenite molecule.

Occurrence.—Hardystonite was discovered and described by Wolff (185), and little has been added to his observations. It was first found in the Parker shaft at a depth of about 900 feet, in granular mixture with willemite, rhodonite, and franklinite. Later it was found in considerable abundance in several parts of the ore bodies worked through the Parker shaft, but it has not yet been identified from any other part of the deposit at Franklin. Masses of several pounds weight and of coarse columnar texture, free from any other mineral, have been found. It has also been seen associated with brown vesuvianite, with complex crystals of brown apatite, and intimately intermixed with franklinite and bright-green willemite. It appears to have been formed under the influence of the pneumatolytic conditions prevalent somewhere in that part of the mine, which developed such a peculiar assemblage of minerals as is scarcely known elsewhere.

The presence of lead, shown by Jenkins and Bauer to exist in all hardystonite, is of economic importance, as it is injurious to the quality of the zinc produced from the ore. Hence the presence of all minerals containing lead is carefully checked in the assay office at the mines.

The composition of hardystonite is closely analogous to that of melilite, and X-ray examination shows that the unit cell, space group, and atomic arrangement are the same in the two minerals, which differ only in that hardystonite contains zinc in the place of magnesium-aluminum.

VESUVIANITE

Varieties beryllium vesuvianite and cyprine. Formula uncertain. Tetragonal

Forms.—*c*(001), *a*(100), *m*(110), *f*(120), *e*(101), *p*(111), *t*(331), and *s*(311).

Combinations on crystals of vesuvianite

	Forms	Localities	Illustration
1	*c*, *a*, *m*, *p*	Penfield, Parker shaft.	
2	*a*, *m*, *r*, *e*, *p*, *t*, *s*	Canfield collection, Parker shaft.	
3	*a*, *m*, *p* (beryllium vesuvianite)	Franklin	Fig. 137

Occurrence.—Although vesuvianite was named in all the older lists of Franklin minerals, its authentic discovery before 1899 is doubtful, green or brown tourmaline having been commonly mistaken for it. Small red crystals of simple form were noted by Penfield (179), embedded in nasonite from the Parker shaft, and these he afterward verified by measurement (private communication to the author). Similar but more complex crystals were seen in the same association in the Canfield collection.

A mineral from the Parker shaft described by Chester (181) as granular vesuvianite contains too much water properly to be assigned to that species.

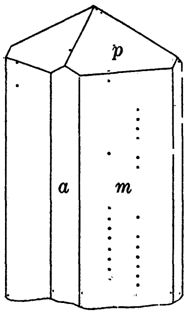


FIGURE 137.—Prismatic crystal of vesuvianite showing the forms *a*(100), *m*(110), and *p*(111). Franklin

Beryllium vesuvianite.—In 1929 Mr. Bauer discovered the presence of beryllium in crystals of a complex silicate of unknown species shortly before discovered at Franklin. Crystallographic and optical tests established the mineral as vesuvianite, a determination with which the analysis was in agreement.

The new variety is found in slender brown prisms embedded in a coarsely granular mixture of green willemite, brown garnet, leucophoenicite, barite, and minor amounts of svabite, gageite, and native copper.

The crystals show a simple combination of the unit pyramid, the prism of the first order, and the base, as shown in figure 137. They are of poor quality for measurement, as is so common with crystals of vesuvianite. Thirteen values of ρ for $p(111)$ on four crystals gave an average value of 36°52′, which gives the element $c = p_0$ as 0.5303; Dana uses the value $c = 0.5372$.

The new variety is optically uniaxial and negative, with absorption in blue light $\omega > \epsilon$, and refractive indices $\omega = 1.712$, $\epsilon = 1.700$. The specific gravity is 3.385 ± 0.002.

Cyprine.—The fibrous copper-bearing variety cyprine was first observed by the author in 1905 in a small dump of unknown origin at the mouth of the Parker shaft. It was in bundles of slightly radiate needles scattered through a coarse-grained feldspathic pegmatite. It is abundant in the specimens and is conspicuous, as its color is blue to blue-green. With it are manganophyllite, yellowish garnet, and native copper in threads and irregular fragments.

As the mineral was not at first recognized as cyprine but was thought to be a new species, material for analysis was separated by crushing and handpicking and careful rejection of all traces of the associated metallic copper, as the mineral itself contains copper in combination. Analysis 1 is similar to that of cyprine from Tellemarken, Norway, but differs from it in details.

In 1922 cyprine was found in abundance in the mine at Franklin, in a crosscut about 400 feet southwest of the Parker shaft and near the 850-foot level, and in the ore body but near the hanging wall. The cyprine was rather coarsely fibrous and was intimately intermingled with brown garnet, pale-pink bustamite, white willemite, and calcite. Part of it was of vivid sky-blue color, and part of it was bluish-green. Polished surfaces of the blue cyprine presented a striking appearance. The refractive indices of the material of the several colors are as follows:

Refractive indices of cyprine

	ϵ	ω
Blue-green cyprine, in pegmatite	1. 698	1. 710
Sky-blue cyprine, in ore	1. 705	1 713
Green cyprine, in ore	1. 712	1. 719

The abundant cyprine found later at Franklin has been analyzed by Shannon (224) and by Bauer (225). The analysis by Bauer, no. 3, was made on material nearly one-third of which consisted of willemite, as seen in thin section, and which also contained minute specks of metallic copper. Mr. Bauer has also furnished the author with two previously unpublished analyses, nos. 4 and 5, of the green and blue portions, respectively, of a single specimen of the mineral, separated by hand picking. The specific gravity of the green portion was 3.45. The difference in color of the two portions does not seem to indicate much difference in composition.

Composition.—Vesuvianite is a calcium aluminosilicate of complex and variable composition, for which no simple formula has yet been generally adopted. The chemical character of the Franklin vesuvianite is shown by the following analyses:

Analyses of vesuvianite

	1	2	3	4	5	6
SiO_2	36. 41	34. 98	32. 42	33. 33	35. 11	34. 25
BeO	. 50	------	------	------	------	9. 20
Al_2O_3	16. 85	16. 30	14. 07	16. 03	17. 68	9. 70
Fe_2O_3	------	3. 00	------	------	------	------
FeO	1. 86	------	. 77	2. 97	. 87	Trace
MgO	1. 38	1. 38	1. 08	3. 09	. 77	3. 17
MnO	1. 75	3. 11	1. 50	3. 56	3. 10	4. 84
ZnO	1. 74	1. 42	21. 71	3. 00	4. 40	4. 86
PbO	Trace	------	------	------	------	------
CuO	1. 85	1. 21	. 99	. 45	. 23	------
CaO	33. 21	34. 70	25. 22	36. 67	34. 43	33. 15
H_2O	3. 75	. 64	2. 38	1. 46	3. 00	1. 31
Na_2O	. 44	------	------	------	------	------
K_2O	. 50	------	------	------	------	------
F	. 36	1. 62	------	------	------	------
B_2O_3	------	. 89	------	------	------	------
	100. 60	99. 25	100. 14	100 56	99. 58	100. 48
$O = F_2$	. 15	. 68	------	------	------	------
	100. 45	98. 57	------	------	------	------

1. Cyprine, fibrous, Parker shaft. George Steiger (195), analyst.
2. Cyprine, fibrous, Franklin. E. V. Shannon (224), analyst.
3. Cyprine containing about 33 percent of willemite, as seen in thin section, Franklin. L. H. Bauer (225), analyst.
4. Material in green grains, Franklin. Bauer and Jenkins (243), analysts.
5. Material in blue grains, Franklin. Bauer and Jenkins (243), analysts.
6. Beryllium vesuvianite, Franklin. L. H. Bauer (272), analyst.

Analysis 6, made by Bauer (272) on a picked sample of the crystals found in 1929, shows the presence of more than 9 percent of beryllium oxide. The probability that beryllium would be found at Franklin in some form was foretold by the observation, by the German spectroscopist Eberhard (200) in 1912, of beryllium lines in the arc spectrum of Franklin willemite. As yet beryllium has not been detected in wet analyses of cyprine, though it may have been present and have been determined with the aluminum. Mr. Nitchie, formerly of the New Jersey Zinc Co.'s laboratory at Palmerton, Pa., found that cyprine shows spectroscopically strong lines of beryllium, although relatively less strong than in spectrograms of brown beryllium vesuvianite.

It now appears certain that the beryllium is not genetically associated with the primary willemite ore but is a post-ore element introduced into the deposit from intrusive pegmatite.

ZIRCON

$ZrSiO_4$. Tetragonal

Forms.—$c(001)$, $a(100)$, $m(110)$, $p(111)$, $u(331)$, $x(311)$, $y(411)$, $z(511)$.

Combinations on crystals of zircon

	Forms	Illustrations
1	*m, p*	
2	*m, p, u*	Fig. 138.
3	*c, a, m, p, u, x, y, z*	Fig. 139.

Occurrence.—Zircon is found sparingly in the pegmatite of the Trotter mine at Franklin in dark-brown crystals of ordinary form and habit (fig. 138). It is not known as a constituent of the zinc-ore deposit, nor has it been reported from Sterling Hill.

A remarkable series of specimens of zircon preserved in the Canfield collection was found near the Hill iron mine on Balls Hill a little south of Franklin. The main group consists of 16 crystals implanted on rough pyroxene and dark-brown garnet. The largest zircon is 2 inches long and half an inch square. The crystals are black and of splendent luster and show only the forms (110), (111), and (331). Other specimens from the same cavity, the only one found, show doubly terminated crystals of greater complexity, as shown in figure 139. In grouping, brilliance, complexity, and large average size of crystals these specimens of zircon are unique, and they are among the most striking features of the Franklin series of minerals. Plate 16, *A*, shows the best group of them in the Canfield collection.

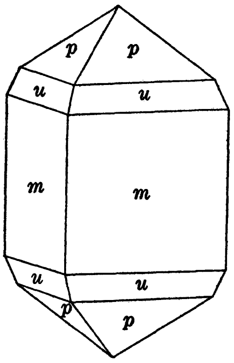


FIGURE 138

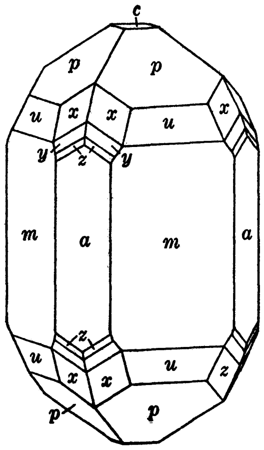


FIGURE 139

FIGURE 138.—Crystal of zircon showing the forms *m*(110), *p*(111), and *u*(331). Balls Hill, Franklin.

FIGURE 139.—Crystal of zircon showing the forms *c*(001), *a*(100), *m*(110), *p*(111), *u*(331), *x*(311), *y*(411), and *z*(511). Balls Hill, Franklin.

THORITE

$ThSiO_4$. Tetragonal

Dark-brown grains as much as half an inch in diameter that were identified as thorite by chemical tests were observed by Kemp (152) in pegmatite from the Trotter mine. They seem to be very scarce there.

In a personal communication Professor Kemp informed the author that the mineral was first recognized by Professor Groth, of Munich, on a visit to Franklin with him. Specimens in the Harvard collection that were given by Groth to Professor Wolff illustrate the occurrence. The thorite is largely altered to glassy orangite and is associated with tiny crystals of zircon in typical pegmatite. The orangite was easily soluble, with gelatinization, which, with its appearance, sufficiently identified it.

DATOLITE

$Ca(BOH)SiO_4$. Monoclinic

Forms.—*c*(001), *b*(010), *a*(100), *M*(110), *o*(120), *t*(013), *g*(012), *m*(011), *x*(101), 𝔖(308), ψ(104), *v*(103), ξ(102), *n*(111), Λ(112), *W*(114), λ($\bar{1}13$), ε($\bar{1}12$), γ($\bar{1}11$), *Q*(122), ι(212), β(121), *U*(123), *D*(133), *C*($\bar{1}25$), ϒ(702), and *k*(4.7.10). Position and letters of Dana.[7]

Combinations on crystals of datolite

	Forms	Illustrations
1	*c, a, M, o, t, g, m,* ϒ, *x,* 𝔖, ψ, *n,* Λ, *W,* β, *U, d*	Fig. 140.
2	*c, a, M, t, g, m, x,* 𝔖, ψ, *n,* Λ, *Q,* β, *D*	Fig. 141.
3	*a, M, m, n,* Λ, ε, γ, *D*	Fig. 142.
4	*c, a, M, m, n, D*	Fig. 143.
5	*c, M, g, m, n,* ε, γ, *D, Q, k*	Fig. 144.
6	*c, a, M, m, n,* ε, γ, *D*	
7	*c, a, M, t, g, m,* ξ, *n,* Λ, ε, *Q,* ι, β, γ, *C*	
8	*c, a, M, m, x, n, C*	
9	*a, M, m, v, C*	Gordon (227), fig. 2.
10	*c, a, b, o, m*	Fig. 145.

The crystals are of a common datolite habit, the unit pyramid being dominant. Etching is common and has affected the unit pyramid chiefly, removing the parts of its surface adjacent to the base. The form *D*(133) is characteristic for the locality and is always seen either as large faces or as narrow truncations.

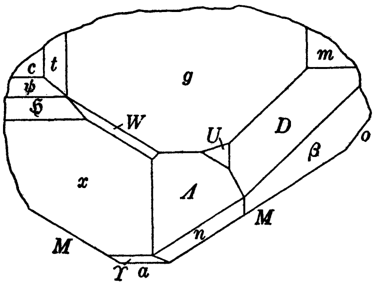


FIGURE 140.—Plan of a part of a crystal of datolite showing the forms *c*(001), *a*(100), *M*(110), *o*(120), *t*(013), *g*(012), *m*(011), ϒ(702), *x*(102), 𝔖(308), ψ(104), *n*(111), Λ(112), *W*(114), β(121), *U*(123), and *D*(133). Parker mine.

Occurrence.—Datolite is one of the pneumatolytic minerals found in the Parker shaft at Franklin. It was reported first by Penfield (173) in his description of roeblingite and later by others, but invariably in small amounts. It is generally massive and glassy-white, filling openings between the other minerals of the aggregate. Some of the openings are 1 or 2 inches across, and the datolite does not fill all of them but

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[7] In 1910 Palache (195) published a list of forms found on Franklin datolite. Ungemach (198) showed that the crystals had been incorrectly oriented and that of the new forms announced only the last two here listed were not already known. The present description is revised in accordance with Ungemach's correction.

only coats the surface of some with crystals. Most such crystals are imperfect through etching, but in one specimen in the Harvard collection, obtained by Wolff at the locality, the crystals are brilliant and measurable. The mass of the specimen consists of characteristically massive hancockite. In the cavity datolite and hancockite have crystallized together, the included needles of the hancockite tinging the datolite red.

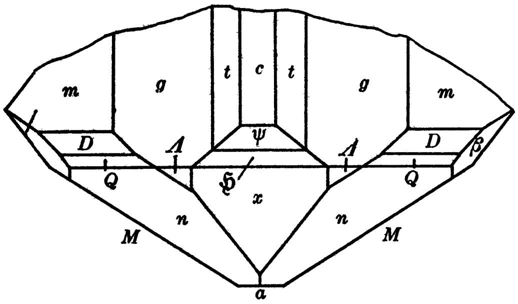


FIGURE 141.—Plan of a crystal of datolite showing the forms *c*(001), *a*(100), *M*(110), *t*(013), *g*(102), *m*(011), *x*(102), 𝔖(308), *ψ*(104), *n*(111), Λ(112), *Q*(122), *β*(121), and *D*(133). Parker mine.

The datolite has not been analyzed. It was carefully tested qualitatively for manganese, and as that element proved to be absent no complete analysis seemed to be needed.

In 1913 datolite with a different habit and association was found and was described by Gordon (227). The specimens consisted of axinite crusted with pale-pink datolite crystallized in rosettes. The simple crystals showed the forms of combination 8. Their faces were rough, and some were clouded as if by the beginning of alteration. Later than the datolite is a deposit of barite, and small cavities are partly filled with needles of clear white calciothomsonite, otherwise unknown at Franklin.

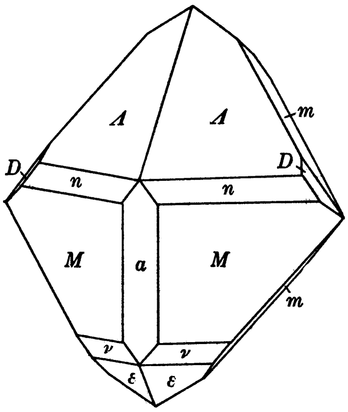


FIGURE 142

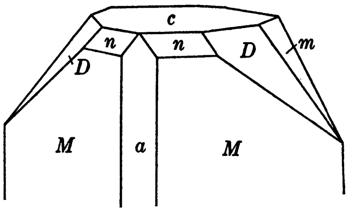


FIGURE 143

FIGURE 142.—Doubly terminated crystal of datolite showing the forms *a*(100), *M*(110), *m*(011), *n*(111), Λ(112), ε($\bar{1}$12), γ($\bar{1}$11), and *D*(133) Parker mine.

FIGURE 143.—Crystal of datolite showing the forms *c*(001), *a*(100), *M*(110), *m*(011). *n*(111), and *D*(133). Parker mine.

In 1926 the variety of datolite called botryolite was found at Franklin in the form of a fibrous crust with a botryoidal surface that coats axinite and rhodonite, and also cahnite in some of the veins in which that mineral was first found. The datolite is snow-white and appears to be contemporaneous with the cahnite. It is interesting to find thus in the same veins three different boron minerals—axinite, cahnite, and datolite.

Still more recently a new habit of datolite was found at Franklin and was described by Berman (273). The crystals are tabular parallel to the clinopinacoid, with nearly equal development of the forms *o*(120) and *m*(021), which have approximately equal inclinations to the clinopinacoid. Thus a pseudotetragonal symmetry is developed, as shown in figure 145. The determination of the mineral was confirmed by optical means and by a partial analysis.

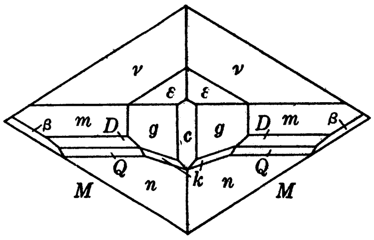


FIGURE 144.—Plan of a crystal of datolite showing the forms *c*(001), *M*(110), *g*(012), *m*(011), *n*(111), ε($\bar{1}$12), γ($\bar{1}$11), *Q*(122), *β*(121), *D*(133), and *k*(4.7.10). Parker mine.

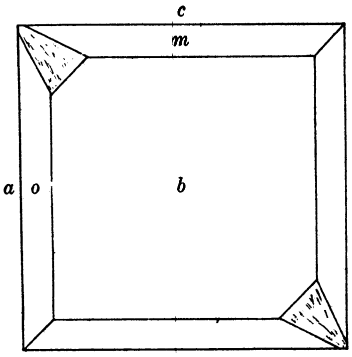


FIGURE 145.—Projection on the clinopinacoid of a crystal of datolite, tabular parallel to that face, showing the forms *c*(010), *b*(010), *a*(100), *o*(120), and *m*(011). Franklin.

EPIDOTE GROUP

Although epidote itself is comparatively unimportant among the minerals of the Franklin district, the epidote group is well represented by four species, one of which, hancockite, is found only in the district. The material several times reported as clinozoisite has finally been determined to be chlorophoenicite.

ZOISITE

$Ca_2(AlOH)Al_2(SiO_4)_3$. Orthorhombic

Zoisite has been found at Franklin, but only as a microscopic constituent of the pseudomorphs after microcline described on pages 60–61.

EPIDOTE

$Ca_2(AlOH)(Al,Fe)_2(SiO_4)_3$. Monoclinic

Crystals of epidote, small and poorly developed, and dark to light-green crystalline aggregates of the mineral are not uncommon in the pegmatite of both Franklin and Sterling Hill near its contacts with the ore bodies. Epidote is also fairly abundant in the iron mines south of Franklin, both in the ore and in the associated pegmatite.

The mineral was noted as early as Nuttall's time (7), but it is relatively of little significance in the mineralogy of the district.

HANCOCKITE

$(Pb,Ca)_2(AlOH)(Al,Fe,Mn)_2(SiO_4)_3$. Monoclinic

Forms.—*c*(001), *a*(100), *e*(101), *r*($\bar{1}$01), and *n*($\bar{1}$11).

Habit.—Hancockite is found in very small lath-shaped crystals, in drusy cellular aggregates, and in compact masses. The crystals are striated parallel to their length and have rounded faces that permit of only very poor measurement on the goniometer. The angles measured approximate those of epidote.

Optical properties.—The color of the massive mineral is dull brick-red, brownish-red, or maroon. That of the crystals when separately examined is yellowish-brown with strong pleochroism—yellowish-brown for vibrations parallel to the axis of symmetry, and somewhat various for vibrations normal to that direction, being delicate rose-red at the attached end (and in some crystals throughout) and grading to pale greenish-yellow at the free end.

The axial plane is parallel to the clinopinacoid; $2V=50°$, about. The mineral is optically negative; $r>v$ (perceptible); the absorption $Z>X$. $\alpha=1.788\pm0.003$, $\beta=1.81\pm0.01$, $\gamma=1.830\pm0.003$ (Larsen). The luster is vitreous, the hardness 6.5 to 7, and the specific gravity 4.03.

Composition.—Hancockite is a member of the epidote group, very distinct in containing lead and strontium in place of part of the calcium of epidote. The presence of manganese allies it to piedmontite.

Analysis of hancockite

[C H Warren (179), analyst]

	Percent	Molecular ratio	
SiO_2	30. 99	0. 516	=6×0. 084
Al_2O_3	17. 89	. 176	0. 262=3×0. 087
Fe_2O_3	12. 33	. 077	
Mn_2O_3	1. 38	. 009	
PbO	18. 53	. 083	. 368=4×0. 092
MnO	2. 12	. 030	
MgO	. 52	. 013	
CaO	11. 50	. 205	
SrO	3. 89	. 037	
H_2O	1. 62	. 090	=1×0. 090
	100. 77		

The molecular ratio of $SiO_2 : R_2O_3 : RO : H_2O$ is not far from 6 : 3 : 4 : 1, from which may be derived the formula adopted.

Occurrence.—Hancockite was recognized as a new mineral and described by Penfield and Warren (179), from whose paper the facts stated above are taken with slight additions. It was found in considerable abundance in the Parker shaft in association with other rare and peculiar silicates. As the dump of that mine was removed the mineral was found throughout its extent in characteristic brick-red masses interspersed with granular garnet and scales of biotite. In drusy parts of such masses its tiny crystals line the cavities and are abundantly included in clear crystals of axinite, datolite, and willemite, to all of which it lends its reddish-brown color.

Since Penfield's description of hancockite was published it has been found in but one other association—in a specimen of barium feldspar from the same locality (see p. 59), which is colored red by microscopic inclusions of hancockite.

The mineral was named for the late Mr. E. P. Hancock, formerly of Burlington, N.J., an enthusiastic and lifelong collector of Franklin minerals.

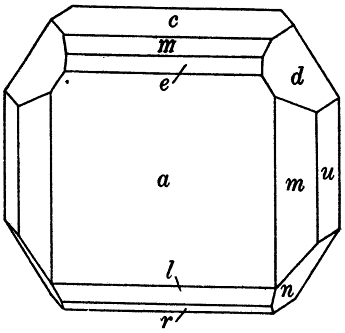


FIGURE 146.—Crystal of allanite showing the forms *c*(001), *a*(100), *m*(110), *u*(210) 𝔪(102), *e*(101), *r*($\bar{1}$01), *l*($\bar{2}$01), *d*(111), and *n*(111) Franklin.

ALLANITE

$(Ca,Fe)_2(AlOH)\ (Al,Ce,Fe)_2(SiO_4)_3$. Monoclinic

Forms.—*a*(100), *c*(001), *m*(110), *u*(210), 𝔪(102), *e*(101), *σ*($\bar{1}$03), *i*($\bar{1}$02), *r*($\bar{1}$01), *l*($\bar{2}$01), *o*(011), *d*(111), *n*($\bar{1}$11), and *w*(211).

Combinations on crystals of allanite

	Forms	Illustrations
1	*a, c, m*	Eakle (150), fig. 1.
2	*a, c, m, e, l, d, n*	Eakle (150), fig. 2.
3	*a, c, m, u,* 𝔪*, e, r, l, d, n*	Fig. 146. Eakle (150), fig. 3.
4	*a, c, m, u, e,* 𝔪*, i, r, l, d, n, w*	Eakle (150), fig. 4.
5	*a, c, m, e, i, r, l, o, d, n*	Eakle (150), fig. 5.

Habit.—The crystals are commonly tabular parallel to the orthopinacoid, and many are elongated in the direction of the orthoaxis. The faces are dull and pitted and give poor reflections on the goniometer, but the forms listed were well established by numerous measurements.

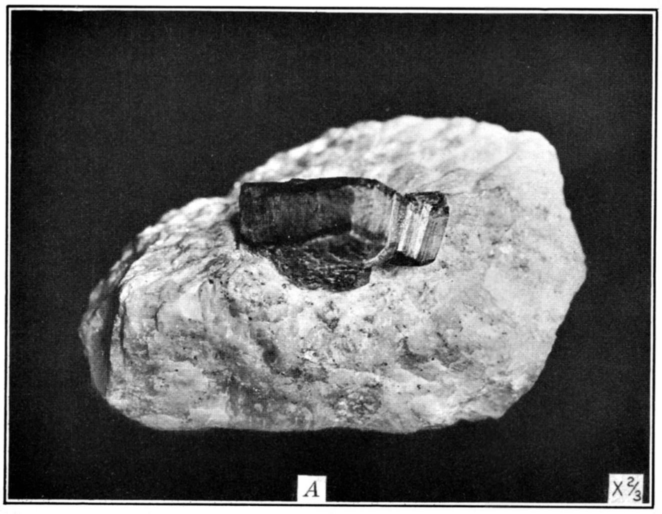
The cleavage is very imperfect parallel to the orthopinacoid and to the base and is a little better nearly parallel to the unit prism but departs about 6½° from parallelism. The specific gravity is 3.84 (Hunt). The mineral is coal-black and opaque, but in thin section it is transparent, brown, and strongly pleochroic; *X* yellow, *Y* dark red-brown, *Z* grayish brown. The absorption is strong of rays parallel to *Y*. Refrac-

A. GROUP OF CRYSTALS OF ZIRCON FROM A CAVITY.
Hill iron mine.

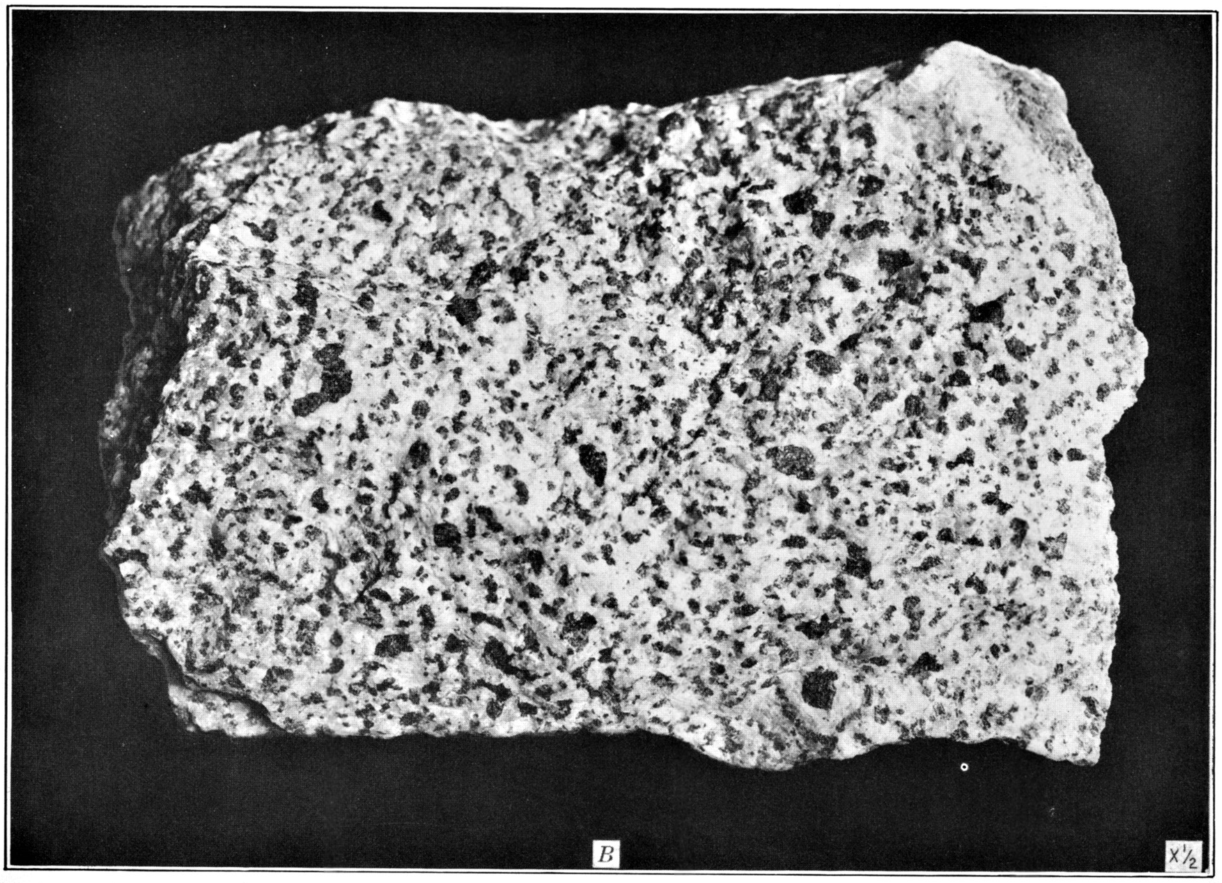
B. ALLANITE CRYSTAL IN PEGMATITE.

C. GROUP OF CRYSTALS OF CALAMINE ON A STALACTITIC SURFACE.
Passaic mine.

D. BLADED CRYSTALS OF CALAMINE COATING TROOSTITE.
Sterling Hill.



A. HEMIMORPHIC CRYSTALS OF TOURMALINE IN LIMESTONE.
Franklin.



B. IMPERFECT CRYSTALS OF NORBERGITE IN LIMESTONE.
Franklin.

tive index about 1.74 and birefringence weak. The axial plane is parallel to the clinopinacoid. $Bx_a \wedge c =$ 36° (about), in acute angle β.

Composition.—The only analysis of allanite from Franklin is given below. It is that of a typical allanite, which is a hydrous silicate of aluminum and calcium with more or less iron, manganese, and a few of the rare-earth metals. The material analyzed probably contains some ferrous iron and also a little of some other rare earth, such as Pr_2O_3 or Nd_2O_3.

Analysis of allanite

[T. S. Hunt (83), analyst]

SiO_2	30.20	MgO	1.70
Al_2O_3	13.05	MnO	Trace
Fe_2O_3	18.25	Volatile	1.30
Ce_2O_3	16.60		
La_2O_3	6.90		99.76
CaO	11.76		

Occurrence.—Allanite is found at Franklin only in the pegmatite. It was first recognized by Jackson (51), who found it on the dump of one of the old iron mines. It can still be found in imperfect black crystals in the pieces of pegmatite on several of those old dumps. This was the material analyzed by Hunt.

In sinking the Trotter shaft on Mine Hill much pegmatite was encountered, and in places, especially where the coarse pegmatite was in contact with either limestone or zinc ore, allanite was abundant. The crystals are tabular, and many are thin and highly brittle, so that they are extracted from the matrix with much difficulty. Plates as much as 1.5 by 3 inches were found, but few complete crystals are more than an inch in their greatest dimension. The crystals were described by Eakle (150), and the foregoing description has been taken from his paper. Plate 16, *B*, shows a crystal embedded in the pegmatite, and figure 146, after Eakle, shows the commonest combination.

AXINITE

Varieties manganoaxinite and ferroaxinite. $HBAl_2Ca_2(Mn,Fe)Si_4O_{16}$. Triclinic

Forms.—In the list below, the letter and symbol preceding the equal sign are those used by Dana, with crystals in the "Dana position", and the letter and symbol following the equal sign are those used by Goldschmidt, with crystals in the "Winkeltabellen position."

Forms on crystals of axinite

$a(100) = l(1\bar{2}0)$
$b(010) = M(100)$
$c(001) = m(001)$
$m(110) = u(1\bar{1}0)$
$M(1\bar{1}0) = c(010)$
$T(120) = X2\bar{1}0)$
$h(3\bar{1}0) = h(1\bar{3}0)$
$\gamma(1\bar{2}0) = \gamma(120)$
$w(130) = w(1\bar{1}0)$
$s(201) = s(1\bar{2}1)$
$f(011) = f(102)$
$y(021) = y(101)$
$X(0\bar{2}1) = b(\bar{1}01)$
$\mu(0\bar{4}1) = \mu(\bar{2}01)$
$W(312) = W(232)$
$\mathfrak{A}(534) = \mathfrak{A}(4\bar{5}4)$
$x(111) = x(1\bar{1}1)$
$\nu(131) = \nu(2\bar{1}1)$
$e(\bar{1}11) = e(011)$
$o(132) = o(112)$
$Y(\bar{1}31) = Y(111)$
$V(\bar{1}\bar{1}2) = V(\bar{1}12)$
$z(1\bar{1}2) = z(0\bar{1}2)$
$r(1\bar{1}1) = r(0\bar{1}1)$
$\pi(2\bar{2}1) = \pi(0\bar{2}1)$
$\delta(1\bar{3}2) = \delta(\bar{1}\bar{1}2)$
$n(1\bar{3}1) = n(\bar{1}\bar{1}1)$

Combinations on crystals of axinite

[Letters and position according to Dana]

	Forms	Localities	Illustrations
1	*a, b, m, M, s, X, W, x, V, r.*	Trotter mine....	(Penfield).
2	*b, m, M, w, f, s, y, W,* $\mathfrak{A}$*, x, e, Y, r,* π.	Trotter mine....	Figure 147.
3	*a, b, m, M, s, f, y, X, x, r.*	Parker shaft ...	Figure 148.
4	*b, m, M,* γ*, w, s, y, x, e, o, Y, z, r.*	Gooseberry iron mine.	Figure 149.
5	*a, b, m, M, w, T, s, f, X,* μ*, W, x, e, o, Y, V, r.*	....	(Aminoff, fig. 19.)
6	*a, c, m, M, s, f, X, W,* $\mathfrak{A}$*, x, e, o, r.*	....	(Aminoff, fig. 20.)

Aminoff lists 10 other combinations similar to the last two in the table.

Crystallography.—Aminoff (215) has discussed the crystallography of the Franklin manganoaxinite in detail. He computed the elements from the measurement of 11 crystals and found them almost the same as those of the ferroaxinite from France. Hence the substitution of iron for manganese in this mineral produces but slight morphotropic effect. The axial ratios of the varieties are, for the ferroaxinite from Dauphiny (Goldschmidt, Winkeltabellen), $a:b:c = 0.7812:1:0.9771$; $\alpha = 91° 49'$, $\beta = 82° 1'$, $\gamma = 102° 38'$; and for the manganoaxinite from Franklin (Aminoff), $a:b:c = 0.7797:1:0.9764$; $\alpha = 91° 55'$, $\beta = 81° 51'$, $\gamma = 102° 53'$.

Aminoff describes the new form $\mathfrak{A}(534)$, which had been found and figured by the author also and is thus well confirmed. The forms listed by Aminoff are included in the above list.

Composition.—Axinite is of rather complex composition, but it may be briefly characterized as an acid borosilicate of calcium, aluminum, and manganese, with some iron and zinc.

Analyses of axinite

	1	2
SiO_2	42.77	42.47
B_2O_3	5.10	5.05
Al_2O_3	16.73	16.85
Fe_2O_3	1.03	1.16
CuO	.12	.11
PbO	....	.09
ZnO	1.48	1.53
MnO	13.69	13.14
MgO	.23	.26
CaO	18.25	18.35
H_2O	1.29	1.21
	100.69	100.22

1. Crystals, specific gravity 3.358. W. E. Ford (187), analyst.
2. Massive mineral, specific gravity 3.306. W. E. Ford, (187), analyst.

As the two analyses differ by less than 1 percent in the amount of each constituent, the Franklin axinite is apparently of rather uniform composition. It contains more manganese than any other axinite yet studied and differs but little in composition from the pure type of manganoaxinite as defined by Schaller.

Optical properties.—Axinite is optically biaxial and negative; $2V=74^\circ$ (measured), $r<v$ (strong); the crystals from Franklin are generally plates parallel to the pyramid $x(111)$ and the acute bisectrix emerges almost normal to that face. When a crystal is oriented in the "Dana position" the directions of the axes of elasticity, expressed in gnomonic coordinates, are for X, $\phi=53^\circ$, $\rho=55^\circ$; for Y, $\phi=156^\circ$, $\rho=72^\circ$; for Z, $\phi=-93^\circ$, $\rho=42^\circ$, all in sodium light. The refractive indices for sodium light are: $\alpha=1.684$, $\beta=1.692$, $\gamma=1.696$, all ± 0.001. The pleochroism is X=yellow, Y=yellow, Z=colorless (Berman). Under the iron-arc spark most axinite from Franklin shows no fluorescence, but a few specimens fluoresce with a vivid pinkish-red tint.

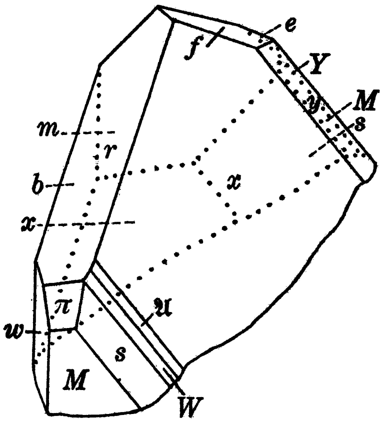


FIGURE 147

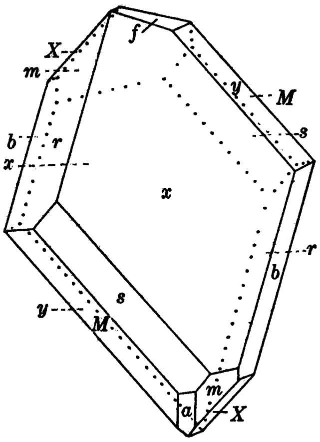


FIGURE 148

FIGURE 147.—Crystal of axinite, variety manganoaxinite, showing the forms $b(010)$, $m(110)$, $M(1\bar{1}0)$, $w(1\bar{3}0)$, $s(201)$, $f(011)$, $y(021)$, $W(312)$, $\mathfrak{A}(534)$, $x(111)$, $e(\bar{1}11)$, $Y(\bar{1}31)$, $r(1\bar{1}1)$, and $\pi(2\bar{2}1)$. Trotter mine.

FIGURE 148.—Crystal of axinite, variety manganoaxinite, showing the forms $a(100)$, $b(010)$, $m(110)$, $M(1\bar{1}0)$, $s(201)$, $f(011)$, $y(021)$, $X(0\bar{2}1)$, $x(111)$, and $r(1\bar{1}1)$. Parker shaft.

Occurrence.—Axinite has been found at Franklin at many localities. It was first discovered in the Trotter mine, where it was found in the shaft in great abundance. It formed lamellar masses and tiny brilliant crystals mixed chiefly with rose-colored rhodonite, polyadelphite, biotite, and barite. The crystals are generally pale yellow or yellowish green, but some are pale rose-colored or even quite colorless. The yellow color is peculiar to the axinite of the locality. The dominant habit of the crystals is tabular parallel to the pyramid $x(111)$, as shown in figures 147 and 148; the rare forms $V(\bar{1}\bar{1}2)$ and $X(0\bar{2}1)$ are seen, as well as the new form mentioned above, $\mathfrak{A}(534)$. Penfield first described and figured the crystals in a paper by Genth (145), giving analyses of crystals and of massive material. Genth's material was reanalyzed by Ford (187), who showed that the original water determinations were slightly too low.

Yellow axinite was one of the more abundant minerals of the pneumatolytic deposit revealed in sinking the Parker shaft. It was generally in massive granular or lamellar form, and masses of many pounds in weight were not rare. Intimately mixed with it were polyadelphite, manganophyllite, and hancockite; barite and rhodonite were less abundant. A few crevices in the massive material are lined with drusy coatings of brilliant tabular crystals, some of which are attached by such slender bases as to be developed practically on all sides, as shown in figure 148. The axinite crystals show the same variations from the dominant honey-yellow color as those from the Trotter mine. Although not analyzed, they are doubtless of similar composition.

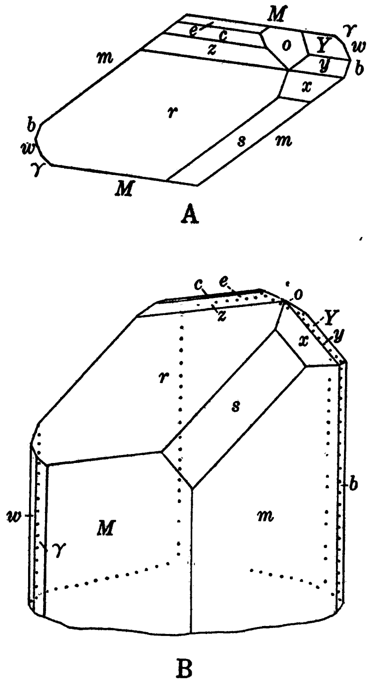


FIGURE 149.—Crystal of ferroaxinite showing the forms $b(010)$, $m(110)$, $M(1\bar{1}0)$, $\gamma(1\bar{2}0)$, $w(1\bar{3}0)$, $s(201)$, $y(021)$, $x(111)$, $e(\bar{1}11)$, $o(\bar{1}32)$, $Y(\bar{1}31)$, $z(1\bar{1}2)$, and $r(1\bar{1}1)$. Gooseberry iron mine. A, Plan; B, clinographic projection.

The development of the north end of the mine has revealed abundant axinite not different in general character from that just described but developed in larger and more showy groups of crystals. Some of the crystals are an inch across and are quite transparent, although badly striated and not measurable.

Ferroaxinite.—Specimens obtained during the sinking of the Palmer shaft showed a cavity in gneiss lined mainly with crystals of apophyllite. Besides that mineral and pyrite, there is on one specimen a clove-brown axinite in minute crystals, too poorly developed for measurement but apparently of the ordinary habit of the mineral.

In the Hancock collection there is a single specimen, from the Gooseberry iron mine, containing axinite. It consists chiefly of massive crystalline epidote embedded in calcite. When the calcite was removed with acid the cavities revealed rough crystals of epidote, fibers of actinolite, and minute crystals of arsenopyrite, and also a few brilliant clove-brown crystals of axinite of the form illustrated in figure 149. They are entirely unlike the other crystals described and resemble those of the ferroaxinite of better-known localities, being prismatic and striated parallel to the vertical axis.

PREHNITE

$H_2Al_2Ca_2Si_3O_{12}$. Orthorhombic

Character.—Prehnite is found in faintly yellowish-white coarse lamellar to platy aggregates, some of the plates being in fan-shaped groups. An imperfect pinacoidal cleavage shows a pearly luster. The specific gravity is 2.89 to 2.96. In appearance the mineral is wholly unlike any other prehnite known to the author, and its nature was not suspected until the results of the analyses were available.

Composition.—Prehnite is an acid orthosilicate of calcium and aluminum. The early analyses gave quite unsatisfactory ratios for prehnite until it was discovered that the mineral was mixed with pectolite, but after correction for the presence of enough of that mineral to account for the alkalies found, both gave fairly satisfactory ratios. After it was learned that pectolite is fluorescent under the iron-arc spark, whereas prehnite is not, some of the material from which analysis 2 was made was again separated, first in a heavy solution and finally under the spark, and thus a sample almost free from pectolite was obtained. Analysis 3, made of this sample, shows the presence of only about 2 percent of impurity and gives an almost exact ratio for prehnite.

A specimen of more typical prehnite from Franklin, found in the Hancock collection, shows a perfect basal cleavage. It is optically biaxial and positive, 2V is medium to large, and *Z* is normal to the cleavage; $\alpha=1.617$, $\beta=1.625$, $\gamma=1.643$, all ±0.002; β is parallel to the cleavage (Berman).

Analyses of prehnite

	1	2	3
SiO_2	42. 93	43. 30	43. 06
Al_2O_3	21. 86	22. 70	24. 98
Fe_2O_3		. 34	. 31
CaO	26. 64	27. 35	27. 00
MnO	. 60	. 30	. 06
PbO	2. 51	--------	--------
Na_2O	. 51	. 93	. 10
K_2O	. 23	. 18	. 10
H_2O	4. 55	5. 09	4. 43
	99. 83	100. 19	100. 04

1. Material of specific gravity 2.892; about 7.27 percent of pectolite. C. H. Warren, analyst. (Private communication.)
2. Material of specific gravity 2.965; about 11.35 percent of pectolite. George Steiger, analyst (U.S. Geol. Survey, unpublished.)
3. Material separated under iron-arc gap spark; about 1.7 percent of pectolite. F. A. Gonyer (277), analyst.

The presence of a small amount of lead in the material of analysis 1 may indicate that it is a lead-bearing prehnite; more probably, however, it is due to a few admixed grains of nasonite, with which the material is associated.

Occurrence.—According to Mr. T. Lang, of Franklin, a considerable amount of the material of analysis 1 was found on the dump of the Parker shaft with the new silicates discovered in 1897. The analysis by Warren was made during the examination of the new material by Penfield and Warren, but as it gave a poor ratio it was never published, and the author is indebted to him for its use here. In the specimens seen by the author prehnite is intimately mixed with yellow garnet, grains of franklinite, and scales of biotite, all readily visible. After the analysis was made, grains of transparent white pectolite were discovered in the material, so intimately mixed with the prehnite that separation of either to a pure product is extremely difficult.

In the Hancock collection a single specimen of prehnite in more typical form was found. It was labeled simply "Franklin Furnace," and nothing is known of its source, but others resembling it were found on the dumps of the Parker shaft. In it rosettes and crusts of thin white plates of prehnite line cavities in a mass of manganese garnet and biotite. Its nature was established by optical determination by Mr. Berman, who furnished the optical data given above.

CUSPIDINE

$Ca_4Si_2F_2O_7$. Monoclinic

Physical character.—Cuspidine has been found at Franklin only as glassy-white fragments of crystals associated with nasonite and the other peculiar silicates of the Parker shaft. Its specific gravity is between 2.965 and 2.989.

Composition.—Cuspidine appears to be a calcium orthosilicate that contains fluorine in the place of one-eighth, molecularly, of the oxygen. Opinions differ regarding the place of the fluorine in the compound; hence several formulas have been proposed for the mineral, though all are derived from the empirical formula given above.

Analysis of cuspidine

	1	2	3
SiO_2	32. 36	31. 40	0. 539 =2×0. 270
F	9. 05	9. 94	. 476 =2× . 238
CaO	61. 37	58. 66	1. 094 =4× . 273
MnO	. 71	--------	. 018
Na_2O	. 48	--------	
K_2O	. 27	--------	
	104. 24	100. 00	
$O=F_2$	3. 81	--------	
	100. 43	--------	

1. Crystal fragments, Franklin. C. H. Warren (195), analyst.
2. Composition computed from the formula adopted.
3. Molecular ratio of no. 1.

Inspection of the analysis shows that the material, though rather low in fluorine, had practically the composition of cuspidine, and it is believed to have been that mineral.

Occurrence.—The author is indebted to Dr. C. H. Warren for the analysis of Franklin cuspidine (Palache, 195) and for the facts here given regarding its discovery. The material was isolated by hand picking and by heavy solution and was analyzed by Warren when Penfield and he were studying the new silicates from the Parker shaft. At that time he found no satisfactory interpretation of the analysis, the identity of the mineral remained hidden, and his notes were laid aside. Of the 1.5 grams of material separated, none was saved from the analysis, and no physical characters were determined except the specific gravity.

On learning that the author was studying Franklin minerals, Dr. Warren kindly sent him the record of the analysis and has accepted the interpretation of it that identifies the mineral as cuspidine. The discovery of cuspidine among the minerals from the Parker shaft is interesting, especially as confirming the pneumatolytic origin of that peculiar assemblage of species. The only other known occurrences of cuspidine—in metamorphosed limestone blocks ejected from Monte Somma and in the peperino of the Alban Hills—are typical examples of pneumatolytic genesis.

HUMITE GROUP

Minerals belonging in the humite group, although not known in the zinc-ore deposits, are fairly abundant in the Franklin limestone throughout its extent. In the older lists of Franklin minerals they are recorded as chondrodite, and only very recently have studies been made of sufficient accuracy to determine their true nature. Larsen, Bauer, and Berman (261) have established the fact that the commonest of them is norbergite, a species first described by Geijer in 1926. Chondrodite is found only as cores in grains of norbergite and in small amounts in the limestone of the Rudeville quarry.

NORBERGITE

$Mg(OH,F)_2.Mg_2SiO_4$ Orthorhombic.

$a : b : c = 1.10 : 1 : 1.897,\ p_o = 0.723,\ q_o = 1.897$

Forms.—*c*(001), *D*(110), *M*(011), *N*(021), *e*(111), *d*(221).

Crystallography.—Crystals of norbergite are very rare, the only measurable one known having been presented to the Harvard Mineralogical Museum in 1906 by Dr. Ungemach, of Paris, who fonud it with a few others in the Nicoll limestone quarry at Franklin, then active. This crystal, about half an inch in diameter, is shown in figure 150 and from a different position in Berman's paper (261). The relation of norbergite to the other members of the group is discussed at length there and need not be considered here. It is enough to say that the angles are practically the same as those of humite and the crystal was supposed to be humite until analyzed.

Physical properties.—Norbergite ranges in color from tawny (Ridgway's 13''j) to chamois (Ridgway's 19''b), and the lighter-colored varieties have lower indices of refraction than the darker ones, indicating a lower iron content. It has a hardness of 5.5 and in general appearance resembles the other members of the humite group. Its specific gravity is 3.20.

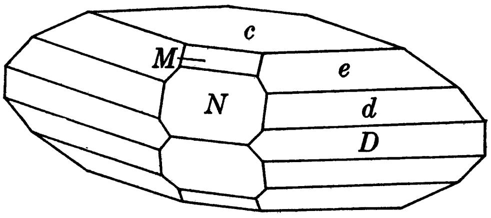


FIGURE 150.—Crystal of norbergite, thick-tabular parallel to the base, drawn with the brachyaxis in front and showing the forms *c*(001), *M*(011), *N*(021), *D*(110), *e*(111), and *d*(221) Nicoll quarry, Franklin

The optical properties of norbergite from Franklin are similar to those reported by Geijer for the mineral from Norberg. It is positive; $2V$ is 50°, about; the dispersion is slight, and it is slightly pleochroic. The refractive indices differ somewhat—those of the darker, analyzed material are: $\alpha = 1.565$, $\beta = 1.570$, $\gamma = 1.591$, $2V = 49°$; those of the chamois-colored crystals are: $\alpha = 1.561$, $\beta = 1.566$, $\gamma = 1.587$, $2V = 50°$; and those found by Geijer (245a) for the Norberg mineral are: $\alpha = 1.563$, $\beta = 1.567$, $\gamma = 1.590$, $2V = 49°30'$.

Composition.—Norbergite is a basic magnesium fluosilicate in which the molecular ratio of $Mg(OH,F)_2$ to Mg_2SiO_4 is 1 to 3. The analyzed material from Franklin falls short of satisfying the accepted formula, as it contains far too little fluorine, and the hydroxyl is almost negligible.

Analyses of norbergite

	1	2	3
SiO_2	28. 63	28. 54	29. 60
Al_2O_3	3. 12	. 09	--------
Fe_2O_3	--------	. 69	--------
FeO	. 73	. 82	--------
MgO	59. 42	56. 45	59. 56
CaO	--------	1. 01	--------
MnO	. 04	18	--------
F	12. 78	13. 70	18. 72
H_2O	. 32	2. 90	--------
CO_2	--------	1. 21	--------
	105. 04	105. 59	107. 88
$O = F_2$	5. 38	5. 77	7. 88
	99. 66	99. 82	100. 00

1. Norbergite crystal, containing about 2 percent of chondrodite, Franklin. L. H. Bauer (261), analyst.
2. Norbergite, Norberg, Sweden. Per Geijer (245a), analyst.
3. Composition of theoretical mineral: $MgF_2.Mg_2SiO_4$.

Occurrence.– The tawny-yellow crystal that was measured, and others of paler color and not so sharply developed, were found in the Nicoll quarry of the Franklin Iron Co. In 1905 the author found norbergite abundant in the Fowler quarry, in granular masses associated with black spinel, fluorite, and pyrrhotite. Plate 17, *B*, shows the abundance of the mineral. He also found very pale yellow grains, but at that time no crystals, in the Iron Co.'s quarry.

The Parker shaft encountered several pegmatite dikes cutting the Franklin limestone. According to Nason (163) the limestone adjacent to the dikes contained much chondrodite, together with phlogopite and tremolite. The pegmatitic origin of norbergite and chondrodite could not be established in the other localities mentioned, as it was at the Parker shaft, but it is considered probable at all the localities where those minerals were found.

CHONDRODITE

$Mg(OH,F)_2.2MgSiO_4$. Monoclinic

Physical character.--Chondrodite is not known in crystals but forms the cores of norbergite grains (261). It is more nearly colorless and has a higher index of refraction than the norbergite, has little pleochroism, and shows polysynthetic twinning, which ends abruptly at the norbergite. The optical constants of the chondrodite cores are given by Larsen (262) as follows: Negative; $2V$ large; $\alpha = 1.594$, $\beta = 1.607$, and $\gamma = 1.619$.

Occurrence.—At Franklin chondrodite is known only as described above, but dark orange-red "chondrodite" in rude crystals with spinel and garnet was found in a prospect shaft on the Tuttle farm, about half a mile southeast of the Parker shaft. Specimens were seen in the Kemble collection.

Yellow grains in limestone from Rudeville were proved optically to be chondrodite.

Neither chondrodite nor norbergite has been specifically reported at Sterling Hill, but there can be little doubt that one or both were formed in the limestone there, where contact-metamorphic conditions were similar to those in the limestone at Franklin.

KENTROLITE

Probably $3PbO.2Mn_2O_3.3SiO_2$. Orthorhombic

Forms.--*b*(010), *m*(110), *o*(111).

Habit.—Kentrolite has been observed on a single specimen in which minute crystals coat a cavity in calcite together with willemite. These crystals are hardly larger than 0.1 millimeter in any dimension. They are black and have fairly bright faces which gave measurements identifying the mineral as kentrolite. The appearance of the crystals is absolutely reproduced by figure 1 for kentrolite in Goldschmidt's "Atlas der Krystallformen", 5, tafel 8. No chemical nor optical tests were practicable because of the extreme scarcity of the material. The writer is indebted for his specimens to Mr. Lazard Cahn, who first discovered the presence of these minute crystals under his binocular.

LEUCOPHOENICITE

$H_2Mn_7Si_3O_{14}$. Monoclinic

Forms.—*c*(001), *b*(010), *a*(100), *m*(110), *s*(120), *e*(101), *t*(102), *x*(103), $r(\bar{1}01)$, $i(\bar{1}02)$, $y(\bar{1}03)$, $z(\bar{1}04)$, *o*(011), *f*(012), $p(\bar{1}11)$, *l*(121), $n(\bar{1}21)$, $u(\bar{1}22)$, *j*(122), $k(\bar{2}11)$, *d*(123), $h(\bar{1}23)$, and $q(\bar{1}24)$.

Combinations on crystals of leucophoenicite

	Forms	Illustrations
1	*c, b, a, s, e, r, i, y, o, l, n*	Fig. 151.
2	*c, b, a, s, r, y, o, l*	
3	*c, b, a, e, t, r, i, o, l, n, u, d, h.* Twin	Fig. 152.
4	*b, s, t, r, l, n*	
5	*c, b, e, r, t, o, l, d*	
6	*c, b, m, s, x, r, i, y, o, f, d, q*	
7	*c, b, o, l, n, d*	
8	*b, o, l, n, d*	
9	*c, a, e, x, r, i, z, u, k*	Figs. 153, 154.
10	*a, e, x, r, i, y, z, o, u, k.* Twin	
11	*c, b, a, e, t, r, i, f, n, d, h, p*	
12	*a, x, r, i, z, u, k*	
13	*c, a, s, e, x, r, i, y, z, u, k* Twin	Fig. 155.
14	*c, b, a, i, y.* Twin	Fig. 156.
15	*c, b, a, m, s, e, r, i, o, y, u, q, p, j*	Fig. 157.

Habit.—Leucophoenicite is commonly found in isolated crystalline grains or in massive granular form. Crystals are rare and are generally of epidote habit, more or less elongated parallel to the orthoaxis, and with a striated orthodome zone. Some, however, are tabular parallel to the orthopinacoid or to an orthodome. The crystals are generally minute, and many are twinned on the base, either as contact or as interpenetrating twins, and with numerous lamellae in parallel growth.

The crystallography of leucophoenicite was first described by the author (195) in 1910 and more fully (257), in 1927, Penfield (179), who established the species in 1899, having been unable to determine on his material even the crystal system. The first crystals measured came from a specimen in the collection of Mr. Canfield, who most kindly consented to sacrifice part of it for the purpose. Some 10 crystals, showing combinations 1 to 8, proved measurable, but many were fragmentary, and none were of first-class quality. The position chosen was that which gave the simplest symbols and at the same time brought the plane of twinning and cleavage into the position of the basal pinacoid. No interpretation of the highly peculiar assemblage of forms showed the slightest resemblance to the form series of any member of the humite group. to which leucophoenicite is chemically related.

Physical properties.—The cleavage is imperfect but is distinct parallel to the basal pinacoid. The hardness is 5.5 to 6, and the specific gravity is 3.848. The color ranges from brown through light purplish-red to raspberry-red (whence the name). The mineral is faintly pleochroic—rose-red for vibrations parallel to the base and colorless for those normal to it, and it is also colorless in thin section. It is negative; $2V = 74° \pm 5°$; r>v (slight); $\alpha = 1.751$, $\beta = 1.771$, $\gamma = 1.782$, all ± 0.003 (Larsen).

Composition.—Leucophoenicite is a basic silicate of manganese, of closely similar type of composition to humite but containing no fluorine and with manganese in place of magnesium. The Franklin material contains more or less calcium, zinc, magnesium, and ferrous iron in place of about an eighth of the manganese, and practically negligible amounts of alumina, soda, and potash. The analyses differ only in the relative amounts of the several bivalent oxides, and analysis 3 shows only about a third of the normal amount of water. With that exception the analyses give very closely a molecular ratio of $RO : SiO_2 : H_2O = 7 : 3 : 1$, in which RO is chiefly MnO. The corresponding formula is $H_2Mn_7Si_3O_{14}$, or, stated in molecular form, $Mn(OH)_2.3Mn_2SiO_4$. The close chemical similarity of this formula to that of humite, $Mg(OH,F)_2.3Mg_2SiO_4$, pointed out by Warren (179), is striking, but in spite of it, as stated above, there seems to be no crystallographic similarity between the two.

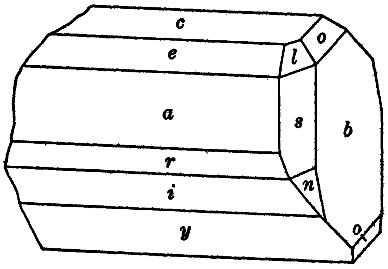


FIGURE 151.—One end of a crystal of leucophoenicite prismatic parallel to the orthoaxis, showing the forms *c*(001), *b*(010), *a*(100), *s*(120), *e*(101), *r*($\bar{1}$01), *i*($\bar{1}$02), *y*($\bar{1}$03), *o*(011), *l*(121), and *n*($\bar{1}$21). Parker shaft, Franklin.

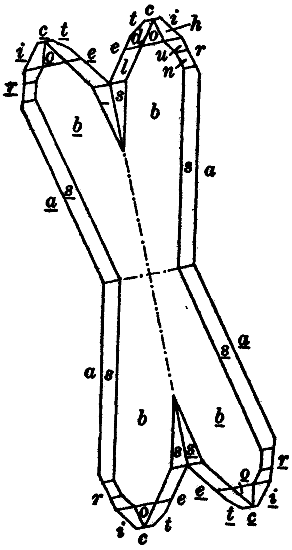


FIGURE 152

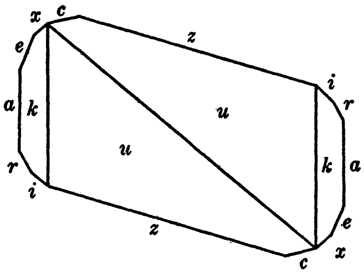


FIGURE 153

FIGURE 152.—Projection on the clinopinacoid of twin crystals of leucophoenicite twinned on the base and showing the forms *c*(001), *b*(010), *a*(100), *e*(101), *t*(102), *r*($\bar{1}$01), *i*($\bar{1}$02), *o*(011), *l*(121), *n*($\bar{1}$21), *u*($\bar{1}$22), *d*(123), and *h*($\bar{1}$23). Parker shaft, Franklin.

FIGURE 153.—Projection on the clinopinacoid of a crystal of leucophoenicite showing the forms *c*(001), *a*(100), *e*(101), *x*(103), *z*($\bar{1}$04), *i*($\bar{1}$02), *r*($\bar{1}$01), *u*($\bar{1}$22), and *k*($\bar{2}$11). Franklin.

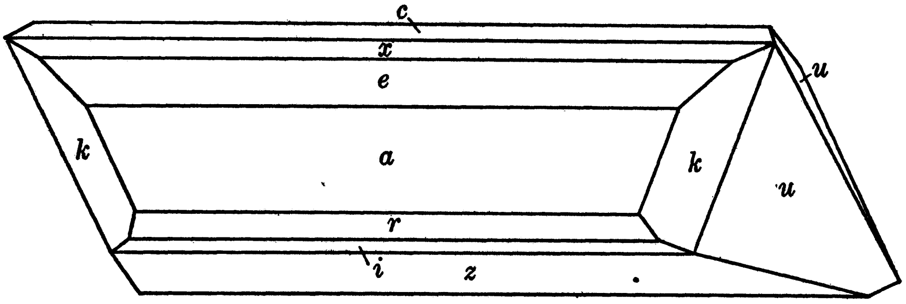


FIGURE 154.—Clinographic projection of the crystal of leucophoenicite illustrated in figure 153, showing the prismatic development parallel to the orthoaxis. Franklin.

Analyses of leucophoenicite

	1	2	3
SiO_2	26. 36	25. 28	26. 74
MnO	60. 63	60. 34	65. 19
ZnO	3. 87	5. 35	1. 39
FeO	Trace	Trace	. 93
MgO	. 21	. 30	2. 06
CaO	5. 67	4. 26	1. 22
Na_2O	. 39	. 90	. 53
K_2O	. 24	. 18	. 14
Al_2O_3	----------	1. 45	. 78
H_2O	2. 64	2. 10	. 85
	100. 01	100. 16	99. 83

1. Average of two analyses. C. H. Warren (179), analyst.
2, 3. Jenkins and Bauer (243), analysts.

Occurrence.—Leucophoenicite is fairly abundant in specimens from the pneumatolytic contact zone in the Parker shaft. It is found as grains and imperfect crystals intimately associated with bright-green willemite and sparse crystals of brown vesuvianite. Its color makes it conspicuous and rather attractive, but it is easily mistaken in some of its color shades for phases of willemite and garnet, and it was at first taken to be clinohedrite.

Besides the material from the original locality, leucophoenicite was identified in 1906 by Penfield in specimens in the Brush collection that had been found in the Buckwheat mine many years before. In those specimens it is in crystalline grains in calcite with green willemite and is quite similar in appearance to material in the type specimens, but it had been overlooked or mistaken for another substance (private communication to the author). It was also found in the complex specimens from the Buckwheat mine that contain pyrochroite (see p. 50), in which it is partly massive and mixed with franklinite and dull-pink garnet, and partly in free crystals, as described above.

More recently two interesting finds have been reported by H. H. Hodgkinson, of Franklin. One was a small cavity in ore, an opening in a vein consisting of leucophoenicite and willemite in granular mixture. The cavity is lined with pale-yellow drusy garnet on whose surface are implanted crystals of leucophoenicite and willemite and a single white scalenohedron of calcite. The willemite is pale green, of brilliant luster and long prismatic habit, with the complex form of combination 14 (p. 82). The leucophoenicite is in clear-red crystals, in striking contrast to their background. They are slender prismatic forms, both simple and twinned, the longest being doubly terminated, about one-third of an inch long, and showing the forms of figure 153. The twin shown in figure 155 and combinations 10, 11, and 12 came from this specimen. The crystals have suffered somewhat from etching, and the angle readings obtained were poor, but they sufficed to establish the forms—the orthodome $z(\bar{1}04)$ and the pyramids $u(\bar{1}22)$ and $k(\bar{2}11)$ being characteristic.

Leucophoenicite was also found by Mr. Hodgkinson in the north end of the mine near the hanging wall of the west leg of the ore body, within 2 feet of a pegmatite dike, in a continuous seam with swells and pinches, the swells making vugs in which the crystals had formed. The cavities have walls of layered ore containing much franklinite, which, near the margins of the cavities, is in cubic crystals. The walls of the cavities are lined with gray calcite merging inward to pale rhodochrosite, poorly crystallized in parallel groups of rhombohedrons. On the carbonates is a coating of silky, felted sussexite, commonly in a thin, closely adhering film. Massive dull-brown leucophoenicite forms a central mass 4 inches across, crystallized toward the center, either in slender, platelike crystals, shown in figure 156, their broad surfaces deeply striated by twinning, with bright surfaces of the base or basal cleavage; or in isolated stouter and more brilliant crystals, like figure 157. The latter are clear vivid pink and the plates are clear to opaque dull brown. Some of the platy crystals are aggregated in fan-shaped groups rising from the massive matrix.

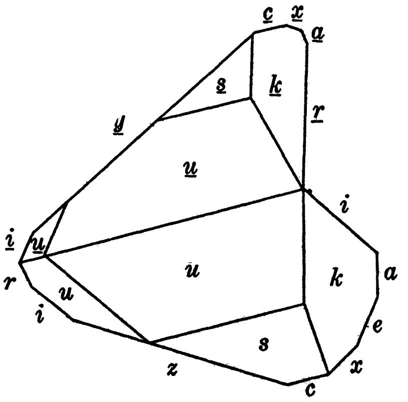


FIGURE 155

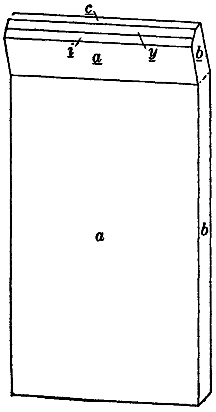


FIGURE 156

FIGURE 155.—Projection on the clinopinacoid of a crystal of leucophoenicite twinned on the base, showing the forms $c(001)$, $a(\bar{1}00)$, $s(120)$, $e(101)$, $x(103)$, $r(\bar{1}01)$, $i(\bar{1}02)$ $y(\bar{1}03)$, $z(\bar{1}04)$, $u(\bar{1}22)$, and $k(\bar{2}11)$. Franklin.

FIGURE 156.—Unsymmetrical crystal of leucophoenicite twinned on the base, showing on one part the forms $a(100)$ and $b(010)$ and on the other part the forms $c(001)$, $a(100)$, $b(010)$, $i(\bar{1}02)$, and $y(\bar{1}03)$. Franklin.

These specimens have added much to our knowledge of the crystallography of leucophoenicite and are the most attractive yet found of that peculiar mineral.

There has also been found a striking vein occurrence of leucophoenicite with willemite, the vivid color contrast with the green willemite being typical.

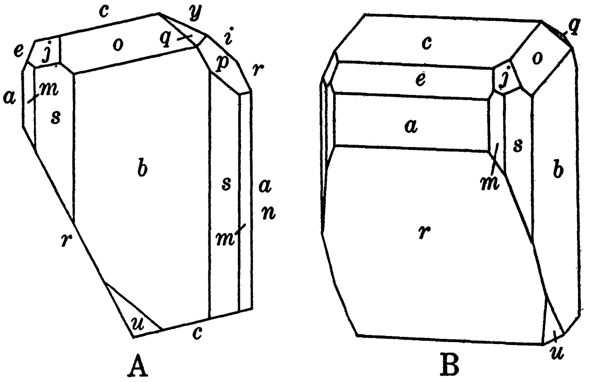


FIGURE 157.—Crystal of leucophoenicite showing the forms $c(001)$, $b(010)$, $a(100)$, $m(110)$, $s(120)$, $e(101)$, $r(\bar{1}01)$, $i(\bar{1}02)$, $y(\bar{1}03)$, $u(\bar{1}22)$, $g(\bar{1}24)$, $p(\bar{1}11)$, and $j(122)$. Franklin. A, Projection on the clinopinacoid; B, clinographic projection.

CALAMINE

$(ZnOH)_2SiO_3$. Orthorhombic-hemimorphic

Forms.—$b(010)$, $m(110)$, $s(101)$, $t(301)$, $e(011)$, $i(031)$.

Habit.—Isolated crystals of calamine are rare, and none showing double termination were observed. The crystals are generally grouped in subparallel or radiate fashion, forming fan-shaped, crested, stalactitic, or mammillary aggregates. The crested masses, illustrated in plate 16, *C*, are coarsely to finely crystalline and form the surfaces of large flat slabs or of coarse stalactites. From their characteristic appearance they are known among the zinc miners as "maggot ore." Calamine is also found in compact fibrous and chalky coatings. Its color is snow-white in masses, but much of it is stained brown or yellow by ferruginous clay. It is rarely bluish and transparent or colorless.

No measurable crystals were discovered by the author among the many specimens examined, and the only crystallographic data on Franklin calamine are those given by Pratt (158).

Composition.—Calamine is a basic zinc silicate having a chemical structure analogous to that of clinohedrite. The white crystallized calamine is almost absolutely pure, as shown by analysis 1, below. The massive forms are mixed with clay, and the analyses (p. 106) indicate that the so-called "vanuxemite" of Shepard (110) is merely a mixture of equal parts of calamine and of clay of the composition of halloysite: $H_4Al_2Si_2O_9 + H_2O$.

Occurrence.—Calamine has been found at Franklin only in minor amount, associated with the altered sphalerite in small cross veins secondary to the main ore body. In such a small vein, exposed in 1905 in the east wall of the Buckwheat open cut, radiate clusters of minute thin-tabular transparent crystals of calamine were found, attached to the limonite-coated quartz of which the vein was mainly composed. Remnants of sphalerite in the cavities showed that that mineral was probably the source of the calamine. Nowhere on Mine Hill do conditions seem to have been favorable to the formation or rather to the preservation of calamine, which, however, may have been formed from the primary zinc minerals.

The great masses of calamine discovered at Sterling Hill have been fully described on pages 22–23.

Analyses of calamine

	1	2	3	4
SiO_2	24.15	24.95	34.50	34.25
Al_2O_3 Fe_2O_3	.19	-------	18.40	18.45
ZnO	67.55	67.58	33.24	33.75
CaO	.12	-------	-------	-------
H_2O	7.95	7.47	13.67	13.55
	99.96	100.00	99.81	100.00

1. White calamine, Sterling Hill. Clarke and Steiger (182), analysts.
2. Composition computed from the adopted formula.
3. Vanuxemite, Sterling Hill. C. W. Cross (113), analyst.
4. Computed composition of a mixture of equal parts of calamine and halloysite.

CLINOHEDRITE

$H_2CaZnSiO_5$. Monoclinic-domatic

Forms.—$a(100)$, $b(010)$, $f(210)$, $h(320)$, $m(110)$, $m_1(\bar{1}10)$, $n(120)$, $n_1(\bar{1}20)$, $l(130)$, $d(150)$, $e(101)$, $e_1(\bar{1}0\bar{1})$, $p(111)$, $p_1(\bar{1}1\bar{1})$, $q(\bar{1}11)$, $q_1(11\bar{1})$, $r(\bar{3}31)$, $s(\bar{5}51)$, $t(\bar{7}71)$, $k(\bar{3}11)$, $k_1(31\bar{1})$, $A(\bar{3}1\bar{1})$, $g(\bar{5}11)$, $u(\bar{5}31)$, $v(\bar{1}71)$, $w(\bar{1}51)$, $o(\bar{1}31)$, $o_1(13\bar{1})$, $x(\bar{1}3\bar{1})$, $x_1(131)$, $y(\bar{1}2\bar{1})$, $j(25\bar{1})$, and $B(434)$. The form $B(434)$ is new. Measurement on two faces gave for it: $\phi=71°45'$, $\rho=37°45'$; computed for (434) $\phi=71°47'$, $\rho=37°44'$.

Combinations on crystals of clinohedrite

	Forms	Authorities	Illustrations
1	$b, h, m, m_1, n, l, e, e_1, p, p_1, q, r, s, t, u, o, x, y$.	Penfield (175)	
2	m_1, p, q_1, s, t, z	do	
3	$b, m, m_1, p, q, q_1, t, u, o_1, z$	Palache (257)	
4	$a, b, h, m, m_1, n, l, p, u$	do	Fig. 158.
5	$b, m, m_1, l, d, e, p, q, r, s, t, u, k, v, w$.	do	Fig. 159.
6	m, n, p, r, u	do	
7	$b, m, l, e, e_1, p, q, q_1, o, o_1, r, s, t, u, g, x$.	do	Fig. 160.
8	$a, b, f, m, p, q, q_1, s, t, k, e, o, x, n$.	do	
9	b, m, m_1, e, p, u	do	Fig. 161.
10	$b, m, e, p, q_1, k_1, x, j$	do	Fig. 162.
11	$b, m_1, n_1, e, p, p_1, A$	do	Fig. 163.
12	$b, m_1, n_1, p, p_1, q, t, A, x_1$	do	Fig. 164.
13	$a, m, m_1, e, p, p_1, q_1, s, u, B$	do	Fig. 165.

Habit.—Crystals of clinohedrite are generally prismatic or tabular, but some are wedge-shaped because of the peculiar distribution of the faces in the domatic class of monoclinic crystals. The mineral is found also in granular and lamellar aggregates.

Physical properties.—The cleavage is perfect parallel to the clinopinacoid but is not invariably developed; where it is, the cleavage surfaces have a pearly luster. The crystals are brilliant, glassy, and transparent and range in color from amethystine to snow-white or colorless. The mineral is strongly pyroelectric. Under the iron-arc spark it fluoresces strongly with a somewhat orange tint, not easily distinguished from the yellow fluorescence of pectolite. Its specific gravity is 3.28 to 3.335, and its hardness is 5.5.

Clinohedrite is optically negative, the birefringence is 0.01, and the axial plane and bisectrix are normal to the clinopinacoid. $Y \wedge c = -28°$; $2V$ (medium large); $\alpha = 1.662$, $\beta = 1.667$, $\gamma = 1.669$.

Composition.—Clinohedrite is a calcium-zinc silicate, analogous in chemical structure to calamine. Some of it contains small amounts of oxides of manganese, magnesium, and iron.

Analyses of clinohedrite

	1	2	3	4	5
SiO_2	27.22	26.73	25.71	27.39	27.87
ZnO	37 44	37.13	34.55	36.78	37.76
CaO	26.25	26.25	27.62	27.41	26.02
MnO	.50	1.11	.29	-------	-------
MgO	.07	-------	.36	-------	-------
FeO	-------	-------	.08	-------	-------
H_2O	8.56	8.09	7.63	8.42	8.35
PbO	-------	-------	1.06	-------	-------
CO_2	-------	-------	2.48	-------	-------
$(Fe, Al)_2O_3$	.28	.37	.30	-------	-------
	100.32	99.68	100.08	100.00	100.00

1. Parker shaft; average of two analyses. H. W. Foote (175), analyst.
2. Parker shaft; 1925. L. H. Bauer (257), analyst.
3. Franklin; 400-foot level, 1928. L. H. Bauer (257), analyst.
4. Analysis 3 recomputed to 100 percent after deducting 5.42 percent of carbonate, equivalent to the CO_2 found, and 3.74 percent of larsenite, equivalent to the lead found.
5. Composition computed from the formula.

The molecular ratio yielded by the analyses shows nearly equal parts of the four constituents—SiO_2, ZnO, CaO, and H_2O; hence the derived formula is simple. The close agreement of the several analyses is also noteworthy.

Occurrence.—Clinohedrite was first described by Penfield and Foote (175), from whose paper this description is chiefly taken. It was seen by them in a few specimens found on the dump of the Parker shaft (not the Trotter mine, as stated by Penfield and Foote) and was supposed to have come from a depth of about 1,000 feet, but the exact location in the mine and the form and geologic relations of the deposit are not known. This is the more unfortunate because in the specimens and closely associated with the clinohedrite were found the rare minerals hancockite, nasonite, glaucochroite, and roeblingite, of which only nasonite is known elsewhere. The many other minerals also found there indicate that the assemblage was formed under peculiar conditions, information regarding which would be of much interest.

The type specimen of clinohedrite in the Hancock collection is a group of lovely amethystine crystals lining a cavity an inch across in a mass of franklinite ore mixed with green willemite and massive hancockite. In other specimens veins of clinohedrite cut massive axinite and hancockite, and lamellar clinohedrite lines cavities and contains embedded prismatic crystals of clear-green willemite and also fills the interstices in a mixture of green willemite and glaucochroite

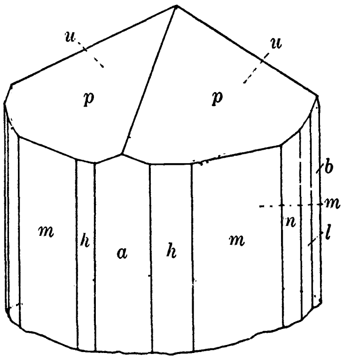


FIGURE 158

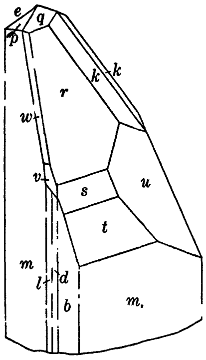


FIGURE 159

FIGURE 158 — Prismatic crystal of clinohedrite showing the forms $a(100)$, $b(010)$, $h(320)$, $m(110)$, $m_1(\bar{1}10)$, $n(120)$, $l(130)$, $p(111)$, and $u(\bar{5}31)$ Parker shaft

FIGURE 159 — Crystal of clinohedrite showing the forms $b(010)$, $m(110)$, $m_1(\bar{1}10)$, $d(150)$, $l(130)$, $e(101)$, $p(111)$, $q(\bar{1}11)$, $r(\bar{3}31)$, $s(\bar{5}51)$, $t(\bar{7}71)$, $k(\bar{3}11)$, $u(\bar{5}31)$, $v(\bar{1}71)$, and $w(\bar{1}51)$ Parker shaft The crystal is viewed with the orthoaxis in front instead of in the usual position

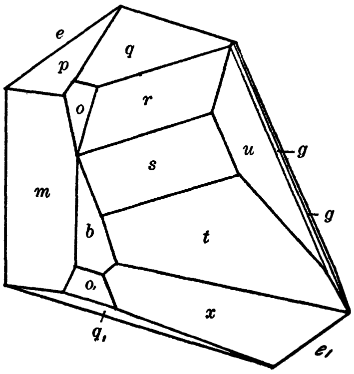


FIGURE 160

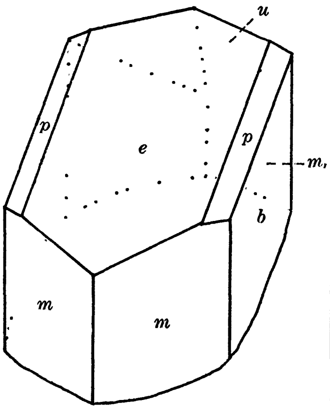


FIGURE 161

FIGURE 160 — Doubly terminated crystal of clinohedrite showing the forms $b(010)$, $m(110)$, $e(101)$, $e_1(\bar{1}0\bar{1})$ $p(111)$, $q(\bar{1}11)$, $q_1(11\bar{1})$, $o(131)$, $o_1(13\bar{1})$, $r(\bar{3}31)$, $s(\bar{5}51)$, $t(\bar{7}71)$, $u(\bar{5}31)$, $g(\bar{5}11)$, and $x(\bar{1}3\bar{1})$ Parker shaft The crystal is viewed with the orthoaxis in front instead of in the usual position

FIGURE 161 — Stout prismatic crystal of clinohedrite showing the forms $b(010)$, $m(110)$, $m_1(\bar{1}10)$, $e(101)$, $p(111)$, and $u(\bar{5}31)$ Parker shaft

In 1914 clinohedrite was identified by the author on two specimens from Franklin obtained for the Harvard collection by Mr. Cahn. There is little doubt that they came from the deeper levels at the north end of the ore body. In one of them short, stout crystals of clinohedrite (fig. 161) are thickly implanted over several square inches of a surface of massive ore that contains vugs in which are crystals of hodgkinsonite and willemite. The clinohedrite crystals are white or faintly amethystine and are not more than a tenth of an inch in greatest dimension. Because of their habit and the pearly luster on the clinopinacoid they were at first mistaken for gypsum.

The other specimen shows a vein one-fifth of an inch thick in ore made up of franklinite and granular hodgkinsonite The vein is drusy, containing fan-shaped clusters of white, opaque platy crystals of clinohedrite, strongly resembling barite or calcite, of the habit shown in figure 162, with pink crystals of hodgkinsonite and clear white calcite.

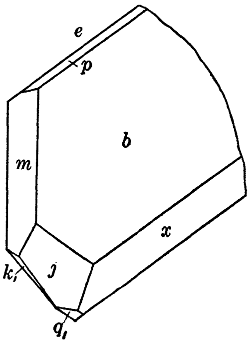


FIGURE 162

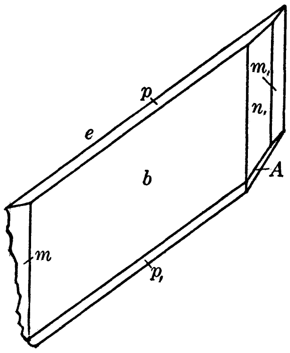


FIGURE 163

FIGURE 162 – Projection on the clinopinacoid of a crystal of clinohedrite showing the forms $b(010)$, $m(110)$, $e(101)$, $p(111)$, $q_1(11\bar{1})$, $k_1(31\bar{1})$, $x(\bar{1}3\bar{1})$, and $j(25\bar{1})$ Parker shaft

FIGURE 163 — Projection on the clinopinacoid of a crystal of clinohedrite showing the forms $b(010)$, $m(110)$, $m_1(\bar{1}10)$, $n_1(\bar{1}20)$, $e(101)$, $p(111)$, $p_1(\bar{1}1\bar{1})$, and $A(\bar{3}1\bar{1})$ Franklin.

In 1928 in the mine at Franklin, on the 400-foot level in the north end, specimens were found that contained clinohedrite associated with several other species as described on page 81. The clinohedrite is fairly abundant in clusters of prismatic crystals lining cavities and intergrown with needles of larsenite It is snow-white or glassy and transparent, with optical properties identical with those of the mineral from the occurrence first described The prismatic habit is developed parallel to the zone containing the forms *e*, *p*, *b*, and p_1. These crystals are shown in figures

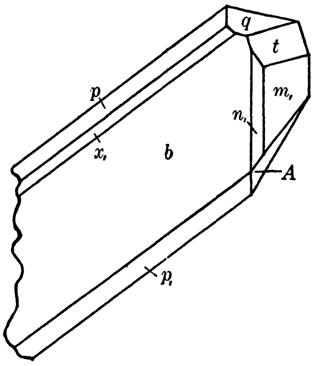


FIGURE 164 — Projection on the clinopinacoid of a crystal of clinohedrite showing the forms $b(010)$, $m_1(\bar{1}10)$, $n_1(\bar{1}20)$, $p(111)$, $p_1(\bar{1}1\bar{1})$, $q(\bar{1}11)$, $t(\bar{7}71)$, $A(\bar{3}1\bar{1})$, and $x_1(131)$ Franklin

163 and 164 and are markedly different in habit from any others hitherto described.

The crystal shown in figure 165 came from another specimen of this lot. It is doubly terminated and shows the new form $B(434)$.

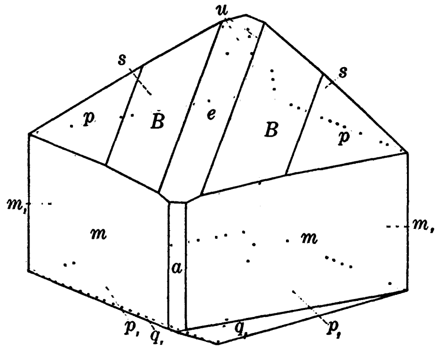


Figure 165.—Doubly terminated crystal of clinohedrite showing the forms $a(100)$, $m(110)$, $m_1(\bar{1}10)$, $e(101)$, $p(111)$, $p_1(\bar{1}1\bar{1})$, $q_1(11\bar{1})$, $s(551)$, $u(\bar{5}31)$, and $B(434)$. Franklin

HODGKINSONITE

$Mn(ZnOH)_2SiO_4$ Monoclinic

Forms.—$c(001)$, $a(100)$, $m(110)$, $U(320)$, $l(210)$, $N(012)$, $Q(023)$, $s(011)$, $o(021)$, $R(401)$, $v(\bar{4}03)$, $w(\bar{2}01)$, $t(\bar{4}01)$, $p(111)$, $G(223)$, $r(221)$, $i(441)$, $P(\bar{1}11)$, $F(\bar{2}23)$, $J(423)$, $h(623)$, $L(\bar{4}23)$, $f(211)$, $Z(\bar{2}11)$, $n(311)$, $g(421)$, $E(\bar{4}21)$, $z(625)$, $y(\bar{3}12)$, $A(\bar{2}61)$, $B(\bar{5}32)$, $k(243)$, $H(131)$, $M(\bar{6}21)$, $d(176)$, $e(\bar{1}.12.6)$, $X(456)$, $T(11.5.1)$. Doubtful forms: $C(\overline{12}.5.9)$, $D(\bar{8}.11.3)$, $q(552)$, $x(\bar{3}05)$, $u(\bar{3}22)$.

Combinations on crystals of hodgkinsonite

	Forms	Illustrations
1	*m, s, r*	Fig. 166.
2	*c, m, s, o, w, t, r*	
3	*c, m, s, o, v, w, t, p, r, n*	Fig. 167.
4	*c, m, l, s, o, v, e, t, r, n, D*	
5	*c, m, l, s, o, v, w, t, r, n, E, z, y, B, C*	
6	*c, m, s, v, p, r, n, z, y, B*	
7	*m, s, o, w, r, E*	
8	*c, m, s, o, w, t, r, P, E, A*	Fig. 168.
9	*c, m, l, s, o, t, r, A*	
10	*c, m, l, s, o, v, w, t, r, P, n, E, z, y, B*	Fig. 169.
11	*c, l, s*	Fig. 170.
12	*c, m, l, s*	Fig. 171.
13	*c, a, m, s, o, t, r, P, z*	
14	*c, m, s, x, q, u*	Palache (203), fig. 2.
15	*c, m, l, P, d, e, X*	Gordon (227), fig. 1.
16	*c, m, U, l, s, o, v, w, t, p, r, P, E, T.* (*U* and *T* not shown.)	Fig. 172.
17	*c, m, s, p, r, P, E*	Fig. 173.
18	*c, m, l, s, o, R, v, w, t, p, r, F, f, g, E*	Figs. 174, 175.
19	*c, m, l, N, Q, s, o, R, v, w, t, p, G, r, i, F, J, h, L, f, Z, g, E, k, H, M.* (*N, Q, J, L,* and *Z* not shown.)	Fig. 176.

Habit.—Hodgkinsonite is found both granular and in crystals which are generally small and of acute pyramidal habit determined by the development of the unit prism and the steep hemipyramid $r(221)$. The other faces are generally seen in modifications of the acute forms, but in one lot of specimens the crystal are of stout prismatic habit. On etched crystals t pyramid $r(221)$ is replaced by a group of facets whose average position corresponds to the form $q(552)$. The clinodome and prism faces are smooth, but generally dull and poorly reflecting. The faces of other forms, although small, give good reflections for measurement.

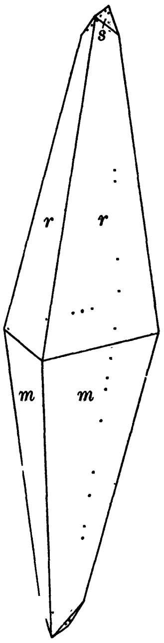


Figure 166

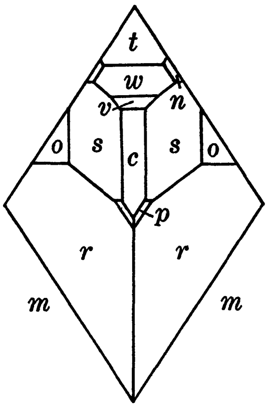


Figure 167

Figure 166.—Acute pyramidal crystal of hodgkinsonite formed by the combination of the forms $m(110)$, $r(221)$, and $s(011)$ Franklin.

Figure 167.—Plan of a crystal of hodgkinsonite showing the forms $c(001)$, $m(110)$, $s(011)$, $o(021)$, $v(\bar{4}03)$, $w(\bar{2}01)$, $t(\bar{4}01)$, $p(111)$, $r(221)$, and $n(\bar{3}11)$ Franklin.

The crystallographic data in the first description of hodgkinsonite by Palache and Schaller (203) were based on poor and scanty material. Much better crystals were later obtained, and the results here presented include both the published data and those obtained in later studies. The measured crystals were generally minute, rarely more than 0.1 inch long, but

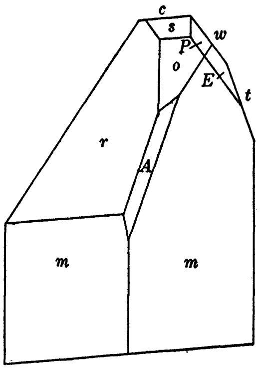


Figure 168

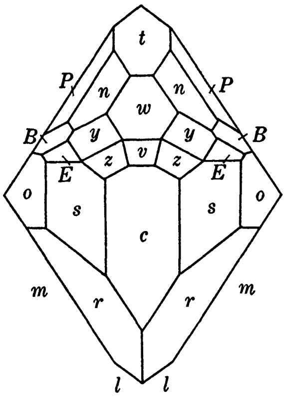


Figure 169

Figure 168.—Projection on the clinopinacoid of a crystal of hodgkinsonite showing the forms $c(001)$, $m(110)$, $s(011)$, $o(021)$, $w(\bar{2}01)$, $t(\bar{4}01)$, $r(221)$, $P(\bar{1}11)$, $E(\bar{4}21)$, and $A(\bar{2}61)$ Franklin.

Figure 169.—Plan of a crystal of hodgkinsonite showing the forms $c(001)$, $m(110)$, $l(210)$, $s(011)$, $o(021)$, $v(\bar{4}03)$, $w(\bar{2}01)$, $t(\bar{4}01)$, $r(221)$, $n(\bar{3}11)$, $P(\bar{1}11)$, $E(\bar{4}21)$, $z(625)$, $y(\bar{3}12)$, and $B(\bar{5}32)$. Franklin.

the faces gave good reflections. The illustrations show the considerable range of habit. The stout prismatic crystals of figures 170 and 171 were in cavities with crystals of hetaerolite and willemite. They were clear yellow and because of their pronounced pseudo-orthorhombic habit they were not recognized as hodgkinsonite until they were measured.

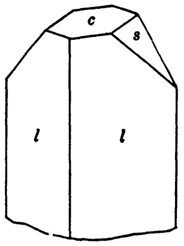


FIGURE 170

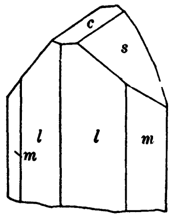


FIGURE 171

FIGURE 170.—Stout prismatic crystal of hodgkinsonite showing the forms *c*(001), *l*(210), and *s*(011) Franklin.

FIGURE 171.—Stout prismatic crystal of hodgkinsonite similar to that shown in figure 170 but showing also the form *m*(110) Franklin.

In 1923 Gordon (227) described small crystals of hodgkinsonite with forms not observed by the author. Two of them—*d*($\bar{1}76$) and *e*($\bar{1}.12.6$)—approximate closely the position of clinodomes but are regarded by the author as definitely established pyramids.

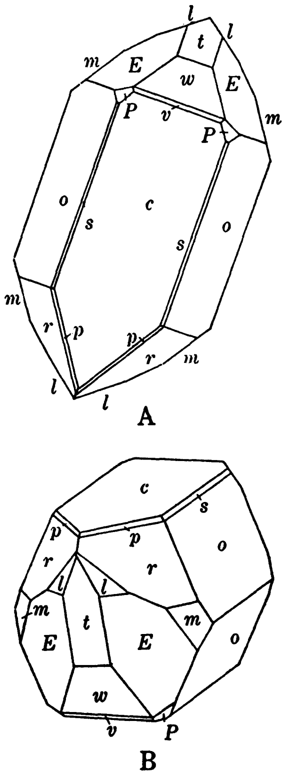


FIGURE 172.—Crystal of hodgkinsonite showing the forms *c*(001), *m*(110), *l*(210) *s*(011), *o*(021), *v*($\bar{4}03$), *w*($\bar{2}01$), *t*($\bar{4}01$), *r*(221), *E*($\bar{4}21$), *p*(111), and *P*($\bar{1}11$) Franklin. A, Plan, B, clinographic projection.

In 1928 Palache (257) described hodgkinsonite crystals of new and complex habits which were measured and drawn by L. W. Lewis. The crystals of combinations 16 and 17 are remarkable in having the clinodome zone dominant, the prisms being merely minute truncations. Combinations 18 and 19 were the most complex crystals of this mineral yet found. Figures 174, 175, and 176 show two of several small gemlike doubly terminated pink crystals delicately attached to larger, singly terminated crystals of the same habit. One end of a doubly terminated crystal only 2 millimeters in its greatest diameter, shown in figure 176, gave reflections from 44 faces of 26 forms, 15 of which belong to forms new to the mineral. The crystals are elongated parallel to the vertical axis, with the unit prism and the pyramid *r*(221) dominant and in approximately equal development.

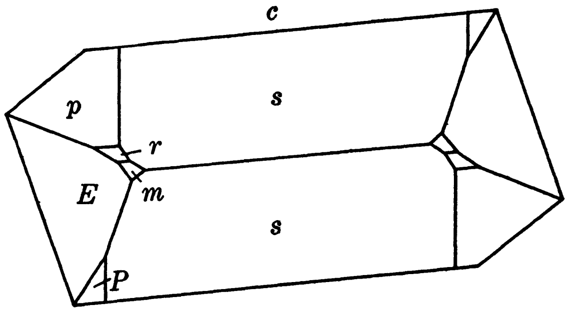


FIGURE 173.—Projection on the clinopinacoid of a crystal of hodgkinsonite showing the forms *c*(001), *m*(110), *s*(011), *p*(111), *r*(221), *P*($\bar{1}11$), and *E*($\bar{4}21$). Franklin.

Physical character.—The cleavage is very perfect parallel to the base; the specific gravity, determined with the pycnometer on a gram of selected fragments, is 3.91; and the hardness is slightly less than 5. The color is typically clear bright pink but ranges to clear reddish brown and rarely to distinct yellow.

Optical character.—Hodgkinsonite is optically biaxial and negative; $2V$ is 50° to 60°; $Y=\beta$; $Z\wedge c=38°$; the axial plane is parallel to the clinopinacoid. $\alpha=1.724$ (lavender), $\beta=1.742$ (almost colorless), $\gamma=1.746$ (lavender) (Berman).

Composition.—Hodgkinsonite is a basic zinc-manganese silicate, which generally contains practically negligible amounts of iron, calcium, and magnesium. Schaller (203) found a doubtful trace of lead but no iron or chlorine.

Analyses of hodgkinsonite

	1	2	3	4
SiO_2	19. 86	19. 00	19. 14	19. 27
ZnO	52. 93	51. 66	50. 45	52. 20
FeO	--------	--------	. 77	--------
MnO	20. 68	21. 82	22. 70	22. 76
CaO	. 93	. 60	. 60	--------
MgO	. 04	1. 02	. 52	--------
H_2O at 110°	5. 77	5. 98	5. 40	5. 77
	100. 21	100. 08	99. 58	100. 00

1. Average of several analyses. W. T Schaller (203), analyst.
2. Analysis made in 1913. Jenkins and Bauer (243), analysts.
3 Analysis made in 1925. Jenkins and Bauer (243), analysts.
4 Composition computed from derived formula.

Except for unimportant differences in the amounts of the minor constituents, the analyses agree closely and give a molecular ratio of ZnO:MnO:SiO_2:H_2O as

2:1:1:1, from which the formula $Mn(ZnOH)_2SiO_4$ is derived.

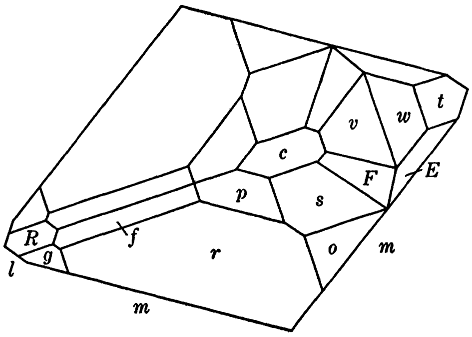


FIGURE 174.—Plan, drawn with the orthoaxis toward the front instead of in the usual position, of a crystal of hodgkinsonite showing the forms *c*(001), *m*(110), *l*(210), *s*(011), *o*(021), *v*($\bar{4}$03), *w*($\bar{2}$01), *t*($\bar{4}$01), *R*(401), *r*(221), *p*(111), *f*(211), *g*(421), *F*($\bar{2}$23), and *E*($\bar{4}$21) Franklin.

Pyrognostics.—Hodgkinsonite decrepitates when held in the blowpipe flame but fuses readily and quietly to a brown enamel. Heated in the closed tube it decrepitates strongly, splitting into numerous thin cleavage flakes that yield water and turn brown. It is readily soluble in acids, yielding gelatinous silica.

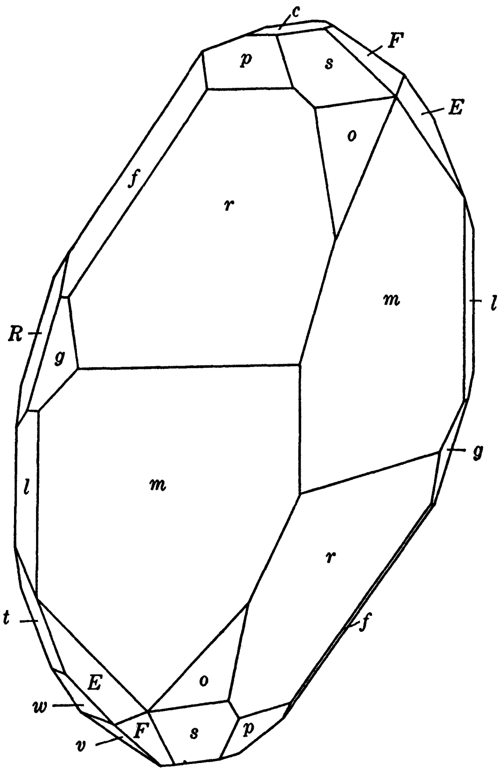


FIGURE 175.—Clinographic projection, also drawn with the orthoaxis toward the front, of the crystal whose plan is shown in figure 174.

Occurrence.—Hodgkinsonite was discovered in Franklin in 1913 by H. H. Hodgkinson, for whom it is named. It was found in the northern part of the ore body, in that part of the Parker mine formerly known as the Hamburg mine, near the hanging wall of the west leg of the ore body, between the 850-foot and 900-foot levels. It has since been found in several specimens and may be considered an abundant mineral.

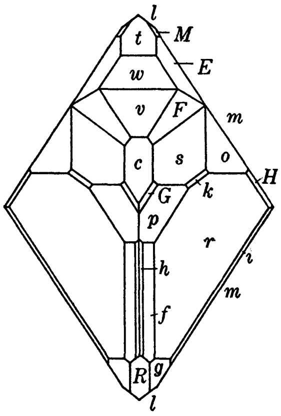


FIGURE 176.—Plan of a complex crystal of hodgkinsonite showing the forms *c*(001), *m*(110), *l*(210), *s*(011), *o*(021), *v*($\bar{4}$03), *w*($\bar{2}$01), *t*($\bar{4}$01), *R*(401), *p*(111), *G*(223), *r*(221), *i*(441), *F*($\bar{2}$23), *h*(623), *f*(211), *g*(421), *k*(243), *H*(131), *E*($\bar{4}$21), and *M*($\bar{6}$21) Franklin.

It forms seams in massive granular ore of the typical willemite-franklinite mixture, the seams being generally very thin with but a film of the mineral, which is almost everywhere associated with barite and not uncommonly with native copper. In places the seams thicken to thin veins, and some crystals of the mineral are as much as 0.8 inch across, sharply angular, and apparently with good crystal faces, but in reality determined in their form almost wholly by the older, platy barite that encloses them. The clear-pink color and brilliant cleavage of the hodgkinsonite, together with the snow-white barite, make such specimens both striking and attractive in appearance. One mass of ore with a surface 8 inches square is at least half covered with hodgkinsonite.

Only one vein has been found in which the angular cells formed by the intersecting plates of barite were not wholly filled by hodgkinsonite, so that the latter mineral was free to develop crystal faces. Other crystals were found in cavities in thicker veins free from barite. These crystals, the largest half an inch long, were much affected by solution, the faces being generally dull or faceted. They were accompanied by black rhombohedral crystals of pyrochroite and scalenohedral crystals of calcite, both later than and encrusting the hodgkinsonite, which is implanted directly on willemite and franklinite and in one specimen on manganese garnet.

In an open vein found in 1927 very fine crystals of hodgkinsonite were found with well-developed crystals of green willemite, tephroite, and barite. The hodgkinsonite crystals were implanted on the vein walls and were of the habit shown in figure 172, with the clinodome zone dominant. Some of them were of a rhodonite-pink color and some of a clear-red tone like that of some spessartite. Veins filled solidly with hodgkinsonite yielding cleavage surfaces an inch across were found in the Stanton collection. The mineral is common in veins throughout the northern part of the mine at Franklin.

GAGEITE

$4(\mathrm{Mn,Mg,Zn})(\mathrm{OH})_2 \cdot 6(\mathrm{Mn,Mg,Zn})_2\mathrm{SiO}_4 \cdot 3\mathrm{H_2O}$ Orthorhombic

Character.—Gageite forms minute colorless or pink needles or laths with a high vitreous luster, grouped radially, in bundles, or matted together. It appears to be orthorhombic and is optically negative; $2V$ moderate; $r<v$ (extreme); Z parallel to the fibers. Lying on the chief crystal face, which is probably the unit prism, the laths show the emergence of X on the edge of the field; $\alpha = 1.723$, $\beta = 1.734$, $\gamma = 1.736$, all ± 0.003 (Larsen). The specific gravity is 3.584.

Composition.—Gageite is a hydrous silicate of manganese, zinc, and magnesium. The molecular ratio of $\mathrm{RO} : \mathrm{SiO_2} : \mathrm{H_2O}$ is 16 : 6 : 7, from which is derived the formula given above. The mineral was believed by Phillips (196) to be chemically akin to leucophoenicite.

Analyses of gageite

	1	2	3	
SiO_2	24.71	23.58	0.392	= 6×0.065
MnO	50.19	53.74	.758	
MgO	11.91	9.95	.247	} 1.053 = 16× .066
ZnO	8.86	3.96	.049	
FeO		.03		
Al_2O_3		.15		
H_2O	[a] 4.43	8.24	.457	= 7× .065
	100.00	99.65		

[a] Water determined by difference.

1. R. B. Gage (196), analyst.
2. L. H. Bauer (257), analyst.
3. Molecular ratios of no. 2.

Before the blowpipe the clear crystals assume at once a light-bronze color that darkens on further heating to deep bronze or nearly black, but they do not fuse. In the closed tube they yield water with the change of color. They dissolve at once in warm dilute nitric acid.

Occurrence.—Gageite, named after R. B. Gage, of Trenton, N.J., and first described in a preliminary paper by Phillips (197), was found, associated with zincite, willemite, calcite, and leucophoenicite, in specimens from the Parker shaft. The crystals are described as showing faces under the microscope, but none were measured and no optical data were given.

The best-defined specimens of gageite known to the author are those described at length under pyrochroite (see p. 50), which contain distinct crystals with square cross sections but no measurable faces. Their optical characters, determined by Larsen, established their identity with type material studied by him. It has also been determined by optical methods as constituting coatings of silky fibrous appearance and bronze color in cracks in massive ore from the Franklin mines, but sufficient material for a confirmatory analysis has not been found.

In recent years gageite has been found abundantly at Franklin, especially associated with the arsenate chlorophoenicite. It forms pale-pinkish fibrous aggregates and seems to be a replacement product or a pseudomorph after some unidentified mineral. One specimen, supplied by Captain Rowe, contained sufficient material in a pure state to furnish a gram sample, of which an analysis was made. As Gage's original analysis was made on a very small sample, the confirmation of the composition of the mineral by the new analysis was gratifying.

TOURMALINE

Formula complex Hexagonal rhombohedral-hemimorphic

Forms.—$c(0001)$, $a(11\bar{2}0)$, $m(10\bar{1}0)$, $\sigma(21\bar{3}0)$, $l(52\bar{7}0)$, $m_1(01\bar{1}0)$, $h(41\bar{5}0)$, $g(10\bar{1}2)$, $r(10\bar{1}1)$, $y(40\bar{4}1)$, $j(01\bar{1}4)$, $n(01\bar{1}3)$, $e(01\bar{1}2)$, $z(01\bar{1}1)$, $s(03\bar{3}2)$, $o(02\bar{2}1)$, $t(21\bar{3}1)$, $u(32\bar{5}1)$, and $v(7.5.\overline{12}.1)$.

Combinations on crystals of tourmaline

	Forms		Localities	Collection or authority	Illustrations
	Antilogous pole	Analogous pole			
1	a, m, m_1, r, o		Sterling Hill	Canfield collection	
2	c, a, m, r	r_1, o_1	do	Kemble collection	Fig. 177.
3	c, a, m, r, e	o_1	Franklin	Canfield collection	
4	a, m, m_1, r, y, o, u	c_1, e_1	do	Ungemach	Fig. 181.
5	m, r, o	c_1, e_1, r_1	do	do	
6	$c, a, m, m_1, \sigma, l, g, r, n, j, e, s, v, o, t$	r_1, o_1	do	Palache	Fig. 182.
7	c, a, m, m_1, r		Rudeville	Eakle (162)	
8	a, m, m_1, r, o, u	c_1, e_1	do	Palache	
9	a, m, m_1, o	c_1, r_1	Fowler quarry	Canfield collection	Fig 178
10	a, m, r, o	c_1, r_1	do	do	
11	a, m, r, o	c_1, r_1, e_1	do	Kemble collection	Fig 179.
12	c, a, m, r, e	r_1, o_1	do	Hancock collection	Fig. 180
13	a, m, r, y, o	c_1, r_1, e_1	do	Columbia collection	

Nos. 1 to 8 were seen on brown and 9 to 12 on green crystals.

Habit.—Tourmaline is found in crystals, either tabular parallel to the base or prismatic, and as a rule strikingly hemimorphic. Completely developed single crystals, some of them 2 inches long and 1½ inches in diameter, are embedded in limestone. The most common colors are cinnamon-brown and green, but some crystals have a green exterior shading to yellow within.

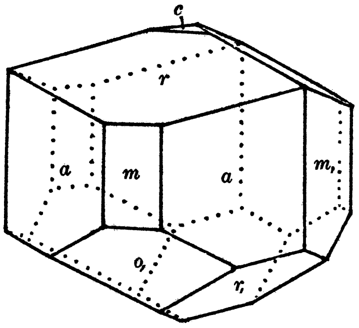


Figure 177.—Stout prismatic crystal of tourmaline showing the forms *c*(0001), *m*(10$\bar{1}$0), *a*(11$\bar{2}$0), *r*(10$\bar{1}$1), *r*$_1$(01$\bar{1}\bar{1}$), and *o*(02$\bar{2}$1) Sterling Hill

Composition.—Tourmaline is a complex borosilicate of aluminum, generally containing also one or more other metallic bases. There is only one available analysis, given below, of a Franklin tourmaline, which belongs to the magnesium tourmaline variety. From the analysis may be derived, following the Penfield-Foote model formula for tourmaline and also ignoring the small amounts of titanium, iron, sodium, potassium, and fluorine as negligible, the generalized formula $Al_4(Mg,Ca)_3(B,OH)_2Si_4O_{19}$.

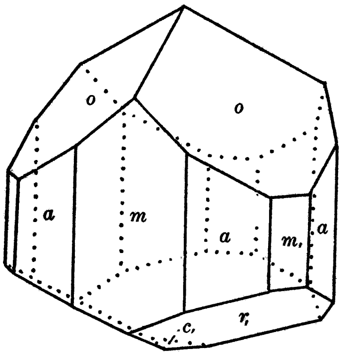


Figure 178

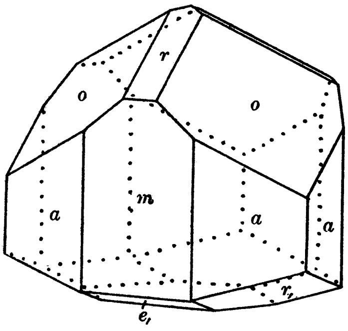


Figure 179

Figure 178.—Stout prismatic crystal of tourmaline showing the forms *a*(11$\bar{2}$0), *m*(10$\bar{1}$0), *m*$_1$(00$\bar{1}$0), *o*(02$\bar{2}$1), *r*$_1$(10$\bar{1}\bar{1}$), and *c*$_1$(000$\bar{1}$) Fowler quarry, Franklin.
Figure 179.—Stout prismatic crystal of tourmaline showing the forms *m*(10$\bar{1}$0), *a*(11$\bar{2}$0), *r*(10$\bar{1}$1), *o*(02$\bar{2}$1), *c*$_1$(000$\bar{1}$), *r*$_1$(01$\bar{1}\bar{1}$), and *e*$_1$(01$\bar{1}\bar{2}$) Fowler quarry, Franklin.

Analysis of tourmaline

[Brown tourmaline, Rudeville. R. B. Riggs (134), analyst]

SiO_2	35.25	K_2O	0.18
Al_2O_3	28.49	H_2O	3.10
B_2O_3	10.45	F	.78
TiO_2	.65		
FeO	.86		100.37
MgO	14.58	$O=F_2$	.33
CaO	5.09		
Na_2O	.94		100.04

Occurrence.—Tourmaline is not a characteristic mineral of the zinc-ore bodies—indeed, it is unknown in them except for two brown crystals showing combinations 1 and 2, respectively, one each in the Canfield and Kemble collections. They were found in the calamine deposit at Sterling Hill but may well have been introduced there mechanically during the formation of the secondary calamine ore. It is rather remarkable that tourmaline was not formed in the pneumatolytic zone of the Parker shaft, where all the conditions, including an intrusive magma rich in boron and fluorine, would lead one to expect its presence.

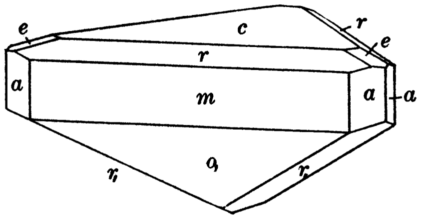


Figure 180.—Thick-tabular crystal of tourmaline showing the forms *c*(0001), *m*(10$\bar{1}$0), *a*(11$\bar{2}$0), *r*(10$\bar{1}$1), *e*(01$\bar{1}$2), *r*$_1$(01$\bar{1}\bar{1}$), and *o*$_1$(02$\bar{2}\bar{1}$) Fowler quarry, Franklin.

It is abundant, however, in the white limestone about Franklin. The most interesting locality is the Fowler quarry (see pl. 1), where were found, many years ago, in a broad zone extending across the whole front of the quarry, crystals isolated in the limestone that were remarkable for their large size, perfection of form, brilliant coloring, and striking hemimorphic development. (See pl. 17, *A*, and figs. 178, 179, and 180.) They are commonly green, some of them bright grass-green on the surface and progressively lighter inward, others greenish yellow throughout. These crystals have not been analyzed, nor have such crystals been found in recent years. A few light brownish-yellow crystals of similar form have been found occasionally in a railroad cut in limestone near Franklin station.

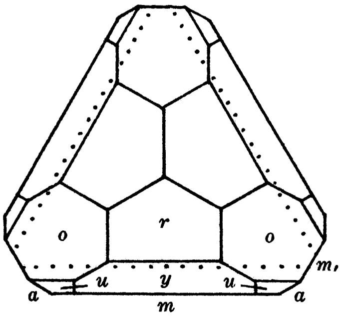


Figure 181

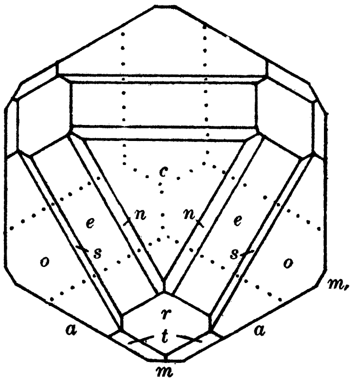


Figure 182

Figure 181.—Plan of a crystal of tourmaline showing the forms *a*(11$\bar{2}$0), *m*(10$\bar{1}$0), *m*$_1$(01$\bar{1}$0), *r*(1$\bar{1}$10), *y*(40$\bar{4}$1), *o*(02$\bar{2}$1), and *u*(32$\bar{5}$1). Franklin Iron Co.'s quarry
Figure 182.—Plan of a crystal of tourmaline showing the forms *c*(0001), *a*(11$\bar{2}$0), *m*(10$\bar{1}$0), *m*$_1$(01$\bar{1}$0), *r*(10$\bar{1}$1), *n*(01$\bar{1}$3), *e*(01$\bar{1}$2), *s*(03$\bar{3}$2), *o*(02$\bar{2}$1), and *t*(21$\bar{3}$1). Franklin Iron Co.'s quarry.

In the Franklin Iron Co.'s quarry brown tourmaline is abundant in the limestone, with titanite, arsenopyrite, pyrrhotite, pyrite, fluorite, and other associates. Some of it is glassy and transparent, though apt to be flawed. Rarely are the large crystals well developed, but some of them show striking hemimorphism. Some of the crystals are highly complex—figures 181 and 182 show two that were studied. Besides the determinable forms there are several facets which, although plane, do not have rational indices and are probably solution planes.

At Rudeville (Hamburg) the quarries have at times yielded abundant brown tourmaline crystals of forms similar to those of the crystals just described. Isolated crystals and crystal groups, some of them of many and large individuals, were seen in numerous collections. Eakle (162) described and figured these crystals, and Riggs (134) analyzed them.

Light-brown tourmaline associated with corundum was at one time found on Mine Hill. It was mistaken for vesuvianite and was widely distributed in collections, hence the erroneous presence of the name "vesuvianite" in the older lists of Franklin minerals.

Black tourmaline was not seen in the field or in any collection. Mr. Hancock stated, however, that he had seen specimens on Balls Hill, doubtless in the pegmatite abundant there.

ROEBLINGITE

$H_{10}Ca_7Pb_2Si_5S_2O_{28}$. System?

Character.—Roeblingite is found in dense white compact masses made up of tiny prismatic crystals with parallel extinction and weak double refraction but too minute to enable the crystal system to be determined. The luster is rather dull, like that of unglazed porcelain; the hardness is just less than 3; and the specific gravity is 3.433.

Roeblingite is optically biaxial and positive; $2V$ small; elongation negative; $\alpha = 1.64$, $\beta = 1.64$, $\gamma = 1.66$. Under the iron-arc spark it gives a very pale pink fluorescence or none at all.

Composition.—As originally interpreted roeblingite is a lead-bearing calcium silicate containing a sulphite molecule. Later study by Blix (281a), however, has shown that no sulphite molecule is present but that all the sulphur is present as sulphate. The formula deduced by Blix is $2PbSO_4.Ca_7H_{10}Si_6O_{24}$.

Analyses of roeblingite

	1	2	3	4
SiO_2	23. 58	23. 57	24. 90	24. 86
CaO	25. 95	23. 12	27. 14	27. 08
SrO	1. 40	2. 79	--------	--------
MnO	2. 48	2. 49	--------	--------
Na_2O	. 40	--------	--------	--------
K_2O	. 13	--------	--------	--------
H_2O	6. 35	6. 60	6. 28	6. 22
PbO	31. 03	30. 04	30. 65	30. 80
SO_2	9. 00	--------	--------	--------
SO_3	--------	10. 81	11. 03	11. 04
CO_2	--------	. 61	--------	--------
	100. 32	100. 03	100. 00	100. 00

1. Average of two analyses. H. W. Foote (173), analyst.
2. Average of three analyses. R. Blix (281a), analyst.
3. Same as 2, after replacing SrO and MnO by their equivalent quantities of CaO, CO_2 by its equivalent quantity of silica, and recalculating to 100 percent.
4. Calculated for $2PbSO_4.Ca_7H_{10}Si_6O_{24}$.

Occurrence.—Roeblingite was described by Penfield and Foote (173), to whose data as given above little has been added. It was found, according to Mr. Nason, who sent the mineral to Penfield, at the 1,000-foot level of the Parker shaft near a contact of pegmatite and limestone, where a great abundance of garnet was developed. The largest mass found weighed about 5 pounds and was about the size and shape of a coconut. It, as well as other smaller masses found, was the center of a mass of cellular axinite, which in turn was contained in massive garnet. The many other associated minerals are of similar character to those accompanying the lead silicates nasonite and hancockite, found later in a similar pneumatolytic deposit, probably not far distant in the mine. But little of the mineral was preserved, and no other find was made until 1927, when a small amount was found, associated with calcium larsenite, clinohedrite, and other minerals characteristic of the Parker shaft mineral paragenesis.

Roeblingite was named in honor of the late Col. W. A. Roebling, of Trenton, N.J., the celebrated engineer, well known to mineralogists as an appreciative mineral collector.

XONOTLITE

$Ca_3Si_3O_8(OH)_2$. Monoclinic

Crystallography.—Xonotlite is found at Franklin in long needlelike crystals with striated prismatic zones and tapering terminations showing no measurable faces. Through X-ray study by Mr. Harry Berman the dimensions of the unit cell were provisionally determined to be: $a_0 = 8.55$ angstroms, $b_0 = 7.34$ angstroms, $c_0 = 7.03$ angstroms, $\beta = 90° \pm$. From these data were computed the following linear crystallographic elements: $a:b:c = 1.165:1:0.958$, $\beta = 90° \pm$.

The needles are elongated parallel to the b-axis, oscillation X-ray photographs around which show that it is an axis of symmetry. The monoclinic character was established by study of the planes $(h0l)$ in the prismatic zone, which was found to possess no plane of symmetry. As far as could be detected the angle β does not differ sensibly from 90°, but more precise measurements may establish a slight obliquity.

Physical properties.—Most of the clear, colorless crystals of xonotlite are minute needles, and no cleavage could be observed megascopically, but the microscope reveals a cleavage normal to α and hence in the elongated zone. The hardness is 6; the specific gravity is 2.71 as determined by floating some crystals in a solution of that density.

Optical properties.—Xonotlite is biaxial and positive, with $2V$ small; $Z=b$; the extinction angle was not measured as the positions of the crystallographic axes a and c are not known; $\alpha=1.586$, $\beta=1.586$, $\gamma=1.594$.

Composition.—The composition of the Franklin xonotlite is shown by the following analysis, for the use of which the author is indebted to Mr. L. H. Bauer, chemist of the New Jersey Zinc Co.:

Analysis of xonotlite from Franklin

[By L H Bauer]

	1	2		3
SiO_2	48.60	0.8092		3×0.2697
CaO	44.64	.7962	0.8093	$3\times .2698$
MnO	.49	.0069		
MgO	.25	.0062		
H_2O	3.97	.2203		$1\times .2203$
	97.95			

1. Percentage by weight.
2. Molecular equivalents.
3. Molecular ratio.

The analysis, made on 0.0856 gram of material, shows a slight deficiency, which is probably in large part water. The water was driven off only at red heat and is surely basic.

From the analysis and the X-ray data the formula for xonotlite may be given as $Ca_3Si_3O_8(OH)_3$, with two molecules in the unit cell. This formula fits the X-ray data and the specific gravity determination very well.

Occurrence.—Xonotlite forms parallel bundles of slender needles associated with a spongy mass of clinohedrite in a vein cutting the typical hancockite-garnet-caswellite replacement product of the ore. In the clinohedrite vein, together with the xonotlite, are barite, clear-green willemite, and a few somewhat altered crystals of rhodonite. The specimen supplying the material for study was found in 1933 in a drift in the north end of the 500-foot level of the mine at Franklin.

GANOPHYLLITE

$H_{12}Mn_7Al_2Si_8O_{32}$ Monoclinic

Physical character.—Terminated crystals of ganophyllite are not known at Franklin, but the mineral is found in rosettes of imperfect crystals or needles and in irregular grains embedded in bustamite. It is noteworthy for its extremely perfect micaceous cleavage, which makes it easily mistaken for mica in some specimens. In others the crystals are fibrous parallel to the orthoaxis, and in them the cleavage runs lengthwise and the resemblance to mica is lacking. Its color is light brown, its hardness is 4 to 4.5, and the specific gravity of the Harstigen mineral is 2.84.

Optical character.—Ganophyllite is optically biaxial and negative; $2V=26°$; $r<v$ (easily perceptible); Z is normal to the cleavage; $\alpha=1.573$, $\beta=1.603$, $\gamma=1.604$ (Larsen, 230). These optical data are different from those determined by Hamberg on the mineral from Harstigen, but determinations by Larsen on material from there agreed well with those made on material from Franklin.

Composition.—Ganophyllite is an aluminum-manganese silicate, classed as a zeolite by its discoverer, Hamberg. The following analysis was made on only 73.5 milligrams of material and is slightly incomplete because of the small amount available.

Analysis of ganophyllite

	1	2
SiO_2	39.18	40.48
Al_2O_3	8.57	8.59
Fe_2O_3	Trace.	....
MnO	36.33	41.83
ZnO	3.67	....
CaO	2.04	....
H_2O+	5.70	9.10
H_2O-	1.65	
	97.12	100.00

1. Ganophyllite, Franklin. E. V. Shannon (230), analyst.
2. Composition computed from the formula given above.

Comparison of the incomplete analysis with the composition computed from the accepted formula serves definitely to identify the mineral as ganophyllite, and the analysis also shows that aluminum is an essential constituent of the mineral. The material from Franklin contains small amounts of zinc and calcium instead of the lead and alkali metals found in the mineral from Harstigen. As the molecular ratio, in the analysis, of MnO to ZnO plus CaO is very nearly 6 to 1, possibly (ZnO, CaO) is also one of the essential constituents.

Occurrence.—Ganophyllite was first identified at Franklin by Palache (195) in 1909, a few needles being found on a single specimen of fibrous calamine sent for identification by the Foote Mineral Co. It was found again in 1921 in a few specimens that were described by Larsen and Shannon (222 and 230). The radiating needles of ganophyllite form rosettes, some of which are two-thirds of an inch in diameter, implanted on rhodonite in the open center of a thin vein, together with bustamite, axinite, barite, and willemite.

A rather different phase of the same association is shown by a specimen in the Harvard collection, in which a vein half an inch thick cuts the ordinary layered ore. Bustamite lines one wall of the vein, and upon it is implanted the ganophyllite, which shows on the fracture surface of the vein as slender brown cleavage surfaces. Axinite, in the customary yellow crystals, is later than both the other minerals.

Ganophyllite may be counted as one of the rarer minerals at Franklin, as it is at its only other known locality, the Harstigen mine, Pajsberg, Sweden.

APOPHYLLITE

$(Ca,Zn,Mn,K,Na)_2Si_3O_8.3\frac{1}{2}H_2O$. Tetragonal

Forms.—*c*(001), *a*(100), *r*(210), and *p*(111).

Habit and occurrence.—A few specimens of apophyllite were found during the sinking of the Palmer shaft which show rosette-shaped groups and platy single crystals, some of which are half an inch across. The apophyllite is implanted upon green epidote lining an irregular cavity in hornblende gneiss. With it are numerous crystals of pyrite, minute distorted crystals of brown garnet, and a very few crystals of pale-brown axinite. The cavity was found in the gneissic footwall rock of the ore body, in which the shaft was sunk, and at a depth of 600 feet on the incline.

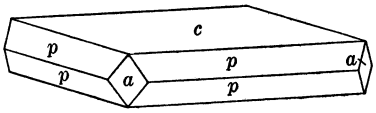


FIGURE 183.—Tabular crystal of apophyllite showing the forms *c*(001), *a*(100), and *p*(111) Palmer shaft.

Groups of pale-pink crystals, showing only the unit pyramid and the base, implanted on crumbly limestone, were found in the mine at Franklin, on the 300-foot level, north. They were the material analyzed.

Composition.—Apophyllite is a hydrous silicate of calcium and potassium. Although not strictly a zeolite, as it contains no aluminum, it is generally classed with that group on account of its behavior before the blowpipe.

Analysis of apophyllite

	1	2	
SiO_2	50.90	0.847	$=3\times0.282$
CaO	24.74	.441	$0.516=2\times0.258$
ZnO	1.79	.022	
MnO	.47	.007	
K_2O	3.70	.039	
Na_2O	.42	.007	
H_2O	17.71	.984	$=3\frac{1}{2}\times0.281$
	99.73		

1. Apophyllite, Franklin. L. H. Bauer (273), analyst.
2 Molecular ratio of no. 1.

From the molecular ratio shown is derived the formula given above, which, although not the formula ordinarily assigned to apophyllite, is of the same general type. It will be noted that the material analyzed, although undoubtedly apophyllite, differs in composition from the ordinary type of that mineral by appreciable amounts of all the constituents and especially in containing zinc and manganese to the molecular amount of about one-sixteenth of the bivalent bases.

ZEOLITES

HEULANDITE

$H_4CaAl_2(SiO_3)_6.3H_2O$ Monoclinic

Forms.—*c*(001), *b*(010), *t*(201), and *s*($\bar{2}$01)

Habit and occurrence.—Heulandite has been seen only once in the district, on a small fragment of limestone from the 1,000-foot level in the Sterling Hill mine, with crystals of hematite. The heulandite crystals are short and thick and prismatic parallel to the clinoaxis, as shown in figure 184.

STILBITE

$H_4(Na_2,Ca)Al_2Si_6O_{18}$ $4H_2O$ Monoclinic

Forms.—*a*(100), *b*(010), *c*(001), *m*(110), and *f*($\bar{1}$01).

Habit and occurrence.—Stilbite was found in clusters of indistinct crystals in cavities of a porous replacement area in pegmatite. The feldspar has been replaced by epidote, actinolite, and calcite, and stilbite was one of the last minerals to crystallize in the cavities.

Stilbite was also found in crystals, with tennantite, galena, sphalerite, and actinolite, in the Sterling Hill mine at the 900-foot level. (See p. 35.) The stilbite crystals are pale yellow, radially grouped, and the individuals are penetration twins of the form shown in figure 185.

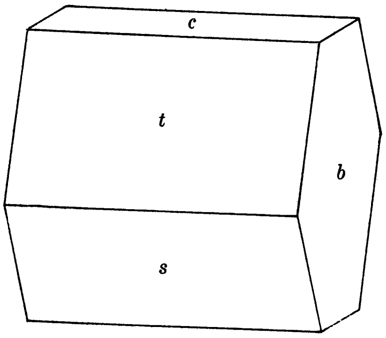


FIGURE 184

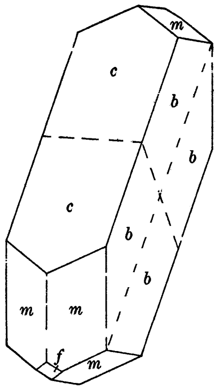


FIGURE 185

FIGURE 184.—Crystal of heulandite, prismatic parallel to the orthoaxis, showing the forms *c*(001), *b*(010), *t*(201), and *s*($\bar{2}$01) Sterling Hill

FIGURE 185.—Interpenetration twin crystal of stilbite, showing the forms *c*(001), *b*(010), *m*(110), and *f*($\bar{1}$01) Sterling Hill

Very similar but smaller crystals were found coating dark-gray limestone in the Sterling Hill mine at the 1,000-foot level. When found they were at first mistaken for epistilbite and were so reported.

THOMSONITE

Variety calciothomsonite. $2(Na_2,Ca)Al_4Si_4O_{16}$ $5H_2O$ Orthorhombic

Occurrence.—Thomsonite has been found at Franklin only within the last few years and was described by Gordon (227) as calciothomsonite. Radial aggregates of fine needles are associated with garnet, axinite, barite, and datolite and form a fanlike radiation on the face of the specimen, measuring 4 inches from tip to circumference. The specific gravity is 2.45. Thomsonite is optically positive; $2V=48°$; $\alpha=1.530$, $\beta=1.532$, $\gamma=1.542$, all ±0.001 (measured in mercury light).

Composition.—The following analysis shows the composition of calciothomsonite:

Analysis of calciothomsonite

[J. E. Whitfield (227), analyst]

	Percent	Molecular ratio		
SiO_2	36. 44	0. 607	=4	×0. 150
Al_2O_3	30. 34	. 298	=2	×0. 149
CaO	15. 94	. 284	0. 343=2. 3	×0. 150
MgO	Trace.			
Na_2O	3. 50	. 056		
K_2O	. 18	. 002		
H_2O+	13. 26	. 751	=5	×0. 150
H_2O-	. 26			
	99. 92			

Gordon suggests that the varieties of the thomsonite series are best explained as consisting of mixed crystals, with the end members: $H_6CaAl_2Si_2O_{11}$ (calciothomsonite) and $H_2Na_2Al_2Si_3O_{11}$ (natrolite$-H_2O$). The sodium end member can enter the mixed crystal only to a maximum of about 50 percent.

MICA GROUP

Several species of mica are abundant at both Franklin and Sterling Hill but have been little studied and are known by superficial tests only. There are no analyses of any of the unaltered micas, and without analyses accurate determinations are not possible.

MUSCOVITE

$H_2KAl_3Si_3O_{12}$. Monoclinic

One specimen in the Hancock collection was identified as muscovite by optical tests. It consists of irregular flakes of greenish-white mica embedded in limestone and was found in the Furnace quarry at Franklin.

Muscovite has also been noted as a more or less common constituent of the pegmatites.

Barium muscovite.—A massive pink mineral with obscure cleavage, intermixed with microcline, garnet, manganophyllite, and franklinite, proved under the microscope to have the optical properties of muscovite. A purified sample was analyzed by Bauer (282) with the results shown below.

Analysis of barium muscovite

SiO_2	41. 37	BaO	9. 89
Al_2O_3	32. 64	K_2O	6. 33
MnO	. 62	Na_2O	1. 51
CaO	. 36	H_2O	4. 05
MgO	1. 55		
ZnO	1. 84		100. 16

This analysis, together with the optical properties, seems to establish this mineral as a barium muscovite, practically identical with the substance to which the variety name "oellacherite" was given by Dana.

BIOTITE

Formula complex. Manganophyllite. Monoclinic

Occurrence.—Lustrous black mica is common in the contact deposits at both Franklin and Sterling Hill. It has generally been called biotite, but tests made on several specimens from the Parker shaft and the Trotter mine show the presence of considerable manganese. Hence it seems probable that the black mica of those localities, at least, should be regarded as belonging in the variety manganophyllite, as Chester (161) assigned it.

Caswellite.—An alteration of the black mica to a bronzy, dull copper-red substance, described by Chester (161) under the name "caswellite," was fairly common on the dump of the Parker shaft, especially in specimens containing much yellow garnet. It is micaceous, inelastic, and weakly doubly refracting and has a hardness of about 3. The analysis indicates a highly hydrous calcium-manganese silicate to which no definite formula can be assigned and which shows little relation in composition to the original mica. Specimens examined under the microscope by the author showed a diverse and complex structure composed of a mixture of substances, none of which could be identified. Hence it seems safe to conclude that the name "caswellite" cannot be used with any definite mineralogic significance.

Analysis of caswellite from Trotter mine, Franklin

[A. H. Chester (161), analyst]

SiO_2	38. 74	MgO	5. 52
Fe_2O_3	6. 85	Ignition	4. 64
Al_2O_3	6. 58		
Mn_2O_3	15. 95		100. 58
CaO	22. 30		

PHLOGOPITE

Formula complex. Monoclinic

Mica of golden-brown, yellow, and white tints is widely disseminated in the Franklin limestone, and wherever tested it has been found to have a small optical axial angle. Hence it is regarded as phlogopite, although chemical evidence is lacking.

Very perfect pyramidal crystals of such mica, some of them more than 4 inches long, were seen in the Canfield collection, and one of them is illustrated in plate 18, *A*. They were found in the limestone near Franklin, the best of them near the Catholic Church (locality 12, pl. 1). A specimen in the same collection showed mica with a greenish metallic sheen on the cleavage due to paper-thin enclosures of epidote. Beautifully formed but small crystals of phlogopite are abundant in the limestone at Rudeville, as, indeed, in most of the limestone quarries of the region.

Abundant large and well-formed crystals of phlogopite, quite comparable in quality to any seen in the local collections, were found in 1910 in the large Fowler limestone quarry. They are generally embedded in calcite, which separates very cleanly from them, but in a few specimens the embedding matrix was pure-white fluorite in coarsely cleavable masses.

CHLORITE

$H_8Mg_5Al_2Si_3O_{18}$. Monoclinic

Chlorite is rare at Franklin. A massive, very fine grained dull-green form of chlorite was identified on a single specimen, probably found in the Parker shaft, sent by the Foote Mineral Co. for examination. The chlorite is mixed with yellow garnet, willemite, and manganiferous biotite and is so related to the biotite as to make it seem highly probable that it is the result of the alteration of that mineral.

Platy crystals of dark-green chlorite line the cavity in which crystals of friedelite (see p. 89) of great perfection were formed. The optical properties of the mineral seem to indicate penninite, but no detailed examination was possible. The outer portions of the specimen are also composed of very compact chlorite, much slickensided.

In recently found specimens of sphalerite, described on page 28, the last mineral deposited in the open vugs was a delicate coating of silvery scales of a chlorite containing a little iron and probably to be identified with diabantite, according to an optical determination by Berman.

SERPENTINE GROUP

SERPENTINE

$H_4(Mg,Mn,Zn)_3Si_2O_9$. Monoclinic

Physical character.—Serpentine is found in massive, compact, cryptocrystalline, and fibrous forms, also as pseudomorphs. It is not uncommon at Franklin but does not seem to have been found at Sterling Hill. It was early observed by Brush (95) as veinlets of chrysotile at the Hamburg mine. Similar fibrous chrysotile, consisting of radiate groups of silky fibers embedded in calcite and known locally as "wavellite," has been described by Foshag (241). The fibers are light-brown, and some of them are a quarter of an inch long. They are associated with massive brown serpentine and grains of franklinite. The fibrous serpentine is biaxial and negative; $2V$ medium; elongation positive; X and the plane of the optic axes are parallel to the length of the fibers; extinction parallel; $\alpha=1.546$, $\beta=1.550$, $\gamma=1.557$. The optical characters and the composition given by the analysis show the material to be normal serpentine.

A much more common form of serpentine is translucent, hornlike, and brownish and is associated with a gray carbonate and with pale-green radiate willemite in secondary veins cutting the ore. Such veins were especially abundant in the Buckwheat mine, and some of the serpentine there was cut as an ornamental stone under the name "smithsonite." Possibly, however, much of the so-called "smithsonite" was really a form of bementite, which is found in the same association and can be distinguished from serpentine only by its greater hardness and higher indices of refraction.

The brown serpentine has been shown by analyses to be manganiferous. It is described by Larsen as optically a metacolloid and negative; $2V$ medium; $\alpha=1.561$, $\beta=1.567$, $\gamma=1.568$.

The name "vorhauserite" has been used at Franklin for the manganiferous serpentine, and the usage is perhaps justified by the fact that, among the analyses of serpentine listed in Dana's "System of mineralogy" that of vorhauserite is the only one that shows manganese oxide. The variety is not well defined, however, and it seems unnecessary to revive the term. Some of the more highly manganiferous serpentine seems to have the character of the material that has been called "neotocite", and it is so described on pages 118-119.

Serpentine is also the product of the alteration of rhodonite and possibly of other manganesian minerals. Some of it is in grayish or yellowish pseudomorphs after rhodonite, in places very hard through the infiltration of silica. It is more commonly found, however, as translucent, brownish to reddish-brown cryptocrystalline masses intermingled with grains of franklinite or bits of feldspar, biotite, or garnet. Such material, locally often called "hydrorhodonite", was not uncommon on the dumps of the Trotter and Parker shafts. It was not analyzed or studied in detail.

Composition.—Serpentine is a hydrous magnesium silicate of rather diverse composition, as it may contain more or less of other elements in place of part of the magnesium. At Franklin, especially, it generally contains manganese and zinc.

Analyses of serpentine

	1	2	3	4	5	6	7
SiO_2	41.70	43.65	40.41	42.58	41.32	41.47	39.62
MgO	29.54	30.92	41.30	43.48	32.58	38.40	33.60
MnO	7.44	7.12	1.70	------	7.57	.71	3.42
FeO	------	------	.51	------	1.57	.90	2.39
ZnO	4.10	3.62	------	------	.14	------	4.14
CaO	------	------	------	------	.96	.83	.37
Fe_2O_3	2.80	------	------	------	------	------	------
Al_2O_3	------	------	------	------	.65	.10	1.30
H_2O+	14.04	14.69	14.30	13.94	12.44	14.51	14.06
H_2O-	------	------	------	------	.94	2.31	1.18
CO_2	------	------	1.41	------	------	------	------
Alkalies	------	------	------	------	------	.42	------
	99.62	100.00	99.63	100.00	98.17	99.65	100.08

1. Serpentine, Franklin. G. A. Koenig (132), analyst.
2. Same, after deducting 4.08 percent of franklinite, equivalent to the Fe_2O_3 found, and recomputing to 100 percent.
3. Serpentine, Buckwheat mine. H. E. Merwin, analyst (unpublished).
4. Same, after deducting 3.63 percent of carbonates, equivalent to the CO_2 found, and recomputing to 100 percent.
5. Manganiferous serpentine, Franklin. E. V. Shannon (240), analyst.
6. Chrysotile, Franklin. W. F. Foshag (241), analyst.
7. Serpentine, Franklin. Jenkins and Bauer (243), analysts.

BEMENTITE

$H_{10}Mn_8Si_7O_{27}$. Orthorhombic

Physical character.—Crystals of bementite are not known, but the mineral is found in massive granular form, breaking into rectangular blocks; in radiate or stellate masses with minute foliate structure; and in compact, hornlike form.

It has cleavages of different perfection in three mutually perpendicular directions and therefore parallel to the three pinacoids. Its hardness is 4.5, and its specific gravity is 2.981 (Koenig, Trotter mine) or 3.202 (Steiger, Parker shaft). Its color is pale yellow to yellowish brown, with a pearly luster on perfect cleavages.

Bementite is optically negative. Cleavage flakes on the basal cleavage show the emergence of a symmetrical biaxial interference figure with a very small axial angle, the hyperbolas barely opening as the section is revolved. The axial plane is parallel to the brachypinacoidal cleavage. *X* is normal to the basal cleavage. $\alpha = 1.624$, $\beta = 1.650$, $\gamma = 1.650$.

Composition.—Bementite is a hydrous manganese silicate, generally containing some iron, zinc, magnesium, and calcium in place of part of the manganese. Its chemical character has been discussed by Larsen, who deduced the formula here adopted, showed the general similarity of its composition to that of serpentine and the similarity of its optical and other physical characters to those of certain forms of serpentine, and suggested that it be regarded as the manganese end member of the serpentine series. It is noteworthy in this connection that some of the bementite and some of the manganiferous serpentine at Franklin can be distinguished from each other only by differences of hardness and optical characters.

Analyses of bementite

	1	2	3	4	5	6
SiO_2	39.00	38.06	38.36	37.93	39.01	37.03
MnO	42.12	53.71	39.22	53.56	52.65	54.65
FeO	[a] 3.75		4.94			
ZnO	2.86		2.93			
MgO	3.83		3.35			
CaO	Trace		.62			
H_2O+	8.44	8.23	8.01	8.51	8.35	8.32
H_2O-			.60			
Al_2O_3			.96			
Fe_2O_3			.71			
	100.00	100.00	99.70	100.00	100.00	100.00

[a] FeO lost and estimated by difference.

1 Bementite, Trotter mine G. A Koenig (133), analyst
2 Same analysis recomputed to 100 percent after substituting for FeO, MgO, and ZnO their molecular equivalent of MnO
3 Bementite, Parker shaft. George Steiger (195), analyst
4 Same analysis recomputed to 100 percent after deducting Al_2O_3, Fe_2O_3, and H_2O- and substituting for FeO, MgO, ZnO, and CaO their molecular equivalent of MnO.
5 Composition computed according to Larsen's formula
6. Composition computed according to Palache's formula.

The water in bementite is undoubtedly constitutional, as shown by the following statement furnished by Mr. Steiger:

	Percent of mineral
Water lost at 100° C	0.60
150°	.24
240°	.16
Low red heat	7.57
Blast heat	.04

The molecular ratio of $SiO_2 : MnO : H_2O$ shown by the analyses is close to 4:5:3, and Palache accordingly derived the formula $H_6Mn_5Si_4O_{16}$, but it is equally close to 7:8:5, from which Larsen derived the formula $H_{10}Mn_8Si_7O_{27}$. The actual composition of the material analyzed is about midway between the two and is not correctly expressed by either formula, nor, indeed, can it be expressed by any formula so simple.

Occurrence.—Bementite was first described by Koenig (133) and was named for C. S. Bement, of Philadelphia. The type material from the Trotter mine consisted of stellate masses and veinlets of friable particles embedded in calcite. But little of the substance was found, and as the physical description was very incomplete, bementite stood as a somewhat doubtful species.

In 1905 the author obtained from Mr. J. J. McGovern, of Franklin, specimens of bementite that he had collected at the Parker shaft in 1903, amounting to about 20 pounds. In appearance this material is unlike that from the Trotter mine, being coarsely crystallized and yielding the cleavage blocks already described. The close agreement in composition of the two sorts of material, as shown by the analyses, and the determination of its crystalline character seem to justify the acceptance of bementite as a definite mineral species.

Bementite was further established as a species by the discovery of large manganese deposits in western Washington in which bementite is a principal mineral. In their description of the deposits Pardee, Larsen, and Steiger (217) showed the essential identity of the bementite there with the Franklin mineral, and further, that caryopilite and ectropite, described from Långban, Sweden, are also identical with bementite (239).

In the course of this study of the Franklin minerals bementite has been found to be more widely distributed at Franklin than had been suspected. Many secondary veins consisting largely of calcite have a layered structure parallel to the walls, owing to the development of a brown serpentinous mineral and of white radiate willemite. Some of the brown mineral is manganiferous serpentine, and some of it is bementite. (See pl. 18, *B*.) They have the same dense hornlike texture and conchoidal fracture, but the bementite has a hardness of 5 to 6 and a refractive index of 1.64, whereas the serpentine is soft and has an index of 1.56.

Bementite has been identified also in minute wormlike deep-brown stalactites coating crystals of tephroite and willemite in open veins. It is thought to be present in microscopic veinlets replacing the barium feldspar of the Parker shaft. (See p. 59.)

NEOTOCITE

$MnO\ SiO_2.nH_2O$ Amorphous

Character.—Neotocite is black and coal-like but is brown in thin section. Its fracture is conchoidal and its hardness is about 4. Its refractive index is 1.57±0.02.

The neotocite from Franklin has not been analyzed. It is related in composition to serpentine and is probably to be regarded as an alteration product of bementite, but, unlike that mineral, it is invariably amorphous.

Occurrence.—A specimen from the Trotter mine, found in the Hancock collection, was identified by Larsen as neotocite. It forms a vein in limestone. The amorphous material contains a few needles of what is probably bementite.

Similar material was identified in a specimen of calcium larsenite, where it forms a brown border about grayish bementite.

DESAULESITE

$4(Ni,Zn,Fe)O\ 3SiO_2\ 6H_2O$ Amorphous

Character.—Desaulesite forms crusts and formless aggregates filling cavities in purple fluorite and replacing rough crystals of niccolite. The aggregates are built up loosely in gratelike or spongelike porous forms, the linear, intersecting, cylindroid rods being covered with faceted knobs like crystalloid bodies. It is found also in massive compact layers and in earthy form. Its color is yellowish green to bright apple-green and emerald-green. Its refractive index is 1.59.

Desaulesite was named by Koenig in honor of Maj. A. B. de Saules, former manager of the Trotter mine. As described by Koenig (137), it was found in some abundance in intimate association with chloanthite at the Trotter mine. The specimens in the Hancock collection show it associated with niccolite and chloanthite in such a way as to leave no doubt that it is an alteration product of those minerals.

Composition.—Desaulesite is a hydrous nickel silicate related to genthite but containing little or no magnesium.

Analyses of desaulesite

	1	2	3	4	
SiO_2	31. 62	27. 33	30. 89	0. 512	=3×0. 171
NiO	38. 22	43. 78	46. 08	. 616	0. 661=4× . 165
ZnO	4. 00	1. 92	2. 17	. 025	
FeO	2. 03	1. 19	1. 34	. 018	
MnO		. 11	. 13	. 002	
CaO	. 71	Trace			
MgO	. 42	Trace			
As_2O_5	4. 77				
As_2O_3		7 99			
H_2O+	7. 14	10. 59	19. 39		1. 077=6× . 180
H_2O-	9. 44	6. 57			
	98. 35	99. 48	100. 00		

1. Original material, 0 28 gram G. A. Koenig (137), analyst
2 Abundant material L H Bauer (243), analyst
3. Analysis 2 recomputed to 100 percent after deducting 8.42 percent of $NiAs_2$, equivalent to the As_2O_5 found
4 Molecular ratio computed from no 3.

The analysis by Koenig is unsatisfactory. He explained the arsenic as present in annabergite, nickel arsenate, 12 percent of which would have to be deducted. The residue could then be computed approximately to the formula of garnierite. Optical examination of typical material failed to reveal any trace of annabergite but showed minute metallic specks that might well be one of the arsenides. In the new analysis the arsenic was determined by Bauer to be the trioxide, which could be better explained if present in a nickel arsenide, such as chloanthite, and the analysis was so interpreted.

The molecular ratio obtained leads to a formula of the same type as that assigned to genthite, except that magnesium is lacking. Desaulesite may therefore be grouped with deweylite and genthite as shown below:

Deweylite	$4MgO\ 3SiO_2.6H_2O$.
Genthite	$2NiO\ 2MgO\ 3SiO_2.6H_2O$
Desaulesite	$4NiO\ 3SiO_2.6H_2O$.

TALC

$H_4Mg_3Si_4O_{12}$ Monoclinic

Talc is found but rarely in the district and chiefly as pseudomorphs. A beautifully sharp pseudomorph of clear-green talc after octahedral spinel, embedded in limestone from Franklin, was seen in the Hancock collection; also a talc pseudomorph after the typical calamine of Sterling Hill, a specimen that appears to be unique. In the dolomite stripping from the Buckwheat mine talc was found both in massive form and in disseminated scales.

Minute rosettes of talc are associated with the finely crystallized willemite found at Franklin. It seems to have been the latest mineral to form and has the appearance of the variety sometimes known as "nacrite."

Talc has also been found in pseudomorphs after crystals of pyroxene. This is the material listed as pyrallolite by Robinson (22) and by Alger (39).

HALLOYSITE

$H_4Al_2Si_2O_9.H_2O$. Amorphous

Halloysite has not been found in the district as a distinct mineral but is believed to be a principal constituent of the harsh yellow clay, rich in zinc, that was called "vanuxemite" by Shepard (110). Cross (113) showed that the vanuxemite has the composition of a mixture of equal parts of calamine and halloysite. It appears to be analogous to the "tallow clay" of the Joplin mining district, Mo.

TITANITE

$CaTiSiO_5$. Monoclinic

Forms.—*c*(001), *b*(010), *m*(110), *n*(111), *l*($\bar{1}12$), *t*($\bar{1}11$), and *w*($\bar{2}21$).

Combinations on crystals of titanite

	Forms	Illustrations
1	*c*, *m*, *n*. Commonest type	
2	*c*, *b*, *m*, *n*, *t*, *w*	Fig. 186.
3	*c*, *b*, *m*, *n*, *l*, *t*, *w*. Twin on (100)	Fig. 187.

Habit.—Light-brown to dark-brown, rather simple crystals of characteristic titanite habit, an inch in diameter, are found sparingly in the pegmatite at both Franklin and Sterling Hill. The best specimens were found in the Trotter mine.

Titanite was also found occasionally in the pegmatite and ore of the iron mines. Handsome dark-brown crystals were collected in 1905 in the limestone of the Franklin Iron Co.'s quarry, associated with brown tourmaline, edenite, pyrrhotite, and graphite. The largest crystal was 1½ inches across, and smaller crystals (see figs. 186 and 187) were abundant.

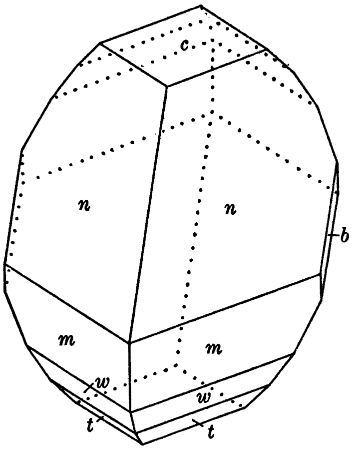


FIGURE 186

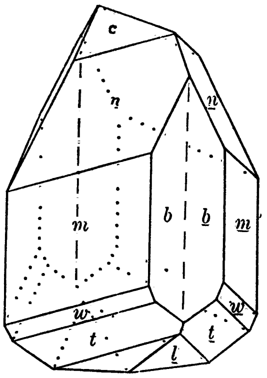


FIGURE 187

FIGURE 186.—Crystal of titanite showing the forms $c(001)$, $b(010)$, $m(110)$, $n(111)$, $t(\bar{1}11)$, and $w(\bar{2}21)$. Franklin Iron Co.'s quarry.

FIGURE 187—Crystal of titanite twinned on the orthopinacoid, showing the forms $c(001)$, $b(010)$, $m(110)$, $n(111)$, $l(\bar{1}12)$, $t(\bar{1}11)$, and $w(\bar{2}21)$. Franklin Iron Co.'s quarry.

PHOSPHATES, ARSENATES, AND VANADATES

APATITE GROUP

APATITE

$CaF(Ca,Mn)_4(PO_4)_3$. Hexagonal

Forms.—$c(0001)$, $m(10\bar{1}0)$, $r(10\bar{1}2)$, $x(10\bar{1}1)$, $y(20\bar{2}1)$, and $s(11\bar{2}1)$.

Combinations on crystals of apatite

	Forms	Illustrations or authority
1	*m, x.* The almost universal type at Franklin	Fig. 188.
2	*m, c, s.* Trotter mine	Koenig.
3	*c, m, r, x, y, s.* Parker shaft	Fig. 189.

Habit.—Apatite occurs generally in rather rough prismatic crystals, the largest 4 inches long and 1 inch in diameter. The color is commonly green or bluish-green, ranging to gray and brown. Some of the crystals are glassy and almost transparent, but most of them are opaque.

Composition.—Apatite is calcium fluophosphate. The Franklin apatite contains little or no chlorine.

Analysis of apatite

	1	2	3
P_2O_5	39.59	0.279	3×0.093
CaO	46.64	.832 } 0.851	9× .095
MnO	1.35	.019	
ZnO	.03		
Ca	3.57	.089	1× .089
F	3.37	.177 } .178	2× .089
Cl	.04	.001	
Al_2O_3	.56		
Fe_2O_3	.77		
$CaCO_3$	2.82		
H_2O	.52		
	99.26		

1. Average of two analyses of light apple-green crystals embedded in calcite, specific gravity, 3.22, Franklin. S. L. Penfield (119), analyst.
2. Molecular equivalents of the essential constituents.
3. Molecular ratio giving the formula $(Ca,Mn)_3P_2O_8 \, CaF_2$, or its equivalent, $CaF(Ca,Mn)_4(PO_4)_3$.

Small amounts of manganese and zinc take the place of part of the calcium, and the material analyzed has for that reason been classed as manganapatite (Dana, 146). It was, however, manifestly somewhat altered and contained nearly 2 percent of carbon dioxide; hence the manganese may have been present only as the carbonate.

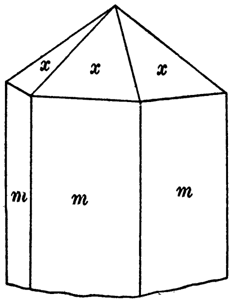


FIGURE 188

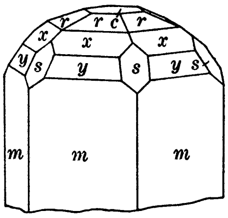


FIGURE 189

FIGURE 188.—Simple crystal of apatite of the common type at Franklin, showing the forms $m(10\bar{1}0)$ and $x(10\bar{1}1)$

FIGURE 189—One end of a more complex crystal of apatite showing the forms $c(0001)$, $m(10\bar{1}0)$, $r(10\bar{1}2)$, $x(10\bar{1}1)$, $y(20\bar{2}1)$, and $s(11\bar{2}1)$. Parker shaft.

All the apatite crystals embedded in the Franklin limestone appear to be free from arsenic, but all those in or associated with the ores show the presence of arsenic by qualitative tests. Some, indeed, contain more arsenate than phosphate and are described under the head of svabite. (See p. 121.)

Occurrence.—Apatite is found sparingly in the ore from most of the openings on Mine Hill. It has been seen associated with fowlerite, franklinite, and feldspar from the Trotter mine, in calcite from the Buckwheat mine, and in light-brown crystals embedded in hardystonite from the Parker shaft. It is found in pegmatite near contacts with limestone and in the ore body.

Apatite appears to have been relatively more abundant at Sterling Hill than at Franklin. Large crystals and columnar aggregates implanted on jeffersonite or franklinite or embedded with both in calcite were seen in several collections.

In most of the limestone quarries careful search shows the presence of small prisms of bright-green apatite in the limestone, generally associated with other metamorphic minerals. It was noted particularly at the Franklin Iron Co.'s quarry, in slender prisms, and the Losey collection contains stout, well-formed blue crystals of apatite from the limestone.

SVABITE

$Ca(F,OH)(Ca,Zn,Mn)_4(AsO_4,PO_4)_3$. Hexagonal

Habit.—Svabite has the same crystal habit as apatite, with rough hexagonal prisms, some of which show a rounded pyramidal termination. The color is gray to grayish green, and in its general appearance there is nothing to differentiate it from apatite.

Refractive index.—The following table, taken from Bauer and Berman (273), shows the variation of refractive indices and specific gravity with the ratio of phosphate and arsenate in apatite and svabite. The optical data therefore suffice to indicate whether a given specimen is rich or poor in arsenic. There is no other way, except by chemical analysis, to distinguish the two species as they are found at Franklin.

Variation in index of refraction and specific gravity with composition in the apatite-svabite series

	Phosphate	Arsenate	Index of refraction (ω)	Specific gravity
	Percent	*Percent*		
Apatite	42. 3	0	1. 634	3. 20 –
Do	28. 4	16. 2	1. 664	3. 446
Svabite	12. 5	35. 2	1. 684	3. 542
Do	0	54. 4	1. 707	3. 54 –

Composition.—The following analysis was made on a crystal that proved to be composed of the arsenate and the phosphate in the molecular ratio of about 2 to 1:

Analysis of svabite

[L. H. Bauer (273), analyst]

As_2O_5	35. 24	H_2O	1. 32
P_2O_5	12. 54	CO_2	Trace
CaO	45. 89	Insoluble	. 29
ZnO	1. 54		
MnO	1. 23		100. 81
MgO	. 84	$O=F_2$	. 59
PbO	. 51		
F	1. 41		100. 22

The analysis yields a rather poor molecular ratio for an apatite but is unmistakably that of a member of the apatite group, as confirmed by the crystallographic character.

Occurrence.—As far as they have been tested optically or chemically all the apatitelike crystals associated with the Franklin ores have been found to contain arsenic. Those in which As_2O_5 is molecularly in excess of P_2O_5, which include about two-fifths of the crystals examined, have been classed as svabite. As they came from all parts of the deposit the mineral is not uncommon in the district, although not in large amount in any one place. Hitherto svabite has been reported only from Harstigen and Jakobsberg, Sweden.

HEDYPHANE

$(Ca,Pb)_4(PbCl)As_3O_{12}$. Hexagonal

Forms.—$c(0001)$, $m(10\bar{1}0)$, $x(10\bar{1}1)$, $v(11\bar{2}2)$, $s(11\bar{2}1)$.

Habit.—Hedyphane is found as small brilliant crystals in open veins with willemite and calcite, as rough crystals embedded in calcite, and as coarse granular masses. It is white to light buff, has a rough conchoidal fracture and a decidedly greasy luster, is brittle, and has a hardness of about 3. It is optically uniaxial and negative; $\omega=2.026$, $\epsilon=2.010$, both ± 0.01. Under the iron-arc spark it gives a rather indistinct bluish gray fluorescence.

Composition.—Hedyphane is a chloroarsenate of lead and calcium—in other words, a calcium-rich mimetite.

Analysis of hedyphane

[W F Foshag (238), analyst]

PbO	52. 77	H_2O	0. 08
CaO	14. 98	Insoluble	. 17
MnO,FeO	. 28		
MgO	. 10		101. 53
ZnO	. 23	$O=Cl_2$	. 67
As_2O_5	29. 94		
Cl	2. 98		100. 86

The molecular ratio shows a slight excess of calcium over lead, with approximately the general composition of mimetite, hence Foshag defines hedyphane chemically as that member of the chloroarsenates of the apatite group in which calcium is molecularly the dominant metal.

Occurrence.—Hedyphane was first described from the Franklin district by Foshag and Gage (238) in 1925. It was found at a depth between 500 and 600 feet on the east side of the ore body in the mine at Franklin, near the point where the two newly described arsenic minerals schallerite and chlorophoenicite were found. It is associated with willemite, rhodonite, native copper, and calcite, in veins an inch or more thick. As the rhodonite and willemite are vividly colored some of the specimens are very showy. In some places hedyphane is the most abundant mineral, enclosing the rest; in other places calcite is the gangue, and there the hedyphane is not uncommonly in rough crystals against the calcite.

The first measurable crystals were described by Palache and Berman (251). They were found with willemite of a peculiar flat, tabular habit in thin veins with small vugs. The high luster of the hedyphane crystals is striking. (See fig. 190.)

A special interest attaches to the finding of hedyphane at Franklin because it is one of the most abundant of the arsenic-bearing minerals at Långban, Sweden, and had not previously been found elsewhere, except in the similar nearby Swedish deposits.

DESCLOIZITE

$(Pb,Zn)_2(OH)VO_4$. Orthorhombic

Minute pale-yellow crystals, too rough to yield measurements, were found implanted on a fragment of decayed jeffersonite in the Hancock collection and proved on chemical examination to be descloizite. The specimen was collected by Mr. Hancock at Sterling Hill, and the mineral is doubtless an alteration product of galena, which is abundant at the locality.

Deep-red needles of microscopic size were found in a vein at Franklin that contained particularly fine crystals of tephroite, hodgkinsonite, and green willemite. The needles were too minute for accurate measurement, but their crystal angles were approximately the same as those of descloizite, and chemical tests for vanadium and their high refractive index confirmed that identification. Their vivid red color is probably due to a small amount of contained manganese.

ARSENIOSIDERITE

$Ca_4Fe(AsO_4)_3.3Fe(OH)_2$

The Canfield collection contains specimens, reported as found in the Taylor mine in 1874, which consist of rosettes of a brown, silky-fibrous mineral implanted on a fracture surface of massive franklinite ore. Mr. Canfield believed the mineral to be a new species. The author was unable to identify the mineral from the small amount available, but it has now been identified by Larsen as probably the iron-calcium arsenate, arseniosiderite. The optical characters reported are long laths, red-brown, faintly pleochroic, nearly uniaxial, optically negative, refractive index 1.73 to 1.88.

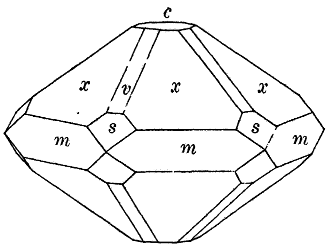


FIGURE 190

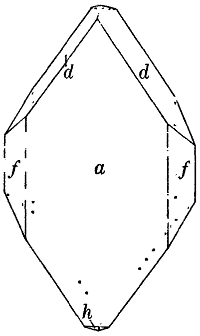


FIGURE 191

FIGURE 190 — Bipyramidal crystal of hedyphane showing the forms *c*(0001), *m*(10$\bar{1}$0), *x*(10$\bar{1}$1), *v*(11$\bar{2}$2), and *s*(11$\bar{2}$1) Franklin

FIGURE 191 · Crystal of allactite showing the forms *a*(100), *f*(210), *h*($\bar{1}$01), and *d*(131) Palmer shaft

I am indebted for this information to Mr. E. V. Shannon, formerly of the United States National Museum, who also stated that he had found arsenic in a minute speck tested, thus confirming the determination.

ALLACTITE

$Mn_3As_2O_8.4Mn(OH)_2$. Monoclinic

Forms.—*a*(100), *f*(210), *h*($\bar{1}$01), and *d*(131). (Position and letters of Aminoff.)

Optical character.—Allactite is brownish red, optically biaxial and negative, $2V$ is very small, and r>v (very strong); $\alpha = 1.761$, $\beta = 1.786$, $\gamma = 1.787$, all ± 0.003 (Larsen).

Occurrence.—Allactite, a rare manganese arsenate, was formerly known only from Långban and Nordmark, Sweden. It was identified on a specimen from the Palmer shaft in the Hancock collection, a small piece of coarse brownish calcite containing grains of franklinite and a little galena. A cavity an inch across is lined with rough crystals of calcite and a few of franklinite, the allactite crystals being implanted upon both. They are grouped in rosettes, the largest of which is a sixth of an inch across. The crystals are attached by their orthopinacoids in subparallel groups, their terminal pyramid faces producing a gently warped surface. Minute crystals are sufficiently distinct for measurement, and there is no doubt of the identity of the species, which has been verified by blowpipe tests. The habit of the groups and even the dominant form of the crystals are the same as those of the type material from Sweden as described by Sjögren.

Allactite has been identified in several other specimens found at Franklin, as crusts of brownish needles on the surfaces of slickensides and as very thin veins. The well-defined optical properties enable the determination of the species with certainty.

A few clusters of pale-brown crystals of allactite were found at Sterling Hill in 1929, in cavities in a calcite vein. With it were beautiful clear-green crystals of willemite, pale-blue fluorite, and a white fibrous mineral packed about the willemite.

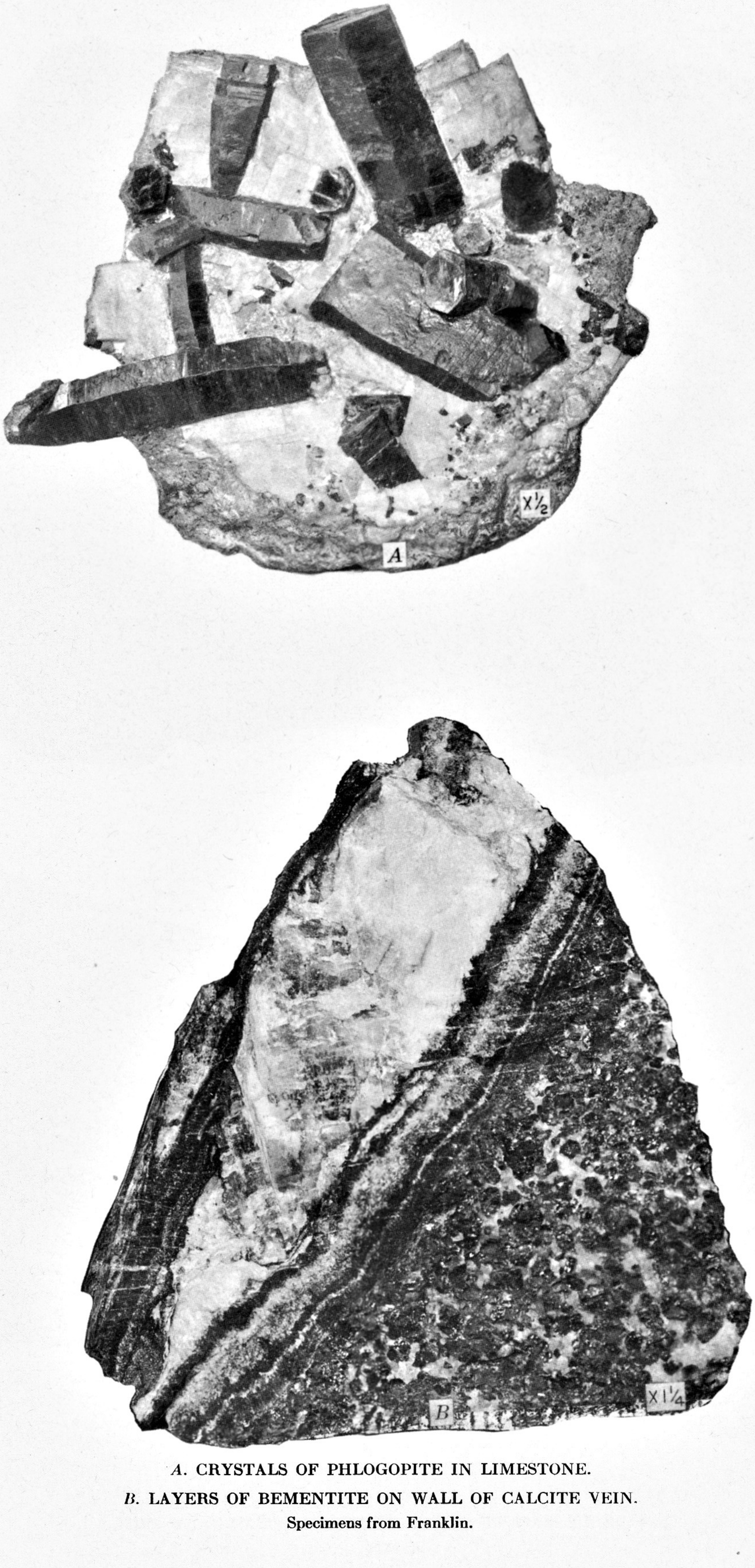
CHLOROPHOENICITE

$(Mn,Zn)_3As_2O_8.7(Mn,Zn)(OH)_2$. Monoclinic

$a \quad b \quad c = 2.357 \quad 1 \quad 2.153$, $\beta = 74°26'$

Forms.—*c*(001), *a*(100), *s*(106), *r*(102), *k*($\bar{1}$04), *h*($\bar{2}$03), and *p*(111).

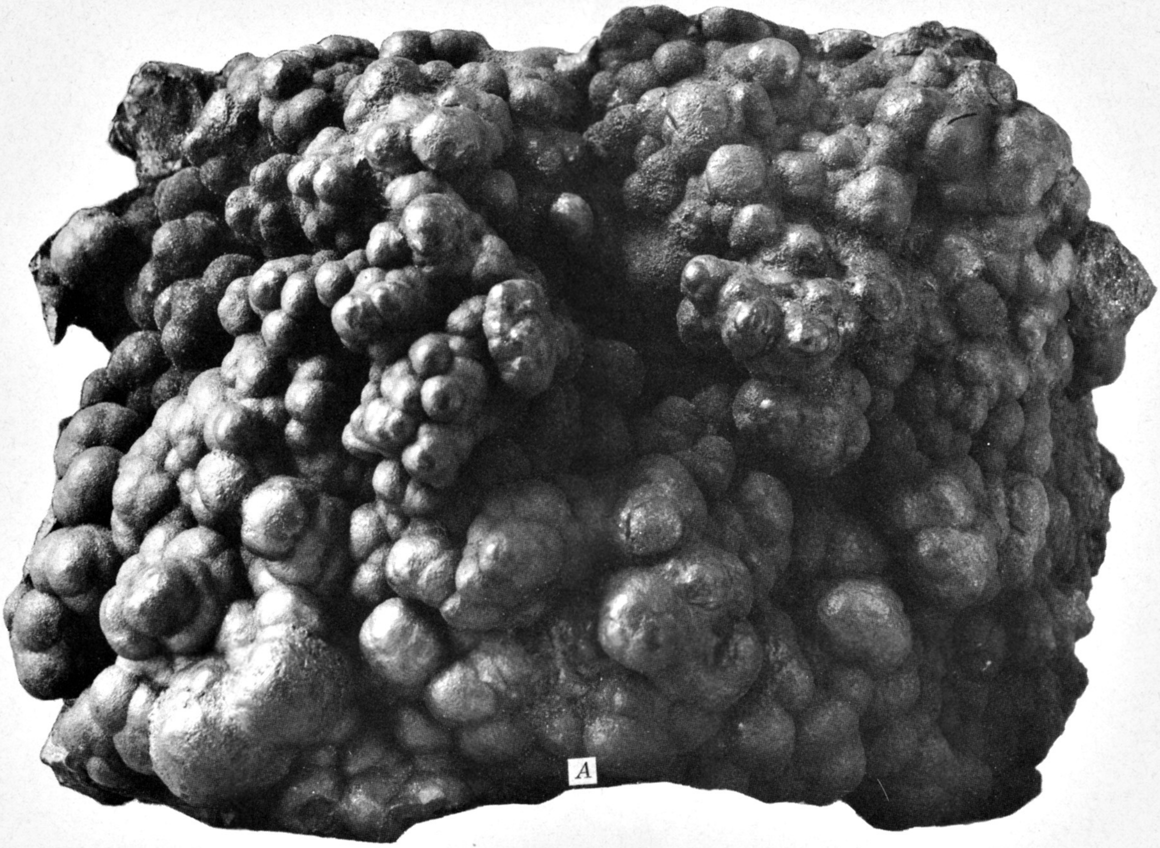
Habit.—Chlorophoenicite forms slender crystals, as much as a third of an inch long, prismatic parallel to the orthoaxis. The crystals are deeply striated parallel to their length, the orthodome zone is somewhat warped, and the terminal faces, of which there are not more than two on any crystal, are etched and give poor readings; hence the crystallographic data are poor. The elements adopted were derived from the measurement of 14 crystals, which showed a wide range in individual angles. The form series is peculiar, and the position selected was that giving the simplest indices for the best-developed forms. The cleavage plane, generally the brightest face of the orthodome zone, was taken as the orthopinacoid and the next best face as the basal pinacoid. The epidotelike habit is shown in figure 192, which is taken from the paper by Foshag, Berman, and Gage (246). In it the point of view is changed from the usual one in order to show both terminal faces.

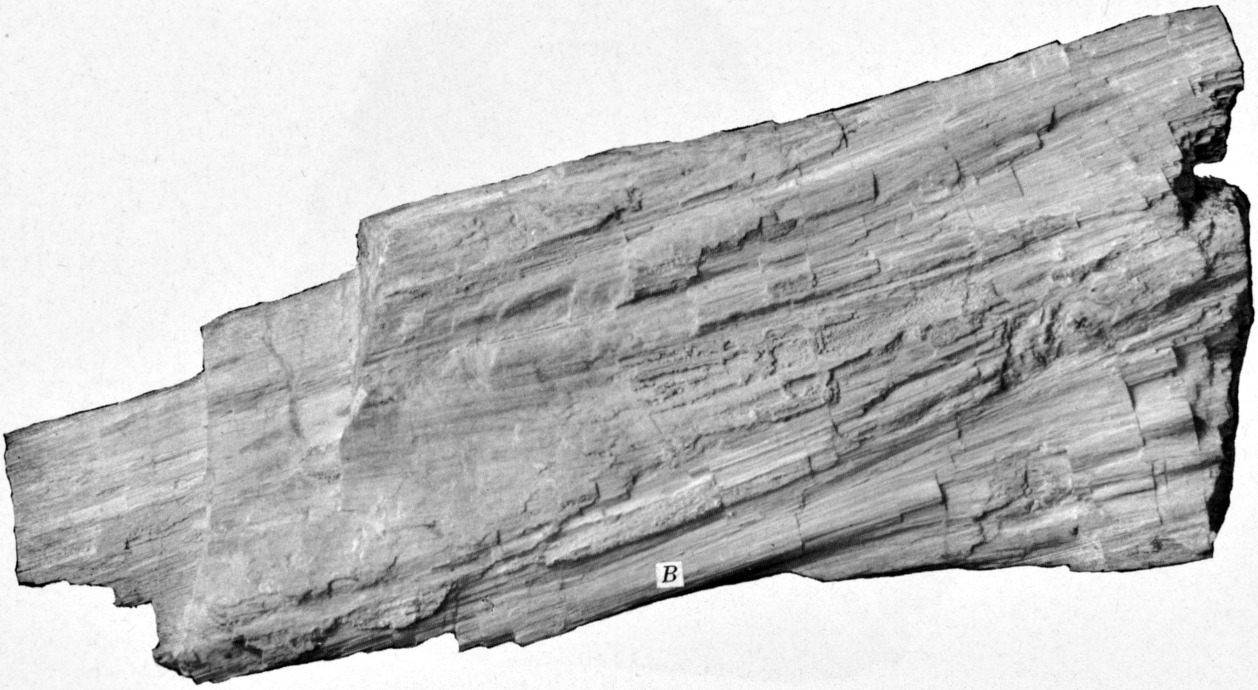


A. CRYSTALS OF PHLOGOPITE IN LIMESTONE.

B. LAYERS OF BEMENTITE ON WALL OF CALCITE VEIN.

Specimens from Franklin.





A. BOTRYOIDAL MASS OF HYDROHETAEROLITE.
Sterling Hill.

B. FIBROUS MASS OF SUSSEXITE FROM A SECONDARY VEIN.
Franklin.

Physical properties.—Chlorophoenicite is light grayish green in natural light but is pink or light purplish red in artificial light, hence its name, from Greek words for those colors. It is optically biaxial and negative; the plane of the optic axes is the plane of symmetry; $2V = 83° \pm 2°$; $r > v$ (strong); $\alpha = 1.682$, $\beta = 1.690$, $\gamma = 1.697$. The cleavage is good parallel to the orthopinacoid, the luster is vitreous to pearly, especially on cleavage surfaces, and the hardness is 3 to 3.5. The specific gravity is 3.46.

Composition.—Chlorophoenicite is a hydrous manganese-zinc arsenate containing some magnesium, calcium, and iron.

Analysis of chlorophoenicite

[W F Foshag (231), analyst]

	Percent	Molecular ratio	
MnO	34. 46	0. 486	0. 951 = 10×0. 095
ZnO	29. 72	. 365	
FeO	. 48	. 007	
MgO	1. 34	. 033	
CaO	3. 36	. 060	
As_2O_5	19. 24	. 084	= 1×0. 084
H_2O	11. 60	. 644	= 7×0. 092
	100. 20		

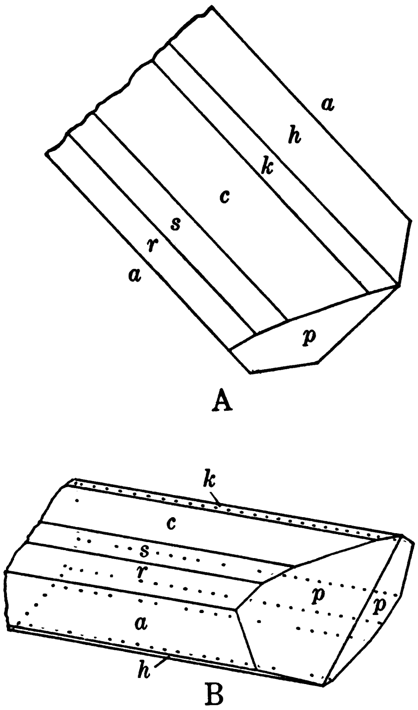


FIGURE 192 · Crystal of chlorophoenicite showing the forms *c*(001), *a*(100), *s*(106), *r*(102), *k*($\bar{1}$04), *h*($\bar{2}$03), and *p*(111) Franklin. A, Plan, B, clinographic projection

The analysis yields the empirical formula $10(Mn,Zn)O.As_2O_5.7H_2O$, although the arsenic is rather low for that composition. The formula may be interpreted as $(Mn,Zn)_3As_2O_8.7(Mn,Zn)(OH)_2$. Heated in the closed tube the mineral gives off water at a low temperature and turns black with a brilliant luster but does not fuse. Before the blowpipe it is fusible with difficulty, without decrepitation.

Occurrence.—Chlorophoenicite, discovered by Gage in 1923, was described in a preliminary paper by Foshag and Gage (231) and more fully by Foshag, Berman, and Gage in 1924. It was first found in pillars of ore between the 500- and 600-foot levels in the mine at Franklin, where crystals of it were implanted on the surfaces of cracks and slickensides in massive franklinite-willemite ore, associated with crystals of leucophoenicite and calcite and more rarely of tephroite. Its slender needles resemble rather closely crystals of transparent willemite.

Chlorophoenicite has also been found in radiate aggregates of acicular crystals on the 900-foot level in the mine at Sterling Hill, associated with calcite and barite.

In 1928 Palache (257) described flattened prisms that were doubtfully identified as clinozoisite, though their optical characters did not agree very closely with those of that mineral. Later study by Bauer and Berman (273) has shown that the crystals are undoubtedly chlorophoenicite, and that name should be substituted for clinozoisite in lists of Franklin minerals.

Another interesting occurrence of chlorophoenicite was seen in a single specimen from Franklin. In a cavity in a carbonate vein is an aggregate of needles of chlorophoenicite, thin bundles of needles being grouped with great regularity as a six-rayed star. Although this may be a twin aggregate, it seems more likely that the growth was controlled by a calcite crystal that was partly replaced along definite crystallographic directions by chlorophoenicite and then wholly removed, leaving this skeletal growth of fibers.

MAGNESIUM CHLOROPHOENICITE

$(Mg,Mn)_3As_2O_8.7(Mg,Mn)(OH)_2$. Monoclinic

Habit.—Magnesium chlorophoenicite is found in fibers, grouped in radial aggregates implanted on the surface of a narrow open vein composed of zincite and carbonates. Some of the rosettes have a diameter of two-fifths of an inch.

The only specimen was collected by the late George Stanton in the Franklin mine on the 750-foot level at pillar 859.

Physical properties.—The fibers are white or colorless but are stained brown on some surfaces. They show the same single excellent cleavage lengthwise of the fibers that is characteristic of chlorophoenicite. The specific gravity is 3.37.

Optical properties.—The mineral is optically biaxial and positive, with a small optic angle. The plane of the optic axes is across the fibers—that is, parallel to the plane of crystal symmetry. The extinction angle could not be measured on the material available; $r < v$ (strong); $\alpha = 1.669$, $\beta = 1.672$, $\gamma = 1.677$, all ± 0.003 (Berman).

Composition.—Magnesium chlorophoenicite is similar in composition to chlorophoenicite but contains magnesium in place of all the zinc and part of the manganese of that mineral. The following analysis was made in the chemical laboratory of the department of mineralogy at Harvard University on about 0.4 gram of material that could not be completely purified without loss of too much of the mineral itself.

Analysis of magnesium chlorophoenicite

	1	2			4	5
SiO_2	3. 36	0. 056				
Fe_2O_3	3. 85	. 024				
ZnO	8. 90	. 109				
MgO	29. 95	. 743	0. 743	= 10×0. 093	39. 64	39. 31
MnO	15. 57	. 219	. 188		18. 05	17. 29
As_2O_5	21. 16	. 092	. 092	= 1× . 092	28. 00	28. 04
H_2O	10. 81	. 601	. 601	= 7× . 086	14. 31	15. 36
$CaCO_3$	6. 29	. 063				
	99. 89	......			100. 00	100. 00

1. Magnesium chlorophoenicite, Franklin. F. A. Gonyer (277), analyst.
2. Molecular equivalents of the constituents.
3. Molecular ratio of remainder after deducting 5.55 percent of franklinite, 6.29 percent of calcite, and 12.49 percent of willemite.
4. Composition of remainder recomputed to 100 percent.
5. Composition of mineral computed from formula, assuming the molecular ratio of MnO to MgO as 1 to 4.

The material analyzed was known to contain calcite and willemite, and in interpreting the analysis the assumption was made that all the ZnO and SiO_2 found was contained in willemite and that all the Fe_2O_3 found was contained in franklinite. On this assumption the material contained 24.32 percent of impurities, consisting of 6.29 percent of calcite, 12.48 percent of willemite, and 5.55 percent of franklinite. The molecular ratio of the remainder gives the empirical formula $10(Mg,Mn)O.As_2O_5.7H_2O$, which is of the same form as that of chlorophoenicite but differs in containing magnesium in place of zinc, the molecular ratio of MgO to MnO being 4 to 1.

The difference in composition is reflected in the lower specific gravity, lower refractive indices, and opposite optical sign of the mineral as compared with chlorophoenicite. This may explain the fact previously discovered that some specimens of what was taken to be chlorophoenicite are optically positive.

HOLDENITE

$8MnO\ 4ZnO\ As_2O_5.5H_2O$ Orthorhombic

$a\ b\ c = 0.3802\ 1\ 0.2755$

Forms.—*c*(001), *b*(010), *a*(100), *m*(110), *l*(120), *n*(130), *e*(011), *f*(031), *d*(102), *p*(111), *q*(211), *r*(311), *s*(131), *w*(151), *t*(251), *x*(182), and *u*(7.16.2).

Habit.—Holdenite is found in crystals tabular parallel to the face taken as the macropinacoid, the largest crystal on the specimen being a third of an inch in greatest diameter. The crystals differ little in habit and about two-thirds of the forms are found on all of them. The base was seen but once, and *n*(130) and *e*(011) were each found well developed on but two crystals. The forms *f*(031), *w*(151), and *x*(182) were also found on only one crystal, the most complex measured, shown in figure 193. The pyramid *u*(7.16.2), seen on all the crystals, with relatively large faces has a considerable range in its angular position. As shown in the figure, it is in a zone with *t*(251) and *s*(131), and the angles measured on this one crystal agree well with the computed values. On other crystals, however, the angles are different and on some have values that correspond approximately to the simpler indices (491), but the deviation is considerable, and preference was given to the more complex symbol.

Physical properties.—Holdenite has a poor cleavage parallel to the brachypinacoid. Its hardness is 4, and its specific gravity, determined by floating in Clerici solution, is 4.07. The color ranges from clear pink to deep red and yellowish red. The mineral is biaxial and positive; the plane of the optic axes is parallel to the brachypinacoid, with the acute bisectrix emerging normal to the macropinacoid. $2V = 30°20'$ (measured), $28°58'$ (computed); r>v (easily perceptible). $\alpha = 1.769$ (parallel to *c* axis), $\beta = 1.770$ (parallel to *b* axis), $\gamma = 1.785$ (parallel to *a* axis) (Larsen).

Composition.—Holdenite is a basic arsenate of manganese and zinc in which the molecular ratio of manganese to zinc is approximately 2 to 1.

Analysis of holdenite

	1	2	3			4
SiO_2	2. 01	0. 033				
As_2O_5	17. 40	. 076	0.076		= 1×0.076..	18. 96
MnO	37. 75	. 532	.532	0.914	= 12× .076..	46. 78
FeO	1 80	. 025	.025			
ZnO	28. 08	. 345	.279			26. 83
CaO	3. 80	. 067	.042			
MgO	1. 45	. 036	.036			
H_2O	6. 62	. 367	.367		= 5× .073..	7. 43
PbO	Trace	......				
Mn_2O_3	Trace	......				
Al_2O_3	Trace	......				
	98. 91	......				100. 00

1. Slightly impure material. E. V. Shannon (248), analyst.
2. Molecular equivalents of no. 1.
3. Molecular ratio of remainder after deducting 2 49 percent of calcite and 7 38 percent of willemite.
4. Composition computed from the derived formula.

About 0.42 gram of nearly pure material was prepared by Mr. Berman for analysis. The presence of calcite was proved optically and by the effervescence of grains on solution in acid, but the sample was not large enough to permit the determination of CO_2. The assumptions were made that the deficiency of the analysis, 1.09 percent, represents CO_2, that the SiO_2 was present in willemite, and that the material therefore contained 2.49 percent of calcite and 7.38 percent of willemite. After deducting the molecular equivalents of those constituents from column 2 the molecular ratio of the remainder leads to the formula $12RO.As_2O_5.5H_2O$. As manganese and zinc oxides are present in the molecular ratio of about 2 to 1, the formula may be written as at the head of this article. The only other mineral at all resembling holdenite in composition is chlorophoenicite, also from Franklin, to which was assigned the formula $10RO.As_2O_5.7H_2O$.

History.—Holdenite was first described in 1927 by Palache and Shannon (248). It was named in honor of the late A. F. Holden, of Cleveland, in whose collection, now at Harvard University, the only known specimen of the mineral was discovered in 1913, mislabeled leucophoenicite. It is a slab of massive franklinite ore with a slickensided surface 4 by 3 inches, clearly one wall of a veinlet. The crystals of holdenite were attached for the most part directly to the vein wall or to a thin coating of manganiferous calcite. With them were minute amounts of barite, galena, pyrochroite, and fibrous willemite. Crystals were measured by the author in 1914, and practical certainty was reached that they were a new arsenate of manganese. After years of search for more of the mineral had proved fruitless, a part of the only specimen was sacrificed for analysis, the results of which confirmed the previous conclusion that the mineral is a hitherto unknown arsenate.

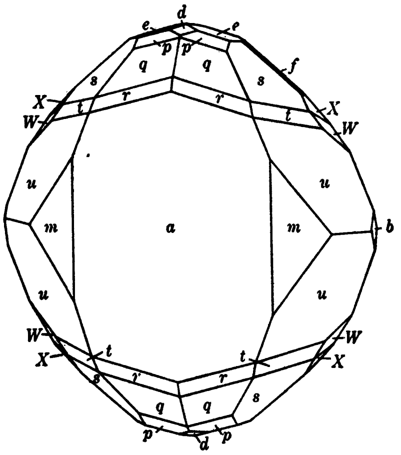


FIGURE 193.—Crystal of holdenite showing all the forms known for the mineral except *c*(001), *l*(120), and *n*(130) Franklin.

BOROARSENATES

CAHNITE

$Ca_4B_2As_2O_{12}.4H_2O$ Tetragonal-sphenoidal *a* *c*=1 0.615

Forms.—*a*(100), *m*(110), *p*(111), *o*($1\bar{1}1$).

Habit.—Single, pseudotetrahedral crystals of cahnite are very rare, as the mineral is generally found in interpenetrating twins with parallel axes, the twinning plane being the first-order prism. The characteristic feature of the crystals is the cross formed by the regular intersection of the twinned edges of the sphenoids and the coincidence of the prism faces, which are generally bright. The crystals are white and transparent, with a glassy luster. The cleavage is very perfect parallel to the prism of the first order, which increases the general resemblance of the mineral to barite, with which it is not uncommonly associated. The hardness is 3, and the specific gravity is 3.156.

Optical character.—Cahnite is uniaxial and positive; $\omega = 1.662$ and $\epsilon = 1.663$; birefringence therefore very weak. Because of its low birefringence and considerable dispersion, cahnite shows abnormal interference colors, making the mineral easily recognizable under the microscope (Berman, 249).

Composition.—Cahnite is a hydrous boroarsenate of calcium and it fuses quietly at about 3, yielding the green flame of boron. It is easily and completely soluble in dilute hydrochloric acid. In the closed tube, heated alone it yields water and becomes opaque but does not fuse. Heated with potassium carbonate and carbon it yields an arsenic mirror.

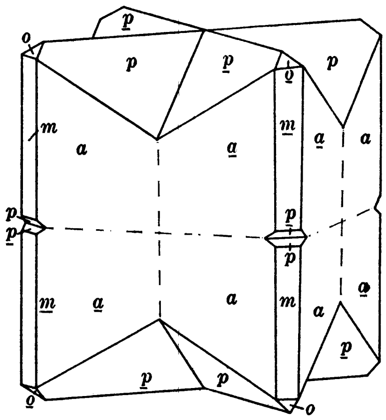


FIGURE 194.—Crystal of cahnite twinned on *m*(110), showing the forms *a*(100), *m*(110), *p*(111), and *o*($1\bar{1}1$) Franklin.

Analyses of cahnite

	1	2	3	4	5
CaO	38.27	37.13	37.62	0.671 = 4 × 0.168	37.64
B_2O_3	10.14	11.64	11.86	.169 = 1 × 0.169	11.74
As_2O_5	36.79	37.47	38.05	.166 = 1 × 0.166	38.54
H_2O	11.75	11.78	12.42	.689 = 4 × 0.172	12.08
PbO	1.15	Trace	......		
MgO	24	......	......		100.00
ZnO	Trace	1.58	......		
CO_2	Trace	......	......		
	98.34	99.60	99.85		

1 Slightly impure sample, weight 0.1 gram, containing a little hedyphane and calcite. L. H. Bauer (249), analyst.

2 Slightly impure sample, weight 0.26 gram. L. H. Bauer (249), analyst.

3. Very pure sample, weight 0.5 gram. L. H. Bauer (249), analyst.

4. Molecular ratio computed from 3.

5. Composition computed from the formula $4CaO.B_2O_3.As_2O_5.4H_2O$

The close agreement of the three analyses of different samples of the mineral is striking. The molecular ratio leads to the simple formula $4CaO.B_2O_3.As_2O_5.4H_2O$ or $Ca_4B_2As_2O_{12}.4H_2O$. Cahnite is thus an entirely new type chemically.

Occurrence.—Cahnite has been found only at Franklin. The first crystals seen were on specimens that probably came from the Parker shaft. They present two distinct types of paragenesis. In one type cahnite is implanted, together with barite and pyrochroite, on the walls of cavities in beautifully crystallized axinite. In the other type crystals of cahnite, calcite, and olive-green willemite are implanted on massive friedelite and barite or on garnet. One crystal in such a specimen, exceptional in being untwinned, is a quarter of an inch in diameter.

The specimens found by Mr. Stanton in 1926 came from pillar 229 north, 36 feet above the 700-foot level of the Franklin mine. They all contain axinite, which forms veins with small open cavities. Resting on the axinite are crystals of rhodonite, barite, hedyphane (some of it being in crystals), and willemite of either the usual prismatic habit or in thin plates with the base dominant. The cahnite is later than all those minerals and is implanted upon them. The only mineral later than cahnite is datolite, in a coating of fibrous nature, like the so-called botryolite at Arendal, Norway. The datolite coats all the other minerals in the veins, although most of the crystals of cahnite are free from it and clearly belong to the same period of deposition. Cahnite has also been found in a neighboring part of the mine associated only with rhodonite, on crystals of which it is implanted.

Still another association came to light early in 1927. Specimens from the picking table showed small drusy cavities in franklinite, lined with dodecahedral crystals of garnet. The garnet is pink on the free surfaces but shows successively white and yellow layers toward the walls of the cavities. Tiny glass-clear crystals of cahnite are implanted on the garnet and show to the minutest detail the complete symmetry of the twin figured above. The only associated mineral is light-brown to yellow biotite in long, slender prismatic crystals projecting into the cavities.

In 1927 a small vein containing cahnite implanted on crystallized rhodonite was found near the locality of 1926. The crystals of cahnite are symmetrical twins of a size which, in comparison with any found before, may fairly be called gigantic, the largest being three-quarters of an inch square. Figure 195 shows a photograph and drawing of these extremely symmetrical interpenetrating twins.

All the localities so far mentioned were in the northern part of the mine, but in 1928 cahnite was discovered in the south end of the mine also, in pillar 1239, 20 feet below the 750-foot level and 15 feet from the hanging wall. It there forms tiny crystals associated with calcite.

History.—A few minute implanted crystals of cahnite were first observed and sketched by Lazard Cahn about 1911. The specimens containing them were submitted to the author for study and became part of the Holden collection at Harvard University. The tiny white glassy crystals were characteristically twinned, and their form and angles suggested strongly a relation to the barium-bearing zeolite edingtonite, but material for analysis or for any but the simplest chemical tests was lacking. However, the author believed that it could be shown that the mineral contained calcium instead of barium, and he therefore regarded it as a calcium edingtonite. The name cahnite was proposed for it in recognition of Mr. Cahn's indefatigable efforts to preserve and to make known to science the rarer Franklin minerals. The name appeared in the American Mineralogist in 1921 in the title of a paper that was neither read nor printed.

Thus the matter stood until 1926, when George Stanton, of Franklin, rediscovered the mineral in moderate abundance in veins in massive ore in the northern part of the mine. Its identity remained concealed at first, as the newly found material was poorly crystallized. Mr. Bauer had established its peculiar chemical nature before the characteristic twin crystals were again found. A spectroscopic examination of one of the original crystals was then made by Mr. Nitchie at the Palmerton laboratory of the New Jersey Zinc Co., which established the complete chemical identity of the two finds.

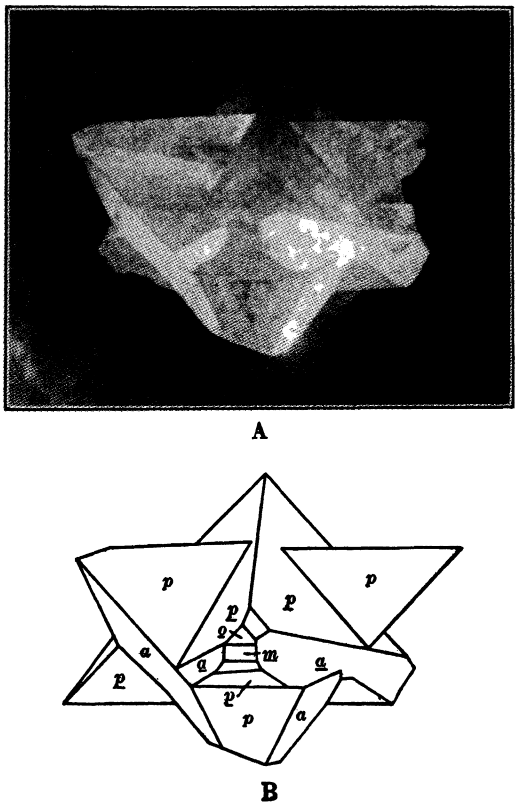


FIGURE 195.—Crystal of cahnite showing the same sort of twinning illustrated in figure 194. Franklin. A, Photograph, B, drawing in the same position.

BORATES

SUSSEXITE

$H(Mn,Mg,Zn)BO_3$. Orthorhombic

Physical character.—Sussexite is found in silky fibers in parallel groups that constitute the filling of thin veins, the fibers being either parallel to the vein walls or transverse to them. It also forms felted fibrous masses.

Sussexite is white, with a tinge of yellow or pink, and translucent. Its luster is silky to pearly. Its hardness is 3, and its specific gravity is 3.42 (Brush) or 3.123 (Penfield).

Sussexite is biaxial and optically negative. Its fibers are parallel to the vertical axis. $X=c'$, $Z=$ bisectrix in the acute angle of the unit prism. $\alpha=1.630$, $\beta=1.712$, $\gamma=1.709$ (Larsen).

Composition.—Sussexite is an acid borate of manganese and magnesium, having the general formula $HRBO_3$, in which R includes manganese, magnesium, zinc, and in some material iron and calcium, though the last two may be merely impurities.

Analyses of sussexite

	1	2	3	4	5
B_2O_3	31.89	33.31	[a]33.16	29.20	30.52
MnO	40.10	38.08	37.58	47.27	49.40
MgO	17.03	15.92	16.29	9.15	9.56
ZnO		3.24	3.87	3.14	
H_2O-	9.59	8.53	.10	7.97	8.33
H_2O (250°)		.90	7.80		
Fe_2O_3			.60		
FeO				.15	.16
CaO			.10	1.94	2.03
SiO_2			.50	1.30	
	98.61	99.98	100.00	100.12	100.00

[a] Difference.

1. G. J. Brush (95), analyst.
2. S. L. Penfield and E. S. Sperry (135), analysts.
3. E. Pointevin and H. V. Ellsworth (229), analysts.
4. L. H. Bauer (257), analyst.
5. No. 4 recomputed to 100 percent after deducting 4.5 percent of willemite, equivalent to the SiO_2 found.

The molecular ratio of $B_2O_3 : RO : H_2O$, computed from the analyses, is very nearly 1 : 2 : 1, from which the accepted formula is derived.

The analysis by Pointevin and Ellsworth (no. 3) was made in order to establish the optical characters of the mineral on analyzed material. The optical constants determined by them are essentially the same as those found by Larsen and given above.

Occurrence.—Sussexite was first described by Brush (95) from material collected by Mixter and himself at the Hamburg mine at Franklin, where it was associated with carbonates of manganese and magnesium and blackened pyrochroite in secondary veins cutting massive franklinite ore. Plate 19, *B*, shows a typical but unusually large specimen. A later analysis of the original material by Penfield (135) confirmed Brush's formula. Well-authenticated specimens of silky fibrous sussexite, less compact than the type material and embedded in massive ore, were seen in collections from the Parker shaft and from the Taylor mine; it is reported also from the Trotter mine. Nevertheless it was found in very small amounts at all localities, and but little of the mineral is preserved in collections. Much of what is labeled sussexite is a form of tremolite asbestos cemented by calcite or by the mixture of fibrous calcite and zincite known locally as "calcozincite." From these sussexite can be readily distinguished by its characteristic flame reaction for boron as well as by its optical character.

During 1913 and 1914 considerable amounts of sussexite were found with pyrochroite and leucophoenicite (see p. 51) in the northern part of the Parker mine. A specimen in the Harvard collection shows the delicate white fibers intergrown with pale-pink rhodochrosite in a thin vein.

In 1927 a specimen was found on the picking table at Franklin so different in appearance from normal sussexite that it was not recognized as such until analysis had proved its nature. The material forms a vein in massive ore, largely composed of yellow willemite intermingled with a dull-pink massive substance with the appearance of garnet, which is the sussexite. When crushed it shows under the microscope a felted fibrous texture quite unlike the usual parallel and separable fibrous texture of ordinary sussexite. It is biaxial and negative; $2V$ small, elongation negative, parallel extinction; $\alpha=1.65$, $\beta=1.71$, $\gamma=1.715$. Analysis 4, made of this material, is that of a sussexite with much less magnesium and correspondingly more manganese than the type material. It constitutes a distinct facies of sussexite, which is one of the considerable number of minerals known only from Franklin.

FLUOBORITE

$6MgO\ B_2O_3.3(F_2,H_2O)$ Hexagonal

Character.—Fluoborite is found as hairlike material in fluffy, loosely felted aggregates filling cavities in pyrochroite that contain crystals of mooreite, some of which enclose fibers of fluoborite. Associated and easily confused with it are fibrous white rosettes of willemite. It is found also in compact fibrous form intimately mixed with an ill-defined hydrous zinc carbonate, as veinlets in zincite. Some of the veinlets are fluorite.

Its crystallographic character cannot be determined directly, as the fibers are too small. The type material from Sweden is definitely hexagonal, however, and X-ray powder spectrographs of the material from both localities indicate that they have essentially the same crystal structure.

Fluoborite is optically uniaxial and negative. The fluffy material has a specific gravity of 2.88 and refractive indices $\omega=1.548$ and $\epsilon=1.518$; the material associated with zincite has a specific gravity of 2.92 ± 0.01 and indices $\omega=1.547$ and $\epsilon=1.522$.

Composition.—Fluoborite is a hydrous fluorine-bearing magnesium borate in which fluorine and water seem to be interchangeable. The fluffy material is so light that difficulty was experienced in obtaining enough for analysis, and both sorts of material are so mixed with other minerals that a pure sample could not be separated. The best analyses, however, after eliminating known impurities, give molecular ratios in close agreement with that of the type material and yielding the same formula, although the Sterling Hill material contains more fluorine than the type material from Sweden.

Analyses of fluoborite

	1	2	3	4	5	6	7
MgO	60. 07	46. 33	62. 07	67. 38	1. 487		
ZnO	2. 41	15. 00	2. 05		. 030	0. 007	1.538 = 6×0.256
MnO	1. 93	4. 13	2. 09		. 028		
CaO	1. 19				. 021	. 021	
B_2O_3	17. 25	10. 87	18. 68	17. 40	. 246		.246 = 1×0.246
F	17 60	9. 83	17. 14	17. 00	. 463		.753 = 3×0.251
H_2O	5. 22	10. 62	1. 29	5. 37	. 290		
CO_2	1. 23	5. 22			. 028	. 028	
SO_3		. 27					
	106. 90	102. 27	103. 32	107. 15			
$O=F_2$	7. 41	4. 14	7. 22	7. 15			
	99. 49	98. 13	96. 10	100. 00			

1. Material associated with zincite, about 97 percent pure, Sterling Hill. L. H. Bauer (267), analyst.
2. Material associated with mooreite, large carbonate impurity, Sterling Hill. L. H. Bauer (267), analyst.
3. Material of 2 after treatment with hydrochloric acid until effervescence ceased; deficiency in total presumably due to loss of water.
4. Theoretical composition computed from formula adopted.
5. Molecular equivalents of 1, based on F_2 for fluorine.
6. Molecular equivalents of carbonate impurity deducted.
7. Molecular ratio of remainder, leading to formula adopted.

In its relatively large content of fluorine, fluoborite seems to stand alone among the borates. In other respects it is rather similar in composition to sussexite and hambergite, neither of which, however, contains fluorine.

Occurrence.—Fluoborite was discovered at Norberg, Sweden, by Geijer and described and named by him (245a) in 1926. It had not been found elsewhere until its discovery by Bauer and Berman (267) at Sterling Hill in 1929. It was first found there, associated with altered pyrochroite, rhodochrosite, and zincite, in a vein in normal calcite-franklinite-willemite ore. Later it was found also as veinlets in zincite, associated with carbonates, part of them being hydrous.

SULPHATES

BARITE

$BaSO_4$. Orthorhombic

Forms.—*c*(001), *a*(100), *b*(010), *m*(110), *η*(320), *λ*(210), *d*(102), *u*(101), *o*(011), *z*(111), *P*(116), *v*(115), and *l*(104).

Combinations on crystals of barite

	Forms	Localities	Illustration
1	*c, u, m*		
2	*c, d, o*	Taylor mine	
3	*c, a, b, m, η, λ, u, d*	North end of workings.	
4	*c, m, l, d, o, P, v, z*	Parker shaft	Fig. 195.

Occurrence.—Barite in small amounts is a rather widely distributed mineral at Franklin. It is found in veins of many types, generally as one of the last minerals to crystallize. Genth (145) noted it associated with axinite at the Trotter shaft, and Penfield (173) found it among the rare minerals of the Parker shaft. Several specimens from the Parker shaft were seen, in which the barite was faintly bluish and filled cavities in axinite and rhodonite. It forms platy aggregates and in one cavity a few small crystals of the habit of figure 196 but with the additional forms *P*(116) and *v*(115), too minute to be figured.

Prismatic crystals of pale-yellow barite with the forms *c*(001), *d*(102), and *o*(011) incrust the specimen of friedelite from the Taylor mine that was found in the Kemble collection.

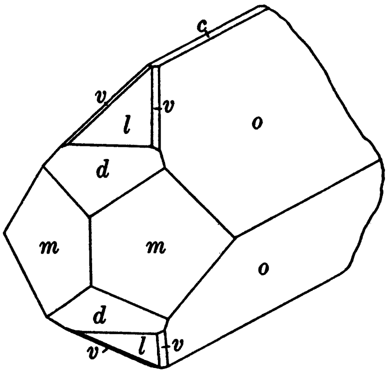


FIGURE 196.—End of prismatic crystal of barite showing the forms *c*(001), *m*(110), *l*(114), *d*(102), *o*(011), and *v*(115) Trotter shaft.

The best crystals seen, combination 3, were associated with green willemite and hodgkinsonite as described on page 85. Barite is rarely absent from veins containing hodgkinsonite.

CELESTITE

$SrSO_4$. Orthorhombic

Forms.—*c*(001), *a*(100), *m*(110), *o*(011), *d*(102), *z*(111).

Occurrence.—Crystals of celestite, either prismatic parallel to the brachyaxis or tabular parallel to the base, and showing all the forms listed except *a*, were described and figured by Gordon (222). The crystals are described as brilliant and colorless, rarely more than a tenth of an inch in size, and coating cavities in rhodochrosite that was associated with calcite and franklinite. The celestite was biaxial and positive, $\alpha = 1.621$, $\beta = 1.625$, $\gamma = 1.631$.

Gordon's description of celestite from Franklin drew attention to its presence, and it has since been noted on several specimens in small veins, where it plays the same part that the more common barite generally does.

In 1930 celestite was reported from Sterling Hill, where good crystals tabular to the macropinacoid (fig. 197) were found in a cavity in franklinite ore.

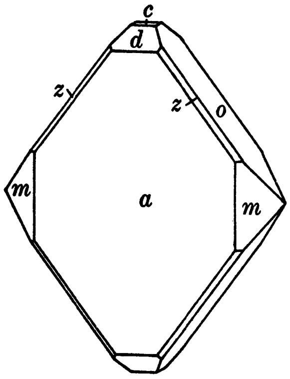


FIGURE 197

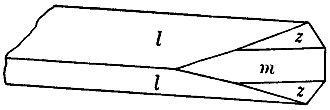


FIGURE 198

FIGURE 197.—Crystal of celestite tabular parallel to the macropinacoid, showing the forms c(001), a(100), m(110), d(102), o(011), and z(111) Sterling Hill

FIGURE 198.—Crystal of anglesite prismatic parallel to the macroaxis, showing the forms m(110), l(104), and z(111) Sterling Hill

ANGLESITE

$PbSO_4$. Orthorhombic

Forms.—*m*(110), *l*(104), and *z*(111).

Occurrence.—Anglesite, associated with cerusite and galena, was seen only on several specimens of the T. Lang collection that had been found in the calamine pits at Sterling Hill. It is partly in massive coatings on lumps of galena and partly in crystal aggregates filling cavities in the same parent mineral. Obviously it is a rare and unimportant mineral in the district.

ANHYDRITE

$CaSO_4$. Orthorhombic

Anhydrite is known only in a single small specimen found at Franklin in 1928. It is a small nodule, an inch across, enclosed in limestone, that appears to be a fragment of a carbonate vein. Its center is a compact, finely granular mass of pure pale-bluish anhydrite, bordered by a zone containing some gypsum plates in the anhydrite. A more distinct border wholly surrounding the anhydrite consists of pale-pink sussexite, and a thin film of pale-yellow serpentine separates the nodule from the enclosing fine-granular limestone.

GYPSUM

$CaSO_4.2H_2O$. Monoclinic

Gypsum was identified in a single specimen, given to the author at Franklin, which shows a secondary carbonate vein in massive ore. The filling is chiefly calcite in coarse curved lamellae which, where they reach the vein cavities, are covered with radiate acicular crystals of calcite in parallel position to the underlying calcite. Lying across the ends of the slender crystals of calcite and but lightly attached to them are several clear, colorless crystals of gypsum, the largest a fifth of an inch long. The crystals have rounded faces owing to solution and are not measurable but appear to be bounded by ordinary forms. In the same cavities are masses of honey-yellow willemite of curious platy form.

Gypsum was found in 1927 at Sterling Hill on the 1,100-foot level. The single specimen in hand shows a veinlike mass of selenite consisting of a single crystal with perfect cleavage. The specimen is too small to show the true relation of the gypsum to the granular ore which it cuts.

MOOREITE

$7(Mg,Zn,Mn)(OH)_2.(Mg,Zn,Mn)SO_4.4H_2O$. Monoclinic

Forms.—*c*(001), *b*(010), *a*(100), *d*(101), $f(\bar{1}01)$, $g(\bar{1}02)$, *e*(011), *p*(121), $s(\bar{1}11)$, $t(\bar{1}13)$, $v(\bar{1}15)$.

Habit.—Mooreite forms glassy white tabular crystals in cavities and crevices in pyrochroite, partly intergrown with fluoborite. The crystals are tabular parallel to the clinopinacoid (see fig. 199) and are generally grouped in subparallel aggregates. Some small doubly terminated crystals of almost ideal development were seen. A bluish-white variety of slightly different composition was found in some of the crevices but not in crystals.

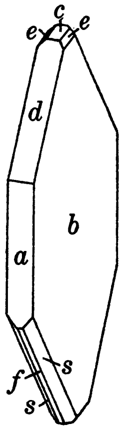


FIGURE 199.—Crystal of mooreite tabular parallel to the clinopinacoid, showing the forms c(001), a(100), b(010), d(101), $f(\bar{1}02)$, e(011), and $s(\bar{1}11)$. Sterling Hill.

Physical properties.—Mooreite is clear glassy white and has a perfect clinopinacoidal cleavage. Its specific gravity is 2.470. The variety called δ-mooreite is bluish white and granular and its cleavage is less perfect. Its specific gravity is 2.665. The hardness of both varieties is about 3.

Both varieties are optically biaxial and negative. In mooreite $2V = 50° \pm$; $X = b$; $Z \wedge c = 44°$; $r > v$ (perceptible); $\alpha = 1.533$, $\beta = 1.545$, $\gamma = 1.547$. In δ-mooreite $2V = 40° \pm$; $\alpha = 1.570$, $\beta = 1.584$, $\gamma = 1.585$.

Composition.—Mooreite is a basic hydrous sulphate of magnesium, zinc, and manganese. There are no known minerals to which it is closely related. The two varieties differ chiefly in the relative proportion of the three metallic bases. Which of the two is chemically the more typical of the species cannot be decided, and possibly one of them is being developed at the expense of the other.

Analyses of mooreite

	1	2	3	4
MgO	25.38	0.629	17.27	0.427
MnO	11.93	.167 } 1.096 = 8×0.137	17.98	.253 } 1.003 = 7×0.143
ZnO	24.58	.300	26.30	.323
SO_3	10.99	.136 = 1×0.136	11.64	.145 = 1×0.145
H_2O	27.12	1.506 = 11×0.137	26.39	1.466 = 10×0.146
B_2O_3	----------		Present.	
SiO_2	----------		.08	
	100.00		99.66	

1. Average of two analyses, recomputed to 100 percent after deducting unessential constituents. L. H. Bauer (267), analyst.
2. Molecular ratio of no. 1.
3. δ-mooreite. L. H. Bauer (267), analyst.
4. Molecular ratio of no. 3.

From the molecular ratios may be derived the following formulas for the two varieties: Mooreite, $7R(OH)_2.RSO_4.4H_2O$, in which R is Mg:Zn:Mn=4:2:1; δ-mooreite, $6R(OH)_2.RSO_4.4H_2O$, in which R is Mg:Zn:Mn=5:4:3.

Occurrence.—Mooreite is found in cavities and crevices in pyrochroite in a vein in normal calcite-franklinite-willemite ore at Sterling Hill. It was described in 1929 by Bauer and Berman (267), who named it for Gideon H. Moore, late chemist of the Passaic Zinc Co., who first described the minerals brushite, chalcophanite, and hetaerolite.

UNCONFIRMED SPECIES

The following list gives the names of species which have been reported in previous lists as found in the district but which, in the author's opinion, have not been confirmed. For none of them could specimens or authentic descriptions be discovered.

Anatase. Seymour (97). A mistake for rutile.

Annabergite. Assumed by Koenig (137) to be present as an impurity in desaulesite but not known as a definite mineral at Franklin.

Beryl. Robinson (22) and in all later lists. As no specimens were seen in any collection it is believed that green microcline was mistaken for beryl in early days.

Chrysocolla. Seymour (97). Reported also by Darton (126) at Sterling Hill but not verified.

Clinozoisite. Palache (257). Reported doubtfully as such but now definitely known to be chlorophoenicite.

Epistilbite. Palache (257). A mistake for stilbite.

Pyroxene group: Augite, coccolite, diallage, sahlite. All these names are found in the earlier lists, but none of them could be verified by specimens.

Rammelsbergite and smaltite. These two minerals have been reported only through mistake for chloanthite. (See *b*, below.)

Vivianite. Fowler (21). Included in most lists on Fowler's authority, but unsupported by specimens or description.

Wad. Valiant (189). Probably is really psilomelane.

Yttrocerite. Gibbs (15). A doubtful occurrence, never confirmed.

APPENDIX

(*a*) Page 19. Bayley, W. S., Iron mines and mining in New Jersey; New Jersey Geol. Survey Final Rept., ser. 7, 1910. By an oversight this work was omitted from the bibliography. It contains several references to the magnetite mines at Franklin, especially on pages 226, 227, and 255.

(*b*) Page 31. Holmes, R. J., X-ray study of arsenides and antimonides of nickel and cobalt [abstract]: Am Mineralogist, vol. 20, p. 198, 1935. The author finds that "chloanthite" from Franklin gives an X-ray powder pattern for rammelsbergite. It is not shown, however, that chloanthite may not also be present.

(*c*) Page 48. Ramdohr, Paul, Neue Beobachtungen über die Verwendbarkeit opaker Erze als "geologische Thermometer"; Zeitschr. prakt. Geologie, Band 39, pp. 74–75, 1931. Franklinite is shown in this paper to be probably not homogeneous. The investigation is incomplete.

(*d*) Page 65. Peacock, M. A., On pectolite; Zeitschr. Kristallographie, A, Band 90, pp. 97–111, 1935. In this paper there is a new drawing of the figure of pectolite in triclinic interpretation.

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