

The lead silicates from Franklin, New Jersey: occurrence and composition

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ABSTRACT. The lead silicate minerals from Franklin, New Jersey, occurred in two separate assemblages. One of these is characterized by esperite associated with hardystonite and occasional larsenite. The second assemblage can be considered as two parts: one consists of margarosanite, barysilite, nasonite, and ganomalite; the other contains roebingite and hancockite, together with a number of highly hydrated phases. Chemical analyses indicate that these species conform to their theoretical compositions. There are no simple lead silicates at Franklin; all are compound silicates of Pb with Mn, Zn, and Ca.

KEYWORDS: lead silicates, barysilite, esperite, ganomalite, hancockite, larsenite, margarosanite, nasonite, roebingite, Franklin, New Jersey, USA.

At the end of the 19th century a remarkable suite of uncommon minerals was found on the Parker dump, near the Parker shaft of the Franklin Mine, in Franklin, Sussex County, New Jersey. This suite included a number of unknown minerals which were subsequently described as new species. A number of these were lead silicates: roebingite (Penfield and Foote, 1897), nasonite and hancockite (Penfield and Warren, 1899), and margarosanite (Ford and Bradley, 1916). Barysilite, already known from Långban, Sweden, was also found here by Shannon and Berman (1926), as was ganomalite (Dunn, 1979).

Two other lead silicate minerals were described from Franklin. Esperite was originally described as *calcium larsenite* by Palache *et al.* (1928a, b), and was redefined and renamed by Moore and Ribbe (1965). Larsenite was described by Palache *et al.* (1928a, b). Both esperite and larsenite have been included with the other lead silicate minerals from Franklin in previous discussions (Palache, 1935) but, as noted below, their paragenesis is markedly different from the others. There are no known simple lead silicates at Franklin; all are compound silicates of Pb with Ca, Mn, or Zn. These species, together with their chemical formulae, are listed in Table I.

History and occurrence

Inasmuch as the Franklin Mine was mined-out and flooded in 1954, examination of the geologic relations of the occurrences of the lead silicates was not possible. Recourse was made to mine maps and interviews with former employees of the New Jersey Zinc Company who had examined these occurrences, most notably John L. Baum, retired resident geologist for the Franklin Mine.

Table I. The lead silicate minerals found at Franklin, New Jersey

| | |
|---------------|--|
| BARYSILITE | $\text{Pb}_8\text{Mn}(\text{Si}_2\text{O}_7)_3$ |
| ESPERITE | $\text{Ca}_3\text{PbZn}_4(\text{SiO}_4)_4$ |
| GANOMALITE | $\text{Pb}_9\text{Ca}_5\text{MnSi}_9\text{O}_{33}$ |
| HANCOCKITE | $\text{PbCa}(\text{Al}, \text{Fe}^{3+})_3(\text{SiO}_4)_3(\text{OH})$ |
| LARSENITE | PbZnSiO_4 |
| MARGAROSANITE | $\text{Pb}(\text{Ca}, \text{Mn})_2\text{Si}_3\text{O}_9$ |
| NASONITE | $\text{Pb}_6\text{Ca}_4\text{Si}_6\text{O}_{21}\text{Cl}_2$ |
| ROEBLINGITE | $\text{Pb}_2\text{Ca}_6(\text{SO}_4)_2(\text{OH})_2(\text{H}_2\text{O})_4[\text{Mn}(\text{Si}_3\text{O}_9)_2]$ |

The lead silicate minerals occurred in two separate and markedly different parageneses. The one containing esperite, hereafter called the *esperite assemblage* was apparently not localized. Esperite was found throughout the northern end of the Franklin orebody. Esperite and larsenite were originally encountered on the 400 foot level, approximately 1080 feet north of the north side of the Palmer Shaft pillar (Palache *et al.*, 1928a, b). Esperite was subsequently found on the 1100 foot level in the area of the Palmer shaft pillar and at other places in the northern end of the orebody, but larsenite was not recorded from additional locations.

The other lead silicate minerals all came from a

quite restricted occurrence in the Franklin Mine, referred to herein as the *restricted assemblage*. The lead silicates (ganomalite, margarosanite, barysilite, nasonite, hancockite, and roebingite) were all found in samples first encountered in approximately the early 1890s. They were not encountered again until the mid-1950s when, as part of the closing down of the Franklin Mine, support pillars which had remained in place above the Palmer shaft (to prevent caving-in and to give support) were removed. At this time, geologists and miners recognized the very uncommon samples they were mining were markedly similar to those encountered at the end of the last century. Examination of mine maps showed that these support pillars enclosed two large vertical stopes which had been mined by hand in the early 1890s, when these minerals were first found. At the time of the initial discovery, ore was being removed from many parts of the Franklin Mine through the Parker shaft, and thus the fact that the occurrence was localized was not known at that time. Examination of mine maps by the writer has failed to find any other occurrences of these minerals. As best as it can be determined, the *restricted assemblage* was found between the 786 and 900 foot levels, and within 300 feet north and south of the 00 N/S coordinate of the mine, with reference to the maps and coordinates given by Frondel and Baum (1974). The lead silicate minerals of the *restricted assemblage* occurred within calcium silicate units and not, as a rule, with the ore units. These lead-bearing calcium silicate units were in a zone approximately 8–10 feet in thickness which was, at its closest, approximately 10 feet from the hanging wall contact with the Franklin Marble.

According to Nicholas Trofimuk, the miner who recovered this material in the early 1950s, these lead silicate minerals were present in many parts of the Palmer shaft support pillar, but varied in relative abundance.

Experimental methods

The samples studied herein were verified by X-ray powder diffraction methods, and were analysed using an ARL-SEMQ electron microprobe utilizing an operating voltage of 15 kV and a sample current of 0.025 μ A, measured on brass. The standards used were PbO (Pb), manganite (Mn), baryte (Ba), celestine (Sr,S), synthetic ZnO (Zn), and hornblende (Si,Al,Fe,Mg,Ca,K,Na). Samples with volatiles were first checked for homogeneity using a small beam spot and then analysed employing a larger beam spot to minimize volatilization. All data were corrected using a modified version of the MAGIC-4 computer program. Some qualification is needed for statements of relative abundance of the various species. For the most part, the studied samples were collected non-systematically by miners over at least 60 years. Because two of the lead silicate species, margarosanite and esperite, are vividly fluorescent in ultraviolet radiation, they were likely 'overcollected' relative to other less appealing assemblages. This study therefore attempts to draw scientific information from samples collected un-systematically.

The esperite assemblage

Esperite was originally described by Palache *et al.* (1928a, b) as a Ca–Pb–Zn silicate which was then tentatively assumed to be related to larsenite, PbZnSiO_4 , and was named *calcium larsenite*. Re-study of this material by Moore and Ribbe (1965)

Table II. Microprobe analyses of esperite

| | C6175-1 | 143620 | 143612 | 143605 | 143609 | C6175-3 | 143614 | B17314 | C6175 | 144877 | Average of 10 | Bauer** (1928) | Theory* |
|--|---------|--------|--------|--------|--------|---------|--------|--------|-------|--------|------------------|-------------------|---------|
| SiO ₂ | 24.7 | 25.4 | 25.0 | 25.1 | 26.7 | 26.4 | 25.1 | 25.4 | 24.9 | 24.5 | 25.3 | 24.10 | 25.12 |
| CaO | 15.8 | 16.8 | 16.1 | 16.4 | 17.3 | 18.0 | 16.3 | 16.4 | 15.6 | 15.8 | 16.4 | 16.36 | 17.57 |
| ZnO | 31.9 | 31.6 | 31.4 | 32.8 | 31.9 | 32.3 | 33.2 | 34.2 | 32.8 | 30.6 | 32.3 | 30.61 | 34.00 |
| PbO | 28.0 | 23.9 | 26.9 | 27.0 | 26.0 | 23.6 | 28.3 | 27.7 | 28.6 | 28.2 | 26.8 | 27.63 | 23.31 |
| MgO | 0.3 | 0.9 | 0.3 | 0.3 | 0.9 | 0.7 | 0.2 | 0.3 | 0.2 | 0.4 | 0.4 | 0.4 | 0.23 |
| MnO | 0.7 | 0.6 | 0.6 | 0.6 | 0.7 | 0.6 | 0.5 | 0.5 | 0.6 | 0.9 | 0.6 | 0.57 | |
| Total | 101.4 | 99.2 | 100.3 | 102.2 | 103.5 | 101.6 | 103.6 | 104.5 | 102.7 | 100.4 | 101.8 | 100.10 | 100.00 |
| <u>Number of ions on the basis of 16 oxygens</u> | | | | | | | | | | | | | |
| Si | 4.01 | 4.05 | 4.06 | 4.01 | 4.09 | 4.07 | 4.00 | 3.98 | 4.02 | 4.02 | 4.04 | 3.98 | 4.00 |
| Ca | 2.75 | 2.87 | 2.80 | 2.80 | 2.84 | 2.97 | 2.78 | 2.76 | 2.69 | 2.78 | 2.80 | 2.89 | 3.00 |
| Zn | 3.83 | 3.72 | 3.76 | 3.87 | 3.61 | 3.67 | 3.90 | 3.96 | 3.90 | 3.71 | 3.80 | 3.73 | 4.00 |
| Pb | 1.22 | 1.02 | 1.17 | 1.16 | 1.07 | 0.98 | 1.21 | 1.17 | 1.24 | 1.25 | 1.15 | 1.23 | 1.00 |
| Mg | 0.07 | 0.21 | 0.07 | 0.07 | 0.21 | 0.15 | 0.05 | 0.07 | 0.05 | 0.10 | 0.09 | 0.06 | |
| Mn | 0.10 | 0.08 | 0.08 | 0.08 | 0.09 | 0.08 | 0.07 | 0.07 | 0.08 | 0.12 | 0.08 | 0.08 | |

* --Theoretical composition for $\text{Ca}_2\text{PbZn}_4(\text{SiO}_4)_4$. Accuracy of data: $\pm 3\%$ of amount present.
 ** --In Palache *et al.* (1929b); includes 0.48% FeO and 0.12% H₂O.

indicated that this phase was not related to larsenite, but was instead a tecto-zincosilicate. They renamed it esperite in honour of Esper S. Larsen, Jr. and noted that the sample they studied had a Ca:Pb ratio of nearly 3:1, while the original sample of Palache *et al.* had a Ca:Pb ratio of 2.35:1. Inasmuch as there is only one published analysis of esperite, its composition was investigated to ascertain the degree of variance in the Ca:Pb ratio, and to confirm its formula. These analyses are presented in Table II.

The analytical data indicate that the chemical composition of esperite varies principally in the Ca:Pb ratio. The average of ten microprobe analyses (Table II) yields a formula, calculated on the basis of 16 oxygen atoms, $\text{Ca}_{2.80}\text{Pb}_{1.15}\text{Mn}_{0.08}\text{Mg}_{0.09}\text{Zn}_{3.80}\text{Si}_{4.04}\text{O}_{16.00}$, in excellent agreement with the formula $\text{Ca}_3\text{PbZn}_4(\text{SiO}_4)_4$ proposed by Moore and Ribbe (1965). It is noteworthy that each of the samples has less than 4 Zn atoms per formula unit; it is likely that Mn and Mg proxy for Zn and that small amounts of Pb substitute for Ca.

Esperite is moderately widespread at Franklin, and usually occurs as massive, very fine-grained aggregates with a dull to slightly greasy lustre and a slightly conchoidal fracture. Some masses have an apparent but weak foliation, which appears to be stress-related and not crystallographically oriented. Some samples may be interlayered with willemite, but most consist of highly irregular, somewhat nodular aggregates (up to 9 cm), associated with willemite, franklinite, and frequently with hardystonite. Esperite is strongly fluorescent (greenish yellow) in short-wave ultraviolet radiation, except where it is in direct contact with franklinite; fluorescence is diminished at such contacts. Esperite assemblages are generally low in calcite, an otherwise quite abundant mineral at Franklin. Franklinite, if present, is usually rimmed by willemite and sometimes by hodgkinsonite.

The most common and texturally interesting of the associated minerals is hardystonite, $\text{Ca}_2\text{ZnSi}_2\text{O}_7$, a member of the high-temperature melilite group. Although hardystonite occurs without esperite in many parts of the Franklin orebody, the northern end of the mine, where esperite occurred, contained much hardystonite in intimate association with esperite. In thin-section (fig. 1), esperite replaces hardystonite along fractures and cleavage traces; this replacement gives rise to a 'feathery' interface between the two species, as observed in hand-specimens. In addition to hardystonite, hodgkinsonite, $\text{MnZn}_2\text{SiO}_4(\text{OH})_2$, occurs with esperite, frequently forming at the interface between hardystonite and esperite. Where hodgkinsonite is present between these species, it is crystallographically parallel to the fibrosity of the esperite aggre-



FIG. 1. Esperite (dark) replacing hardystonite (light) along cleavage planes and fractures (NMNH 144877). Maximum dimension of sample is 25 mm.

gates, as evidenced by thin-section examination. The crystallographic orientation of this intergrowth could not be determined.

Hardystonite. Although not a lead silicate mineral *per se*, hardystonite has been little studied since the original description by Wolff (1899), and the subsequent crystal structure determinations by Warren and Trautz (1930) and Louisnathan (1969). Hardystonite was locally abundant in the Franklin Mine, occurring between calcite-bearing willemite/franklinite ore and non-calcite-bearing ore, in addition to other assemblages. Microprobe analyses of hardystonite are given in Table III. Examination of the data indicate that hardystonite is relatively invariant in composition. Small amounts of Al, Mg, and Mn apparently substitute for Zn. The lead content, although low, is somewhat persistent; no samples studied were Pb-free. The cathodoluminescence of these hardystonite samples was proportional in intensity to the amount of Pb present.

Table III. Microprobe analyses of hardystonite

| | 122676 | C6243 | 143607 | C2644 | R6729 | Theory* |
|--------------------------------|--------|-------|--------|-------|-------|---------|
| CaO | 35.3 | 34.9 | 34.3 | 35.8 | 34.5 | 35.75 |
| PbO | 0.8 | 0.9 | 1.2 | 0.3 | 0.5 | |
| MgO | 0.3 | 0.2 | 0.2 | 0.6 | 0.3 | |
| MnO | 0.8 | 1.7 | 0.1 | 0.3 | 0.5 | |
| ZnO | 22.3 | 22.9 | 23.5 | 24.0 | 23.7 | 25.94 |
| SiO ₂ | 38.7 | 38.3 | 38.8 | 38.9 | 38.6 | 38.31 |
| Al ₂ O ₃ | 0.3 | 0.5 | 0.2 | 0.3 | 0.1 | |
| Total | 98.5 | 99.2 | 99.3 | 100.2 | 98.7 | 100.00 |

Number of ions on the basis of 7 oxygens

| | | | | | | |
|----|------|------|------|------|------|------|
| Ca | 1.98 | 1.96 | 1.98 | 1.98 | 1.99 | 2.00 |
| Pb | 0.01 | 0.01 | 0.02 | 0.00 | 0.01 | |
| Mg | 0.02 | 0.02 | 0.02 | 0.05 | 0.02 | |
| Mn | 0.04 | 0.08 | 0.00 | 0.01 | 0.02 | |
| Zn | 0.86 | 0.89 | 0.91 | 0.91 | 0.91 | 1.00 |
| Si | 2.03 | 2.00 | 2.03 | 2.01 | 2.02 | 2.00 |
| Al | 0.02 | 0.03 | 0.01 | 0.02 | 0.01 | |

*---Theoretical composition for Ca₂ZnSi₂O₇.

Accuracy of data: ±3 percent of the amount present.

Larsenite is among the rarest of the lead silicates from Franklin. It was noted *in situ* only once and may have come from a very restricted assemblage. It is found as prismatic, equant 1–3 mm crystals in seams, in willemite/franklinite ore, which is in contact with esperite and hardystonite. Calcite, if present, is quite minor. Larsenite is clearly secondary and is associated with secondary willemite, clinohedrite, and hodgkinsonite. Representative microprobe analyses of larsenite are presented in Table IV, and conform closely to the theoretical composition.

Unnamed species. At the contact between esperite and hardystonite, where esperite replaces hardystonite in an irregular 'feather'-like intergrowth (fig. 1), there occur abundant microcrystals of clinohedrite and willemite, and an unknown phase in small (4 μm) crystals, which are uniform in composition from crystal to crystal, and have a very strong, bright blue cathodoluminescence. These grains have the chemical composition: SiO₂ 27.3, MgO 5.9, CaO 14.0, MnO 0.9, ZnO 26.1, PbO 25.5, sum = 99.7 wt.%. Preliminary attempts to calculate this analysis as a magnesian esperite yielded unsatisfactory results. The presence of substantial Mg, which is not found in amounts greater than 1.0 wt. % in these esperite analyses, coupled with the very characteristic bright blue cathodoluminescence, suggests that this is likely to be a new species, albeit one which cannot be characterized at this time due to very small grain size and extreme paucity of

Table IV. Microprobe analyses of larsenite

| | C6174 | 137999 | Theory* |
|------------------|-------|--------|---------|
| SiO ₂ | 17.2 | 17.5 | 16.98 |
| CaO | 0.1 | 0.2 | |
| ZnO | 24.0 | 24.1 | 22.31 |
| PbO | 59.1 | 58.6 | 61.21 |
| Total | 100.4 | 100.4 | 100.00 |

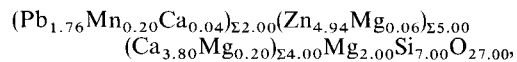
Number of ions on the basis of 4 oxygens

| | | | |
|----|------|------|------|
| Si | 1.01 | 1.02 | 1.00 |
| Ca | 0.01 | 0.01 | |
| Zn | 1.04 | 1.03 | 1.00 |
| Pb | 0.93 | 0.92 | 1.00 |

*---Theoretical composition for PbZnSiO₄.

Accuracy of data: ±4 percent of the amount present.

material. Presuming Mg is essential to this mineral, a rational formula can be calculated on the basis of Si = 7 atoms and yields (after cation assignment on the basis of ionic radii), the formula



or ideally, $\text{Pb}_2\text{Zn}_5\text{Ca}_4\text{Mg}_2\text{Si}_7\text{O}_{27}$.

Another unknown phase was noted within esperite by Ito (1968) and this mineral is a Ca–Zn silicate, which Ito reported as thin seams, 1–5 μm in width, lining fractures in esperite. This phase was not observed in this study.

The restricted assemblage

Unlike the esperite assemblage, which was moderately widespread as noted above, the other lead silicate minerals occurred in a very limited area of the mine known as the Palmer shaft pillar area. Unfortunately, their spatial distribution within that area remains largely unknown. Comparison of many hundreds of specimens in public and private collections indicates that for discussion purposes, the restricted assemblage can be subdivided into two parts:

A *margarosane* assemblage consisting of margarosane, $\text{Pb}(\text{Ca},\text{Mn})_2\text{Si}_3\text{O}_9$; barysilite, $\text{Pb}_8\text{Mn}(\text{Si}_2\text{O}_7)_3$; ganomalite, $\text{Pb}_9\text{Ca}_5\text{MnSi}_9\text{O}_{33}$; and nasonite, $\text{Pb}_6\text{Ca}_4\text{Si}_6\text{O}_{21}\text{Cl}_2$, together with other non-Pb-bearing phases described below. In this assemblage all the Pb-bearing phases are anhydrous. However, the dominant associated phases do contain hydroxyl.

A *roebingite* assemblage consisting of roebingite, $\text{Pb}_2\text{Ca}_6(\text{SO}_4)_2(\text{OH})_2(\text{H}_2\text{O})_4[\text{Mn}(\text{Si}_3\text{O}_9)_2]$, (Moore and Shen, 1984; Braithwaite, 1985; Dunn *et al.*, 1982), and hancockite, $\text{PbCa}(\text{Al}, \text{Fe}^{3+})_3(\text{SiO}_4)_3(\text{OH})$, together with numerous other phases, some of which are highly hydrated phases such as charlesite (Dunn *et al.*, 1983a), and ganophyllite (Dunn *et al.*, 1983b).

The margarosanite assemblage

Margarosanite, $\text{PbCa}_2\text{Si}_3\text{O}_9$, is one of the two most common lead silicate minerals in this assemblage; the other is nasonite. Margarosanite is associated with most of the accessory calcium silicate phases, including andradite, manganaxinite, prehnite, rhodonite, johannsenite, and a large number of other species including, in part, bustamite, vesuvianite, baryte, grossular, willemite, and microcline. Margarosanite occurs in a variety of textures, but the majority of samples consist of thin, wispy aggregates. The most commonly associated minerals are prehnite, microcline (non-plumbian), and manganaxinite. Margarosanite is also intimately associated with minehillite, $(\text{K}, \text{Na})_{2-3}(\text{Ca}, \text{Mn}, \text{Fe}, \text{Mg}, \text{Zn})_{28}[\text{Zn}_4\text{Al}_4\text{Si}_{40}\text{O}_{112}](\text{OH})_{12}$, a new phase related to reyerite (Dunn *et al.*, 1984), and is found in apparent chemical equilibrium with more phases than the other lead silicates, except nasonite.

Table V. Microprobe analyses of margarosanite

| | C6153 | R6455 | C6412-5 | 143608 | C6328 | Theory* |
|---|-------|-------|---------|--------|-------|---------|
| SiO_2 | 34.3 | 34.9 | 34.6 | 34.3 | 35.1 | 34.98 |
| PbO | 45.2 | 44.9 | 47.5 | 47.4 | 44.6 | 43.27 |
| CaO | 20.2 | 20.5 | 20.8 | 21.0 | 20.6 | 21.75 |
| MnO | 0.4 | 0.6 | 0.4 | 0.2 | 0.6 | |
| FeO | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | |
| ZnO | 0.6 | 0.6 | 0.7 | 0.8 | 0.4 | |
| Total | 100.7 | 101.6 | 104.1 | 103.8 | 101.4 | 100.00 |
| <u>Number of ions on the basis of 9 oxygens</u> | | | | | | |
| Si | 3.00 | 3.00 | 2.96 | 2.95 | 3.00 | 3.00 |
| Pb | 1.06 | 1.04 | 1.09 | 1.10 | 1.03 | 1.00 |
| Ca | 1.89 | 1.88 | 1.91 | 1.93 | 1.89 | 2.00 |
| Mn | 0.03 | 0.04 | 0.03 | 0.01 | 0.04 | |
| Fe | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | |
| Zn | 0.03 | 0.04 | 0.04 | 0.05 | 0.03 | |

* --Theoretical composition for $\text{PbCa}_2\text{Si}_3\text{O}_9$.
Accuracy of data: ± 4 percent of the amount present.

The chemical composition of margarosanite from these various assemblages is fairly constant. Microprobe analyses of some of these samples are presented in Table V. The minor amounts of Fe, Mn, and Zn proxying for Ca are very small; most samples approach end-member composition.

Barysilite, $\text{Pb}_8\text{Mn}(\text{Si}_2\text{O}_7)_3$, is apparently less common than nasonite or margarosanite. It occurs as platy, subparallel crystals in lamellar aggregates. It is a late-stage mineral in part, but also forms coarse-grained assemblages with some of the calcium silicate minerals at Franklin, including andradite, manganaxinite, nasonite, rhodonite, and others. As a late-stage mineral, it frequently occurs as a crack-filler in fractured silicates, johannsenite being a notable example. Barysilite also is the dominant phase in a coarse-grained willemite-andradite-barysilite breccia, and is found in thin seams and on slickensides. Aside from very limited associations with hancockite and margarosanite, barysilite occurs consistently with only one of the lead silicates, nasonite. Microprobe analyses of barysilite are presented in Table VI, where it can be seen that the composition of barysilite is remarkably uniform.

Ganomalite was first reported from Franklin by Dunn (1979) and it remains a rare mineral from this deposit; only a few specimens are known. It occurs as euhedral crystals within coarsely crystallized clinohedrite, $\text{CaZnSiO}_3(\text{OH})_2$, which fills vugs in willemite-franklinite-andradite ore. In this assemblage, ganomalite co-exists with nasonite, a species with which ganomalite was formerly thought to be

Table VI. Microprobe analyses of barysilite.

| | C6391 | C6390 | C6392 | 139290 | R8823 | Theory* |
|--|-------|-------|-------|--------|-------|---------|
| SiO_2 | 16.7 | 17.1 | 17.3 | 17.5 | 17.6 | 16.27 |
| PbO | 79.0 | 78.4 | 78.7 | 78.0 | 77.5 | 80.53 |
| MnO | 3.8 | 3.7 | 3.6 | 3.5 | 3.8 | 3.20 |
| CaO | 0.5 | 0.6 | 0.5 | 0.7 | 1.0 | |
| Total | 100.0 | 99.8 | 100.1 | 99.7 | 99.9 | 100.00 |
| <u>Number of ions on the basis of 21 oxygens</u> | | | | | | |
| Si | 6.00 | 6.08 | 6.12 | 6.16 | 6.12 | 6.00 |
| Pb | 7.65 | 7.50 | 7.49 | 7.38 | 7.26 | 8.00 |
| Mn | 1.16 | 1.11 | 1.08 | 1.04 | 1.12 | 1.00 |
| Ca | 0.19 | 0.23 | 0.19 | 0.26 | 0.38 | |

*--Theoretical composition for $\text{Pb}_8\text{Mn}(\text{Si}_2\text{O}_7)_3$.
Accuracy of data: ± 4 percent of the amount present.

isostructural. Because these two minerals are in contact, in euhedral crystals in apparent chemical equilibrium, and because microprobe analyses of ganomalite from Franklin and Jacobsberg in Sweden showed that all samples had consistent amounts of Mn, Dunn *et al.* (1985) showed that ganomalite has essential Mn, and has space group *P*3, with *a* = 9.82 and *c* = 10.13 Å. The revised chemical formula for ganomalite is $\text{Pb}_9\text{Ca}_5\text{MnSi}_9\text{O}_{33}$.

Nasonite, $\text{Pb}_6\text{Ca}_4\text{Si}_6\text{O}_{21}\text{Cl}_2$, is the only halogen-bearing lead silicate mineral at Franklin. Its chlorine content is relatively invariant and its chemical composition is very close to the theoretical composition, as evidenced by the microprobe analyses presented in Table VII. *Nasonite* occurs with more species than any other lead silicate mineral from Franklin. It was present in many of the samples examined. Although *nasonite* occurs with mostly high-temperature phases, it is usually the last-formed mineral present in such assemblages; for example, it occurs as interstitial fillings in radial *johannsenite*. No other Cl-bearing minerals are known from the lead silicate assemblages.

The roeblingite assemblage

The second of the restricted assemblages is one which is notable for the presence of a number of

Table VII. Microprobe analyses of *nasonite*

| | C6225 | C6229 | C6408 | R9292 | Theory* |
|--|-------|-------|-------|-------|---------|
| SiO ₂ | 19.1 | 19.0 | 19.2 | 18.9 | 18.23 |
| CaO | 12.6 | 12.9 | 12.7 | 13.0 | 11.33 |
| FeO | tr. | tr. | 0.3 | tr. | |
| MnO | tr. | tr. | 0.3 | tr. | |
| PbO | 65.8 | 66.0 | 64.8 | 66.0 | 67.67 |
| Cl | 3.0 | 3.0 | 3.4 | 3.5 | 3.60 |
| O=Cl | 0.7 | 0.7 | 0.8 | 0.8 | 0.81 |
| Total | 99.8 | 100.2 | 99.9 | 99.9 | 100.00 |
| Number of ions on the basis of 23 (O + Cl) | | | | | |
| Si | 6.11 | 6.06 | 6.07 | 6.00 | 6.00 |
| Ca | 4.31 | 4.41 | 4.30 | 4.42 | 4.00 |
| Fe | 0.00 | 0.00 | 0.08 | 0.00 | |
| Mn | 0.00 | 0.00 | 0.08 | 0.00 | |
| Pb | 5.56 | 5.67 | 5.52 | 5.64 | 6.00 |

*--Theoretical composition for $\text{Pb}_6\text{Ca}_4\text{Si}_6\text{O}_{21}\text{Cl}_2$.

Accuracy of data: ± 4 percent of the amount present.

Table VIII. Microprobe analyses of *hancockite*.

| | Original analysis†† | C6420-1 | C6420-2 | C6420 | Theory* |
|--|---------------------|---------|---------|-------|---------|
| SiO ₂ | 30.99 | 29.1 | 28.9 | 28.9 | 27.73 |
| Al ₂ O ₃ | 17.99 | 16.3 | 16.2 | 14.5 | 15.68 |
| Fe ₂ O ₃ | 12.33 | 14.5 | 14.4 | 14.2 | 12.28 |
| Mn ₂ O ₃ ** | 1.38 | 2.7 | 2.5 | 2.5 | |
| CaO | 11.50 | 10.0 | 9.6 | 9.9 | 8.62 |
| SrO | 3.89 | 3.6 | 3.0 | 2.4 | |
| PbO | 18.53 | 26.3 | 26.6 | 29.3 | 34.32 |
| MnO | 2.12 | ** | ** | ** | |
| MgO | 0.52 | tr. | tr. | tr. | |
| H ₂ O | 1.62 | 1.37† | 1.37† | 1.37† | 1.37 |
| Total | 100.77 | 103.9 | 102.6 | 103.1 | 100.00 |
| Number of ions on the basis of 8 cations | | | | | |
| Si | 2.93 | 2.87 | 2.89 | 2.95 | 3.00 |
| Al | 2.00 | 1.89 | 1.91 | 1.74 | 2.00 |
| Fe ³⁺ | 0.88 | 1.08 | 1.09 | 1.09 | 1.00 |
| Mn ³⁺ | 0.10 | 0.20 | 0.19 | 0.20 | |
| Ca | 1.17 | 1.06 | 1.03 | 1.08 | 1.00 |
| Sr | 0.21 | 0.20 | 0.17 | 0.14 | |
| Pb | 0.47 | 0.70 | 0.72 | 0.80 | 1.00 |
| Mn ²⁺ | 0.17 | 0.00 | 0.00 | 0.00 | |
| Mg | 0.07 | 0.00 | 0.00 | 0.00 | |
| H | 1.02 | 0.90 | 0.91 | 0.93 | 1.00 |
| Σ3 ⁺ ions + Si | 5.91 | 6.04 | 6.08 | 5.98 | 6.00 |

*-- Theoretical composition for $\text{CaPbFe}^{3+}\text{Al}_2(\text{SiO}_4)_3(\text{OH})$.

**-- Oxidation state of Mn calculated as described in text.

†-- Water from theoretical composition.

††-- Analysis by Warren in Penfield and Warren (1899).

Ba and Zn present only as traces in analyses of this study. Accuracy of data: ± 5 percent of the amount present; tr. = trace

phases with (OH) and H₂O, brecciated and vuggy textures, and containing *roeblingite* and *hancockite* as the lead silicate minerals.

Roeblingite, formerly considered to be $\text{Pb}_2\text{Ca}_7\text{O}_{14}(\text{OH})_{10}(\text{SO}_4)_2$, was redefined by Dunn *et al.* (1982) as $(\text{Ca},\text{Sr})_2(\text{Mn},\text{Ca})_2\text{Pb}_4(\text{SO}_4)_4\text{Si}_{12}\text{O}_{28}(\text{OH})_{20}$, on the basis of analyses of material from Franklin and Långban, Sweden. More recently, Braithwaite (1985) has shown, using TGA and infra-red spectra, that *roeblingite* contains H₂O in appreciable amounts, and that not all H is present as hydroxyl. This supports the structural formula, $\text{Pb}_2\text{Ca}_6(\text{SO}_4)_2(\text{OH})_2(\text{H}_2\text{O})_4[\text{Mn}(\text{Si}_3\text{O}_9)_2]$, of Moore and Shen (1984). At Franklin, *roeblingite* occurs as porcelaneous, massive, very fine-grained, irregular, 1–15 cm aggregates of lenticular or roughly spherical shape. It is also found with *willemite* as vein-fillings. The more common spherical aggregates are frequently enclosed in a fine-grained and altered mixture of *prehnite* and *hancockite*, with minor *andradite* and *franklinite*, and sparse *xonotlite*. Some assemblages, with small (2–10 mm) *roeblingite* segregations are associated with *manganaxinite*, *barite*, and other species. The

rarest of the roeblingite assemblages is that associated with charlesite and ganophyllite; it was described in detail by Dunn *et al.* (1983a).

Hancockite is a Pb-bearing member of the epidote group, in which half of the Ca is replaced by Pb and Sr. Some Mn^{3+} apparently substitutes for Al and Fe^{3+} in small amounts. Microprobe analyses of hancockite are presented in Table VIII, together with the original analysis of Warren in Penfield and Warren (1899). For the microprobe analyses, total Mn was calculated as Mn^{3+} in part because Mn^{3+} was found to be present by Warren, in part because of the strong red colour which is consistent with the absorption of Mn^{3+} in the visible range, and also because the sum of Si, Al, Fe^{3+} , and Mn^{3+} approximates 6 atoms. The idealized chemical formula for hancockite is $CaPb(Al_2Fe^{3+})_{x_3}(SiO_4)_3(OH)$.

Hancockite occurs in massive samples, admixed with andradite, franklinite, and minor manganaxinite. These samples are several kilograms in mass, brick-red in colour, and extremely inhomogeneous at the microprobe level. Hancockite also forms in vuggy recrystallized aggregates, intimately associated with clinohedrite, roeblingite, manganaxinite and prehnite, with minor amounts of willemite, clinohedrite, baryte, franklinite, and hendricksite; the preponderance of studied material is of this nature. The microprobe analyses presented in Table VIII were obtained from euhedral, bright red, recrystallized crystals of secondary generation.

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