ETTRINGITE FROM FRANKLIN, NEW JERSEY*

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Abstract

Ettringite at Franklin, New Jersey occurs as white to colorless crystals 2–3 millimeters across with the only crystal form $\{10\bar{1}2\}$. The axial ratio determined from their measurement is $a:c=1:0.9554$. Specific gravity is 1.77 (meas); 1.79 (cal). Perfect $\{10\bar{1}0\}$ cleavage. Optically $(-)$, $\omega=1.491$, $\epsilon=1.470\pm0.001$. After heating to 110° C, optically $(+)$, $\omega=1.538$ $\epsilon=1.541$. Chemical analysis: CaO 27.3, Al$_2$O$_3$ 5.1, SiO$_2$ 3.1, SO$_3$ 12.8, B$_2$O$_3$ 3.2, H$_2$O 48.6, Total 100.1. A general formula can be written: $Ca_6(Si, Al, B)_3(SO_4)_2(O, OH)_{12}(OH)_4\cdot26H_2O$ of which there are 8 formula weights per unit cell. The unit cell dimensions are $a_0=22.28$ Å, $c_0=21.29$ Å giving a ratio $a_0:c_0=1:0.9556$.

Introduction and Occurrence

During the latter part of 1945 an occurrence of unusual minerals was encountered in the Franklin mine of The New Jersey Zinc Company at Franklin in Sussex County, New Jersey. Immediately above the 800 ft. level, about 15 feet in the ore from the hanging wall, and close to the north side of the Palmer shaft pillar, the occurrence was noticed by the miners and called to the attention of the geologist. Specimens were collected for eventual study from the vein system which was arranged in an H pattern and connected with a potash feldspar zone above. The veins, a foot or so wide, consisted largely of andradite garnet and manganophyllite but there were local concentrations of hancockite near the floor and of other silicates and native copper closer to the feldspar above. The silicates such as roeblingite, hancockite, clinohedrite, xonotlite, rhodonite, thompsonite and datolite post date emplacement of the feldspar and represent a reworking of the adjacent veins by solutions which have corroded cavities and formed spongy zones in the garnet-mica vein system. Fig. 1.

Conspicuous among the crystallized minerals in the cavities were white

H HANCOCKITE
G GARNET
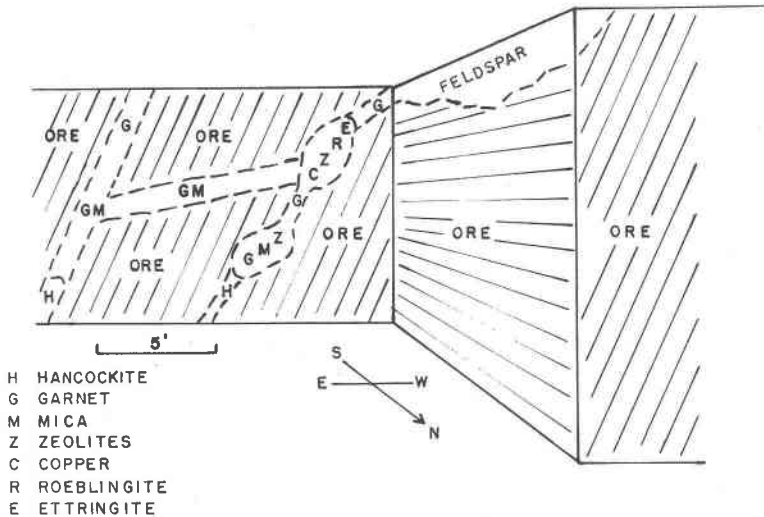M MICA
Z ZEOLITES
C COPPER
R ROEBLINGITE
E ETTRINGITE

Fig. 1. Vein system of banded ore.

to partially clear crystals of ettringite with the only form a low hexagonal dipyramid. Since these crystals were quite unlike any other mineral described from Franklin, they were not immediately identified. The most spectacular specimens show a surface of minute light brown muscovite crystals coating the cavities in garnet-manganophyllite vein rock. On this surface clinohedrite crystals nearly a half inch in diameter are accompanied by white tufts of thompsonite and crystals of ettringite attached by an edge. Subsequently additional material came to light elsewhere in the mine and was collected for its fluorescence due to admixed clinohedrite. Crystals of ettringite in the second occurrence completely coated the 2 inch by 4 inch surface preserved, but they are etched and unsuited for measurement.

PHYSICAL PROPERTIES

The Franklin ettringite has as the only crystal form the flattened hexagonal dipyramid, $\{10\bar{1}2\}$, (Fig. 2). This is a habit heretofore not described for ettringite, although the form was observed by Lehmann (1874) and noted in the original description of the mineral. The largest crystals are 4 millimeters across whereas the average size is between 2 and 3 millimeters. A few are colorless and transparent and give excellent signals on the reflecting goniometer but most are milky white with etched and pitted faces. The measured ρ angle of $\{10\bar{1}2\}$ is 28°53′ giving an axial ratio of $a:c=1:0.9554$. This compares well with an axial ratio of $a_0:c_0=1:0.9556$ derived from x-ray measurements.
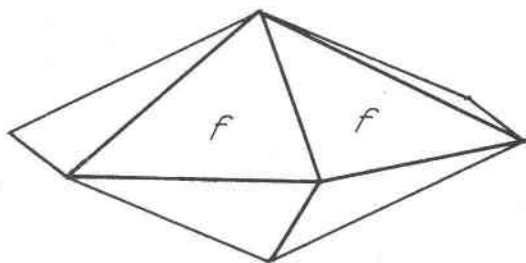
FIG. 2. Ettringite crystal.

The specific gravity of the Franklin ettringite is 1.77 as measured by the suspension method in a mixture of bromoform and acetone. (Calculated specific gravity, 1.79.) There is perfect $\{10\overline{1}0\}$ cleavage. The optical properties are at greater variance from published data than the other physical properties and are shown in Table 1 compared with those of ettringite from Scawt Hill and Ettringen. The indices of refraction of the Franklin mineral were obtained on colorless crystals; those of white crystals are slightly higher.

Both the refractive indices and birefringence of the Franklin ettringite are considerably greater than ettringite from Scawt Hill and Ettringen. Larsen and Berman (1934) give the indices of refraction as $\omega = 1.488$, $\epsilon = 1.474$ which Bannister (1936) suggests were probably obtained on partially dehydrated material. This seems unlikely for as the mineral dehydrates ϵ increases more rapidly than ω and the birefringence becomes less. Although the source of the Larsen and Berman material is unknown,

TABLE 1. OPTICAL PROPERTIES OF ETTRINGITE

Locality	1 Franklin	2 Scawt Hill	3 Ettringen	4 Synthetic
ω	1.491 ⎫ ±0.001	1.4655	1.4661	1.464
ϵ	1.470 ⎭	1.4618	1.4612	1.458
	uniaxial	uniaxial	uniaxial	uniaxial
	$(-)$	$(-)$	$(-)$	$(-)$
		After heating to 110° C.		
ω	1.538	1.50 mean index	1.513	
ϵ	1.541		1.522	
	uniaxial	uniaxial	uniaxial	
	$(+)$	$(+)$	$(+)$	

1. Determined during present study.
2. Bannister (1936) by minimum deviation.
3. Brauns (1922). Indices after heating determined during present study.
4. Lerch, Ashton and Bogue (1929).

it is probable that the indices reported by them were obtained on a mineral approaching the Franklin ettringite in composition.

CHEMICAL COMPOSITION

A chemical analysis of the Franklin ettringite was made by Mr. Jun Ito on 800 milligrams of carefully selected material, mostly colorless crystals. The analysis is compared in Table 2 with earlier analyses.

TABLE 2. CHEMICAL ANALYSIS OF ETTRINGITE

	1. Franklin	2. Scawt Hill	3. Ettringen
CaO	27.3	26.6	27.27
Al_2O_3	5.1	7.0	7.76
SiO_2	3.1		
SO_3	12.8	18.8	16.64
B_2O_3	3.2		
H_2O-	39.4		
H_2O+	9.2	46.3	45.82
CO_2	Trace	0.8	
	—	—	—
Total	100.1	99.5	97.49
Sp.G.	1.770	1.772	1.750

1. Franklin, N. J. Jun Ito *analyst*.

2. Scawt Hill, Antrim County, Ireland, M. H. Hey analyst in Bannister (1936).

3. Ettringen, Germany, Lehmann (1874).

The presence in the Franklin ettringite of B_2O_3 and SiO_2 and lesser amounts of Al_2O_3 and SO_3 than in other ettringite argue that this mineral might be regarded as a new species. However, since in all its crystallographic and physical properties it corresponds to those of ettringite, it seems wise to consider it a variety rather than a new mineral.

The formula for the Franklin ettringite, adhering closely to the chemical analysis can be written expressing the content of the unit cell as follows:

$$Ca_{48}[SiO_3(OH)]_5[Al(OH)_4]_{10}[B(OH)_4]_9[SO_4]_{16}[(OH)_4]_8 \cdot 208H_2O$$
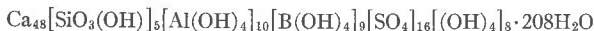
The following general formula for the Franklin mineral (1) for which there are 8 formula weights per unit cell compares with the accepted formula of ettringite (2) as:

1. $Ca_6(Si, Al, B)_3(SO_4)_2(O, OH)_{12}(OH)_4 \cdot 26H_2O$

2. $Ca_6 \quad Al_2 \quad (SO_4)_3 \quad\quad (OH)_{12} \cdot 26H_2O$

X-ray Study

Both rotation and Weissenberg x-ray photographs were taken with the crystal rotating about the c axis and a horizontal axis normal to the $\{10\bar{1}0\}$ cleavage. The rotation photograph about c corresponded spot for spot with the classic rotation photograph of ettringite from Scawt Hill, County Antrim, Ireland first published by Bragg and Bragg (1933), and later by Bannister (1936) and by Bragg (1937). The spots of this photo-

TABLE 3. Unit Cell Dimensions of Ettringite

	1 Franklin	2 Scawt Hill[1]	3 Ettringen	4 Synthetic[2]
a_0	22.28 Å	22.47 Å	22.46 Å	22.46 Å
c_0	21.29	21.46	21.42	21.44
c_0/a_0	0.9556	0.9551	0.9537	0.9546

[1] The unit cell dimensions for ettringite given by Bannister (1936) were $a_0 = 11.26$ Å, $c_0 = 21.48$ Å (kX converted to angstrom units) determined by the rotation method.

[2] The unit cell dimensions for synthetic ettringite were determined by the powder method, Bureau of Standards (1958), as $a_0 = 11.23$ Å $c_0 = 21.44$ Å.

graph (Scawt Hill) are elongated parallel to the rotation axis, whereas the spots on the photograph of the Franklin mineral are sharp. The rotation photograph of a Franklin crystal rotating about the $[10\bar{1}0]$ axis gave well defined layer lines, measurement of which yielded an identity period along the axis of 19.27 Å; $(d_{10\bar{1}0})$. Using this value the length of the a axis was determined as 22.25 Å; roughly twice the length reported by Bannister.

Because of the identity of the c axis rotation photographs of the Franklin and Scawt Hill material, it seemed reasonable to assume that the unit cell dimensions would be similar. Professor C. E. Tilley kindly furnished a cleavage fragment of Scawt Hill ettringite for examination. A rotation photograph about $[10\bar{1}0]$ yielded $d_{10\bar{1}0}$ slightly greater than that given by the Franklin mineral.

A specimen of ettringite from Ettringen, the original locality, was kindly loaned the authors by Professor Joseph Murdoch. Professor Murdoch obtained this specimen from Dr. Hanswilhelm Beil of Göttingen for the purpose of comparing it with a mineral from Crestmore, California suspected of being ettringite. X-ray photographs of the Ettringen mineral also yielded an a_0 similar to that of the Franklin ettringite. From this evidence one must conclude that the a axis of ettringite is approxi-

mately twice that given by Bannister (1936) resulting in a unit cell of four times the volume. It is interesting to note that Lehmann (1874) and Brauns (1922) gave indices for the crystal forms observed by them that are compatible with the doubling of the a axis.

In Table 3 the unit cell dimensions of ettringite from Franklin, Scawt Hill, and Ettringen are given determined from O-layer line Weissenberg photographs made during the present study.

TABLE 4. d SPACINGS OF ETTRINGITE

Copper radiation, nickel filter

hkil	Franklin				Synthetic Nat. Bu. Standards	
	Measured			Calculated	Measured	
	d, Å	I		d, Å	d, Å	I
20$\bar{2}$0	9.65	10		9.648	9.73	10
22$\bar{4}$0	5.58	8		5.570	5.61	8
22$\bar{4}$2	4.93	2		4.935	4.98	2
20$\bar{2}$4	4.65	3		4.660	4.69	4
22$\bar{4}$4	3.84	5		3.848	3.88	5
42$\bar{6}$2	3.44	4		3.449	3.48	3
60$\bar{6}$0	3.21	6		3.216	3.24	2
60$\bar{6}$4	2.75	1		2.756	2.77	4
62$\bar{8}$2	2.59	3		2.595	2.62	2
42$\bar{6}$6	2.54	4		2.543	2.56	5
44$\bar{8}$6	2.19	2		2.190	2.21	4

The unit cell dimensions of the Franklin ettringite are smaller than those of the mineral from other localities. These undoubtedly reflect the substitution of boron and silicon for sulfur and aluminum. The smaller dimensions are also shown in the d spacings of Table 4. This table lists only the stronger lines. A complete list of d spacings is given by the National Bureau of Standards (1959). In Table 4 the indices of the National Bureau of Standards data are changed to conform with a doubling of the a axis.

The space group of ettringite was determined as $P6_3/mmc$, the same as given by Bannister (1936). The calculated specific gravity of the Franklin ettringite is 1.79. The specific gravity of 8 $[Ca_6Al_2(SO_4)_3(OH)_{12} \cdot 26H_2O]$ calculated by the NBS (1959) using their lattice constants is 1.754 at 25° C.

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