ART. XXX.—*Contributions to the Crystallization of Willemite;* by S. L. PENFIELD.

As far as known willemite is a mineral of rare occurrence. The manganese variety, troostite, is found at Franklin, Sussex Co., New Jersey, in sufficient quantity to make it a valuable ore of zinc. It also occurs sparingly at the Merritt mine, Socorro Co., New Mexico, an analysis and description of it having been given by Prof. F. A. Genth.* In the summer of 1891, while collecting for the U. S. Geological Survey, the writer found a well crystallized specimen on the dump of the Sedalia Copper Mine, near Salida, Chaffee Co., Colorado and, as far as known, these three are the only localities for the mineral in the United States.

Our knowledge of the crystallization of willemite is limited to a description by A. Levy† of the simple crystals from Moresnet near Altenberg and to measurements with the contact goniometer of the large troostite crystals from New Jersey by E. S. Dana‡ and Des Cloizeaux.§ From the similarity of the rhombohedral angles of willemite, Zn_2SiO_4 and phenacite Be_2SiO_4 it has been assumed by Groth‖ that willemite probably crystallizes like the latter in the rhombohedral-tetartohedral division of the hexagonal system, but no crystals have ever been described which were sufficiently modified to show the tetartohedrism.

Willemite from the Merritt Mine, New Mexico.

Through the kindness of Mr. Geo. W. Fiss of Philadelphia, Pa., the author has been supplied with a suite of specimens containing crystals suitable for measurement on the reflecting goniometer. The crystals are colorless, transparent and measure on the average about $0{\cdot}5^{mm}$ in greatest diameter. Some exhibit a dark center with transparent exterior, or with simply the extremities of the prism clear. The crystals occur as aggregations or as druses lining cavities in the rock. The forms which have been identified are:

c, 0001, O	e, $01\bar{1}2$, $-\frac{1}{2}$
a, $11\bar{2}0$, i-2	u, $2\bar{1}\bar{1}3$, $\frac{2}{3}$-$2l$ or $\frac{\frac{2}{3}P2}{4}\frac{l}{r}$
r, $10\bar{1}1$, 1	v, $\bar{1}3\bar{2}5$, $-\frac{1}{5}{}^3r$ or $-\frac{\frac{3}{5}P\frac{3}{2}}{4}\frac{r}{l}$
z, $01\bar{1}1$, -1	

* Proc. Am. Phil. Soc., xxiv, p. 43, 1887. † Ann. Mines, iv, p. 513, 1843.
‡ System of Min., Sixth Edition, p. 460.
§ Manuel de Minéralogie. 1862, p. 43.
‖ Tabellarische Uebersicht der Mineralien, 1889, p. 111.

Figures 1 and 2 represent the ordinary developments of the faces. The rhombohedron of the second order, *u* was ob-

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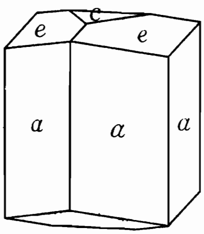

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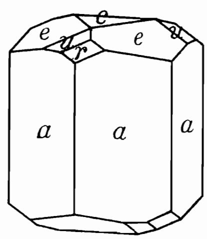

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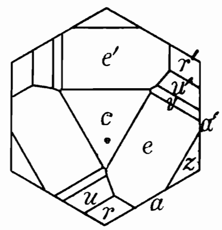

served intersecting both extremities of the vertical axis and always in the position required by rhombohedral tetartohedrism. The rhombohedrons *z* and *v* are of rare occurrence. All of the forms which have been observed are represented in the basal projection, fig. 3. Among a suite of specimens from this locality in the cabinet of the late Prof. F. A. Genth, sent to the writer by Dr. F. A. Genth, Jr., only the simple combination of prism and basal plane was observed.

The crystals are brilliant and give good reflections, but the faces are commonly vicinal, which renders the measurements somewhat uncertain. There was a decided tendency for the basal plane to develop into a flat vicinal rhombohedron, while the prism seemed always to be slightly warped or twisted. Although the measurements of similar angles show a considerable variation, the best of them, judging from the character of the signals, agree closely with the values calculated from the fundamental measurement of Lévy, $p \wedge p$, $30\bar{3}4 \wedge 03\bar{3}4 = 51° 30'$. It was decided, therefore, to retain his axial ratios, $a : c = 1 : 0{\cdot}6696$.

The following is a list of some of the calculated and measured angles.

		Calculated.	Average measurement.	Number of times measured.	Limits.
$c \wedge e$,	$0001 \wedge 01\bar{1}2$	= 21° 8′	21° 6′	11	20° 40′–21° 28′
$e \wedge e'$,	$01\bar{1}2 \wedge \bar{1}012$	= 36 23	35 48	11	35 5–36 24
$a \wedge e$,	$11\bar{2}0 \wedge 01\bar{1}2$	= 71 48	71 39	7	71 14–71 57
$r \wedge e$,	$10\bar{1}1 \wedge 01\bar{1}2$	= 31 59	32 2	7	31 36–32 38
$r \wedge e'$,	$10\bar{1}1 \wedge \bar{1}012$	= 58 51	58 45	2	58 25–59 5
$c \wedge r$,	$0001 \wedge 10\bar{1}1$	= 37 42½	37 56	1	
$c \wedge z$,	$0001 \wedge 01\bar{1}1$	= 37 42½	37 57	1	
$e \wedge u'$,	$01\bar{1}2 \wedge \bar{1}2\bar{1}3$	= 11 45½	11 25	3	11 21–11 27
$e \wedge u$,	$01\bar{1}2 \wedge 2\bar{1}\bar{1}3$	= 31 36	31 51	1	
$c \wedge u$,	$0001 \wedge 2\bar{1}\bar{1}3$	= 24 3	23 24	1	
$u \wedge u'$,	$2\bar{1}\bar{1}3 \wedge \bar{1}2\bar{1}3$	= 41 20	40 49	1	
$e \wedge v$,	$01\bar{1}2 \wedge \bar{1}3\bar{2}5$	= 7 7	7 23	1	

Willemite from the Sedalia Mine, Salida, Colorado.

At this locality it was observed in transparent, colorless crystals up to 3^{mm} in diameter, having the habit shown in fig. 4. The mineral was identified by its blowpipe reactions and the following measurements:

	Measured.	Calculated.
$e \wedge e$, $1\bar{1}02 \wedge 01\bar{1}2 =$	35° 35′	36° 23′
$a \wedge e$, $\bar{1}2\bar{1}0 \wedge 01\bar{1}2 =$	71 42	71 48

The crystal faces are warped and striated and on some of them low, vicinal prominences are developed, which are unsymmetrical with reference to the rhombohedron *e* and indicate clearly that the crystals are tetartohedral. When mounted in Canada balsam these rather flat crystals show with convergent polarized light a normal uniaxial interference figure, and a strong positive double refraction.

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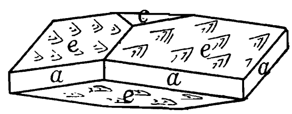

Willemite or Troostite from Franklin, N. J.

The crystals from this locality, which are commonly found imbedded in calcite, are usually rather coarse and show simple combinations of *a*, $11\bar{2}0$; *r*, $10\bar{1}1$; *e*, $01\bar{1}2$ and *c*, 0001. In the private collection of Mr. Frederick A. Canfield of Dover, N. J., there are, however, two specimens which are worthy of special description, as the crystals exhibit combinations which are very unusual for the Franklin mines and are also beautiful illustrations of rhombohedral-tetartohedrism. These specimens were kindly loaned to the writer, who takes this opportunity of expressing his thanks to Mr. Canfield.

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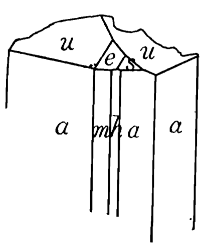

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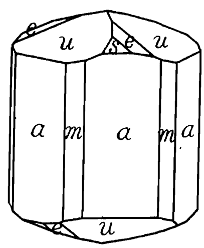

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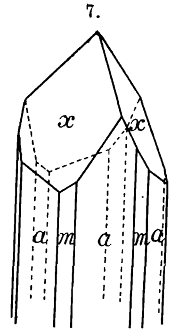

On one specimen there were several nearly transparent, green prisms, attached to a gangue of massive willemite and franklinite. One of these, about 30^{mm} long by 20^{mm} in diameter, was so attached that only a part of its faces were developed, which are represented in about their natural proportion in fig. 5. The prominent rhombohedron u is of the second order, and if it corresponds in position to u in the New Mexico willemite, $2\bar{1}\bar{1}3$, $\frac{2}{3}$-$2l$, then the terminal faces are those of the lower, instead of the upper end of the crystal,* and if symmetrically developed would appear as in fig. 6. The rhombohedron s is $11\bar{2}3$, $\frac{2}{3}$-$2r$ and e is $01\bar{1}2$, $-\frac{1}{2}$. The prisms are of the first order m, of the second order a and of the third order h, $3\bar{1}\bar{2}0$, i-$\frac{3}{2}l$, although the symbol of the latter is uncertain, as satisfactory measurements could not be made.

The second specimen contained long prisms of nearly transparent, pale-green willemite, imbedded in a pink manganiferous calcite. Only one of these, measuring about 6^{mm} in diameter, was well terminated, fig. 7. The rhombohedron x is of the third order and has the symbol $3\bar{1}\bar{2}1$, 1^3l or $\frac{3P\frac{3}{2}}{4}\ \frac{l}{r}$. The prismatic faces are bright but the rhombohedron is dull so that measurements were made only with a contact goniometer, as follows:

	$a \wedge x$, $2\bar{1}\bar{1}0 \wedge 3\bar{1}\bar{2}1$	$a \wedge x$, $11\bar{2}0 \wedge 3\bar{1}\bar{2}1$	$x \wedge x$, $3\bar{1}\bar{2}1 \wedge \bar{2}3\bar{1}1$
Measured ----	$28\frac{1}{2}°$	$54\frac{1}{2}°$	102°
Calculated --	28 5′	53 59′	102 10′

This interesting and very unusual combination of prisms terminated only by a rhombohedron of the third order is similar to that exhibited by some of the phenacite crystals from Mt. Antero, Colorado.†

On the cleavage of Willemite.

Statements are made by various authors that willemite has a distinct basal cleavage, while the manganese variety, troostite, cleaves parallel to a prism of the second order, and this variation, together with the differences in crystalline habit and chemical composition have been cited as grounds for regarding the two minerals as distinct species.

During the course of this investigation the subject of cleavage has been carefully considered. On the crystals from Moresnet either a basal or a prismatic cleavage may be produced by placing a knife blade in appropriate positions on the crystals and pressing until they break. The cleavages are poor, they can scarcely be called distinct and both are about equally perfect, although, owing to the prismatic shape, the basal is

* Owing to the rhombohedral-tetartohedrism the upper and lower ends of a crystal can not be interchanged without changing the symbols of the faces.

† This Journal, III, xxxvi, p. 320, 1888.

perhaps more easily produced. It was moreover observed that milky, white crystals yielded the basal cleavage more readily than clear, transparent ones. If the crystals are broken without care they usually show only an irregular to conchoidal fracture. The same holds true for the transparent crystals from Franklin, while the ordinary massive specimens usually present only irregular fractures. A good prismatic cleavage, which may occasionally be observed, is perhaps of secondary origin, resulting from pressure. All attempts to produce cleavages on the crystals from Salida and the Merritt mine failed, owing to their shape and small size.

In conclusion, therefore, the author believes that there are no essential differences in cleavage or crystallization between willemite and troostite which warrants their separation into distinct species.

Laboratory of Mineralogy and Petrography,
Sheffield Scientific School, November, 1893.