Art. XXXVII.—*A Crystallographic Study of Millerite*; by Charles Palache and H. O. Wood.

The crystallographic character of millerite was first defined by Miller in 1835 in a paper* interesting historically as containing the first presentation of his index system of notation. He determined the forms *o*, (0001), *b*, (10$\bar{1}$0), *k*, (21$\bar{3}$0), *e*, (01$\bar{1}$2), *r*, (10$\bar{1}$1), r_1, (01$\bar{1}$1) and *v*, (50$\bar{5}$2) on crystals without natural terminations, but which had been broken across. And on a single terminated crystal with dull faces, he found the form *t*, (03$\bar{3}$1) by contact measurement. The angle $o \wedge r = 20° 50'$ was the average of several readings, and led to the axial ratio a : c = 1 : 0·3295 which is at present accepted. In the lack of details as to faces and measurements, we are forced to conclude that he, at that time, considered five kinds of cleavage present, parallel to *o*, *e*, *r*, r_1, and *v*. In his Mineralogy† the matter is presented somewhat differently. The prism *a*, (11$\bar{2}$0) is added, and instead of *v*, (50$\bar{5}$2), is given e_1, (10$\bar{1}$2), without explanation. He also states that possibly the appearance of cleavage on both positive and negative rhombohedrons, *r* and r_1 and *e* and e_1, is due to concealed twinning on the vertical axis. The occurrence of the rhombohedron *v*, (50$\bar{5}$2), is therefore left in doubt, and cleavage parallel to the base and to the two rhombohedrons *r* and *e* is indicated.

In 1892, Laspeyres‡ described beyrichite and paramorphs of millerite after beyrichite. He concludes that all millerite is derived from beyrichite, and that for the crystals of both minerals examined, the crystallographic characters are identical. The forms observed were *b*, (10$\bar{1}$0), *a*, (11$\bar{2}$0), *i*, (41$\bar{5}$0), *r*, (10$\bar{1}$1) and *e*, (01$\bar{1}$2); the two last both as cleavages and as dull terminal faces, and each in apparently positive and negative positions through twinning about the vertical axis. The axial ratio a : c = 1 : 0·3277 was derived from measurement of the cleavage rhombohedron.

The form *i*, (41$\bar{5}$0), is based on poor measurements, the average differing by more than a degree from the calculated value, and therefore is to be regarded as very doubtful.

In 1893, the same author in a paper§ on the various nickel deposits of the Rhine, describes various occurrences of millerite. On specimens from two localities, terminated but not measurable crystals were observed, on which *c*, (0001) and *r*, (10$\bar{1}$1) were present together with the ordinary prism forms.

The list of forms known on millerite up to the present time

* Phil. Mag., vi, 104, 1835. † Phillips Mineralogy, 163, 1852.

‡ Zeitschr. f. Kryst., xx, 535, 1892.

§ Das Vorkommen und die Verbreitung des Nickels im Rheinischen Schiefergebirge. Verh. Nat.-hist. Ver. Rheinl., l, 142, 1893.

reads then as follows: *b*, $(10\bar{1}0)$, *a*, $(11\bar{2}0)$, *k*, $(21\bar{3}0)$, *c*, (0001), *e*, $(01\bar{1}2)$, *r*, $(10\bar{1}1)$, and doubtful *i*, $(41\bar{5}0)$, *v*, $(50\bar{5}2)$ and *t*, $(03\bar{3}1)$. Cleavage parallel to *r* and *e* is established.

In the Mineral Cabinet of Harvard University is a suite of specimens derived from the collection of Prof. J. D. Whitney, illustrating the occurrence of millerite, and its associated minerals, at the old Nickel Mine at Orford, Province of Quebec. The beauty, perfection and unusual size of these crystals of millerite led to their study, and examination of the literature revealed the fact that no detailed description of this occurrence existed. Such a description is here presented, since the study of this material has added largely to our knowledge of the crystallography of millerite.

The nickel deposit occurs on the east side of Brompton Lake in Orford Township, Province of Quebec. It consists, as may be gathered from scattered notes in the Canadian Survey Reports, of a large vein chiefly composed of granular white calcite which traverses serpentine. Mingled with the calcite and especially abundant near the vein walls are considerable masses of a bright green chrome-garnet in granular aggregates, and of a light colored diopside, both granular and in long stout crystals. Millerite in grains and prisms is scattered irregularly through the vein matter. The deposit has long been known, and it seems to have been worked for a short time in the seventies, but was abandoned soon, the nickel content of the vein material, less than one per cent, having been too small to pay for extracting.

The specimens in hand consist chiefly of chrome-garnet, partly in granular masses, partly in aggregates of minute individual crystals held together by a cement of calcite, the removal of which with acid causes the mass to crumble. In the latter case, and indeed wherever the garnet is in contact with the calcite, it is in sharp crystals, with the dodecahedron as the dominant form. On a few crystals the dodecahedron edges were truncated by planes, which on measurement proved to be those of two hexoctahedrons, (358) and (459), the latter new to garnet. The faces were extremely narrow and the reflections poor, hence the considerable variations in the position of the faces.

Symbol.		Observed angles (av.).		No. of faces.	Calculated angles.	
Miller.	G_1.	ϕ	ρ		ϕ	ρ
(358)	$\frac{3}{8}\ \frac{5}{8}$	32° 12′	35° 37′	6	30° 58′	36° 05′
(385)	$\frac{3}{5}\ \frac{8}{5}$	21° 00′	60° 08′	5	20° 33′	59° 40′
(583)	$\frac{5}{3}\ \frac{8}{3}$	31° 21′	71° 42′	5	32° 00′	72° 21′
(459)	$\frac{4}{9}\ \frac{5}{9}$	39° 16′	35° 26′	6	38° 39′	35° 26′
(495)	$\frac{4}{5}\ \frac{9}{5}$	23° 36′	62° 43′	5	23° 58′	63° 05′
(594)	$\frac{5}{4}\ \frac{9}{4}$	28° 46′	68° 17′	5	29° 03′	68° 46′

The garnet is green in color, varying from a yellowish tone in massive specimens to a deep emerald-green in the sparkling transparent crystals.

The following analysis by T. Sterry Hunt is taken from Dawson, Geology of Canada, p. 497.

	I.	II.
SiO_2	36·65	
Al_2O_3	17·50	
Cr_2O_3	6·20	6·93
FeO	4·97	4·80
CaO	33·20	33·29
MgO	0·81	
Volatile	0·30	
Total	99·63	

The analysis shows that the garnet is ouvarovite, but with a very small proportion of chromium.

Specks of chromite are embedded in the garnet, in places quite abundantly.

The pyroxene is yellow-gray or pale green, and is either in isolated crystals embedded in calcite, in granular masses consisting almost wholly of this mineral, or in minute crystals implanted on the surface of garnet aggregates. The crystals are prismatic and are often large, up to six or more inches in length. The pinacoids *a*, (100) and *b*, (010) are dominant, and narrow faces of the prisms *m*, (110) and *i*, (130) are always present. These forms always have smooth and brilliant faces; the terminating planes, on the contrary, are always dull and measurements could be obtained only with great difficulty. The forms *p*, ($\bar{1}01$) and *u*, (111) are always present and occasionally minute faces of *c*, (001), *s*, ($\bar{1}11$), and several other pyramids not corresponding to established pyroxene forms were noticed. Twins on the common pyroxene law, (100) the twinning plane, are common. No analysis of this material could be discovered.

The calcite vein-filling is snow-white and very coarsely granular, individual cleavage rhombs up to three inches across being at hand. It is characterized by an extreme development of pressure-twinning parallel to *e*, ($01\bar{1}2$), so that a parting parallel to the negative rhombohedron with smooth reflecting surfaces scarcely inferior to those of the cleavage, is often obtained. The occurrence of this twinning-parting in the calcite is especially noteworthy, since this identical structure is also developed in the millerite, as will be shown presently.

Millerite occurs scattered through the massive garnet, more abundantly at the boundary between garnet or pyroxene and calcite, and finally wholly embedded in calcite. The aggregates of garnet, pyroxene, calcite and millerite are such that no sequence of formation can be recognized, all appearing rather to have crystallized together. When in the massive garnet the millerite is in grains of small size. On contact surfaces as developed by removal of calcite with acid, the millerite is either in short stout prisms loosely implanted on the garnet and projecting into the calcite with developed terminal planes; or it is in long and relatively slender striated prisms, which lie parallel to the garnet surface and adhere to it closely, being bent, twisted and contorted in extraordinary fashion as though, after formation, the crystals had been pressed down

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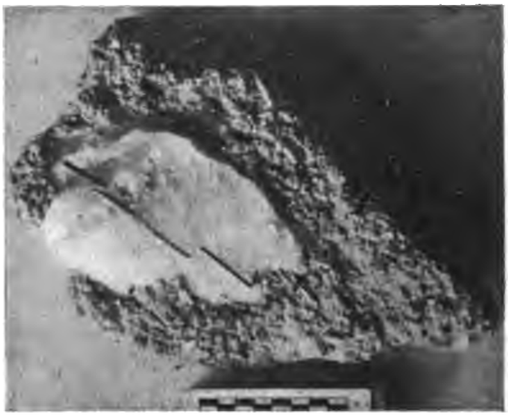

to fit all the irregularities of the uneven underlying surface. Their appearance is unique; and no explanation of their probable mode of formation has occurred to us. So soon as the millerite passes from the immediate contact zone, and is embedded in calcite, the crystals are free from these extreme dislocations; the long prisms are sometimes warped and knicked by pressure-twinning, but entirely lose the crushed appearance as described above. Crystals may be seen crushed and twisted where they lie prone, but which pass into the calcite and become immediately relatively straight and plane-surfaced. The millerite crystals in the calcite reach dimensions quite unusual for this mineral. Prisms two millimeters in diameter and four centimeters long are present among our specimens. They are said to reach a length of eight centimeters or more (three inches). These prisms are generally sharply trigonal in outline, the three faces bright and polished and the angles rounded and striated. No terminated crystals of this type were found, all showing terminal planes of cleavage only. A striking and hitherto unknown character of the mineral was first seen and interpreted on one of the triangular cleavage fragments shown in fig. 2. This crystal consists of three segments, the upper and lower ones parallel, the intermediate portion in twin position to the other two, a face of the form *e*, $(01\bar{1}2)$, being the twinning plane. $10\bar{1}1 \wedge 10\bar{1}0$ (twin), measured 21° 23′½, calculated 21° 25′. The form of the twin suggested that it might be due to the presence of a gliding plane and produced by pressure; and experiment soon showed this to be the case. A crystal held firmly and subjected to shearing stress can be offset readily. The same

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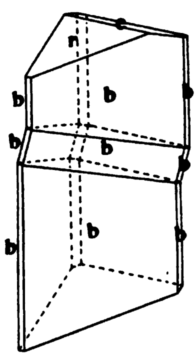

result may be obtained by placing the crystal on a yielding support, and pressing upon it transversely with a knife-edge, in which case a fine lamella is thrown into twin position. The gliding takes place with equal ease, of course, parallel to each of the three rhombohedron planes. With very slender crystals it is difficult to produce the twinning, the pressure breaking the brittle substance to pieces, and this probably accounts for the failure to recognize this remarkable property of millerite hitherto. Careful tests on millerite crystals from a number of localities were uniformly successful, and showed it to be a general property of the mineral. In view of the ease with which this gliding twinning can be obtained, and of the striking effect produced, it seems that millerite should take equal rank with calcite as an illustration of this interesting phenomenon.

Highly perfect cleavage is present parallel to the unit rhombohedron, *r*, $(10\bar{1}1)$, and also to the negative rhombohedron, *e*, (01$\bar{1}$2), the latter identical with the gliding plane. No difference in the quality of the two cleavages can be detected, and planes of both are generally produced when a crystal is broken. No indication of a cleavage parallel to a prism, such as Laspeyres found in millerite derived from beyrichite, was observed.

The Orford millerite is characterized by brilliant metallic luster, and a pale brass-yellow color which is quite constant on all planes and surfaces of the mineral. Laspeyres' conclusion mentioned above, that all millerite is derived from beyrichite, a conclusion based largely on an observed color change, finds absolutely no support in this occurrence.

No analysis of the millerite was made. Careful qualitative tests for copper and cobalt gave only negative results, and it is probably very nearly pure nickel sulphide.

Crystallography.

A number of crystals showing natural terminal planes were obtained from several of the specimens by removal of calcite with hydrochloric acid. In the majority of cases, the crystals were attached to the matrix by an end and thus showed but a single termination; two or three crystals of poor quality were found which were attached by prism faces and thus showed both terminations. These crystals were in all cases small, from 2 to 5^{mm} in length, and from $0{\cdot}1^{mm}$ to 1^{mm} in diameter. In habit they vary from slender prisms to short stubby crystals of diameter equal to or greater than their length.

In all thirty-two crystals were measured. Of these twenty-eight were measured completely in the two-circle goniometer. Four were measured for special angles.

From the data obtained in measurement, the following forms were established, those marked with a star being new: *b*, (10$\bar{1}$0), *a*, (11$\bar{2}$0), *k*, (21$\bar{3}$0), *d*, (72$\bar{9}$0*), *r*, (10$\bar{1}$1), *v*, (50$\bar{5}$2), *p*, (02$\bar{2}$1*), *s*, (21$\bar{3}$1*) and *u*, (4$\bar{1}$53*). Doubtful values for the following forms were found. These need confirmation for their establishment. *i*, (41$\bar{5}$0), *f*, (9·4·$\bar{1}\bar{3}$·0*), *g*, (31·13·$\bar{4}\bar{4}$·0*), *t*, (03$\bar{3}$1), *h*, (30$\bar{3}$1*), *x*, (40$\bar{4}$1*), *j*, (50$\bar{5}$1*), *l*, (09$\bar{9}$1*), *m*, (0·18·$\bar{1}\bar{8}$·1*), *n*, (52$\bar{7}$6*), *o*, (7·4·$\bar{1}\bar{1}$·9*), *q*, (51$\bar{7}$4*), and *w*, (42$\bar{6}$5*). The only forms satisfactorily established which we did not find on the Orford mineral are the base *c*, (0001), which was observed by both Miller and Laspeyres, and the rhombohedron *e*, (01$\bar{1}$2) observed by the latter.

Measurements were obtained from the dominant rhombohedrons from which a satisfactory axial ratio could be calculated.

For r, $(10\bar{1}1)$

10 readings,	very good signals,	average	value	of	$\rho=20° \ 43'·4$
11 "	good	"	"	"	$\rho=20° \ 42'·8$
4 "	fair	"	"	"	$\rho=20° \ 43'·5$
12 "	poor	"	"	"	$\rho=20° \ 41'·5$
37 "	all sorts	"	"	"	$\rho=20° \ 42'·6$

For p, $(02\bar{2}1)$

3 readings,	very good signals,	average	value	of	$\rho=37° \ 07' \frac{1}{3}$
6 "	good	"	"	"	$\rho=37° \ 03' \frac{1}{2}$
6 "	fair	"	"	"	$\rho=37° \ 07' \frac{1}{2}$
6 "	poor	"	"	"	$\rho=37° \ 17' \frac{1}{3}$
12 "	very poor	"	"	"	$\rho=37° \ 12' \frac{1}{3}$
Mean of 24 "	selected	"	"	"	$\rho=37° \ 09'·0$
Mean of 15 "	best	"	"	"	$\rho=37° \ 05'·8$

(The word selected as used above means that, using the averages found in the columns above, the whole number of readings whose signals were very good, good and fair was summed with half the number of readings whose signals were poor and very poor, and the general average then taken, weighted in this manner to avoid giving undue influence to the relatively large number of inferior readings.)

Using the formula $pp_0\sqrt{3}=\tan\ \rho$ and the above values, we obtain,

$$p=1, \quad \rho=20° \ 42'·6, \quad p_0=0·21828$$
$$p=2, \quad \rho=37° \ 05'·8, \quad p_0=0·21830.$$

Taking the value of $p_0=0·2183$ we have from the relation

$$c=\tfrac{3}{2}\,p_0, \quad a:c=1:0·3274.$$

This value of p_0, which is based on a large number of measurements, is probably to be given preference over Miller's value; it is exceedingly near the value of p_0 for beyrichite found by Laspeyres.

Found, millerite	$p_0=0·2183$
Miller "	$p_0=0·2197$
Laspeyres, beyrichite	$p_0=0·2185$

Accordingly a table of angles based on the new value is presented to replace that given in Goldschmidt, Winkeltabellen, p. 242. It contains the new forms, and in a supplement those doubtful ones not yet fully established. This constitutes Table I.

TABLE I—MILLERITE.

Hexagonal. Rhombohedral-hemihedral.

$c=0{\cdot}32745$ $lgc=9{\cdot}51514$ $lga_0=0{\cdot}72341$ $lgp_0=9{\cdot}33905$ $a_0=5{\cdot}2895$ $p_0=0{\cdot}2183$. (G_2)

Number.	Letter.	Symb. G_2.	Bravais.	ϕ.	ρ.	ξ_0.	η_0.	ξ.	η.	x Prisms $x:y$.	y.	$d = lg\ \rho$.
1	*c*	0	0001	0° 00′	0° 00′	0° 00′	0° 00′	0° 00′	0° 00′	0	0	0
2	*b*	∞	$10\bar{1}0$	30° 00′	90° 00′	90° 00′	90° 00′	30° 00′	60° 00′	0·5773	∞	∞
3	*a*	∞0	$11\bar{2}0$	0° 00′	90° 00′	0° 00′	90° 00′	0° 00′	90° 00′	0	∞	∞
4	*k*	4∞	$21\bar{3}0$	10° 53′	90° 00′	90° 00′	90° 00′	10° 53′	79° 06′	0·1924	∞	∞
5	*d*	$\frac{11}{5}\infty$	$72\bar{9}0$	17° 47′	90° 00′	90° 00′	90° 00′	17° 47′	72° 13′	0·3207	∞	∞
6	*r*	1	$10\bar{1}1$	30° 00′	20° 42′	10° 42′	18° 08′	10° 11′	17° 50′	0·1890	0·3274	0·3781
7	*v*	$\frac{5}{2}$	$50\bar{5}2$	30° 00′	43° 23′	25° 18′	39° 18′	20° 05′	36° 30′	0·4726	0·8186	0·9452
8	*p*	−2	$02\bar{2}1$	30° 00′	37° 06′	20° 42′	33° 13′	17° 33′	31° 29′	0·3781	0·6544	0·7562
9	*e*	$-\frac{1}{2}$	$01\bar{1}2$	30° 00′	10° 42′	5° 24′	9° 18′	5° 20′	9° 15′	0·0945	0·1634	0·1890
10	*s*	41	$21\bar{3}1$	10° 53′	45° 00′	10° 42′	44° 29′	7° 41′	43° 59′	0·1890	0·9823	1·0003
11	*u*	−21	$\bar{4}\bar{1}53$	19° 06′	38° 00′	10° 42′	28° 37′	9° 25′	28° 12′	0·1890	0·5457	0·5775
?	*i*	2∞	$41\bar{5}0$	19° 06′	90° 00′	90° 00′	90° 00′	19° 06′	70° 53′	0·3464	∞	∞
?	*f*	$\frac{17}{5}\infty$	$9{\cdot}4{\cdot}\bar{13}{\cdot}0$	12° 31′	90° 00′	90° 00′	90° 00′	12° 31′	77° 28′	0·2220	∞	∞
?	*g*	$\frac{19}{6}\infty$	$31{\cdot}13{\cdot}\bar{44}{\cdot}0$	13° 17′	90° 00′	90° 00′	90° 00′	13° 17′	76° 42′	0·2361	∞	∞
?	*h*	3	$30\bar{3}1$	30° 00′	48° 36′	29° 33′	44° 29′	22° 01′	40° 31′	0·5671	0·9823	1·1343
?	*t*	−3	$03\bar{3}1$	30° 00′	48° 36′	29° 33′	44° 29′	22° 01′	40° 31′	0·5671	0·9823	1·1343
?	*x*	4	$40\bar{4}1$	30° 00′	56° 31′	37° 06′	52° 38′	24° 39′	46° 15′	0·7562	1·3098	1·5724
?	*j*	5	$50\bar{5}1$	30° 00′	62° 07′	43° 28′	58° 35′	26° 14′	49° 57′	0·9452	1·6372	1·8905
?	*l*	−9	$09\bar{9}1$	30° 00′	73° 37′	59° 33′	71° 15′	28° 40′	56° 11′	1·7014	2·9470	3·4030
?	*m*	−18·18	$0{\cdot}18{\cdot}\bar{18}{\cdot}1$	30° 00′	81° 38′	73° 37′	80° 22′	29° 41′	59° 02′	3·4030	5·8940	6·8060
?	*n*	$\frac{3}{2}\ \frac{1}{2}$	$5{\cdot}2{\cdot}\bar{7}{\cdot}6$	13° 59′	21° 29′	5° 24′	20° 54′	5° 03′	20° 44′	0·0945	0·3820	0·3935
?	*o*	$\frac{5}{3}\ \frac{1}{3}$	$7{\cdot}4{\cdot}\bar{11}{\cdot}9$	8° 57′	22° 03′	3° 36′	21° 48′	3° 21′	21° 46′	0·0630	0·4002	0·4051
?	*q*	$-\frac{3}{4}\ \frac{5}{4}$	$\bar{6}\bar{1}74$	22° 24′	31° 47′	13° 18′	29° 49′	11° 35′	29° 09′	0·2363	0·5730	0·6198
?	*w*	$\frac{6}{5}\ \frac{2}{5}$	$42\bar{6}5$	10° 53′	21° 48′	4° 19′	21° 27′	4° 01′	21° 23′	0·0756	0·3929	0·4001

Table II shows the character of the combinations observed on the measured crystals, the numbers under each letter indicating the number of faces of that form found on the given crystal.

TABLE II.

	b	*a*	*k*	*d*	*r*	*p*	*v*	*s*	*u*
A	6	1	.	.	2	.	.	.	.
1	6	.	1	1	1	1	.	.	.
2	6	2	3	2	2	1	.	.	6
3	6	2	1	2	3	3	.	.	.
4	6	2	.	2	3	.	.	.	6
5	3	1	.	.	3	1	.	.	1
6	4	.	.	.	3	3	.	.	.
7	6	6	2	.	3	.	.	.	3
8	6	.	.	.	3	3	.	.	.
9	6	4	.	4	3	3	.	.	1

	b	*a*	*k*	*d*	*r*	*p*	*v*	*s*	*u*
12	6	4	.	1	3	.	.	.	.
13	6	2	.	.	.	.	.	.	.
14	4	.	.	.	.	3	.	.	1
15	*x*	.	.	.	*x*	*x*	.	.	*x*
16	4	.	.	.	3	3	2	.	.
17	3	.	.	.	3	3	.	.	.
18	3	.	.	.	3	3	1	.	.
19	1	.	..	1	3	1	.	5	1
20	1	.	.	.	3	3	2	.	.
21	1	.	.	.	3	3	2	.	.
22	.	.	.	.	3	.	.	3	.
23	2	.	.	.	1	.	1	.	.
24	6	.	.	.	1	3	.	.	.
25	2	.	.	.	2	1*	.	.	.
26	3	.	.	.	1	.	.	.	2
27	3	.	.	.	1*	.	.	.	4
30	2	.	.	.	3	.	.	.	.
31	.	.	.	.	x*	.	.	.	.

(The star indicates that the crystal was doubly terminated, but the faces on one end only are given.)

The forms may be characterized as follows:

Prisms.

The prisms usually show a triangular cross-section with rounded corners, but sometimes the cross-section is nearly circular. This is due in part to the development of three or four prisms, partly or completely, and in part to the oscillatory combination of these prisms. The prism zone is badly striated in its length from this cause and in measurement yields signals every few degrees.

b, $(10\bar{1}0)$. Twenty-four out of the twenty-eight crystals which were measured systematically showed faces of the first order prisms, and eleven of these showed all its faces. It is easily the dominant form on the mineral, and it is the least striated of any prism. In most cases it was developed trigonally.

a, $(11\bar{2}0)$. The second order prism was also undoubtedly present on nine crystals, although but one had every face. Its faces when large were considerably striated.

k, $(21\bar{3}0)$. This known prism was found developed incompletely, but none the less surely on four crystals. Its faces were narrow and poorly characterized.

d, $(72\bar{9}0)$. This new prism was found developed incompletely on seven crystals, and the data establishing it are given in full in the following table:

Crystal.	Signal.	Reading. ϕ	
1	very poor	16° 48′	
2	very poor	17° 30′	
2	very poor	17° 33′	
3	poor	17° 58′	
3	poor	17° 59′	
4	good	17° 47′	
4	very good	17° 51′	
9	fair	17° 11′	
9	good	17° 42′	
9	poor	18° 25′	
9	fair	18° 26′	
12	very poor	17° 45′	
19	fair	16° 48′	
Average	fair to poor	17° 47′	average.
Calculated		17° 47′	

The calculated value of ϕ for this form is curiously in exact agreement with the mean of the measurements. So, although

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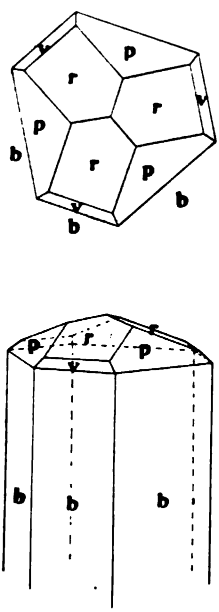

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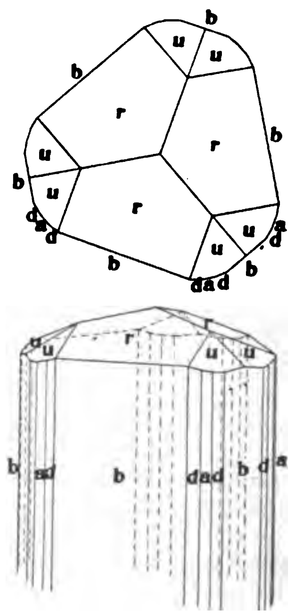

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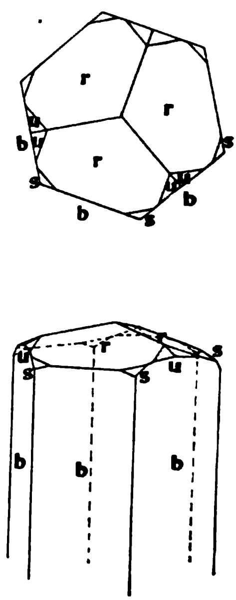

this precise agreement is of course mere chance, it is near enough to establish the form and there are faces enough, well distributed among the crystals, to confirm it. Its faces are narrow and quite indistinguishable from the oscillation planes with which it is associated.

Rhombohedrons.

These are the chief terminating faces whether they occur as cleavage or as crystal planes. The faces, when crystal planes, are not very bright, although the markings and roughnesses which make them dull are never well characterized.

r, (10$\bar{1}$1). The unit rhombohedron was found on all but two of the measured crystals. In a very few instances it was certainly cleavage; and in a few cases it was impossible to say whether cleavage or natural growth had produced the facet. It was developed in relatively large and perfect facets, constituting the dominant terminating form. While not always of good reflecting quality, the faces were usually definite and exhibited no definite markings.

p, (02$\bar{2}$1). Next to *r* the new rhombohedron *p* is best developed as a termination. It is not found as cleavage. It occurs in rather large faces of dull reflecting power for the most part. It is missing from nine crystals only out of the twenty-eight measured, occurring, therefore, with less frequency than *r*. No definite markings were seen on its faces. The observations on which it is based are stated in summary form on p. 349.

v, (50$\bar{5}$2). This rhombohedron, noted by Miller in his first paper, but omitted from his Mineralogy, occurs on five of the crystals, three of them, singly terminated, showing two faces each. The measurements on which the form is based follow.

Crystal.	Signal.	Readings. ϕ	ϕ_1*	ρ
16	good	$\bar{2}$9° 39′	29° 39′	44° 03′
16	good	$\bar{1}$49° 41′	29° 41′	43° 57′
18	very good	$\bar{1}$49° 19′	29° 19′	43° 23′
20	poor	$\bar{3}$0° 42′	30° 42′	43° 33′
20	good	$\bar{1}$50° 07′	30° 07′	43° 25′
21	fair	$\bar{2}$9° 52′	29° 52′	43° 24′
21	good	$\bar{1}$50° 10′	30° 10′	43° 25′
24	fair	89° 31′	29° 31′	43° 51′
Average	very good to fair		29° 53′	43° 39′
Calculated			30° 00′	43° 23′

Scalenohedrons.

These forms are entirely new to millerite. They are present on the Orford mineral as small but distinct facets on over half the crystals measured. The faces are fairly bright, yielding good images, and for the most part they are not pitted or striated.

s, (21$\bar{3}$1). This scalenohedron occurs on two singly terminated crystals, in one case five of its faces being present. The measurements which establish it are given below.

* ϕ_1 is the value of ϕ referred to the first sextant on the right, that is, the difference between ϕ and the nearest multiple of 60°.

Crystal.	Signal.	Readings. ϕ	ϕ_1	ρ
19	fair	$\bar{1}$1° 13′	11° 13′	44° 59′
19	very poor	$\bar{4}$9° 03′	10° 57′	44° 59′
19	good	$\bar{1}$30° 55′	10° 55′	45° 01′
19	good	$\bar{1}$69° 06′	10° 54′	45° 01′
19	very poor	109° 10′	10° 50′	45° 01′
22	fair	$\bar{4}$9° 24′	10° 36′	44° 55′
22	fair	$\bar{1}$31° 16′	11° 16′	45° 00′
22	poor	$\bar{1}$69° 29′	10° 31′	45° 00′
	Mean of 8		10° 54′	44° 59′·5
	Calculated		10° 53′·	45° 00′·

The form is seen to be well established by these results.

u, $(\bar{4}\bar{1}53)$. This scalenohedron occurs on ten crystals, in two cases all its faces being present. The faces, however, are not very bright. They are rough and pitted for the most part and the images are only fair. The data follow.

This scalenohedron and the uncertain ones, *n*, *o*, *q* and *w*, lie in the zone with the rhombohedrons *r* and *p*, and their faces generally appear as striations or roundings of the edges between *r* and *p*, or as shown in figure 4, without *p*.

Crystal.	Signal.	Readings. ϕ	ϕ_1	ρ
2	extremely poor	20° 02′	20° 02′	30° 07′
2	fair	40° 23′	19° 37′	30° 33′
2	good	139° 21′	19° 21′	30° 03′
2	good	160° 57′	19° 03′	30° 01′
2	extremely poor	$\bar{1}$01° 08′	18° 52′	30° 01′
2	very poor	$\bar{7}$8° 14′	18° 14′	30° 01′
4	very poor	40° 33′	19° 27′	30° 11′
4	extremely poor	139° 42′	19° 42′	30° 11′
4	extremely poor	160° 26′	19° 34′	30° 11′
4	extremely poor	$\bar{1}$00° 00′	20° 00′	30° 11′
4	extremely poor	$\bar{8}$0° 05′	20° 05′	30° 11′
4	extremely poor	20° 37′	20° 37′	30° 11′
5	very poor	141° 36′	21° 36′	30° 40′
7	extremely poor	138° 41′	18° 41′	30° 40′
7	extremely poor	161° 25′	18° 35′	30° 40′
7	extremely poor	$\bar{7}$9° 32′	19° 32′	30° 40′
9	poor	$\bar{5}$9° 52′	20° 08′	30° 42′
19	very poor	159° 51′	20° 09′	30° 45′
26	poor	41° 20′	18° 40′	30° 00′
26	very poor	18° 51′	18° 51′	29° 49′
27	poor	41° 07′	18° 53′	29° 42′
27	poor	100° 12′	19° 48′	29° 42′
27	very poor	161° 48′	18° 12′	29° 42′
27	very poor	138° 38′	18° 38′	29° 42′
	Mean of all (24)		19° 24′·	30° 04′
	Mean of best		19° 05′	30° 07′
	Calculated		19° 06′	30° 00′·

Doubtful Forms.

The following forms, for one reason or another, given in detail under each form, are presented as possibly present on the species, but not as established beyond cavil.

i, (41$\bar{5}$0). This form was reported by Laspeyres, but not very well established by his measurements. We obtained poor measurements partly confirming it, but the form is still in doubt, neither his measurements nor ours being good enough to certify it. Our measurements follow.

Crystal.	Signal.	Reading. ϕ
2	extremely poor	18° 52′
2	extremely poor	18° 58′
2	poor	19° 01′
Average	very poor	18° 57′
Calculated		19° 06′·4

The agreement of our measurements with the calculations is better than that of Laspeyres's measurements, but the faces noted were all on one crystal, and two of them were very doubtful.

f, (9·4·$\bar{13}$·0). This prism is new and the measurements on which it is based follow.

Crystal.	Signal.	Reading. ϕ
7	fair	12° 26′
12	poor	12° 29′
14	very good	12° 29′
Average	fair to good	12° 28′
Calculated		12° 31′·2.

The agreement is close enough to establish the form, but the faces are few in number, though well distributed. The signals, however, are good, and in the case of crystal 14, at least, the reading corresponds to a definite face of good quality which can be seen in the goniometer. In this respect the face differs from most of the oscillation planes and, moreover, it is placed very close to its computed position. Therefore the form is regarded as probable, but confirmation is necessary.

g, (31·13·$\bar{44}$·0). This prism, so far as our measurements go, is better established than the form *i*, and so is given, but it has complex indices and altogether is a doubtful form.

Crystal.	Signal.	Readings. ϕ
2	extremely poor	13° 11′
8	extremely poor	13° 22′
14	good	13° 19′
Average	poor	13° 17′·3.
Calculated		13° 17′

Besides the signals reflected from faces of these forms which are more or less well established, there were read, in the prism zone, signals reflected from faces in thirty-two positions (reduced to the positive sextant) which corresponded more or less well to prisms of complex indices. For the most part only one face of each of these forms was seen, and the signals were generally of very poor quality. These facts together with the complexity of the indices deduced, and the certainty of the occurrence of oscillation-vicinals whose signals correspond to no prism however complex, render the establishment of any of them very doubtful. Therefore all are rejected and none of the data is published.

Doubtful Rhombohedrons.

t, ($03\bar{3}1$). This rhombohedron was reported by Miller on the strength of a contact measurement on a rough terminated crystal. We can not confirm the form, but one face on one crystal was found approximating to its position.

Crystal.	Signal.	Readings. ϕ	ρ
24	very poor	30° 00′	48° 56′
Calculated		30° 00′	48° 36′

h, ($30\bar{3}1$). This rhombohedron is new and very doubtful, relying for its establishment on two measurements on two different crystals.

Crystal.	Signal.	Readings. ϕ	ρ
23	very poor	30° 00′	48° 42′
24	fair	150° 00′	48° 10′
Mean	poor	30° 00′	48° 26′
Calculated		30°	48° 36′

The form is therefore certainly indicated, but by no means established.

x, ($40\bar{4}1$). This form also is new and rests on a single measurement whose signal was of fair quality. The measured value for ρ was 56° 34′; the calculated value of ρ is = 56° 31′49″; apparently the form only lacks the finding of more faces to establish it.

j, ($50\bar{5}1$). One face only supports this form.

Crystal.	Signal.	Readings. ϕ	ρ
23	poor	29° 46′	62° 26′
Calculated		30° 00′	62° 07′

l, ($09\bar{9}1$). Only one face of this form was found. This gave a fair signal showing a definite face.

Crystal.	Signal.	Readings. ϕ	ρ
25	fair	29° 25′	73° 05′
Calculated		30° 00′	73° 37′

m, (0·18·$\bar{1}\bar{8}$·1). Only one face of this form was found which yielded two signals of fair quality.

Crystal.	Signal.	Readings. ϕ	ρ
24	fair	30° 00′	82° 32′
24		30° 00′	80° 20′
Calculated		30° 00′	81° 38′·

No stress is laid on the probability of the occurrence of *l* and *m*. The faces were plainly visible in both cases.

Doubtful Scalenohedrons.

n, (52$\bar{7}$6). This form was found on three crystals, in one case four of its faces being present. The data follow:

Crystal.	Signal.	Readings. ϕ	ϕ_1	ρ
5	good	104° 52′	15° 08′	21° 18′
5	poor	133° 21′	13° 21′	21° 18′
8	poor	$\bar{1}$33° 14′	13° 14′	21° 22′
8		$\bar{4}$6° 39′	13° 21′	21° 22′
8		73° 01′	13° 01′	21° 22′
8	very poor	$\bar{1}$66° 45′	13° 15′	21° 22′
14	poor	$\bar{1}$67° 14′	12° 46′	21° 26′
Mean	poor	....	13° 26′·5	21° 21′
Calculated		....	13° 54′	21° 29′

Although we have left the form in doubt it is clear that it is more than indicated. The agreement of measurements with calculations is only fair, but there are many faces well distributed.

o, (7 · 4 · $\bar{1}\bar{1}$ · 9). This form was found on three crystals, in one case four faces being present. The data are given in full:

Crystal.	Signal.	Readings. ϕ	ϕ_1	ρ
5	poor	$\bar{8}$° 52′	8° 52′	22° 03′
5	very poor	$\bar{5}$0° 58′	9° 02′	22° 00′
8	extremely poor	$\bar{7}$° 30′	7° 30′	21° 22′
18	poor	$\bar{9}$° 51′	9° 51′	21° 19′
18	extremely poor	$\bar{1}$71° 40′	8° 20′	21° 51′
18		$\bar{1}$28° 24′	8° 24′	21° 36′
18	poor	$\bar{4}$9° 46′	10° 14′	21° 09′
Mean	very poor	....	8° 53′	21° 37′
Calculated		....	8° 57′	22° 03′

This form, therefore, is not to be rejected without consideration although the data cannot be said to establish it.

q, $(\bar{6}\bar{1}74)$. This form rests on two readings made on a single crystal. This crystal was the richest in forms of any measured. The agreement is not very bad. The form is at least indicated.

Crystal.	Signal.	Readings. ϕ	ϕ_1	ρ
2	poor	$\bar{8}3°$ 05′	23° 05′	32° 00′
2	very poor	$\bar{9}7°$ 33′	22° 27′	32° 00′
Mean	poor	....	22° 46′	32° 00′
Calculated		....	22° 24′	31° 47′

w, $(42\bar{6}5)$. Only one reading supports this form. It in consequence is very doubtful.

Crystal.	Signal.	Readings. ϕ	ϕ_1	ρ
5	fair	70° 26′	10° 26′	21° 47′
Calculated		....	10° 53′	21° 48′

Résume.

The Orford millerite has yielded a number of terminated, measureable crystals from which the new axial ratio $a:c = 1:0{\cdot}2183$ is calculated. In addition to the forms previously known, one new prism, two rhombohedrons and two scalenohedrons are definitely established and a number of uncertain forms observed but not established.

The presence of a gliding plane parallel to the negative rhombohedron, along which pressure twins of great perfection can be easily obtained, is also determined.

Millerite has been thought to be hemimorphic like the nearly related cadmium sulphide, greenockite, and has been so classified by Groth. The sharply defined trigonal character of many of the prisms of Orford millerite seem to give some basis for this assumption; and doubly terminated crystals were therefore eagerly sought for in the hope that the question might be settled by definite observations. A few crystals doubly terminated were found but they were poor crystals and so far as measurements could be made upon them showed no unlikeness between the two ends. Our evidence on this matter is therefore not conclusive.

On the surface of a single hand specimen of very rich green chrome garnet which was originally covered with a thin layer of calcite, there appeared on the removal of the latter with acid a number of tiny clusters of crystals of a gray to white metallic mineral which seem to be rammelsbergite, an arsenide of nickel. The crystals are minute and invariably so deeply striated that no satisfactory measurements could be obtained. Still inasmuch as this mineral has never been found before in crystals that permitted of measurement except in one zone, a number of the crystals were studied carefully and a provisional axial ratio was calculated for the species. It was found to be like the other members of the marcasite group in habit and the flat dome which was found on all measured crystals was taken by analogy with arsenopyrite as the brachydome (014). The prism zone was so deeply striated that no reliance could be placed on the readings made from it; but an orthodome was found on nearly all the crystals very faintly developed but which gave fairly uniform readings for ρ. This was taken as (102), a choice that gave the simplest indices for the prism forms and a ratio most nearly like that of the other members of the group, although differing widely from any of them. The observations follow:

Rammelsbergite ?.

$0\frac{1}{4}$ av. of 7, $\phi = 0° 00'$, $\rho = 16° 06'$ } $p_o = 2{\cdot}0176$
$\frac{1}{2}0$ av. of 4, $\phi = 90° 00'$, $\rho = 45° 15'$ } $q_o = 1{\cdot}1545$

$a : b : c = 0{\cdot}57222 : 1 : 1{\cdot}1545$

Form.		Calculated.		Measured.		No. of
G.	Miller	ϕ	ρ	ϕ	ρ	observations.
0 ∞	010	00° 00′	90° 00′	00° 00′	90° 00′	6
∞	110	60° 13′	90° 00′	60° 44′	90° 00′	3
∞ 2	120	74° 02′	90° 00′	74° 26′	90° 00′	4
2 ∞	210	41° 09′	90° 00′	42° 30′	90° 00′	2
$0\frac{1}{4}$	014	00° 00′	16° 06′	00° 00′	16° 06′	7
$0\frac{1}{3}$	013	00° 00′	21° 03′	00° 00′	20° 30′	2
$0\frac{1}{2}$	012	00° 00′	29° 59′	00° 00′	29° 45′	1
02	021	00° 00′	66° 35′	00° 00′	66° 50′	1
$\frac{1}{2}0$	102	90° 00′	45° 15′	90° 00′	45° 15′	4

The amount of the mineral present on our specimens was so small that sufficient for analysis could not be secured. Its doubtful determination as rammelsbergite is based on blowpipe reactions for arsenic and nickel obtained on minute crystals. No test for sulphur could be obtained. It is hoped that more and better material may ultimately be obtained which will enable the character of this mineral to be definitely established.

EXPLANATION OF THE FIGURES.

Fig 1 shows a photograph of a specimen from which calcite has been partly removed by solution in hydrochloric acid. Several large straight prisms of the millerite may be seen still partly embedded in the calcite. On the surface of the pyroxene matrix may be seen several smaller broken and twisted millerite crystals.

Fig. 2 shows a twin crystal produced by pressure, twinned parallel to the rhombohedron *e*, $(01\bar{1}2)$. The upper termination is formed by single planes of the two cleavages, parallel to *r* and *e*; the lower termination is by a single plane of the *r* cleavage.

Fig. 3 shows in plan and perspective the commonest type of crystal found. The proportions of the rhombohedrons may vary but some or all of the faces of the three are generally found.

Fig. 4 and Fig. 5 show the mode in which the scalenohedrons occur in combination. Of these forms *u* is much the more frequent, *s* having been observed on but two crystals.

Harvard Mineralogical Laboratory,
June 1904.