ART. VII.—*Pyromorphite from British Columbia, Canada* ;*
by O. BOWLES.

Introduction.—During the summer of 1907 Prof. W. A. Parks of the University of Toronto visited the Society Girl Mine in Southeastern British Columbia, situated a short distance east of the famous St. Eugene Mine in the Moyie District. Here he collected a large number of well-crystallized specimens of pyromorphite, which were brought to the Mineralogical Laboratory of the University of Toronto, where the writer was permitted to investigate them.

General description.—In this locality the pyromorphite is found in association with galena and cerussite in the fractured country rock. The cerussite and pyromorphite appear to be of secondary origin through the decomposition of galena in fracture cavities. A white clay surrounding the pyromorphite crystals suggests the probable action of percolating water, which may have supplied the phosphorus from organic matter at higher levels.

The mineral occurs in the form of densely crowded crystal aggregates. Most of the crystals are wax-yellow in color, while some are green; and these two varieties exhibit some interesting differences which are described later. The crystals are brittle, of a resinous luster, and in their property of light transmission vary from opacity or sub-translucency in the larger to clear transparency in many of the smaller ones.

Crystallography.—The crystals are of one type only, being prismatic or slender acicular in habit. They occur in three ways: (1) as separate individuals, (2) in radiating groups, or (3) in tapering barrel-shaped aggregates. In some instances the minute radiating crystals, crowded together over the surface, possess a moss-like appearance. The needles may attain a length of an inch or more, but those having faces sufficiently bright to permit measurement with any degree of accuracy are of almost microscopic dimensions. As the crystals are very brittle and easily broken, it was a matter of some difficulty to obtain specimens with terminal faces. In small, well-protected pockets a considerable number were found, and about forty-five were studied carefully on the two-circle goniometer of the Goldschmidt type.

Pyromorphite belongs to the hexagonal-bipyramidal class. The forms observed by me are as follows:—

$$\begin{array}{llll} c \{0001\}, & m \{10\bar{1}0\}, & a \{11\bar{2}0\}, & x \{10\bar{1}1\}, \quad y \{20\bar{2}1\} \\ \pi \{40\bar{4}1\}, & \epsilon \{30\bar{3}4\}, & & \end{array} \quad (\text{See fig. 1})$$

* The data contained in this paper were embodied in a thesis accepted by the University of Toronto for the degree of Master of Arts.

The basal pinacoid, $c \{0001\}$, is very poorly developed. Reflections could be obtained from it on only five of the crystals studied. On many of the crystals it was so rough and uneven that it appeared to be merely a fracture surface.

FIG. 1.

The prism of the first order, $m \{10\bar{1}0\}$, is the most prominent form on all crystals, and is usually represented by well-reflecting surfaces, from which satisfactory readings may be obtained. These faces commonly exhibit minute longitudinal striations.

A very important fact which has not, to the writer's knowledge, been as yet observed is to be noted in connection with the prismatic faces. They do not exhibit an absolute parallelism, but converge slightly toward the upper end of the c axis. From this it would appear that the symbol $\{10\bar{1}0\}$ is only approximately correct, the true prism faces being replaced by vicinal planes which depart from the theoretical position of the real prisms by a definite measurable angle. Only in exceptional cases are true prism faces present, for almost invariably they are replaced by these vicinal planes. The readings for all the faces in the prismatic zones of twenty-one crystals give a mean angle of $89^\circ 33'$ between the normal and the vertical axis. The Miller symbol thus becomes $\{135 \cdot 0 \cdot \bar{1}35 \cdot 1\}$. The frequent recurrence of these faces, indicating an approximately constant deviation from the theoretical value, gives weight to the theory of S. M. Websky,* that vicinal planes are not accidental, due to distortion of the crystal, but that they follow some definite law which has its foundation in the internal molecular arrangement. In the table of angles it will be noted that the other forms show considerable variation from the calculated values also, but it must be remembered that the values for these forms were obtained from poorly reflecting surfaces, while in the case of the prism faces well-defined images were obtained.

The prism of the second order, $a \{11\bar{2}0\}$, was observed on two crystals only, the faces being very narrow, and in some instances curved. As shown by the table on page 42, the readings are, however, sufficient to indicate that the faces are undoubtedly prisms of the second order.

The unit bipyramid, $x \{10\bar{1}1\}$, is the most prominent of all the pyramidal forms. The faces are in most cases very dim,

* Zeitschr. d. d. Geolog. Ges., xv, p. 677, 1863.

and on the goniometer give no distinct signals. The bipyramid $y\{20\bar{2}1\}$ was found on three crystals only, and in each case the faces were very indistinct. They are proportionally very much smaller than the faces of the unit bipyramid. The bipyramid $\pi\{40\bar{4}1\}$ was observed with very narrow edges on one crystal only. As no distinct images could be obtained from these faces, several readings were taken, and the results averaged.

The bipyramid $\epsilon\{30\bar{5}4\}$ is a new form. It was represented on six of the crystals, and, though the faces are extremely minute, the averages of a large number of readings approximate to the theoretical values so nearly that the form is established with certainty. The average reading of four of the best faces gives a value $32^\circ 28'$ for the angle ρ , the calculated value being $32^\circ 31'$. A form having this symbol is recorded for apatite, which also belongs to the hexagonal-bipyramidal class. The bipyramid of the second order, $s\{11\bar{2}1\}$, is the only form recorded by Dana or Goldschmidt which finds no representation on these crystals.

All forms observed by me, as well as those given by Dana, together with their calculated and observed angles, are indicated in the following table:

TABLE OF ANGLES.

		ρ		ϕ	
Forms		Observed	Calculated	Observed	Calculated
	Dana	Bowles			
c	{0001}	{0001}	0° 09'	0°	-- --
m	{10 $\bar{1}$ 0}	{10 $\bar{1}$ 0}	90° 03'	90°	0° 0°
		Vicinal	89° 33'	0°	-- --
a	{11 $\bar{2}$ 0}	{11 $\bar{2}$ 0}	90° 07'	90°	30° 04' 30°
x	{10 $\bar{1}$ 1}	{10 $\bar{1}$ 1}	40° 37'	40° 22'	0° 13' 0°
y	{20 $\bar{2}$ 1}	{20 $\bar{2}$ 1}	59° 16'	59° 32'	0° 13' 0°
π	{40 $\bar{4}$ 1}	{40 $\bar{4}$ 1}	74° 07'	73° 37'	0° 06' 0°
s	{11 $\bar{2}$ 1}	----	-- --	55° 49'	-- -- 30°
ϵ	----	{30 $\bar{5}$ 4}	32° 28'	32° 31'	0° 07' 0°

Chemical Analysis.—As extremely pure crystals of both the yellow and green varieties were at hand, it seemed advisable to make an analysis of each in order to obtain if possible some adequate explanation for the variation in color. The chemical analysis was, in general, based on the method outlined by Medicus.* The results are as follows:

*Chemische Analyse; Kurze Anleitung zur Gewichtsanalyse, Dritte Auflage, p. 91, 1897.

	Yellow Variety	Green Variety
PbO	80.20%	80.13%
CaO	0.59	0.56
FeO	0.86	0.46
P ₂ O ₅	16.12	15.65
As ₂ O ₅	0.41	0.90
Cl ₂	2.52	2.59
CaF ₂	trace	----
Insol.	0.08	0.05
	<hr/>	<hr/>
	100.78	100.34
Less oxygen equivalent of Cl	0.57	0.59
	<hr/>	<hr/>
	100.21	99.75

Although there is considerable difference to be observed in the results of these two analyses, such as the striking variation in the amounts of iron and arsenic, it can, nevertheless, be shown that the analyses are to be relied upon; for if the molecular ratios are calculated from the above determination, it will be seen that in each case the results point to the generally accepted formula for pyromorphite.

	Yellow Variety Molecular Ratios				Green Variety Molecular Ratios		
	I	II	III		I	II	III
PbO	0.324	0.346	9.03	PbO	0.323	0.340	8.95
CaO	0.010			CaO	0.010		
FeO	0.012			FeO	0.007		
P ₂ O ₅	0.013			P ₂ O ₅	0.110		
		0.115	3.00			0.114	3.00
As ₂ O ₅	0.002			As ₂ O ₅	0.004		
PbCl ₂	0.036	0.036	0.94	PbCl ₂	0.037	0.037	0.98

Since the combined molecular ratios of the oxides of lead, calcium, and iron, and the pentoxides of phosphorus and arsenic, are almost exactly in the proportion 3 to 1, we may assume that those values are very nearly correct. Hence if we give to the combined ratios of the pentoxides of phosphorus and arsenic the value 3, we obtain the simplified ratios in columns III. In each case these are approximately 9:3:1, which, as remarked above, is in close agreement with the generally accepted formula $9\text{PbO} \cdot 3\text{P}_2\text{O}_5 \cdot \text{PbCl}_2$, or in more simplified form $\text{Pb}_5\text{Cl}(\text{PO}_4)_3$.

In some cases the green color has been accounted for by the presence of a small amount of copper, but here no trace of copper is to be found. Leonhard* states that the yellow

* N. Jahrbuch für Min. und Geol., 1867, p. 449.

variety differs from the green only in its smaller content of arsenic. He records an analysis which indicates that the green pyromorphite contains 0.66 per cent arsenic pentoxide, while the yellow variety contains none. The analyses given above show a somewhat similar relationship; for, although arsenic is present in both, there is a larger per cent in the green variety. This fact, and the presence of a larger quantity of iron oxide in the yellow variety, are the only marked differences brought out by the chemical analyses.

Specific Gravity.—This was determined by means of a Muthmann capillary-tube pycnometer. Extremely pure material of both varieties was obtained, and a comparatively large amount (about eight grams) was used, in order to insure accurate results. Crystal fragments about the size of fine shot were employed. Several determinations were made, and the results are tabulated below:

	Yellow Variety	Green Variety
I	7.011	7.055
II	7.016	7.052
III	7.012	7.046
IV	7.014	7.053
	<hr/>	<hr/>
Average	7.013	7.051

From the above results it is evident that the green pyromorphite has a higher density than the yellow. Dana* gives the specific gravity of the pure mineral a rather wide range, varying from 6.5 to 7.1. This British Columbian pyromorphite then approaches the higher limit set by Dana. The results obtained are slightly higher than those of Bauer,† who gives a variation of 6.9 to 7.0.

In conclusion I desire to acknowledge valuable assistance rendered by Prof. T. L. Walker of the University of Toronto, under whose direction the investigations were conducted. I am indebted to Prof. W. A. Parks of the same institution for selecting the material, and for information regarding its occurrence and associations.

Mineralogical Laboratory, University of Michigan,
Ann Arbor, Mich., March 8th, 1909.

* System of Mineralogy, p. 770.

† Lehrbuch der Mineralogie, 2te Auflage, 1904, p. 805.