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THE CRYSTALLIZATION OF THE CALCITE FROM THE COPPER MINES OF LAKE SUPERIOR

BY
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ACCOMPANIED BY SIX PLATES

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LAKE SUPERIOR CALCITES.

INTRODUCTION:—The copper mines of the Keweenaw Peninsula on the southern shore of Lake Superior have long been noted among mineralogists for their rich product of crystallized minerals, among which, after the native copper, calcite easily comes first in the interest and beauty of its specimens.

The present paper presents the results of an extended study of a large series of these calcite crystals. Such a study seemed desirable in view of the fact that the extremely rich crystallographic material here offered had been almost entirely neglected by American students; scattered papers in French and German contain with one exception the only published descriptions of Lake Superior calcites, and while these are excellent as far as they go, they were based on limited material and cover but a small portion of the field.

The material at the author's disposal for this study amounted in all to more than two hundred crystals, and he feels warranted in believing that among them were specimens of all the more important crystal types that have been found in the region. The bringing together of so large and fine a collection of these calcites was made possible only by the liberality of the owners and directors of many mineral cabinets, who allowed the author the free use of the material in their possession, and he desires here to express his thanks and obligations to all those who thus aided him. The following list will show the sources of the studied material. It includes only the number of the crystals actually measured; at least as many more were in hand and studied with less detail.

From the collection of :

C. S. Bement	10	crystals.
Brush Cabinet, Yale University	3	"
J. N. Cox	1	"
B. F. Chynoweth	1	"
G. L. English & Co.	4	"
L. L. Hubbard	22	"
Harvard Mineralogical Museum	21	"
J. H. Lathrop	5	"
R. Pumpelly	12	"
W. D. Schoonmaker	1	"
J. H. Sears	1	"
H. L. Smyth	2	"
Delia M. Stickney	1	"
U. S. National Museum	1	"
Geo. Vaux, Jr.	5	"
W. B. Whiting	21	"
Measured crystals	111	

To Dr. L. L. Hubbard, the author owes a special measure of thanks for his unceasing kindness in. supplying material as well as advice and assistance essential to the success of this study; and acknowledgments are due to Mr. W. W. Stockly for the care involved in the final preparation of the plates for publication.

In all of the crystallographic work the author has had the constant advice and aid of Professor Victor Goldschmidt of Heidelberg, for which he would here express his deep obligations.

LITERATURE:—The earlier writers who studied the Lake Superior copper mines make frequent mention of the abundant and beautiful crystallizations of calcite found in the veins; and the fact that these crystals were from the first valued and preserved by collectors is witnessed by the specimens in many collections bearing dates almost as far back as the beginning of mining in the region. But none of these earlier references to the Lake Superior calcites contain any crystallographic descriptions, save the most vague and general, and we are indebted to the German mineralogist; vom Rath, for the first detailed study of crystals from this locality. In a paper* published in 1867 he describes and figures four crystals which exhibit very well the commoner habits of calcite of this region; and his remarks on the dominant forms and on the twinning of these crystals have been fully confirmed by later studies. He published further a description of a complex twin crystal in 1874.

*G. vom Rath, Mineralogische Mittheilungen. Poggendorf's Annalen, vol. 132, 1867, p. 387, vol. 152, 1874, p. 17.

The next study of these crystals was made by Hessenberg* in 1870. He describes two combinations, of forms for the most part new and having highly complicated symbols. The crystals, which appear to have been rather poorly adapted to measurement, were afterwards re-examined by Irby† who altered and simplified many of the symbols found by Hessenberg, but found additional forms of quite as complex a character. But few of these forms of Irby's have been observed a second time and are probably to be considered as vicinal.

Des Cloizeaux figured a crystal of Lake Superior calcite in his Manuél de Minéralogie, Vol. 1, plate XLV, published in 1862; the text in which the figure is briefly described did not appear however until 1874. The crystal was similar to some of vom Rath's.

In 1891, Césaro‡ described a complex crystal with some rare planes.

In 1895 Palache§ described a specimen preserved in the Munich cabinet. A reproduction of his figure is given in figure 8, plate XII, and will be referred to later.

Thus in all, up to the present time, there have been described and figured ten combinations of Lake Superior calcites, exhibiting about twenty-eight well established forms and a number of more or less uncertain ones.

*Hessenberg, Mineral. Notizen. Abhandlungen der Senckenbergischen naturforschenden Gesellschaft. Band VII, 1870, p. 257.

†J. R. McD. Irby. On the Crystallography of Calcite. Inaugural Dissertation, Bonn, 1878. Abstract in Zeitschrift für Krystallographie, Vol. 3, 1879.

‡Césaro, Calcite from Lake Superior. Annales de la Soc. geol, Belgique. 1891, Vol. 18,

§C. Palache, Calcite von Lake Superior, Zeitschrift für Krystallographie. Vol. XXIV, 1895, p. 589.

OCCURRENCE OF THE CALCITE:—Calcite occurs abundantly as a vein mineral throughout the copper deposits of Lake Superior. Its deposition appears not to have been confined sharply to any one period of vein filling, but continued through several stages of the process.

According to Pumpelly,‖ who gave special attention to the paragenetic relations of the various minerals, there were two well marked periods of calcite deposition toward the end of the filling of both fissure veins and amygdaloidal cavities, between which was a period of copper and datolite deposition; while in rare cases there seems to have been an earlier calcite deposit, preceding almost wholly the copper deposit.

The double period of calcite deposition is well shown in the frequent crystals whose growth has been interrupted by the deposit of a coating of copper, the subsequent enclosure of which by a second generation of calcite material in perfect crystallographic continuity with the first often produces "shadow crystals" of great beauty. This interruption in the growth of the crystal is generally marked in addition by a decided change in habit, due to the altered conditions of growth during the two periods. Figure 15, Plate XIV, shows such a "shadow crystal," the inner crystal, outlined by copper, bounded by a positive scalenohedron and the basal plane, the outer one showing only negative scalenohedrons. The cleavage in such a crystal, however, extends unbroken through the whole mass, except for the slight irregularity apt to be caused by the thin layer of tough copper.

In a large number of cases it is certain that calcite was the last mineral to crystallize in the deposit, and to this fact we owe in large measure the great abundance of splendid crystals, the open spaces giving free opportunity for complete crystal development.

It is unfortunate for our study of these calcites that in very many cases the exact locality or mine from which a crystal was obtained has not been recorded. The variety in mode of formation of the deposits that have been worked for copper in this region would give ground to hope that had more data been available it might have proved possible to trace a definite relation between them and the habit of the crystals formed under their various influences. The crystal habit varies in a striking manner, but we are hardly justified in saying more than that, while the crystals exhibit well-marked types in certain districts or groups of mines, slight dependence upon the nature of the deposit has been recognized. Reference to these "district types" will be found below under the description of crystal combinations.

‖Raphael Pumpelly. The Paragenesis and Derivation of Copper and its Associates on Lake Superior. American Journal of Science, Vol. II, 1871. See also Geol. Sur. Mich., I, Pt. II, p.19.

General Description of the Calcite:—The calcite crystals are for the most part transparent, the colorless ones being sometimes absolutely pellucid and flawless even when quite large. The colorless condition is perhaps the most common; but very many are tinted a pale to deep wine yellow, and inclusions of native copper give to some a reddish color. Where the copper is in finely divided scales or spangles it makes a charming "aventurine" effect. Some of the "shadow crystals" mentioned above have the inner crystal of milky white material, while the exterior is colorless, thus heightening the contrast marked by the copper deposition. This milky condition is very common and characteristic in crystals from the Pewabic-Quincy lode, but is otherwise not common in the region. One crystal from the Bement collection was quite black and opaque through abundant inclusions of a powdery black material of undetermined nature.

It is rare to find a crystal other than the most minute in which cleavage cracks are not more or less developed, and the iris colors induced along these planes often add largely to the beauty of the specimen, expecially in water-clear crystals.

The crystal planes are for the most part of great perfection and high lustre, even in large crystals. Certain forms, however, tend to unevenness through striation, and etching phenomena are by no means rare. A discussion of these characters will be found below.

As would be expected there is a wide range in the size of the crystals, but they by no means rival those from other localities in the attainment of extremely large dimensions. The largest crystal from Lake Superior known to the writer is now in the Harvard Mineralogical Museum; it measures about six inches in height and in diameter. Crystals of from two to four inches in height are by no means uncommon and are often remarkable, as well for the perfection of their planes as for the symmetrical development of the many forms frequently found in combination upon them.

One character which lends these crystals a peculiar value both to the crystallographer and to the mineral collector is their tendency to develop as isolated crystals. Often implanted on a sheet of copper or on the wall of a cavity lined with copper or quartz, sits a single symmetrical crystal. Again the calcites are found implanted on delicate threads of copper, giving opportunity for the growth of doubly terminated crystals of more than ordinary completeness. Such perfect forms are, however, of exceptional occurrence and incrustations with occasional crystals rising from their midst, or drusy coatings are the rule.

Crystallization:—The table on the following pages contains a list of all the forms observed on crystals of calcite from Lake Superior. The letters there used to designate the forms are those used by Goldschmidt in the Index der Krystallformen der Mineralien, this being the only list published in which a complete enumeration of the multitude of calcite forms, together with letters for each one, has been attempted. In the column headed "D" are given the letters used by Dana in the System of Mineralogy, 1892, for such forms as appear in his incomplete list. In assigning letters to the many new forms found in this investigation, Goldschmidt's table, on page 141 of the above work, has been used. These letters* have been used both in the gnomonic projection plate and in the crystal drawings. The three columns containing for each form the symbol according to Goldschmidt, Naumann. and Bravais-Miller, will facilitate reference to most works containing descriptions of calcite. The Goldschmidt symbol here given is that found under the heading"G_2" in his work.

All the forms named were observed by the author except where noted in the last column, which contains also the names of other observers who have described any of the forms. The word new opposite any form indicates that it is new to calcite.

A supplementary list contains all forms recorded for this region which can not be regarded as well established or have been called in question. Forms such as those of Hessenberg which have been revised by later study of the same crystals have not been included.

*In the case of the letter *θ* a different type has been used in text and plates.

Table of forms of Lake Superior Calcite.

No.	Letter		Symbol			Remarks
	Gld. Pal.	D.	Goldsch.	Naumann	Bravais-Miller	
1.	o	c	0	0R	0001	vom Rath, Hessenberg
2.	b	m	∞	∞R	$10\bar{1}0$	
3.	a	a	$\infty 0$	∞P2	$11\bar{2}0$	vom Rath
4.	ζ	ζ	$\frac{5}{2}\infty$	∞R2	$31\bar{4}0$	
5.	θ	—	4∞	∞R3	$21\bar{3}0$	
6.	ψ	—	$\frac{4}{3}\infty$	$\infty R^{\frac{11}{9}}$	$10.1.\overline{11}.0$	new
7.	π	π	10	$\frac{2}{3}$P2	$11\bar{2}3$	
8.	λ	—	20	$\frac{4}{3}$P2	$22\bar{4}3$	
9.	ν	—	30	2P2	$11\bar{2}1$	new
10.	ω	—	$\frac{16}{3}0$	$\frac{32}{9}$P2	$16.16.\overline{32}.9.$	new
11.	z ·	ω	+28.28.	+28R	$28.0.\overline{28}.1.$	
12.	s ·	ν	+13.13.	+13R	$13.0.\overline{13}.1.$	
13.	r ·	θ	+10.10.	+10R	$10.0.\overline{10}.1.$	vom Rath
14.	m ·	M	+4	+4R	$40\bar{4}1$	vom Rath, Hessenberg
15.	k ·	k	$+\frac{5}{2}$	$+\frac{5}{2}$R	$50\bar{5}2$	vom Rath, Des Cloizeaux
16.	R ·	—	+2	+2R	$20\bar{2}1$	new
17.	p ·	r	+1	+R	$10\bar{1}1$	vom Rath, Hess., Des Cloiz.
18.	δ ·	e	$-\frac{1}{2}$	$-\frac{1}{2}$R	$\bar{1}012$	vom Rath, Hess., Des Cloiz.
19.	θ · *	—	$-\frac{7}{8}$	$-\frac{7}{8}$R	$\bar{7}078$	
20.	λ ·	L	$-\frac{8}{7}$	$-\frac{8}{7}$R	$\bar{8}087$	Irby
21.	ξ ·	A	$-\frac{4}{3}$	$-\frac{4}{3}$R	$\bar{4}043$	
22.	π ·	Π	$-\frac{7}{5}$	$-\frac{7}{5}$R	$\bar{7}075$	vom Rath, Des Cloizeaux
23.	ρ ·	h	$-\frac{3}{2}$	$-\frac{3}{2}$R	$\bar{3}032$	
24.	σ ·	—	$-\frac{11}{7}$	$-\frac{11}{7}$R	$\overline{11}.0.11.7.$	
25.	τ ·	—	$-\frac{13}{8}$	$-\frac{13}{8}$R	$\overline{13}.0.13.8.$	
26.	φ ·	f	−2	−2R	$\bar{2}021$	vom Rath, Des Cloizeaux
27.	ω ·	—	$-\frac{11}{4}$	$-\frac{11}{4}$R	$\overline{11}.0.11.4.$	
28.	Γ ·	ψ	−3	−3R	$\bar{3}031$	
29.	△ ·	χ	$-\frac{7}{2}$	$-\frac{7}{2}$R	$\bar{7}072$	vom Rath, Des Cloizeaux
30.	Π ·	d	−8	−8R	$\bar{8}081$	vom Rath

* In the figures the other form of *theta* is used.

No	Letter		Symbol			Remarks
	Gld. Pal.	D.	Goldsch.	Naumann	Bravais-Miller	
31.	Σ·	Σ	$-11.11.$	$-11R$	$\bar{11}.0.11.1.$	
32.	u:	—	$-\frac{11}{13}\frac{2}{13}$	$-\frac{2}{13}R4$	$\bar{5}.\bar{3}.8.13.$	new
33.	v:	Ψ	$+1\frac{1}{5}$	$+\frac{1}{5}R\frac{11}{3}$	$7.4.\bar{11}.15.$	vom Rath
34.	g:	G	$+1\frac{1}{3}$	$+\frac{1}{3}R\frac{7}{3}$	$52\bar{7}9$	
35.	w:	w	$+1\frac{2}{5}$	$+\frac{2}{5}R2$	$31\bar{4}5$	vom Rath
36.	f:	—	$+1\frac{5}{11}$	$+\frac{5}{11}R\frac{9}{5}$	$7.2.\bar{9}.11.$	
37.	e:	E	$+1\frac{1}{2}$	$+\frac{1}{2}R\frac{5}{3}$	$41\bar{5}6$	
38.	b:	—	$+1\frac{2}{3}$	$+\frac{2}{3}R\frac{4}{3}$	$71\bar{8}9$	vom Rath only
39.	a:	—	$+1\frac{7}{10}$	$+\frac{7}{10}R\frac{9}{7}$	$8.1.\bar{9}.10.$	vom Rath only
40.	G:	—	$+\frac{11}{5}1$	$+R\frac{9}{5}$	$72\bar{9}5$	
41.	H:	λ	$+\frac{5}{2}1$	$+R2$	$31\bar{4}2$	
42.	J:	—	$+31$	$+R\frac{7}{3}$	$52\bar{7}3$	
43.	K:	ν	$+41$	$+R3$	$21\bar{3}1$	vom Rath, Des Cloizeaux
44.	L:	—	$+\frac{35}{8}1$	$+R\frac{13}{4}$	$17.9.\bar{26}.8.$	
45.	M:	—	$+51$	$+R\frac{11}{3}$	$7.4.\bar{11}.3.$	
46.	N:	ϒ	$+\frac{11}{2}1$	$+R4$	$53\bar{8}2$	
47.	P·	—	$+\frac{13}{2}1$	$+R\frac{14}{3}$	$17.11.\bar{28}.6.$	new
48.	P:	y	$+71$	$+R5$	$32\bar{5}1$	
49.	T:	ζ	$+10.1$	$+R7$	$43\bar{7}1$	vom Rath
50.	U:	μ	$+13\ 1$	$+R9$	$54\bar{9}1$	vom Rath
51.	Π:	—	$+43$	$+3R\frac{11}{9}$	$10.1.\bar{11}.3$	new
52.	Γ:	—	$+\frac{19}{4}4$	$+4R\frac{9}{8}$	$17.1.\bar{18}.4.$	new
53.	△:	—	$+54$	$+4R\frac{7}{6}$	$13.1.\bar{14}.3.$	new
54.	Σ:	—	$+\frac{26}{5}4$	$+4R\frac{6}{5}$	$22.2.\bar{24}.5.$	new
55.	Θ:	—	$+\frac{16}{3}4$	$+4R\frac{11}{9}$	$40.4.\bar{44}.9.$	new
56.	Φ:	—	$+\frac{11}{2}4$	$+4R\frac{5}{4}$	$9.1.\bar{10}.2$	new
57.	Λ:	—	$+\frac{40}{7}4$	$+4R\frac{9}{7}$	$32.4.\bar{36}.7.$	new
58.	Ξ:	—	$+64$	$+4R\frac{4}{3}$	$14.2.\bar{16}.3.$	
59.	𝔓:	—	$+74$	$+4R\frac{3}{2}$	$51\bar{6}1$	
60.	ℑ:	—	$+10\ 4$	$+4R2$	$62\bar{8}1$	

No.	Letter		Symbol			Remarks
	Gld. Pal.	D.	Goldsch.	Naumann	Bravais-Miller	
61.	U	—	$+62$	$+2R\frac{7}{3}$	$10.4.\bar{14}.3.$	new
62.	𝔅:	Q	$+\frac{32}{5}\frac{8}{5}$	$+\frac{8}{5}R3$	$16.8.\bar{24}.5.$	
63.	P	—	$+92$	$+2R\frac{10}{3}$	$13.7.\bar{20}.3.$	new
64.	M	—	$+\frac{16}{5}\frac{4}{5}$	$+\frac{4}{5}R3$	$8.4.\bar{12}\ 5.$	new
65.	Z	—	$+\frac{8}{5}\frac{4}{5}$	$+\frac{4}{5}R\frac{5}{3}$	$16.4.\bar{20}.15.$	new
66.	N	—	$+\frac{20}{11}\frac{8}{11}$	$+\frac{8}{11}R2$	$12.4.\bar{16}.11.$	new
67.	𝔴:	—	$+\frac{5}{2}\frac{1}{2}$	$+\frac{1}{2}R\frac{11}{3}$	$7.4.\bar{11}.6.$	new
68.	𝔟	—	$+\frac{14}{5}\frac{3}{5}$	$+\frac{3}{5}R\frac{31}{9}$	$20.11.\bar{31}.15.$	new
69.	𝔞	—	$+\frac{25}{7}\frac{6}{7}$	$+\frac{6}{7}R\frac{28}{9}$	$37.19.\bar{56}.21.$	new
70.	b:	Γ	$-\frac{11}{4}\frac{1}{2}$	$-\frac{1}{2}R4$	$\bar{5}384$	vom Rath, Des Cloizeaux
71.	𝔉:	p	$-\frac{16}{5}\frac{4}{5}$	$-\frac{4}{5}R3$	$\bar{8}.\bar{4}.12.5.$	vom Rath, Irby, Des Cloiz.
72.	F	—	$-\frac{7}{2}1$	$-R\frac{8}{3}$	$\bar{11}.\bar{5}.16.6.$	new
73.	A	—	$-\frac{26}{7}\frac{8}{7}$	$-\frac{8}{7}R\frac{5}{2}$	$\bar{14}.\bar{6}.20\ 7.$	new
74.	I	—	$-\frac{31}{8}\frac{5}{4}$	$-\frac{5}{4}R\frac{12}{5}$	$\bar{17}.\bar{7}.24,8.$	new
75.	Y	—	$-\frac{56}{13}\frac{20}{13}$	$-\frac{20}{13}R\frac{11}{5}$	$\bar{32}.\bar{12}.44.13.$	
76.	𝔭:	x	-52	$-2R2$	$\bar{3}\bar{1}41$	vom Rath, Des Cloizeaux
77.	B	—	$-\frac{64}{11}\frac{28}{11}$	$-\frac{28}{11}R\frac{13}{7}$	$\bar{40}.\bar{12}.52.11.$	new
78.	𝔛:	N	-84	$-4R\frac{5}{3}$	$\bar{16}.\bar{4}.20.3.$	vom Rath
79.	C	—	$-\frac{18}{7}\frac{4}{7}$	$-\frac{4}{7}R\frac{10}{3}$	$\bar{26}.\bar{14}.40.21.$	Irby
80.	I·	—	$-3\frac{7}{8}$	$-\frac{7}{8}R\frac{55}{21}$	$\bar{38}.\bar{17}.55.24.$	new
81.	D	—	$-\frac{7}{2}\frac{5}{4}$	$-\frac{5}{4}R\frac{11}{5}$	$\bar{8}.\bar{3}.11.4.$	new
82.	E	—	$-\frac{7}{4}\frac{7}{22}$	$-\frac{7}{22}R4$	$\bar{35}.\bar{21}.56.44.$	new
83.	K	—	$-\frac{13}{8}\frac{5}{4}$	$-\frac{5}{4}R\frac{6}{5}$	$\bar{11}.\bar{1}.12.8.$	new
84.	𝔡	—	$-\frac{44}{31}\frac{32}{31}$	$-\frac{32}{31}R\frac{3}{2}$	$\bar{36}.\bar{4}.40.31.$	·new
85.	𝔠	—	$-\frac{28}{17}\frac{16}{17}$	$-\frac{16}{17}R\frac{3}{2}$	$\bar{20}.\bar{4}.24.17.$	new
86.	𝔣	—	$-\frac{32}{13}\frac{14}{13}$	$-\frac{14}{13}R\frac{13}{7}$	$\bar{20}.\bar{6}.26.13.$	new
87.	𝔤:	K	-21	$-R\frac{5}{3}$	$\bar{4}\bar{1}53$	

NOTE: The paper of Césaro op. cit was not accessible to the author and the forms observed by him are therefore not included above.

Supplementary List of uncertain forms of Lake Superior Calcite.

No.	Letter		Symbol			Remarks
			Goldsch.	Naumann	Bravais-Miller	
1.			$+18.18$	$+18R$	$18.0.\bar{18}.1.$	vom Rath Probably 19 R or $\frac{35}{2}$ R (Golds.), either of which conforms better with the series of rhombohedron forms.
2.			$+\frac{15}{6}\frac{1}{2}$	$+\frac{1}{2}R\frac{11}{3}$	$7.4.\bar{11}.6.$	Irby. Dull face, approx. readings.
3.			$+\frac{70}{27}\frac{14}{27}$	$+\frac{14}{27}R\frac{11}{3}$	$98.56.\bar{154}.81.$	Hess., Césaro. Probably same as No. 2.
4.			$-\frac{19}{11}\frac{10}{11}$	$-\frac{10}{11}R\frac{8}{5}$	$\bar{13}.\bar{3}.16.11$	Forms 4 to 8 inclusive were described by Irby. All were in striated zones, determined mostly from a single measurement, and are not established, especially as the author's study has shown the forms in this vicinity very subject to the formation of vicinal planes.
5.			$-\frac{32}{13}\frac{8}{13}$	$-\frac{8}{13}R3$	$\bar{16}.\bar{8}.24.13.$	
6.			$-\frac{23}{9}\frac{5}{9}$	$-\frac{5}{9}R\frac{17}{5}$	$\bar{11}.\bar{6}.17.9.$	
7.			$-\frac{109}{41}\frac{22}{41}$	$-\frac{22}{41}R\frac{40}{11}$	$\bar{51}.\bar{29}.80.41.$	
8.			$-\frac{129}{56}\frac{17}{28}$	$-\frac{17}{28}R\frac{52}{17}$	$\bar{69}.\bar{35}.104.56.$	

GNOMONIC PROJECTION OF CALCITE FORMS:—In order to study the relations of a large number of crystal forms it is necessary to represent them as projected upon a plane. The method here used to do this is known as the *gnomonic projection*. It is constructed as follows: A sphere Is Imagined as described about the centre of the crystal and a radius of the sphere is drawn normal to each face of the crystal. These radii are extended to intersect a plane tangent to the sphere at the point where the normal to the basal plane emerges, which plane is made to coincide with the plane of the construction. The points of intersection of the face-normals with the plane of projection represent the faces of the crystal. In such a projection the points representing all the faces of a zone—that is, all faces that are parallel to a single direction and whose mutual intersections are therefore parallel—lie along a straight line; and it is this property of the projection which is most useful In the study of so large a number of forms as we have to do with here.

Plate XVI is a gnomonic projection of the forms observed on Lake Superior calcite. It will be noted that the basal plane appears in the centre of the projection; the rhombohedrons lie along six lines diverging at sixty degrees from the centre, positive and negative forms in alternate sectants; the scalenohedrons lie within the sectants; and the prisms are indicated by arrows at the margin pointing to their position, they not appearing as points since the normals to the prism planes are parallel to the plane of projection and hence do not intersect it.

It will at once be noted how certain zone lines stand out In the projection by reason of the number of planes distributed along them. A few words may well be devoted to the more important of these zones before the discussion of the individual forms is entered upon.

The most interesting zone, as being the most characteristic for this locality, is the one containing the planes δ, -½ R, b□ -½R 4; and Ж□, -4R $^{5}/_{3}$, with many others between. Very few calcites from Lake Superior can be found which do not show one or more of the scalenohedrons of this zone; and on many crystals three or four may be present. Of the nine scalenohedrons in the zone four are new and peculiar to this locality, and the form b□, -½R4, is, as vom Rath first stated, the characteristic form for the region.

A second zone, notable for its richness in forms, is that stretching between m· ,+4R, and □□, +4R 2, containing in this portion nine positive scalenohedrons, of which all but three are here observed for the first time.

The zones containing the various rhombohedrons are of course conspicuous from the great number of planes lying in them, but other localities exhibit the same richness In these forms. The same is true of the zone stretching between two faces of p·, the unit rhombohedron, and beyond in both directions. This is the most important zone among the calcite forms as a whole, containing the commonest scalenohedrons of the species; it is well represented in our crystals by numerous forms, but does not have the peculiar significance for this region possessed by some other zones.

Of the other less important zones that may be traced among the forms of the projection, those of most interest are the ones connecting the many new scalenohedrons grouped about λ· ,-$^{8}/_{7}$R,, and those near p· ,+R, and K:, +R3.

It is probable that the more important zone lines represent directions along which the molecular forces were particularly active during the growth of the crystal. The activity of these forces is controlled in a way not at all understood as yet by the environment of the crystal during growth; according as the conditions favor the one set of forces or the other, faces of forms in the various zones come to bound the crystal, and that variety of combinations is produced which is described by the term "crystal habit." Molecular forces acting along lines transverse to the chief zones are also effective in producing faces upon the crystal, and the points where two or more zones intersect, very commonly mark the most frequently occurring and best developed forms.

FORMS AND COMBINATIONS:—The forms given above in the table, will now be described, singly or in groups as their relative importance and mode of occurrence on the crystals demand.

No. 1, *Basal Plane*. This form appears very rarely on crystals on which positive scalenohedrons dominate the combination, but where negative forms control the habit it is rarely absent, though often small. It is generally bright, but appears sensitive to etching agents and is one of the first planes to become dull when the crystal is attacked.

These observations do not agree with those of Pumpelly* whosays: "The basal termination on scalenohedrons of calcite is as rare on Lake Superior as elsewhere, and in the few instances where I have seen it, it lacks the polish which indicates perfect growth."

The form will be observed in various degrees of development in several of the drawings.

Nos. 2 to 6, *Prisms.* The prismatic development is notably rare on Lake Superior calcites. Figure 8, plate XII, reproduces a crystal of prismatic habit, as does figure 21, plate XIV. But these are exceptional types, and generally where prisms occur they are subordinate to other forms, as in figure 20, plate XV. The prism of the second order, ∞P2, was noted more often than was ∞R; but the commonest of the prism forms is the new one, *ψ*, ∞R $^{11}/_{9}$, which is shown in figure 3, plate XI, and elsewhere. Its faces, often rounded, were sharp and bright on many crystals, and the form may be taken as well established and as rather characteristic for the region.

*loc. cit. p. 21.

Nos. 7 to 10. *Pyramids of second order*. These are of minor importance, none of them having been observed more than once. Of the two that are new, ω, $^{33}/_{9}$P2, is shown in figure 9, plate XIII; the other occurred on a crystal not here figured.

Nos. 11 to 16. *Positive rhombohedrons*. While rarely dominant, these forms are highly characteristic for the region, and are seldom entirely lacking. The steeper forms, Nos. 11, 12, and 13, are of rare occurrence.

m·,+4R, is however the commonest form of all and plays an important part in the development of the crystals. Rarely very large, it is still present on almost every crystal, is always of the most perfect quality and its admirable reflections were very commonly used to orient the crystal for measuring. About it, as is well shown in the projection and in such crystals as are illustrated by figures 5 and 7, plate XII, are clustered many zones and forms, evidencing the importance of the form. Its characteristic deltoid or triangular shape may be seen in figure 14, plate XIII, and figures 20 and 24, plate XV.

k·, +$^{5}/_{2}$R, occurs rather often as a narrow truncation of the obtuse edge of the common scalenohedron K:,+R3.

R· ,+2R. This new rhombohedron is the dominant form on a magnificent crystal of the Hubbard collection, shown in figure 6, plate XII. It was not observed elsewhere, but the size and perfection of the faces left nothing to be desired in its determination.

p· ,+R. This form occurs only less frequently than +4R on Lake Superior crystals, a notable fact since it is not a common form for most localities. Its faces are generally good, though sometimes dulled by etching. As it is the cleavage rhombohedron, it was always used to orient the forms—that is to determine whether positive or negative—and as few crystals are so fortunate as to have escaped some slight bruise, sufficient, with the easy cleavage of calcite, to develop cracks or to break off a corner, faces of +R were hardly ever absent even when not present as crystal planes.

Nos. 18 to 31. *Negative Rhombohedrons*.

δ· ,-½R, appears very frequently as a terminal plane, sometimes alone, and with plane faces, more often striated deeply by oscillatory combination with scalenohedrons of the principal zone, a feature not of course confined to this locality.

λ· , $-^8/_7$R, occupies an important place in the zonal development of these calcites, and appears with sharp, plane faces on many crystals, examples of which may be seen in figure 5, plate XII, figure 10, plate XIII, and figure 16, plate XIV. It seems to be confined to crystals of negative scalenohedral habit.

The forms numbered 19, 21 to 25, and 27 are for the most part limited to a few crystals on which they form zones striking in the sharpness which these slightly differing forms may be recognized. Figure 1, plate XI, a beautiful specimen from the Bement collection, and figure 20 plate XV, from the same source, are the best representatives of this type; in others they merge together more or less, forming rounded surfaces with horizontal striations.

φ· , -2R, is the most common of the negative rhombohedrons. It is generally of brilliant lustre, and its ordinary position, truncating the acute edge of the scalenohedron K:, +R3, as in figure 3, plate XI, makes its identification easy in many cases. Its appearance is very different on crystals of the negative scalenohedral type, such as shown in figures 9 and 13, plate XIII.

r· , -3K, forms rhombohedral crystals, the polar edges obliquely truncated by +R, the lateral edges rounded by an indeterminate scalenohedron, which is often deeply etched.

Δ· ,$-^7/_2$R, was observed on several crystals.

II· ,-8R, occurs in a variety of combinations. See figures 24 and 22, plate XV, where it is the bearer of a simple combination of unusual type, the crystals being quite opaque from the abundance of inclusions as described above, page 165.

Σ·• , -11R, was observed only once.

No. 32. *u*:, $-^2/_{13}$R4. This new negative scalenohedron in the principal zone is of interest as occurring on several crystals as a narrow plane truncating the edge between the basal plane and the scalenohedron -½R4, in the manner shown in figure 23, plate XV.

Nos. 33 to 50. *Positive Scalenohedrons* of the principal zone. These forms fall naturally into two groups, comprising, 1st: those between two faces of +R (see projection) Nos. 33 to 39; 2nd: those lying beyond +R in the zone, Nos. 40 to 50. In the first group the forms are very prone to merge together, forming with -½R, a rounded surf ace giving a continuous train of reflections in the goniometer. The forms named were, however, well determined; some of them are nearly always present, as the terminations, with -½R, of crystals having the positive scalenohedral habit. Rarely the crystal is shortened in the direction of the chief axis, and the terminal planes become enlarged so as to give them the importance of dominant forms.

It is to forms of the second group, Nos. 40 to 50, that the crystals so frequently referred to as of positive scalenohedral habit owe their shape. The form K:, +R3, is generally the bearer of these combinations, as is well shown in figure 3, plate XI; upon it the steeper forms of the zone, including the prism of the second order (∞P2) appear as a series of narrow faces parallel to the lateral edges, often merged into a striated, rounded surface. The same is true of the flatter forms which are, however, less numerous, forming a transition to +R and through this form to the series of the first group. Crystals of this habit, more or less modified by negative forms and rhombohedrons, are very abundant, comprising perhaps more than a third of those studied. To this type belonged all the crystals described by vom Rath. They are the characteristic product of the mines of: the Ontonagon District, of which the old Minnesota and the National are among the best known. The perfection of symmetrical development of some of the calcites of this type, the abundance and brilliancy of their planes and their transparency combine to place them among the most remarkable crystals known to mineralogy.

H:, +R2, beside occurring as above described, was observed frequently with small, bright faces on crystals of negative type as shown in figure 17, plate XIV.

K:, +R3, is rarely absent from Lake Superior calcites. Either it is dominant as above, or it is in equally balanced development with negative forms, as in figure 1, plate XI, or it occurs as a subordinate form on crystals of negative habit, as in figure 13, plate XIII. In whatever manner it occurs, its faces are always of the finest, remaining bright after most of the other forms have suffered from etching.

P· , $+R^{14}/_3$. New, observed on two crystals not here figured.

U:, +R9, is figured by vom Rath as the dominant form on one of his crystals. Though not so observed by the writer, it was found on several specimens as a narrow face.

The remaining forms of this group were not observed except as subordinate members of the principal zone.

Nos. 51 to 60. *Positive scalenohedrons of the parallel zone, +4R to -2R*.

The interest attaching to this zone has been pointed out under a previous heading. Representatives of the zone are found on many crystals, and it appears specially characteristic of the water-clear specimens from the Central mine which, except for these forms, display a negative scalenohedral habit. Figure 2, plate XI, and figure 17, plate XIV, show typical combinations in which these forms are prominent and their relations will be best understood by examination of these drawings.

II□, $+3R^{11}/_9$, stands apart from the rest of the group as falling within +4R in the zone. It was observed on but two crystals, one of which is shown in figure 5, plate XII. The faces were particularly bright and plane.

□□ ,+4R2 was the most frequently observed of these forms; its bright faces occurred sometimes without any other member of the group, but generally between it and +4R is a series of the intermediate forms.

Nos. 52 to 57 are all new; Nos. 58 and 59 had been before observed by Hessenberg. Although these nine forms lie so near together their faces were always sufficiently distinct to give sharp reflections in the goniometer, and as all but one of them were observed at least once quite alone, each member of the very complete series may be accepted as established.

Nos. 61 to 69. *Positive scalenohedrons of various zones.*

U, $+2R^{7}/_{3}$, new to calcite, is a very common and characteristic form for the Lake Superior crystals. Always with brilliant faces, and lying in a zone with +4R, its recognition is generally easy. Figure 4, plate XI, shows it as the dominant form of the combination; more often it is subordinate in size as in figure 2, plate XI, figure 7, plate XII, and figure 14, plate XIII.

□□, $+{}^{8}/_{5}R3$, Observed but once on the crystal shown in figure 9, plate XIII.

P, $+2R^{10}/_{3}$. New—a small face observed only on the crystal shown in figure 7, plate XII.

M, $+{}^{4}/_{5}R3$, New—well developed on one crystal as shown in figure 9, plate XIII.

Z,$^{4}/_{5}R^{5}/_{3}$. New—observed on several crystals, but generally somewhat rounded and tending to pass over to the next form. Shown in figure 17, plate XIV.

N, $+—{}^{8}/_{11}R2$. New—a common form on crystals of negative habit, with smooth faces, often quite large. It is nearly in the zone of the acute edge of -½R4, which makes it easily recognizable in most cases Shown in figure 6, plate XII, and in figure 19, plate XIV.

□□, $+½R^{11}/_{3}$; □, $+{}^{3}/_{5}R^{31}/_{9}$; □, $+{}^{6}/_{7}R^{28}/_{9}$; These three new forms lie in a zone between +R3 and +R. They occur with small, bright faces, sometimes altogether as in figure 5, plate XII, or separately, as in figure 7, plate XII, on a few crystals of negative scalenohedral habit.

Nos. 70 to 78. *Negative scalenohedrons of the zone -½R4 to -* $4R^{5}/_{3}$

This zone has already been pointed out as the most characteristic for the region. Many crystals are combinations exclusively of forms of this zone, a feature the more marked, as negative scalenohedrons as a rule play a subordinate part in the crystallization of calcite, and though certain of the forms here prominent are of common occurrence elsewhere, on no other crystals does the zone as a whole assume any importance.

b□, -½R4, is the form which fills the most noteworthy role in the development of Lake Superior calcites. Its faces are usually plane and lustrous, giving good reflections in the goniometer. But in crystals where its planes are of relatively large size, it is often much facetted and broken by numerous vicinal planes, most of them very near it in position, and some of sufficiently constant recurrence to be established as independent forms. They will be discussed on a subsequent page. It was the occurrence of these forms on the crystals measured first by Hessenburg, and re-examined by Irby, that occasioned the large discrepancies in their results. Only by examination of a larger suite of crystals could their true character be determined.

-½R4 appears often as the bearer of the combination, as in figures 23 and 19, plate XV. More frequently it is in balanced development with the form -2R2, as in figures 15 and 18, plate XIV. In such crystals its bright faces are in marked contrast to the deeply striated faces of the steeper form. It is this type of crystal that is found most abundantly at the present day, chiefly from the Quincy mine and others in the Pewabic belt. Quite as often it is found as a subordinate form, both on crystals of a negative habit, as in figures 1 and 2, plate XI, and on those of positive habit, as figure 3, plate XI. In short, it occurs in all possible varieties of development, and is rarely absent.

□□ ,$-{}^{4}/_{5}R3$, is far less common than the last, but is still a frequent form. Figure 12, plate XIII, shows it as the dominant form of a combination, and it plays the same part in Irby's figure 6. This, however, is rare, and it is more apt to appear as a subordinate face of the negative zone on crystals of positive scalenohedral habit, like that figured by Des Cloizeaux. Its faces are of good quality,

F,$-R^{8}/_{3}$. New—observed but once, as shown in figure 11, plate XIII.

A,$-{}^{8}/_{7}R^{5}/_{2}$. New—observed but once, as a striated face, but well determined by the zonal relations, as shown in figure 6, plate XII.

I,$-{}^{5}/_{4}R^{12}/_{5}$. New—observed but once as a narrow face in the chief zone, as shown in figure 14, plate XIII.

Y,$-{}^{20}/_{13}R^{11}/_{5}$, was first observed by vom Rath on Bergen Hill calcite, and had not again been recognized. Here it is of frequent occurrence, sometimes, as in figure 4, plate XI, of dominant character, more often as a narrow face in the zone. Faces generally deeply striated or dull.

□□,-2R2, is only less common than -½R4, with which it is nearly always associated. Its faces are not always striated, as described above, but are plane and lustrous.

B,$-{}^{28}/_{11}R^{13}/_{7}$. New—observed on two crystals as a narrow face in the zone, as shown in figure 17, plate XIV.

Ж□ ,$-4R^{5}/_{3}$, was often observed, and sometimes with large faces; always of good lustre. Shown in figure 8, plate XII, and in several of vom Rath's figures.

Nos. 79 to 87. *Negative scalenohedrons of other zones*.

The three forms, Nos. 79, 80 and 81, belong to a zone which is of peculiar interest from its nearness, both, in position and direction to the principal negative zone just described. It is as though some disturbing force had been active during crystal growth, pulling the faces slightly out of their normal positions. It is doubtless to such abnormal forces that we are to ascribe the formation of the so-called "vicinal planes," and as such, these are to be regarded, though they are here sufficiently definite in their occurrence to be recognized as independent forms.

C,$-{}^{4}/_{7}R^{10}/_{3}$, was one of the many planes, near to -½R4, observed by Irby on a single crystal. It alone has been confirmed by the study of the larger series at the author's command. It is a very common form, either as the bearer of rich combinations like those shown in figure 5, plate XII, and in figure 17, plate XIV; or as a vicinal to -½R4 in the shape of facets as shown in figure 19, plate XIV, and in figure 7, plate XII. Figure 10, plate XIII, reproduces a crystal of special interest as exhibiting all the forms of this abnormal zone without any of the typical forms being present. The crystal sufficiently defines the character of the two new forms of the zone, I·,$-⅞R^{55}/_{21}$, and D,$-{}^{5}/_{4}R^{11}/_{5}$, neither of which was observed more than twice.

No. 82, E, $-{}^{7}/_{22}R4$. New—observed on but one crystal, as a narrow truncation of the edge between 0P and C, $-{}^{4}/_{7}R^{10}/_{3}$, as shown in figure 5, plate XII. The faces were somewhat uneven.

No. 83, K,$-{}^{5}/_{4}R^{6}/_{5}$, is a new form of special interest, and is very characteristic for the region. Many crystals had been examined which were very nearly cubical in outline, but their faces so rounded and broken that it was impossible even to say whether the dominant form was a rhombohedron or a scalenohedron. At length the crystal reproduced in figure 13, plate XIII, was sent to the author as a very rare form from the Ridge mine, and it gave a satisfactory solution of most of the problematic crystals. The dominant form was the scalenohedron in question, $-{}^{5}/_{4}R^{6}/_{5}$; it approximates so closely to the rhombohedron $-{}^{7}/_{5}R$, whose angles are within less than a degree of 90 degrees, that the cubical appearance of the rough crystals on which it occurred is readily understood. Owing to the selection of the point of view, this effect is unfortunately rather poor in the drawing. On this crystal the planes were highly polished and gave excellent reflections; it was not observed in measurable condition on other specimens.

No. 84, □, $-{}^{32}/_{31}R^{3}/_{2}$, and No. 85, □,$-{}^{16}/_{17}R^{3}/_{2}$, are new forms in a zone with $-{}^{8}/_{7}R$ and -½R4. The crystal on which they were observed was etched in parts, and it is possible that these are etch faces, which would in a measure explain their complex symbols. They are shown in figure 12, plate XIII. The second of the two was also observed on other crystals.

No. 86, □, $-{}^{14}/_{13}R^{13}/_{7}$, a new form, and No. 87, □□, $-R^{5}/_{3}$, occur, together with No. 85, in a zone on three crystals of the type shown in figure 16, plate XIV. The large development of these forms on several splendid crystals, and the perfect quality of their faces establish them as good forms despite the complex symbols which must be employed to satisfy the measured position. The crystal figured is also remarkable for its twinning, described below.

RÉSUMÉ:—A brief review of the foregoing descriptions shows the following facts. Of the 85 crystal forms observed by the author on Lake Superior calcites, 59 have not been before described from that locality, and 32 are new to the species.

The forms most prominent by reason of their common occurrence, are -½R4, +R3, +4R, +R, -2R2, and 0P.

As peculiarly characteristic of the locality, the following forms may be named: -½R4, +4R, $+2R^{7}/_{3}$, $+{}^{8}/_{11}R2$, $-{}^{8}/_{7}R$, $\infty R^{11}/_{9}$, and the forms having the general symbol 4Rn.

Two general types of habit are recognized in which the positive and the negative scalenohedrons dominate respectively, but there are many crystals of intermediate habit in which both groups of forms occur in balanced development. The prismatic and rhombohedral habits are rare.

There are but few exceptions to the rule that the crystal planes are of good quality, and give excellent reflections for measurements.

The formation of vicinal planes is most marked in the neighborhood of the form -½R4.

TWINNING:—Twinned crystals are a common feature of Lake Superior calcites. Twinning occurs according to two laws: first, the twin and composition face is 0P; second, the twin and composition face is -½R. Of these two laws the first is exemplified in a far greater number of cases.

A simple twin on 0P is shown in figure 20, plate XV, reproducing a remarkably perfect and symmetrical crystal from the Bement collection. In this crystal the twinning has not resulted in the appearance of any re-entrant angles as is so often the case; it is simply expressed in the horizontal boundary dividing the upper and lower portions of the crystal, and in the reversal of the ordinary alternate relation of the faces above and below. Such simple twins were also shown by the fine crystal in the U. S. National Museum at Washington, by a splendid specimen in the Hubbard collection, and by the crystal in the Harvard Cabinet, already mentioned as of unusual dimensions. They do not, however, seem to be of common occurrence.

A much more frequent expression of this twinning, is that shown in figure 17, plate XIV. Here a thin band or lamella through the centre of the crystal is alone in twinning position, the portions above and below it retaining their normal relation. This layer is parallel to 0P, and occupies almost invariably the very centre of the vertical dimension of the crystal. Sometimes it is of no greater thickness than a very thin sheet of paper, and may be traced as a fine hair-line or seam on the glassy surface of the crystal. Figure 17 shows such a case, the cross-section accompanying it aiding to show the interruption in the crystal growth caused by the twinning. The various faces are cut off sharply by this almost invisible boundary, some forms, however, such as m· , continuing their growth beyond the re-entrant caused by the twin lamella.

Again, the twin lamella may be of greater thickness, showing crystal planes on its surface as in figure 19, plate XIV. And in very exceptional cases the lamella grows outward along the edges, beyond the boundaries of the main crystal, producing wing-like segments of a second crystal in twin position to the parts of the first above and below. Two such specimens were studied, one of which, a superb crystal over two inches in height, from the Hubbard collection, is figured in figure 16, plate XIV. The other was from the Pumpelly collection, and was much smaller and less perfect, but was bounded by the same rare planes as the first named. Very often, too, several lamellae in alternate twin position are intercalated in the crystal centre.

The occurrence of this twin seam or "Naht" was first described by vom Rath, and is a characteristic feature of the Lake Superior crystals, not known elsewhere.

Twins on the face of -½R are not rare, and often take the form shown in figure 18, plate XIV, the distortion of the faces of -2R2, there indicated, being a common feature. This form of twin was observed only on crystals of negative type, chiefly from the Quincy mine; the finest example seen was a very large specimen in the Hubbard collection not here figured. Many crystals show numerous twin lamellae parallel to -½R, and on some such, sent to me by Dr. Hubbard, he pointed out that the summits were injured in such a way as to suggest a blow or impediment during growth sufficient perhaps to produce a pressure on the crystal through which the twinning was induced in the well-known manner. In a few cases these fine twin lamellae traverse the crystal in such numbers and with such regularity as to produce a marked striation on the bounding faces.

STRIATION AND ETCHING:—Both phases of crystal imperfection are commonly illustrated on these calcites. Several cases of characteristic striation have already been cited, for example, that parallel to the combination edges of the planes of the principal negative zone; this affects all the faces of the zone, but particularly the forms b□ and Y.

Other examples may here be noted. In figure 5, plate XII, striations are well marked parallel to the edge between λ· and C. In figure 14, plate XIII, v-shaped striations will be seen on m- parallel to its intersection edges with the faces of 4Rn. Deep striations are frequent parallel to the edges of! intersection of N with b□ or its vicinals. In figure 2, plate XI, is show a horizontally striated face lying between m· and U; it is found to be produced by the oscillatory combination of the forms *θ*□, $+4R^{11}/_{9}$, and II□, $+3R^{11}/_{9}$. In the same way, in figure 9, plate XIII, the striation face between □□ and C is caused by combination of ω and m.

The effects of etching have not been introduced into the figures, though many of the crystals studied showed interesting samples of that process. As the faces produced by it are almost always rounded or rough, and of variable position, they cannot for the most part be given places as independent forms. Some of the features may, however, be noted.

Many crystals of positive habit show among their terminal planes more or less even faces lying slightly out of the principal zone. This is probably an etch form, as measurements on various crystals gave very discordant results for its position. The crystals which show this form have very often suffered a deep corrosion of the upper parts of the faces of K:, +R3; these parts are roughened and pitted while the remainder of the crystal is unharmed. The portion of the face affected is generally bounded below by a curve which is symmetrically located on all the faces.

On one fine specimen from the collection of Mr. Whiting, deep triangular etch figures appeared on the faces of the form U,$-2R^{7}/_{3}$; unfortunately the crystal was too large to mount on the goniometer, and the position of the sharp faces which bounded the pits within, could not be determined.

In the description of the form K, $-^{5}/_{4}R^{6}/_{5}$, mention was made of the many rough and rounded crystals whose form was probably deter- mined by it. The rough surfaces of these crystals give evidence of having been produced by etching processes.

Nothing is known as to the agents producing these etching effects in this region; nor can they be correlated with any particular period of deposition, or mode of formation.

COURSE OF INVESTIGATION:—The crystallographic studies, the results of which have here been given in brief form, have extended over a period of nearly three years, during which new material has constantly been obtained. Some of the new forms discovered have already been announced in the pages of Groldschmidt's Krystallographische Winkeltabellen, Berlin, 1897, p. 396, and table, pp. 82-86, but many more have been added to the list since the publication of that work. It will be noted that the measurements and tables of angles on the basis of which the new forms have been established, are not given in this paper. Those who desire to consult these data are referred to a paper shortly to appear in the Zeitschrift für Krystallographie, where a full discussion will be given.

The measurements were made for the most part on a goniometer with two circles (Goldschmidt Model 1895), which proved itself especially effective in the study of the complex crystals in hand. Small crystals were generally available, and where such were not to be had, and specimens too large to be mounted on the two-circle instrument were to be measured, recourse was had to the ordinary horizontal goniometer (Fuess, No. 2.)

Mineralogical Museum, Harvard University, July 1898.

EXPLANATION OF PLATES.

Fig. 1. Bement Coll. (171). Locality not stated, but similar crystals in the coll. come from Owl Creek Vein, Copper Falls Mine. Transparent, yellowish, 1 inch high.

Fig. 2. Hubbard Coll. (86). Central Mine. Colorless, 1 inch high.

Fig. 3. Harvard Cabinet, (33). Minnesota Mine, Ontonagon district. Transparent, yellowish, 1 inch high.

Fig. 4. Whiting Coll. (9). Colorless, ¼ inch high.

Fig. 5. Whiting Coll. (3). Colorless, minute. The face C which occurs on this crystal, and is referred to twice on page 179, is the face running diagonally down from p-.

Fig. 6. Hubbard Coll. (268). Colorless, 3 inches high.

Fig. 7. Whiting Coll. (54). Colorless, 1 inch high.

Fig. 8. Munich Cabinet. Reproduced from Zeit. für Kryst., *loc. cit.* p. 589.

Fig. 9. Brush Coll. (127). Twin lamella parallel to 0P. Colorless, 1½ inch high.

Fig. 10. Pumpelly Coll. (168). Phoenix Mine. Colorless, etched, small.

Fig. 11. Harvard Cabinet (129). Some faces etched, copper inclusions. Under ½ inch.

Fig. 12. Hubbard Coll. (258). Minute, colorless, etched in part.

Fig. 13. B. F. Chynoweth (259). Ridge Mine, Ontonagon district. Yellowish, 1 inch high.

Fig. 14. Whiting Coll. (18). Water-clear, 2 inches high.

Fig. 15. Harvard Cabinet (30). Central Mine. "Shadow Crystal," with copper inclusions, 1 inch high.

Fig. 16. Hubbard Coll. (266). Yellowish, 2½ inches high. Twin on 0P.

Fig. 17. Vaux Coll. (136). Water-clear, 2½ inches high (with vertical section). Twin lamella parallel to 0P shown.

Fig. 18. Hubbard Coll. Quincy Mine. Twin on -½R, copper inclu-clusions, 2 inches high.

Fig. 19. Hubbard Coll. (75). (Drawn in orthographic projection.) Twin on 0P. Yellowish, 1 inch high.

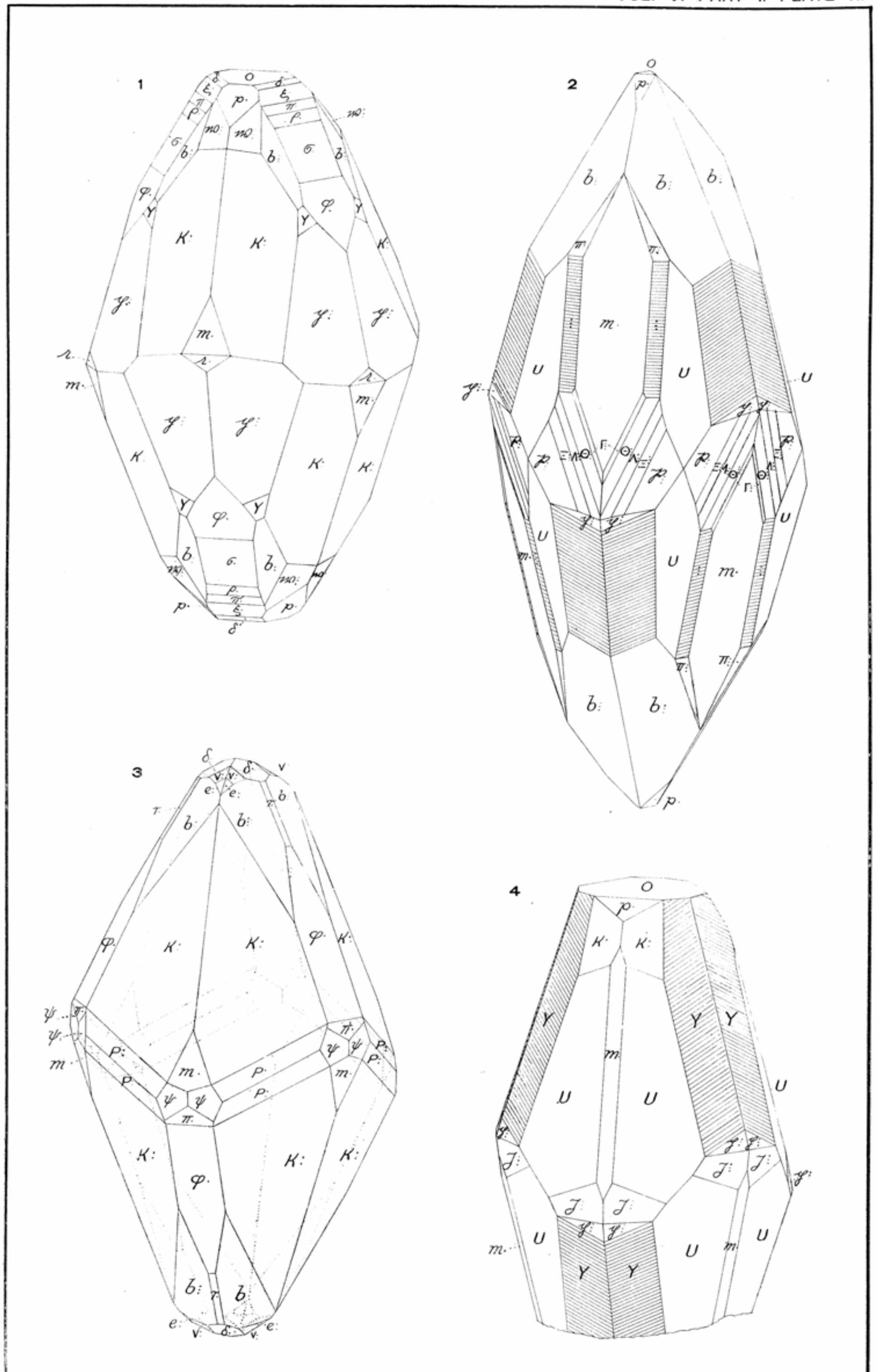
Fig. 20. Bement Coll. (164). Owl Creek Vein, Copper Falls Mine. Yellowish crystal, 2 inches high. Twin on 0P.

Fig. 21. Harvard Cabinet (143). Colorless, minute.

Fig. 22. Bement Coll. (165). Ridge Mine, Ontonagon district, 1 inch high, black from inclusions.

Fig. 23. H. L. Smyth (124). Colorless, ¼ inch high.

Fig. 24. W. D. Schoonmaker (139). One corner of large crystal 2 inches high, transparent.



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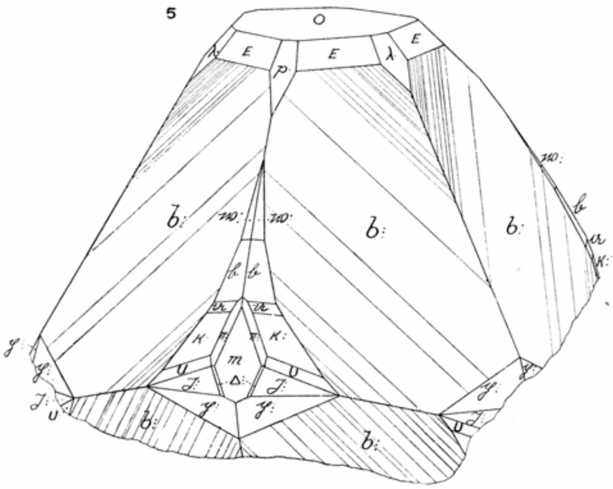

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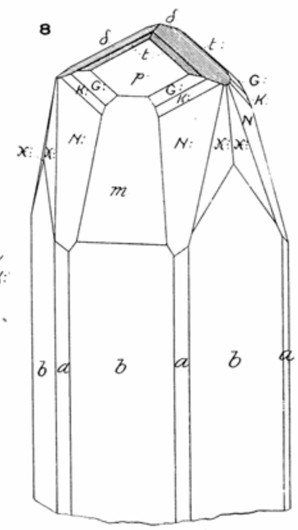

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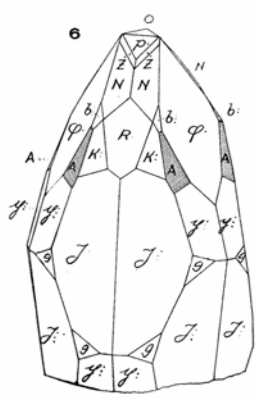

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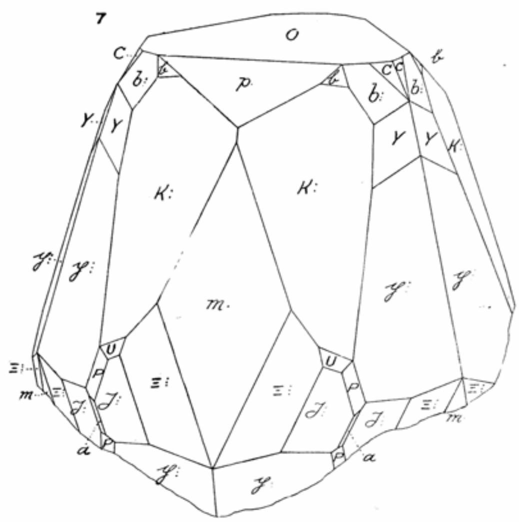

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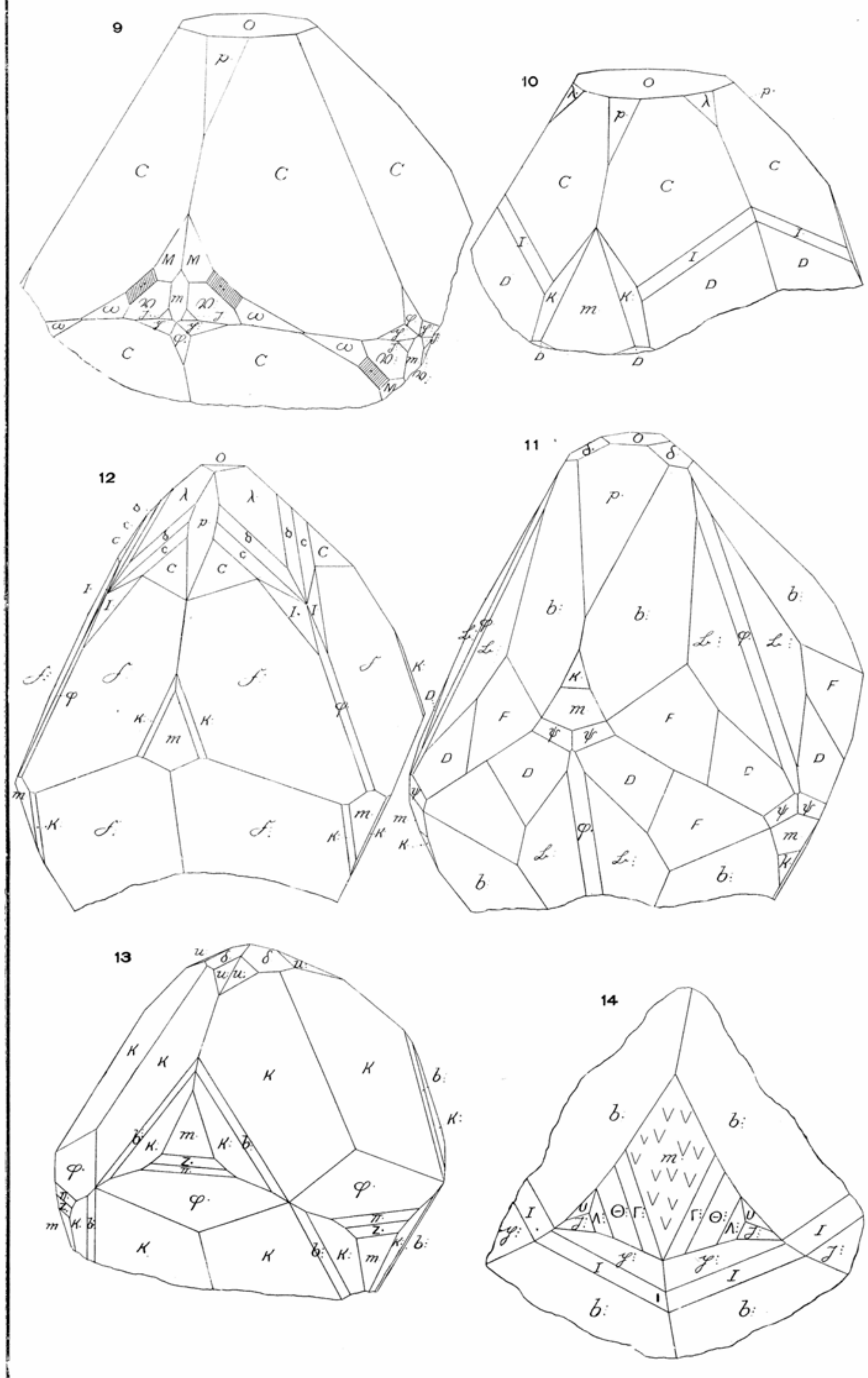

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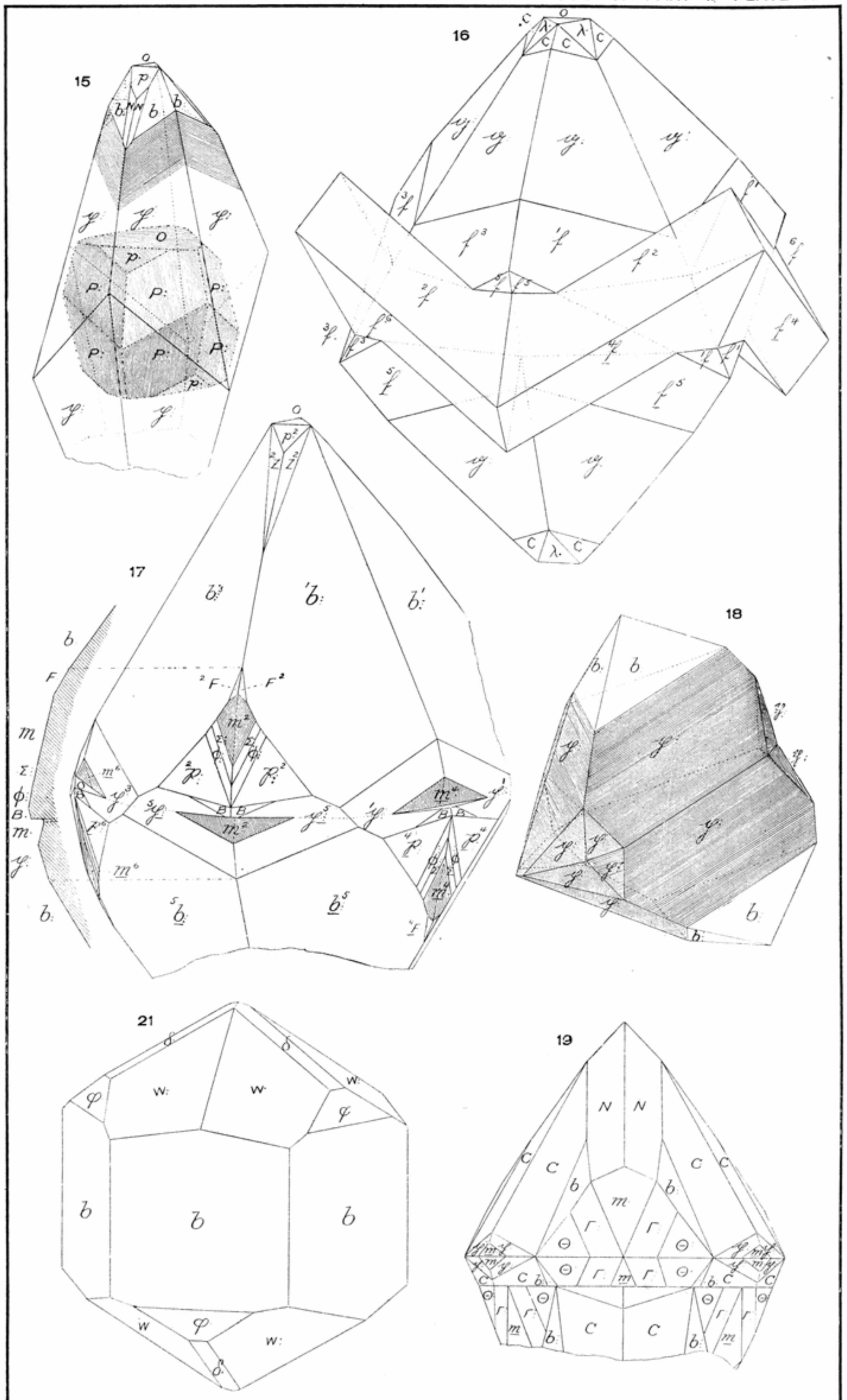

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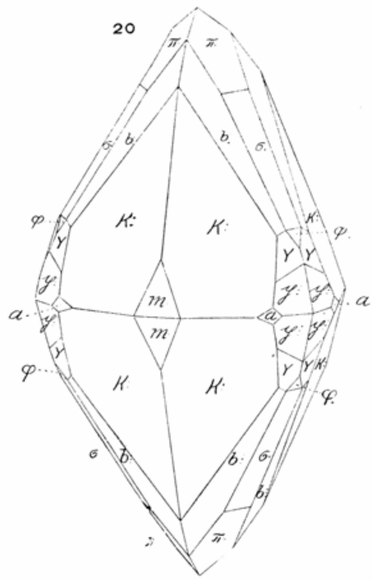

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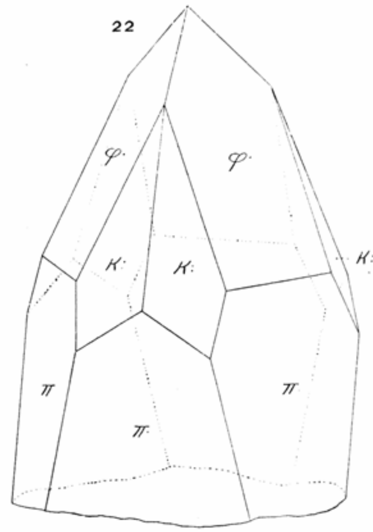

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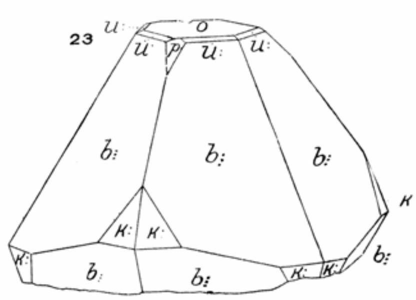

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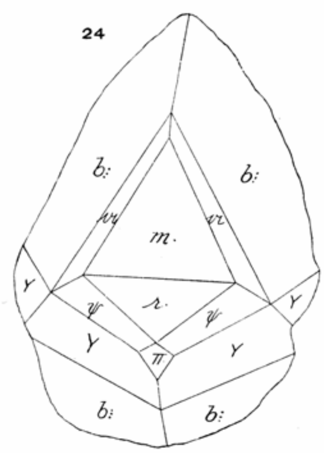

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