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EMPLECTITE AND THE ZINKENITE GROUP

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Summary

Two-circle measurements of seven crystals of emplectite ($Cu_2S \cdot Bi_2S_3$) from Johanngeorgenstadt, Saxony, gave 26 forms of which 21 are new. Setting the striated zone vertical and the cleavage parallel to $a(100)$ the crystals are orthorhombic with the elements: $p_0=0.8093$; $q_0=0.6389$. $a:b:c=0.7894:1:0.6389$.

The published orientations and unsatisfactory elements of emplectite are critically examined. The new data on emplectite strengthen the accepted isomorphism with chalcostibite. Suitably reorientated, zinkenite also shows good correspondence as far as the meagre data on this mineral go.

Emplectite

A critical study of the isomorphous relations supposed to exist among the members of the Zinkenite Group of Dana[1] led to a search in the Harvard Mineral Collection for measurable material which might throw further light on these imperfectly known minerals. The search was unsuccessful except in the case of emplectite (*Kupferwismuthglanz*), of which we were fortunate in finding a number of richly developed crystals enabling us to correct and extend considerably the scanty crystallographic data of this species. The improved knowledge of emplectite also suggested a revised presentation of the crystallography of the zinkenite group.

The measurable crystals of emplectite were detached from a specimen from Johanngeorgenstadt in Saxony, a locality from which measurements have not been previously reported. The emplectite, in some cases partly filmed with limonite, is associated with quartz and chalcopyrite. The crystals are striated prisms with an average thickness of about half a millimeter. The shape of the cross-section is in some cases a fairly regular, but strongly rounded, orthorhombic prism. In some cases the cross-section is flattened parallel to the perfect cleavage which is pinacoidal and lies in the

[1] *System*, 6th ed., **1892.** Goldschmidt discusses the spelling of zinkenite (zinckenite) at some length (*Index*, III, 332, **1891**) and recommends the latter form. Both spellings have been used from the first; we prefer the simpler form adopted by Dana.

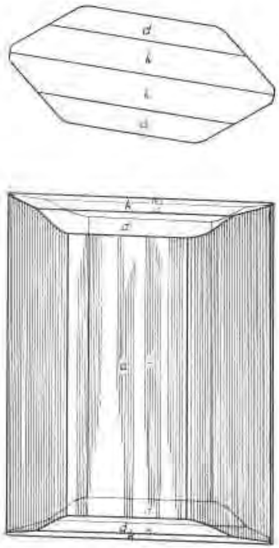

FIG. 1

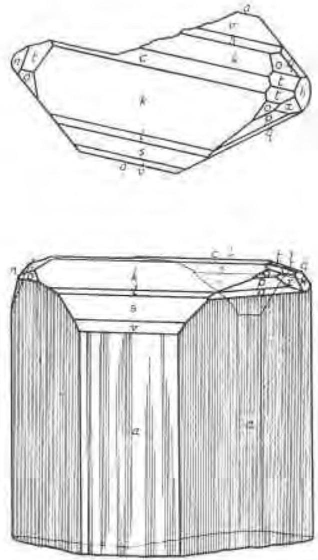

FIG 2

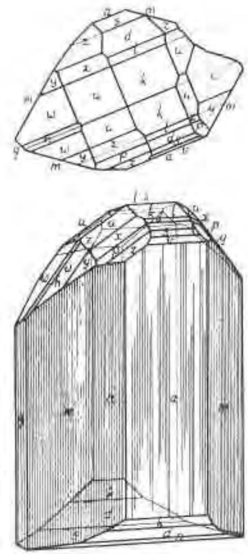

FIG. 3

FIG. 1. EMPLECTITE. Typical simple crystal (1.0×0.45 mm.) showing the curved striated prism zone, the front pinacoid (cleavage) and the two dominant macrodomes. Forms: *a*(100), *k*(103), *d*(101).

FIG. 2. EMPLECTITE. Crystal of common type (0.4×0.25 mm.) with large macrodomes and small brachydomes and pyramids. Forms: *c*(001), *a*(100), *h*(021), *n*(061), *k*(103), *l*(203), *s*(503), *v*(703), *o*(112), *p*(111), *q*(332), *t*(136), *x*(233).

FIG. 3. EMPLECTITE. Doubly terminated crystal with unusually well developed pyramidal forms (0.5×0.3 mm.) Forms: *a*(100), *m*(110), *g*(130), *h*(021), *k*(103), *l*(203), *d*(101), *s*(503), *v*(703), *p*(111), *u*(133), *w*(163), *x*(233), *y*(263), *z*(433). The hemimorphic appearance is deceptive; the lower termination has minute pyramidal faces like those in fig. 2.

striated zone; in others the flattening follows a pair of dominant parallel prism faces. Irregular cross-sections due to alternations of the prism and cleavage pinacoid are also represented.

The striated prisms are terminated, under favorable conditions at both ends, by large and brilliant faces of domatic aspect which evidently form a vertical zone with the plane of cleavage (fig. 1). Closer examination reveals the presence of numerous pyramidal faces which are for the most part exceedingly small. In some cases the pyramids are better developed and arranged in discernable radial zones (fig. 2) or in zones parallel to the dominant dome zone (fig. 3).

On the two-circle goniometer the striated zone gives trains of weak and valueless reflections with a few good single images or bright bundles of nearly coincident signals. The plane of the cleavage almost invariably gives a strong reflection; the other pinacoid in the striated zone is, on the other hand, rarely seen as a true face. The best prism signals were recorded and found to lie in simple positions; but it would have been impossible to choose a satisfactory unit form in the striated zone without reference to the terminations. This is also true, as we found by trial, of unterminated needles of emplectite from the Tannebaum-Stolln mine, Swartzenberg, Saxony, the source of the material on which the original measurements were made.

The terminal faces are brilliant, smooth planes giving good single images which vary in brightness according to the size of the face. The signals from the larger faces leave nothing to be desired, and even the reflections from the smallest faces fall into positions which vary within tolerably narrow limits.

The observations on seven selected crystals are summarized in the following table. From the weighted averages of all the good observations we determined the symmetry and elements of emplectite as follows:

EMPLECTITE: orthorhombic, holohedral

$$p_0 = 0.8093$$
$$q_0 = 0.6389$$
$$a:b:c = 0.7894:1:0.6389$$

From these elements we obtained the calculated angles in the following table which agree satisfactorily with the observations.

TABLE I. EMPLECTITE: TWO-CIRCLE ANGLE-TABLE.

Form	Calculated		Observed av.		Observed limits		No. of faces	No. of crystals	Av. quality of signal
	ϕ	ρ	ϕ	ρ	ϕ	ρ			
c 001	..	0°00′	..	0°00′	..	..	5	5	fair
b 010	0°00′	90 00	0°09′	90 00	..	..	1	1	fair
a 100	90 00	"	89 54	"	89°48′–90°09′	..	9	6	poor
g 130	22 53½	"	23 01	"	22 58 –23 04	..	2	2	poor
i 230	40 11	"	39 52	"	..	..	1	1	fair
r 560	46 33	"	46 10	"	46 00 –46 20	..	..	..	..
m 110	51 42½	"	51 49½	"	51 39 –52 00	..	2	1	poor
j 430	59 22	"	59 00	"	..	..	1	1	excellent
h 021	0 00	51 57	0 02	51 53	–0 12 – 0 13	51°45′–52°08′	9	4	fair
n 061	"	75 22½	"	75 32	" "	75 15 –76 07	9	4	fair
k 103	90 00	15 06	89 54	15 06	89 48 –90 09	14 53 –15 43	14	7	excellent
l 203	"	28 21	"	28 23	" "	28 04 –28 40	12	7	poor
d 101	"	38 59	"	38 59½	" "	38 49 –39 08	10	5	excellent
e 403	"	47 10½	"	47 25½	" "	46 54 –48 10	4	2	poor
s 503	"	53 27	"	53 36	" "	53 18 –54 09	10	7	fair
f 201	"	58 17½	"	58 48	" "	58 48 –58 48½	2	2	poor
v 703	"	62 05½	"	62 37	" "	61 10 –63 27	7	6	poor
o 112	51 42½	27 16½	51 39	27 18½	51 12 –52 18	27 12 –27 32	8	5	poor
p 111	"	45 52½	51 40	45 54½	" 52 01	45 48 –46 10	8	4	fair
q 332	"	57 07	51 37	57 10	51 12 –51 58	57 00 –57 21	4	2	poor
t 136	22 53½	19 07½	23 06	18 36	22 57 –23 44	18 30 –18 53	4	2	poor
u 133	"	34 44½	22 54	34 38½	22 39 –23 12	34 20 –34 50	11	4	good
w 163	11 55½	52 33½	11 57½	52 30	11 44 –12 09	52 20 –52 38	8	3	good
x 233	40 11	39 54	40 08	40 01½	39 52 –40 40	39 45 –40 17	11	6	good
y 263	22 53½	54 12½	22 56	54 09	22 44 –23 06	54 00 –54 19	12	5	good
z 433	59 22	51 25½	59 22	51 22½	59 11 –59 36	51 03 –51 35	5	2	fair

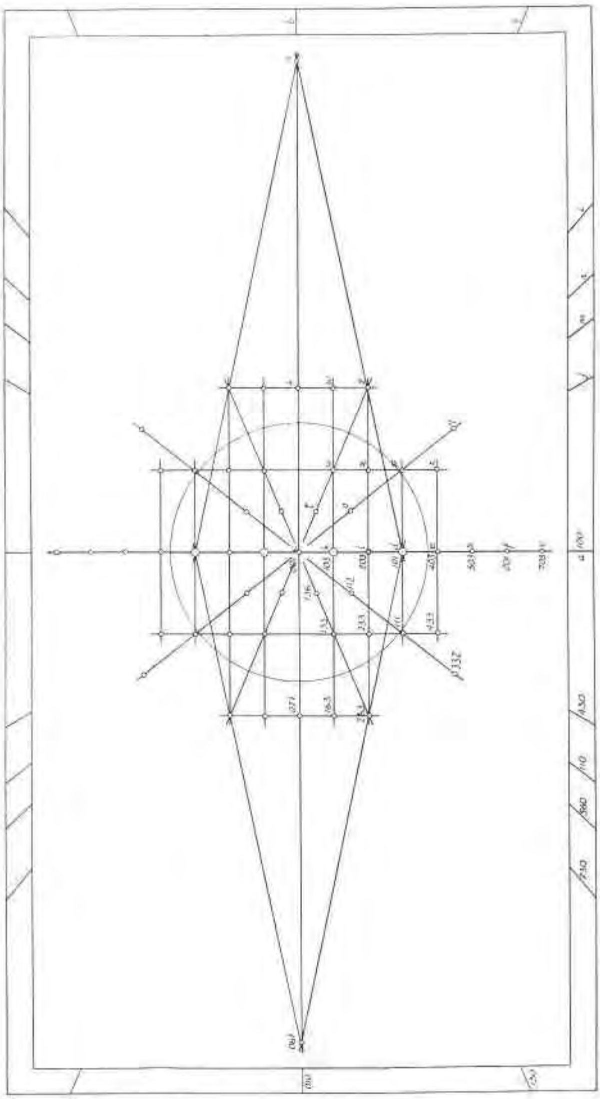

Fig. 4. Emplectite. Gnomonic projection of the known forms on the plane normal to the axis of the striated zone. The dominant terminal forms, *k*(103), *d*(101), are shown in larger points.

Of the forms given, $a(100)$, $m(110) = g(110)$ of Dauber,[2] $r(560) = z(110)$ of Weisbach,[3] $k(103)$, $d(101)$ have been observed before; the remaining twenty-one forms are new. The prismatic form $r(560)$ was not observed by us but the form is included on the basis of Weisbach's measurements. The remainder of Weisbach's forms in the striated zone, $x(170)$, $y(120)$, $u(320)$, were based on single unsatisfactory measurements; since, furthermore, the true symbols of these forms are exceedingly complicated, they are rejected as uncertain.

In view of the general similarity of habit of the crystals measured, a special table of combinations is unnecessary. The last three columns of Table I give the equivalent information. Since the quality of the terminal faces is approximately constant, the average quality of the signal from each form gives an approximate measure of its average relative size.

Figure 4 gives a gnomonic projection of the known forms of emplectite on the plane normal to the axis of the striated zone. The diagram displays orthorhombic symmetry and the projection points group themselves in well defined radial and parallel zones indicating that the striated zone is properly chosen as the prism zone. The simplest symbols would be obtained by choosing y as the unit pyramid (111); but to preserve the analogy with chalcostibite, to be discussed presently, we have decided to take p as the unit with a, the plane of cleavage, as the front pinacoid (100). Although the list of symbols obtained with this choice of unit is slightly less simple than that based on y as unit, the position and unit form we have adopted leads to d as the unit macrodome (101), a stronger form than l, and m as the unit prism (110), the form which is mainly responsible for the shape of the prismatic part of the crystals.

Previous Orientations and Elements. The elements we have given for emplectite differ very considerably from those in the works of reference when transformed into corresponding positions. This is due to the fact that Weisbach,[4] whose measurements are the last which have been published, observed only the cleavage-pinacoid, two forms in the macrodome zone and a number of poorly developed faces in the unsatisfactory striated zone. Weisbach thus

[2] *Pogg. Ann.*, **92**, 241, 1854.
[3] *Pogg. Ann.*, **128**, 435, 1866.
[4] *Pogg. Ann.*, **128**, 435, 1866.

obtained a good value for the element $p_0(=c/a)$; but due to an unhappy choice of unit prism, $z(110)$Weisbach = $r(560)$ of this paper, Weisbach's $q_0(=c)$ has a complicated relation to the value of this element as determined by the new terminal forms. To bring out correspondence between sartorite and emplectite Groth[5] assumed that Weisbach's $z(110)$ should have the symbol (650). The resulting elements, which have no practical relation to emplectite, were transformed into a new position and widely adopted. It will be of some value to examine briefly the published orientations and elements of emplectite and see how they were obtained.

Dauber, *Pogg. Ann.*, **92,** 241, 1854.

Orientation: Like ours; axis of the striated zone is the c-axis; cleavage parallel to $a(100)$.

Elements: $a:b:c=0.8000:1:0.6520$; calculated from the observed angles: $a(100)\wedge d(101)=50°49'$; $a(100)\wedge g(110)=38°39\frac{1}{2}'$.

These elements, derived from the first measurements made on emplectite, are similar to ours.

Weisbach, *Pogg. Ann.*, **128,** 435, 1866; Victor Goldschmidt, *Winkeltabellen*, **1897.**

Orientation: Like Dauber's and ours; axis of the striated zone is the c-axis; cleavage parallel to $a(100)$.

Elements: $a:b:c=0.9601:1:0.7738$; calculated from the observed angles: $a(100)\wedge d(101)=51°08'$; $a(100)\wedge z(110)=43°50'$.

Weisbach failed to find Dauber's $g(110)$ and took $z(110)$, which corresponds to our $r(560)$, as unit prism. With $z(560)$ Weisbach's observations lead to elements which are close to ours: $a:b:c=0.8001:1:0.6448$ (Weisbach). All subsequent presentations of emplectite rest on Weisbach's observations.

Groth, *Tabellarische Übersicht*, 2nd ed., **1882**; 3rd ed., **1889.**

Orientation: The axis of the striated zone is the b-axis; cleavage parallel to $c(001)$.

Elements: $a:b:c=0.5385:1:0.6204$; obtained from Weisbach's measurements, giving the symbol (650) to Weisbach's $z(110)$, and then interchanging the axes so that a (Groth) $=1/2c$ (Weisbach), c (Groth) $=a/2c$ (Weisbach).

Victor Goldschmidt, *Index*, **1886.**

Orientation: The axis of the striated zone is the a-axis; cleavage parallel to $c(001)$.

Elements: $a:b:c=0.7738:1:0.9601$, obtained by interchanging the a- and c-axes of Weisbach.

Goldschmidt rejects Groth's artificial symbol (650) for Weisbach's form z in favour of the original symbol (110).

[5] *Tabellarische Übersicht*, 2nd ed., **1882.**

Dana, *System*, 6th ed., **1892**. Groth, *Tabellarische Übersicht*, 4th ed., **1898**. Spencer, *Min. Mag.*, **11**, 191, 1897. Buttgenbach, *Tableaux*, **1918**. Groth, *Tabellen*, **1921**. Doelter, *Handbuch*, **1925**.

Orientation: Like that of Croth, 1882; the axis of the striated zone is the b-axis; cleavage parallel to $c(001)$.

Elements: $a:b:c=0.5430:1:0.6256$, obtained from Weisbach's measurements exactly as were those of Groth, using the artificial symbol (650) for the form z, but employing the measured angle $a(100)\wedge k(103)=75°05'$ instead of $a(100)\wedge d(101)=51°08'$.

Hintze, *Handbuch*, **1902**.

Orientation: Like that of Groth (1882); Dana (1892); the axis of the striated zone is the b-axis; cleavage parallel to $c(001)$.

Elements: $a:b:c=0.6517:1:0.6256$, calculated from Weisbach's observed angles, $a(100)\wedge k(103)=75°05'$; $a(100)\wedge z(110)=43°50'$, and transformed exactly as stated under Groth (1882). Hintze's elements thus correspond exactly with those of Groth (1882) with the original symbol (110) restored to the form z.

Hofmann, *Z. Krist.*, **84**, 177, 1933.

Orientation: Like that of Hintze (1902).

Elements: $a:b:c=1.573:1:3.729$, obtained from a determination of the dimensions of the unit cell. Transforming our elements into Hofmann's position and trebling the c-axis, we obtain: $a:b:c=1.5652:1:3.7068$. Although the trebled c-axis in this position is an acceptable choice for emplectite, we prefer to conform to the orientation and elements established for chalcostibite in Ernst's elaborate study (*N. Jahrb. f. Min.*, Beil. **LVI A**, 275, 1927).

The Zinkenite Group

Dana's zinkenite group comprises minerals with the general formula, $RS(As, Sb, Bi)_2S_3$. The crystallographically known members of the group are:

Zinkenite	$PbS \cdot Sb_2S_3$
Sartorite (scleroclase)	$PbS \cdot As_2S_3$
Emplecite	$Cu_2S \cdot Bi_2S_3$
Chalcostibite (wolfsbergite, guejarite)	$Cu_2S \cdot Sb_2S_3$

These four minerals have been presented as an isomorphous orthorhombic group by Groth,[6] Goldschmidt[7] and Dana,[8] each using a different orientation. Later Goldschmidt[9] abandoned the isomorphous grouping in the interest of simple symbols, and more recently Groth [10] divided the group placing zinkenite (orthorhom-

[6] *Tabellarische Übersicht*, 2nd ed., 24, **1882**.

[7] *Index*, I, 548, **1886**.

[8] *System*, 6th ed., 111, **1892**.

[9] *Winkeltabellen*, **1897**.

[10] *Mineralogische Tabellen*, **1921**.

bic, possibly monoclinic) with sartorite (monoclinic), retaining emplectite and chalcostibite as an isomorphous pair. A detailed study of sartorite by Smith and Solly[11] showed that this mineral is monoclinic with a form system even stranger than that of calaverite. Sartorite thus falls definitely out of the orthorhombic group.

The scanty crystallographic data on zinkenite rest on early measurements by Rose[12] supplemented by approximate measurements by Spencer[13] on material referred without complete certainty to zinkenite. Zinkenite occurs in striated and channeled orthorhombic prisms of hexagonal appearance due apparently to repeated twinning on a plane in the striated zone. Single crystals are rare and the known forms are the three pinacoids which are usually feebly developed, a dome *k* inclined to the axis of the striated zone at 14°42′ and a prismatic form ϵ inclined at 29°40½′ to the pinacoid which lies in zone with the dome. There is no cleavage.

Correspondence between zinkenite and emplectite is obtained in two positions:

1. Making the axis of the striated zone of zinkenite the *b*-axis and placing the form *k* in brachydome position, we have:

Zinkenite	Emplectite
$k(061)$; $\rho=75°18'$	$n(061)$; $\rho=75°22'$
$\epsilon(203)$; $\rho=29\ 40\frac{1}{2}$	$l(203)$; $\rho=28\ 21$

2. Setting the axis of the striated zone vertical and the dome *k* in macrodome position:

Zinkenite	Emplectite
$k(103)$; $\rho=14°42'$	$k(103)$; $\rho=15°06'$
$\epsilon(430)$; $\rho=60\ 19\frac{1}{2}$	$j(430)$; $\rho=59\ 22$

In the absence of cleavage in zinkenite we have adopted the second and simpler alternative, thereby bringing the striated zone into the same position as in emplectite.

In a detailed study of chalcostibite Ernst[14] has retained the orientation and elements of Goldschmidt.[15] In this position the striated zone is set vertical and the cleavage plane is made the front pinacoid, which is the position we have adopted for emplectite.

[11] *Min. Mag.*, **18**, 259, 1919.
[12] *Pogg. Ann.*, **7**, 91, 1826.
[13] *Min. Mag.*, **11**, 188, 1897.
[14] *N. Jb. Min.*, Beil. **56**, A, 275, 1927.
[15] *Winkeltabellen*, **1897**.

TABLE II. THE ZINKENITE GROUP.

		Zinkenite	Emplectite	Chalcostibite
Composition		$PbS \cdot Sb_2S_3$	$Cu_2S \cdot Bi_2S_3$	$Cu_2S \cdot Sb_2S_3$
Habit		Striated prismatic zone. Dominant macrodomes.	Striated prismatic zone. Dominant macrodomes.	Striated prismatic zone. Dominant macrodomes.
Orientation		Striated zone vertical. No cleav.	Striated zone vertical. Cleav. (100)	Striated zone vertical. Cleav. (100)
Elements		$p_0=0.7870$ $q_0=0.5980$ $a=0.7598$ $c=0.5980$	$p_0=0.8093$ $q_0=0.6389$ $a=0.7894$ $c=0.6389$	$p_0=0.7818$ $q_0=0.6275$ $a=0.8026$ $c=0.6275$
Angles,	$(001)\wedge(103)$	14°42′	15°06′	14°36½′
	$(001)\wedge(101)$	(38 12)	38 59	38 01
	$(001)\wedge(111)$	(44 40)	45 52½	45 04½
	$(010)\wedge(110)$	(52 46)	51 42½	51 15
Forms in common	(001)	*b*	*c*	*b*
	(010)	*a*	*b*	*a*
	(100)	*c*	*a*	*c*
	(430)	*ε*	*j*	*j*
	(110)	·	*m*	*h*
	(230)	·	*i*	*d*
	(130)	·	*g*	*g*
	(103)	*k*	*k*	*u*
	(101)	·	*d*	*t*
	(503)	·	*s*	*s*
	(201)	·	*f*	*f*
	(111)	·	*p*	*ρ*
	(133)	·	*u*	*τ*
	(233)	·	*x*	*X*
	(433)	·	*z*	*ψ*

Table II and fig. 5 exhibit the correspondence between the crystallographically known orthorhombic members of the zinkenite group. As was rightly surmised but unhappily stated in the past, emplectite and chalcostibite form an isomorphous pair. The new data now show that the correspondence appears not only in

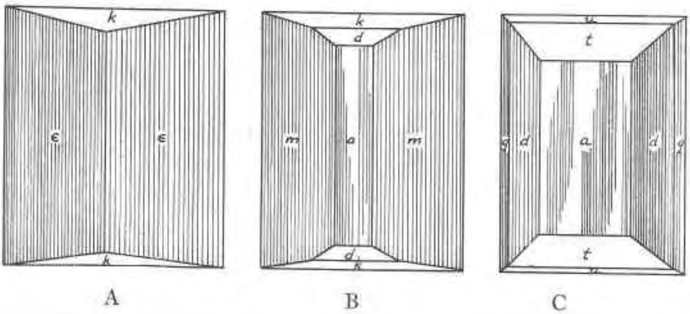

FIG. 5. ZINKENITE GROUP. Simple crystals in corresponding positions.

A. ZINKENITE with ε(430), *k*(103); after Rose (1826) in Victor Goldschmidt, *Atlas*, IX, Plate 65, fig. 2, **1923.**

B. Emplectite with *a*(100) cleavage, *m*(110), *k*(103), *d*(101).

C. Chalcostibite (wolfsbergite) with *a*(100) cleavage, *g*(130), *d*(230), *u*(103), *t*(101). Simplified after Ernst, *N. Jb. Min.*, Beil. **56 A,** fig. 1, 283, 1927.

the composition, habit, orientation with respect to cleavage, elements and angles, but also in a list of 15 forms in common. As far as the data go zinkenite also corresponds well with emplectite and chalcostibite, but the agreement should be regarded as provisional. Although zinkenite gives its name to the group, it is now the most imperfectly known member.